AN INVESTIGATION OF WELDED AND CAST JOINTS FOR A.C.S.R. CONDUCTORS

by

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Approved:

In Charge of Major Work.

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AN INVESTIGATION OF WELDED AND CAST JOINTS FOR A.C.S.R. CONDUCTORS

In the conventional joints for aluminum core steel reinforced (A.C.S.R.) conductors the path of the electric current in the outer strands passes through two mechanical contacts, while for the inner strands the number of contacts is considerably more. It is recognized that the present techniques of making compression joints is considered by many to be satisfactory. However, it is obvious that a continuous metal joint would be superior. Recent advances in welding make the construction of such a joint possible.

In the joints constructed for experimental purposes each strand of a 397,500 C M conductor was brought out between two aluminium sleeves and Heliarc welded. In the finished joint the weld bonds the inner and outer sleeves and the individual conductors. The ends of the joint are compressed to prevent ingress of moisture which may be injurious to the conventional steel compression sleeve which connects the steel cores together.

Tests of the individual strand resistance as measured between the central part of the joint and the
strands showed the strand resistances to be uniform and equal to an equivalent length of strand. This shows that each strand was satisfactorily connected at the weld. Overall resistance, heat and mechanical tests indicate that the welded-compression joint should be satisfactory in the field.

In addition to the welded-compression joint two cast-aluminium joints were also investigated. These, however, due to poor bonding were found unsatisfactory.

Shang-Jen Tsou
University of British Columbia
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AN INVESTIGATION OF WELDED AND CAST JOINTS FOR A.C.S.R. CONDUCTORS

1. INTRODUCTION

An important consideration in the installation of power transmission lines is the making of conductor joints which will retain throughout the useful life of the conductor both high electrical conductivity and mechanical strength. During service conductors are exposed to extreme variations in temperature and tension, vibration stresses, short-circuit currents and atmospheric corrosion for a period of 50 years or more.

The main difficulty in making a satisfactory joint in Aluminum-Core-Steel Reinforced (A.C.S.R.) conductors is due to the formation of aluminum oxide on the surface of the strands. Several types of joints have been developed and among them are the bolted and clamped joints, twisted sleeve joints, threaded compression joints, core joints and compression sleeve joints. Most of these, with the exception of the compression sleeve joint have been found unsatisfactory for large size A.C.S.R. conductors.

According to Gordon E. Tebo's (7) investigations deterioration of twisted sleeve joints is indicated first by increase of resistance and heating. This is followed in

x All numbered references given in References.
extreme cases by the appearance of holes in the sleeve, produced by internal arcing, and finally the conductor fails mechanically at or near one end of the sleeve.

The threaded compression joints have a very bad operating record. After 20 years in service on a 110 kv line, several hundred such joints in 312,000 cm A.C.S.R. conductors were tested, and more than 50% had a resistance greater than 10 time normal. In most cases the high resistance was in the threaded connection.

According to the Report made by W.J. Nichols (6) on all 132 kv lines, prior to 1938, the A.C.S.R. conductors were jointed in midspan by cone-type joints gripping the steel and aluminum strands separately by means of steel and aluminum cones respectively. These joints were thoroughly tested before adoption, both for mechanical strength, 95% of the breaking strength of the conductor being required, and for conductivity, the resistance having to be less than that of an equivalent length of conductor. In 1938, the compression joint was introduced on new lines and for the maintenance of existing lines. The reason for this change was the increasing number of failures of cone-type joints. The cone-joint failures began to take a general form of break in the conductor, usually some 12 - 18 inches from one end of the joint. There was evidence of heating at the break and also in the joint, the steel strands showing signs of heating over the length between the joint and the break. This evidence pointed to
high resistance in the aluminum portion of the joint, with the resultant transfer of current to the steel core in the joint and back to the aluminum strands a short distance outside it. This high resistance was checked and it was found that the resistance of many joints had increased seriously in service.

Experience with compression sleeve joints (7) has been generally satisfactory. Occasionally, however, an aluminum conductor burns off at or near a compression sleeve. Examination usually discloses improper cleaning of strands of the conductor and the sleeve. The resultant high resistance causes heating, arcing, annealing, and finally rupture of the conductor. The location of this rupture is usually just at the entry to the sleeve, but is sometimes a foot or more away from the sleeve. Investigation in such cases has shown high inter-strand resistance in the joint with consequent uneven current distribution. The few high-conductivity but overloaded strands become red-hot in the vicinity of the joint.

Besides the above-mentioned methods of jointing A.C.S.R. conductors, the A.I.A.G. in Switzerland has developed so-called Alutherm procedure for welded conductor joints. The original strength of the cable being somewhat diminished in the welds, joints in the spans were mechanically reinforced by aluminum sleeves which were pressed onto the cable. Unfortunately there is very little data available on a welded joint by this method.
It is quite clear, that if the conductors are jointed together by any of these methods, the interface is essentially a discontinuous region, and there is a more or less abrupt change in the conditions of current flow from one conductor to the other. If the conductors are welded together, the joint is mechanically and electrically continuous, and there is in general less disturbance in the current flow, provided that the weld is homogeneous and of uniform conductivity.

The art of welding, necessitated by the demands of industry in wartime, has progressed considerably. A method known as the "HELLIARC" process (1) has been developed which can be used in the welding of corrosion-resistant metals. The question therefore, arose as to whether this technique could be applied in making satisfactory A.C.S.R. conductor joints.

The idea of a welded-compression joint was discussed with Mr. Laird of the Vancouver Office of the Aluminum Company of Canada, and also with Mr. Underwood of the Vancouver office of the Dominion Oxygen Company. As a result of these discussions these two companies supplied the necessary materials and some equipment for the construction of two experimental joints.

During the investigation certain difficulties arose which suggested the idea of making cast aluminum joints containing 12% silicon. Two experimental joints were constructed and tested. The results of the tests were not as hoped for.
However, recent developments in aluminum solders may make this technique feasible and plans are now under way to make up experimental joints employing aluminum solder. The details are discussed in a later section of this thesis.
11. INVESTIGATION

A. Welded-compression Joint for A.C.S.R. Conductors

1. Procedure

Two experimental joints were constructed for the investigation. These are shown in photographs #1, 2 and 3. Photograph #4 shows the 100-ton model E hydraulic press used in making the joints.

In the development of the welded-compression joint for A.C.S.R. conductors, an endeavour was made to use standard parts and equipment in so far as possible. Care was taken to ensure that the electrical conductivity of the joint and the tensile strength were not impaired by damage to aluminum strands and steel core during assembly or by heating during the welding operation. The constructional details of the experimental joints are shown in drawings Fig. 1, 2, and 3.

The following procedure was employed in assembling the joints: First the aluminum end or outer sleeves were placed on each of two conductors to be jointed. Then approximately 16 inches of the aluminum strands of one conductor were unwound and fanned out. Care was taken not to unduly bend the strands during this operation. The inner sleeve was then placed over the steel core of this conductor. Next, the strands of the other conductor
Photograph #1 showing the component parts of the welded-compression joint (A) standard steel sleeve (B) Inner aluminum sleeve (C) End or outer sleeves.

Photograph #2 showing welded-aluminum compression joint prior to welding.
Photograph #3 showing (1 & 2) welded-aluminum compression joints and (3 & 4) cast aluminum joints prior to testing.

Photograph #4. Hydraulic compressor 100 ton capacity Model E.
were fanned out back to about 4 inches. The steel sleeve was then put in place and the steel compression joint made in the conventional manner. Following this the inner aluminum sleeve was placed centrally over the steel sleeve and compressed in place. The aluminum strands were then returned more or less to their original position in such a manner that the ends of the strands lay along the outer ends of the inner sleeve. The end or outer sleeves were then driven in place so that the ends of the strands were held firmly as shown in photograph #2. The two ends of each outer sleeve were then compressed and the ends of the strands were welded together and to the sleeves by Heliarc welding.

2. **Electrical Conductivity Test.**

In general it may be stated that a joint which has a low resistance initially may be expected to give satisfactory service. For reference the resistance of a joint is compared with that of the equivalent length of conductor. In this particular case the specifications on 397,500 C.M. A.C.S.R. conductors are as follows:

- Number of aluminum strands ............... 26
- Number of layers .......................... 2
- Diameter of aluminum strand ............. 0.1236"
Number of steel strands ............... 7
Diameter of steel strand ............. 0.0961
Outside diameter of the conductor .... 0.783
Ultimate strength, pounds .......... 16190#
Weight, pounds per mile ............ 2885#
Approximate current capacity ........ 590 amp.
Resistance at 50°C for 60 cycle, ohms
per conductor per mile ............. 0.259 ohms
Resistance at 25°C for 60 cycle, ohms
per conductor per mile ............. 0.235 ohms.

The following resistances were obtained with an
Evershed and Vignoles "Ductor":

The result was as follows:
(Room temperature 20°C)
Resistance of 397,500 C.M. A.C.S.R. .... 44 microhms per foot
Resistance of welded aluminum compression
Joint No. 1, 23" long ................. 34 microhms
Resistance of welded aluminum compression
Joint No. 2, 25" long ................. 40 microhms.

From these data it is seen that the resistance
of Joint No. 1 in terms of the resistance of an
equivalent length of the 397,500 A.C.S.R. cable is
$$\frac{34 \times 12}{23 \times 44} = 40.4\%$$
and that the resistance of Joint No. 2 is
$$\frac{40 \times 12}{25 \times 44} = 43.8\%.$$
These results are in very close agreement with the figures given by Mr. R. Lemire (5) of the Hydro-Electric Power Commission of Ontario, which states that a well-made joint is about 40% of the resistance of the same length of cable.

The welded-compression joint No. 2 has a higher resistance than the No. 1. This might explain the fact that the No. 2 joint was welded first, with a current at 100 amp. which was not high enough. The No. 1 joint was welded at a higher current - 120 amp. which gave a better result.

It was found, following a suggestion in Mr. Tebo's paper, that the individual strand resistance as measured between the central part of the joint and strands was uniform and equal to that of an equivalent length of strand. This shows that each strand was satisfactorily connected at the weld.

3. Heating Test.

For the heating test an 18 kw, 600A, 30 v Hawthorn D.C. generator was used, this being the only big current source available.

All the samples of conductor joints were connected in series. The current was kept constant by adjusting the field current of the generator. During the tests the room temperature was almost constant at $18^\circ C$. After two hours time an approximate steady state was reached.
The Heating Test was repeated six times, the longest one being continued for ten hours. The results of these tests were almost the same. The temperatures obtained in still air at current loading 750 amp. for the cable and the welded aluminum compression joints are listed in Table 1 and plotted in Fig. 4.

Taking the average steady state temperature rise for cable and for the joints, the following results are obtained:

Temperature rise for the cable
\[ 118^\circ - 18.5^\circ = 99.5^\circ C. \]

Temperature rise for Joint No. 1
\[ 80^\circ - 18.5^\circ = 61.5^\circ C. \]

Temperature rise for joint No. 2
\[ 84^\circ - 18.5^\circ = 65.5^\circ C. \]

The temperature rise of the joints in percentage with respect to the cable:
For welded-compression joint No. 1 is
\[ \frac{61.5}{99.5} \approx 62\% \]
For welded-compression joint No. 2
\[ \frac{65.5}{99.5} \approx 66\% \]

These results indicate that the welded aluminum compression joint has a lower temperature rise and better conductivity than the cable itself which meets the essential requirement for conductor-
joints in transmission lines.

**TABLE 1**

Cable and Welded-compression joint

Temperatures obtained in still air

with a current of 750 Amperes DC.

<table>
<thead>
<tr>
<th>Time</th>
<th>Joint No. 1</th>
<th>Joint No. 2</th>
<th>Cable</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-00</td>
<td>18.5°C</td>
<td>18.5°C</td>
<td>18.5</td>
</tr>
<tr>
<td>0-05</td>
<td>22.0</td>
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<td>80.0</td>
<td>84.0</td>
<td>116.0</td>
</tr>
<tr>
<td>2-00</td>
<td>77.5</td>
<td>79.0</td>
<td>107.0</td>
</tr>
</tbody>
</table>

4. **Tensile Strength Test.**

The tensile strength test was made in the Federal Forest Products Laboratory at the University of British Columbia.

In order to provide adequate gripping by the stamps of the testing machine, standard steel compression sleeves and short pieces of
Photograph #5 showing the results of tensile test on experimental Joint #1. The break occurred in the special grip shown at the left.
aluminum sleeving were compressed on the ends of the experimental cables. The overall length of each joint plus two cables ends was approximately 76 inches.

Only one sample joint (#1) was tested. It was found to break at 15,200 pounds ultimate in the special grip as shown in photograph #5. The welded-compression joint was unaffected and there was no measurable permanent elongation. The elongation of the cable itself was

\[
\frac{77 \frac{1}{8}'' - 76''}{76'' - 23''} \times 100 = 2.1\%
\]

As was mentioned previously the ultimate strength of 397,500 A.C.S.R. conductor is 16,190 pounds. It is therefore seen that the test-load applied was approximately 94% of maximum for the cable. This is quite satisfactory as the safety factor of the joint is at least 1.9 since the break occurred in the cable grip. Normally a safety factor of 2 to 2.2 is used.

The effect of compressing the inner end of the outer sleeve is shown in photographs #6 and 7. While the damage to the strands in this case was not detrimental excessive flattening could cause over-heating.

5. Microscopic Examination

In order to ascertain the effect of heating due
to the welding operation the following microscopic examinations were made of the steel core and the aluminum strands and sleeves.

(1) Steel Cores.

Two specimens of the steel core were examined; one from the welded compression joint and the other from unheated piece of conductor. Examination of the microphotographs (photographs #8-9) shows that there is no apparent difference in the microstructure of the steel cores.

(11) Welded Aluminum.

An examination of the welded aluminum was made by microphotographing a longitudinal section of the welded joint. A longitudinal section was used instead of a cross-section because it was impossible to determine the actual position of the ends of the welded strands inside the joint. The microstructure of the longitudinal section is shown in photograph #10.
Photograph #6.
Showing damage to strands due to compression of the outer sleeve.

Photograph #7.
Showing the junction of the inner and outer sleeves, strands and steel core.
Photograph #8.
Microstructure of unheated steel strand and portion of steel sleeve.

4—Steel sleeve
4—Zinc coating on steel strand
4—Steel strand.

Photograph #9.
Microstructure of heated steel strand and portion of steel sleeve.

4—Steel sleeve
4—Zinc coating on steel strand
4—Steel strand.

Magnification - 200
Exposure - 40 seconds
Treatment - Picric acid etching.
Photograph #10
Microstructure of welded aluminum strand and sleeve.

-Weld (left-hand portion)
-Strand

Magnification - 120X
Exposure - 1 minute
Treatment - H\textsubscript{2}O 0.5 cc
and H\textsubscript{2}O 99.5 cc.

Examination of the microstructure shows that there is excellent bonding between the conductor strand and the aluminum sleeve. This substantiates the results of the heating test.

6. **Heliarc Welding Technique.**

Heliarc welding (1) is an electric arc-welding process. Highly concentrated heat is produced by an arc drawn between the work and a single, virtually non-consumable, tungsten electrode. Heliarc welding differs from other arc-welding processes in that the welding zone is at all times shielded by a sheath of inert gas that excludes the oxidizing atmosphere. Argon, the
inert gas most generally used, is fed through a nozzle surrounding the electrode in the head of the Heliarc torch, and flows out to blanket completely the electrode, the arc, and the weld puddle.

This protective blanket of inert gas is the unique feature of the process; because of it, aluminum can now be successfully fusion-welded without the aid of flux, which was never possible before. With Heliarc welding, there is no spatter or deposition of chemical salts, and no cleaning is required. The completed weld, if properly made, is smooth and clean, and most cases require no finishing treatment of any kind.

The selection of welding current depends on the type of metal welded. For example, direct current with reverse polarity was originally used for the Heliarc welding of magnesium, but is not recommended for work on any other metal. Direct current with straight polarity is suitable for welding stainless steel, copper, and copper alloys, but should not be used on magnesium or aluminum.

Heliarc welding is also widely used with alternating current. Research has revealed that a high frequency stabilization current superimposed on alternating current gives better results.
than when low-frequency welding current alone is used. High-frequency stabilized alternating current in combination with the advantages of argon gas, has made possible the welding of aluminum without flux.

The standard torch can be used with either direct or alternating current. Fitted to the rear of the handle are three lengths of hose. The first supplies argon, and the second supplies cooling water which circulates through the body of the torch. The third hose carries the power cable and also serves as an outlet for the cooling water. Thus, the power cable is completely surrounded by water. This feature makes it possible to carry extremely high currents on a relatively small, light, and flexible cable.

With a water flow of less than one pint a minute, the torch has a normal maximum rating of 250 amperes. Full protection against overheating of the torch due to failure of the water supply is afforded by a special fuse inserted in the cable circuit which automatically shuts off the power.

The argon supply is conducted through the body of the torch and emerges from the gas orifices in the head of the torch. It is then
guided down toward the weld puddle by the gas-shielding cup which surrounds the tungsten electrode.

B. Aluminum Cast Joint for A.C.S.R.

As mentioned in the introduction the conductor joint should possess high electrical conductivity and mechanical strength and it should retain these qualities through the entire useful life of the conductor. The welded-compression joint has been shown by experiment to possess these requirements. However, in making this type of joint considerable equipment is required and the procedure is rather complicated.

For these reasons a cast-aluminum joint was investigated.

1. Procedure.

Two experimental cast-joints were constructed for investigation. These are shown in photograph #3.

The mould for making the joints is shown in photograph #11. The mould is made from a piece of 1\(\frac{1}{2}\)" diameter steel pipe about two feet long. The pipe was split in two longitudinally and jointed together by means of 3 pairs of 1\(\frac{1}{2}\)" hinges. The mould shown in the photograph was later modified by drilling two 7/8" diameter holes 11\(\frac{1}{2}\)" apart to replace the V slot shown. These two holes provide the inlet
and outlet for the casting metal. In assembling the joint, the two layers of aluminum strands were cut back approximately $3/4"$ for inner layer, and $1\frac{1}{2}"$ for the outer layer. In order to prevent the molten metal from damaging the aluminum strands at the end of the cast-joint two short pieces of $1"$ outer diameter aluminum conduit were placed at each end of the joint, so as to form an integral part of the joint. The connection of steel cores of the cable was made with the conventional steel compression sleeve. The leakage of molten metal from the ends of the mould was prevented by two split steel rings. These details are shown also in photograph #11.

Photograph #11 showing the mould and component parts of the cast-aluminum joint.
Prior to casting the aluminum joint all surface dirt was cleaned from the strands and the mould was preheated to 350°F with a gasoline torch. The cast metal was poured at a temperature of 1350°F.

The cast-aluminum joints which are shown in photograph #3 prior to the testing are approximately 18" long and 1 1/2" outside diameter.

2. **Electrical Conductivity Test.**

The electrical resistance as determined with an Evershed and Vignoles "Ducter" were as follows:

- Resistance of cast-aluminum joint #3, 18" long, 36 microhms.
- Resistance of cast-aluminum joint #4, 18" long, 38 microhms.

From these data it is seen that the resistance of joints #3 and #4 in terms of the equivalent length of 397500 c.m. A.C.S.R. conductor are respectively:

\[
\frac{36 \times 12}{18 \times 44} = 55\% \\
\text{and } \frac{38 \times 12}{18 \times 44} = 58\%.
\]

3. **Heating Test of Cast Joints.**

The heating test for the cast joints was made at the same time as the welded-compression joints. The results are listed in the Table 11 and plotted in Fig. 4.

The average steady state temperature of the cast
joint No. 3 at the end of two hours was found to be 112°C which was very close to the temperature of the cable, i.e. 113°C. The average steady state temperature of the cast joint No. 4 was found to be 160°C. It is to be noted that this temperature is higher than the temperature of the cable.

These results indicate unsatisfactory bonding of the aluminum strands and the casting.

**TABLE II**

Cable and Cast-joint Temperatures

Obtained in Still Air with a Current of 750 amperes D.C.

<table>
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<th>Time</th>
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<th>Joint No. 4</th>
<th>Cable</th>
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<td>18.5°C</td>
<td>18.5</td>
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<td>0-05</td>
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<td>165.0</td>
<td>119.0</td>
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<tr>
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<td>122.5</td>
</tr>
<tr>
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</tr>
<tr>
<td>2-00</td>
<td>112.0</td>
<td>165.0</td>
<td>107.0</td>
</tr>
</tbody>
</table>
4. **Tensile Strength Test.**

One sample of the joint (#4) was tested in a similar manner to the welded-compression joint. This joint which failed in the casting at an ultimate strength of 10,140 pounds is shown in photograph #12.

Photograph #12 showing the tensile test failure of cast-aluminum joint in the casting.
5. **Microscopic Examination.**

The microstructure of two of the aluminum strands shown in the cross-sectional view of photograph #13 is shown in photograph #14.

Photograph #13 showing cross-sectional view of cast-aluminum joint.
The above micro-photograph shows clearly that there is unsatisfactory bonding of the strands and the casting. This confirms the results of the resistance and of the heating test.
III. DISCUSSION AND PROSPECTUS

It has been shown in this limited investigation of welded-aluminum joints that:

(a) Welding can be successfully used in making a superior joint in A.C.S.R. conductors.

(b) The technique at present must be considered as too complicated for field use.

(c) The design of the joint should be modified slightly as shown in Fig. 1 and the ends of the inner sleeve should be of such a diameter as to allow all the strands to lie around the perimeter as indicated in Section A-A of Fig. 1.

(d) The inner end of the outer sleeve should not be compressed.

The casting of aluminum joints by the procedure used in this investigation results in an unsatisfactory joint. It is evident that the surface of the aluminum strands should be tinned.

During this investigation and following the construction of the cast joint it was learned that the aluminum Company of America (2) and (3) have developed a new type flux and solder which will permit the soldering of aluminum cables. Using these new materials there appears to be two possible methods of making joints in A.C.S.R. cable which will meet all electrical and mechanical requirements. It is therefore proposed that after making the conventional steel compression
sleeve joint, the strands as arranged in photograph #11 could be tinned with the solder. Instead of using a removable mould a piece of aluminum conduit which has been previously tinned on the inside could be used as an integral part of the joint. The solder then could be poured into the mould to make the casting. If need be the ends of the conduit could be plugged with solid aluminum rings and then compressed slightly to reduce weathering of the solder.

Another technique which warrants investigation is that of making the conventional compression joint with standard parts, however, the inner surface of the aluminum sleeve should be tinned and also a portion of each conductor strand. After compressing the sleeve the whole joint would be heated to $350^\circ F$ to allow sweating of the solder. If necessary the joint could be re-compressed to provide a permanent clamping of the strands.

In prospectus an investigation is to be made of two possible types of joints just discussed.
IV REFERENCES


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Mr. G.A. Van Dervoort, Chief Operations Engineer, B.C. Power Commission.
FIG. 2. OUTER ALUMINIUM SLEEVE FOR WELDED-COMPRESSION JOINT.

Scale 1:1
FIG. 3. INNER ALUMINIUM SLEEVE FOR WELDED-COMPRESSION JOINT.

Scale 1:1
FIG. 4. TEMPERATURE RISE IN STILL AIR AT CURRENT LOADING FOR CABLE AND CONDUCTOR JOINTS.