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PEELING, GLUING AND BONDING CHARACTERISTICS OF NIGERIAN PLANTATION-GROWN GMELINA ARBOREA (ROXB.)

by

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ABSTRACT

The gluing properties of plantation-grown gmelina wood (Gmelina arborea Roxb.) from Nigeria were investigated. Three wood peeling temperatures - 20°C, 50°C and 85°C; two glue types - urea-formaldehyde (UF) and phenol-formaldehyde (PF); two glue spreads - 25 kg/MDGL (55 lb) and 32 kg/MDGL (70 lb); and two closed assembly times - 10 minutes and 20 minutes were used. Veneers from the sample logs were peeled tight and were 1.27 mm (0.05 in) thick. The specific gravity for the logs was determined and its influence on the probable end uses of gmelina plywood discussed.

Three 5-ply plywood panels were made, for each treatment combination for 72 in all. A total of 1438 shear test specimens were used. The UF specimens were tested dry and after vacuum-pressure treatment whereas the PF specimens received vacuum-pressure and boil-dry-boil tests. Bond quality was evaluated on the basis of wood shear strength and percentage wood failure. Results were compared to the U.S., British and German Plywood Standards.

Wood peeling temperature was highly significant regardless of glue type and bond quality testing method. Heating of gmelina logs prior to peeling did not improve veneer peel-quality. Veneers were of the highest peel-quality (basis: Thickness variation and surface roughness) when logs were peeled at 20°C. The highest peeling temperature

yielded the lowest peel-quality.

Bond quality, (percentage wood failure), was consistently reduced by increasing peeling temperature and was lowest at 85°C in all the UF and PF treatments, regardless of bond quality testing method.

Ignoring glue spreads, panels made from veneers cut at temperatures of 50°C and 85°C gave the highest shear strength values among the UF treatments. On the other hand, panels from veneers cut at temperatures of 20°C and 85°C gave the highest shear strength values among the PF treatments.

All factors considered, treatment combination of Spread 55 - Time 20, arising from veneers cut at the control temperature of 20°C, gave an impressive bond quality in all the UF and PF treatments used.

Five of the 12 PF treatments used, regardless of type of bond quality testing method, pass the U.S. Plywood Standard; one passes the British Standard; while all pass the German Standard. On the other hand, five of the 12 UF treatments from vacuum-pressure test pass the U.S. Standard; two pass the British Standard; while all pass the German Standard. Furthermore, all the 12 UF treatments from dry test pass the U.S. Standard; six pass the British Standard; while all pass the German Standard.

From the results obtained, plantation-grown Gmelina arborea wood from Nigeria, with a specific gravity of 0.41 ± 0.027 (as determined), was found suitable for use as construction plywood, core and crossband veneer for decorative panel as well as container veneer and plywood.

The dominant factor accounting for the general trend of low percentage wood failure was attributed to veneer surface inactivation, resulting from surface aging of veneers.

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INTRODUCTION

1.1 Objective and Scope of Study

This study proposes an hypothesis that the wood of the Nigerian plantation-grown Gmelina arborea Roxb. (referred to hereafter by its trade name, gmelina) can be peeled into high quality veneer and glued into commercially acceptable plywood.

This investigation has been prompted by the publication of the International Union of Forestry Research Organizations (IUFRO 1973) in which the Forest Products Research Laboratory (FPRL), Princes Risborough, England indicated that gmelina wood was an unsuitable plywood species. The research centre obtained its sample logs from Thailand, Sarawak and an unspecified African country. In the same publication, the Centre Technique du Bois, Paris, France reported that gmelina wood is moderately suited for construction plywood, container veneer and plywood, and inner plies for decorative panels. The sample logs used by the French research centre were obtained from the Ivory Coast, in West Africa. No published reports have been found on the gluability of this wood in Nigeria.

The findings of the FPRL, Princes Risborough, England, are considered of significant importance to the wood-based panels industry in Nigeria for two reasons:

1. The United Kingdom is the most important single market for all wood products export from Nigeria, accounting for about 90% of the veneer and plywood export in 1972.
2. The current objective of management of gmelina plantations, in

at least two of the States in Nigeria, has incorporated future supply of sawlogs and veneer logs (Alade 1970, Enemuoh 1970). In the Western State[1], for example, it is intended that about 30 trees per acre from the existing and future plantations will be allowed to grow into sawlog and veneerlog sizes concurrent with pulpwood harvesting.

To test the proposed hypothesis, therefore, plywood panels from plantation-grown gmelina wood[2] from Nigeria, will be prepared, and standard glueline tests will be conducted. The following plywood production variables will be used:

1. Three levels of wood peeling temperature
2. Two adhesive types
3. Two levels of glue spread
4. Two closed assembly times

Results from this study could serve to indicate whether to accept or reject the suitability of gmelina wood for use as plywood. If results are encouraging, the study could have an impact on plantation management and on the wood-based panel industry in Nigeria.

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[1] Now comprising three New States - Oyo, Ogun and Ondo after February 1976.

[2] The logs used for study were part of consignment of logs shipped to SNC-Rust Limited of Montreal, Canada, from Nigeria, for pulping studies.

1.2 Background Information on the Nigerian Wood-based Panel Industry

1.2.1 Log supply situation

Log supply is one of the major current problems confronting the Nigerian wood industries. Various studies (Okigbo 1964, Eklund et. al. 1966, Wellwood 1966, Huuhtanen 1975) have indicated the seriousness of this situation in the forseeable future. The problem of log supply is not peculiar to Nigeria. Grudzinski (1975) has indicated that this factor has posed a problem in all areas of the world where the plywood mills are fairly concentrated. Nevertheless, the Nigerian case has not resulted from industrial concentration as such but from a limited wood-resource base.

The total land area in Nigeria is about 93 million ha of which the productive high forest reserves (the only source of industrial wood supply) accounts for only 1.9 million ha or about 2%. The growth rate and rate of forest regeneration after logging is quite low. Natural regeneration has been inadequate, even where attempts were made to induce it (Lowe 1966). Bamgbala and Oguntala (1970) put the timber yield from the natural moist forest in Nigeria at about 35 m_r^3 per ha. With a rotation of about 50 years in the high forests, this seemed a low figure.

Increasing efforts have been made to improve and restock the forests. The two methods used to encourage the regeneration and growth of the economically desirable tree species, are the Tropical Shelterwood System (T.S.S.) and the Enrichment Planting. Anakwenze (1966) and Oseni and Abayomi (1970) have pointed out that T.S.S. has proved a failure in Nigeria while Igugu and Bamgbala (1970) indicated that

Enrichment Planting has had little success.

In view of the foregoing, the long term prospect of wood supply situation in Nigeria seems to depend on the development of plantations of fast-growing species for sawlogs, veneerlogs and pulpwoods. As indicated by Fox (1972), the fast growth of planted trees is perhaps the most important advantage of the developing countries. The Federal and States governments in Nigeria seem committed to this concept as evidenced by their forest policy statements. Nigeria has a vast forest land, as distinct from productive high forests, that accounts for about 35% of the total land area. With better land use planning, enough land could still easily be allocated to Forestry for afforestation purposes.

Afforestation schemes were started in Nigeria before 1950. By 1950 and 1969, the country had a total of 7,468 ha and 51,560 ha of planted areas respectively (Oseni and Abayomi 1970). The planted area was estimated to increase to a total of 61,548 ha by 1970 (Enabor 1973). Plantings are being stepped up in the poorly stocked, highly degraded and the savannah areas of the country with fast growing exotic and indigenous species. *Gmelina arborea* is one of the major exotic species established in the plantations. In order to safeguard the future supply of timber, Nigeria proposes to establish a minimum of 12,140 ha of plantation, annually.

1.2.2 Growth and yield of gmelina in Nigeria.

Gmelina has become a popular plantation species in Nigeria for six major reasons:

1. The seeds are readily available.

2. It is easy to propagate from seeds and cuttings.
3. It coppices well.
4. It shows adaptability to a wide range of soil and climatic conditions.
5. It is fast growing and has ability to coppice for about 50 years (Scherpe 1968).
6. It suppresses the growth of weeds at an early age, thus reducing cleaning and weeding costs.

Gmelina grows very well in Nigeria. In a 2-year old plantation, the average g.b.h. (girth at breast height) recorded is 38.1 cm with a height of 12.2 m (Alade 1970). In another 7-year old plantation, the mean g.b.h. of 298 trees thinned per acre is 35.5 cm with a mean height of 8.5 m (Enemuoh 1970). Aladejana (1971) also reported a mean g.b.h. of 88.6 cm with a corresponding height of 1902 cm for 30 randomly selected trees in another 7-year old plantation.

Chittenden et. al. (1964) quoted a yield of about 84 m^3 per ha in a 12-year old plantation on poor sandy soils of the Derived Savannah Zone of Nigeria. They also reported a yield of about 252 m^3 per ha on the most favourable Savanna sites and in the Rain Forest Zone, 10 and 8 years respectively, after planting. From studies conducted by the Federal Department of Forestry, Ibadan, a yield of about 184 m^3 per ha, with a Mean Annual Increment of about 23-27 m^3 was reported for an 8-year old gmelina plantation at Omo Forest Reserve (Modugu 1977).

1.2.3 An overview of the industry.

Nigeria is a major African producer of wood-based panels. The actual wood-based panels production for 1973 was 55,000 m^3 (FAO 1975a) in the following product categories:

i)	Hardwood Plywood	45,100 m^3
ii)	Veneer Sheets	1,200 m^3
iii)	Blockboard, Laminboard, Battenboard . .	8,700 m^3
	Total	55,000 m^3

Wood-based industries have played a major role in the economy of Nigeria, contributing substantially to employment and value - added in manufacturing. Since the industrial survey publications in Nigeria have always treated all the wood-based industries as a single sector, it is difficult to appraise the percentage contribution being made by the wood-based panel industry. Nevertheless, within the many wood-based industries of the country, the sawmilling, wood-based panel and the furniture are the most important.

1.2.3.1 Employment

The wood-based industries have been the largest employment sector for labor in Nigeria, apart from agriculture and fisheries (Adeyoju 1968). With a total employment of 11,910 workers in 1963, the wood-based industries accounted for 17.5% of the total employment in manufacturing. The total number of workers employed decreased to 11,240 and 11,540 in 1967 and 1969 resulting in a decreased share of 14.6% and 11.3% respectively, of the total manufacturing employment. In spite of these decreases, Enabor (1976), however, indicated that the wood-based industries still ranked second to the textile industries in the country's manufacturing employment.

1.2.3.2 Value-added

The value-added in the wood-based industries in 1963 was $13.1 million, representing 8.5% of the national total. Although by 1967, the value-added in these industries had increased to $14.5 million, it represented a reduced share of 5.9% of the value-added in all the manufacturing industries. Again an increase to $23.4 million by 1970 accounted for only 4.2% of the national total (Enabor 1976). Rate of expansion and level of efficiency have been indicated as some of the factors controlling to value-added in manufacturing within the wood-based industries. Thus, the small-scale of operations and inefficiency within the sawmilling industry could have significantly accounted for the decreased share of value-added in manufacturing from the wood-based industries.

1.2.3.3 Development

Nigeria's production of wood-based panels began in 1946 when the first veneer mill was established as part of African Timber and Plywood (A.T.& P)[3] Company in Sapele. For almost two decades, this was the only operating mill in the country, producing veneer and plywood for export and domestic consumption. Now, there are four operating wood-based panel mills in the country located at Sapele, Calabar, Ologbo and Epe. Another wood processing complex, having facilities for veneer and plywood production is planned for Ondo at an investment of about

[3] A.T.& P. accounts for about 40% of Nigeria's production of plywood and as indicated by Wellwood (1966), it was the largest of its kind in the World, though no longer the most modern.

$20 million. This proposed mill is expected to start production under the 1976-1980 Development Plan.

1.2.3.4 Export trade

There is no co-operative selling and shipping of the wood-based panels among the four operating mills in the country. Each mill undertakes the shipment of its products. Export trade has accounted for an increasing share of the total wood-based panels production over the years. This averaged 69% (FAO 1975b) during the seven year period of 1962 to 1968. Export trade was highest in 1970 when it accounted for about 91% of the total production. Due to increased domestic consumption, the share exported has decreased dramatically since then. It was about 45% in 1971 and from FAO estimates for 1972 and 1973 (FAO 1975b), export trade was expected to account for only about 42% and 38% respectively.

The main markets for veneer and plywood are the United Kingdom, Germany, Holland, Denmark, Italy and the United States of America. However, the bulk of the plywood exported goes to the United Kingdom.

Veneer and plywood have contributed an average of $2.7 million, annually, to the Nigerian foreign exchange earnings since 1964. Export earnings from these commodities account for about 27%, 24% and 14% of the total export earnings of about $10.1 million (1971), $10.6 million (1972), and $19.4 million (1973) respectively from all wood products (Nigeria 1972, FAO 1974).

1.2.4 Prospects of development

1.2.4.1 Domestic consumption of plywood

A major prospect for development of the wood-based panel industry in Nigeria lies internally. There is currently a booming trade for plywood. Apparent plywood consumption increased substantially from 9,000 m^3 in 1962 to 26,000 m^3 in 1971, giving an increase of about 289% or an annual growth rate of 12.5% (FAO 1975b). Consumption was estimated to increase to 30,000 m^3 and 34,000 m^3 in 1972 and 1973 respectively.

Of the total wood-based panel consumption in 1967 and 1971, plywood accounted for a share of about 64.3% and 66.7% respectively. This was expected to increase to 71.4% and 72.3% by 1972 and 1973 respectively.

1.2.4.2 Utilization of wood-based panels

The major use of wood-based panels in Nigeria is in manufacturing, accounting for about 50% of the total annual domestic consumption of veneer and plywood. Paneling, boat building and wood-based components jointly account for about 40%; while the remaining 10% goes into packaging and other forms of uses (Enabor 1972).

The furniture industry has contributed a great deal to increased use of wood-based panels in Nigeria and more furniture mills are proposed for the country. For the 1970-74 Development Plan Period, the Federal and States governments in Nigeria proposed an investment of about $2 million on two wooden furniture factories. This is considered an incentive for further development within the wood-based panel industry. Development may not necessarily take a form of increased number of operating mills, but rather that of increased production capacity of the existing ones via higher output.

Enabor [illegible] consumption

Enabor (1976) projected a consumption of 102,000 to 132,000 m^3 (r) of wood-based panels in Nigeria by 1985. Similarly, he forecasted a consumption of 231,000 to 363,000 m^3 (r) by 2000 A.D. Even though forecasts are sometimes erroneous, future consumption of wood-based panels, in Nigeria, is indeed anticipated to increase with growth in population[4] and higher per capita income.

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4 The country's population increased from 56 million in 1963, to an estimated 80 million in 1973.

2.0 LITERATURE REVIEW

This literature review initially covers some of the most important process steps in plywood production including:

1. Log heating
2. Log peeling
3. Veneer drying

A further section of the review focuses on adhesion of wood and factors affecting plywood bond quality as well as some characteristics of the two adhesives - phenol-formaldehyde (PF) and urea-formaldehyde (UF) used to make experimental plywood. Some of the different national plywood standards and specifications used to evaluate study results, are surveyed.

As only limited information is available on the gluability of gmelina wood, the chapter concludes by giving a general review of the gluability of hardwoods.

2.1 General Wood Properties of Gmelina

Gmelina wood is diffuse porous and, as indicated by Esan (1966), fast growth does not change the density of the wood. Growth rings are visible and from studies done on the wood grown in Thailand (Lamb 1968) and Nigeria (Esan 1966), they appeared to be annual. The wood in appearance is straw yellow to creamy white (Lamb 1968). He (Lamb) further reported that selected samples of the wood show fiddle back mottling and a fine sheen on quarter sawn boards. Gmelina wood is indicated to contain a high resin content. Sample logs from Nigerian plantations were peeled, in the country, into 2.25 mm thick veneers for match splints. Veneers were found to be smooth, straight grained and of medium texture.

2.2 Log Heating

Heating of logs before veneering is a conditioning process (TRADA 1967) commonly practised in the hardwood plywood industry. It decreases the ratio of compressive to tensile strength of wood thereby giving a more uniform material (Hancock 1977a).

Several heating systems have so far been developed. These include circulating hot water, steam heating, electrical heating, water/air heating and high pressure heating (Seidel 1952; Fleischer and Downs 1953[5], Lickess 1957; Kubinsky and Sochor 1968). Of these, hot water systems of heating are the most commonly practiced in the plywood industry (Feihl 1972). Hot water systems give better uniformity compared to steaming and also ensure freedom from block end splits (Fleischer 1959; Anon 1968).

Heating of logs helps to plasticize the wood for best veneer cutting. With most woods, the fibers and hard knots present in the wood are softened and cutting becomes easier. Fleischer (1948), Lutz (1960), Anon (1968) and Palka (1974) reported that log peeling as a result of prior heating becomes easier and smoother veneers are produced without excessive lathe checks. Lathe checks, as ascertained by Chow (1974), contribute in large measure to reduced shear strength of plywood. Considerable reduction in damage to lathe knives has been reported, when

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5 Original not seen. Cited from reference of O. Feihl 1972.

peeling heated logs (Lickess 1957; Feihl and Godin 1975). Ellwood and Erickson (1962) reported that there is loss of moisture by vaporization when logs are steamed prior to peeling. There is, generally, loss of moisture through evaporation, as the heated logs begin to cool after removal from the heating mediums. These must have facilitated the shorter veneer drying time resulting from heated logs indicated by Anon (1968) and Kollman et. al. (1975). Batey (1955) showed that tight veneers produced from heated bolts reduce plywood face checking. Generally, Nakamichi and Konno (1965) pointed out that heating is essential for hardwoods from which lumber cores are to be cut.

The optimum cutting temperature for any wood is a function of its specific gravity, presence of hard knots, tendencies for end splitting and color changes (Fleischer 1959). The heating period required to obtain such optimum temperature, as well as the rate of temperature changes within the wood to give it, are functions of the green specific gravity of the wood, the type of vat used for heating and its temperature and warm-up period, the initial log temperature and diameter, the temperature required within the log as well as the outside air temperature (MacLean 1946, Fleischer 1959, Seidel 1952, Nakamichi and Konno 1965, Altukhov 1965, Garrison 1967, Anon 1968, Feihl 1972, Feihl and Godin 1975).

As cutting from too cold or too hot logs results in lower veneer peel-quality, (Feihl and Godin 1975), each wood species therefore cuts best within a certain temperature range. With too low a peeling temperature, loose or rough veneers are produced (Fleischer 1959; Feihl and Godin 1970) while too high temperature tends to soften the wood excessively thereby resulting in woolly-surfaced veneers. Palka (1974) reported that for most species, with the exception of low density ones (e.g. poplar and western red cedar), peel-quality improves when veneers are cut from logs heated, usually to a temperature range of 49-71°C.

Optimum cutting temperatures vary between hardwoods and softwoods. Fleischer (1959) stated that best cutting temperatures in hardwood species are roughly related to the wood density. Hardwoods of low specific gravity ($\leq$ 0.40) are reported to cut well at room temperature (the specific gravity of *Gmelina arborea* used for this study falls within this group of hardwoods). Medium density hardwoods are reported to cut well at a temperature of 60°C; while yellow birch is indicated to cut best at a temperature of about 71°C. Furthermore, Feihl and Godin (1975) pointed out that soft species such as poplar and basswood cut best at a temperature of about 32°F (0°C).

Cutting temperatures have also been correlated to the veneer nominal thickness intended to be peeled irrespective of wood-type. Fleischer (1959) indicated that thin veneers of 0.16 cm (1/16 inch) or thinner cut at lower temperatures without serious degrade (the veneer nominal thickness peeled for this study also falls within this group - 0.127 cm [1/20 inch]).

Many investigators (Fleischer 1948, Grantham and Atherton 1959, Corder and Atherton 1963, Hailey et al. 1968) have reported on the various effects of heating on veneer cutting. These studies were, however, conducted on softwood species. In their study on hardwood species, Wangaard and Saraos (1959) showed that there was an impressive degree of improvement in the tightness of veneers obtained from white and red lauan bolts heated in water at about 71°C compared to unheated bolts.

All the foregoing emphasizes the existence of an optimum cutting temperature for each wood.

2.3 Log Peeling

One of the aims of rotary cutting of logs is the production of veneers in uniform thickness, reasonable tightness and smoothness for gluing into plywood. These properties serve to achieve good bonding during gluing. As indicated by Bryant et. al. (1965), poor glue bonds in core veneers, as well as excessive panel-thickness variation, are largely accounted for by the extent of veneer-thickness variation. They also pointed out that gluing of such veneers requires greater pressures in panel pressing so as to promote intimate contact between all the glued laminates. Lutz et. al. (1969) also reported that variation in veneer thickness can cause problems of show-through of the core veneer in decorative panels.

Various studies have revealed that efficient rotary-cutting of logs hinges on many variables. These include the log diameter, the moisture content of the wood, the knife pitch angle, the nose-bar openings of the lathe, the lathe conditions and to a certain extent the lathe cutting speed.

Log diameter has been found to influence, significantly, the peel-quality obtained during rotary-cutting of logs (Fleischer 1949). For example, Kovanen (1963) demonstrated that tensile strength of Finnish birch veneers decreases with decreasing initial log diameter. A similar trend was reported by Cade and Choong (1969) in their study with Southern pine. From their study, veneer tensile strength perpendicular to the grain improves with increasing log diameters. Sivananda et. al. (1973) also ascertained that thickness variation of Vellapine (Vateria indica) veneers increased at reduced diameters of the logs.

For production of veneer of high peel-quality, the lathe has to be accurately adjusted for proper knife angle and adequate nose-bar openings. Panshin et. al. (1962) and Feihl and Godin (1963) identified lathe adjustment as a key to proper cutting of thin veneers of uniform thickness. This adjustment has also been recognised essential (Fleischer 1956, Hancock and Hailey 1975) for cutting smooth veneers of uniform thickness. Too large a knife angle and insufficient nose-bar pressure were reported to influence veneer thickness variation (Barefoot and Salehuddin 1962) as well as resulting in loose and rough veneer (Feihl and Godin 1970).

The pitch angle (the knife cutting angle) is the angle the plane of the knife tip and centre of rotation of the lathe spindles makes with the knife face (Hancock and Hailey 1975). Fleischer (1949), Wangaard and Saraos (1959), Kovanen (1963), Knospe (1964), Barefoot and Salehuddin (1962) and Feihl and Godin (1967) all refered to the pitch angle as a major factor responsible for veneer thickness uniformity. The knife angle used at any particular cutting period has been related to the veneer nominal thickness peeled. Available studies indicated that the angle should decrease as the veneer thickness decreases. Hancock and Feihl (1976) for example, recommended a pitch angle of 90° 30' when peeling veneers thinner than 0.84 mm (1/30 in.) for all diameters. To maintain a constant bearing on the knife, it has also been pointed out that the knife angle should decrease as the diameter of the log being peeled decreases (Fleischer 1949 and 1956, Kovanen 1963, Palka and Holmes 1973). This has been reinforced by Hancock and Hailey (1977). Their research study indicates that a modified pitch rail with a gradual increase in rub length gives superior results at small log diameters. For any particular wood, there is an optimum range of pitch angle in cutting within which veneer peel-quality can be maximised. Madison (1951) and (1957) found an optimum pitch angle of 89°50' and 90°-93° adequate for peeling 0.32 cm (1/8 inch) thick Western larch veneer and 0.13 cm (1/20 inch) thick aspen veneer respectively. A knife angle of 90° was indicated adequate (Wangaard and Saraos 1959) for cutting veneers of uniform thickness from Philippian white and red lauan. For most species, they, and Feihl and Godin (1970) reported an optimum level of knife angle varying between 89°31' and 90°30' when peeling 0.32 cm (1/8 inch) thick veneers.

Another lathe variable considered to play a dominant role in determining veneer peel-quality is the pressure bar compression (Fleischer 1949, Leney 1960, Koch 1964, Palka 1970, Cumming and Collett 1970, Lutz 1974). Fleischer (1949) pointed out that within the range of nose-bar settings, up to the point where over-compression of veneer occurs, increased pressure seemed to result in greater veneer tightness and smoothness. Barefoot and Salehuddin (1962) demonstrated that insufficient nose-bar pressure could influence variation in veneer thickness when peeling small diameter bolts from woods of *Albizzia procera*.

The horizontal opening (gap) is the horizontal distance between knife tip and bar tip and it is the main control on veneer roughness while the vertical opening (lead), which controls the veneer thickness variability, is the vertical distance between knife tip and bar tip (Hancock and Feihl 1976). Fleisher (1949), Collins (1960), Feihl et al. (1963), Feihl (1964), Lutz and Patzer (1966) all recognised the size of the horizontal roller-bar openings as an important variable influencing veneer thickness, roughness and lathe check formation. Lutz and Patzer (1966) reported that the veneer nominal thickness decreased with a decreased roller-bar gap when cutting Southern pine and yellow-poplar veneers. Also from their study, use of smaller gap improved the smoothness of veneers cut from yellow-poplar. Feihl (1964) reported that the use of smaller gaps result in smoother but too thin veneers when peeling curly birch logs. The nose-bar lead is not as important as the gap in determining veneer peel-quality. Fleischer (1949),however pointed out that suitable veneer cutting is obtained when the lead is varied approximately according to the nominal thickness of the veneer.

Various studies (Madison 1951 and 1957, Feihl et al. 1963, Cumming and Collett 1970) have shown, however, that there is an optimum range of gap and lead within which satisfactory veneer can be obtained. This optimum varies with species as well as veneer nominal thickness. Hancock and Feihl (1976) indicated that,generally, the gap is 5 to 15% narrower than the thickness of the veneer being peeled. They further indicated that,irrespective of type of bar used during peeling, the gap for a given species and given thickness is the same as long as the lathe is in good working condition.

From the literature reviewed above, it is quite obvious that a judicious selection of knife angle, horizontal and vertical pressure bar openings will serve to optimize veneer peel-quality during cutting with respect to species, veneer nominal thickness and log size.

2.4 Veneer Drying

Drying of freshly cut veneers, when properly controlled, reduces their moisture content to a level suitable for gluing into plywood. The rate of veneer drying is a function of the veneer initial moisture content, its thickness, species, dryer temperature, its air velocity and relative humidity (Bethel and Carter 1950, Bethel and Hader 1952, Fleischer 1953, Holden Jr. 1956, Milligan and Davies 1963, Lutz 1974). The condition of peel-quality, especially the tightness of the veneer, was indicated by Bethel and Hader (1952) to affect veneer drying. Loose peeled veneers, as they pointed out, dry at a faster rate than tight peeled veneers.

The moisture present in veneer prior to drying affects the total drying time. As sapwood and heartwood veneer pieces differ in moisture content, effective veneer segregation prior to drying helps to improve the drying control (Carroll and Dokken 1970). In hardwoods where distinction between sapwood and heartwood may be difficult, Carroll and Dokken (1970) suggested the use of moisture meters to effectively achieve green sorting. Variability in moisture content of the dried veneer sheets has been reported as one of the causes of under-cured and washed out glue-lines and panel blow-ups during pressing (Fleischer 1958, Carroll and Dokken 1970).

Comstock (1971) and Walters (1971) pointed out that the density of the veneer may be a factor in the total drying time because denser woods have slower drying time. Bethel and Hader (1952) reported differences in the drying time of different species. Fleischer (1953) also reported that redwood and sweetgum heartwood veneers dried at a slower rate than yellow-poplar heartwood.

The rate of heat transfer to veneer surfaces during drying was identified as an important factor (Comstock 1971, Lutz 1974) in controlling rate of veneer drying. This rate is a function of the veneer thickness (Bethel and Hader 1952, Fleisher 1953). They also reported that veneer drying time is a function of the dryer temperature. The higher the temperature, the more accelerated the drying becomes and the shorter the total drying time.

Drying should, however, be cautiously carried out as excessive drying with too high temperature results in veneer surface inactivation. As defined by Chow (1969a), "surface inactivation is due to the properties of veneer surfaces after thermal treatment whereby their reception of glue is made difficult". Northcott (1957) and Northcott et. al. (1959) pointed out that too high veneer drying temperatures and too long drying time are some of the factors inducing low wood failures in plywood. The inferior joints caused by increased drying temperature and time are pointed out by Currier (1958) to be results of reduced wettability of the veneers by the adhesives. Sisterhenm (1961) also showed that plywood made from Douglas-fir veneers dried to 232°C (450°F) developed a significantly lower bond quality compared to those made from veneers dried to a temperature of 191°C (375°F). Chow et. al. (1973) further indicated that overdrying or underdrying of veneers seriously affect the bond quality obtained.

Carroll and Dokken (1970) nevertheless reported that surface inactivation occurs not as a result of the use of too high veneer drying temperature but that of overdrying at too high temperature. According to them, the weaker bond quality obtained from such veneers is due to loss in strength of wood and not necessarily that of an adhesion. They further indicated that veneer surface inactivation can be avoided by the use of lower temperature at the dry end of the dryer.

2.5 Adhesion and Adhesives

2.5.1 Adhesion: Wood bonding theories

Adhesion in wood is a complicated phenomenon. There are many factors that influence bonding in wood,and as stated by Allen (1967), it is often difficult to distinguish which factor is dominant. Apart from the type of adhesive used, joint quality in an adhesive bond depends on the nature of the substrate and the conditions existing during the bonding process (Collett 1972). The forces that cause an adhesive to wet, spread and attach to the surface of a solid have been ascribed (DeLollis 1968) to chemical bonds, mechanical entanglement, physical and chemical adsorption due to polar groups, electrostatic forces of attraction inherent in all matter and to combinations thereof. From DeLollis viewpoint,therefore, it is quite obvious that mechanical and specific adhesion are essential to bonding in wood.

2.5.1.1 Mechanical theory

Mechanical adhesion in wood is effected by anchorage due to penetration into and hardening within capillaries in adherend surfaces

(Bikerman 1961, Heitler 1966). Marian and Stumbo (1962a) have indicated that mechanical adhesion certainly exerts an influence in wood, depending on joint type and condition of surfaces of the adherend members. They stated further that rough or damaged surfaces will influence mechanical adhesion but for smooth and undamaged surfaces, the influence is minimized. According to Parker and Taylor (1966), highly polished surfaces contain small peaks and troughs and so will give little adhesion. Patton (1970) further stated that surface roughness is essential for good bonding. Experimenting with planed, sanded, sawn and combed maple wood samples, Maxwell (1945), however, reported that the planed samples yielded stronger bonds and highest shear strength. This tends to disprove the mechanical adhesion theory, advanced by Bikerman (1947), which was based on the inherent roughness of surfaces.

In view of these findings, it is evident that mechanical adhesion alone is insufficient for bonding strength in wood. Total adhesion in wood is dependent upon mechanical and specific adhesions (Kollman et. al. 1975). Marian and Stumbo (1962a), in a particularly elegant experiment, indicated that the physico-chemical forces are mainly responsible for adhesion in wood. According to them, mechanical adhesion only contributes about 10-20% of the total adhesion strength.

2.5.1.2 Adsorption theory

The basis of this theory is specific adhesion which results from forces of adhesion acting between the molecules of the wood and the adhesive. As indicated by Marian and Stumbo (1962a), specific adhesion is caused by primary valence forces or secondary valence (Van der Waals) forces. Baier et. al. (1968) and Zisman (1963) reported that the three requirements necessary for developing a strong adhesive joint are:

1. Good wetting by the adhesive liquid.
2. Solidification.
3. Sufficient deformability necessary to reduce the effect of elastic stresses in the formation of the joint.

According to Marian and Stumbo (1962b), the wetting helps to assist spreading and penetration of the adhesive into the wood. DeBruyne and Houwink (1951) remarked in their discussion of adhesion theory that wetting of the surface by the adhesive is a necessary prerequisite for good gluing. The mutual attraction between the wood surface and the adhesive (resulting from the adhesive wetting power) has been attributed to different physical and chemical phenomena (DeBruyne 1947). Collett (1972) ascertained that the covalent bond plays a very important role in specific adhesion while the ionic bond was identified as of lesser importance. In this connection, therefore, the forces of molecular attraction were stated by Kollman et al. (1975) to play an important role in the adhesion between wood and glue. Zisman (1965) also remarked that adhesion is caused by forces between molecules in or near the surface of the two contacting materials and that these are primarily of van der Waals and hydrogen bonding type.

All the foregoing emphasizes the fact that an adhesive must spread and wet well the wood substrate to ensure good bonding since the forces that are causing the attraction between the wood and the glue act only over short distances (Zisman 1965). As it is, not all liquids that wet wood well can form strong joints with it. In this regard, the internal cohesive strength of the adhesive itself on solidification must be high in order to obtain strong joints.

2.5.2 Adhesives: UF and PF resin adhesives

Choice and performance of any resin adhesive for satisfactory bonds in wood varies with species. As indicated by Northcott and Hancock (1966), the service life of any bond is dependent on such factors as:

1. Conditions of service
2. Type of glue
3. Type of glue joint
4. Properties of the substrate

Investigating the gluing characteristics of Determa (Ocotea rubra Mez) Thomas (1959) reported that satisfactory bonds of maximum wood strength were easily obtained with the use of UF, RF and MF glues as well as casein glue. On the other hand, gluing was difficult with PF glue. This, as he explained, was due to the wax-like substances present in the wood. Thus, the incompatibility of the PF glue with Determa could be due to difference in polarity, which, as Thomas indicated, could result in the failure of the glue to wet the wood or penetrate adequately. However, the concept of adhesive and adherent having similar polarity which was postulated by DeBruyne, was no longer considered a precondition for the formation of adhesive bond (DeBruyne 1962). Thus, the difficulty encountered when gluing Determa wood with PF glue could have been due to some other factors. Generally, PF resin adhesives require a certain amount of water to react or polymerize

(Hancock 1977b). Furthermore, Laidlaw (1976) remarked that apart from choice of timber species in plywood manufacture, proper choice of adhesives serve to determine plywood strength as well as its ability to withstand environmental degrading effects.

UF and PF glues came into commercial use in the plywood industries at about 1930 (Parker and Taylor 1966, Kollman et. al. 1975). These two synthetic glues have been widely used since then. A lot of modifications have also been done, especially with the UF glue to improve upon durability and ability to withstand exposures to adverse weather conditions.

2.5.2.1 UF glue

UF glue produces a nearly colorless glueline. The glue also has the ability to cure at ambient temperatures. It is, however, unsuitable for service conditions of high humidity and temperatures above 60°C (SIRA 1970). Blomquist and Olson (1957) indicated that plywood made with this glue suffers an appreciable losses in joint strength when exposed to temperatures from about 27°C (80°F) to 70°C (158°F). Bergin (1958) also stated that at a temperature of about 70°C and higher, deterioration of the glue becomes more rapid. For these reasons, therefore, UF glue is restricted to interior uses.

Compared to PF glue, UF is deficient in long-term durability. The viscosity of the glue, its degree of cure and its adhesive formulation have been reported to influence the wood bond durability obtained with the use of the UF glue. Rice (1965) investigated the effect of resin viscosity on plywood bond durability. He reported that resin viscosity (a measure of molecular weights and dispersion) results in a more durable glue-wood bond. Steiner (1973) further showed that molar ratio ranges of Formaldehyde/Urea (F/U) = 2.0 to 1.8 yielded slower bond deterioration under accelerated aging conditions than resins with F/U ratio in the range of 1.6 to 1.4.

2.5.2.2 PF glue

PF glue is more durable than UF glue. It is quite suitable for service conditions of extreme temperature and humidity. Laidlaw (1976) experimented on the bond durability of plywood bonded with PF and UF glues, following a period of over 18 years of exposure. He found that the PF glues used without fillers or extenders or with only small addition of fillers maintained an efficient bond over the prolonged test periods while the UF glues gave satisfactory service for shorter periods. Muller (1953)[6] reported that the durability of phenolic wood glue joints is correlated with the wood species used as well as the glue-line thickness.

In the plywood industries, fillers, extenders and hardeners are often used with the UF and PF glues. A filler is used to control the flow of the resin while the sole function of the extenders is to reduce the amount of adhesives to be used to maintain an effective glueline. Hardeners are a blend of materials designed to give optimum working properties and bond quality (Hill 1952) and are essential in most cases in glue mixes.

All the foregoing emphasizes the fact that proper selection of glue and its formulation are important factors in gluing (Bryant and

[6] Original not seen. Cited from reference of Kollman *et al.* 1975.

(Stensrud 1954) in order to achieve the desired glue joint quality and durability (Blomquist 1954).

2.6 Factors Affecting Plywood Bond Quality

2.6.1 Glue spreading

Proper glue spreading is essential as it ensures uniform distribution of the liquid glue. In order to obtain good wood-glue bond, Brown et. al. (1952) have emphasized that the glue must flow, transfer from spread to unspread surfaces, wet all surfaces, penetrate into the wood capillaries, and solidify into a strong substance. The flow of the glue is retarded if the glue rapidly hardens before pressure is applied. Thus, the rapidity with which the glue begins to set is of primary importance. Penetration is necessary to produce a strong mechanical bond but it should not be excessive, to avoid a starved glueline. Depending on the adhesive, solidification is achieved by curing or chemical polymerization, hardening by physical cooling, loss of solvent by evaporation, and gelling of a dispersed polymeric solid (Collett 1972).

Furthermore, the amount of glue spread and the nature of resin formulation varies with respect to the type of glue and wood species. Jarvi (1967) indicated that heavier glue spreads usually require more press time. He also pointed out that the glue mixes for Southern pine require more phenolic resin content than normally used for Douglas-fir. This is probably due to differences in the degree of absorptivity of the two species.

2.6.2 Assembly time

In plywood manufacturing, assembly time is the time elapsing between glue spreading and press closing. As indicated by Chow et al. (1973) the assembly time allows for some moisture absorption by the veneer and some reduction in viscosity of glue due to moisture loss. This serves to ensure that there is just the right amount of water in the panel glueline during bond curing.

There seems to be a correlation between the maximum assembly time allowed during gluing and the moisture content of the veneer. At low veneer moisture content, prolonged assembly time results in a starved glueline condition. This leads to a situation whereby it becomes impossible for the glue to cure as most of the water in the glue is being readily absorbed into the wood while some is lost through evaporation. There is thus a lack of cohesive strength in the glueline and this results in low wood failure.

On the other hand, at higher veneer moisture content, prolonged assembly time is essential to facilitate high wood failure results. More so, as it provides enough time for the excess water in the glueline to be evaporated. For example, Northcott et al. (1959) reported that short assembly time can induce undercure of phenolic resins thereby producing low wood failure.

With long open assembly time, the PF resin has been noted to lose much of its moisture and shows a darkening in color as a result (Troughton and Chow 1972). Martin (1956) attributed this discoloration to quinone methide formation caused by oxidation. As indicated by Chow (1969b), this quinone methide formation reduces the number of methylol groups present in the PF resin. This makes covalent bonding with wood ineffective and therefore fails to produce durable glue-wood bonds. However, with the addition of polyethylene glycol 200 to the PF resin, Troughton and Chow (1972) were able to induce an increased wetting capacity of the glue on the treated wood thereby improving the bond quality obtained under prolonged open assembly time. It has to be indicated that PF glues, generally, require a certain amount of water to ensure favourable curing or polymerization.

2.6.3 Glueline thickness

Specific adhesion in wood requires a strong continuous glueline in order to form a strong joint. Using 36 phenolic resins, Hse (1971) correlated the glueline thickness to the bond quality produced in Southern pine plywood. He reported that surface tension, contact angle and curing time were related to the glueline thickness within the panels. According to him, wet shear strength and percentage wood failure increased with increased glueline thickness. Rice (1965) indicated that too thin gluelines may bring about locational starved spots all over the glueline. These spots may act as weak points as well as stress concentration areas, thereby causing bond deterioration.

Contrary to these findings, however, Brown et. al. (1952) stated that moderate over penetration of glue, while maintaining a thin, uninterrupted and uniform glueline is a requirement for mechanical and specific adhesion. Thin glueline was also reported best for bond quality in wood (Poletika 1943)[7]. Bergin (1969) showed that adhesive strength generally decreases with an increase glueline thickness.

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[7] Original not seen. Cited from reference of J.T. Rice 1965.

The theory of cracks seems to come into play with regards to these conflicting findings. Thick gluelines are viewed to have a greater potential for crack development than do thin gluelines. this tends to account for the decreased strength associated with thick gluelines.

2.6.4 Pressing

Application of pressure to the panel assembly after gluing promotes good contact between the glued veneer surfaces. It also aids penetration as well as ensuring good glue transfer to the unspread veneer surfaces (Chow et. al. 1973). Depending on the compressive strength of the wood, Kennedy (1965) reported a pressing pressure in the range of 10.5 kg/cm^2 to 14.1 kg/cm^2 (150-200 p.s.i.) for Canadian grown woods. Freeman (1970) also reported a pressure in the range of 13.0 kg/cm^2 to 14.1 gk/cm^2 185-200 p.s.i.) for most plywood mills.

Thus the amount of pressure used at any time, seems to be a function of the wood strength as well as the physical condition of the wood surface. Freeman (1970) investigated the influence of production variables on bond quality of Southern pine plywood. He reported that coarse grain effect and surface roughness induced by it might require higher pressures during the pressing time. Bond quality (in terms of percentage wood failure), as he indicated, increased with increased press pressure.

2.6.5 Degree of cure

The curing temperature of a glueline depends on type of resin adhesive used. Chow et. al. (1973) pointed out that inadequate curing temperature results in undercured bonds. As they indicated, this defect can be accentuated by insufficient pressing time. They further reported that a minimum glueline temperature of about 139°C (250°F) is necessary to pass the CSA 80% wood failure standard with the use of the vacuum-pressure-soak test.

In his investigation of under-cure of phenolic glue bonds, Northcott (1955) showed that percent wood failure was proportional to the degree of cure of the glue used. Chow and Hancock (1969) revealed from their simple spectrophotometric method that the degree of cure of phenolic resins is related to the wood failure and shear strength of the tested plywood panels. Bergin (1965) reported that the rate of cure of casein glues varies with the curing temperature in the range of about -7°C to 21°C (20°F to 70°F). Rate of cure decreased as the temperature decreased. Rudnicki (1976) found that the strength and durability of PF glue bonds are determined by the curing temperature, the curing time and the amount of hardener used.

Generally, the curing process of the plywood panel glueline is a complex one. As stated by Koch (1972), it involves properties of the resin and the wood, assembly times, prepressing procedures and hot pressing techniques.

2.7 Some National Plywood Standards and Specifications.

Plywood bond quality evaluation and specification standards vary from one country to another. While some countries assess plywood bond by percentage wood failure, some favour shear strength as the major criterion of assessment. A combination of these two criteria is being used by the United States Department of Commerce for hardwood and decorative plywood.

Wood failure has for long been indicated as an impracticable means of judging joint strengths in plywood. Truax (1929) stated that under good gluing conditions, joint strengths are not seriously affected by the percentage wood failure developed. Northcott (1955) remarked that, in order to use percentage wood failure to estimate bond strength, there must be a correlation between it and the shear strength. However, from his cleavage test (Northcott 1952) this correlation seemed not to exist. He therefore concluded at that time that the wood failure is of no value in judging plywood bond quality.

The following analysis covers some of the world plywood standards and specifications related to bond quality. Details are included in Appendices 1-4.

2.7.1 British Standard

The British Standard for hardwood plywood does not take into consideration plywood shear strength. Wood failure is the sole criterion of assessment. The BS 1455-1963 specifically applies to plywood manufactured from Tropical hardwoods (Appendix 1). Delamination test is required for the glue bond between individual panels. On the other hand, the adhesion test for the four kinds of bonding - WPB, BR, MR and INT (See Appendix 1) involves wood failure reading. Wood failure is read off on a Master Scale of 0 to 10 corresponding to 0 to 100% wood failure. The British Standard considers an average wood failure reading of 5 (50%) as adequate.

2.7.2 Japanese Standard

The Japanese use the Export Standard specification for Japanese plywood. Shear strength is the sole criterion used to assess the plywood bond quality. Depending on the type of species used to make the plywood, minimum shear strength required for Japanese woods ranges between 7 kg per cm^2 (100 psi) to about 10 kg per cm^2 (142 psi). For tropical woods, the Japanese require only about 8 kg per cm^2 (110 psi) minimum shear strength (Appendix 2).

2.7.3 German Standard

Just as with the Japanese standard, the German standard uses the shear strength as the sole criterion of assessment of plywood bond quality. The standard consists of a lot of requirements. Some of these are related to cold-soaking and boiling cycles. The exterior grade plywood is designated AW100. A minimum shear strength of 10 kg/cm^2 (142 psi) is required for non-coniferous woods (Appendix 3).

2.7.4 United States Standard

The U.S. Department of Commerce voluntary product standard PS51-71 for hardwood and decorative plywood makes use of both the percentage wood failure and shear strength to assess bond quality of plywood. The average wood failure for a particular panel under test is qualified by the average shear strength for such a panel. Specimens are subjected to dry, cyclic-soak and cyclic-boil tests. There is also a specified minimum percentage wood failure for individual specimen tested. For example, for an average failing load of between 18 to 25 kg per cm^2 (250 to 350 psi) the minimum wood failure of test piece required is an average of 30% with each individual specimen not having less than 10% wood failure (Appendix 4).

Of the four plywood standards reviewed above, it is the U.S., British and German standards that will be used to evaluate results from this study. The U.S. standard is favored because it qualifies the percentage wood failure developed at testing with the shear strength obtained. Furthermore, U.S.A. has been an important importer of veneer from Nigeria since 1970. The British standards will be used because Britain is the largest market for Nigerian hardwood plywood. The Federal Republic of Germany is another major European market for Nigerian wood products exports.

2.8. Gluability of Hardwoods

Various studies have been undertaken on the gluability of Tropical and secondary hardwoods in Europe, North America and Japan. Some of these studies, as shown below, are related to the effects of wetting phenomenon on wood gluability.

Troop and Wangaard (1950) investigated the gluing characteristics of 29 tropical American woods using RF and PRF glues. Assessing bond quality in terms of joint shear strength and percentage wood failure developed in the standard block shear test, they reported that many of the woods are suitable for structural uses. Results of their study also showed that shear strengths and wood failure values were, in general, strongly correlated with specific gravity. Defective surfacing of the glued materials and nature of their chemical constituents are some of the reasons they suggested for some abnormal results obtained with some of the species.

Freeman (1959) conducted an experiment relating the wettability of wood to its glue bond quality. Using 22 hardwoods, he found that wettability, pH and specific gravity are closely related to glue bond quality. Glue bond quality improved with increasing wettability in the high density wood (0.80) glued with UF resin adhesive. With specific gravity below 0.80, Freeman discovered that wood specific gravity has more influence on bond quality than wettability. He further indicated that wood specific gravity, acidity and wettability seem to have potential significance in wood adhesion.

Experimenting with 6 tropical hardwoods, Freeman and Wangaard (1960) investigated the effect of wettability of wood on glue-line behavior of two cold-setting urea resins. They reported that during the closed assembly period, glue-line solids content and viscosity increase more rapidly in woods of high wettability than in those of low wettability. These factors are essential in achieving optimum conditions for specific gluing operations.

Carstensen (1961) studied the gluing characteristics of secondary hardwoods, including red alder (Alnus rubra Bong.), cottonwood (Populus trichocarpa Torr. and Gray) and aspen (Populus tremuloides Michx.) as well as some softwood veneers. He reported that within any one species, gluability will vary accordingly because of the wide variations that exist in density, grain configuration, moisture content and veneer surface conditions. He attributed the gluing problems encountered to accumulation of resinous materials on the veneer surfaces.

Bodig (1962) studies wettability of 5 Philippine mahoganies as related to their gluability. He reported that there is a high degree of correlation between the indices of gluability and wettability. This, according to him, reinforces the validity of the specific adhesion thesis.

As he stated further, surface condition of wood has an important effect on its wettability. He also indicated that it is possible to predict relative gluability values of an unknown species by simply measuring its wettability.

Reporting on the gluability of Tectona grandis L. (Teak) and Acacia catechu Willd., Narayamurti et. al. (1962) showed that extractives present in these species affected the gelation time of the animal glue and UF glue used to glue the woods.

The gluability of some California hardwoods including black oak (Quercus kelloggii Newb.), chinkapin (Quercus muehlenbergii Englem.), madrone (Arbutus menziesii Pursh) and tanoak (Lithocarpus densiflora Rehd.) was investigated by Dost and Maxey (1964). They reported that all four woods glue well with PF resin adhesive and with exterior PVA resin emulsion.

Lee (1964) studied the gluability of Gmelina arborea Roxb. from Malaya. Even though he worked with a limited number of test samples, he reported that the wood showed good gluing properties.

The FPRL, Princes Risborough, England (1966) indicated from a consignment of logs from Gambia that good corestock veneers suitable for gluing into plywood can be produced from gmelina wood without any prior heating.

Goto et al. (1967) investigated the effects of specific gravity, wettability, pH and percentage of extractives on the gluing properties of 18 tropical woods. UF glue, PF glue and PVA emulsion adhesives were used to glue the woods. The following findings were reported:

i) Glue-joint strength increased with increase of specific gravity.

ii) There is a high degree of correlation between wettability and specific gravity.

iii) There was no significant relationship between glue-joint strength and pH.

iv) The relationship between glue-joint strength and the percentage of extract either by cold or hot water is not significant.

Chen (1970) studied the effect of extractive removal on adhesion and wettability of 8 tropical woods. Ten percent solutions of sodium hydroxide, acetone and alcohol benzene solvents were used. Gluing was achieved with UF and RF resin adhesives. He reported that extractive removal improved wettability and increased the pH of the wood surface thereby giving a more favorable bond quality.

Using Philippines red lauan (*Shorea negrosensis* Foxworthy), Moriya *et. al.* (1971) investigated the gluing characteristics of laminated wood from this species. RF, PF, UF, PVA emulsion and casein adhesives were used to glue the wood. From the block shear and delamination tests performed, glue joint strength was reported to increase with increase in wood specific gravity.

Yamagishi and Honma (1972) reported on mixed use of two different species in bonding some tropical woods using UF and RF resin adhesives. Bond quality was evaluated dry and after cyclic treatments as well as by delamination tests. They indicated that difference of specific gravity between two species considerably influence the glue bond durability. The higher the difference, the greater the bond quality degradation. They concluded that difference in specific gravity in the mix use should be maintained within ± 0.12.

The gluing properties of 6 hardwoods from Burma were investigated by Chunsi (1973) using PRF, UF and Casein glues. Among the many conclusions reached, he reported that influence of specific gravity on the gluability of the woods varied with type of glue. While the lighter woods glued easily with the three glues, the medium density woods glued well with the UF and PRF glues but poorly with casein glue. With all three glues, the high density woods glued poorly. He concluded further that glue joint strength increased with increase in the pH of the wood, if the influence of specific gravity was excluded. Three of the six woods he used met the requirements for exterior structural lamination with PRF glue.

The FPRL, Princes Risborough, England, and Centre Technique du Bois, Paris, France (IUFRO 1973) investigated some aspects of peeling, drying and gluing of Gmelina arborea Roxb. The former concluded that the wood is not suitable for use as plywood because of wild grain and poor gluability. The sample logs used were heated to 85°C prior to peeling.

On the other hand, the Research Centre at Paris concluded from its study that gmelina wood glues moderately well. There was no indication as to whether the sample logs were heated prior to peeling or not.

Tan (1974), studied the suitability of 9 Malayan hardwoods for plywood manufacture. Gluing was achieved with PF resin adhesives. He arrived at the following conclusions:

i) That wood bulk density is a dominant factor influencing the bonding ability of the woods. Higher density woods (densities of 0.64 g/cm^3, 0.66 g/cm^3, 0.80 g/cm^3 and 0.88 g/cm^3 respectively) were found unsuitable for plywood manufacture because of low percentage wood failures developed.

ii) That thermal degradation, due to increasing veneer drying duration, was significant in reducing bonding ability of the woods.

iii) That an adhesive formulation of higher viscosity than those used for softwoods was found necessary to prevent over-penetration of glue.

All the foregoing emphasizes the fact that bond quality and durability of plywood bonded with different glues are strongly influenced by the wood species involved.

3.0 EXPERIMENTAL PROCEDURES

3.1 Experimental Design

The design of the experiment included four variables. These were two glue types, three peeling temperatures, two glue spreads and two closed assembly times. The experimental steps were as indicated below:

Two glue types - phenol-formaldehyde (PF) and urea-formaldehyde (UF) resin adhesives.

Three veneer peeling temperatures - 20°C (control), 50°C and 85°C.

Two levels of glue spread - approximately 25 kg/MDGL (55 lbs/ MDGL) and 32 kg/MDGL (70 lbs/ MDGL).

Two closed assembly times- 10 and 20 minutes.

All combinations of the above variables gave 24 treatments. Three panels were made under each treatment, thus giving a total of 72 panels for the study.

The veneer nominal thickness peeled was 1.27 mm (0.050 in) while the plywood assembly construction was 5-ply. Furthermore, two types of bond quality tests were used to evaluate bond performance for each type of glue. The Dry and Vacuum-Pressure-Soak tests were used for all the treatments bonded with UF resin adhesive while the Boil-Dry-Boil-Cool and Vacuum-Pressure-Soak tests were used for all the treatments bonded with PF resin adhesive.

3.2 Mat[illegible] [illegible]d pre[illegible]

The logs [illegible] this [illegible]

3.2 Materials and preparation

The logs used for this study were part of the consignment of logs shipped from Nigeria to SNC-Rust Limited of Montreal, Canada, for pulping studies. They were kept in cold storage while in Montreal for about a year prior to their use for this study. The ends and surfaces of the logs had considerably dried out by the time they arrived at the Western Forest Products Laboratory (WFPL), Vancouver (note the lower moisture content value of the sapwood compared to the heartwood in Table 23). The logs were examined visually on arrival at WFPL and 10 logs deemed of reasonable diameters for peeling were selected. One of these 10 logs (Log No. 10) was used for preliminary determination of optimum lathe settings for peeling while the remaining 9 logs (Nos. 1-9) were used for veneer production. Their diameters ranged between 15.4cm to 22.9cm (6-9 in); lengths were about 2.7m (9 ft). They were subjected to water spray for 7 days before any test was performed.

Six out of the 9 logs used for veneer production contained tension wood. The sapwood thickness was quite small and averaged 20 mm (0.8 in). The logs were from a young plantation because growth ring count put their ages at 8 to 12 years. Bark thickness averaged 5.1mm (0.2 in). Furthermore, presence of knots ranged between 4 and 8 for the 9 logs.

3.2.1 Wood characterization

Before the logs were peeled, preliminary investigation into the specific gravity and moisture content of the samples were conducted for each of the logs Nos. 1-9 from which veneers were obtained. The sample's specific gravity was taken as an average of the nine results obtained. It was also essential, as part of the preliminary study, to determine the optimum lathe setting for peeling of the species. Log No. 10 was used for this investigation.

3.2.1.1 Specific gravity determination

Specific gravity of each of the nine logs was determined by the volume measurement method in accordance with the ASTM Standards (ASTM 1975: No. D143-52). Four samples per log yielded a total of 36 samples for the specific gravity determination. Figure 1 shows pattern of cut of test samples from a log. Both the air and oven dried length, width and thickness of each specimen were taken at three different places -- the ends and center of the specimen. A log specific gravity is taken as the average of its four samples.

3.2.1.2 Moisture content determination

The procedure for the determination of the moisture content of each of the nine logs also followed that of the specific gravity. It was in accordance with ASTM standards (ASTM 1975: No. D143-52).

It must be indicated, however, that the moisture content of the logs were determined prior to peeling and, except for the control logs peeled at 20°C (ambient temperature) moisture contents of the logs heated to 50°C and 85°C were also determined following heating operations.

3.2.1.3 Determination of the optimum lathe settings for peeling

All peeling was done at the Western Forest Products Laboratory, Vancouver, on their experimental lathe equipped with a solid nose bar. Log No. 10 which was used for this study was cut into two bolts of 1.1m long each. Based on past peeling experiences of hardwoods of similar veneer thickness (1.27mm), Hailey (1977a), recommended lathe settings of pressure bar horizontal and vertical openings of 1.112mm (0.044 in) and 0.254mm (0.010 in) respectively for rotary peeling of the first bolt from log No. 10. A pitch angle of 89°30' at 25.4cm (10 in) was used. The second bolt was peeled with the same settings but with a change in the pitch to 89°30' at 26.7cm (10-1/2 in). This latter trial was found to improve the quality of the veneer obtained.

In summary, therefore, the optimum lathe settings determined for peeling 1.27mm veneer from *Gmelina arborea* logs (16.1 - 22.2cm diameter ranges) were presented in Table 6.

3.2.2 Log heating

Prior to the heating operations a disk about 30.5cm (1 ft) long was cut from one end of each log. Logs were grouped by diameter to give more uniform heating. For this reason, therefore, log numbers 5, 6 and 7, with diameters[8] of 19.1cm (7.4 in), 19.7cm (7.7 in) and 18.4cm (7.3 in) were used for the 50°C heating. Similarly, for the 85°C heating, log numbers 1, 3 and 9, with diameters of 22.2cm (8.8 in), 21.0cm (8.2 in) and 20.3cm (8.0 in) were used. The diameters of the logs in each of these two groups were assumed close enough to ensure the use of the same heating time. The remaining logs, with diameters of 19.8cm (7.8 in), 16.5cm (6.5 in) and 18.4cm (7.2 in) were peeled at ambient temperature of about 20°C.

Following the MacLean (1946) procedures on rate of temperature changes in short-length round timbers, the initial heating time for the

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[8] Average for both ends.

50°C heating was calculated at about 8 hours. Similarly, the heating time was calculated at about 11 hours for the 85°C heating with the use of his suggested formulae. However, due to certain factors discussed below the ultimate heating time for the 85°C heating exceeded the calculated time by about 8 hours.

Logs were heated immersed in circulating hot water with overhead spray. The temperature changes at the centre of the logs were determined by means of control logs in which thermo-couples were inserted. The drilled holes, through which the thermo-couples passed, were tightly sealed with corks to prevent flow of hot water into the logs. Due to procedural error, however, the temperature changes, 25.4mm (1 in) from the surfaces of the control logs, were not measured with similar uses of thermo-couples. This was not regarded as serious since a relationship exists (MacLean 1946) whereby such temperature changes could be obtained. The initial temperatures of the control logs were taken one minute after inserting the thermo-couples while the subsequent temperature changes within the logs were observed at every one-hour interval.

The vat temperature was maintained at a level slightly higher than that required for peeling. For the 50°C peeling temperature, the vat was maintained at about 55°C (122°F) while it was about 86°C (190°F) for the 85°C peeling temperature. Because of possible technical problems with the heating, a temperature difference of $\pm$ 2°C in the required peeling temperature was viewed as acceptable.

3.2.3 Log peeling

As required for veneer cutting on the lathe, both the heated and unheated logs were bucked into 1.3 to 1.4m (51 to 53 in) bolts. All nine bolts were rotary cut with the same lathe settings (already determined). Throughout the cutting process, the speed of the lathe was maintained at about 36.6 metresper minute (120 feet per minute).

All the veneers were tightly cut. After peeling, the veneer sheets were clipped into pieces about 30cm wide (12 in). To ensure adequate yield of veneer for use, pieces as narrow as 15 to 18cm wide (6 to 7 in) were also preserved.

During the peeling, gmelina wood was noted to produce no disagreeable odor. In appearance, the peeled veneers (from heartwood) were light to medium yellow in color. Veneers were also noted to be straight grained. All veneer pieces were coded and stored in moisture proof plastic bags.

3.2.4 Peel-quality evaluation

According to Hailey et. al. (1968), peel-quality is a technical term used in describing or evaluating the effect of the peeling process on certain physical properties - namely; thickness, roughness and looseness - of green veneer sheets. Since the veneers were peeled thin and tight, only two measures of veneer peel-quality were selected to evaluate the lathe settings used in this study with the different peeling temperatures. These were veneer surface roughness and thickness variation; and all evaluations were made with green veneer sheets.

3.2.4.1 Veneer roughness

Veneer surface roughness was estimated in terms of the reference standard maintained at the Western Forest Products Laboratory (Northcott and Walser 1965) in accordance with Hailey and Hancock (1973) description. All the clipped veneer sheets, irrespective of width, were used for roughness test.

3.2.4.2 Veneer thickness measurement

Veneer thickness variation was measured in accordance with Hailey and Hancock (1973) description. From each set of veneers obtained from a particular peeling temperature, 10 approximately 30 cm wide (12 in) veneer sheets were randomly selectee for veneer thickness measurements.

3.2.5 Veneer drying

The choice of the drying procedures used in this study were based on:

1. The need to avoid, as much as possible, over- or under-drying of the veneer sheets (The effects on the resulting plywood bond were reviewed in Chapter two).
2. Since thirty days had elapsed between the peeling and drying of the veneer sheets, veneers were regarded to have lost a considerable amount of moisture. This was due to frequent removal of the sheets from the plastic bags in which they were kept for roughness and thickness measurements.
3. The likelihood of much moisture content variability among the sheets. Furthermore, no past veneer drying studies of this wood were available to work with.
4. There was difficulty in sorting the veneer sheets into moisture content grades with the use of the moisture meter. This was due to the thinness of the veneer.

For these reasons, therefore, the conventional high temperature drying method was avoided.

Veneer was dried in a forced-air oven, operating at about 152m/minute (500 ft/minute) air speed, while the dryer heating system was completely turned off. For every batch-load of veneer in the oven, 5 wetter and 5 drier pieces were randomly selected and loaded along with the remaining sheets at different locations in the oven. These 10 pieces were continuously weighed until they reached constant weights. All the batch-loads of the three sets of veneer reached constant weights between 5 to 7 hours. The veneer sheets at this stage were regarded to contain a moisture content in the range required for gluing. Veneer[9] moisture content checking prior to gluing indicated that the veneer pieces attained an equilibrium moisture content of between 5.5% and 7.5% regardless of peeling temperature level.

3.2.6 Glues and glue mixing

The two glue types used in this study - UF and PF - are the basic resin adhesives used in the Nigerian veneer and plywood mills.

3.2.6.1 IB-334 Plyophen

On the advice of Dr. Chow and Mr. Hailey (Chow 1977, Hailey 1977b) of the Western Forest Products Laboratory, the PF glue chosen was IB-334 Plyophen (PF IB-334 hereafter). Afolayan (1974) used this glue successfully to produce laminated veneer lumber using Canadian hardwood species.

[9] Veneers were stacked in a controlled temperature-humidity (CTH) room operating at a dry-bulb temperature of about 26.7°C (80°F), a dew-point temperature of about 6.1°C (43°F) and a relative humidity of 26%.

The PF IB-334 glue was supplied ready-mixed by Reichhold Chemicals Limited, Port Moody, B.C. It is a liquid water soluble phenolic resin, which produces high quality exterior adhesives bonds for the plywood industry. The glue was also claimed to provide excellent bonds at competitive press times, as well as being tolerant to conditions of long assembly times and high ambient and stock temperatures.

The percentage of PF solids in the final mix of PF IB-334 glue is 26% as opposed to about 23% for standard PF glue for softwoods. Furthermore, there is twice the concentration of wheat flour in this mix compared to the average plywood mix (See Appendix 5). This has thus necessitated a reduced use of extender in order to accommodate the additional wheat flour.

The viscosity of the resin is about 370-470 cps (Gardner-Holdt) while the viscosity of the glue mix was 1350 cps at 25°C measured by the manufacturer with No. 3 spindle 60 rpm LVF Brookfield viscometer. The recommended glue spread was 27-30 kg/MDGL while higher spreads of about 34 kg/MDGL and 38 kg/MDGL can be used depending on how porous the wood is (Ainsley 1977)[10]. The mixing sequence of the PF IB-334 is shown in Appendix 5.

3.2.6.2 Monsanto UF 109 resin with EK Hardener.

Unlike the PF IB-334 glue, the Monsanto UF 109 glue, using EK Hardener, was prepared at the Western Forest Products Laboratory. The mix is a suitable glue for interior softwood and hardwood plywood. The components of the EK Hardener are urea, ammonium chloride (NH_4Cl), sodium metabisulfite, and walnut shell flour. The urea constitutes the

[10] Personal communication. Ainsley is on the staff of the Reichhold Chemicals Limited that supplied the glue.

bulk of the hardener while the main function of the sodium metabisulfite is to disperse the wheat flour. Similar mix formulation of this glue at the Western Forest Products Laboratory (Rozon 1977) contains about 29.8% of urea formaldehyde solids with a viscosity of about 2944 cps measured by No. 3 spindle at 30 rpm LVF brookfield viscometer 1/2 hour after mixing. The mixing sequence is shown in Appendix 6 (supplied by Hartz 1977).

3.2.7 Glue Spread

The glue was spread at about 25 kg/MDGL and 32 kg/MDGL designed for [illegible]. In all cases, five veneers were assembled to make a panel. A mechanical glue spreader with rubber rolls was used to apply glue to veneers. Since the veneers were peeled tight, it was quite difficult to identify the side with the lathe checks (the loose side). The veneers were therefore assembled without consideration for which side to turn inside or outside. For the 50°C peeled veneers, enough materials were not available for use in all the 24 treatments used in the study. The veneers from gmelina wood were therefore used as cores and crossbands while yellow birch veneers of the same thickness were used for the panel faces and backs.

For each of the 24 treatments, 3 plywood panels were assembled. After gluing, each panel was coded and marked with respect to its glue-type, peeling temperature, glue-spread and closed assembly time.

3.2.8 Plywood Panel pressing

3.2.8.1 Press Pressure

Trial panels were assembled using three levels of platen pressures of about 11 kg/cm^2 (150 p.s.i.), 14 kg/cm^2 (200 p.s.i.) and 18 kg/cm^2 (250 p.s.i.). The three panels obtained were assessed on the basis of the plywood knife-test. The platen pressure of 14 kg/cm^2 (200 p.s.i.) gave the most favourable result. All the assembled panels, therefore, irrespective of glue-type, were pressed with this platen pressure.

3.2.8.2 Pressing Temperature and Time

Following industrial practice, a platen temperature of 127°C was used for pressing the panels glued with UF resin adhesive and 149°C for those panels glued with PF resin adhesive. The assembled panels were pressed with two panels per press opening for 5 minutes with the Monsanto UF 109 glue and 4.5 minutes with the PF IB-334 glue.

In summary, the following specifications and pressing schedule were used when making a typical panel assembly:

1. Five-ply, with a glue spread of 25kg/MDGL or 32 kg/MDGL depending on treatment combination.
2. Ten minutes or 20 minutes closed assembly time depending on treatment combination.
3. Platen temperature of about 127°C (260°F) or 149°C (300°F) depending on glue type.
4. Press pressure of 14 kg/cm^2 (200 p.s.i.)
5. Pressing time of 5 minutes or 4.5 minutes depending on glue type and platen temperature.
6. Hotstacking of the panels glued with PF for 10 minutes.

3.2.9 Test Specimen Preparation

Tension-shear specimens from the plywood panels produced were prepared in accordance with the requirements of the CSA and NBS standards. Because of the small thickness of the panels however, difficulties were encountered when making grooves on the 7.6cm (3 in) wide strips cut from the panels. The circular saw in some cases cut through the entire thickness of the core-ply instead of the two-thirds of it specified. Test specimens obtained from such strips were regarded as "rejects" and were screened out of the lots after cutting.

Specimens were coded by panel of origin to facilitate between and within panel comparison for shear strength and percentage wood failure. Specimens were randomized for the two types of test.

Test specimens vary between 22 and 36 in all the 24 treatments used in this study. In all, a total of 1438 test specimens were stressed to failure. Specimens were coded and marked according to type of bond quality test, panel number, glue-type, peeling temperature, glue spread and assembly time. For example, a sample designated UF-20-55-10 indicates that the sample was from a panel glued with UF resin adhesive; veneers were peeled at 20°C; panel was glued at a spread of 55lb /MDGL (25 kg/MDGL) and panel assembly was pressed after a closed assembly time of 10 minutes.

3.2.10 Bond Quality[11] Testing Procedures

3.2.10.1 Dry Test

The UF test specimens were stressed to failure in a Globe

[11] Wood failure readings, regardless of bond-quality testing method, were based both on gross and fine fibre wood failures.

tension-shear machine in accordance with the NBS/CSA standards. Load was applied at the rate of about 272 kg to 454 kg per minute (600 to 1000 lb. per minute). The ultimate shear strength and wood failure were recorded for each specimen.

3.2.10.2 Vacuum-Pressure Test

This test was used to assess bond quality performance in all the treatments used in this study, irrespective of glue-type. As investigated by Chow and Warren (1972), the vacuum-pressure test was found to be on a par with the cyclic cold-soak test. The vacuum applied was about 63.5cm (25 in) of mercury while the air pressure applied was in the range of about 4.6-4.9 kg/cm^2 (65-70 p.s.i.).

The efficiency of water penetration into the test specimens was not investigated insorder to justify the use of a cycle greater than 30 minutes as was the case with Tan's study (Tan 1974). This was because his study involved the use of denser Malayan hardwoods whereas gmelina is a low to medium density hardwood (specific gravity = 0.41). The 30-minute cycle was therefore viewed adequate. Evidence of adequate water penetration seemed to be provided by the wide differences shown by the wood failure results between the dry and vacuum pressure tests of the treatments bonded with UF glue (Table 10).

Specimens were sheared while wet on the same Globe testing machine used for the dry test. The shear strength was recorded while the wood failure was evaluated after oven-drying the sheared specimens overnight. This served to prevent reading errors due to the darkening by the water.

3.2.10.3 Boil-dry-boil Test

The test specimens glued with PF resin adhesive were subjected to boil-dry-boil test in accordance with DIN68705 and CSA standards. The specimens were sheared wet after having been cooled to room temperature in water. Shear strength was recorded for each specimen and, as before, wood failure was read after drying the sheared specimens overnight in an oven.

3.2.11 Statistical Analysis

Factorial analysis was performed to facilitate the interpretation of the main and interacting effects that could evolve. Treatments were analysed with respect to glue-type as well as type of bond quality test used. Shear strength and wood failure were analysed separately.

Also based on the advice of Dr. Kozak, Faculty of Forestry, an analysis of variance was performed for both the shear strength and wood failure according to type of test. It was hoped that this would show the comparative performance of a treatment with the others. Where significant differences were found, Duncan's New Multiple Range test was applied. In order to facilitate easier factorial analysis of results (Kozak 1977), the same number of test specimens was used in all the treatments. Therefore, the treatment with the smallest number of specimens was used as a standard while the same number of specimens were randomly selected from the other treatments with the use of a Table of random numbers. Thus, 22 specimens per treatment were used for the factorial analysis of variance.

4.0 RESULTS

4.1 Moisture content and specific gravity of gmelina logs used

The initial and peeling moisture contents (MCs) of the log samples used are presented in Table 2. Values are shown separately for sapwood, heartwood and corewood. The sapwood initial MCs are consistently lower than those of the heartwood in all the 9 logs. MC values are in the ranges of 41% to 107% and 67% to 147% for the sapwood and heartwood respectively. The MC of the sapwood increased for three of the six heated logs while the heartwood MC decreased for four of the six heated logs. Nevertheless, the sapwood MCs at peeling are still consistently lower than those of the heartwoods in all the logs.

The average log specific gravity (sp.gr.) as well as mean and standard deviation of gmelina sample logs used, is given in Table 3. The sp.gr. values for the 9 logs are based on ovendry weight and green volume and are in the range of 0.37 to 0.44. This gives a sample mean of 0.41 with a standard deviation of 0.027.

4.2 Log heating and peeling

The water bath temperature changes as well as temperature changes within the log at positions 2.5cm (1 in) and 10.2cm (4 in) from the log surface are shown in Tables 4 and 5 for the 50°C and 85°C (±2°C) heating, respectively. These changes are shown graphically in Figures (Fig.) 2 and 3. The logs heated to 50°C (±2°C) attained that temperature at the calculated heating time of 8 hours (hr) while those heated to 85°C (±2°C) attained that temperature at a heating time of 19 hrs instead of the calculated time of 11 hrs.

The lathe specifications used for veneer cuttingare presented in Table 6.

4.3 Veneer peel-quality

The frequency distribution of visual roughness measurements is given in Table 7 for the veneers peeled from the control bolts (20°C) and bolts heated to 50°C and to 85°C, and is graphically presented in Fig. 4. The mean, maximum, minimum, standard deviation and range are presented in Table 8 for each of the veneer peel-quality attributes measured; namely veneer thickness and veneer roughness. Veneer thicknesses were derived from 10 specimens each for the veneers peeled from the control bolts (20°C) and bolts heated to 50°C and 85°C. On the other hand, the veneer roughness values were derived from 175, 194 and 173 specimens for the veneers peeled from the control bolts (20°C), bolts heated to 50°C and bolts heated to 85°C respectively. Results show that peel-quality was best for the veneers peeled from the control bolts (20°C) while bolts heated to 85°C produced the roughest veneers.

4.4 Veneer moisture content prior to gluing

Table 9 shows the MC of the 10 pieces of veneer checked prior to gluing as well as the average MC for the 10 pieces. These averages are 6.6%, 6.4% and 6.4% for the veneers peeled from the control bolts (20°C) and bolts heated to 50°C and 85°C respectively. These values give no indication of overdrying of veneers with the use of the forced-air drying technique.

4.5 UF resin adhesive

4.5.1 Dry test: Shear strength and wood failure percent

Table 10 summarizes the average shear strength and percentage wood failure for the 12 treatment combinations of peeling temperature (PT), glue spread (GS) and closed assembly time (AT). Individual specimen minimum wood failure in each treatment combination is also shown, as well as treatment codes used in the study. This was done to facilitate comparison of bond quality results with the U.S. Plywood Standard.

Plywood panels made from veneers peeled at 85°C (using a GS of 70 lb/MDGL and an AT of 20 min.) produced the highest shear strength of 389 psi; while those made from veneers peeled at 20°C (using a GS of 55 lb/MDGL and an AT 20 min.) produced the highest percentage wood failure of 70%. Generally, bond quality is best at the PT of 20°C.

The mean, maximum, minimum and range of percentage wood failure for each of the three panels produced for testing in each of the 12 treatments are presented in Table 12. Large variabilities in bond quality, within and between the panels, are noted.

4.5.2 Vacuum-pressure test: Shear strength and wood failure percent

The average shear strength and percentage wood failure for the 12 treatment combinations of PT, GS and AT subjected to this test are also shown in Table 10.

Similar to the dry test, plywood panels made from veneers peeled at 85°C (using a GS of 70 lb/MDGL and an AT of 20 min.) produced the highest shear strength of 307 psi; while those made from veneers peeled at 20°C (using a GS of 55 lb/MDGL and an AT of 20 min.) produced the highest percentage wood failure of 59%. Generally, bond quality is best at the PT of 20°C. There is also a large variability in bond quality within and between panels as shown in Table 13.

4.6 PF resin adhesives

4.6.1 Vacuum-pressure test: Shear strength and wood failure percent

Table 11 shows the average shear strength and percentage wood failure for the 12 treatment combinations of PT, GS and AT. The minimum wood failure percent for each test specimen is also shown as well as treatment codes used.

Plywood panels made from veneers peeled at 85°C (using a GS of 70 lb/MDGL and an AT of 20 min.) produced the highest wet shear strength of 405 psi; while those made from veneers peeled at 50°C (using a GS of 70 lb/MDGL and an AT of 20 min.) produced the highest percentage wood failure of 64%. Generally, panels made from veneers peeled at 20°C give an impressive bond quality.

The mean, maximum, minimum and range of percentage wood failure for each of the three panels produced for testing are presented in Table 14. Values are shown separately for each of the 12 treatments used. Large variabilities in bond quality, within and between panels, are noted.

4.6.2 Boil-dry-boil test: Shear strength and wood failure percent

The average shear strength and percentage wood failure for the 12 treatment combinations of PT, GS and AT are also summarized in

Table 11. The minimum wood failure percent for each test specimen is also shown in order to facilitate comparison of bond quality results with the U.S. Plywood Standard.

In this test, plywood panels made from veneers peeled at 85°C (using a GS of 70 lb/MDGL and an AT of 20 min.) produced the highest shear strength of 334 psi; while those made from veneers peeled at 50°C (using a GS of 70 lb/MDGL and an AT of 20 min.) produced the highest percentage wood failure of 66%.

The mean, maximum, minimum and range of percentage wood failure for each of the three panels produced for testing are presented in Table 15. Values are shown separately for each of the 12 treatments used. Large variabilities in bond quality, within and between panels, are also noted.

4.7 Analysis of variance

4.7.1 Factorial analysis

The results of the dry test shear strength and percentage wood failure for the treatment panels bonded with UF glue (factorial analysis) are summarized in Table 16; showing the significant main and interacting effects at the 0.01 and 0.05 levels. All the significant interacting effects are graphically depicted in Fig. 5 and 6.

Similarly, Table 17 summarizes the factorial analysis results of the vacuum-pressure test shear strength and percentage wood failure for the treatment panels bonded with UF glue. The significant interacting effects at 0.01 and 0.05 levels are graphically depicted in Fig. 7 to 9.

The results of the vacuum-pressure test shear strength and percentage wood failure for the panels bonded with PF glue are presented in Table 18, showing the significant main and interacting effects at the 0.01 and 0.05 levels. All the significant interacting effects are graphically depicted in Fig. 10 to 13.

Table 19 shows the factorial analysis results of the boil-dry-boil test shear strength and percentage wood failure for the treatment panels bonded with PF glue. All the significant interacting effects in this result are graphically depicted in Fig. 14 to 16.

4.7.2 Duncan's multiple range test

The results of the Duncan's multiple range test for direct comparison of the average shear strength and percentage wood failure are presented in Tables 20 and 21 for the treatment panels bonded with UF glue (Dry test and Vacuum-pressure test respectively).

Similarly, results are shown in Tables 22 and 23 for the treatment panels bonded with PF glue (Vacuum-pressure test and boil-dry-boil test respectively).

5.0 DISCUSSION

5.1 Sample specific gravity

The mean sp. gr. of 0.41 ± 0.027 found for the Nigerian plantation-grown gmelina logs used in this study compares favourably to a value of 0.41 ± 0.060 reported by Nokoe-Sagary (1972) for Nigerian plantation-grown gmelina samples. Lamb (1968) also reported a nominal sp. gr. of 0.407 - 0.427 and 0.42 for work done on *Gmelina arborea* samples from Gambia and Malaysia respectively. Furthermore, IUFRO (1973) reported a sp. gr. value of 0.40 for *Gmelina arborea* samples from Thailand and Sarawak.

The mean sp. gr. value of 0.41 ± 0.027 of this study, makes veneer and plywood produced from *Gmelina arborea* wood suitable for various end uses (elaborated further in the discussion).

5.2 Log heating

Because of technical problems with the heating, logs numbered 1, 3 and 9 did not attain a temperature of 85°C (± 2°C) required for their peeling at the calculated time of 11 hr, but rather at an extended time of 19 hr. The temperature regulator of the vat had to be adjusted several times before it was able to give the required temperature. The question of overheating the log for the 19-hour period did not arise for two reasons:

1. The water bath temperature did not at any time attain a temperature of 85°C (± 2°C) until 18-19 hr. heating period.
2. The temperature within the log cannot exceed that of the

heating medium. The logs can therefore not attain a temperature of 85°C (± 2°C) required for their peeling without the vat maintaining that temperature.

5.3 Veneer peel-quality

5.3.1 Thickness

As shown in Table 8.9., the average veneer thicknesses were 1.25 mm, 1.22 mm and 1.19 mm; with standard deviations of 0.08 mm, 0.10 mm and 0.05 mm for the control bolts (20°C), bolts heated 8 hr. (to 50°C) and bolts heated 19 hr. (to 85°C) respectively. These averages are slightly below the objective veneer nominal thickness of 1.27 mm (0.05 in) by about 2%, 4% and 6% respectively. Even though the average veneer thickness is lowest at 85°C PT, thickness variation is under best control because of its smallest range compared to the other PTs. Generally, results show that veneer thickness variation is under good control as the three means are equal at the 0.05 level.

5.3.2 Roughness

As similarly shown in Table 18., the average veneer roughnesses were 0.15 mm, 0.21 mm and 0.24 mm for the control bolts (20°C), bolts heated 8 hr. (to 50°C) and bolts heated 19 hr. (to 85°C) with standard deviations of 0.05 mm, 0.07 mm and 0.06 mm respectively. The corresponding veneer roughness ranges are 0.12 mm, 0.38 mm and 0.38 mm for the three veneer PTs of 20°C, 50°C and 85°C. On the basis of these average and range values, the logs peeled at 20°C give the best veneer smoothness results. Generally, veneer roughness is very good and well within the limits for high quality veneer.

In view of the above, therefore, it can be stated that variation in thickness and roughness of veneer were not improved by heating the gmelina bolts to temperatures of 50°C and 85°C prior to peeling. Measurements by the visual roughness method indicated increased roughness at high PTs. Kinoshita and Ohira (1971), McMillin (1958) and Feihl (1964) reported from their studies on certain hardwoods (Philippine red lauan and yellow birch) that improved veneer peel-quality was obtained when these woods were heated prior to peeling. Madison (1957), however, indicated that heating of quaking aspen (Populus tremuloides) and big tooth aspen (Populus grandidentata) bolts above room temperature increased the fuzziness of the veneer surfaces.

5.4 Plywood bond quality

5.4.1 Treatment panels bonded with UF glue

5.4.1.1 Dry test: Shear strength and wood failure percent

The dry test shear strength results of the factorial analysis shown in Table 16 indicate that the PT and the GS are highly significant factors (i.e. significant at the 0.01 level). The interaction between PT and AT is significant at the 0.05 level. The presence of this interaction obscures any interpretation that could have been made on the main effects. This interaction may be more clearly understood by referring to Fig. 5. At the PT of 20°C, AT of 10 and 20 min have negligible influence on the shear strength of the treatment panels bonded with UF glue. At the PT of 50°C, however, prolonged AT of 20 min results in lower shear strength. A mild effect is produced at the highest PT of

85°C with the AT of 20 min. producing a higher shear strength.

Generally, plywood panels made from veneers cut at the PT of 85°C produce the highest shear strength at both levels of AT thus giving the most favourable bond quality on the basis of shear strength. At this PT, the shear strength of about 28 kg/cm^2 (398 psi) given by the treatment combination of Spread 70 - Time 20 is not statistically significant at the 0.05 level from the dry shear strength of about 26.8 kg/cm^2 (381 psi) and 25.5 kg/cm^2 (362 psi) given by the treatment combinations of Spread 70 - Time 10 and Spread 55 - Time 10 respectively. The lowest dry shear strength of about 21.5 kg/cm^2 (306 psi) is given by the treatment combination of Spread 55 - Time 10 at the PT of 20°C.

From the factorial analysis for wood failure shown in Table 16, the PT and the interaction of PT with GS and AT are highly significant. This interaction is better depicted in Fig. 6. Except for the treatment combination of Spread 70 - Time 20, bond quality, in terms of percentage wood failure, is consistently reduced at the higher PT for the remaining treatment combinations of Spread 55 - Time 10, Spread 55 - Time 20 and Spread 70 - Time 10 respectively. Generally, bond quality (in terms of percentage wood failure) is best for the plywood panels made from veneers cut at the PT of 20°C.

As shown in Table 21, treatment UF-20-55-20 produced the highest percentage wood failure of 70%, which is not significantly different at the 0.05 level from the percentage wood failures of 62% and 61% produced by treatments UF-20-70-10 and UF-50-70-20 respectively. The lowest percentage wood failure is produced by treatment UF-85-70-10.

5.4.1.2 Vacuum-pressure test: Shear strength and wood failure percent

The factorial analysis results for the shear strength samples of the UF glued panels, subjected to vacuum-pressure test, follow the same pattern as the dry test. As shown in Table 17, the PT is highly significant (0.01 level) whereas the GS is significant at the 0.05 level. The interaction between the PT and GS is highly significant. As depicted in Fig. 7, bond quality, in terms of wet shear strength, is slightly affected at both spread levels of 55 lb/MDGL and 70 lb/MDGL at the PT of 20°C and 85°C respectively. While wet shear strength is slightly higher with the higher spread at the PT of 20°C, the lower spread, on the other hand, gives a slightly higher shear strength at the PT of 85°C. The lower spread also gives higher shear strength at the PT of 50°C. Generally, plywood panels made from veneers cut at the PT of 85°C, produce the highest shear strength values at the two spread levels.

As shown in Table 20, the highest shear strength of about 22.4 kg/cm^2 (319 psi) given by treatment UF-85-55-20 is not significantly different at the 0.05 level from those given by treatments UF-50-55-10 (20.7 kg/cm^2 i.e. 295 psi), UF-50-55-20 (21.0 kg/cm^2 i.e. 299 psi), UF-85-70-20 (21.6 kg/cm^2 i.e. 307 psi) and UF-85-55-10 (20.7 kg/cm^2 i.e. 295 psi). In this test, the lowest shear strength of about 17.5 kg/cm^2 (249 psi) is given by treatment UF-50-70-20.

As further shown in Table 17, the vacuum-pressure test wood failure results for the UF glued panels indicate that the PT and the GS are highly significant factors, as well as the interaction between the PT, GS and the AT. The interaction between the PT and the GS is significant at the 0.05 level. As depicted for the interactions in

Fig. 8 and 9, bond quality, in terms of percentage wood failure, is consistently reduced at the PT of 50°C and 85°C. The lowest percentage wood failure is obtained at the PT of 85°C for each of the treatment combinations of Spread 55 - Time 10, Spread 55 - Time 20, Spread 70 - Time 10 and Spread 70 - Time 20.

As noted in Fig. 9, the influence of treatment combinations of Spread 55 - Time 20 and Spread 70 - Time 10 on percentage wood failure is not significant. These two treatments, at the PT of 20°C, give the highest percentage wood failure. At the PT of 50°C, there is no significant influence of treatment combinations of Spread 55 - Time 20 and Spread 70 - Time 20 on percentage wood failure. Bond quality at this PT is best with the treatment combination of Spread 55 - Time 20. Each of the four treatment combinations exerts a distinct influence on percentage wood failure at the PT of 85°C with treatment UF-85-55-20 giving the most favourable result.

The wood failure ranking in Table 21 shows that the highest percentage wood failure of 59% given by treatment UF-20-55-20 is not significantly different at the 0.05 level from the value of 56% given by treatment UF-20-70-10. The lowest percentage wood failure of 11% is given by the treatment combination of Spread 70 - Time 10 at the PT of 85°C.

5.4.2 Treatment panels bonded with PF glue

5.4.2.1 Vacuum-pressure test: Shear strength and wood failure percent

More interactions of the main effects are noted with the shear strength of the PF glued test samples subjected to vacuum-pressure test than for the UF glued test samples. As noted in Table 18, PT, GS and AT are highly significant (at the 0.01 level). Similarly, the interaction between PT and AT is highly significant. The interaction between PT and GS is significant at the 0.05 level. Fig. 10 and 11 depict these interactions. As shown in Fig. 10, higher wet shear strength is produced at each of the PT with the higher spread of 70 lb/MDGL. The spread of 55 lb/MDGL gives the highest shear strength at the PT of 20°C, whereas the spread of 70 lb/MDG gives the highest shear strength at the PT of 85°C (Fig. 10).

As shown in Fig. 11, wet shear strength is slightly higher with the AT of 10 min. at the PT of 50°C whereas the AT of 20 min. produces a slightly higher shear strength at the PT of 85°C. Generally, plywood panels made from veneers cut at the PT of 20°C and 85°C produce the highest wet shear strength values. From the shear strength ranking presented in Table 22, the highest shear strength value of about 28.5 kg/cm^2 (405 psi) is given by the treatment combination of Spread 70 - Time 20 at the PT of 85°C. This is, however, not statistically significant at the 0.05 level from the values of about 27.9 kg/cm^2 (397 psi) and about 26.9 kg/cm^2 (382 psi) given by the treatment combinations of Spread 70 - Time 10 (at PT of 20°C) and Spread 70 - Time 10 (at PT of 85°C). The lowest shear strength of about 21.7 kg/cm^2 (308 psi) is given by the treatment combination of Spread 55 - Time 10 at the PT of 50°C.

The factorial analysis (Table 18) for the wood failure of the PF treatments subjected to vacuum-pressure test shows that the PT, AT, PT-AT interaction and PT-GS-AT interaction are all highly significant.

The significant interactions are shown in Fig. 12 and 13. Fig. 12 shows that bond quality, in terms of percentage wood failure, is lowest at the PT of 85°C. Higher percentage wood failure is produced by the prolonged AT of 20 min. at each level of PT as against the AT of 10 min. The AT of 10 min. produces the highest percentage wood failure at the PT of 20°C; while the AT of 20 min. produces the highest percentage wood failure at the PT of 50°C.

As shown in Fig. 13, percentage wood failure decreased consistently between 20°C and 85°C PT for each of the treatment combinations of Spread 55 - Time 20, Spread 70 - Time 10, Spread 70 - Time 20 and Spread 55 - Time 10. At the PT of 85°C, the highest percentage wood failure is produced by the treatment combination of Spread 55 - Time 20. For the three treatment combinations of Spread 55 - Time 10, Spread 55 - Time 20 and Spread 70 - Time 10, the highest percentage wood failures are produced at the PT of 20°C. For this particular test, however, the highest and most favourable bond quality is given by the treatment combination of Spread 70 - Time 20 at the PT of 50°C. From the wood failure ranking presented in Table 23, the percentage wood failure of 64% given by the treatment is significantly different at the 0.5 level to the value shown by any other treatment. The lowest percentage wood failure of 7% is given by the treatment combination of Spread 55 - Time 10 at the PT of 85°C.

5.4.2.2 Boil-dry-boil test: Shear strength and wood failure percent

Shear strength results for this test (Table 19) indicate that the PT, GS and AT are highly significant. Similarly, the interaction of the PT with the AT is highly significant. From Fig. 14, the lower AT of 10 min. produces higher wet shear strength than the prolonged AT of 20 min. at the PT of 20°C and 50°C. At the PT of 85°C, however, the prolonged AT of 20 min. gives a higher wet shear strength. Furthermore, with the AT of 10 min. the highest wet shear strength is produced at the PT of 20°C; whereas with the AT of 20 min. the highest wet shear strength is given at the PT of 85°C.

Generally, plywood panels made from veneers cut at temperatures 20°C and 85°C give the most favourable bond quality. From the shear strength ranking presented in Table 22, the highest wet shear strength of about 23.5 kg/cm^2 (334 psi) is given by the treatment combination of Spread 70 - Time 20 at the PT of 85°C. This, however, is not significant at the 0.05 level from the values of about 22.6 kg/cm^2 (322 psi) and 22.1 kg/cm^2 (315 psi) given by the treatment combinations of Spread 70 - Time 10 (at the PT of 20°C) and Spread 70 - Time 10 (at the PT of 85°C). The lowest shear strength of 16.8 kg/cm^2 (239 psi) is given by the treatment combination of Spread 55 - Time 20 at the PT of 50°C.

Wood failure results for same test (Table 19) indicate that the PT, GS and AT are highly significant. Similarly, the interactions between the PT and GS as well as PT and AT are highly significant. From the interaction shown graphically in Fig. 15, the PT of 85°C gives the lowest bond quality (in terms of percentage wood failure) at each of the spread levels of 70 lb/MDGL and 50 lb/MDGL. With the lower spread, percentage wood failure is highest at the PT of 20°C, while the higher spread gives the highest percentage wood failure at the PT of 50°C.

Fig. 16 shows a similar trend in bond performance to Fig. 15. The prolonged AT of 20 min. results in higher percentage wood failure than the lower AT of 10 min. at all three levels of PT. For the AT of 10 min., percentage wood failure is highest at the PT of 20°C and lowest at the PT of 85°C. For the AT of 20 min., percentage wood failure is highest at the PT of 50°C and lowest at the PT of 85°C. Generally, plywood panels made from veneers cut at 50°C gave the highest percentage wood failure for this particular test. From the wood failure ranking presented in Table 23, the highest percentage wood failure of 66% given by the treatment combination of Spread 70 - Time 20 at the PT of 50°C is significantly different at the 0.05 level to the value shown by any other treatment. The lowest percentage wood failure of 12% is given by treatment combinations of Spread 55 - Time 10 (at the PT of 50°C) and Spread 55 - Time 10 (at the PT of 85°C).

5.4.3 Probable factors accounting for low percentage wood failures in the treatments.

The following explanations are presented as the possible causes of low bond quality performance (in terms of percentage wood failure) shown by the treatments, especially with the use of PF glue:

1. The veneers used for the study were not obtained from fresh logs. The logs peeled were from the consignment shipped from Nigeria to SNC-Rust Company Limited, of Montreal. They had been kept in cold storage by the company for at least a year prior to their use. The sapwood zone had dried out considerably and veneers from this wood zone were also used when constructing certain of the panels. Discoloration of such veneers to a dark brown or blackish color had already occurred, as noticed at

peeling. Further veneer discoloration occurred between the 30 days that expired between the peeling and drying of the veneers.

2. There is also the problem of influence of surface aging of veneer prior to gluing. Eighty days expired between the peeling and gluing of the veneers. Surface aging of wood has been reported to drastically reduce its wettability and, in turn, the quality of the glue bond (Gray 1962, Marian 1962, Marian and Stumbo 1962b, Stumbo 1964, Herczeg 1965 and Collett 1972). The relationship between wood wettability and its gluability has also been noted in Section 2.8.

It was noticed that where the discolored veneers were used as cores, low or zero percentage wood failures were developed. No attempt was made to give the veneers light surface sanding prior to gluing. The introduction of such a variable would have doubled the number of treatments used. Due to the limited amount of veneer available, it was impossible to include this variable. Walters (1973), for example, reported that poor gluing resulted from decreased surface wettability and surface inactivation but could be improved upon by giving the veneers a light surface sanding prior to gluing. He obtained higher percentage wood failure for the sanded veneers compared to the unsanded veneers.

Comparing the results of the PF treatments, vacuum-pressure test, with the UF treatments, vacuum-pressure test (Tables 10 and 11), the PF IB-334 glue used seems to be more sensitive to surface inactivation, resulting from surface aging of veneers, than the Monsanto UF 109 glue used, thus accounting for its lower percentage wood failure.

3. Variability in bond quality between and within panels is a usual phenomenon. This is illustrated by Tables 12 to 15. Regardless of type of bond quality test, large variability in percentage wood failure was observed with both the UF and PF treatments alike. This is indicated by the wide ranges shown in columns 11-13 of Tables 12 to 15 respectively.

In addition, and more likely, this variability is the result of such factors as:

i) differences in veneer moisture content at gluing.

ii) panel edge effect.

iii) differences in degree of cure of glueline.

iv) human factor introduced during veneer gluing especially with regards to the open assembly time (Not introduced as a variable in the study).

v) stress concentrations inherent in the test specimens during shear testing.

It was noticed, for example, that longer open assembly time was used when gluing with the PF glue than the UF glue. This was due to the difficulty encountered while spreading the glue on the veneers. Because it was less viscous than the UF glue, it was leaking out of the roller spreader. The glue was therefore spread on one face of the veneer then the piece was flipped over for the spreading of the other face. The effect of long open assembly time on phenolic glue has been reviewed in Section 2.6.2.

4. The PF resin used was more caustic (pH 12.5 - 13.5) than the UF resin (pH 8.4). The buffering capacity of the UF resin, therefore, would be low at high panel pressing temperature of 127°C (260°F). Due to moisture and natural acids in wood (uronic acids of hemicelluloses), hydrolysis condition may be created. This weakens the wood structure in the vicinity of the glueline, thereby causing failure at lower shear loads with higher percentage wood failures as evidenced by vacuum-pressure results of both glues in Tables 10 and 11.

5. As reviewed in Section 2.1, the resin content of gmelina wood is high. The low percentage wood failures exhibited by the PF and UF treatments could, therefore, be due to interference of the wood extractives with the glues. The PF resin has a pH of 12.5 to 13.5, which should be enough to saponify the extractives on the veneer surfaces (Chow 1977b). However, the PF treatments showed lower percentage wood failure values compared to the UF treatments (UF has a pH of 8.5). This, seems to contradict the interference concept. The definite influence of the extractives of the wood on bond quality is therefore difficult to make.

It is the view of the writer that with fresh veneers, better bond quality could be obtained with gmelina wood.

5.4.4 Comparison of study results with some National Plywood Standards

As indicated in Section 2.7, the U.S., British and German Plywood Standards will be used to assess bond quality results obtained in this study.

5.4.4.1 U.S. Hardwood plywood standard

The specifications of the U.S. Department of Commerce Voluntary Product Standard PS 51-71 for Technical and Type I (both Exterior Grades) Hardwood plywood are:

Average failing load (psi)	Average Wood failure (%)	Individual specimen minimum wood failure (%)
Under 250	50	25
250 - 350	30	10
Above 350	15	10

PF treatments from this study that meet the above Exterior Grade Plywood requirements are as follows:

Treatments	Average failing Load (psi)	Average Wood failure (%)	Individual Specimen minimum wood failure (%)
PF-Vacuum-Pressure			
1. PF-20-55-20	318	45	15
2. PF-20-70-10	397	31	10
3. PF-20-70-20	337	34	10
4. PF-50-55-20	313	45	10
5. PF-50-70-20	317	64	30
PF-Boil-dry-boil			
1. PF-20-55-20	255	43	10
2. PF-20-70-10	322	38	10
3. PF-20-70-20	276	34	10
4. PF-50-55-20	239	46	10
5. PF-50-70-20	258	66	10

As noted in the above comparison, three of the five treatments, from each of the bond quality testing methods, passing the U.S. standard are treatment combinations arising from the PT of 20°C. The remaining two treatments come from the PT of 50°C. No treatment combination arising from the PT of 85°C meets this standard. It can therefore be concluded that a PT of 85°C produces roughest veneers (compared to the PT of 20°C and 50°C) (Table 8) which, when glued into plywood, result in low bond quality - in terms of percentage wood failure.

Among the five treatments that meet the U.S. standard, the shear strength of about 22.3 kg/cm^2 (317 psi) obtained from treatment PF-50-70-20 is not statistically different at the 0.05 level to the value

[illegible] 22.4 kg [illegible]

of about 22.4 kg/cm^2 (318 psi) obtained from treatment PF-20-55-20 (Vacuum-pressure test). On the basis of the U.S. standard, therefore, treatment PF-20-55-20 may be of greater industrial importance than treatment PF-50-70-20. It facilitates lower production costs because higher energy consumption is required to heat logs to 50°C as well as higher adhesive cost at a spread of 70 lb/MDGL as against 55 lb/MDGL. However, where the industry hopes to maximise bond quality with respect to shear strength and percentage wood failure, treatment PF-50-70-20 is most suitable.

Also comparing treatments PF-20-55-20 and PF-20-70-10, the shear strength of about 27.9 kg/cm^2 (397 psi) obtained for the latter is statistically different at the 0.05 level from the shear strength of about 22.4 kg/cm^2 (318 psi) obtained for the former. Treatment PF-20-55-20 may, however, be of industrial importance because of its lower glue cost (both treatments are from the same PT and produce the highest percentage wood failure values). Nevertheless, where the industry hopes to maximise bond quality in terms of wood shear strength, treatment PF-20-70-10 is most favourable.

This same analysis applies exactly to the five PF-Boil-dry-boil treatments that meet the U.S. standard. Treatment PF-20-55-20 is preferred because of advantage of lower production cost in heating and adhesive cost; treatment PF-50-70-20 is preferred where both high shear strength and percentage wood failure are of prime importance and treatment PF-20-70-10 is most favoured where very high shear strength is most desirable.

UF treatments that also meet the U.S. standard are as follows:

Treatments	Average failing Load (psi)	Average Wood failure (%)	Individual Specimen minimum wood failure (%)
<u>UF-Dry Test</u>			
All the Twelve Treatments used. UF-20-55-10 through UF-85-70-20	306-389	35-70	10-35
<u>UF-Vacuum Pressure</u>			
1. UF-20-55-10	264	38	10
2. UF-20-55-20	274	59	15
3. UF-20-70-10	260	56	15
4. UF-20-70-20	277	44	10
5. UF-50-55-10	295	33	10

Since vacuum-pressure results give better information on bond quality performance than the dry test, the five treatments listed above will only be viewed as the UF treatments meeting the U.S. standard. Of these five treatments, four arise from the PT of 20°C and none from the 85°C. This also suggests that even with the UF glue, the PT of 85°C fails to produce plywood of adequate bond quality regardless treatment combination. Among the five treatments listed, treatment UF-20-55-20 is most favoured to a plywood industry. It facilitates lower production cost because higher energy cost is required to heat logs to 85°C and lower glue cost is ensured at a spread of 55 lb/MDGL as against 70 lb/MDGL. High shear strength and percentage wood failure are both maximised in the treatment. All five treatments are considered adequate for producing Interior grade plywood.

5.4.4.2 British Hardwood Plywood Standard

The British Standard B.S. 1455:1963 for Tropical Hardwood Plywood specifies an average percentage wood failure of 50%. The study PF and UF treatments that meet this standard are as follows.

Treatments	Average Wood failure (%)
PF-Vacuum Pressure	
PF-50-70-20	64
PF-Boil-dry-boil	
PF-50-70-20	66
UF-Dry Test	
UF-20-55-10	57
UF-20-55-20	70
UF-20-70-10	62
UF-20-70-20	52
UF-50-55-10	53
UF-50-70-20	61
UF-Vacuum Pressure	
UF-20-55-20	59
UF-20-70-10	56

On the basis of the British Standard, the only PF treatment that meets the standard (PF-20-70-20) is considered adequate for use as Weather and boil-proof, Boil-resistant and Moisture resistant Exterior grade plywood. On the other hand, the two UF treatments under Vacuum-pressure test that meet the standard are considered adequate for use as

Interior grade plywood. Out of these two treatments, however, UF-20-55-20 is of greater industrial importance than treatment UF-20-70-10 since its spread of 55 lb/MDGL ensures lower cost of adhesive consumption than the spread of 70 lb/MDGL for the other treatment. Its higher percentage wood failure of 59% is not statistically different at the 0.01 level from the average of 56% for the other treatment.

5.4.4.3 German[12] Hardwood Plywood Standard

The German standard, Deutshe Industrie Normen DIN 68705-1968 specifies an average shear strength of 10 kp/cm^2 (142 psi). All the 24 treatments used in this study, regardless of glue type and bond quality testing methods, meet the German Hardwood Plywood Standard. Shear strength values are in the range of about 16.8 to 28.5 kg/cm^2 (239 to 405 psi).

Cost consideration may justify the use of treatment PF-20-55-20 and UF-20-55-20 with average shear strengths of about 22.4 kg/cm^2 (318 psi) and about 19.3 kg/cm^2 (274 psi) respectively under vacuum-pressure test.

5.5 Probable end uses of _Gmelina arborea_ Veneer and Plywood

From the findings of this study, _Gmelina arborea_ plywood is suited for the following uses:

5.5.1 Construction plywood

Specific gravity in the range of 0.41 to 0.55, is one of the physical properties of wood considered of major importance for construction plywood (Lutz 1971). With a specific gravity of 0.41 ± 0.027 as

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[12] Same as Japanese Standard this s

found for Gmelina arborea in this study, the wood is marginally suitable for construction plywood. Shear strength is another mechanical property of major importance. From the glueline shear strength obtained in this study, therefore (Table 11), the wood is quite suitable for construction plywood. This ranges between 239 - 405 psi (about 16.8 kg/cm^2 - 28.5 kg/cm^2) for the PF treatments that pass the various World plywood Standards already discussed. These shear strength values compare favourably and in some cases more favourably (Hancock 1977c, Chow and Warren 1972, Walters 1973, Hse 1971) to the plywood shear strengths found from diverse studies for some woods used for construction plywood. Other essential considerations are moderate weight and ease of gluing. Lamb (1968) reported a density range of 30 to 31 lb./cu.ft. for Gmelina arborea grown in Nigeria, India, Gambia and Malaysia. This, as he indicated, puts the wood in the right weight category for many uses. This study has also demonstrated that the wood glues easily depending on treatment combinations of peeling temperature, glue spread and closed assembly time.

Therefore, Gmelina arborea plywood may be considered suitable for building construction as subfloor, wall sheathing, roof sheathing and siding panels; overlaid panels; and concrete forms.

5.5.2 Core and Crossband veneer for decorative plywood

Specific gravity is also one of the physical properties considered of major importance for core and crossband veneers for decorative plywood (Lutz 1971). For such a use, a typical specific gravity range of 0.32 to 0.45 is required. The specific gravity of gmelina wood

(0.41 ± 0.027) satisfies this requirement. On this basis, therefore, veneers from gmelina are quite suitable for use as core and crossbands for decorative plywood. As indicated by Lutz (1971), uniformity of wood structure is particularly desirable for crossband veneers meant to be used as decorative panels in order to minimize "telegraphing" of the grain to the face. Thus, diffuse-porous hardwoods like yellow birch and yellow-poplar have been reported as good veneer species. As a diffuse-porous hardwood, gmelina has been found from this study to yield relatively smooth veneers. Ease of gluing, straight and fine, uniform grain are other desirable veneer qualities when considering veneers for use as cores and crossbands for decorative plywood. As discussed in Section 2.1 and Section 3.2.3, gmelina wood satisfies these requirements. This seems to strengthen the suitability of gmelina wood for use as core and crossband veneers for decorative plywood for products like furniture, flush doors and case goods.

5.5.3 Container veneer and plywood

Woods meant to be cut into veneers for use as container veneer and plywood are expected to possess the following physical and mechanical properties: specific gravity in the range of 0.36 to 0.65, light color, freedom from odor, high stiffness (MOE), high shock resistance (MOR) and high strength in tension perpendicular to the grain. Since the only mechanical property measured in this study is the shear strength, it becomes difficult to access the gmelina veneers on the basis of MOE and MOR. However, on the basis of the shear strength and the physical property involving specific gravity, color and odor (See Section 3.2.3), gmelina wood is suitable for use as container veneer and plywood.

Since the veneers used for this study were not obtained from fresh-cut gmelina logs, it is difficult to assess the suitability of the wood for use as decorative veneer and plywood on the basis of attractiveness and figure.

6.0 SUMMARY, SUGGESTIONS FOR FURTHER STUDIES AND CONCLUSION

6.1 Summary

The data listed below contribute to the knowledge of the bonding characteristics of *Gmelina arborea* wood:

1. Even though the presence of a significant interacting effect may obscure interpretation of a significant main effect in a statistical analysis, the effects of the peeling temperatures used are nevertheless found highly significant regardless of glue type and bond quality testing method.
2. Similarly, the effects of the glue spreads used (a major factor in total cost of plywood manufacture) are found highly significant in 3 of the 4 ANOVA's for shear strength results.
3. Veneers of the highest peel-quality are produced with the 20°C (control) peeling temperature whereas the temperature of 85°C yields veneers of the lowest peel-quality.
4. Thus, the study has demonstrated that gmelina wood can be satisfactorily rotary-cut into good veneers without any prior heating.
5. Bond quality, in terms of percentage wood failure, is consistently reduced by increasing peeling temperature and is lowest at the peeling temperature of 85°C in all the UF and PF treatments used, reagrdless of bond quality testing method.
6. The peeling temperature of 20°C (control) gives the best bond quality results in terms of percentage wood failure in all the UF treatments used, regardless of type of bond quality

testing method.

7. In spite of the distinctive performance of the treatment combination of Spread 70 - Time 20 at the peeling temperature of 50°C, the treatments arising from the 20°C (control) peeling temperature also give the most impressive bond quality results in terms of percentage wood failure in all the PF treatments regardless of bond quality testing method.

8. Among the UF treatments used, ignoring glue spreads, those arising from the peeling temperatures of 50°C and 85°C give the highest shear strength values regardless of type of bond quality testing methods. In most cases, shear strength differences are marginal between these two peeling temperatures.

9. Among the PF treatments used, ignoring glue spreads, those arising from the peeling temperatures of 20°C and 85°C both give the highest shear strength values regardless of type of bond quality testing methods.

10. At the peeling temperature of 20°C (control), treatment combination of Spread 70 - Time 10 gives the most favourable bond quality among the UF treatments, regardless of type of bond quality testing method. However, the shear strength and percentage wood failure values developed are not significant at the 0.05 level from those given by treatment combination of Spread 55 - Time 20. Among the PF treatments, however, the treatment combination of Spread 70 - Time 10 develops a significantly higher shear strength than treatment combination of Spread 55 - Time 20, while the latter has a significantly

higher percentage wood failure in one of the bond quality testing methods used.

11. At the peeling temperature of 50°C, the highest percentage wood failure is developed with the treatment combination of Spread 70 - Time 20 regardless of glue type and bond quality testing method.

12. At the peeling temperature of 85°C, the highest shear strength is developed with the treatment combination of Spread 70 - Time 20 regardless of glue type and bond quality testing method.

13. All factors considered, the treatment combination of Spread 55 - Time 20, at the peeling temperature of 20°C (control), gives an impressive bond quality in all the UF and PF treatments used.

14. Five of the 12 PF treatments used, regardless of type of bond quality testing method, pass the U.S. Plywood Standard; one passes the British Standard; while all pass the German Standard. On the other hand, five of the 12 UF treatments from vacuum-pressure test pass the U.S. Standard; two pass the British Standard; while all pass the German Standard. Furthermore, all the 12 UF treatments from dry test pass the U.S. Standard; six pass the British Standard; while all pass the German Standard.

15. From the results of this study, plantation-grown *Gmelina arborea* wood, with a specific gravity of 0.41 ± 0.027 (as determined), is suitable for use as construction plywood, core and crossband veneer for decorative panel as well as container veneer and plywood.

6.2 Suggestions for further studies

Conclusive evidence has been presented for the suitability of Gmelina arborea wood for veneer and plywood production depending on the treatment combinations of wood peeling temperature, glue spread and closed assembly time.

However, further work would be necessary to improve upon the bond quality achieved with the wood, especially using PF resin adhesive. Suggested areas of study are as follows:

1. Determination of the optimum peeling temperature.
2. Effects of veneer drying schedules on bonding characteristics of the wood.
3. Effects of assembly time (open and close), pressing time, temperature and pressure trials on bond quality.
4. Glue formulation and optimum glue spread trials.
5. Nature of the resin present in the wood and its effect on wettability and gluability of gmelina wood.

6.3 Conclusion

The findings of this study are considered of research, industrial and economic importance to the wood-based panel industry in Nigeria as well as the States Forestry Services responsible for plantations establishment. Management of gmelina plantations in Nigeria for future supply of veneer logs is considered a justifiable investment.

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Table 1. Descriptive features of the *Gmelina arborea* logs used for study.

Log Number	Estimated age from Growth Ring Count[1]	No. of knots present in log	Log diameter* (cm)	Bark thickness cm)	Sapwood thickness (cm)	Presence of Tension wood
1	8	5	22.2	4.1	2.8	Yes
2	10	8	18.4	4.3	1.7	No
3	12	3	21.0	5.8	1.5	Yes
4	9	4	16.5	3.0	1.8	Yes
5	10	6	19.1	4.6	2.0	No
6	8	5	19.7	4.3	2.7	Yes
7	9	5	18.4	5.3	1.7	Yes
8	10	7	19.7	5.8	1.5	No
9	12	4	20.3	3.6	1.8	Yes

* Average for both ends of the log.

1 It was found convenient to use growth rings to estimate age of the logs since, as reported by Lamb (1968), growth rings are noted to be visible and usually annual for *Gmelina arborea* grown in Thailand.

Table 2. Initial and peeling moisture content (%) of the *Gmelina arborea* logs used for study.

Log Number	Peeling temp(^{o}C)	Initial MC (%)			Peeling MC (%)		
		Sapwood	Heartwood	Corewood	Sapwood	Heartwood	Corewood
2	20	90	124	132	90	124	132*
4	20	82	107	90	82	107	90*
8	20	96	114	104	96	114	104*
5	50	45	67	76	61	65	78
6	50	41	79	67	88	104	73
7	50	107	147	118	105	149	139
1	85	53	123	103	45	76	111
3	85	59	128	101	67	120	81
9	85	91	115	107	78	85	79

* Since these logs were not heated, peeling MCs were not determined. They were assumed to be same as the initial MC previously determined.

Table 3. Specific gravity[1] of the <u>Gmelina arborea</u> logs used for study.

Log Number	Log Average[2] Specific Gravity	Sample Mean Specific Gravity
1*	0.42	
2	0.44	
3*	0.37	Mean = 0.41 SD[3] = 0.027
4*	0.43	
5	0.38	
6*	0.44	
7*	0.41	
8	0.41	
9*	0.37	

1 Determined by Volume Measurement Method.

2 Average for four test samples.

3 SD = Standard Deviation.

* Logs with Tension wood (Identified by visual examination of Pith displacement).

Table 4. Water bath and log temperature changes against time of heating - 50°C.

Nominal heating temperature: 50°C[1] ± 2°C

Heating Period (hours)	Water Bath Temperature (°C)	Wood Temperature at core, 4 in from Log Surface, recorded by Thermocouples (°C)	Wood Temperature at 1 in from the Log Surface, Estimated[2] (°C)
0	21.5	17.8	18.8
1	46.6	20.1	27.9
2	46.4	25.3	30.7
3	45.6	30.1	36.0
4	45.0	33.9	37.7
5	48.8	36.9	42.2
6	52.9	38.0	47.9
7	53.0	39.8	50.0
8	54.4	41.6	51.8

1 A wood temperature of 50°C ± 2°C was considered acceptable for the 50°C heating since it was difficult to control the temperature within the vat.

2 Using MacLean (1946) formulae

Table 5. Water bath and log temperature changes against time of heating - 85°C.

Nominal heating temperature: 85°C ± 2°C

Heating Period (hours)	Water Bath Temperature (°C)	Wood Temperature at core, 4 in from Log Surface, recorded by Thermocouples (°C)	Wood Temperature at 1 in from the Log Surface, Estimated[2] (°C)
0	20.1	17.7	18.4
1	50.5	19.2	29.3
2	70.4	25.1	41.4
3	81.6	45.0	60.0
4	81.4	60.1	64.3
5	81.5	64.9	68.0
6	81.5	67.4	72.5
7	81.6	68.9	76.2
8	81.5	69.9	77.5
9	81.4	70.8	78.8
10	81.5	71.4	79.7
11	81.3	71.8	79.5
12	81.3	72.1	80.4
13	81.1	72.3	80.7
14	80.9	72.4	80.4
15	82.1	72.3	81.7
16	82.3	72.3	81.8
17	82.9	72.6	82.4
18	87.0	73.7	86.5
19	86.9	75.6	86.4

1 A Wood temperature of 85°C ± 2°C was considered acceptable for the 85°C heating.

2 Using MacLean (1946) formulae.

Table 6. Lathe specifications for peeling:

1.27 mm (0.05 in) *Gmelina arborea* green veneer.
9 bolts sampled*

Horizontal Gap	1.11 mm (0.044 in)
Vertical Gap	0.25 mm (0.010 in)
Veneer Thickness	1.27 mm (0.05 in)
Nosebar Type	Solid nosebar
Nosebar Face Angle	14^{o}
Knife Thickness	15.88 mm (5/8) in
Knife Length	167.64 cm (66 in)
Rockwell Hardness	56
Main Bevel	23^{o}
Cutting Angle (at 10-1/2 in)	89^{o} 30'
Speed of Cut	120 fpm

* Diameters of the bolts ranged between 16.5 cm (6.5 in) to 22.2 cm (8.8 in).

Table 7. Peel-quality attributes: Veneer roughness measurement.

Total No. of Veneer sheets sampled	Roughness Scale	in Equivalent	mm Equivalent	Frequency	Frequency %
<u>20°C Peeling</u>					
175	0	0.000	0.00	0	0.0
	1	0.005	0.13	143	81.7
	2	0.010	0.25	32	18.3
<u>50°C Peeling</u>					
194	0	0.000	0.00	2	1.0
	1	0.005	0.13	65	33.5
	2	0.010	0.25	120	61.9
	3	0.015	0.38	7	3.6
<u>85°C Peeling</u>					
173	0	0.000	0.00	0	0.0
	1	0.005	0.13	26	15.0
	2	0.010	0.25	132	76.3
	3	0.015	0.38	13	7.5
	4	0.020	0.51	2	1.2

Table 8. Veneer peel-quality statistics.

1.27 mm (0.05-in) *Gmelina arborea* green veneer

Veneer Attributes	Peeling temperature	Mean (mm)	SD* (mm)	Max (mm)	Min (mm)	Range (mm)
1. Thickness	20°C (Control)	1.25	0.08	1.37	1.17	0.20
	50°C (Heated 8 hr.)	1.22	0.10	1.32	1.04	0.28
	85°C (Heated 19 hr.)	1.19	0.05	1.27	1.14	0.13
2. Roughness	20°C (Control)	0.15	0.05	0.25	0.13	0.12
	50°C (Heated 8 hr.)	0.21	0.07	0.38	0.00	0.38
	85°C (Heated 19 hr.)	0.24	0.06	0.51	0.13	0.38

N.B. * Standard Deviation.

Table 9. Veneer moisture content prior to gluing.

Sample Number	VENEER MOISTURE CONTENT (%)		
	VENEER PEELING TEMPERATURE (°C)		
	20	50	85
1	6.6	6.8	7.4
2	7.3	5.9	6.2
3	6.5	6.1	5.5
4	6.4	7.3	6.3
5	7.3	6.4	6.6
6	5.7	6.4	6.4
7	6.7	6.0	7.2
8	7.2	6.9	6.4
9	6.0	6.0	6.0
10	5.8	6.5	5.8
Average	6.6	6.4	6.4

N.B. 1. CTH Room Conditions: Temperature = Dry bulb 80°F; Dew Point 43°F

Relative Humidity = 26%.

2. Time of conditioning in the CTH Room = 15 days.

Table 10. Average shear strength and average wood failure of 5-ply *Gmelina arborea* Plywood bonded with Urea-Formaldehyde (UF) glue.

	DRY TEST				VACUUM-PRESSURE TEST			
Treatments	Mean Shear Strength (psi)	Mean Wood Failure (%)	Minimum Specimen Wood Failure (%)	No. of Test Specimens	Mean Shear Strength (psi)	Mean Wood Failure (%)	Minimum Specimen Wood Failure (%)	No. of Test Specimens
UF-20-55-10	306	57	20	34	264	38	10	34
UF-20-55-20	312	70	35	35	274	59	15	36
UF-20-70-10	332	62	30	28	260	56	15	36
UF-20-70-20	326	52	10	28	277	44	10	36
UF-50-55-10	312	53	10	22	295	33	10	25
UF-50-55-20	353	38	10	27	299	24	0	30
UF-50-70-10	334	40	10	24	253	18	5	23
UF-50-70-20	353	61	15	26	249	31	5	26
UF-85-55-10	362	39	15	30	295	24	0	36
UF-85-55-20	342	38	15	30	319	24	10	30
UF-85-70-10	381	35	10	23	281	11	0	29
UF-85-70-20	389	47	10	27	307	14	0	30

N.B.

1. Figures rounded to the nearest unit.
2. Treatment codes are as follows:

e.g. UF-20-55-10

- 10 → Closed assembly time (min)
- 55 → Glue spread (lb. IMDGL)
- 20 → Peeling temperature (^{o}C)
- UF → Glue used (Urea-formaldehyde)

Table 11. Average shear strength and average wood failure of 5-ply *Gmelina arborea* Plywood bonded with Phenol-Formaldehyde (PF).

	VACUUM PRESSURE TEST				BOIL-DRY-BOIL TEST			
Treatments	Mean Shear Strength (psi)	Mean Wood Failure (%)	Minimum Specimen Wood Failure (%)	No. of Test Specimens	Mean Shear Strength (psi)	Mean Wood Failure (%)	Minimum Specimen Wood Failure (%)	No. of Test Specimens
PF-20-55-10	346	20	0	36	288	21	5	35
PF-20-55-20	318	45	15	30	255	43	10	34
PF-20-70-10	397	31	10	31	322	38	10	33
PF-20-70-20	337	34	10	30	276	34	10	28
PF-50-55-10	309	16	0	25	247	12	0	26
PF-50-55-20	313	45	10	22	239	46	10	23
PF-50-70-10	354	20	0	35	304	30	5	35
PF-50-70-20	317	64	30	30	258	66	10	30
PF-85-55-10	321	7	0	36	259	12	0	33
PF-85-55-20	330	19	5	28	286	16	5	35
PF-85-70-10	382	15	0	29	315	16	0	22
PF-85-70-20	405	10	0	36	334	16	0	31

N.B. 1. Figures rounded to the nearest unit.

2. Treatment codes are as follows:

e.g. PF-20-55-10

- 10 → Closed assembly time (min)
- 55 → Glue spread (lb/MDGL)
- 20 → Peeling temperature (^{o}C)
- PF → Glue used (Phenol-formaldehyde)

Table 12. Within - and between - panel variation in bond quality of 5-ply *Gmelina arborea*. Plywood bonded with UF glue: Dry test wood failure.

Treatments	Mean Wood Failure (%) Panels			Max.Wood Failure (%) Panels			Min.Wood Failure (%) Panels			Range Panels		
	1	2	3	1	2	3	1	2	3	1	2	3
UF-20-55-10	38	72	62	55	100	95	20	50	35	35	50	60
UF-20-55-20	77	69	63	95	95	85	55	55	35	40	40	50
UF-20-70-10	60	51	76	90	90	95	35	40	50	55	50	45
UF-20-70-20	43	57	51	85	90	90	10	25	20	75	65	70
UF-50-55-10	56*	46*	57	70	95	95	40	10	20	30	85	75
UF-50-55-20	29*	47	35*	45	80	90	15	15	10	30	65	80
UF-50-70-10	52*	23*	36	95	40	75	10	10	10	85	30	65
UF-50-70-20	65*	49*	71	95	90	95	30	15	45	65	75	50
UF-85-55-10	37	43	36	55	60	60	20	15	20	35	45	40
UF-85-55-20	25	48	47	45	90	100	15	15	15	30	75	85
UF-85-70-10	19	34	46	40	85	70	10	10	15	30	75	55
UF-85-70-20	47	48	46	90	75	75	20	10	15	70	65	60

N.B.

* Panels with yellow birch veneers as faces and backs.

1. Figures rounded to the nearest unit.
2. The Grand Mean Wood Failure of the Means of the above 3 panels for a particular treatment may not be same as in Table 10 due to rounding.
3. Panels 1, 2 and 3 above are same as those in Table 13 respectively. Half of the test samples from each panel was used for the above test while the other half was used for the test in Table 13.

Table 13. Within - and between - panel variation in bond quality of 5-ply *Gmelina arborea* Plywood bonded with UF glue: Vacuum-pressure test, wood failure.

	Mean Wood Failure (%)			Max. Wood Failure (%)			Min.Wood Failure (%)			Range		
	Panels			Panels			Panels			Panels		
Treatments	1	2	3	1	2	3	1	2	3	1	2	3
UF-20-55-10	44	42	32	70	70	55	10	10	15	60	60	40
UF-20-55-20	60	67	51	95	95	90	25	20	15	70	75	75
UF-20-70-10	81	70	37	100	90	65	50	30	15	50	60	50
UF-20-70-20	42	31	58	90	60	95	10	10	20	80	50	75
UF-50-55-10	24*	38*	35	35	55	75	15	20	10	20	35	65
UF-50-55-20	12*	47	14*	40	60	55	5	30	0	35	30	55
UF-50-70-10	23*	17*	11	85	55	15	10	5	5	75	50	10
UF-50-70-20	16*	6*	68	40	10	85	5	5	35	35	5	50
UF-85-55-10	11	39	21	30	65	50	0	0	0	30	65	50
UF-85-55-20	15	38	20	35	75	45	10	10	10	25	65	35
UF-85-70-10	7	7	18	20	20	60	0	0	0	20	20	60
UF-85-70-20	10	19	9	35	75	40	0	0	0	35	75	40

N.B. * Panels with yellow birch veneers as faces and backs.

1. Figures rounded to the nearest unit.

2. Because of rounding, the Grand Mean Wood Failure of the means of the above 3 panels for a particular treatment may not be same as in Table 10.

Table 14. Within - and between - panel variation in bond quality of 5-ply *Gmelina arborea*. Plywood bonded with PF glue: Vacuum-pressure test, wood failure.

	Mean Wood Failure (%)			Max.Wood Failure (%)			Min.Wood Failure (%)			Range		
	Panels			Panels			Panels			Panels		
Treatments	1	2	3	1	2	3	1	2	3	1	2	3
PF-20-55-10	28	13	13	75	30	35	5	0	0	70	30	35
PF-20-55-20	39	51*	49*	80	80	80	15	25	30	65	55	50
PF-20-70-10	37	32	25	80	60	85	10	10	10	70	50	75
PF-20-70-20	18	45	37	45	80	75	10	15	10	35	65	65
PF-50-55-10	3	6	35	10	15	80	0	0	0	10	15	80
PF-50-55-20	38	31	52	90	75	95	10	10	10	80	65	85
PF-50-70-10	21	8*	29*	50	25	70	0	0	0	50	25	70
PF-50-70-20	64	68*	52*	95	95	80	35	30	35	60	65	50
PF-85-55-10	6	8	7	10	30	45	0	0	0	10	30	45
PF-85-55-20	24	24	13	50	75	40	5	5	5	45	70	35
PF-85-70-10	15	28	8	30	65	30	5	5	0	25	60	30
PF-85-70-20	4	3	18	15	10	55	0	0	0	15	10	55

N.B. * Panels with yellow birch veneers as faces and backs.

1. Figures rounded to the nearest unit.
2. The Grand Mean Wood Failure of the means of the above 3 panels for a particular treatment may not be the same as in Table due to rounding.
3. Panels 1, 2 and 3 above are same as those in Table 15 respectively. Half of the test samples of each of the panel was used for the above test while the other half was used for the test in Table 11.

Table 15. Within - and between - panel variation in bond quality of 5-ply *Gmelina arborea* Plywood bonded with PF glue: Boil-dry-boil test, wood failure.

	Mean Wood Failure (%)			Max.Wood Failure (%)			Min.Wood Failure (%)			Range		
	Panels			Panels			Panels			Panels		
Treatments	1	2	3	1	2	3	1	2	3	1	2	3
PF-20-55-10	31	12	12	90	35	20	5	5	5	85	30	15
PF-20-55-20	35	42*	53*	90	75	90	10	15	10	80	60	80
PF-20-70-10	39	49	32	90	75	80	10	15	10	80	65	70
PF-20-70-20	27	44	32	80	95	80	10	10	10	70	85	70
PF-50-55-10	5	13	14	20	55	40	0	0	0	20	55	40
PF-50-55-20	23	19	69	90	45	95	10	10	25	80	35	70
PF-50-70-10	29	24*	34*	40	55	90	5	10	5	35	45	80
PF-50-70-20	18	85*	82*	55	100	95	10	50	70	45	50	25
PF-85-55-10	20	12	7	55	45	25	0	0	0	55	45	25
PF-85-55-20	11	22	13	15	55	40	5	5	5	10	50	35
PF-85-70-10	14	6	22	45	10	55	0	0	0	45	10	55
PF-85-70-20	7	21	18	45	35	60	0	0	0	45	35	60

N.B. * Panels with yellow birch veneers as faces and backs.

1. Figures rounded to the nearest unit.
2. The Grand Means of the three means above may not be same as in Table 11 due to rounding.

Table 16. Analysis of variance for testing the effects of peeling temperature, Glue Spread and Closed Assembly Time on UF Glue bond quality in 5-ply <u>Gmelina arborea</u> Plywood: Dry test.

Shear Strength

Source of variation	Degrees of Freedom	Sum of Square	Mean Square	F Ratios
Peeling temperature (PT)	2	$0.16784E\times10^6$	83920.	31.26**
Glue Spread (GS)	1	35887.	35887.	13.37**
Closed Assembly Time (AT)	1	2920.0	2920.0	1.22
PTxGS	2	6532.1	3266.1	1.09
PTxAT	2	19442.	9721.1	3.62*
GSxAT	1	541.23	541.23	0.20
PTxGSxAT	2	13396.	6698.0	2.50
Error	252	0.67649×10^6	2684.5	
Total	263	0.92304×10^6		

Wood Failure

Source of variation	Degrees of Freedom	Sum of Square	Mean Square	F Ratios
Peeling temperature (PT)	2	18612	9306.2	18.12**
Glue Spread (GS)	1	8.0152	8.0152	0.02
Closed Assembly Time (AT)	1	558.55	558.55	2.71
PTxGS	2	2782.4	1391.2	1.09
PTxAT	2	1183.9	591.95	1.15
GSxAT	1	1256.7	1256.7	2.45
PTxGSxAT	2	9459.4	4729.7	9.21**
Error	252	0.12941×10^6	513.54	
Total	263	0.16327×10^6		

** Significant at the 0.01 level.

* Significant at the 0.05 level.

Table 17. Analysis of variance for testing the effects of Peeling Temperature, Glue Spread and Closed Assembly Time on UF Glue bond quality in 5-ply Gmelina arborea. Plywood: Vacuum-pressure test.

Shear Strength

Source of variation	Degrees of Freedom	Sum of Square	Mean Square	F Ratios
Peeling Temperature (PT)	2	44448.0	22224.0	5.7269**
Glue Spread (GS)	1	19605.0	19605.0	5.0518*
Closed Assembly Time (AT)	1	9636.5	9636.5	2.4832
PTxGS	2	34173.0	17087.	4.4030**
PTxAT	2	10069.0	5034.5	1.2973
GSxAT	1	352.37	352.37	0.90800E-01
PTxGSxAT	2	1778.0	889.0	0.22909
Error	252	0.97794×10^6	3880.7	
Total	263	0.10980×10^6		

Wood Failure

Source of variation	Degrees of Freedom	Sum of Square	Mean Square	F Ratios
Peeling Temperature (PT)	2	44537.0	22269.0	49.693**
Glue Spread (GS)	1	3000.4	3000.4	6.6954**
Closed Assembly Time (AT)	1	606.06	606.06	1.3524
PTxGS	2	3114.4	1557.2	3.4749*
PTxAT	2	196.21	98.106	0.21893
GSxAT	1	836.74	836.74	1.8672
PTxGSxAT	2	6993.9	3497.0	7.8036**
Error	252	0.11283×10^6	448.12	
Total	263	0.17221×10^6		

** Significant at the 0.01 level.

* Significant at the 0.05 level.

Table 18. Analysis of variance for testing the effects of Peeling Temperature, Glue Spread and Closed Assembly Time on PF Glue bond quality in 5-ply *Gmelina arborea* Plywood: Vacuum-pressure test.

Shear Strength

Source of variation	Degrees of Freedom	Sum of Square	Mean Square	F Ratios
Peeling Temperature (PT)	2	55543.0	27772.0	9.5261**
Glue Spread (GS)	1	84209.0	84209.0	28.885**
Closed Assembly Time (AT)	1	19605.0	19605.0	6.7247**
PTxGS	2	19768.0	9884.2	3.3904*
PTxAT	2	36216.0	18108.	6.2113**
GSxAT	1	1675.1	1675.1	0.57458
PTxGSxAT	2	6295.6	3147.8	1.0797
Error	252	0.73466×10^6	2915.3	
Total	263	0.95797×10^6		

Wood Failure

Source of variation	Degrees of Freedom	Sum of Square	Mean Square	F Ratios
Peeling Temperature (PT)	2	28089.	14044.	31.326**
Glue Spread (GS)	1	1209.2	1209.2	2.6971
Closed Assembly Time (AT)	1	22644.	22644.	50.507**
PTxGS	2	1630.9	815.44	1.8188
PTxAT	2	14796.	7398.0	16.501**
GSxAT	1	329.64	329.64	0.73525
PTxGSxAT	2	5041.1	2520.5	5.6220**
Error	252	0.11298×10^6	448.34	
Total	263	0.18672×10^6		

** Significant at the 0.01 level.

* Significant at the 0.05 level.

Table 19. Analysis of variance for testing the effect of Peeling Temperature; Glue Spread and Closed Assembly Time on PF Glue bond quality in 5-ply <u>Gmelina arborea</u> Plywood: Boil-dry-boil test.

Shear Strength

Source of variation	Degrees of Freedom	Sum of Square	Mean Square	F Ratios
Peeling Temperature (PT)	2	49995.	24997.	9.16**
Glue Spread (GS)	1	99103.	99103.	36.31**
Closed Assembly Time (AT)	1	35352.	35352.	12.95**
PTxGS	2	7302.8	3651.4	1.34
PTxAT	2	47467.	23734.	8.69**
GSxAT	1	2578.1	2578.1	0.94
PTxGSxAT	2	20499.	10250.	3.76
Error	252	0.68786×10^6	2729.6	
Total	263	0.95015×10^6		

Wood Failure

Source of variation	Degrees of Freedom	Sum of Square	Mean Square	Ratios
Peeling Temperature (PT)	2	30012.	15006.	27.581**
Glue Spread (GS)	1	3864.0	3864.0	7.1021**
Closed Assembly Time (AT)	1	17837.	17837.	32.784**
PTxGS	2	6021.2	3010.6	5.5335**
PTxAT	2	9821.2	4910.6	9.0258**
GSxAT	1	985.23	985.23	1.8109
PTxGSxAT	2	2354.5	1177.3	2.1638
Error	252	0.13710×10^6	544.07	
Total	263	0.20800×10^6		

** Significant at the 0.01 level.

* Significant at the 0.05 level.

Table 20. Duncan's Multiple Range test for Shear Strength of *Gmelina arborea*. Plywood bonded with UF Glue.

T R E A T M E N T   R A N K I N G

Dry Test

	1	2	5	4	3	7	10	6	8	9	11	12
Treatment Mean[2]	306	312	312	326	332	334	342	353	353	362	381	398
	———	———	———	———	———	———						
			———	———	———	———	———					
				———	———	———	———	———	———			
					———	———	———	———	———	———		
								———	———	———	———	
										———	———	———

Vacuum Pressure Test

	8	7	3	1	2	4	11	5	9	6	12	10
Treatment Mean[2]	249	253	260	264	274	277	281	295	295	299	307	319
	———	———	———	———	———	———	———					
			———	———	———	———	———	———				
				———	———	———	———	———	———			
					———	———	———	———	———	———	———	
								———	———	———	———	———

N.B. 1. Means underscored by the same line are not significantly different at the 5% level of significance.

2. Numbers above means refer to treatments as follows:

1	UF-20-55-10	7	UF-50-70-10
2	UF-20-55-20	8	UF-50-70-20
3	UF-20-70-10	9	UF-85-55-10
4	UF-20-70-20	10	UF-85-55-20
5	UF-50-55-10	11	UF-85-70-10
6	UF-50-55-20	12	UF-85-70-20

Table 21. Duncan's Multiple Range test for Wood Failure of *Gmelina arborea.* Plywood bonded with UF Glue.

T R E A T M E N T R A N K I N G

Dry Test

	11	10	6	9	7	12	4	5	1	8	3	2
Treatment Mean[2]	35	38	38	39	40	47	52	53	57	61	62	70
	—	—	—	—	—	—						
					—	—	—	—				
						—	—	—	—			
							—	—	—	—	—	
										—	—	—

Vacuum Pressure Test

	11	12	7	6	9	10	8	5	1	4	3	2
Treatment Mean[2]	11	14	18	24	24	24	31	33	38	44	56	59
	—	—	—									
			—	—	—	—	—					
				—	—	—	—	—				
							—	—	—			
								—	—	—		
											—	—

N.B.

1. Means underscored by the same line are not significantly different at the 5% level of significance.

2. Numbers above means refer to treatments as follows:

1	UF-20-55-10	7	UF-50-70-10
2	UF-20-55-20	8	UF-50-70-20
3	UF-20-70-10	9	UF-85-55-10
4	UF-20-70-20	10	UF-85-55-20
5	UF-50-55-10	11	UF-85-70-10
6	UF-50-55-20	12	UF-85-70-20

Table 22. Duncan's Multiple Range Test for Shear Strength of *Gmelina arborea*. Plywood bonded with PF Glue.

T R E A T M E N T R A N K I N G

Vacuum Pressure Test

	5	6	8	2	9	10	4	1	7	11	3	12
Treatment Mean[2]	308	313	317	318	321	330	337	346	354	382	397	405
(underscore)	—	—	—	—	—	—	—					
(underscore)		—	—	—	—	—	—	—				
(underscore)						—	—	—	—			
(underscore)									—	—	—	
(underscore)										—	—	—

Boil-dry-boil Test

	6	5	2	8	9	4	10	1	7	11	3	12
Treatment Mean[2]	239	247	255	258	259	276	286	288	304	315	322	334
(underscore)	—	—	—	—	—							
(underscore)		—	—	—	—	—						
(underscore)				—	—	—	—					
(underscore)						—	—	—	—			
(underscore)							—	—	—	—		
(underscore)									—	—	—	
(underscore)										—	—	—

N.B. 1. Means underscored by the same line are not significantly different at the 5% level of significance.

2. Numbers above means refer to treatments as follows:

1	PF-20-55-10	7	PF-50-70-10
2	PF-20-55-20	8	PF-50-70-20
3	PF-20-70-10	9	PF-85-55-10
4	PF-20-70-20	10	PF-85-55-20
5	PF-50-55-10	11	PF-85-70-10
6	PF-50-55-20	12	PF-85-70-20

Table 23. Duncan's Multiple Range test for Wood Failure of <u>Gmelina arborea</u>. Plywood bonded with PF Glue.

T R E A T M E N T   R A N K I N G

Vacuum Pressure Test

	9	12	11	5	10	1	7	3	4	2	6	8
Treatment Mean^2	7	10	15	16	19	20	20	31	34	45	45	64
	—	—	—	—								
		—	—	—	—	—	—					
					—	—	—	—				
								—	—			
									—	—	—	

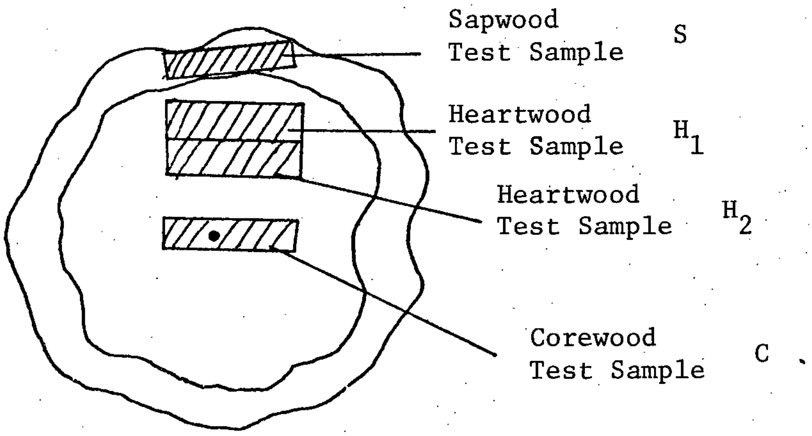
Boil-dry-boil Test

	5	9	10	11	12	1	7	4	3	2	6	8
Treatment Mean^2	12	12	16	16	16	21	30	34	38	43	46	66
	—	—	—	—	—	—						
						—	—					
							—	—	—			
								—	—	—	—	

N.B. 1. Means underscored by the same line are not significantly different at the 5% level of significance.

2. Numbers above means refer to treatments as follows:

1	PF-20-55-10	7	PF-50-70-10
2	PF-20-55-20	8	PF-50-70-20
3	PF-20-70-10	9	PF-85-55-10
4	PF-20-70-20	10	PF-85-55-20
5	PF-50-55-10	11	PF-85-70-10
6	PF-50-55-20	12	PF-85-70-20



Thus, there are four test samples per log.

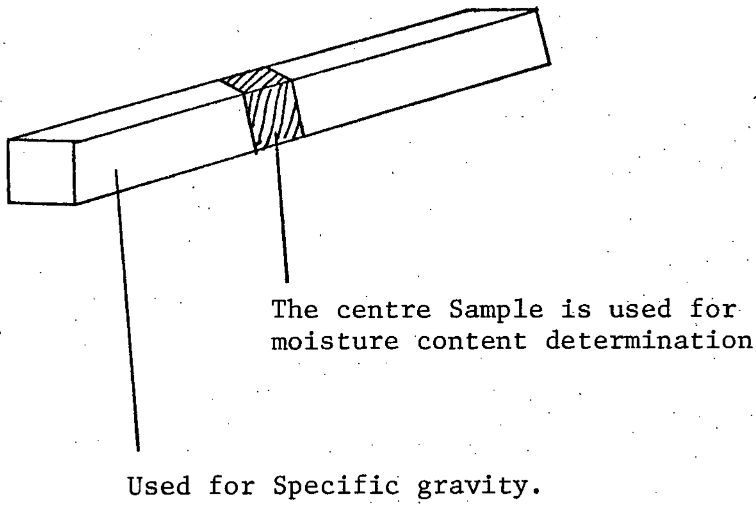


Figure 1. Pattern of cut of Test Samples from Logs for Specific Gravity and Moisture Content Determination Tests.

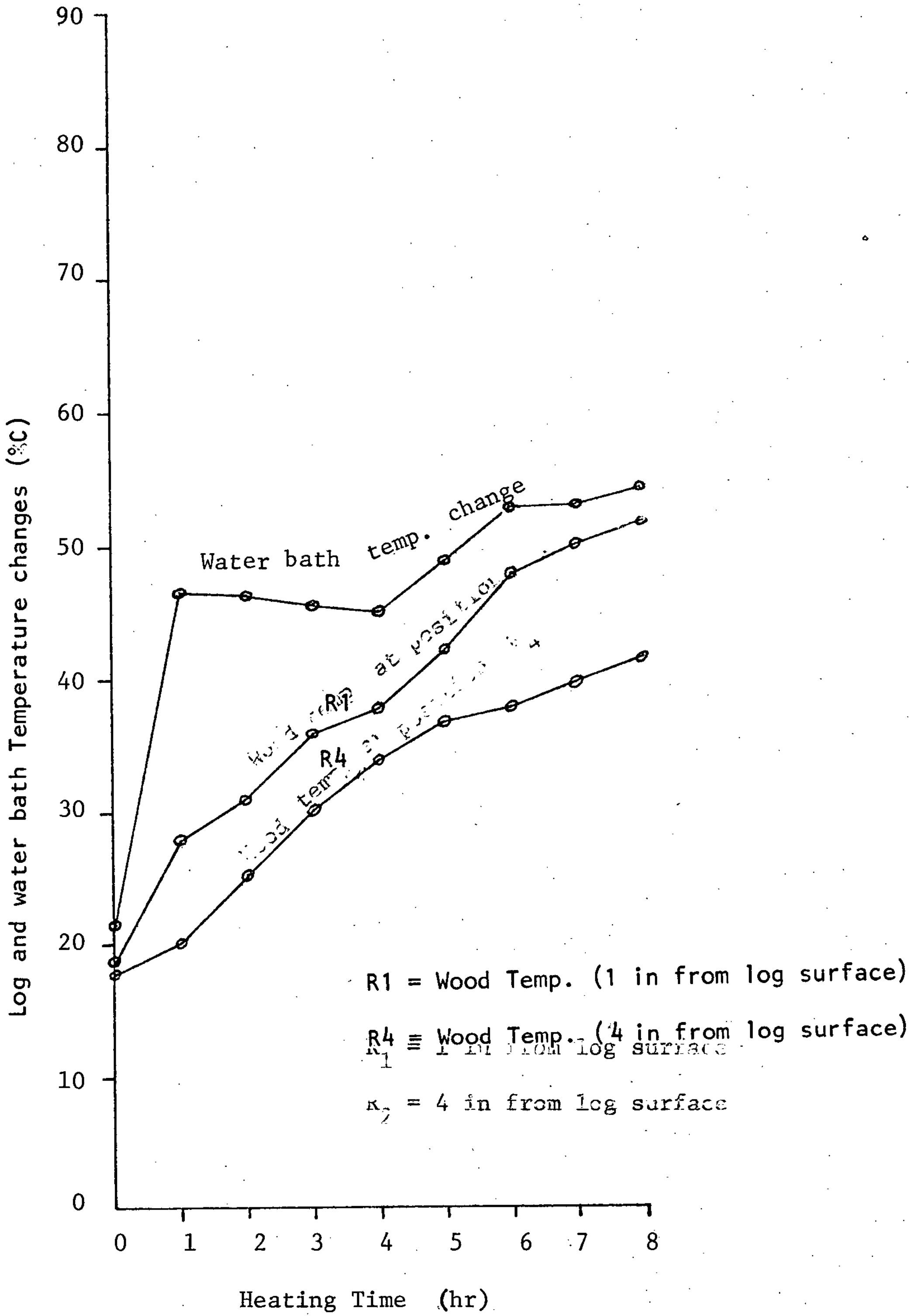


Figure 2. Temperature Changes within a log 8ft long and 7.7 in diameter (50°C Heating).

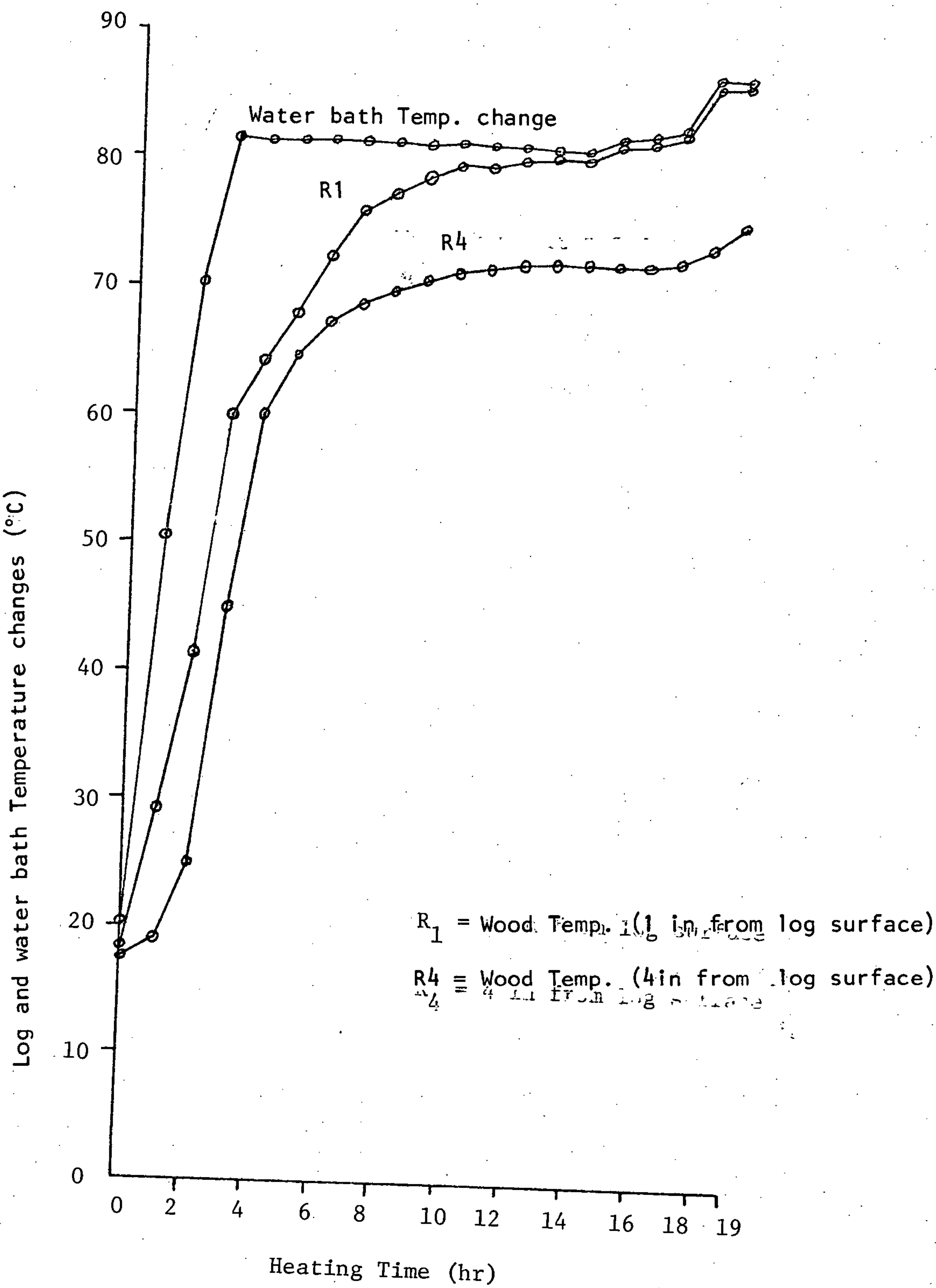


Figure 3. Temperature changes within a log 8ft long and 8.0 in diameter (85°C Heating).

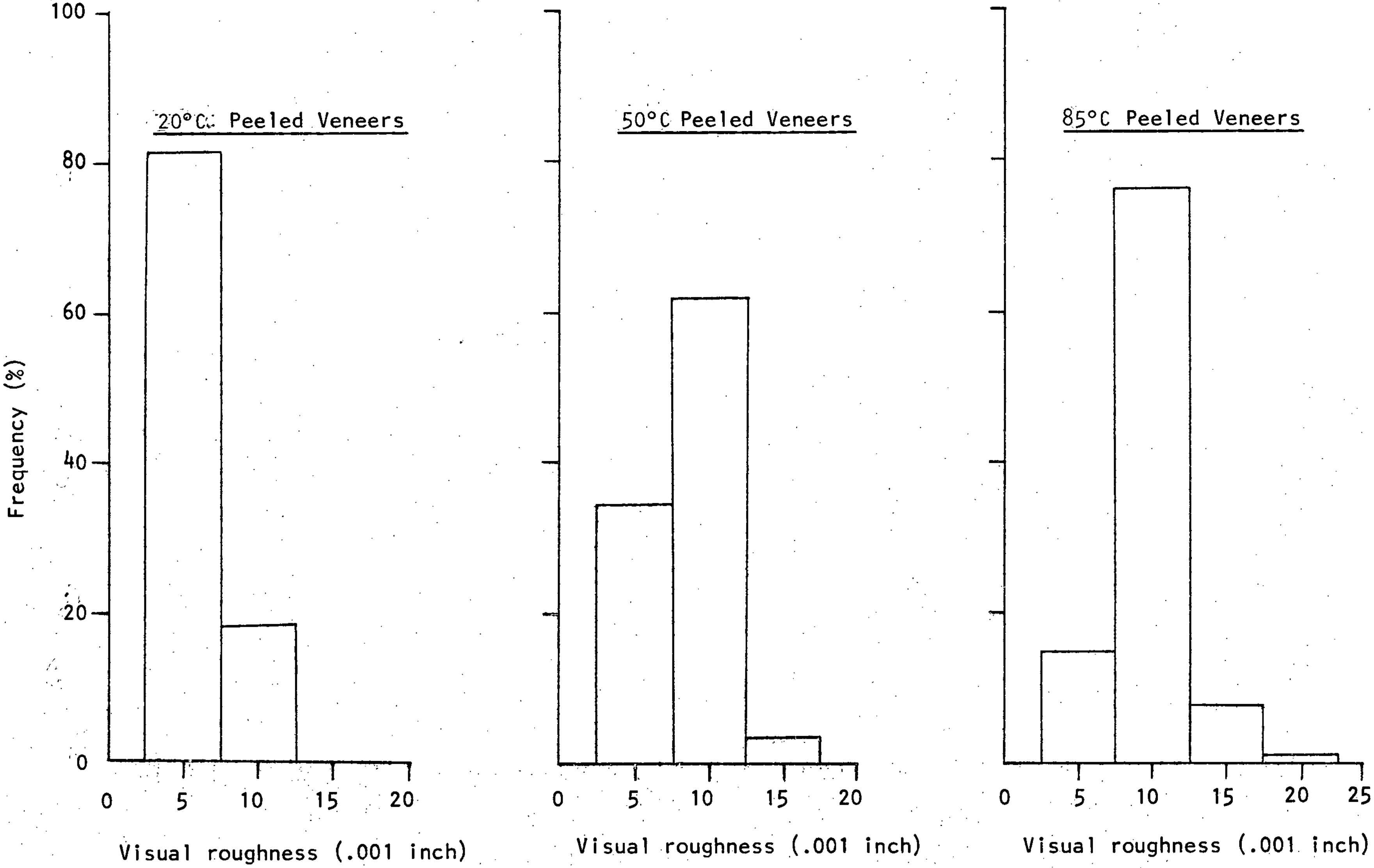


Figure 4. Frequency distribution of visual veneer roughness.

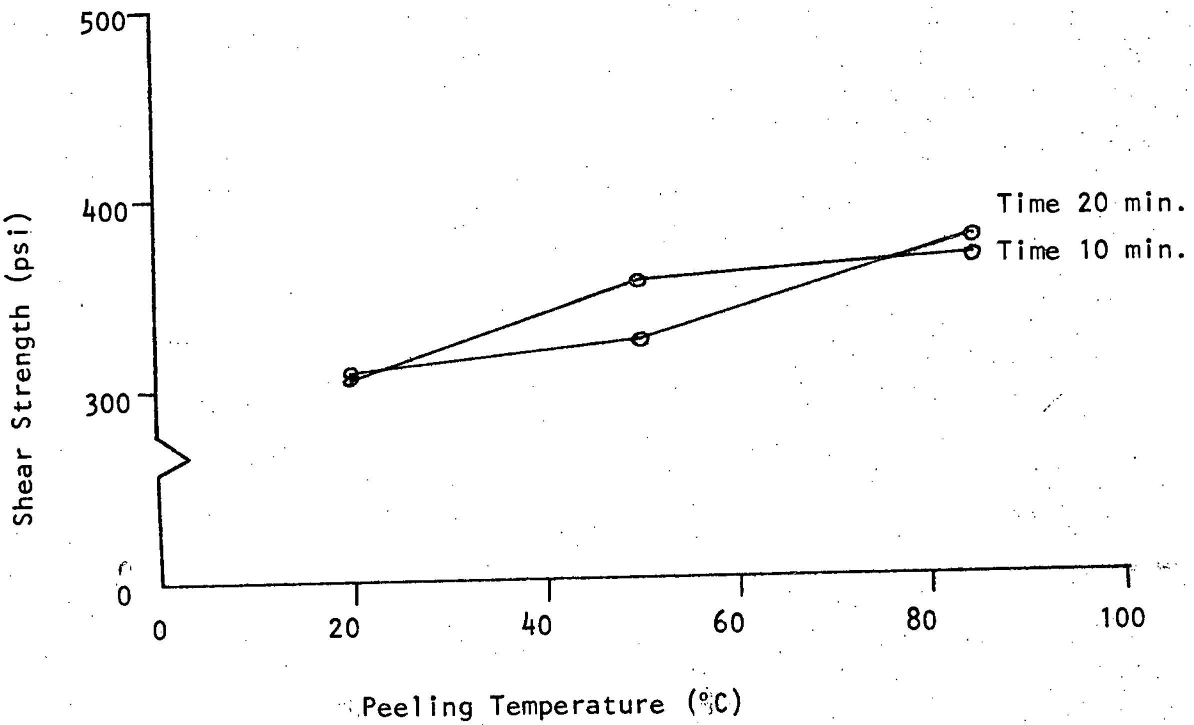


Figure 5. Dependence of bond quality on Peeling Temperature and Closed Assembly Time Interaction-UF Dry Test (Shear Strength).

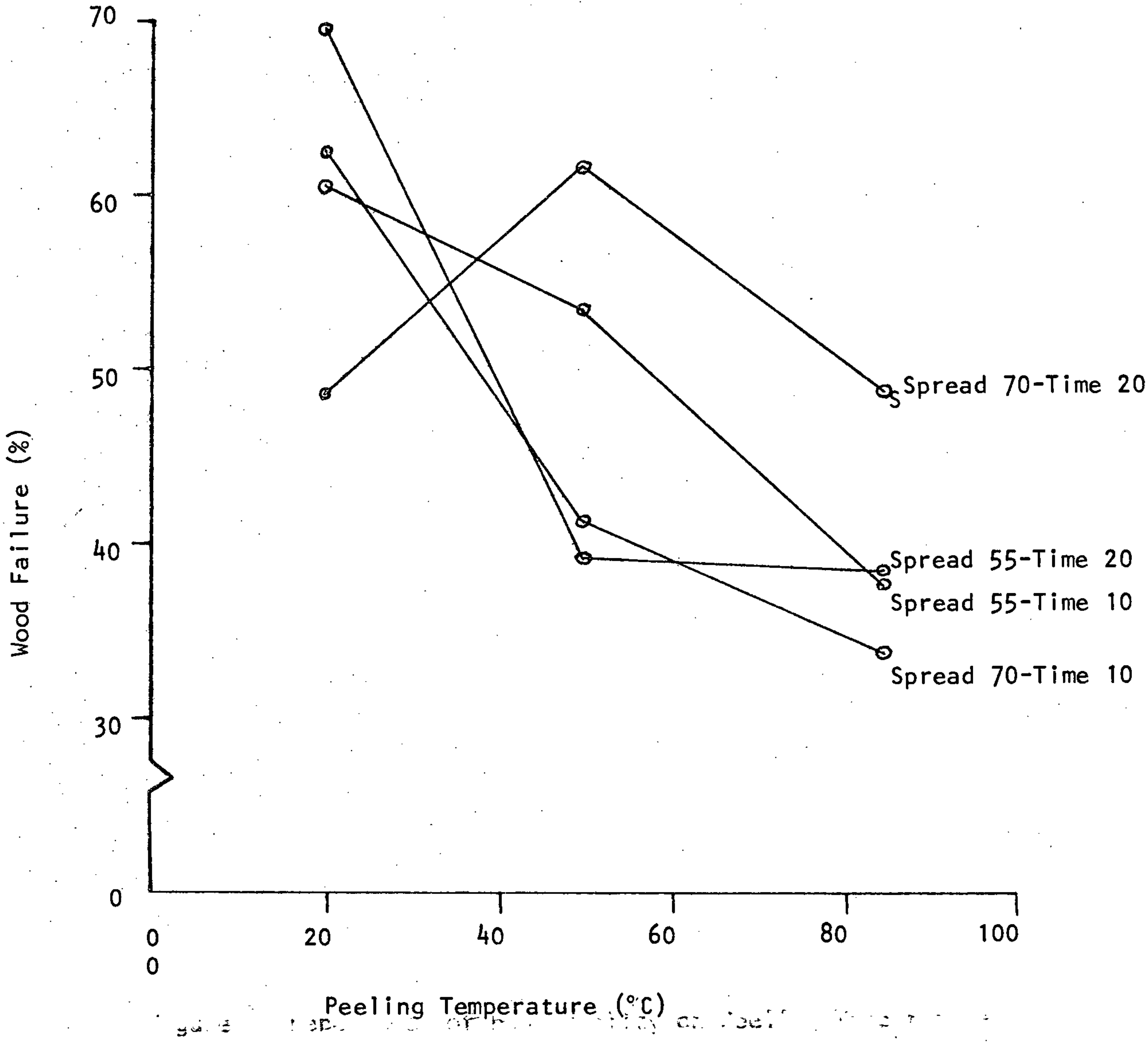


Figure 6. Dependence of bond quality on Peeling Temperature, Glue spread and Closed Assembly Time Interactions -UF Dry Test (Wood Failure).

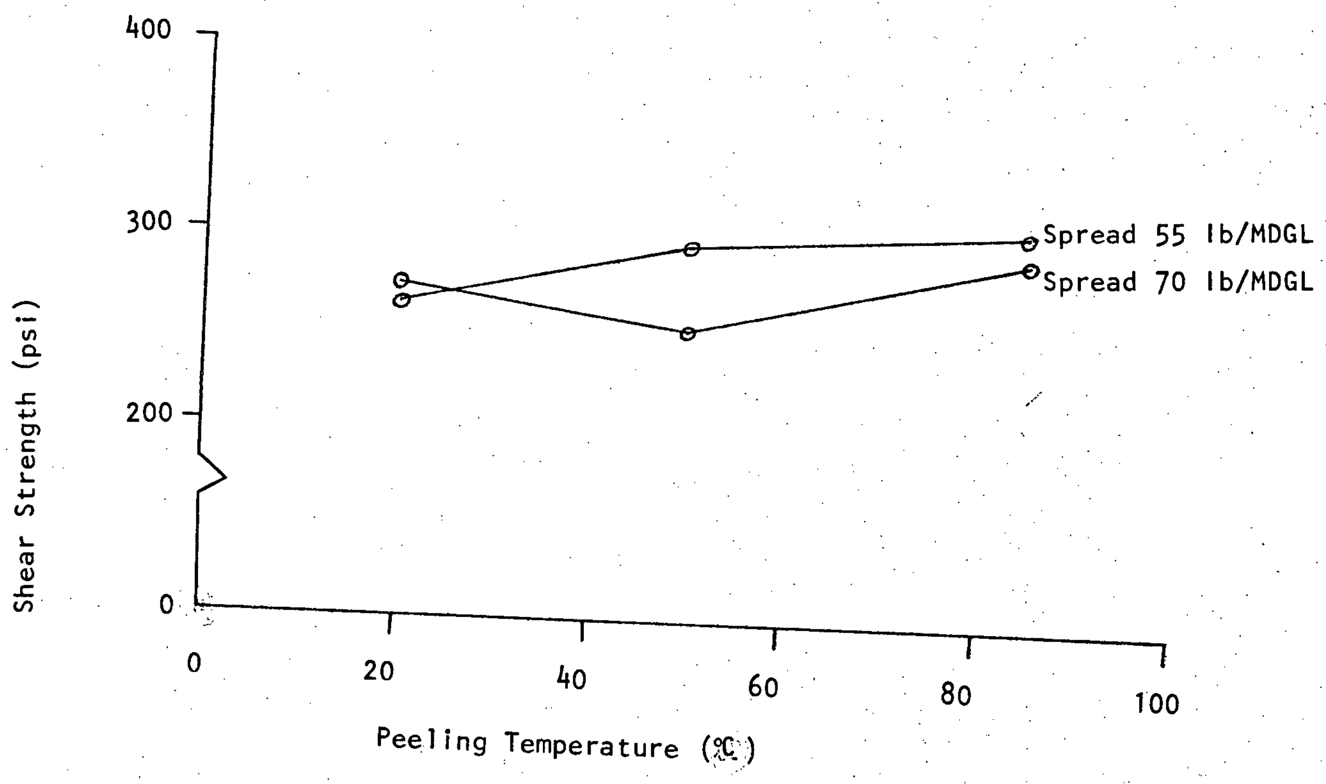


Figure 7. Dependence of bond quality on Peeling Temperature and Glue Spread Interaction-UF Vacuum-pressure Test (Shear Strength).

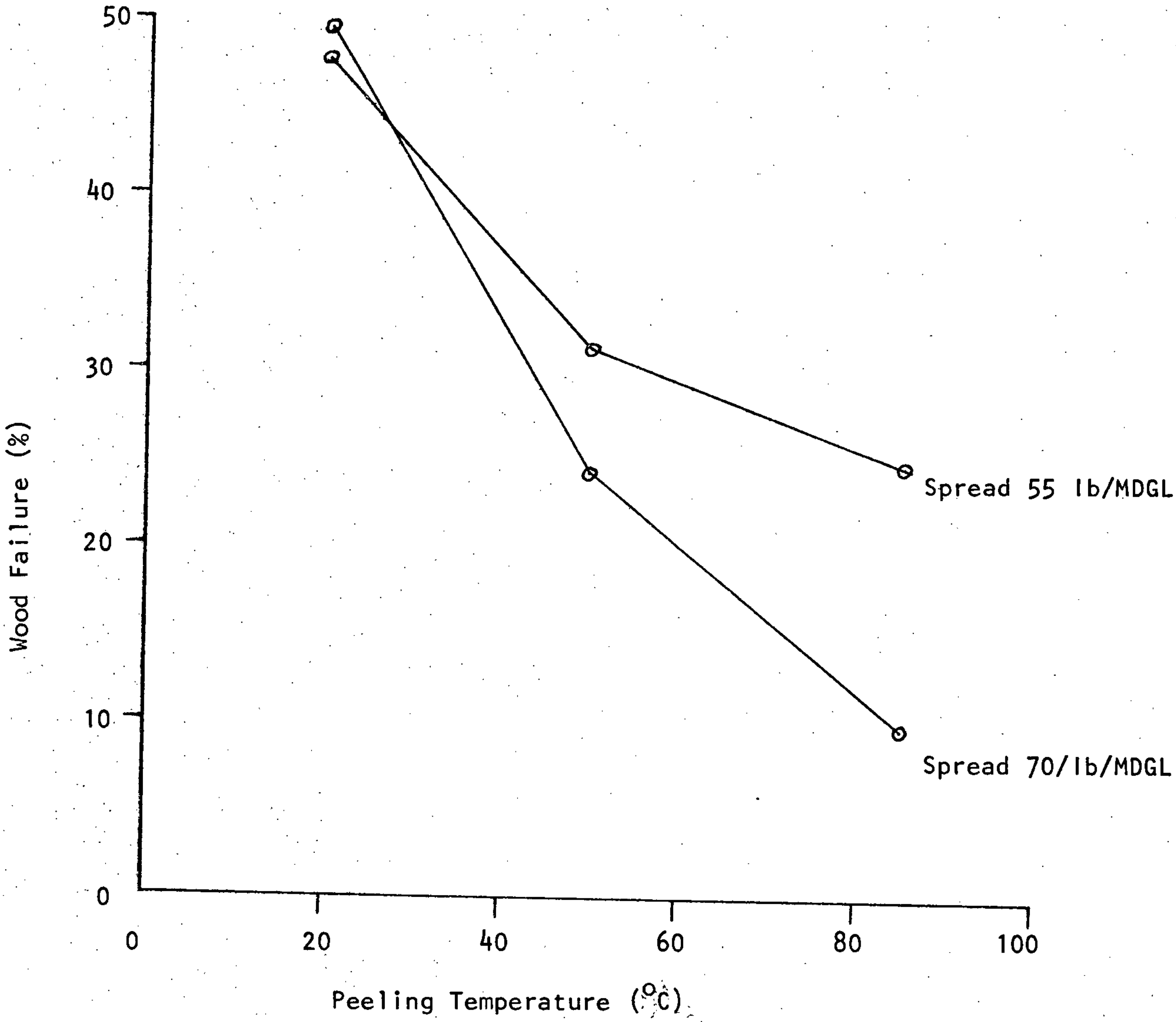


Figure 8: Dependence of bond quality on Peeling Temperature and Glue Spread Interaction-UF-Vacuum-pressure Test (Wood Failure).

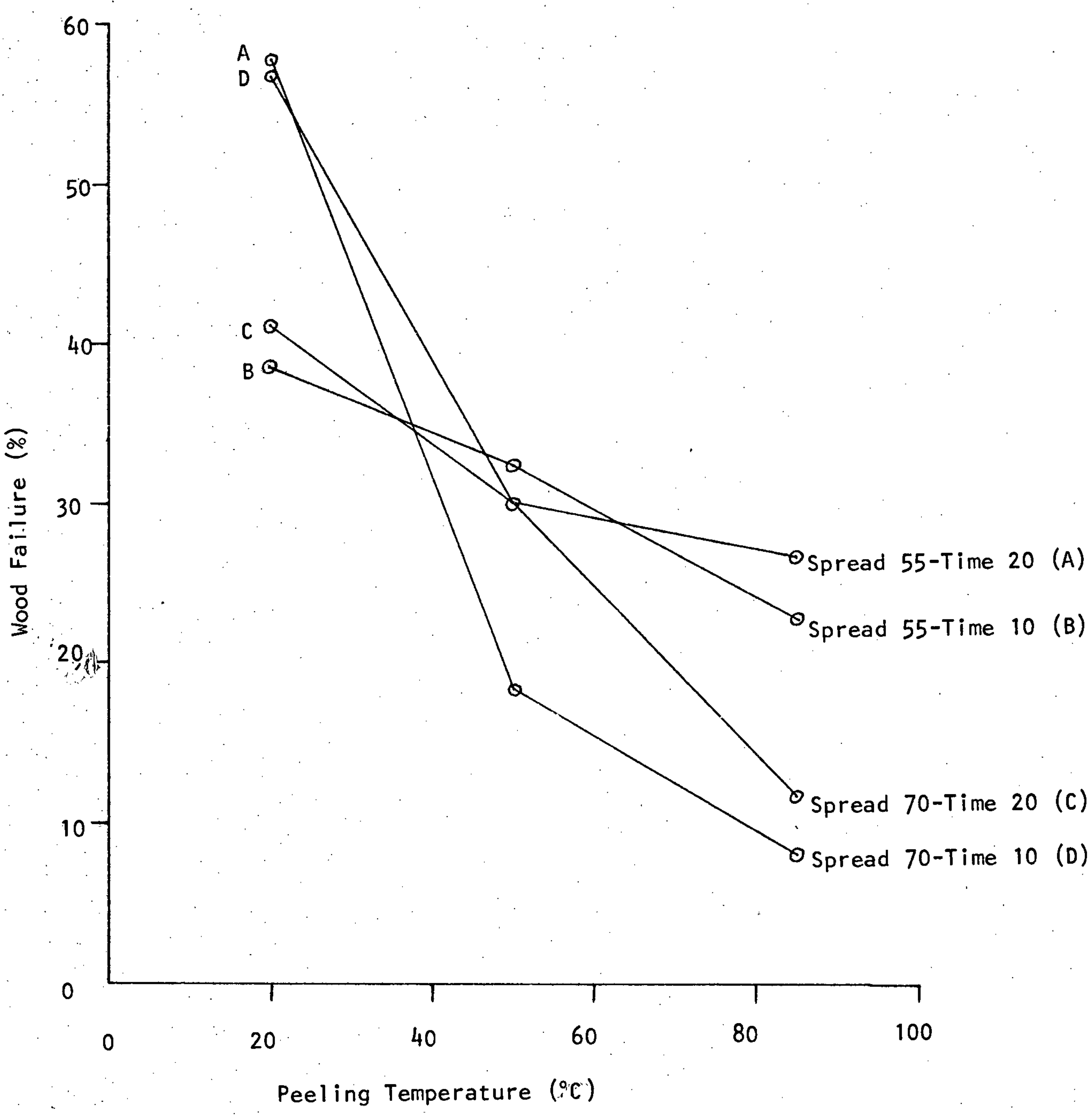


Figure 9. Dependence of bond quality on Peeling Temperature, Glue Spread and Closed Assembly Time Interactions -UF vacuum-pressure Test (Wood failure).

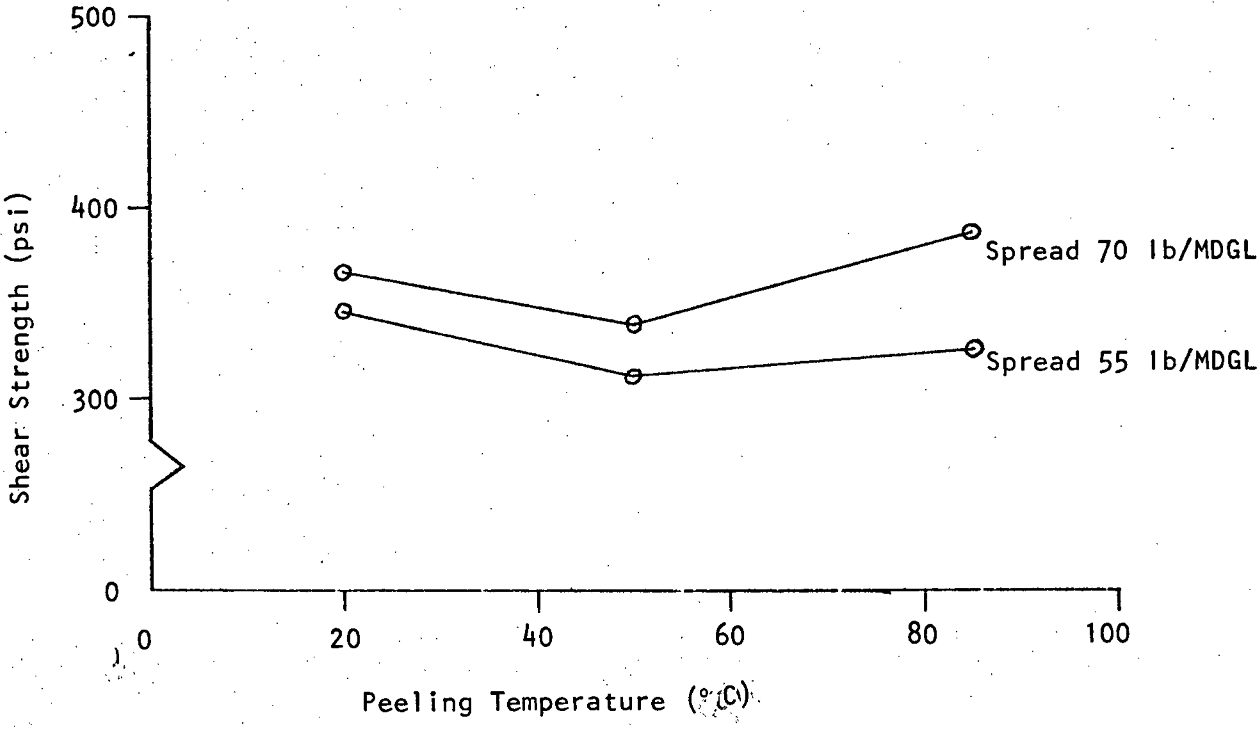


Figure 10. Dependence of bond quality on Peeling Temperature and Glue Spread Interaction-PF Vacuum-pressure Test (Shear Strength).

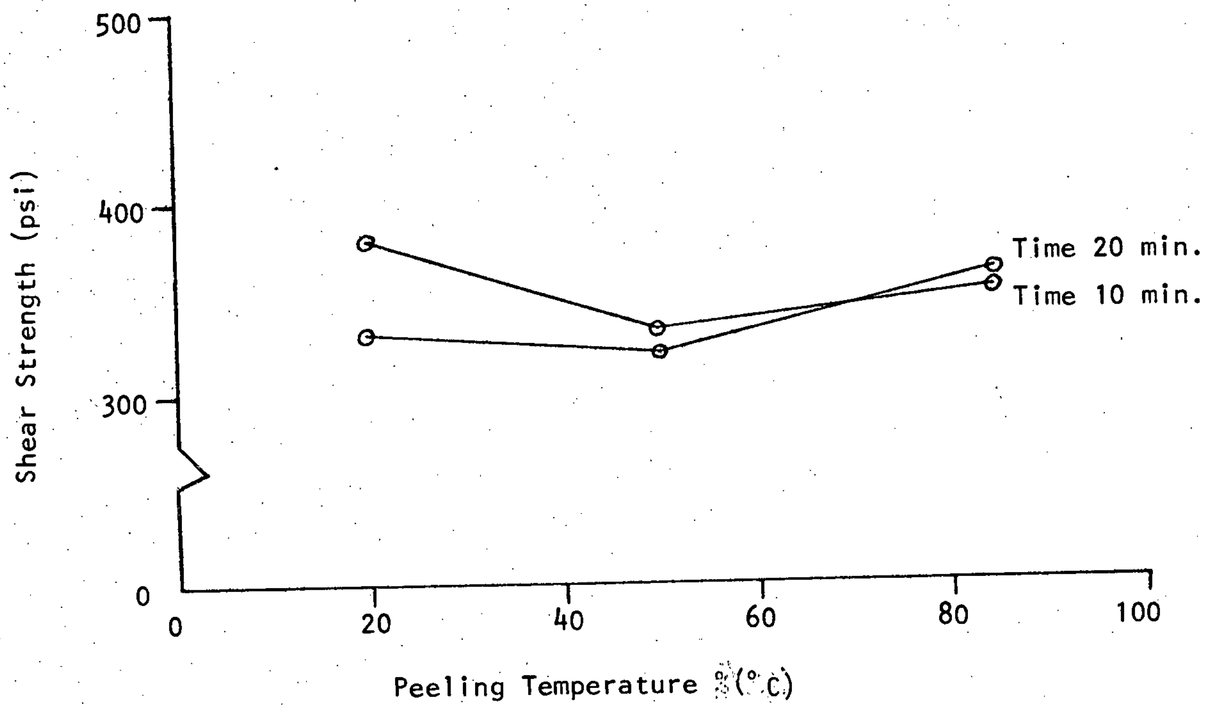


Figure 11. Dependence of bond quality on Peeling Temperature and Closed Assembly Time Interaction-PF Vacuum-pressure Test (Shear Strength).

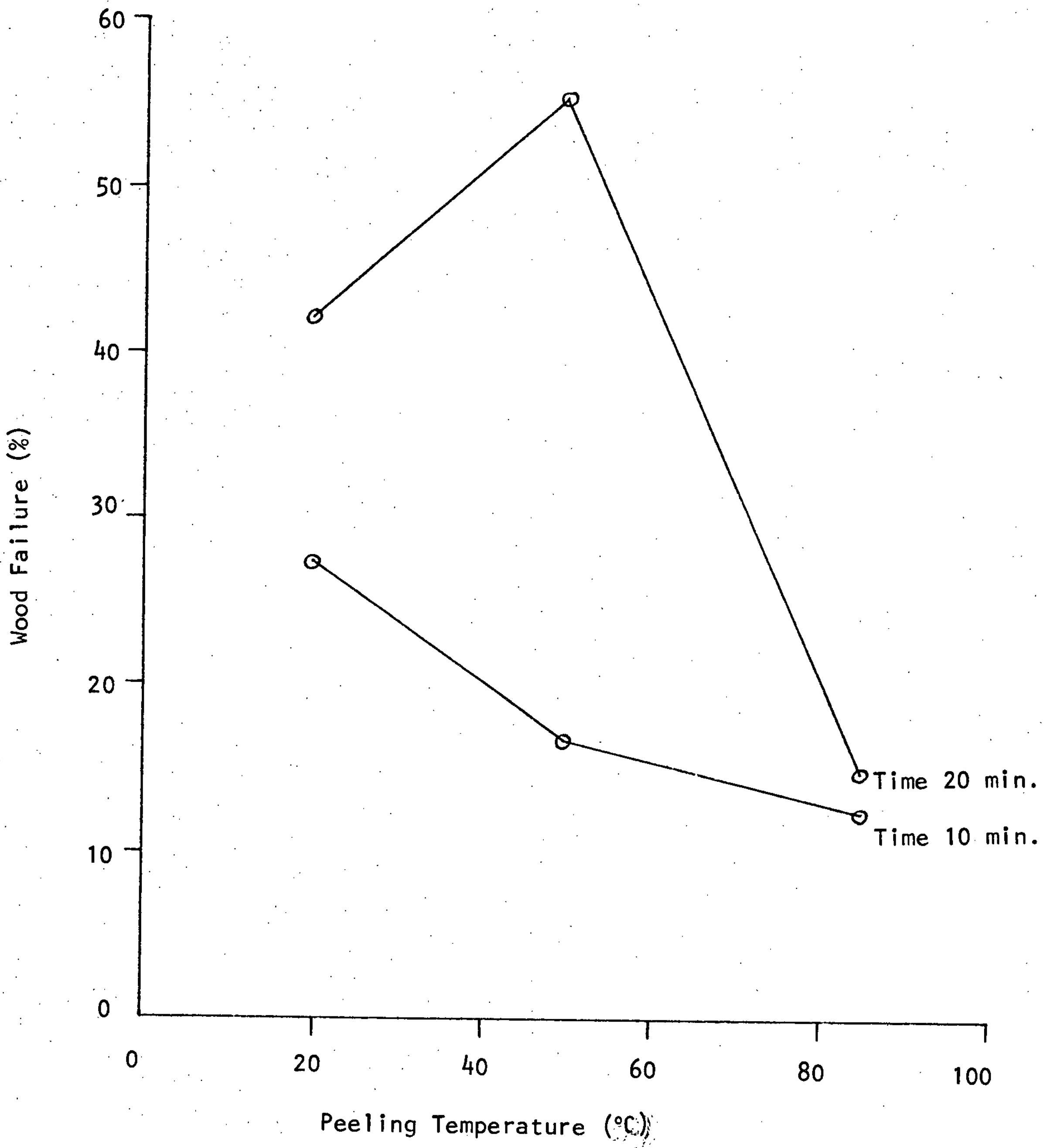


Figure 12. Dependence of bond quality on Peeling Temperature and Closed Assembly Time-Interaction-PF Vacuum-pressure Test (Wood Failure).

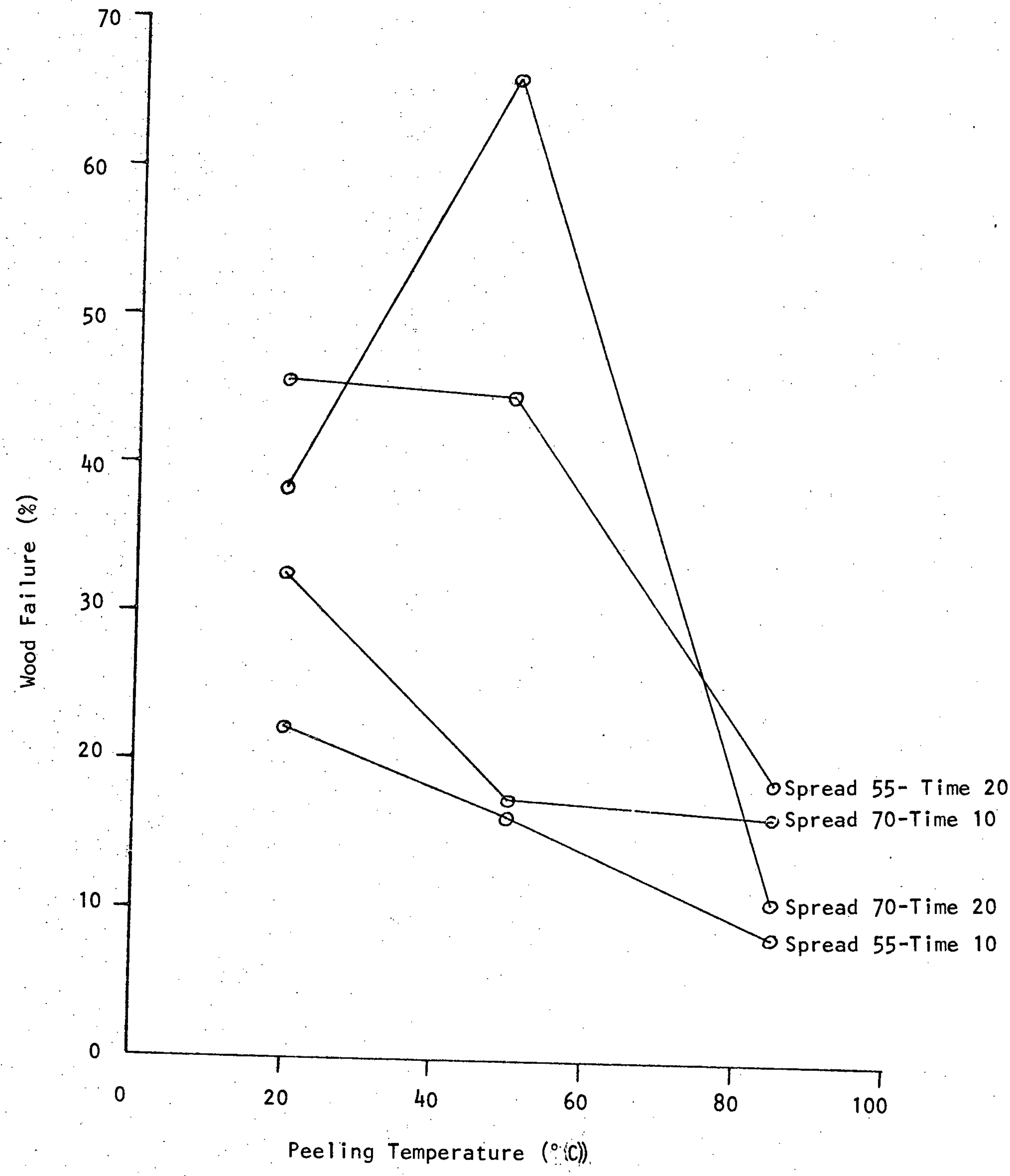


Figure 13. Dependence of bond quality on Peeling Temperature, Glue Spread and Closed Assembly Time Interaction -PF Vacuum-pressure Test (Wood Failure).

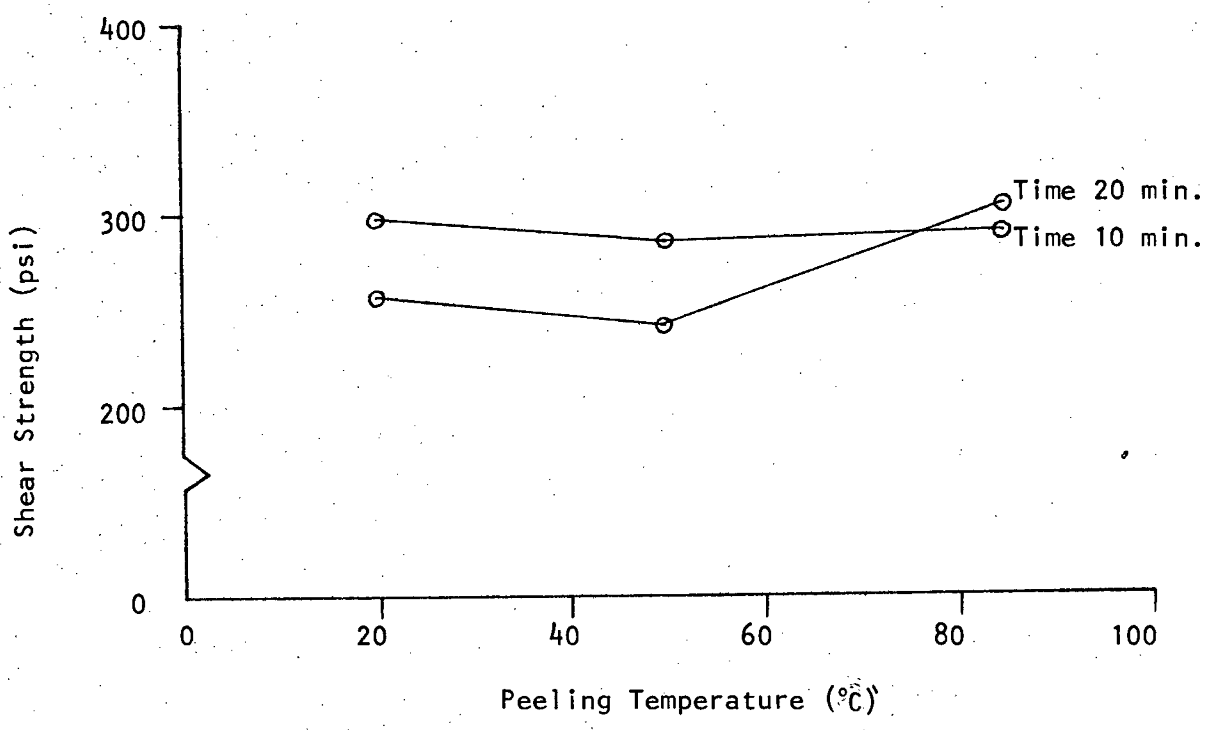


Figure 14. Dependence of bond quality on Peeling Temperature and Closed Assembly Time Interaction-PF Boil-dry-boil Test (Shear Strength).

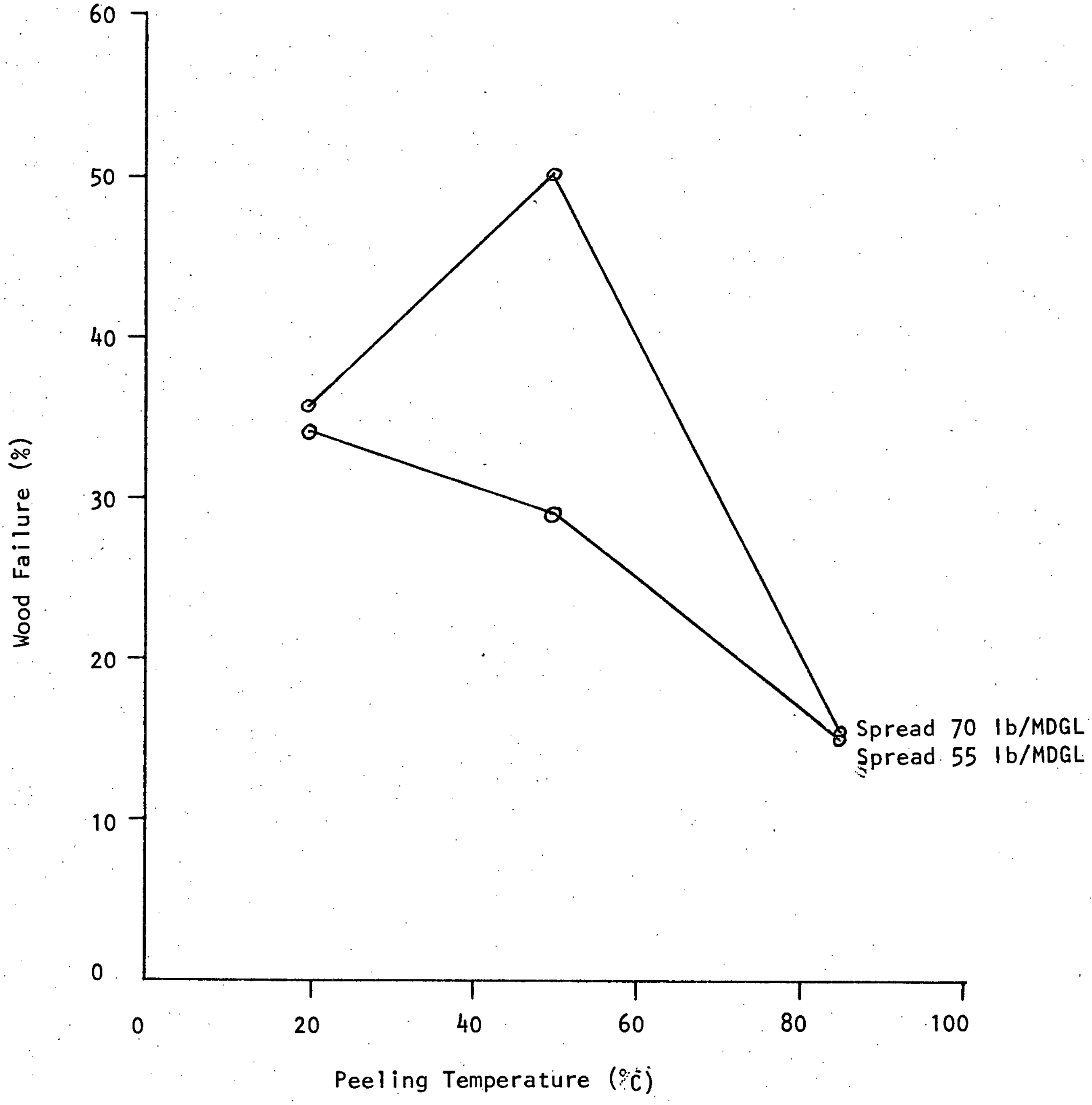


Figure 15. Dependence of bond quality on Peeling Temperature and Glue Spread Interaction-PF Boil-dry-boil Test (Wood Failure).

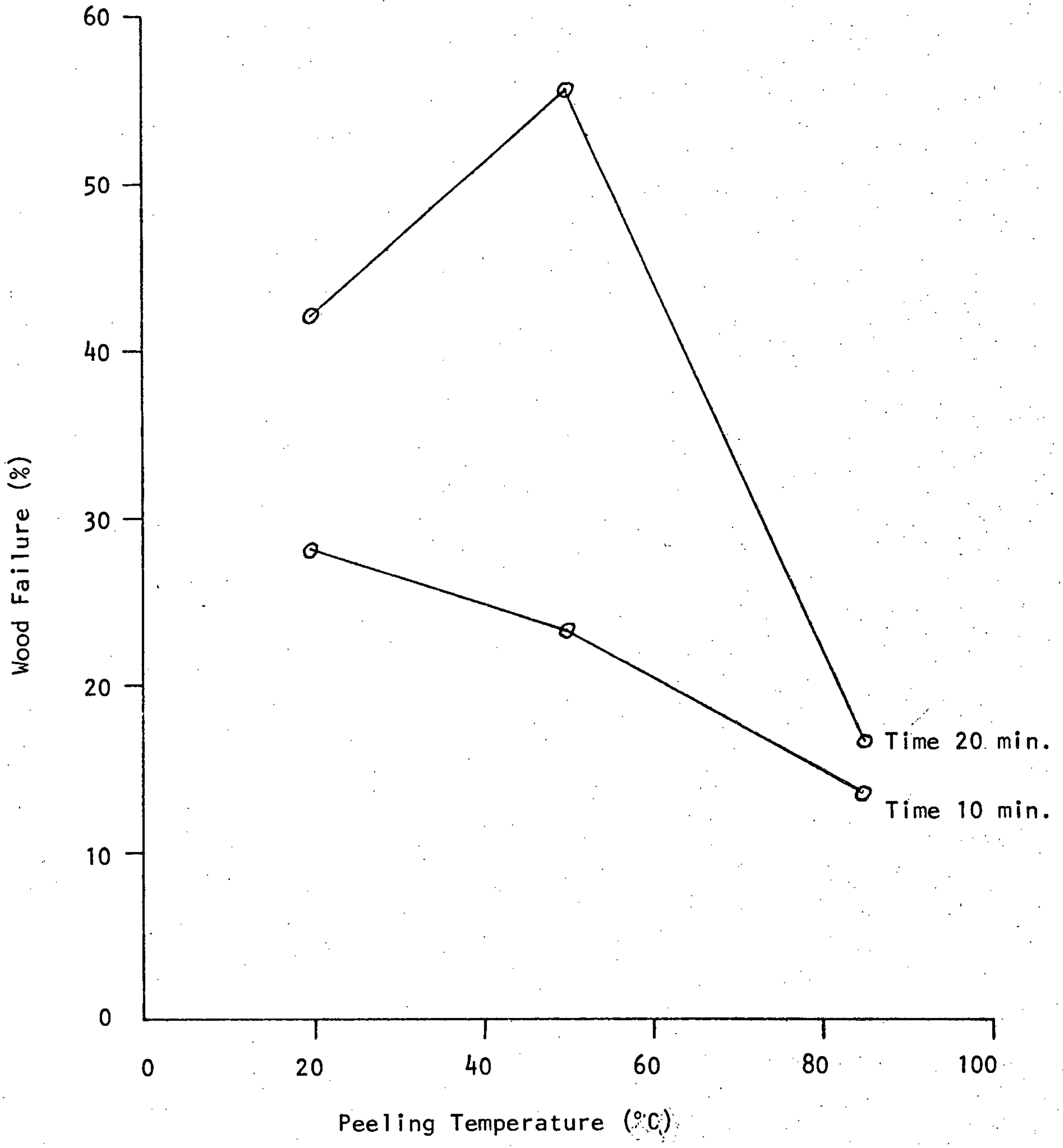


Figure 16. Dependence of bond quality on Peeling Temperature and Closed Assembly Time Interaction-PF Boil-dry-boil Test (Wood Failure).

APPENDIX 1 B. S. 1455:1963 Specification for Plywood manufactured from Tropical Hardwoods.

SPECIFICATION FOR

PLYWOOD

MANUFACTURED FROM TROPICAL HARDWOODS

B.S. 1455 : 1963

Price 10/6 net

BRITISH STANDARDS INSTITUTION

INCORPORATED BY ROYAL CHARTER

BRITISH STANDARDS HOUSE,

TELEGRAMS: STANDARDS AUDLEY LONDON TELEPHONE: MAYFAIR 9000

CONTENTS

BRITISH STANDARD SPECIFICATION FOR

PLYWOOD

MANUFACTURED FROM TROPICAL HARDWOODS

FOREWORD

This British Standard prepared under the authority of the Timber Industry Standards Committee specifies requirements for plywood manufactured from tropical hardwoods and suitable for all general purposes. Although the scope of the previous issue was not restricted to tropical hardwoods, in practice these were the only species used for plywood manufacture in the U.K. This standard does not specify requirements for blockboards or plywood faced with decorative veneer nor certain speciality materials, some of which are covered by the following British Standards:

B.S. 6V3. High strength plywood for aircraft.

B.S. V35. Medium and low strength plywood for aircraft purposes.

B.S. 1088. British-made plywood for marine craft.

B.S. 3444. Blockboard and laminboard.

B.S. ..... (in course of preparation) Plywood treated with preservatives or flame retardants or both.

SPECIAL NOTE In this revision the restriction of applicability of this British Standard to British-made material has been removed. While this allows oversea producers, who supply by far the greater part of the plywood used in the United Kingdom, to comply with the standard if they so wish, it should be borne in mind that the traditional suppliers to this country work to gradings, gluing standards and tests of their own which are well known in the U.K. market. The conditions of these are dictated by the woods available and internal requirements of the particular producing country. If users in the United Kingdom require plywood from overseas producers whose manufacture does not comply with this standard, they should consult their suppliers as to the material most nearly equivalent to the requirements of this standard. Information as to the species, producing countries, sizes, grading and bonding of plywood commonly available in the United Kingdom is given in B.S. 3493, ' Information about plywood '.

The requirements have been modified in the light of experience, and the descriptions of adhesives in Clause 6 have been brought into conformity with those in B.S. 1203*.

The dry test has been deleted as experience shows that the wet tests, and the mycological tests when appropriate provide sufficient control of bond quality.

The term ' Grade ' used in this specification refers to the quality of the veneers forming the face and back of the plywood. According to the defects they contain, each of the veneers classified by a number or symbol and the combination of these (e.g. 1 – 2, 2 – 2, or 2 – 3) defines the grade of the plywood.

The standard neither specifies nor gives advice upon the species of the timbers for plywood manufacture. Sources of supply and supplies themselves vary considerably over short periods, and any list of ' approved ' timbers would not only have to be long to be comprehensive, but might well, by the omission of their names, prejudice the introduction of additional kinds. Purchasers and manufacturers should agree between themselves on the species that are to be used, having regard to the purpose for which the plywood is intended, particularly where immunity to insect attack is essential.

The term ' Bonding ' in this standard refers solely to the type of adhesive used in the manufacture of the plywood.

It should be understood that although some types of adhesive have, over a period of years, proved themselves adequate to resist full exposure to weather, they do not impart this quality to the plywood as a material. It follows that when plywood is to be exposed to weather or to other severe conditions, not only must the appropriate type of adhesive be employed in its manufacture, but also the wood component must be of a suitable species or be treated with fungicidal or insecticidal preservatives, paints or other surface coatings according to circumstances. This standard does not cover such treatment or coating, which should be the subject of special arrangement between the parties concerned.

Some of the tests for the compliance of the plywood with the bonding requirements (Clause 6 and the Appendices) are of necessity somewhat lengthy and troublesome to make. The warranty (Clause 16) does not necessarily mean that the manufacturer has carried out all the tests set out in the Appendices, but, in cases of doubt or dispute, these Appendices enable the purchaser or an arbitrator to satisfy himself that the warranty is substantiated or otherwise.

NOTE 1. Where metric equivalents are given, the British units are to be regarded as the standard. The metric equivalents are approximate. More accurate conversions should be based on the tables in B.S. 350, ' Conversion factors and tables '.

NOTE 2. In place of the customary, but incorrect, use of the pound and kilogramme as units of force, the units called pound-force (abbreviation lbf) and kilogramme-force (abbreviation kgf) have been used in this standard. These are forces which when acting on a body of mass one pound, or kilogramme respectively, give it an acceleration equal to that of standard gravity.

* B.S. 1203, ' Synthetic resin adhesives (phenolic and aminoplastic) for plywood. '

SPECIFICATION

SCOPE

1. This British Standard covers plywood for general purposes manufactured from tropical hardwoods with rotary-cut or sliced veneers bonded together with an adhesive. The term 'plywood' is intended to include 'multi-ply'.

DEFINITIONS

2. For the purposes of this standard the definitions in B.S. 565, 'Glossary of terms relating to timber and woodwork', apply with the following modifications:

Bonding. See Gluing.

Discoloration. Areas, occurring in either streaks or patches, of colour different from that of the surrounding wood and differing from that normally associated with the species.

Gluing. The process of uniting, by means of an adhesive, two or more pieces of wood. When used without qualification the term implies a process characterized by continuity of the union over the whole of the areas of contact.

Rotary Cut (Peeled). (Veneer) produced in a continuous sheet by feeding a knife mounted parallel to the axis into a log rotating in a lathe. Cf. *Sliced*.

Sliced (Flat cut). (Veneer) cut sheet by sheet from a stationary block of wood by a knife mounted approximately parallel with and moving to and fro across the longitudinal axis of the block. In some machines the knife is fixed and the block moves. Cf. *Rotary cut*.

GRADE

3. Plywood shall be graded according to the appearance of the face and back, each being assessed separately after the board has been made and not when in the form of veneer as defined in Clause 2.

Grades of veneer are defined as follows:

Grade 1 veneer. Grade 1 veneer shall be of one or two pieces of firm smoothly cut veneer. When of two pieces the joint shall be approximately at the centre of the board. The veneers shall be reasonably matched for colour. The veneer shall be free from knots, worm and beetle holes, splits, dote, glue stains, filling or inlaying of any kind or other defects. No end joints are permissible.

Grade 2 veneer. Grade 2 veneer shall present a solid surface free from open defects. When jointed, veneers need not necessarily be matched for colour or be of equal width. A few sound knots are permissible, with occasional minor discoloration and slight glue stains and isolated pinholes not along the plane of veneer. Occasional splits not wider than 1/32 in (0.8 mm) at any point and not longer than one tenth of the length of the panel or slightly opened joints may be filled with a suitable filler. This grade shall admit neatly made repairs consisting of inserts of the same species as the veneer, which present solid, level, hard surfaces and are bonded with an adhesive equivalent to that used for bonding the veneers. No end joints are permissible.

NOTE. Grade 2 veneer excluding pinholes can be supplied by agreement between purchaser and supplier.

Grade 3 veneer. Grade 3 veneer may include wood defects, including worm-holes, which are excluded from Grades 1 and 2 in number and size which do not impair the serviceability of the plywood. It may also include manufacturing defects, such as rough cutting, overlaps, gaps or splits, provided these do not affect the use of the plywood. No end joints are permissible.

Other grades. Other grades, appropriate to the end use, may be agreed between purchaser and supplier.

CORES

4. Core veneers may contain knots, open defects, gaps, overlaps or pleats, provided such defects will not cause undulations or impair the smooth finish of the surfaces required for painting or staining. No end joints are permissible. In the cores of plywood faced on at least one side with Grade 1 or Grade 2 veneer, open defects and gaps in the ply adjacent to the Grade 1 or Grade 2 veneer shall not exceed 1/10 in (2.5 mm). It shall be at the purchaser's option to accept the manufacturer's warranty of compliance (Clause 16) or to inspect the veneers before the plywood is assembled.

ASSEMBLY OF VENEERS

5. Unless otherwise specified by the purchaser, the direction of the grain of the veneer shall be at right angles in adjacent plies, except in the case of boards comprising an even number of plies, when the grain of the centre pair shall follow the same direction.

The veneers forming any one ply and the corresponding ply on the opposite side of the central plane of the board shall be of the same thickness and species or of species known to be similar to one another in physical characteristics, and shall be cut by the same method, i.e. either all rotary-cut or all sliced.

The tight side of the veneer should be turned outwards in faces and backs.

Tapes shall not be used internally. When used for making edge joints or repairing splits in face veneers they shall be removed subsequently.

This paragraph shall apply unless otherwise agreed between purchaser and supplier. All plywood thicker than 3/8 in (10 mm) shall be made of not less than 5 plies. The core in 3 ply shall be not more than 60 per cent of the total thickness: for panels with more than three plies, the faces, and all plies running in the same direction as the faces, shall have a total or combined thickness of not less than 40 per cent and not more than 65 per cent of the total thickness of the panel. In the dry state, no face ply shall be thicker than 1/8 in (3 mm) and no inner ply shall exceed 3/16 in (5 mm).

BONDING

6. Bonding between veneers shall be WBP, BR, MR or INT defined* as follows, and these designatory letters shall be used in marking the plywood.

* These designations are those used in B.S. 1203, 'Synthetic resin adhesives (phenolic and aminoplastic) for plywood'.

Type WBP: Weather and boil-proof. Adhesives of the type* which by systematic tests and by their records in service over many years have been proved to make joints highly resistant to weather, micro-organisms, cold and boiling water, steam and dry heat.

Type BR: Boil resistant. Joints made with these adhesives have good resistance to weather and to the boiling water test, but fail under the very prolonged exposure to weather that Type WBP adhesives will survive. The joints will withstand cold water for many years and are highly resistant to attack by micro-organisms.

Type MR: Moisture-resistant and moderately weather-resistant. Joints made with these adhesives will survive full exposure to weather for only a few years. They will withstand cold water for a long period and hot water for a limited time, but fail under the boiling water test. They are resistant to attack by micro-organisms.

Type INT: Interior. Joints made with these adhesives are resistant to cold water but are not required to withstand attack by micro-organisms.

DELAMINATION

7. The glue bond between individual plies shall be adequate† and continuous over the entire area. Any board showing delamination or blistering does not comply with the requirements of this standard.

REMOVAL OF METAL CLIPS

8. All metal clips used for assembly during the manufacture of board shall be extracted or cut away in trimming before delivery.

SCARF JOINTS IN BOARDS

9. When sizes larger than available press sizes are required, scarf joints through the thickness of the board shall be permitted by agreement with the purchaser.

All scarf joints shall be bonded with the equivalent type of adhesive used for the manufacture of the boards themselves, and shall be made with the following inclinations:

a. Board under ½ in (13 mm) thick: 1 in 10.

b. Board ½ in (13 mm) thick and over: 1 in 8.

NOTE. It should be noted that the glue line of any scarf joint is visible on the surface of the board.

TESTING THE QUALITY OF THE ADHESION AND THE KIND OF BONDING IN THE PLYWOOD

10. The appropriate tests for adhesion in the four kinds of bonding are set out in Table 1, which gives the requirements for the particular appendices concerned.

* . present only certain phenolic adhesives have been shown to meet this requirement.

† For interpretation of 'adequate' see Clause 10 and appendices referred to therein.

TABLE 1. SCHEDULE OF TESTS FOR PROVING COMPLIANCE OF THE PLYWOOD WITH THE REQUIREMENT OF ITS DECLARED BONDING

The letters show the appendices giving details of the tests. A dash indicates that the test named in the column is not applicable.

Bonding	Tests		
	Wet test in hot water or steam	Wet test in cold water	Mycological test
WBP	A, B1, C	A, B2*a*, C	A, B3
BR	A, B1, C	A, B2*a*, C	A, B3
MR	A, B1, C	A, B2*a*, C	A, B3
INT	—	A, B2*b*	—

When the adhesion of the plywood is tested by the methods described in Appendices A, B and C the results of the tests shall be as follows:

Bonding WBP, BR and MR. The wet test in hot water or steam. (Appendix B1) and the wet test in cold water (Appendix B2*a*). No glue line shall have a bond quality of less than two, and the average value for all those tested shall be not less than five.

Bonding INT. The wet test in cold water (Appendix B2*b*). At the conclusion of the test, none of the test pieces shall show any delamination, blistering on the surfaces or separation of the joints between veneers at the edges.

Bonding WBP, BR and MR. The mycological test (Appendix B3). At the conclusion of the test none of the test pieces shall show any delamination, blistering on the surfaces or separation of the joints between veneers at the edges.

MOISTURE CONTENT

11. At the time of leaving the factory, finished boards shall have a moisture content determined by the method described in Appendix D of 8 to 12 per cent.

DIMENSIONS OF PLYWOOD BOARDS

12. The dimensions along the grain of the face veneer shall be quoted first.

NOTE. It is not practicable to standardize the sizes of boards at present. Information on the sizes most commonly available are given in B.S. 3493, 'Information about plywood'.

a. Length and width. The length or width of a board shall not be less than the specified size nor more than ⅛ in (3 mm) greater than the specified size.

b. Thickness. Unless otherwise agreed between purchaser and supplier, the nominal thickness shall be that of the board before sanding or scraping.

The thickness of the board shall not differ from the nominal thickness by more than ± 5 per cent for boards up to and including ¼ in (6 mm) thick or ± 3 per cent for boards in excess of ¼ in (6 mm) thick. An additional allowance of 0·008 in (0·2 mm) per side shall be made for scraping or sanding.

Squareness. The lengths of the diagonals of a board shall not differ by more than $\frac{1}{32}$ in per foot (0·25 per cent) of the length of the diagonal.

FINISHING

13. Boards shall be sanded or scraped both sides unless otherwise agreed between purchaser and supplier.

RE-TESTING

14. In the event of failure to comply with any one of the test requirements given in Clauses 10 and 11, the plywood concerned need be re-tested only in respect of that requirement. If the re-test fails, the batch shall be deemed not to comply with this British Standard.

MARKING

15. Each board shall be marked with the following particulars and unless otherwise agreed the mark shall be near an edge on the back.

a. Manufacturer's name or mark.

b. Country of manufacture.

c. The number of this British Standard, i.e. B.S. 1455.

d. Grade for face and back (e.g. 2 – 3). For grades other than 1, 2 or 3 (see Clause 3) the grade mark shall be that agreed between purchaser and supplier.

e. Bonding (i.e. WBP, BR, MR or INT).

f. Nominal thickness of board.

NOTE. The mark B.S. 1455 on the product is a claim by the manufacturer that it complies with the requirements of this British Standard.

The British Standards Institution is the owner of the registered certification trade mark shown below. This mark can be used only by manufacturers licensed under the certification mark scheme operated by the B.S.I. The presence of this mark on a product is an assurance that the goods have been produced to comply with the requirements of the British Standard under a system of supervision, control and testing operated during manufacture and including periodical inspection at the manufacturer's works in accordance with the certification mark scheme of the B.S.I.

Further particulars of the terms of licence may be obtained from the Director, British Standards Institution, 2 Park Street, London, W.1.

MANUFACTURER'S WARRANTY

16. The marking of the boards by the manufacturer as set out in Clause 15 itself constitutes a warranty that the plywood complies with the appropriate requirements of this standard. In cases of dispute or doubt, Clause 10 indicates the procedure for testing the plywood for compliance with the requirements for bonding (Clause 6): the grade (Clause 3) can be decided by inspection.

APPENDIX 2 Export Standard Specifications of Japanese Plywood, Excerpts. (Japan). 1968.

EXPORT STANDARD SPECIFICATION OF

JAPANESE PLYWOOD

Excerpted and Arranged for Commercial Purposes

Effective January 1, 1968

The Japan Plywood Manufacturers' Association
The Japan Specialty Plywood Manufacturers' Association
The Japan Plywood Inspection Corporation
Japan Plywood Exporters' Association

Foreword: This publication has been excerpted and arranged from Basic Rules of Inspection for Common Plywood and Specialty Plywood as set forth jointly by Ministry of Agriculture and Forestry, and Ministry of International Trade and Industry by joint Ordinance No. 1, November 10, 1967.

History: The First standards were promulgated in June, 1950.
The First Revision was announced in August, 1951.
The Second Revision was announced in February, 1954.
The Third Revision was announced in June, 1957.
The Fourth Revision was announced in January, 1958.
The Fifth Revision was announced in May, 1963.
The Sixth Revision was announced in November, 1967.

Interpretation: Any dispute as to interpretation of this unofficial translation for commercial purposes shall be finally decided on the basis of the original text in the Japanese language.

I. EXPORT STANDARD OF COMMON PLYWOOD

Page

SEPARATE PARAGRAPH

Physical Inspection

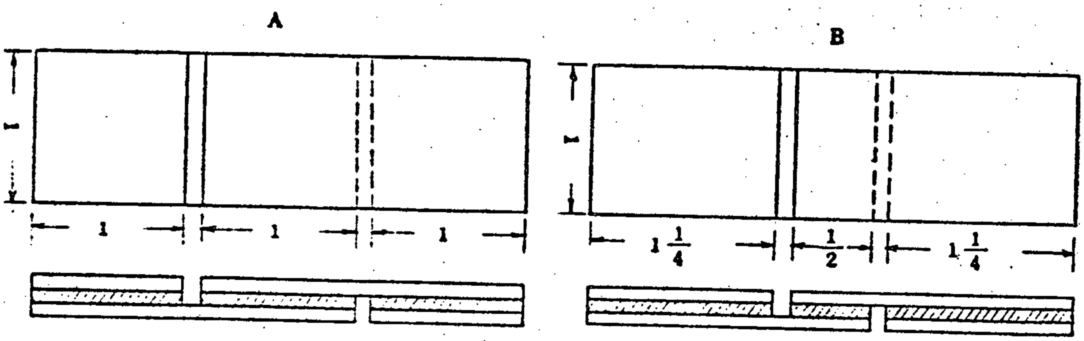
1. Cyclic-boil test

(1) Preparation of Specimen

Specimens shall be prepared in accordance with the following methods from the part of sample which is free from any defect to affect bonding strength of the said specimen.

a. For 3 ply-plywood having face and back veneers in 1/16 in. or more of thickness, four specimens shall be prepared in conformity to drawing A; and for the said plywood having face or back veneer in less than 1/16 in. of thickness or a veneer sheared easily, four specimens shall be prepared in conformity to drawing B.

In this case, one half of total specimens shall be prepared to comprise regular direction of core's reverse check and another half shall be prepared to involve contrary direction of core's reverse check.



(Unit : inch)

b. For 5 ply-plywood, 3 ply-plywood which comprises any two bonded layers respectively in a specimen shall be obtained by means of stripping surplus veneers and specimens shall be prepared from the said 3 ply-plywood in conformity to drawing A.

(2) Testing method

A specimen shall be submerged in boiling water for four hours and then dried at a temperature of 60°C $\pm$ 3°C during 20 hours.

Furthermore, it shall be submerged again in boiling water for four hours and then, shall be continuously kept in the said water until its temperature goes down to a room temperature. Bonding test shall be performed on this specimen under wet conditions. (Bonding test: Both ends of specimen are clamped by grips and are tensioned by a load velocity of 1,320 Lb., maximum per minute and maximum load is measured at the time of rupture.)

(3) Successful standard of test

Bonding strength of specimen shall be equal to or more than the standard figures of bonding strength stipulated in the following Table.

Species of Wood	Standard Figures of bonding strength
Birch	145 (Lbs./sq. in.)
Beech, Oak, Japanese Itaya Kaede (Maple), Japanese Akadamo (Elm), Japanese Shioji (Ash) and Japanese Yachidamo (Ash)	135
Japanese Sen (Caster Arabia), Japanese Hohnoki (Magnolia), Japanese Katsura (Judas Tree) and Japanese Tabu (Lourel)	115
Japanese Shiba (Bass wood)	100
Lauan and Others	110

Note: 1. When a specimen comprises veneers of different wood species, the species having lowest standard figure, out of various standard figures of bonding strength for those species shall be specified for the standard figure of this specimen.

2. Bonding strength of specimen shall be calculated by the following formula. But, provided that a thickness ratio of core sheet in proportion to face sheet is 1.5 or more for this specimen, the above calculated figure shall be multiplied by a coefficient in column of the following table which is classified in conformity to thickness ratio in the said table and the multiplied figure shall be specified as this bonding strength.

Bonding strength Lb./sq. in. = $\frac{p}{b \times h}$, wherein p is maximum load (Lb.) in the test of bonding strength and b is width of bonded surface (surface between both grooves) and h is length of bonded surface (surface between both grooves):

This formula is applicable for a specimen in the form of drawing A, and another specimen in the form of drawing B which is used for cyclic boil test and hot and cold soaking test.

Bonding strength Lb./sq. in. = $\frac{p}{b \times h} \times 0.9$, wherein p, b and h have the same significances with the above formula:

This formula is applicable for a specimen in the form of drawing B which is used dry bonding strength test.

Thickness Ratio	Coefficient
1.50 to less than 2.00	1.1
2.00 to less than 2.50	1.2
2.50 to less than 3.00	1.3
3.00 to less than 3.50	1.4
3.50 to less than 4.00	1.5
4.00 to less than 4.50	1.7
4.50 or more	2.0

2. Hot and cold soaking test

(1) Preparation of Specimen

To conform to the paragraph I-(1).

(2) Testing method

A specimen shall be submerged in hot water at a temperature of 60°C ± 3°C for three hours and then shall be continuously kept in the said water until the temperature goes down to a room temperature.

Bonding test shall be performed for this specimen under wet conditions.

(3) Successful standard of test.

To conform to the paragraph I-(3).

3. Dry bonding test

(1) Preparation of specimen

To conform to the paragraph I-(1).

(2) Testing method

Test of bonding strength shall be performed for a specimen under common conditions.

(3) Successful standard of test.

To conform to the paragraph I-(3).

4. Type I soak delamination test

(1) Preparation of specimen

Four specimens in size of 3 in. square shall be prepared from the part of sample which is free from any defect to affect bonding strength of the said specimen.

(2) Testing method

A specimen shall be submerged in boiling water for four hours and then dried at a temperature of 60°C ± 3°C during 20 hours.

Furthermore, it shall be again submerged in boiling water for four hours and dried at temperature of 60°C ± 3°C during three hours.

(3) Successful standard of test.

The part which does not delaminate in the same bonded layer of a specimen shall have 2 in. or more of length at the side surface.

5. Type II soak delamination test

(1) Preparation of specimen

To conform to the paragraph 4-(1).

(2) Testing method

A specimen shall be submerged in hot water at a temperature of 70°C ± 3°C for two hours and then dried at temperature of 60°C ± 3°C during three hours.

(3) Successful standard of test

To conform to the paragraph, 4-(3).

6. Type III soak delamination test

(1) Preparation of specimen

To conform to the paragraph 4-(1).

(2) Testing method

A specimen shall be submerged in warm water at a temperature of 35°C ± 3°C for two hours and then dried at temperature of 60°C ± 3°C during three hours.

(3) Successful standard of test.

To conform to the paragraph, 4-(3).

7. Moisture content test

(1) Preparation of specimen

Two specimens sized appropriately shall be prepared from the part of sample which is free from any defect to affect moisture content of the said specimen.

(2) Testing method

After weight of specimen is balanced, the specimen shall be dried at a temperature of 100°C to 105°C until it reaches to constant weight. This weight will be balanced and a moisture content shall be measured by the following formula.

But, when moisture content is measured by another process besides the above mentioned method with equal or more degree of accuracy, the measurement may be accorded with this latter process.

$$\text{Moisture content (per cent)} = \frac{W_1 - W_2}{W_2} \times 100$$

wherein W_1 is a weight in gram before drying and W_2 is a bone dry weight in gram.

(3) Successful Standard of Test

13 per cent or less of moisture content for specimen.

APPENDIX 3 DIN 68705 Plywood Standards
(translated) (Germany). 1968

UDC 634-419.3 : 001.4 DEUTSCHE NORMEN January 1968

DIN 68705 Sheet 1

Plywood

Definitions General Requirements Testing

Sperrholz; Begriffe, Allgemeine Anforderungen, Prüfung

1. Scope

This Standard applies to veneer boards and blockboards. It specifies definitions, requirements and testings which are applicable to all types of plywood regardless of its use.

2. Definitions

Plywood shall be taken as meaning all sheets consisting of at least three superimposed layers of wood bonded together with the grain running crosswise. Plywood (symbol SP according to DIN 4076, at present under revision) is therefore a generic definition for various types of sheets. A distinction is made between:

2.1. Veneer board (symbol FU according to DIN 4076)

Plywood in which all plies consist of veneers and are bonded one on top of the other crosswise and parallel to the plane of the sheet. With an even number of veneers the two innermost plies are arranged parallel to the grain.

2.1.1. Diagonally laminated veneer board (symbol SN according to DIN 4076)
Veneer board consisting of at least five plies of veneer bonded to each other in such a way that the directions of the grain of adjacent layers cross at angles of 45° or less.

2.2. Blockboards (symbol TI according to DIN 4076)

Plywood consisting of at least two covering veneers and a core of adjacent strips of wood. In blockboards consisting of three plies the direction of the grain of the core runs crosswise, in blockboards consisting of five plies parallel to the bonded covering veneers. All layers are bonded together crosswise. Blockboards consisting of five plies are mainly produced to meet higher standards of surface condition and dimensional stability.

A distinction is made between various blockboards, according to the type of core. These are:

2.2.1. Laminboard core (symbol STAE according to DIN 4076)
Narrow, laminated strips of wood consisting of rotary cut veneers up to 8 mm thick, bonded together and arranged edgewise to the plane of the board.

2.2.2. Bonded blockboard core (symbol ST according to DIN 4076)
Laminated strips of wood bonded together side by side and usually about 24 mm but not more than 30 mm wide.

2.2.3. Unbonded blockboard core (symbol SR according to DIN 4076)
Laminated strips of wood arranged close together but not bonded and usually about 24 mm but not more than 30 mm wide.

3. Requirements

3.1. Bonding

Choice of plywood bondings shall be governed by the climatic conditions and humidity to which the boards or sheets are subjected in use. A distinction is made between the following types of bonding:

3.1.1. IF 20 (interior plywood)
Bonding resistant when used in rooms with generally low atmospheric humidity (not weather-resistant).

3.1.2. AW 100 (exterior plywood)
Bonding resistant to the effects of the weather and humidity (weather-resistant).

Note: In addition to these bondings the following types can also be produced:

IW 67:
Bonding resistant when used in rooms with high atmospheric humidity and resistant to occasional contact with water up to about 67 °C provided the sheets or boards are protected against direct effects of the weather (not weather-resistant).

A 100:
Bonding resistant to the action of cold and hot water (limited weather resistance).
Particulars relating to resistance refer only to bonding.

4. Testing

4.1. [illegible] (bonding strength)

Plywood produced industrially is usually bonded with hardening synthetic resin glues whose resistance has been established by long-duration and outdoor tests. As a result, it is possible to state short testings which are adjusted to the chemical basis of the resins. When using other bonding agents, other short tests suitable for the appropriate bonding agents must be evolved.

Bonding strength is defined in DIN 53251 as the resistance of glue joints to mechanical destruction. It is tested by means of the knife test and/or the shear test according to DIN 53255, using specimens soaked in water and still wet.

4.1.1. Knife test

4.1.1.1. Sampling

Five specimens measuring 200 mm x 100 mm shall be taken for the knife test from every sheet to be tested (ten specimens from sheets of bonding type AW 100). The dimension 200 mm shall apply to the direction of the grain of the covering veneers. One of the five (ten) specimens must come from the edge of the sheet, the others from the inside of the sheet.

Continued on pages 2 to 4
Explanations on page 4

Translation: Fachtechnisches Übersetzungsinstitut Henry C. Freeman, Düsseldorf

4.1.1.2. Pretreatment of specimens
The following short tests are sufficient for testing bonding provided the stated glues were used.

Bonding IF 20 (urea resins)
Specimens immersed in water for 24 hours at a water temperature of 20 °C ± 2 deg.

Bonding AW 100 (phenolic, phenolic-resorcin or resorcin resins)

a) Cold water test:
Specimens immersed in water for 24 hours at a water temperature of 20 °C ± 2 deg.

b) Boiling test with alternate heating and cooling as follows:
Boiling for 4 hours (100 °C)
Keeping for 16 to 20 hours in hot air at 60 °C ± 2 deg in a hot cabinet according to DIN 50011
Boiling for 4 hours
Cooling for 2 to 3 hours under water at a water temperature of 20 °C ± 5 deg.

Note: Bonding IW 67 (unextended or melamine-reinforced urea resins)
Specimens immersed in water for 3 hours at a water temperature of 67 °C ± 0.5 deg.
Cooling under water for 2 hours at a water temperature of 20 °C ± 5 deg.
Bonding A 100 (melamine resins or mixtures of urea and melamine resins)
Boiling for 6 hours (100 °C)
Cooling under water for 2 hours at a water temperature of 20 °C ± 5 deg.

4.1.1.3. Test procedure
Knife tests according to DIN 53255 shall be carried out on all plies of the five (ten) specimens taken according to Section 4.1.1.1 and pretreated according to Section 4.1.1.2.

4.1.1.4. Assessment of test results
Test results for all glue joints examined shall be designated according to DIN 53255 by the following grading numbers:

1 excellent bonding
2 good bonding
3 adequate bonding
4 inadequate bonding

4.1.2. Shear test

4.1.2.1 Sampling and production of specimens
At least ten simple tension/shear specimens shall be prepared according to DIN 53255 from every sheet to be tested (20 simple tension/shear specimens from sheets of bonding type AW 100). In the case of sheets with five and more layers of veneer the outer veneers shall be removed (e.g. by planing down) to three plies.

4.1.2.2. Pretreatment of specimens
according to Section 4.1.1.2.

4.1.2.3. Testing and evaluation
Shear tests according to DIN 53255 shall be carried out on the ten (20) specimens taken according to Section 4.1.2.1 and pretreated according to Section 4.1.1.2, and the results evaluated.

4.2. Bending strength

The bending strength shall be determined according to DIN 52371 (at present still circulating as draft).

4.3. Moisture content

The moisture content shall be determined according to DIN 52183.

5. Quality safeguard

Depending on the field of application of veneer boards and blockboards, they can or must be subjected to regular supervision of their quality in the form of a statistical quality control (own supervision) and/or a supervision testing (outside supervision).

5.1. Statistical quality control
(own supervision)

5.1.1. Sampling
For own supervision the number of sheets to be selected will depend on the relevant production programme. At least one sheet must be taken at random from every lot (consignment) and, in the case of continuous production, at least one sheet daily, and must be tested for the specified properties.

5.1.2. Control cards
The results of own supervision shall be recorded and entered on control cards. Statistic evaluation covers mean values for sheets and a fluctuation measure. The fluctuation measure chosen can either be the variable s^2, the standard variation s or span R. Supervision of the span does not require any calculations but it is not suitable for systematic evaluations.

For subsequent evaluations, for deciding whether several sheet or board thicknesses and/or constructional combinations should be summarized under a basic lot and for calculating warning and control limits it is necessary to calculate and determine the sum total of individual values Σx_i and their squares Σx_i^2 for each sheet tested.

Warning and control limits for the control cards can be calculated the first time after testing about 25 sheets per lot. They should be fixed annually and entered on new control cards.

Own supervision records must be kept for at least five years.

5.1.3. Testing non-conditioned specimens
Veneer boards and blockboards leaving the press frequently have a lower moisture content than in their state of equilibrium in a standard climate 20/65 DIN 50014. As a rule adjustment of the moisture content of sheets or boards to the standard climate takes about 7 days, even longer in

many cases. A works control is, however, dependent on immediate results in order to take any necessary steps in the production process in good time and it is therefore not possible to wait for complete moisture equilibrium in the case of testings carried out at the works.

The testing of non-conditioned bending specimens can produce systematic variations from measurements undertaken on conditioned specimens. Systematic variations in bending properties of non-conditioned specimens must therefore be taken into account by correction factors for the mean values and for the warning and control limits. Correction factors determined by experiment should be re-examined from time to time.

5.2. Supervision testing (outside supervision)

Outside supervision testings must be carried out every six months by an officially recognized material testing institute on the basis of a supervision agreement, provided regular supervision in accordance with regulations of building authorities does not take place under the direction of a recognized quality control body. A condition for carrying out outside supervision is proof of properly conducted own supervision according to Section 5.1.

5.2.1. Sampling

In outside supervision three sheets or boards shall always be selected at random from a longest possible production period by a representative of or person appointed by the supervisory department and shall be marked immediately so as to prevent confusion. A report on selection of a random specimen shall be drawn up by the person choosing the specimen and countersigned by the works manager or his representative. This report must contain the following particulars:

a) Date and place of sampling;
b) Possible size of stocks from which the sheets or boards are taken;
c) Number and date of production of the boards or sheets belonging to the specimens taken at random;
d) Particulars of how the sample sheets or boards were marked by the person selecting them;
e) A statement to the effect that the specimen was selected at random;
f) Names of persons present during selection of the specimen;
g) Notes on testing and evaluation of records from own supervision.

The report shall be submitted to the competent material testing institute together with the specimen taken at random.

Note: The following material testing institutes (shown in alphabetical order) are at present available for supervision testing:

Bayerische Landesgewerbeanstalt, Nürnberg 2, Gewerbemuseumplatz 2

Bundesforschungsanstalt für Forst- und Holzwirtschaft, Reinbek bei Hamburg, Schloß

Bundesanstalt für Materialprüfung (BAM), Berlin 45 (Dahlem), Unter den Eichen 87

Forschungsinstitut für Holzwerkstoffe und Holzleime, Karlsruhe-Durlach, Dieselstraße 6

Forschungs- und Materialprüfungsamt für das Bauwesen - Otto-Graf-Institut - , Stuttgart-Vaihingen, Robert-Leicht-Straße 209

Institut für Baustoffkunde und Stahlbeton der Technischen Hochschule Braunschweig, Amtliche Materialprüfungsanstalt für das Bauwesen, Braunschweig, Beethovenstraße

Institut für Flugzeugbau und Leichtbau, Technische Hochschule Braunschweig, Braunschweig, Langer Kamp 19b

Institut für Holzforschung und Holztechnik der Universität München, München 13, Winzererstraße 45

Institut für Materialprüfung und Forschung des Bauwesens der Technischen Hochschule Hannover - Amtliche Materialprüfungsanstalt für das Bauwesen, Hannover, Nienburger Straße 3

Staatliche Materialprüfungsanstalt Darmstadt an der Technischen Hochschule Darmstadt

Staatliches Materialprüfungsamt Nordrhein-Westfalen, Dortmund-Aplerbeck, Marsbruchstraße 186

Versuchsanstalt für Stahl, Holz und Steine - Materialprüfungsanstalt der Technischen Hochschule Karlsruhe, Karlsruhe, Kaiserstraße 12

Wilhelm-Klauditz-Institut für Holzforschung an der Technischen Hochschule Braunschweig, Braunschweig-Kralenriede, Bienroder Weg 54 a

State testing institutes abroad can undertake quality supervision testings in cooperation with one of the above-mentioned German institutes.

5.2.2. Testing of own supervision

When sampling according to Section 5.2.1 records of own supervision mentioned in Section 5.1.2 shall be tested.

6. Designation

Plywood sheets or boards in storage dimensions shall be marked by the manufacturer with a stamp on the poorer side.

Other standards

DIN 4076 Wood, wood materials and laminated boards; definitions and symbols
DIN 4078 Plywood; dimensions
DIN 50014 Testing of materials, structural components and equipment; standard climates
DIN 51220 Material testing machines; definition , general directions, classification
DIN 51221 Sheet 1 Tensile testing machines; general requirements
Sheet 3 Tensile testing machines; small tensile testing machines (at present still circulating as draft)
DIN 52183 Testing of wood; determination of moisture content
DIN 53251 Testing of wood glues and wood bondings, determination of bonding strength; general directions
DIN 53255 Testing of wood glues and wood bondings, determination of bonding strength of plywood bondings (veneer boards and blockboards) in the tensile test and knife test
DIN 68330 Veneers; definitions
DIN 68705 Sheet 2 Plywood for general purposes; quality conditions
Sheet 3 Plywood; veneer boards for building, quality conditions
Sheet 4 Plywood; building blockboards, quality conditions (at present still circulating as draft).

Explanations

Standard DIN 68705 has been separated into several standard sheets and extended because a single standard sheet can be adapted more easily to the latest state of technical developments in view of the considerably wider fields of application.

DIN 68705 Sheet 1 contains the general bases for plywood such as definitions, requirements, testing specifications and instructions for safeguarding quality.

DIN 68705 Sheet 2 contains the quality conditions for plywood used for general purposes, i.e. mainly with regard to plywood used for furniture, interior decoration of rooms and for panelling in all fields of application not subject to static stress. The quality requirements for these sheets or boards chiefly cover bonding of the sheets and grading of the covering veneers.

DIN 68705 Sheet 3 contains the quality conditions for veneer boards and DIN 68705 Sheet 4 (at present still circulating as draft) the quality conditions for building blockboards. This Standard applies to plywood specially suitable for use in building by reason of its construction, veneer thicknesses and types of wood.

Plywood
Veneer Boards for Building
Quality Condition

DIN 68705 Sheet 3

Sperrholz; Bau-Furnierplatten, Gütebedingungen

1. Scope

This Standard applies to veneer boards used for building; in general they shall be unsanded.
DIN 68705 Sheet 2 applies to building plywood used for panellings.

2. Definitions

Veneer board used for building (symbol BFU), veneer board particularly suitable for building applications.

For further definitions, see DIN 68705 Sheet 1.

3. Requirements

3.1. Covering veneers and under veneers

3.1.1. Types of wood

The covering and under veneers of veneer boards used in building should be of the following types of woods

Birch, beech, spruce, pine, limba, macoré, mahogany species, gaboon, fir or woods with similar or better weather resistance.

In view of their lower weather resistance, veneers made of Obeche, Ilomba, Samba and Wawa shall be inadmissible.

3.1.2. Quality requirements

The following are permissible:

Wood discolourations and colour faults provided they do not impair the stability of the veneers.

Joints with slight faults only in the case of boards consisting of five and more plies of veneer

Cracks, isolated, up to 3 mm wide in boards consisting of three plies of the veneer, up to 5 mm wide in boards consisting of five and more plies of veneer

isolated, completely intergrown knots and knot places up to 25 mm diameter in boards consisting of three plies of veneer, up to 60 mm diameter in boards consisting of five and more plies of veneer

isolated bore holes caused by insects or their larvae

Covering veneers should not be more than 2.5 mm, under veneers not more than 3.7 mm thick. Covering and under veneers should be composed of strips of any width. Repairs to covering veneers shall be carried out by a method of bonding suitable for the veneer board. Adhesive tapes which impair bonding stability shall be inadmissible.

3.2. Cores

3.2.1. Types of wood

All the types of wood mentioned in Section 3.1.1 can be used for cores (inner layers of veneer) regardless of the types of wood used for covering and under veneers, with the exception of Obeche, Ilomba, Samba and Wawa, provided quality specifications with regard to stability are satisfied.

3.2.2. Quality requirements

The inner plies of veneer must satisfy requirements for covering veneers although a rather higher proportion of sound knots and bore holes caused by insects can be permitted, provided these do not occur frequently or spread over the entire sheet of veneer.

The inner plies of veneer should not be thicker than 3.7 mm. They may be composed of strips of any required width. Adhesive tapes which impair bond stability are inadmissible.

3.3. Board structure

Boards must be built up symmetrical to the middle plane with regard to veneer thicknesses and types of wood and must have the following minimum number of veneer plies for the board thicknesses listed below:

Board thickness mm	No. of plies
up to 8	3
over 8 to 15	5
over 15 to 22	7
over 22 to 29	9

3.4. Bonding

The bonding of the veneer boards specified in this Standard must conform to the types of bonding IF 20 or AW 100 according to DIN 68705 Sheet 1.

Note: In addition to these bondings veneer boards may also be produced by the IW 67 method of bonding.

3.5. Bond strength (quality limits)

Bond strength must be at least 10 kp/cm^2, at least 8 kp/cm^2 in the case of inside veneers consisting of coniferous woods. These limiting values refer to the average values for three boards In this connection none of the three average values for the boards should be more than 10 % below the limit.

3.6. Bending strength (quality limits)

Longitudinal bending strength must be at least 400 kp/cm^2 and cross bending strength at least 150 kp/cm^2. These limiting values refer to average values from three boards. In this connection none of the three average values for the boards may be more than 10 % below the limit.

Continued on pages 2 and 3
Explanations on page 3

3.7. Dimensions and permissible variations

DIN 4078 applies to length and width.

3.8. Moisture content

The moisture content of veneer boards for building according to this Standard should be at least 6 % related to the kiln-dried weight.

3.9. Wood protection

Woods having good natural resistance should be used for plywood subjected for long periods to elevated temperatures and high humidity. Less resistant types of wood must be protected by a preservative.

N o t e : Resistance of veneer boards for building to animal and plant pests is no greater than that of the types of wood employed. When using plywood in building necessary steps must therefore be taken by c o n s t r u c t i v e m e a s u r e s to ensure the necessary protection against moisture, regardless of the type of bonding (see also DIN 68800). When using wood preservatives care should be taken to see that they are compatible with the binders used.

4. Testing

4.1. Bonding (bond strength)

Bond strength shall be tested by the shear test according to DIN 53255. Sampling, production and pretreatment of specimens shall be carried out according to DIN 68705 Sheet 1.

4.2. Bending strength

Testing according to DIN 52371 (at present still circulating as draft)

4.3. Moisture content

Testing according to DIN 52183

5. Quality safeguard

Veneer boards for building according to this Standard must be subjected to regular quality supervision. Such quality supervision consists of a statistic quality control (own supervision) and a supervisory test (outside supervision). Attention is drawn, in connection with implementation of the quality safeguard, to the instructions of the Güteschutzgemeinschaft Sperrholz e.V. (address: 63 Gießen 1, Bahnhofstraße 52-56) on quality supervision of veneer boards for building.

5.1. Own supervision

Own supervision shall be carried out according to DIN 68705 Sheet 1.

5.1.1. Q u a l i t y p r o p e r t i e s

Own supervision of veneer boards for building shall cover bonding (determining bond strength in the shear test) and bending strength.

When testing the bonding strength of bonding type AW 100 the only pretreatment given to the specimens shall be the cold water treatment according to DIN 68705 Sheet 1.

5.1.2. S a m p l i n g

see DIN 68705 Sheet 1.

5.1.3. Q u a l i t y l i m i t s

The limiting values stated in Section 3.6 shall be chosen as the lower warning boundary with a probable falling-short value of not more than 5 %, where necessary taking into account the correction factor mentioned in Section 5.1.3 of DIN 68705 Sheet 1, January 1968 edition.

5.2. Outside supervision

Outside supervision shall be carried out according to DIN 68705 Sheet 1.

5.2.1. Q u a l i t y p r o p e r t i e s

Outside supervision covers bonding (determining bonding strength in the shear test) and the bending strength.

When testing bonding strength in bonding type AW 100 pretreatment of the specimens shall include the cold water treatment and the alternate boiling, heating and cooling treatment according to DIN 68705 Sheet 1.

5.2.2. S a m p l i n g

see DIN 68705 Sheet 1.

5.2.3. Q u a l i t y l i m i t s

The requirements stated in Sections 3.5 and 3.6 with regard to various properties must be satisfied.

5.2.4. T e s t i n g o w n s u p e r v i s i o n

When sampling according to DIN 68705 Sheet 1 records of own supervision (according to DIN 68705 Sheet 1) shall be tested.

6. Designation

Veneer boards for building according to this Standard shall be marked by the manufacturer on the poorer side with a stamp showing the symbol BFU for veneer board for building, the manufacturer's mark, board thickness, type of bonding and DIN number.

Example:
Veneer board for building, manufacturer ....., board thickness 15 mm, bonding AW 100

BFU .... 15 AW 100 DIN 68705

Particulars used for designation (except for the manufacturer's mark) may also be used for orders.

Reference to further standards:

DIN 1052 Wooden structures; calculation and construction

DIN 4078 Plywood; dimensions

DIN 52183 Testing of wood; determination of moisture content

DIN 52371 Testing of plywood; bending test (at present still circulating as draft)

DIN 53255 Testing of wood glues and wood bondings; determination of bond strength of plywood bondings (veneer boards and blockboards) in the tensile test and in the knife test

DIN 68330 Veneers; definitions

DIN 68705 Sheet 1 Plywood; definitions, general requirements, testing

Sheet 2 Plywood for general purposes, quality conditions

Sheet 4 Plywood; blockboards for building, quality conditions (at present still circulating as draft)

DIN 68800 Protection of wood used in buildings

Explanations

The specifications given in DIN 68705 Sheet 3 should be followed for veneer boards which are to be used chiefly for wooden houses constructed in panels and for light-weight roofs. This Standard is adapted to the relevant supplementary regulations for DIN 1052. It includes particulars of approved veneers, bonding and quality safeguards by own and outside supervision required by the building authorities.

In defining strength requirements the Advisory Committee proceeded on the basis that plywood is mainly subjected to bending stresses in wooden houses and light-weight roofs and restricted the quality safeguard, apart from bonding strength, to one characteristic, b e n d i n g s t r e n g t h. In this connection is was assumed that bending-elastic modulus is shown by experience to be linked correlatively with bending strength. The bending strength therefore serves chiefly as a control characteristic which can be subsequently checked in a very simple manner. However, designers and structural analysts need further information which is listed in the following Table. Manufacturers of veneer boards can vary their elastomechanical properties within certain limits by their choice of woods and by the structure of the boards. This latitude could not be fully taken into account in the Table (approximate values). In arriving at calculations for wooden constructions the least favourable table values are applicable in each case if more advantageous values may not be used on the basis of a test certificate of a recognized material institute in an individual case or according to other German standards and specifications.

Property	Symbol	Unit	Numerical value
Bulk density u = 12 %	ϱ	kg/m³	500 to 800
Bending-elastic modulus along the grain	$E_b \parallel$	kp/cm²	70 000 to 120 000
across the grain (3 plies)	$E_b \perp$	kp/cm²	7 000 to 12 000
(5 and more plies)	$E_b \perp$	kp/cm²	30 000 to 70 000
Dynamic modulus of shear	G	kp/cm²	5 000 to 6 000
Lengthwise or crosswise swelling per percent change in wood moisture	q_L	%	0,01 to 0,02
Coefficient of thermal conductivity (calculated value)	λ_R	kcal/(m h deg)	0,12
Vapour diffusion resistance factor	μ	–	300 to 700

APPENDIX 4 NBS Voluntary Product Standard PS 51-71 Hardwood and Decorative Plywood. U. S. Department of Commerce, National Bureau of Standards.

UNITED STATES
EPARTMENT OF
OMMERCE
ILICATION

NBS Voluntary Product Standard

PS 51-71

Hardwood and Decorative Plywood

A Voluntary Standard
Developed by Producers,
Distributors, and Users
With the Cooperation of the
National Bureau of Standards

U.S.
DEPARTMENT
OF
COMMERCE
National
Bureau
of Standards

UNITED STATES DEPARTMENT OF COMMERCE • Maurice H. Stans, *Secretary*

NATIONAL BUREAU OF STANDARDS • Lewis M. Branscomb, *Director*

Voluntary Product Standard

PS 51-71

Hardwood and Decorative Plywood

Technical Standards Coordinator: P. R. Sutula

Abstract

This Voluntary Product Standard for hardwood and decorative plywood establishes the nationally recognized marketing classifications, quality criteria, test methods, definitions, and grade-marking and certification practices for plywood produced primarily from hardwoods. It is intended for voluntary use by reference in trade literature, catalogs, sales contracts, building codes, and procurement specifications to describe the quality aspects of the product and the means to determine conformance.

Requirements are given for wood species, veneer grading, lumber-core, particleboard-core, hardboard-core, glue bond, panel constructions, dimensions, moisture content, sanding, and finishing. Sampling and testing provisions cover dry shear, cyclic-boil, three cycle wet and dry, and cold soak test methods for plywood delamination determinations, and field and laboratory moisture content measuring methods. A glossary of trade terms is provided for better communication and understanding, and provisions are made for panel grade-marking and certification to indicate compliance.

Key words: Decorative plywood; hardwood plywood; plywood, hardwood and decorative; softwood plywood, decorative; veneer grades, decorative softwood and hardwood.

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Contents

VOLUNTARY PRODUCT STANDARDS

Voluntary Product Standards are standards developed under procedures established by the Department of Commerce (15 CFR Part 10, as amended, May 28, 1970). The standards may include (1) dimensional requirements for standard sizes and types of various products, (2) technical requirements, and (3) methods of testing, grading, and marking. The objective of a *Voluntary Product Standard* is to establish requirements which are in accordance with the principal demands of the industry and, at the same time, are not contrary to the public interest.

Development of a VOLUNTARY PRODUCT STANDARD

The Office of Engineering Standards Services of the National Bureau of Standards has been assigned by the Department of Commerce the responsibility to work closely with scientific and trade associations and organizations, business firms, testing laboratories, and other appropriate groups to develop *Voluntary Product Standards*. The Bureau has the following role in the development process: It (1) provides editorial assistance in the preparation of the standard; (2) supplies such assistance and review as is required to assure the technical soundness of the standard; (3) acts as an unbiased coordinator in the development of the standard; (4) sees that the standard is representative of the views of producers, distributors, and users or consumers; (5) seeks satisfactory adjustment of valid points of disagreement; (6) determines the compliance with the criteria established in the Department's procedures cited above; and (7) publishes the standard.

Industry customarily (1) initiates and participates in the development of a standard; (2) provides technical counsel on a standard; and (3) promotes the use of, and support for, the standard. (A group interested in developing a *Voluntary Product Standard* may submit a written request to the Office of Engineering Standards Services, National Bureau of Standards, Washington, D.C. 20234.)

A draft of a proposed standard is developed in consultation with interested trade groups. Subsequently, a Standard Review Committee is established to review the proposed standard. The committee, appropriately balanced, includes qualified representatives of producers, distributors, and users or consumers of the product being standardized. When the committee approves a proposal, copies are distributed for industry consideration and acceptance. When the acceptances show general industry agreement, and when there is no substantive objection deemed valid by the Bureau, the Bureau announces approval of the *Voluntary Product Standard* and proceeds with its publication.

Use of a VOLUNTARY PRODUCT STANDARD

The adoption and use of a *Voluntary Product Standard* is completely voluntary. *Voluntary Product Standards* have been used most effectively in conjunction with legal documents such as sales contracts, purchase orders, and building codes. When a standard is made part of such a document, compliance with the standard is enforceable by the purchaser or the seller along with other provisions of the document.

Voluntary Product Standards are useful and helpful to purchasers, manufacturers, and distributors. Purchasers may order products that comply with *Voluntary Product Standards* and determine for themselves that their requirements are met. Manufacturers and distributors may refer to the standards in sales catalogs, advertising, invoices, and labels on their product. Commercial inspection and testing programs may also be employed, together with grade labels and certificates assuring compliance, to promote even greater public confidence. Such assurance of compliance promotes better understanding between purchasers and sellers.

Voluntary Product Standard PS 51-71
(Supersedes CS 35-61)

Hardwood and Decorative Plywood

Effective August 15, 1971 (See section 8.)

(This Standard, initiated by the Hardwood Plywood Manufacturers Association, has been developed under the *Procedures for the Development of Voluntary Product Standards*, published by the U.S. Department of Commerce, as a revision of Commercial Standard CS 35-61, *Hardwood Plywood.* See Section 9, *History of Project*, for futher information.)

1. PURPOSE

1.1. Purpose—The purpose of this Voluntary Product Standard is to establish nationally recognized quality criteria for the principal types, grades, and sizes of hardwood and decorative plywood. The principal wood species used for hardwood and decorative plywood are hardwoods; however, certain softwood species are also used.[1] The Standard is intended to provide producers, distributors, architects, contractors, builders, and users with a basis for common understanding of the characteristics of this product.

1.2. Intended use—The plywood covered by is Voluntary Product Standard is intended for use as decorative wall panels where esthetic characteristics are important; for cut-to-size and stock panels used for furniture, cabinets, containers, and specialty products; and for marine applications.[2]

2. SCOPE AND CLASSIFICATION

2.1. Scope—This Voluntary Product Standard covers the principal types, grades, and constructions of plywood made primarily with hardwood faces. Included are requirements for wood species and veneer grading; for lumber, particleboard, and hardboard cores; and for glue bond, panel construction, moisture content, and panel dimensions and tolerances. Test procedures are provided for determining conformance with the requirements. Definitions of trade terms, methods of ordering, and methods for identifying products that conform to this Standard are included.

2.2. Classification—Plywood covered by this Standard is classified as follows:

2.2.1. Species—The most commonly marketed species for plywood faces are listed in table 1.

2.2.2. Grades of veneers—The grades of veneers are listed below with the identification symbol for each grade:

Premium grade	(A)
Good grade	(1)
Sound grade	(2)
Utility grade	(3)
Backing grade	(4)
Specialty grade	(SP)

2.2.3. Types of plywood—The types of plywood are listed below in descending order of water-resistance capability. (See table 5.)

Technical — (Exterior)
Type I — (Exterior)
Type II — (Interior)
Type III — (Interior)

2.2.4. Constructions — The constructions, based on the kind of core, are listed below:

1. Hardwood veneer core (3-ply, 5-ply, etc. in odd numbers of plies)
2. Softwood veneer core (3-ply, 5-ply, etc. in odd numbers of plies)
3. Hardwood lumber core (3-ply, 5-ply, and 7-ply)
4. Softwood lumber core (3-ply, 5-ply, and 7-ply)
5. Particleboard core (3-ply and 5-ply)
6. Hardboard core (3-ply)
7. Special core (3-ply or more)

2.2.5. Sizes and thicknesses—Most combinations of length, width, and thickness are available. The common panel sizes are 48 by 84 inches, 48 by 96 inches, and 48 by 120 inches (1 inch equals 25.4 millimeters) with thicknesses ranging from 1/8 to 3/4 inch.

3. REQUIREMENTS

3.1. General—Products represented as complying with this Voluntary Product Standard shall meet all of the requirements specified herein. Terms used in this Standard shall be as defined in section 5.

3.2. Species for faces, backs, and inner plies—The species for the face shall be any hardwood species, and if used for decorative faces, any softwood species listed in table 1 may be used. The panels shall be identified by the species of

[1] This Voluntary Product Standard also includes certain decorative softwood species for nonconstruction uses. Construction grades of softwood and hardwood plywood are covered in the latest edition of Voluntary Product Standard PS 1-66, *Softwood Plywood, Construction and Industrial.*

[2] Additional product information is available from the Hardwood Plywood Manufacturers Association, 2310 S. Walter Reed Drive, Arlington, Virginia 22206.

the face (see 3.14). The species of the back and the inner plies may be any hardwood or softwood species.

TABLE 1. *Categories of commonly used species based on specific gravity ranges*[a]

Category A species (0.56 or more specific gravity)	Category B species (0.43 through 0.55 specific gravity)	Category C species (0.42 or less specific gravity)
Ash, Commercial White	Ash, Black	Alder, Red
Beech, American	Avodire	Aspen
Birch, Yellow, Sweet	Bay	Basswood, American
Bubinga	Cedar, Eastern Red[b]	Box Elder
Elm, Rock	Cherry, Black	Cativo
Madrone, Pacific	Chestnut, American	Cedar, Western Red[b]
Maple, Black (hard)	Cypress[b]	Ceiba
Maple, Sugar (hard)	Elm, American (white, red, or gray)	Cottonwood, Black
Oak, Commercial Red	Fir, Douglas[b]	Cottonwood, Eastern
Oak, Commercial White	Gum, Black	Pine, White and Ponderosa[b]
Oak, Oregon	Gum, Sweet	Poplar, Yellow
Paldao	Hackberry	Redwood[b]
Pecan, Commercial	Lauan, (Philippine Mahogany)	Willow, Black
Rosewood	Limba	
Sapele	Magnolia	
Teak	Mahogany, African	
	Mahogany, Honduras	
	Maple, Red (soft)	
	Maple, Silver (soft)	
	Prima Vera	
	Sycamore	
	Tupelo, Water	
	Walnut, American	

[a] Based on ovendry weight and volume at 12 percent moisture content.
[b] Softwood.

3.2.1. Species categories--Species of wood commonly used for veneers are listed in table 1 and are categorized by specific gravity for the purpose of establishing maximum veneer thicknesses (see table 5). The specific gravity ranges given in the three category headings shall also be used in determining the proper category for unlisted species. The Forest Products Laboratory in Madison, Wisconsin, shall be considered as final evaluator of specific gravity data.

3.3. Veneer grade descriptions—The grade requirements and identification symbols for hardwood veneers are given in 3.3.1 through 3.3.6. Softwood veneer requirements are given in 3.3.7. When unsanded veneers are graded, such characteristics as patches, rough areas of grain, shallow depressions, open splits, and machine marks which may be corrected by sanding are not considered. Panels shall be identified by the veneer grade of the face (see 3.14). A grading tolerance of 5 percent of the shipment or order will be permitted (see appendix).

3.3.1. Premium grade (A)—The veneer shall be smooth, tight-cut, and full-length. When used as a face and when it consists of more than one piece, it shall be edge-matched as outlined in table 2, and as illustrated in figure 1. Edge joints shall be tight. The natural and other characteristics, the types of matching which will be permitted for each species, and the defects which will not be permitted shall be as specified in table 2. Hardwood veneers of species not covered in table 2 may contain small burls, occasional pin knots, color streaks or spots, inconspicuous small patches, and usual characteristics inherent in the given species; however, knots (other than pin knots), wormholes, rough-cut veneer, splits, shake, and doze and other forms of decay will not be permitted.

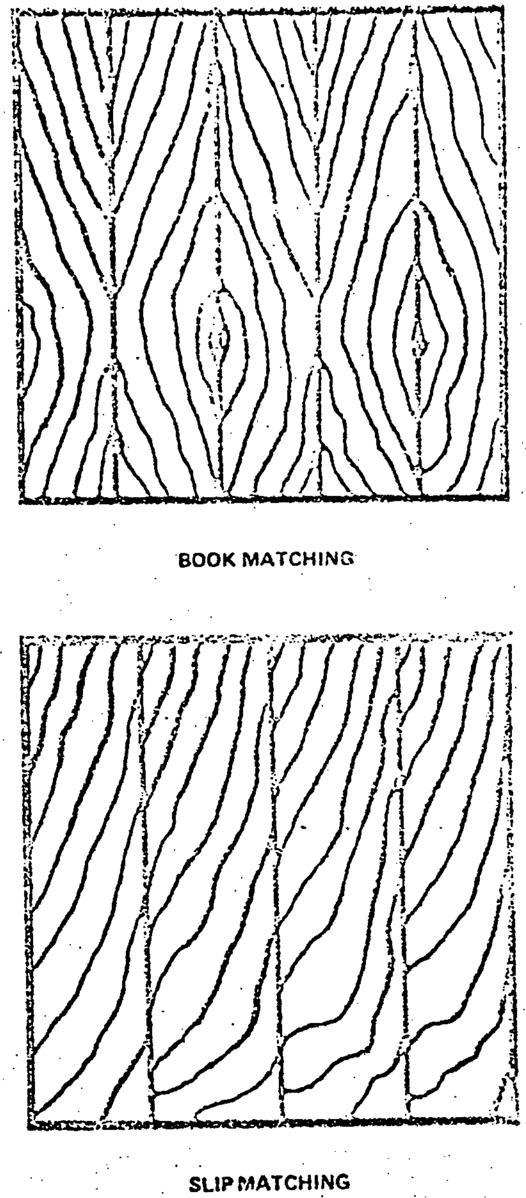


FIGURE 1. *Face matching.*

Table 2. *Summary of veneer characteristics and defects of Premium Grade and Good Grade hardwood species*

Characteristics	Rotary - Half round - Plain sliced birch						Rotary cativo		Plain sliced cherry		Rotary gum - tupelo - magnolia - bay poplar						Quarter sliced gum		Rotary lauan	
	Natural[1]		Select white	Select red	Uniform light	Uniform dark			6	7	Natural		Select for white		Select for red					
	Premium	Good	Premium	Premium	Premium	Premium	Premium	Good	Premium	Good	Premium	Good	Premium	Good	Premium	Good	Premium	Good	Premium	Good
Sapwood	Yes	Yes	Yes	No	Yes	No	Yes	Yes	10%	20%	Yes	Yes	Yes	Yes	No	20%	Yes	Yes	No	No
Heartwood	Yes	Yes	No	Yes	No	Yes	No	No	Yes	Yes	Yes	Yes	No	No	Yes	Yes	Yes	Yes	Yes	Yes
Color streaks or spots	Yes	Yes	Slight	Slight	Slight	Yes	Slight	Slight	Yes	Yes	Yes	Yes	Slight	Slight	Yes	Yes	Yes	Yes	Slight	Slight
Color variation	Yes	Yes	Slight	Slight	Slight	Yes	Slight	Slight	Yes	Yes	Yes	Yes	Slight	Slight	Slight	Yes	Yes	Yes	Slight	Slight
Mineral streaks	Slight	Slight	Slight	Slight	Slight	Slight	Slight	Slight	Slight	Slight	Yes	Yes	Slight	Yes	Slight	Yes	Slight	Slight	Slight	Slight
Small burls	Occ[2]	Yes	Occ	Occ	Occ	Occ	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Occ	Yes	Yes	Yes
Pin knots	Occ	Yes	Occ	Occ	Occ	Occ	Occ	Yes	Occ	Yes	Occ	Yes	Occ	Yes	Occ	Yes	Occ	Yes	Occ	Yes
Knots (other than pin knots)	No	No	No	No	No	No	No	No	No	No	No	Sound	No	No	No	No	No	No	No	No
Worm holes	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No
Open splits of joints	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No
Shake or doze	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No
Rough cut	No	No	No	No	No	No	No	No	No	No	No	Small	No	Small	No	Small	No	No	No	No
Cross bars	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	Occ	Occ	No	No
Inconspicuous patches	Small	Yes	Small	Small	Small	Small	Small	Yes	Small	Yes	Small	Yes	Small	Yes	Small	Yes	Small	Yes	Small	Yes
Type of matching	3	4	3	3	5	5	5	4	3	4	5	None	5	4	5	4	3 & 8	4	5	4

Table 2. *Summary of veneer characteristics and defects of Premium Grade and Good Grade hardwood species—continued*

Characteristics	Quarter sliced lauan		Quarter sliced limba	African and Honduras mahogany				Rotary - Half round - Plain sliced maple				Red and white oak						Pecan Hickory		Walnut			
				Rotary, plain sliced, flat cut		Quarter sliced		Natural		Select white	Uniform light	Rotary		Half round Plain sliced		Rift-comb grain				Half round Plain sliced	Rotary Half round Plain sliced	Quarter Sliced	Quarter Sliced
	Premium	Good	Premium	Premium	Good	Premium	Good	Premium	Good	Premium	Premium	Premium	Good	Premium	Good	Premium	Good	Premium	Good	Premium	Good	Premium	Good
Sapwood	No	No	No	No	No	No	No	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	No	Yes	Yes	Yes	10%	20%	10%	20%
Heartwood	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Color streaks or spots	Slight	Slight	Slight	Slight	Slight	Slight	Slight	Yes	Yes	Slight	Slight	Slight	Yes	Slight	Yes	Slight	Yes	Yes	Yes	Slight	Slight	Slight	Slight
Color variation	Slight	Slight	Slight	Slight	Slight	Slight	Slight	Yes	Yes	Slight	Slight	Yes	Yes	Slight	Yes	Slight	Yes	Slight	Yes	Yes	Yes	Yes	Yes
Mineral streaks	Slight	Slight	Slight	Slight	Slight	Slight	Slight	Small	Small	Slight	Slight	Slight	Yes	Slight	Slight	Slight	Slight	Slight	Yes	Slight	Yes	Slight	Yes
Small burls	Occ	Yes	Occ	Occ	Yes	Occ	Yes	Occ	Yes	Occ	Occ	Occ	Yes	Occ	Yes	Occ	Yes	Occ	Yes	Yes	Yes	Yes	Yes
Pin knots	Occ	Yes	Occ	Occ	Yes	Occ	Yes	Occ	Yes	Occ	Occ	Occ	Yes	Occ	Yes	Occ	Yes	Yes	Yes	Occ	Yes	Occ	Yes
Knots (other than pin knots)	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	Sound	No	Sound	No	Sound
Worm holes	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No
Open splits of joints	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No
Shake or doze	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No
Rough cut	No	No	No	No	No	No	No	No	No	No	No	No	Small	No	Small	No	No	No	No	No	No	No	No
Cross bars	Occ	Yes	Occ	No	No	Occ	Yes	No	No	No	No	No	No	No	No	No	No	No	No	No	No	Occ	Occ
Inconspicuous patches	Small	Yes	Small	Small	Yes	Small	Yes	Small	Yes	Small	Small	Small	Yes	Small	Yes	Small	Yes	Small	Yes	Small	Yes	Small	4
Type of matching	3	4	3	3	None	3	None	3	4	3 & 8	5	3 & 5	4	3	4	3 & 8	4	3	3	3	4	3 & 8	Yes

1 - Rotary ash, rotary basswood, rotary elm, rotary sycamore as birch grades (natural).
2 - Occasional.
3 - Book matched. Matched for color and grain at the joints (this can be furnished slip matched if customer so specifies).
4 - Sharp contrast will not be permitted.
5 - Matched for uniform color.
6 - Occasional gum spot allowed.
7 - Gum spots allowed.
8 - Slip matched. Must be matched in sequence with tight side out.

3.3.2. Good grade (1)—The veneer shall be smooth, tight-cut, and full-length. When used as a face and when it consists of more than one piece, the edge joints shall be tight. The pieces need not be matched for color or grain, but sharp contrasts between adjacent pieces of veneer with respect to grain, figure, and natural character markings will not be permitted. The natural and other characteristics which will be permitted for each species and the defects which will not be permitted shall be as listed in table 2. Veneers of species not covered in table 2 may contain small burls, pin knots, color streaks or spots, inconspicuous patches, and usual characteristics inherent in the given species; however, knots (other than pin knots), wormholes, rough-cut veneer, splits, shake, and doze and other forms of decay will not be permitted.

3.3.3. Sound grade (2)—The veneer shall be free from open defects. Matching for grain or color is not required. The natural and other characteristics which will be permitted and the defects which will not be permitted shall be as listed in table 3.

3.3.4. Utility grade (3) — The natural and other characteristics which will be permitted and the defects which will not be permitted shall be as listed in table 3.

TABLE 3. *Summary of veneer characteristics and allowable defects of Sound, Utility, and Backing Grades*

Defects	Sound Grade (2)[a]	Utility Grade (3)[a]	Backing Grade (4)[a]
Sapwood	Yes	Yes	Yes
Discoloration & Stain	Yes	Yes	Yes
Mineral Streaks	Yes	Yes	Yes
Sound Tight Burls	Max. diam. 1"	Yes	Yes
Sound Tight Knots	Max. diam. ¾"	Yes	Yes
Knotholes	No	Max. diam. 1"	Max. diam. 3"
Wormholes	Filled or Patched[b]	Yes	Yes
Open Splits or Joints	No	Yes; 3/16" for one-half length of panel	1" for one-fourth length of panel; ½" for one half length of panel; ¼" for full length of panel.
Doze & Decay	Firm areas of doze	Firm areas of doze in face. Areas of doze and decay in inner plies and backs provided serviceability of panel is not impaired.	Areas of doze and decay provided serviceability of panel is not impaired.
Rough Cut	Small area	Small area	Yes
Patches	Yes	Yes	Yes
Crossbreaks and Shake	No	Max. 1" in length	Yes
Buck Pockets	No	Yes	Yes
Brashness	No	No	Yes
Gum Spots	Yes	Yes	Yes
Laps	No	Yes	Yes

[a] Defects permitted in Premium and Good Grades will be allowed in this grade (see tables 2 and 4).
[b] Unfilled, inconspicuous, vertical wormholes not larger than 1/16" in diameter will be permitted in tropical hardwoods.

3.3.5. Backing grade (4)—The natural and other characteristics which will be permitted and the defects which will not be permitted shall be as listed in table 3.

3.3.6. Specialty grade (SP) — This grade shall include veneer possessing characteristics unlike any of those described for the above-mentioned grades. Characteristics shall be as agreed upon between buyer and seller. Species such as wormy chestnut, birdseye maple, and English brown oak which have unusual decorative features are considered as Specialty Grade. (Wall panel veneer face grades generally fall in this category.)

3.3.7. Softwood veneers—The face grade requirements for certain decorative softwoods shall be as listed in table 4. All other softwoods for faces, backs, or inner plies shall meet the same grading requirements as specified for hardwoods in 3.3.1 through 3.3.6.

3.4. Thickness of veneers— The maximum veneer thicknesses shall be as provided in table 5. The minimum thicknesses of veneers shall be as agreed upon between buyer and seller.

3.5. Lumber cores—Lumber cores shall be of any species, except that mixing of species in a single core will not be permitted. The maximum permissible widths of core strips shall be 2½ inches for Category A species (see 3.2.1), 3 inches for Category B species, and 4 inches for Category C species. Core grades and core banding requirements shall be as described in 3.5.1 through 3.5.5. Cores shall be conditioned after gluing to equalize moisture content before sanding.

3.5.1. Clear grade—The wood strips shall be full length or finger-jointed and shall be free of knots or other defects which would not properly shape or mold, except that discolorations will be permitted. Wood patches or plugs shall not be used, but wood filler will be permitted.

3.5.2. Sound grade—The wood strips shall be full length or finger-jointed and shall be free

TABLE 4. *Summary of veneer characteristics and allowable defects for Premium Grade and Good Grade decorative softwood species*

Characteristics	Rotary — Sliced — Knotty Veneer: Western red cedar, Premium (A)	Western red cedar, Good (1)	White pine, Premium (A)	White pine, Good (1)
Discoloration	No	Slight	No	Slight
Burls	Yes	Yes	Yes	Yes
Knots	—	—	—	—
Pin knots	Yes	Yes	Yes	Yes
Sound knots	Yes	Yes	Yes	Yes
Spike knots	Slight	Yes[b]	Slight	Yes[b]
Filled knot holes[a]	3/4 in.	1 1/2 in.	3/4 in.	1 1/2 in.
Worm holes	No	No	No	No
Open splits or joints	No	No	No	No
Doze	No	No	No	No
Rough cut	No	Inconspicuous	No	Inconspicuous
Inconspicuous patches	Small	Yes	Small	Yes
Pitch streaks	Small	Small	Small	Small
Pitch pockets	No	Small	No	Small
Crow's foot	Slight	Occasional	No	No
Matching	a or c	a or c	a or c	a or c

Characteristics	Sliced — Vertical grain: Douglas fir, Premium (A)	Redwood, Premium (A)
Sapwood	Limited[d]	No
Heartwood	Yes[e]	Yes[e]
Color streaks	No	No
Color variation	Slight	Slight
Mineral streaks	No	Slight
Small burls	Yes	Yes
Pin knots	No	Yes
Knots	No	No
Worm holes	No	No
Open splits or joints	No	No
Shake or doze	No	No
Rough cut	No	No
Crossbars	No	No
Inconspicuous patches	Yes	Yes
Pitch streaks	Small	No
Pitch pockets	No	No
Matching	c or f	c or f

[a] Randomly spaced for pleasing appearance.
[b] Maximum 2 inches.
[c] Slip matched. Must be matched in sequence with tight side out.
[d] Bright sapwood not permitted.
[e] Six or more annual rings per inch.
[f] Book matched. Matched for color and grain at the joints.

TABLE 5. *Limiting criteria for plywood*

Limiting factors	Technical (Exterior)	Type I[a] (Exterior)	Type II (Interior)	Type III (Interior)
Glue bond (3.9)	Fully waterproof	Fully waterproof	Water resistant	Moisture resistant
Adhesive performance (3.9)	Dry and cyclic boil shear	Dry and cyclic boil shear	3-cycle soak	2-cycle soak
Species or specific gravity category of veneer (3.2)	Specify	Specify	Specify	Specify
Veneer edge joints (3.3)	No tape	No tape	Tape	Tape
Grade of faces or face and back (3.3)	Specify	Specify	Specify	Specify
Grade of hardwood inner plies adjacent to faces (3.3)[b]	2 under A or 1 3 under 2	2 or 3	2 or 3[c]	2 or 3[c]
Grade of softwood inner plies adjacent to faces (3.3.7)[b]	2	2 or 3	2 or 3[c] (4 under 3 or 4)	2 or 3[c]
Grade of other inner plies (3.3.1 through 3.3.7)	3 or 4	3 or 4	3 or 4	3 or 4
Grade of lumber core (3.5)	Not suitable	Specify	Specify	Specify
Particleboard or hardboard core (3.6)	Not suitable	Specify	Specify	Specify
Maximum veneer thickness in inches by specific gravity category (3.2.1):				
Category A	1/12	1/8	3/16	3/16
Category B	1/10	3/16	1/4	1/4
Category C	1/8	1/4	1/4	1/4
Percentage of wood in face direction	40 to 60	No limitation	No limitation	No limitation
Sanding (3.11)	Specify	Specify	Specify	Specify

[a] Not recommended for continuous exposure to moisture.
[b] Specify Grade 2 for solid inner plies.
[c] Where 1/16 inch or thicker faces are used, Grade 4 or better inner plies are permitted.

of defects, except that discolorations, sound knots, and small open defects, if securely patched or plugged with wood or wood filler will be permitted.

3.5.3. Regular grade—The wood strips shall be the same as sound grade, except that tightly butted end joints will be permitted.

3.5.4. Clear edge—The wood strips shall be "regular grade," except that the edge strips shall be 1½ inches or wider "clear grade" to permit shaping or molding.

3.5.5. Banded core—The bands shall be "clear grade." The species, width, number of bands, and grade between bands shall be as agreed upon between buyer and seller. The types of banding shall be as follows:

1. Banded one end (B1E)
2. Banded two ends (B2E)
3. Banded one side (B1S)
4. Banded two sides (B2S)
5. Banded two ends and one side (B2E1S)
6. Banded two sides and one end (B2S1E)
7. Banded two sides and two ends (B4)

3.6. Particleboard and hardboard cores—Particleboard cores shall be in accordance with Commercial Standard CS 236-66, *Mat-formed Wood Particleboard*.[3] Hardboard cores shall be in accordance with Commercial Standard CS 251-63, *Hardboard*.[3]

3.7. Special cores—Cores made of other material may be used providing all other applicable requirements of this Standard are met.

3.8. Construction—Plywood panels shall be constructed with an odd number of plies. All plies shall be combinations of species, thickness, and moisture content to produce a balanced panel. All inner plies, except the core or center ply, shall occur in pairs. Each pair of inner plies shall be of the same thickness and direction of grain. Each ply of each pair shall be placed on

[3] Later issues of this publication may be used providing the requirements are applicable and consistent with the issue designated. Copies are available from the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402.

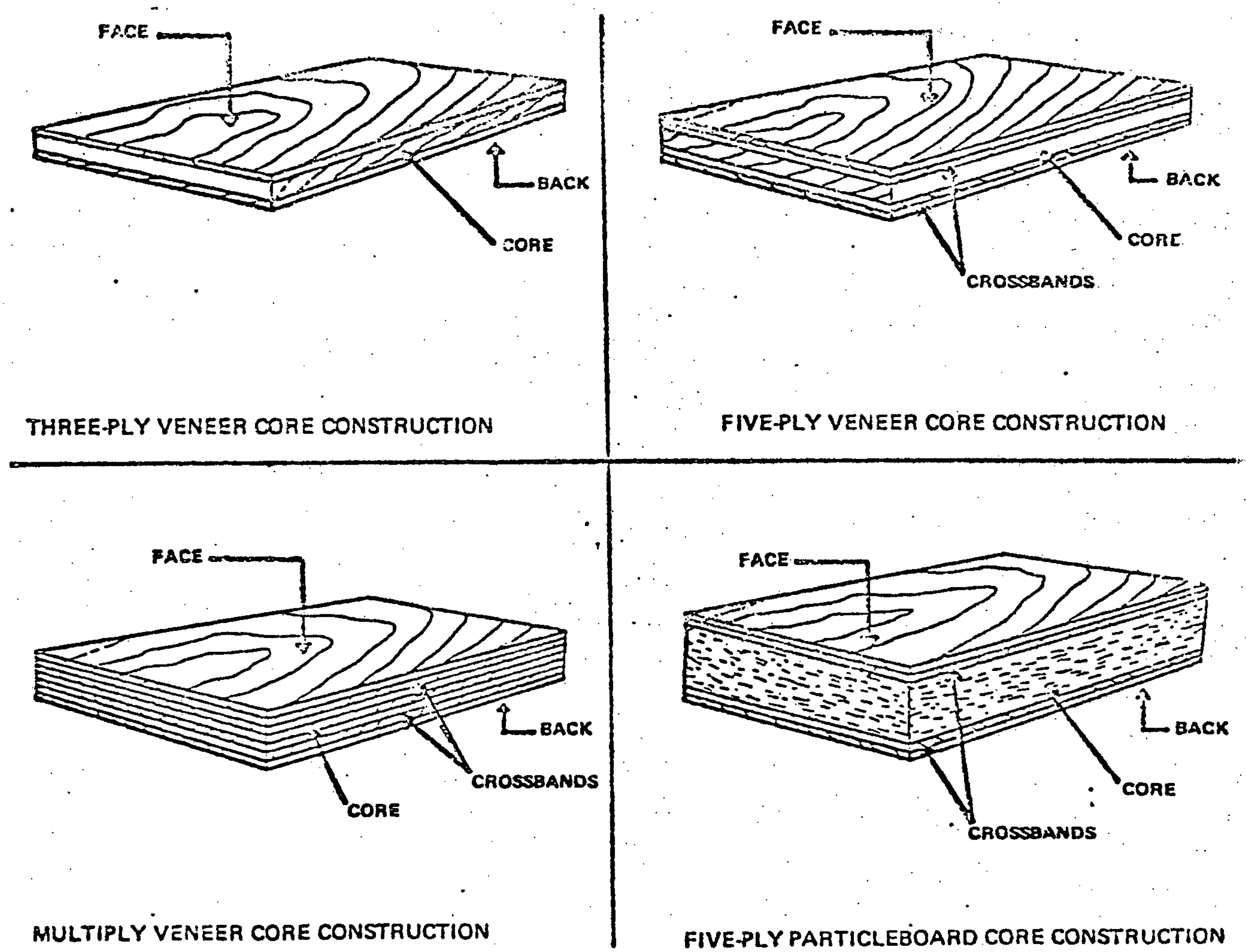
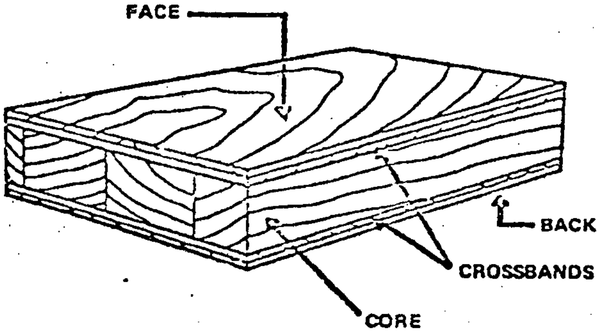
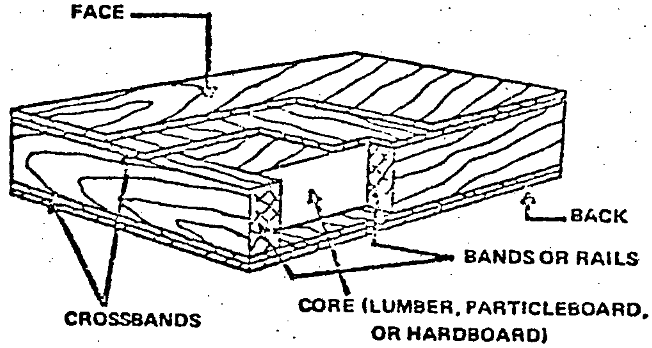


FIGURE 2. *Typical plywood constructions.*



FIVE-PLY LUMBER CORE CONSTRUCTION



FIVE-PLY
CONSTRUCTION WITH BANDING OR RAILING

FIGURE 2. *Typical plywood constructions—continued.*

opposite sides of the core. The grain of all plies shall be at right angles to the grain of the adjacent plies and to the ends or edges of the panel. Some typical constructions are illustrated in figure 2. The limiting criteria for plywood panels shall be as provided in table 5 except for con-iner plywood which shall utilize grade 4 or :ter inner plies adjacent to the faces for each type. (See 3.14 for marking.)

3.8.1. Special construction—Because of special panel constructions and because of special face treatments, certain panels may deviate from a flat surface prior to their application. Such deviation shall not prevent their taking the shape of the surface to which they are applied without the development of defects attributable to this deviation.

3.9. Glue bond requirements—

3.9.1. Technical Type plywood — The glue bond of Technical Type plywood panels shall meet the wood failure requirements given in table 6 when tested in accordance with 4.2, 4.3, and 4.4. Technical Type plywood constructed with

TABLE 6. *Wood failure requirements for Technical and Type I plywood glue bonds*

Average failing load	Minimum wood failure	
	Indiv. specimen	Test piece average
lb/sq in.	Percent[a]	Percent[a]
Under 250	25	50
250 to 350	10	30
Above 350	10	15

[a] These values are the percentage of wood area remaining adhered to the fractured surface in the test area.

hardwood face veneers on softwood inner plies shall also comply with the Exterior Type bond quirements specified in Voluntary Product Standard PS 1-66, *Softwood Plywood, Construction and Industrial.*[6]

[6] See footnote 3, page 6.

3.9.2. Type I plywood — The glue bond of Type I plywood shall meet the same requirements as Technical Type.

3.9.3. Type II plywood—The glue bond of Type II plywood shall be of such quality that specimens shall withstand the 3-cycle soak test described in 4.2 and 4.5.

3.9.4. Type III plywood — The glue bond of Type III plywood shall be of such quality that specimens shall withstand the 2-cycle soak test described in 4.2 and 4.6.

3.10. Dimensions and tolerances—The nominal dimensions of the plywood panels shall be as agreed upon between buyer and seller. The tolerances for the nominal dimensions shall be as follows:

Width:	plus or minus 1/32 in
Length:	plus or minus 1/32 in
Thickness:	
Unsanded:	plus or minus 1/32 in
Sanded:	plus 0, minus 1/32 in except that a sanded tolerance of plus 0, minus 3/64 in will be permitted for panels having a nominal thickness of ¼ in or more.

Note: One inch equals 2.54 centimeters.

3.10.1. Squareness—Panels 4 feet by 4 feet or larger shall be square within 3/32 inch. Panels less than 4 feet in length or width shall be square within 1/16 inch. Squareness shall be determined by measuring the length of the two diagonals of the panel.

3.10.2. Straightness—The edges of panels less than 8 feet long shall be such that a straight line from one corner to the adjacent corner shall fall within 1/16 inch of the panel edge. A departure of 3/32 inch will be permitted for panels 8 feet long and longer.

3.11. Sanding—The types of sanding shall be as described below. The type of sanding and the number of surfaces of the panels to be sanded shall be as agreed upon between buyer and seller, except that in no case shall the plywood be considered as ready for finishing because raised grain due to moisture absorption and marks made in handling the plywood during shipment or storage may require further sanding.

No sanding—Surfaces need not be sanded nor tape removed.

Rough sanding—Sanding hit-or-miss. Tape removal is not required.

Regular sanding—Surfaces shall be clean and free of tape. Sander streaks are not considered defects.

Polish sanding—Surfaces shall be clean and smoothly sanded.

3.12. Moisture content—The moisture content of plywood panels at the time of shipment from the producing mill shall not exceed 12 percent of the ovendry weight, as determined in accordance with 4.7.

3.13. Factory finished panels—The finish of factory finished panels shall be as agreed upon between buyer and seller.

3.14. Marking—All plywood represented as conforming to this Voluntary Product Standard shall be identified by either of the following methods:

(a) Each panel shall be marked with the symbol of this Sandard, PS 51-71, the name or recognized identification of the producer; the species and grade of the face veneer; the type of plywood; the symbol "CP," if container plywood; and the identity of the qualified inspection and testing agency, if applicable (see section 7), or

(b) The shipment or order shall be accompanied by a written certification which states that the panels conform to all of the requirements of Voluntary Product Standard PS 51-71, and identifies the producer; the species and grade of the face veneer; the type of plywood; the qualified inspection and testing agency, if applicable (see section 7); and the specific intended use if container plywood.

4. INSPECTION AND TEST PROCEDURES

4.1. General—The inspection and test procedures contained in this section are to be used to determine the conformance of products to the requirements of this Voluntary Product Standard. Each producer or distributor who represents his products as conforming to this Standard may utilize statistically based sampling plans which are appropriate for each particular manufacturing process but shall keep such essential records as are necessary to document with a high degree of assurance his claim that all of the requirements of this Standard have been met. Additional sampling and testing of the product, as may be agreed upon between purchaser and seller, is not precluded by this section.

4.2. Specimens for glue bond test—

4.2.1. Technical and Type I plywood—Three test pieces shall be cut from each panel selected: one piece from each end of the panel and one piece near the center of the panel. Each test piece shall be of sufficient size to provide at least six specimens for the dry shear test and six specimens for the cyclic-boil shear test (see table 7).

4.2.2. Type II plywood—A total of 10 test specimens shall be cut from each panel selected: two specimens from each end approximately at mid-width of the panel; two specimens from each edge approximately at mid-length of the panel; and two specimens near the center of the panel. Test specimens shall not have common edges (see table 7).

4.2.3. Type III plywood—Three test specimens shall be cut from each panel selected: one from each end of the panel and one near the center of the panel (see table 7).

TABLE 7. *Test specimen sizes*

Type of plywood	Specimen size
Technical & Type I	3¼ inch[a] by 1-inch specimens
Type II (3-cycle)	5-inch[b] by 2-inch specimens
Type III (2-cycle)	6-inch by 6-inch specimens

[a] Parallel to the grain of the outside veneers in 3-, 7-, and 11-ply construction. Perpendicular to the grain of the outside veneers in 5- and 9-ply construction. The preceding applies to specimens for testing the innermost plies. Specimens for testing the outer plies shall always be parallel to the grain of the face veneer in the 3¼ inch dimension.

[b] Parallel to the grain of the face veneers.

4.3. Dry shear test—Shear tests shall be conducted on specimens prepared as shown in figure 3. The ends of each specimen shall be gripped in test machine retaining jaws, and the load shall be applied at the rate of 600 to 1,000 pounds per minute. Specimen notching shall be accomplished in such a way as to assure that when the specimens are subjected to loading, the lathe checks in the center ply of half of the specimens will be in tension, while in the other half the lathe checks will be in compression. An explanation of one method of notching specimens to insure that half of the lathe checks are pulled in tension and half are pulled in compression, is described in American Society for Testing and Materials (ASTM) D 906-64, *Standard Method of Test for Strength Properties of Adhesives in Plywood Type Construction in Shear by Tension Loading.*[5] If the number of plies exceeds three, the outer pairs of glue lines and innermost glue lines shall be tested with separate sets of test specimens. In plywood with face plies thicker than 1/16 inch, the shear area shall be 1 square inch, as shown in figure 3, specimen A. Specimens of plywood with face plies 1/16 inch

[5] Later issues of this publication may be used providing the requirements are applicable and consistent with the issue designated. Copies of ASTM publications are obtainable from the American Society for Testing and Materials, 1916 Race Street, Philadelphia, Pennsylvania 19103.

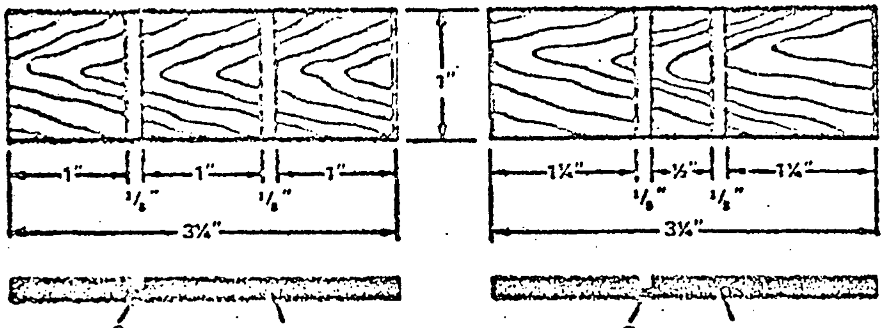


FIGURE 3. *Plywood bond shear test specimens.*

or less in thickness shall be of the form shown in figure 3, specimen B, in which the shear area shall be reduced to ½ square inch without changing the width of the specimen. Test machine loads obtained from specimens of ½ square inch shear area shall be multiplied by 2 to convert to pounds per square inch and then reduced by 10 percent before comparing with the required values set forth in table 6. For shear tests of lumber core plywood, particleboard core plywood, and hardboard core plywood, the core shall be cut away to 1/10 inch in thickness.

4.4. Cyclic-boil shear test — The specimens prepared as shown in figure 3 shall be boiled in water for 4 hours and then dried for 20 hours at a temperature of 145 ± 5 °F (63 ± 3 °C). They shall be boiled again for 4 hours, cooled in water, and then subjected while wet to the test described in 4.3. The values obtained from the six specimens shall meet the applicable requirements given in table 6. If the number of plies exceeds three, the outer pairs of glue lines and innermost glue lines shall be tested with separate sets of test pieces.

4.5. Three-cycle soak test—The 5-inch by 2-inch specimens from each test panel shall be submerged in water at 75 ± 5 °F (24 ± 3 °C) for 4 hours and then dried at a temperature between 120 and 125 °F (49 to 52 °C) for 19 hours with sufficient air circulation to lower the moisture content (based on ovendry weight) of specimens to a maximum of 8 percent. This cycle shall be repeated until all specimens fail or until three cycles have been completed, whichever occurs first. A specimen shall be considered as failing when any single delamination between two plies is greater than 2 inches in continuous length, over ¼ inch in depth at any point, and 0.003 inch in width, as determined by a feeler gage 0.003-inch thick and ½-inch wide. Delamination due to tape at joints of inner plies or defects permitted by the grade shall be disregarded. Nine of the 10 specimens shall pass the first cycle and eight of the 10 specimens shall pass the third cycle.

4.6. Two-cycle soak test—The 6-inch by 6-inch specimens shall be submerged in water at 75 ± 5 °F (24 ± 3 °C) for 4 hours, and then dried at 75 ± 5 °F in an open room for 20 hours. The cycle shall be repeated until all specimens fail or until two cycles have been completed, whichever occurs first. A specimen shall be considered as failing when any single delamination between two plies is greater than 2 inches in continuous length, over ¼ inch in depth at any point and 0.003 inch in width. Separation is determined with a 0.003-inch feeler gage. When this test is applied to lumber core or particleboard core plywood, the core should be cut away to a depth of 1 inch on all four edges, leaving only enough core in this stress-relieved section to produce an approximate balance with the face ply. Delamination due to tape at joints of inner plies or defects permitted by the grade shall be disregarded. If there is a failure of more than one test specimen, the panel shall be classified as defective.

4.7. Moisture content test — The moisture content of the plywood shall be determined as follows: A small test specimen shall be cut from the sample panel; the test specimen shall measure not less than 9 square inches in area and shall weigh not less than 20 grams. All loose splinters shall be removed from the specimen. The specimen shall be immediately weighed to the nearest 0.1 of a gram, and the weight shall be recorded as the original weight. The specimen shall then be dried in an oven at 212 to 221 °F (100 to 105 °C) until constant weight is attained. After drying, the specimen shall be reweighed immediately, and this weight shall be recorded as the ovendry weight. The moisture content shall be calculated as follows:

$$\frac{\text{Original weight} - \text{ovendry weight}}{\text{Ovendry weight}} \times 100 = \text{Moisture content (percent)}$$

APPENDIX 5 The mixing sequence of the PF IB-334 Glue.

c.c. W.B. Smith

August 9, 1974

Mr. F. Alan Tayelor,
Industrial Development Officer,

VANCOUVER, B.C.

Dear Mr. Tayelor:

Bill Hancock has requested that I forward details on the glue mix we prepared for use in bonding veneer for ladder stock at our lab.

The mixes made August 8th were formulated as follows:

IB-334 Plyophen	5,872 gms
Water	1,781 gms
Norprofil	930 gms
Wheat Flour	900 gms
Soda Ash	400 gms

Mix 30 minutes on Bower Mixer at 4000 rpm

IB-334 Plyophen	8,985 gms
Water	1,132 gms
	20,000 gms

Total mix solids: 43.8%
Phenol Formaldehyde solids: 26.0%
Viscosity @ 25°C #3 spindle 60 rpm LVF Brookfield - 1350 cps

This mix differs from a standard plywood mix on two points. First, the PF solids are higher by approximately 3% - 26% as opposed to 23%. Secondly, there is twice the concentration of wheat flour in this mix as in the average plywood mix. This formulation and resin has previously been successfully used in veneer laminating and appears to display the assembly time tolerance required by the process.

Should further assistance be required, please contact me.

Yours very truly,
REICHHOLD CHEMICALS LIMITED

W. C. Ainslie,
Wood Lab. Manager

WCA/jm
c.c. Dr. W. V. Hancock

APPENDIX 6 The mixing sequence of the Monsanto UF 109 Glue.

MONSANTO UF109 RESIN WITH EK HARDENER

Mixing Directions

LBS		GRAMS	
2.86	100 lbs.	1298	WATER at 65° - 70°F.
0.43	15 lbs.	195	MONSANTO EK CATALYST
			Mix 1 Minute
0.0143	½ lb.	6.5	STEROX CD
2.86	100 lbs.	1298	WHEAT FLOUR
			Mix 5 Minutes or Until Lump Free *
1.143	40 lbs.	519	MONSANTO UF109 RESIN
			Mix 3 Minutes or Until Lump Free
2.5714	90 lbs.	1167	MONSANTO UF109 RESIN
		4483.5	Mix 5 Minutes with Cooling Water in Jacket
	345½ lbs. ÷ 35 = 9.87 lbs.		Total Weight of Mix

The mixed glue will have a working life of 24 hours at 70°F. Mixed glue left overnight should be mixed with a fresh batch before using.

* The length of the mixing time prior to the addition of the resin will affect the final viscosity - increasing the mixing time will reduce the viscosity.

HARDWOOD HOT PRESSING SCHEDULE*

UF-109 RESIN WITH EK HARDENER

Rough Panel Thickness	No. of Plies	Panels per Opening	Max. Dist. to Inner Glue Line	Construction Core	Construction Center	Time Settings For Press Time - Mins. 240°F.	Time Settings For Press Time - Mins. 260°F.
3/16	3	2	.183	1/7H		5-1/4	4-3/4
1/4	3	2	.208	1/6M		5-1/2	5
1/4	3	2	.207	1/7H		5-3/4	5-1/4
1/4*	3	1	.063	1/6 or 1/7		3-3/4	3-1/4
3/8	5	1	.138	1/10M	1/7H	4-3/4	4-1/4
1/2	5	1	.181	2x1/7H	1/7H	6	5-1/2
1/2	3	1	.136	1/10M	.262B Plywood	5-1/4	4-3/4
3/4	7		.326	3x1/7H	2x1/7H	8-1/4	7-3/4
3/4	7		.329	1x1/7H	2x3/16H	8-1/4	7-3/4
3/4	7		.352	1x1/10M	2x1/7H	8-3/4	8-1/4
3/4	5		.138	1/10	1/2 Plywood	5-1/4	4-3/4
3/4	5		.163	1/8	1/2 Plywood	5-1/2	5

For construction greater than 3/4" use 8 min. plus 1/2 min. for each additional 1/16 over the 3/4'.

OVERLAYS

1/4 with 1/6 chipboard center - 2 panels per opening	6
1/4 with 1/6 chipboard center and 1/30 - 1/16 face and back	3-3/4
1/2 with 7/16 chipboard center and 1/30 - 1/16 face and back	3-3/4
3/4 with 11/16 lumber or chipboard center	3-3/4

ABOVE TIME INCLUDE 15 SECS. CLOSING TIME AND 15 SECS. FOR CAULS.

SPREADS

	Hemlock	Mahogany
1/10	62	57
1/7	65	60
1/6	67	62

Rough core add 3 to 5 lbs.

Maximum recommended time assembly 8 hours
Minimum recommended time assembly 5 mins.

Pressure 175 lbs. per square inch.
Pressure with chipboard 150-160 lbs. per sq. in.

Note: Should it be necessary to reduce the press temperature to 220°F. add 1-1/2 mins. pressing time over the indicated 240°F. time.