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THE SPOT WELDING OF DISSIMILAR ALUMINUM ALLOYS IN THE 0.040-INCH THICKNESS

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SUMMARY

This report is part of a program on aircraft spot-welding research being conducted at the Rensselaer Polytechnic Institute. The present investigation covers the spot welding of the following dissimilar alloy combinations in the 0.040-inch thickness:

Alclad 24S-T	to	bare 24S-T
Alclad 24S-T	to	52S-1/2H
Alclad 24S-T	to	3S-1/2H
Alclad 24S-T	to	61S-T
Alclad 24S-T	to	R-301-T
Alclad 24S-T	to	Alclad 75S-T
R-301-T	to	Alclad 75S-T
Alclad 75S-T	to	bare 75S-T

The results of this work indicate that in many instances the chemical treatment of dissimilar alloys prior to spot welding is a less difficult problem than the treatment of some similar alloy combinations. If one of the alloys of a dissimilar combination exhibits good treating characteristics in a particular chemical solution although the other alloy does not, the sheet-to-sheet resistance of the dissimilar combination is usually sufficiently low and consistent to enable satisfactory welds to be made.

The results also indicate that all the preceding combinations can be spot-welded with little difficulty. In most cases the optimum weld force for the dissimilar alloys is in the range from 800 to 1200 pounds, depending upon the average surface hardness of the combination. The forge force should be 2.5 times the weld force. A current wave form specified by an average rate of rise of the order of 3000 amperes per millisecond and a forge timing of 38 milliseconds were found highly satisfactory for all combinations.

The maximum average shear strength of sound welds and the current range over which sound welds may be produced are usually intermediate between the corresponding values for each of the component alloys welded individually, assuming that good welding conditions are used in each case.

INTRODUCTION

The desire of aircraft fabricators to introduce joints involving the use of dissimilar alloys in welded aircraft structures resulted in the present investigation. The spot welding of dissimilar combinations had not previously been investigated sufficiently to give proper assurance as to what combinations might be satisfactorily welded and as to the necessary change in welding conditions which should be introduced. In reference 1 a table is presented showing qualitative ratings for the weldability of several alloy combinations. This weldability chart was prepared on the basis of thermal and electrical conductivities and melting points of the various alloys. An investigation completed at the Lockheed Aircraft Corporation in 1942 (reference 2) on the spot welding of non-Alclad 24S-T extrusions to Alclad 24S-T sheet included a study of the corrosion resistance of such a joint and revealed that this particular combination was adaptable to spot welding.

A sound approach to the problem of spot-welding dissimilar alloys involves a quantitative knowledge of the effect of physical characteristics of the material and spot-welding variables. For example, a quantitative study is required to determine the effect of surface hardness on electrode force, current wave form, and electrode tip contour. The surface-treating characteristics of the different alloys involved in the combination, if not already known, must be investigated. The investigation described in this report undertook to determine information of the type mentioned.

On the recommendations of several aircraft companies this investigation covered the spot welding of the following dissimilar aluminum-alloy combinations in the 0.040-inch gage.

Alclad 24S-T	to	bare 24S-T
Alclad 24S-T	to	R-301-T
Alclad 24S-T	to	Alclad 75S-T
Alclad 24S-T	to	3S-1/2H
Alclad 24S-T	to	52S-1/2H
Alclad 24S-T	to	61S-T
R-301-T	to	Alclad 75S-T
Alclad 75S-T	to	bare 75S-T

The chemical-surface-treatment characteristics of these alloys were investigated by means of curves of resistance against time of treatment, and these curves were presented in the preceding report in this series, dealing with the spot welding of 10 different aluminum alloys. (See reference 3.)

The effects of spot-welding variables on the quality of welds in dissimilar alloy combinations were studied by means of strength-current characteristics, in a manner similar to that used for previous investigations of the spot welding of Alclad 24S-T alloy. (See reference 4.)

Only the spot-welding characteristics and static shear strength of the dissimilar alloy combinations were studied in this investigation. Properties such as corrosion resistance, fatigue strength, and impact strengths, should be studied before widespread use of such joints is contemplated.

This investigation, conducted at the Rensselaer Polytechnic Institute, was sponsored by and conducted with the financial assistance of the National Advisory Committee for Aeronautics.

EQUIPMENT

All the welding in this research investigation was performed with a Taylor-Winfield Hi-Wave condenser-discharge welder, type HWRD-36-3CCIT. This machine was equipped with a variable electrode-force system (reference 5) having a maximum electrode-force capacity of 5000 pounds. The throat dimensions of the machine were 36 by $11\frac{1}{2}$ inches. Oscillographic records of the electrode force and primary current were made throughout the investigation. The shear specimens were tested on the 5000-pound range of a 60,000-pound-capacity Baldwin-Southwark hydraulic testing machine.

SPECIMENS

The shear test specimens used throughout this investigation were standard single-spot shear specimens 3/4 inch by 4 inches welded with a 3/4-inch overlap. Strips of five welds each were made for metallographic examination. All specimens were 0.040 inch thick.

DISCUSSION OF RESULTS

The weldability of each dissimilar alloy combination in this investigation was studied by means of strength-current characteristics. These are curves in which the average of the shear strengths of three spot-weld specimens, made at several values of welding current, were plotted as a function of the welding current. On each of these curves the occurrence of defects in the welds was indicated by suitable symbols at the points. Such curves enable a quantitative study of the effects of the following spot-welding variables:

1. Surface condition of the material

2. Electrode-tip force and forge-force timing

3. Welding-current magnitude

4. Welding-current wave form

5. Electrode tip contour

A study of the surface-treatment characteristics of these alloys was undertaken as the first step in this investigation. A detailed discussion of these characteristics appears in reference 3. It suffices here to summarize that information as follows:

1. Alclad 24S-T may be treated to an extremely low, consistent surface resistance by hydrofluosilicic acid (No. 14 solution), containing either 1.5 or 3 percent by volume of H_2SiF_6. This material may also be wire-brushed to produce a low, consistent surface resistance.

2. 52S-1/2H alloy ordinarily shows even better treatment characteristics in the hydrofluosilicic acid than does Alclad 24S-T.

3. The alloys, R-301-T, Alclad 75S-T, bare 75S-T, and 3S-1/2H, may be treated satisfactorily in a hydrofluosilicic-acid solution containing 1.5 percent by volume of acid, but the surface resistances obtained may not be quite so low or so consistent as with Alclad 24S-T.

4. At the present time when alloys bare 24S-T, 61S-T, and 14S-T are to be welded to themselves, they cannot be treated satisfactorily in hydrofluosilicic acid. Bare 24S-T may be treated satisfactorily in 2 percent HNO_3 at 180° F (No. 16 solution), and this solution also works reasonably well for 61S-T and 14S-T.

In the surface treatment of dissimilar alloy combinations it has been observed that if the surface resistances of one of the alloys are low and consistent, while those of the other alloy are high and inconsistent, the resistances of the two alloys in combination will be reasonably consistent and of intermediate magnitude as shown in table I.

This is a very definite advantage, particularly when one of the alloys offers trouble with regard to surface treatment. As a result, when dissimilar alloys are to be welded, all chemical surface treatment may be performed at room temperature in hydrofluosilicic-acid solution, 1.5 percent by volume, provided one of the alloys in each combination has good treating characteristics in this solution.

A summary of chemical-surface-treating procedure for dissimilar alloy combinations is as follows:

A. Degrease in trichloroethylene or alkaline degreaser; treat 8 to 10 minutes in hydrofluosilicic acid (H_2SiF_6), 1.5 percent by volume, 75° F; cold water-rinse; air-dry. Good for any dissimilar alloy combination involving Alclad 24S-T, 52S-1/2H, Alclad 75S-T, bare 75S-T, R-301-T, or 3S-1/2H as one component.

B. Degrease same as in (A); treat 8 to 10 minutes in nitric acid (HNO_3), 2 percent by volume, 180° F; cold water-rinse; air-dry. Good for welding bare 24S-T, 61S-T, and 14S-T to each other.

For the high-strength dissimilar alloy combinations which were investigated, it was considered sufficient to limit the work on any one alloy combination to finding welding conditions which would permit the production of a 600-pound weld approximately in the center of the sound-weld range of the strength-current characteristic. With the other dissimilar alloy combinations involving lower-strength aluminum alloys, the acceptability of any particular curve was judged on the basis of the best results obtainable in welding the low-strength alloy individually. It so turned out that the welding conditions which resulted in these curves in most cases were very nearly optimum with regard to the maximum-size sound weld which could be produced in each case with the particular tip contour used. Any improvement to be effected, therefore, by changing these welding conditions is expected to be slight and of doubtful further practical value.

The surface hardness, the relationship of satisfactory weld force to surface hardness, and satisfactory weld force for spot welding of the aluminum alloys are given in tables II, III, and IV, respectively.

Alclad 24S-T to Bare 24S-T

The first dissimilar alloy combination considered was Alclad 24S-T welded to bare 24S-T. Since each component of this combination involves the same base alloy, the metallographic changes which take place during the welding process would not be expected to differ greatly from those which occur in welding either material individually. That this is true is shown by comparing the photomicrographs of the dissimilar alloy combination in figure 1 with those of figures 6 and 9 in reference 3 for the similar alloy combinations. In this dissimilar alloy combination the amount of pure-aluminum cladding to be assimilated into the weld metal is only half that in welding two sheets of Alclad 24S-T. The penetration of fusion into the bare 24S-T sheet is slightly higher than into the Alclad sheet because of the higher melting point of the cladding on the latter.

Figure 2 shows the optimum strength-current characteristic for this dissimilar alloy combination. In comparing this curve with the optimum curves for Alclad 24S-T and bare 24S-T, figures 5 and 8, respectively, in reference 3, several facts may be noted. The optimum weld force in this case was the same as for welding bare 24S-T and was considerably higher than the 800-pound optimum value for Alclad 24S-T. A forge force of 2000 pounds was shown to be adequate for the dissimilar combination and also for two sheets of 0.040-inch Alclad 24S-T. However, a forge-to-weld force ratio of at least 2:1, and preferably 2.5:1, is highly desirable since the elimination of cracks is made more certain.

From figure 2 it may be seen that, with these welding conditions, weld quality at the upper end of the strength-current characteristic for the dissimilar alloy combination was impaired by the occurrence of expulsion. Increasing the weld force above 1200 pounds resulted in excessive sheet separation at the higher sound-weld points; so this weld force was considered as being optimum for the particular tip contour used.

Figure 2 also shows that sound welds having an average shear strength of 400 to 800 pounds were produced over a current range of nearly 7000 amperes. This is a range in condenser voltage of approximately 400, using a condenser capacitance of 720 microfarads, and a transformer-turns ratio of 300:1. These welding conditions, therefore, enabled the production of sound welds of adequate shear strength over a reasonably wide range in welding current.

Figures 3 and 4 show strength-current characteristics obtained in welding Alclad 24S-T to bare 24S-T with weld forces of 800 pounds and 1000 pounds, respectively. By comparison with figure 2, the improvement in weld quality produced by increasing the weld force from 800 to 1200 pounds is readily apparent. In the former case, defects began to appear in welds having an average shear strength of 700 pounds, while in the latter case welds approaching 900 pounds in strength were not defective. With the lower weld force the current range over which sound welds of more than 400 pounds shear strength were produced was approximately 5000 amperes, compared with the 7000-ampere range obtained with the higher weld force.

Alclad 24S-T to 52S-1/2H

The spot welding of Alclad 24S-T to 52S-1/2H involves joining alloys which differ greatly in chemical composition, 52S being an aluminum-magnesium-chromium alloy, while Alclad 24S-T is an aluminum-copper-magnesium-manganese alloy with a pure-aluminum cladding. This difference might be expected to have considerable effect upon the metallographic structure of the spot welds. That such was the case is evident from the photomicrographs in figure 5. The grain structure of the weld, consisting of an equiaxed zone, caused by the slower cooling of the metal at the center of the weld, and an outer columnar zone, resulting from the chilling of the molten metal, is characteristic of a spot weld in Alclad 24S-T or in 52S-1/2H. The effect of heat on the base metal around the weld appears to be considerably different for the two alloys. The region around the columnar zone of the weld in the Alclad 24S-T alloy is characterized by a zone of grain-boundary fusion and overaged alloy. From the ends of the weld, long stringers of low-melting constituents extend out along the grain boundaries of the sheet.

The region around the weld in the 52S alloy is characterized by an agglomeration of constituents in a narrow zone. This is difficult to see in the dissimilar alloy combination because of the preferential attack of the etch upon the Alclad 24S-T alloy, but it is clearly shown in the photomicrographs of 52S-1/2H alloy spot welds in figure 31, reference 3. There appears to be only slight incipient fusion at the grain boundaries of the heat-affected metal and no overaging. At the ends of the weld, however, there are stringers, probably also of low-melting constituents, extending out into the 52S sheet, as in the Alclad 24S-T material. These stringers in the 52S alloy, however, are not continuous from the weld out as in the 24S alloy, but appear to break off at the zone of segregation.

The curve shown in figure 6 is a good strength-current characteristic obtained with this alloy combination. The maximum shear strength of sound welds was approximately 675 pounds, and the current range over which welds averaging in strength from 400 to 675 pounds were produced was about 8500 amperes. This represents a range in condenser voltage of slightly more than 400 volts, with a condenser capacitance of 720 microfarads and a transformer-turns ratio of 300:1. The current range over which sound, crack-free welds were produced in this case, therefore, is reasonably wide. Attempts to raise the weld force in order to eliminate the expulsion at the last point of the curve of figure 6 were unsuccessful, since this introduced excessive sheet separation.

In comparing the strength-current characteristic of figure 6 with the curves for the individual alloys shown in figures 8 and 29 of reference 3 it is evident that the maximum strength of sound welds in the dissimilar alloy combination, 675 pounds, is intermediate between the maximum 600 pounds for 52S-1/2H, figure 29, and the 850 pounds for Alclad

24S-T, figure 8. The average slope of the characteristic for the dissimilar alloy combination over the 400- to 675-pound strength range was approximately 32.4 pounds per kiloampere. In the 52S-1/2H alloy curve, figure 29, the average slope over the 300- to 600-pound strength range, was approximately 50 pounds per kiloampere. For the Alclad 24S-T curve, figure 8, over the 400- to 850-pound strength range, the slope was about 33.3 pounds per kiloampere. These figures would indicate that the shear strengths of spot welds in the dissimilar alloy combination were considerably less affected by changes in the welding current than in the 52S-1/2H alloy alone. This analysis shows that the spot-welding characteristics of the combination approach those of the 52S-1/2H alloy with regard to the strength obtainable, and those of the Alclad 24S-T alloy with regard to sensitivity to variations in welding current.

Alclad 24S-T to 61S-T

The spot welding of Alclad 24S-T to 61S-T involved the joining of two precipitation-hardenable alloys differing greatly in chemical composition.

Photomicrographs showing the metallographic structure of spot welds in this dissimilar alloy combination are presented in figure 7. The weld metal structure is normal, and the structure of the Alclad 24S-T sheet adjacent to the weld is also characteristic of spot welds in this material. The 61S alloy has a very narrow zone of grain-boundary fusion surrounding the columnar weld zone. At the ends of the welds, this incipient melting is observed to extend out into the sheet for a considerable distance. Unlike the grain-boundary fusion in the 52S alloy, however, these long stringers in the 61S alloy are continuous with the narrow incipient fused zone around the weld, broadening out appreciably at some distance from the weld. In the former alloy the stringers appear not to start from the columnar weld zone but from the outer edge of the region in which agglomeration of the constituents occurs and proceed from this region out into the sheet. Agglomeration of undissolved constituents in a zone surrounding the region of incipient fusion is not apparent in the 61S alloy.

A good strength-current characteristic for this combination is shown in figure 8. The conditions used in making these welds were similar to those used in welding Alclad 24S-T. In the dissimilar alloy combination, sound welds having strengths from 300 to 650 pounds were produced over a current range of about 7000 amperes. The corresponding current range for the 61S-T alloy, using a weld force of 1200 pounds, was about 10,000 amperes, as shown in figure 33 of reference 3. An increase in the maximum-size sound weld produced in the dissimilar alloy combination might result from raising the weld force, but excessive sheet separation would probably result.

Alclad 24S-T to 3S-1/2H

The spot welding of the 3S, aluminum-manganese, alloy to Alclad 24S-T offered no particular difficulty. The microstructures of spot welds in this combination are somewhat peculiar but not surprising. The higher melting temperature range for the 3S alloy is the reason for the smaller extent of fusion in this alloy than in the Alclad 24S-T, as shown in figure 9. Also, in the 3S sheet immediately surrounding the dendritic columnar zone of the weld there is no heat-affected region. This is probably due to the very narrow melting range of this alloy.

The spot-welding characteristics for this dissimilar alloy combination are shown in figure 10. With the welding conditions indicated, it was possible to produce sound welds varying in shear strength from 200 to 475 pounds over a current range of about 8500 amperes. The maximum strength of 475 pounds for a sound weld in the dissimilar alloy combination was about 50 pounds higher than that in the 3S-1/2H alloy alone, as shown in figure 23 of reference 3. However, the slope of the curve is considerably greater for the Alclad 24S-T to 3S-1/2H welds than for the 3S-1/2H welds alone. This may have been due partly to the higher value of electrode force used in the latter case. The higher weld force for the 3S-1/2H alloy was required to prevent expulsion due to higher surface resistance. The use of a weld force of 1000 pounds instead of 800 pounds for the dissimilar alloy combination would be of doubtful advantage, however, since excessive sheet separation would occur at the higher sound weld points on the curve.

Alclad 24S-T to R-301-T

Both the alloys, Alclad 24S-T and R-301-T which are high-strength aluminum alloys, are of the age-hardening type. Alclad 24S-T is normally aged at room temperature, while the properties of the R-301-T alloy are derived from elevated-temperature aging. Each of the alloys is clad to increase the resistance to corrosion. Alclad 24S-T has a pure-aluminum cladding, while R-301-T has an aluminum-alloy cladding.

The metallographic structure of a typical spot weld in this dissimilar alloy combination is shown by the photographs in figure 11. The R-301 alloy is at the top in each picture. In this particular combination there appear to be no outstanding differences in the effect of the heat on the zone immediately surrounding the weld nugget. Each alloy exhibits a zone of grain-boundary fusion and overaging, although the extent of the heat-affected zone may be slightly greater in the Alclad 24S-T alloy. Again the low-melting stringers extending from the ends of the weld are visible in each alloy.

The best strength-current characteristic obtained for the Alclad 24S-T - R-301-T combination is presented in figure 12. Sound welds having an average shear strength of 400 to 750 pounds may be produced over a renge in peak secondary current of about 12,000 amperes. This current range is considerably greater than that for most of the dissimilar alloy combinations previously discussed. In comparing this curve with those of figures 8 and 20 of reference 3 for the individual alloys, it may be seen that the maximum-size sound weld in the dissimilar combination, that is, 750-pound shear strength, is intermediate between the values of 650 and 850 pounds for the R-301-T and Alclad 24S-T alloys, respectively. The slope of the curve for the dissimilar alloys, 29.2 pounds per kiloampere, is slightly less than that for the Alclad 24S-T alloy (33.3 lb per kiloampere) and less than for the R-301-T (35.7 lb per kiloampere). Thus the effect of variations in welding current on the shear strength of the welds is less in the dissimilar combination than in the individual alloys. This is possibly due to the slightly higher weld force, 1000 pounds, for the dissimilar combination, instead of the 800-pound weld force for the individual alloys.

Alclad 24S-T to Alclad 75S-T

The spot welding of Alclad 24S-T to Alclad 75S-T is again the combining of two high-strength, age-hardening aluminum alloys. As with the R-301 alloy, the properties of 75S alloy are derived from elevated-temperature aging.

The microstructure of spot welds made in this dissimilar alloy combination is shown in figure 13. The Alclad 24S-T alloy is at the top in each picture. The 15X photograph reveals that the penetration of fusion in each alloy is approximately the same. Some differences are evident in the two alloys in the effect of the heat on the zone surrounding the weld in the photograph at 100X. The zone of incipient fusion in the Alclad 75S-T alloy is considerably narrower than that in the Alclad 24S-T. In the Alclad 75S-T alloy the zone of overaging appears as a narrow, dense black band surrounding the weld nugget, instead of a broad diffuse zone as in the Alclad 24S-T alloy. In each alloy stringers of extruded low-melting constituents are observed to extend from the ends of the welds far out into the base sheet. It is also observed that the average grain size of the Alclad 75S-T is considerably larger than that of the Alclad 24S-T alloy.

The best strength-current characteristic obtained for this combination is presented in figure 14. The maximum-size sound weld is roughly the same as for the Alclad 24S-T to R-301-T combination, probably 750 to 800 pounds. In comparing this curve with that for the Alclad 75S-T alloy in figure 17 of reference 3 it may be seen that the maximum-size sound weld for the dissimilar alloy combination is slightly greater than for the Alclad 75S-T welded individually. The slope of the curve for the dissimilar combination, 33.3 pounds per kiloampere, is identical with that for the Alclad 24S-T alloy and slightly less than that of 37.5 pounds per kiloampere for the Alclad 75S-T alloy. The weld force for the dissimilar alloy combination was the same as that used for the individual alloys, that is, 800 pounds. Increasing the weld force to 1000 pounds for the combination might result in further slight improvement in the quality of the welds at the upper end of the curve. However, the sheet separation would be expected to increase appreciably and possibly even approach the maximum acceptable value for the very large welds.

R-301-T to Alclad 75S-T

Photomicrographs of a typical spot weld in the dissimilar alloys R-301-T to Alclad 75S-T, which are two of the newer high-strength aluminum alloys in the fully heat-treated condition, are presented in figure 15. The R-301 alloy is at the top in each picture. The photograph at 15X shows a uniform nugget, well centered in the sheets. The picture at 100X shows some rather remarkable differences in the structure of the heat zone surrounding the weld in each alloy. The cladding of the Alclad 75S-T sheet extends into the weld slightly beyond the outer extremity of the dendritic columnar zone. The heat-affected zone of this alloy is similar to that described in the previous discussion of the Alclad 24S-T to Alclad 75S-T combination. Thus there is a narrow zone of grain-boundary fusion surrounding the weld nugget, within which is a narrow, dense black band of overaged alloy. The heat-affected zone of the R-301-T alloy appears to be quite similar to that ordinarily observed in the 24S alloy. This is characterized by a broad, diffuse region of incipient grain-boundary fusion and overaging surrounding the weld nugget, this region becoming more pronounced at the ends of the weld. The cladding of the R-301-T sheet protrudes to the edge of the columnar weld zone. The average grain size of the R-301 sheet is smaller than that of the Alclad 75S-T sheet.

A reasonably good strength-current characteristic for this combination is shown in figure 16. Unfortunately, for this curve, welds were not made at a sufficiently high current to indicate the point at which cracks began to appear in the welds. Inasmuch as the welding conditions were practically identical with those used for the individual alloys, it may be presumed that the maximum-size sound weld which may be produced in the dissimilar combination would have a shear strength in the neighborhood of 700 to 750 pounds, corresponding to the strength obtainable in each alloy welded individually. The approximate slope of the curve in the strength range from 400 to 750 pounds is 33.3 pounds per kiloampere, as in the case of Alclad 24S-T.

Alclad 75S-T to Bare 75S-T

In certain instances it is necessary to fabricate aircraft structures from high-strength aluminum alloys, only one of which is to be exposed to corrosive elements. In such cases it is desirable to join clad and bare alloy in order to obtain the slightly higher strength of the bare alloy. The Alclad 75S-T to bare 75S-T and the Alclad 24S-T to bare 24S-T combinations are examples of such applications.

Photomicrographs of a typical weld in this alloy combination are presented in figure 17. The photograph at 15X reveals that the penetration of the fusion is greater in the bare alloy (at the top of the picture), which is to be expected. Since this is essentially a weld in two similar alloys, the absence of selective attack by the etch enables a clearer metallographic examination of this combination than is possible with many of the dissimilar alloy combinations, one alloy of which is attacked by the etch in preference to the other. As would be expected, the heat-affected zone is similar in both the bare and the Alclad alloy and is typical of the structure seen in the dissimilar alloy welds discussed previously. One very noticeable phenomenon in the photomicrograph at 100X, however, is the dense segregation of dark-etched constituents, at the ends of the welds. This segregation has also been observed in the R-301-T alloy. It probably also occurs in the various dissimilar alloy combinations involving Alclad 75S-T or R-301-T, although, because of the depth of the attack of the etch upon the columnar zone of the weld in such cases, it cannot be observed in the picture.

The optimum strength-current characteristic for the Alclad 75S-T to bare 75S-T combination is shown in figure 18. The maximum-size sound weld obtainable in this combination with the welding conditions used had an average shear strength approaching 750 pounds. This was considerably better than the maximum results obtained with bare 75S-T alone (fig. 14, reference 3) and about the same as those obtained with Alclad 75S-T (fig. 17, reference 3). In this particular curve expulsion of the welds in the dissimilar alloy combination caused the strength to drop to 700 pounds. No significance is attached to the fact that such a drop in strength due to expulsion did occur on this curve, yet did not occur on some of the other curves. The slope of this curve over the sound-weld range above 400 pounds shear strength is approximately 38.9 pounds per kiloampere as compared with a slope of 26.9 pounds per kiloampere for the Alclad alloy and 31.6 pounds per kiloampere for the bare alloy.

The current range over which sound welds may be produced, having an average shear strength of 400 to 750 pounds, is approximately 9000 amperes for the dissimilar alloy combination. This is to be compared with a 10,000-ampere current range for the Alclad alloy and a 7000-ampere range for the bare alloy, with the particular welding conditions used for each. (See reference 3.)

CONCLUSIONS

As a result of this investigation of the spot welding of dissimilar aluminum alloys in the 0.040-inch thickness, the following conclusions have been drawn:

1. Chemical treatment of dissimilar alloys to provide surfaces of uniform resistance for spot welding is not a serious problem, provided one of the alloys may be treated to produce a low, consistent surface resistance. The sheet-to-sheet resistance measurements of the dissimilar alloy combination are almost invariably intermediate between corresponding measurements on the individual alloys treated under the same conditions. Also the consistency of the measurements in the dissimilar combination is usually considerably better than the consistency of the measurements on the alloy which is less amenable to the treatment.

2. All the dissimilar alloy combinations studied were satisfactorily welded with 4-inch-radius dome tips. As previously mentioned, this work was limited to the 0.040-inch gage. In welding a bare alloy to a clad alloy of the same composition the penetration of the fusion in the bare alloy is greater. Likewise in welding of two aluminum alloys having widely different melting temperature ranges, the penetration of the fusion is greater in the alloy with the lower melting range.

3. The optimum weld force for spot-welding dissimilar alloys is usually intermediate between the optimum values for the individual alloys. For 0.040-inch material the optimum weld force is in the range from 800 to 1200 pounds, depending upon the average surface hardness of the combination. (The optimum weld force for a particular job may be defined as the maximum weld force which may be used without the occurrence of excessive sheet separation prior to expulsion, as the welding current is increased.) A forge force of two to three times the weld force has been found suitable for most dissimilar alloy combinations. When possible, a forge-to-weld force ratio of at least 2.5 : 1 is desirable.

4. A wave form having an average rate of current rise of approximately 3000 amperes per millisecond is satisfactory for spot-welding dissimilar aluminum alloys in the 0.040-inch thickness.

5. A forge time (time from the initiation of current flow until the start of forging) of 38 milliseconds is satisfactory for spot-welding dissimilar aluminum alloys in the 0.040-inch thickness, when the wave form previously recommended is used, and the forging force reaches its maximum value in approximately 12 milliseconds.

6. The maximum shear strength of sound welds, and the current range over which sound welds may be produced in each dissimilar alloy combination are usually intermediate between the corresponding values for the component alloys welded individually, assuming that optimum welding conditions are used in each case.

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Rensselaer Polytechnic Institute,
Troy, N. Y., March 5, 1945.

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5. Humphrey, S. M.: Dual Pressure Systems as Applied to Resistance Welding Machines. Welding Jour., vol. 23, Feb. 1944, pp. 135-139.

6. Anon.: Alcoa Aluminum and Its Alloys. Aluminum Co. of Am., 1940.

TABLE I.– SURFACE TREATMENT OF DISSIMILAR ALUMINUM ALLOYS, 0.040-INCH THICKNESS

Chemical solution	Alloy A	Average surface resistance of A (microhms)	Alloy B	Average surface resistance of B (microhms)	Average surface resistance of A & B together
Hydrofluosilicic acid, H_2SiF_6, 3 percent by volume, 80° F, Alloys A & B, 8 min	Alclad 24S-T	4	Bare 24S-T	17	10
		5		19	12
		4		17	10
		4		19	11
		4		62	18
	Alclad 24S-T	5	52S-1/2H	19	13
		5		7	6
		3		28	4
Alloy A, H_2SiF_6, 3 percent 75° F, 8 min Alloy B, HNO_3, 3 percent, 180° F, 8 min	Alclad 24S-T	3	61S-T	13	5
		4		14	7
		9		34	15
Alloys A & B, H_2SiF_6, 1.5 percent, 75° F, 8 min	Alclad 24S-T	6	3S-1/2H	44	4
		4		36	6
		4		33	4
Alloys A & B, H_2SiF_6, 3 percent, 75° F, 8 min	Alclad 24S-T	4	Alclad 75S-T	21	4
		5		78	7
		7		59	11
Alloys A & B, H_2SiF_6, 1.5 percent, 75° F, 8 min	Alclad 24S-T	4	R-301-T	8	5
		4		34	8
		4		11	5
Alloys A & B, H_2SiF_6, 1.5 percent, 75° F, 8 min	Alclad 75S-T	13	Bare 75S-T	51	38
		14		72	35
Alloys A & B, H_2SiF_6, 1.5 percent, 72° F, 10 min	R-301-T	14	Alclad 75S-T	28	25
		36		35	17

TABLE II.- SURFACE HARDNESS OF ALUMINUM ALLOYS

Alloy	Average surface hardness, VPN
Bare 24S-T	145.0
Alclad 24S-T	43.3
Bare 75S-T	193.0
Alclad 75S-T	66.5
R-301-T	112.0
Alclad 24S-T-81	[b]37.6
61S-T	115.0
3S-1/2H	51.4
52S-1/2H	90.7
14S-T [a]	159.0
2S-1/2H	43.0

[a]Extruded shape.

[b]Cladding thickness = 18 percent of sheet thickness on this material instead of 10 percent as normally used for Alclad 24S-T.

TABLE III.- RELATIONSHIP OF SATISFACTORY WELD FORCE TO SURFACE HARDNESS OF ALUMINUM ALLOYS, 0.040-INCH THICKNESS

Average of the surface hardnesses of the alloys, VPN	Satisfactory weld force (lb)
40 to 65	800
66 to 90	1000
91 to 115	1200
116 to 150	1400
Above 150	1600

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TABLE IV.- SATISFACTORY WELD FORCE FOR SPOT-WELDING ALUMINUM ALLOYS,

0.040-INCH THICKNESS

(4-in.-radius-dome- tip electrodes)

[In most cases the optimum weld force will be equivalent to these values or else within 200 lb of these values.]

Alloy	Alclad 24S-T	Bare 24S-T	52S-1/2H	3S-1/2H	61S-T	R-301-T	Alclad 75S-T	Bare 75S-T	24S-T-81	14S-T	2S-1/2H
Alclad 24S-T	800	---	---	---	---	---	---	---	---	---	---
Bare 24S-T	1200	1400	---	---	---	---	---	---	---	---	---
52S-1/2H	1000	1400	1200	---	---	---	---	---	---	---	---
3S-1/2H	800	1200	1000	800	---	---	---	---	---	---	---
61S-T	1000	1400	1200	1000	1200	---	---	---	---	---	---
R-301-T	1000	1400	1200	1000	1200	1200	---	---	---	---	---
Alclad 75S-T	800	1200	1000	800	1000	1000	1000	---	---	---	---
Bare 75S-T	1400	1600	1400	1400	1600	1600	1400	1600	---	---	---
24S-T-81	800	1000	800	800	1000	1000	800	1200	800	---	---
14S-T	1200	1600	1400	1200	1400	1400	1200	1600	1200	1600	---
2S-1/2H	800	1200	1000	800	1000	1000	800	1400	800	1200	800

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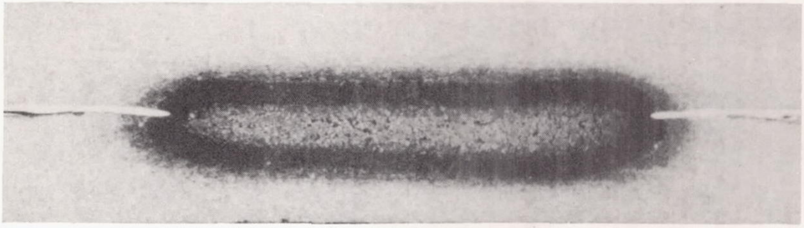
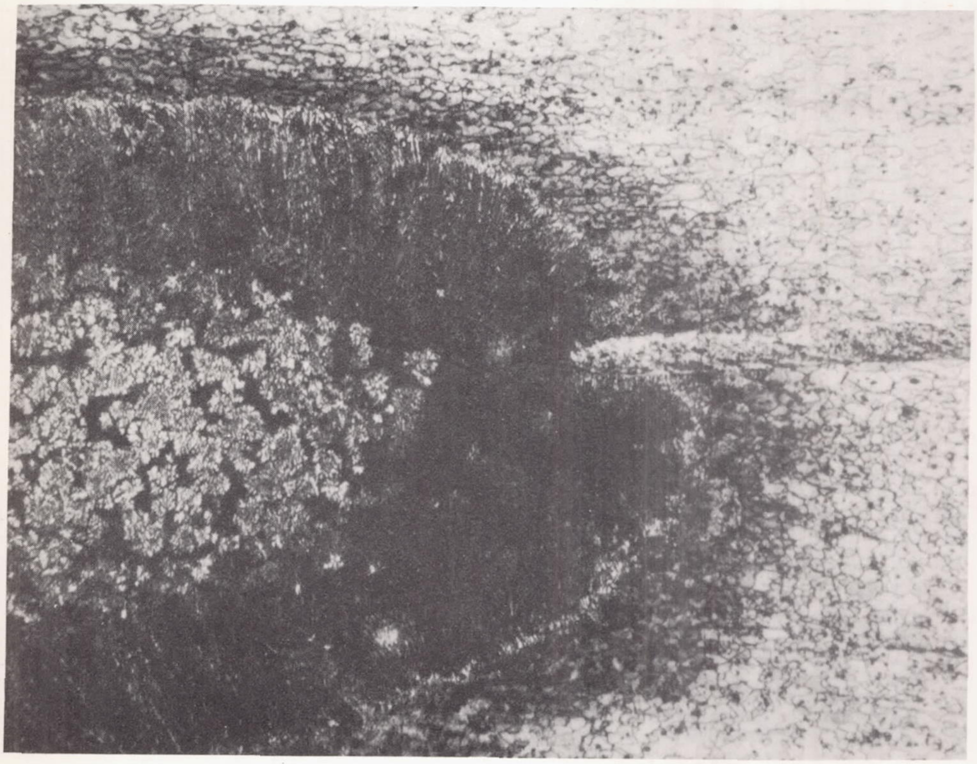


Alclad 24S-T

Bare 24S-T

15X



Alclad 24S-T

Bare 24S-T

100X

Figure 1.- Photomicrographs of a spot weld in Alclad 24S-T to bare 24S-T combination, 0.040 inch.

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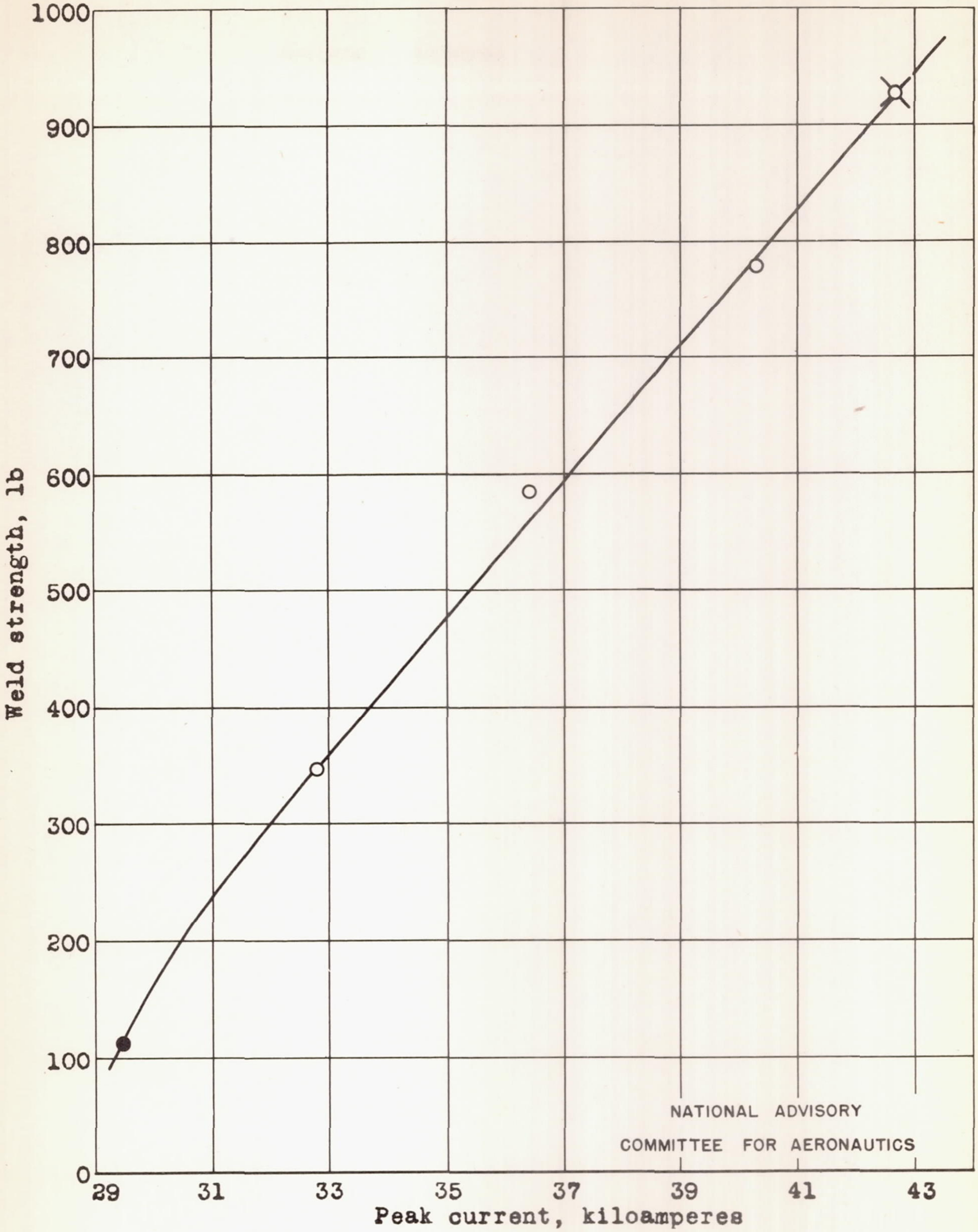

Figure 2.- Strength-current characteristic of Alclad 24S-T to bare 24S-T. Thickness of both alloys, 0.040 inch; electrode dome-tip radius, 4 inches; electrode force, 1200 pounds (weld), 2000 pounds (forge); forge timing, 38 milliseconds; average rate of current rise, 3145 amperes per millisecond.

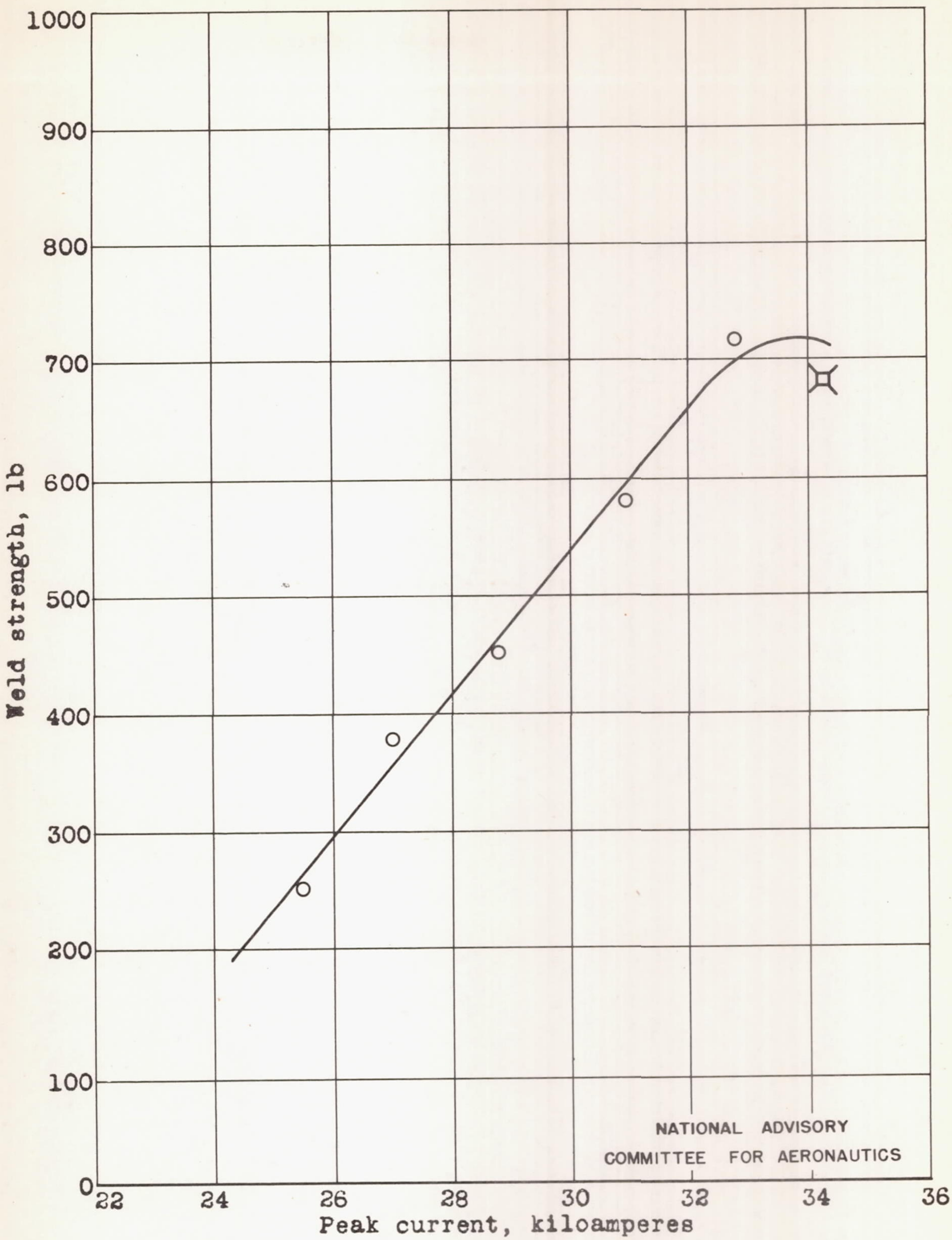

Figure 3.- Strength-current characteristic of Alclad 24S-T to bare 24S-T. Thickness of both alloys, 0.040 inch; electrode dome-tip radius, 4 inches; electrode force, 800 pounds (weld), 2000 pounds (forge); forge timing, 38 milliseconds; average rate of current rise, 2650 amperes per millisecond.

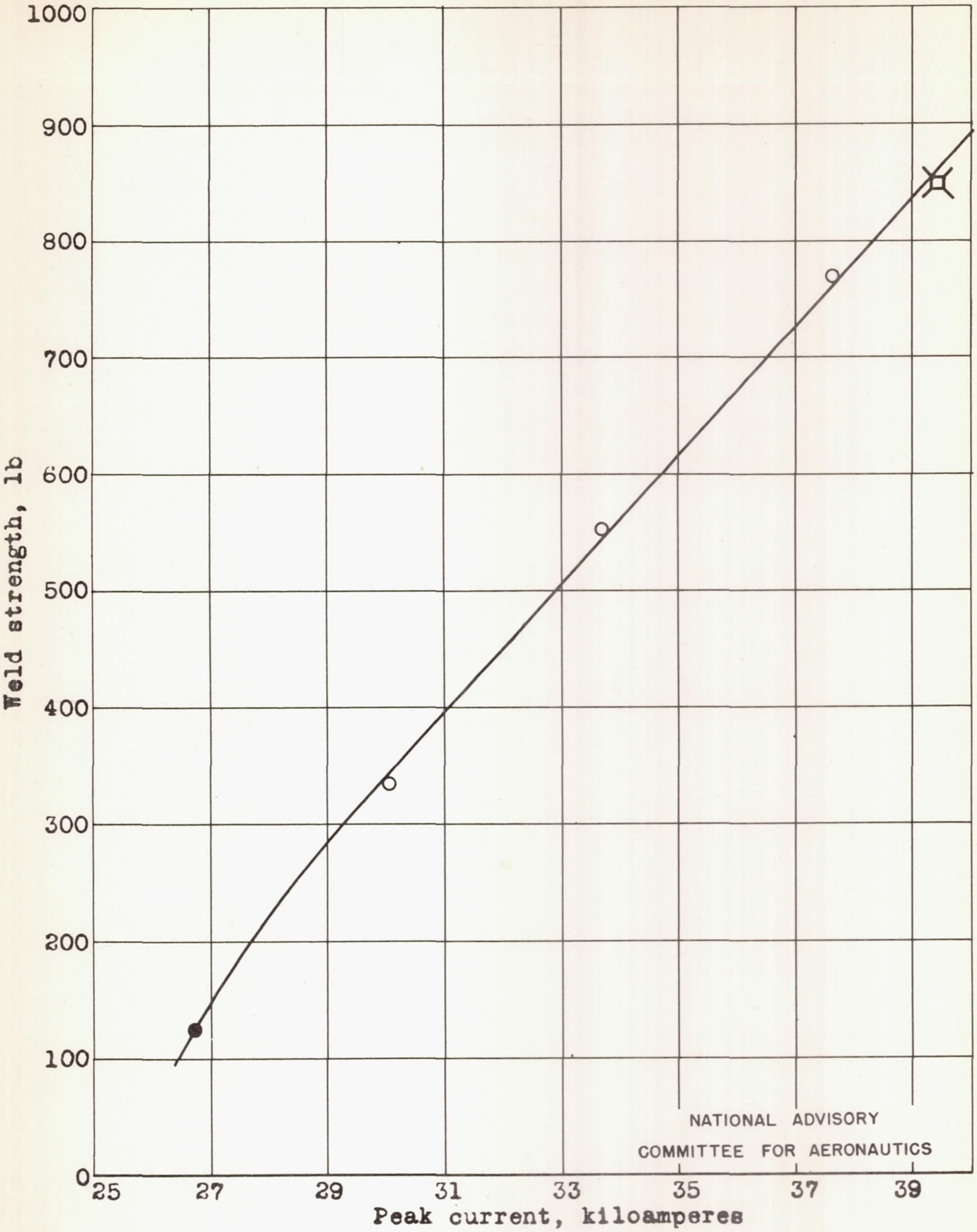

Figure 4.- Strength-current characteristic of Alclad 24S-T to bare 24S-T. Thickness of both alloys, 0.040 inch; electrode dome-tip radius, 4 inches; electrode force, 1000 pounds (weld), 2000 pounds (forge); forge timing, 38 milliseconds; average rate of current rise, 2845 amperes per millisecond.

15X

100X

Figure 5.- Photomicrographs of a spot weld in Alclad 24S-T to 52S-1/2H combination, 0.040 inch.

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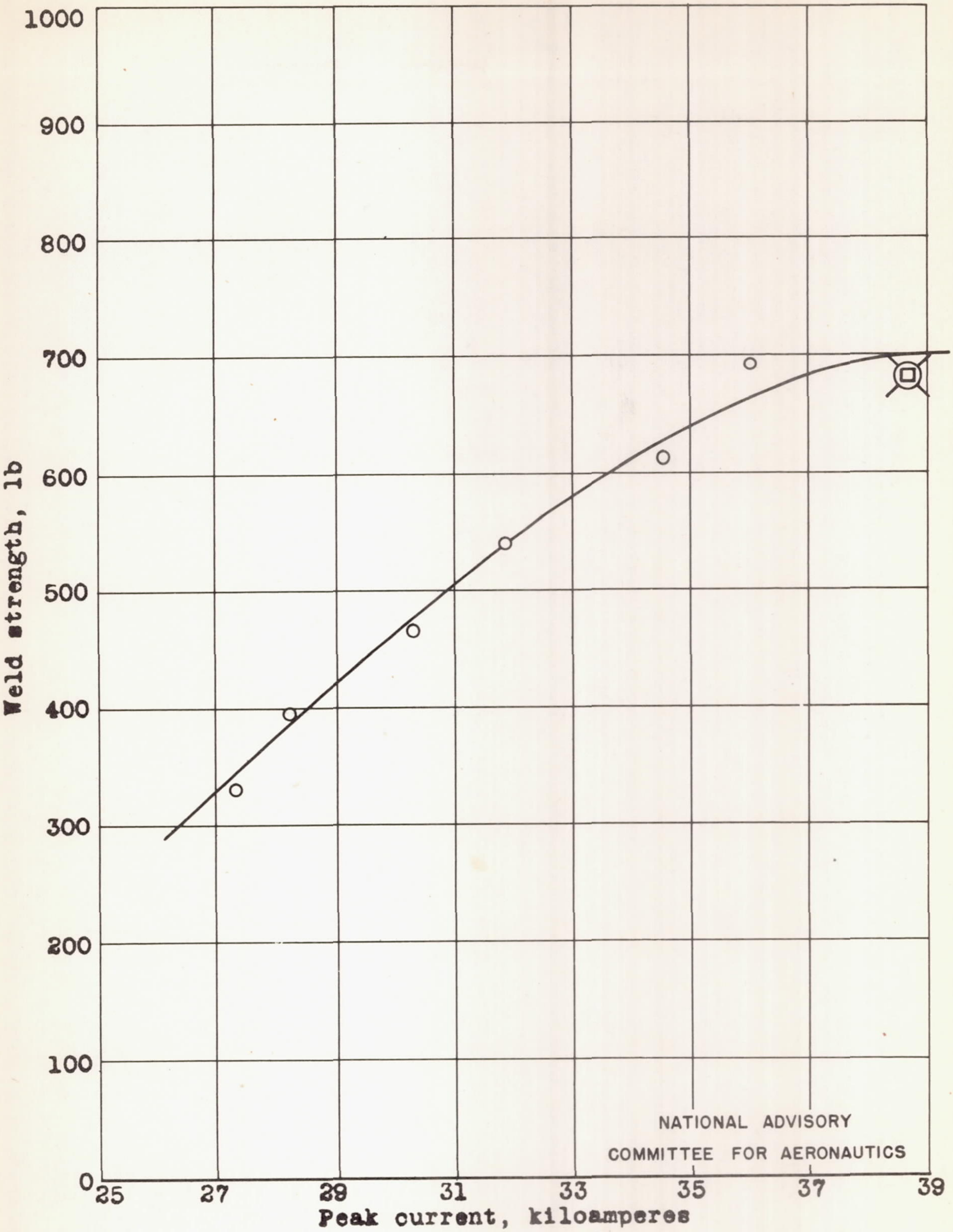
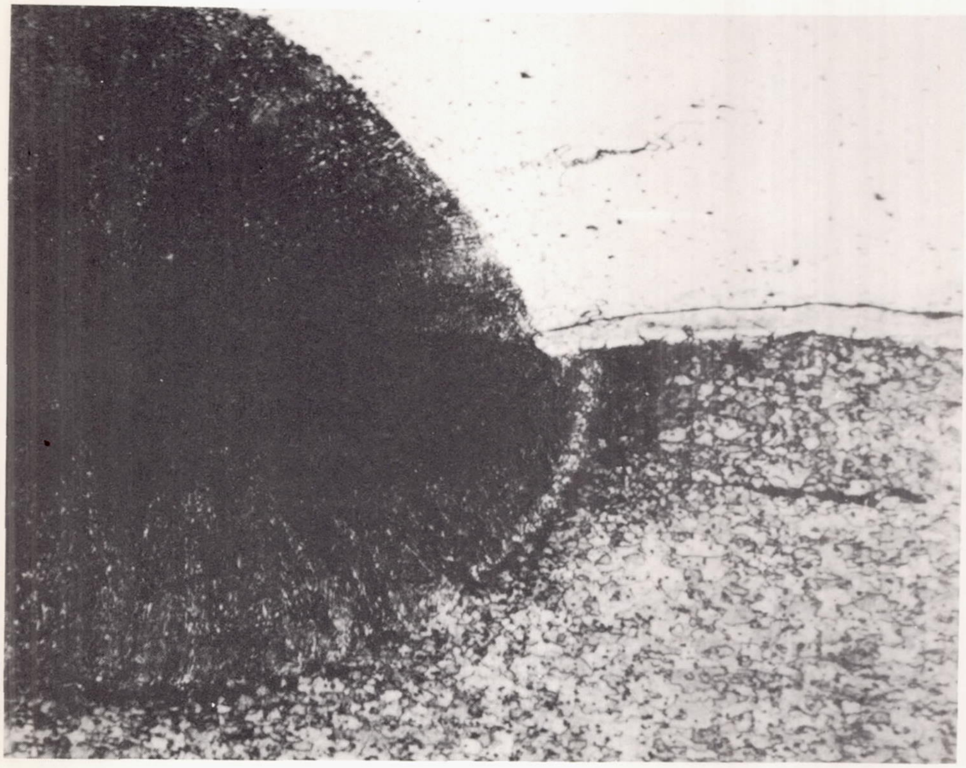


Figure 6.- Strength-current characteristic of Alclad 24S-T to 52S-1/2H. Thickness of both alloys, 0.040 inch; electrode dome-tip radius, 4 inches; electrode force, 800 pounds (weld), 2000 pounds (forge); forge timing, 38 milliseconds; average rate of current rise, 2925 amperes per millisecond.

61S-T

Alclad 24S-T

15X



61S-T

Alclad 24S-T

100X

Figure 7.- Photomicrographs of a spot weld in Alclad 24S-T to 61S-T combination, 0.040 inch.

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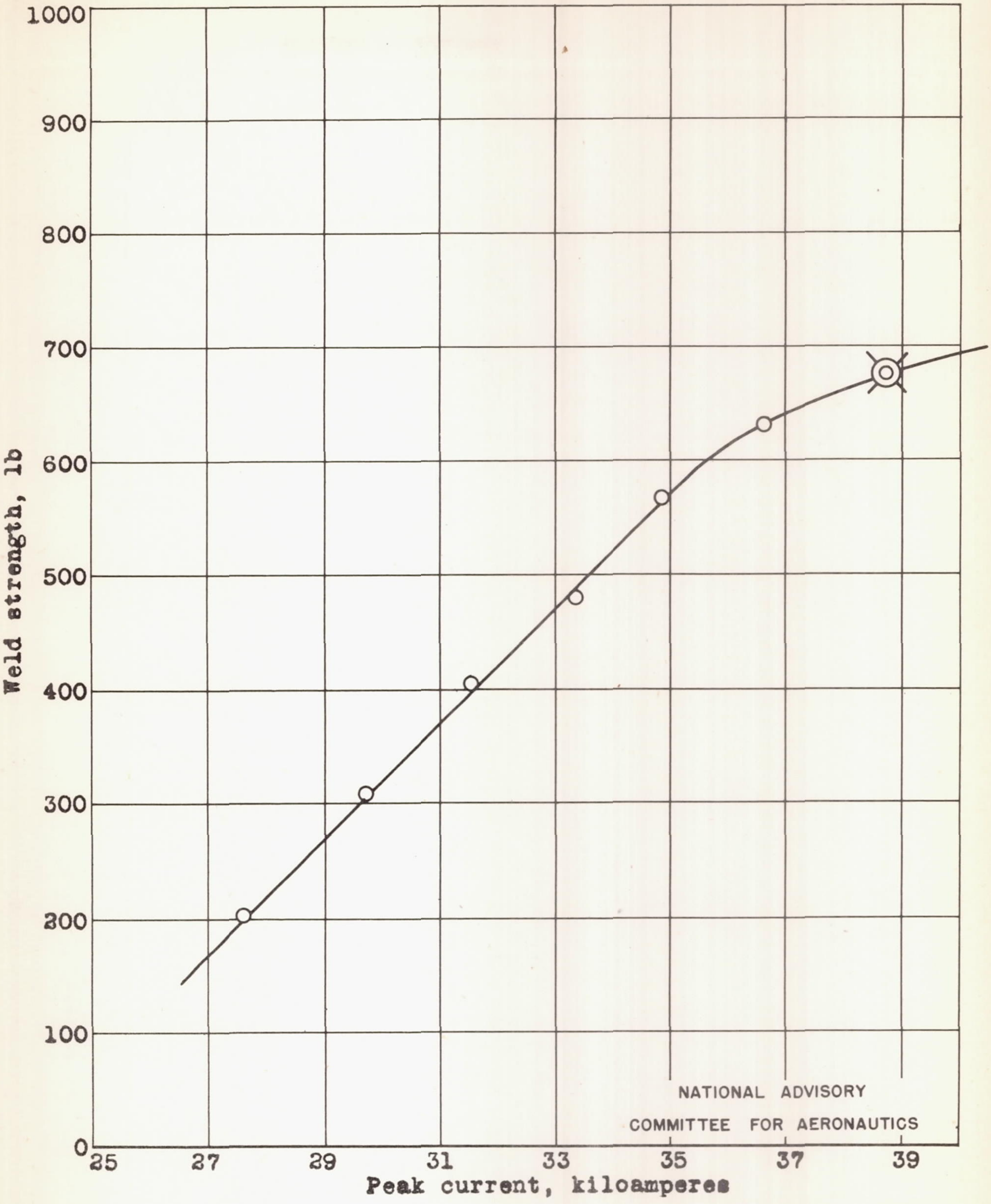
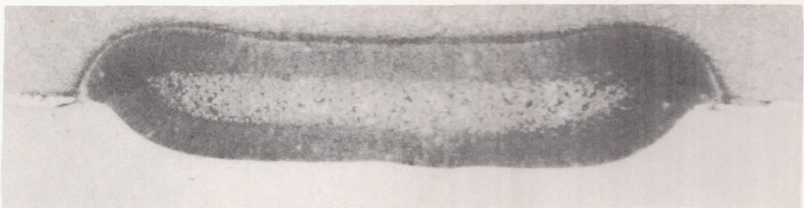


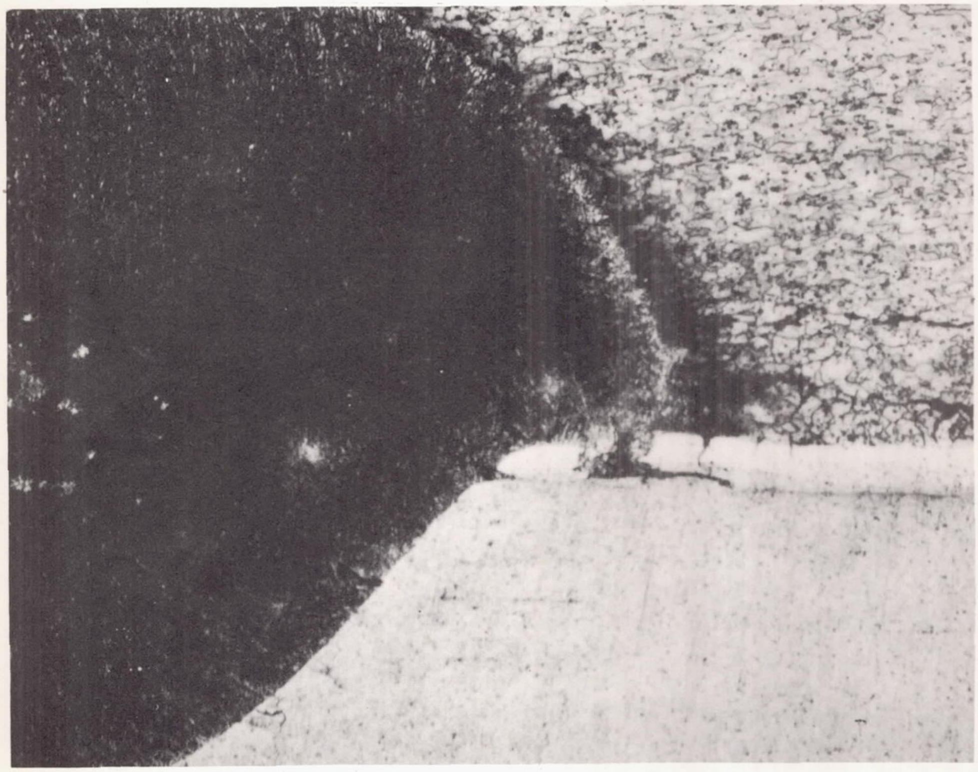
Figure 8.- Strength-current characteristic of Alclad 24S-T to 61S-T. Thickness of both alloys, 0.040 inch; electrode dome-tip radius, 4 inches; electrode force, 800 pounds (weld), 2000 pounds (forge); forge timing, 38 milliseconds; average rate of current rise, 2930 amperes per millisecond.



Alclad 24S-T

3S-1/2H

15X



Alclad 24S-T

3S-1/2H

100X

Figure 9.- Photomicrographs of a spot weld in Alclad 24S-T to 3S-1/2H combination, 0.040 inch.

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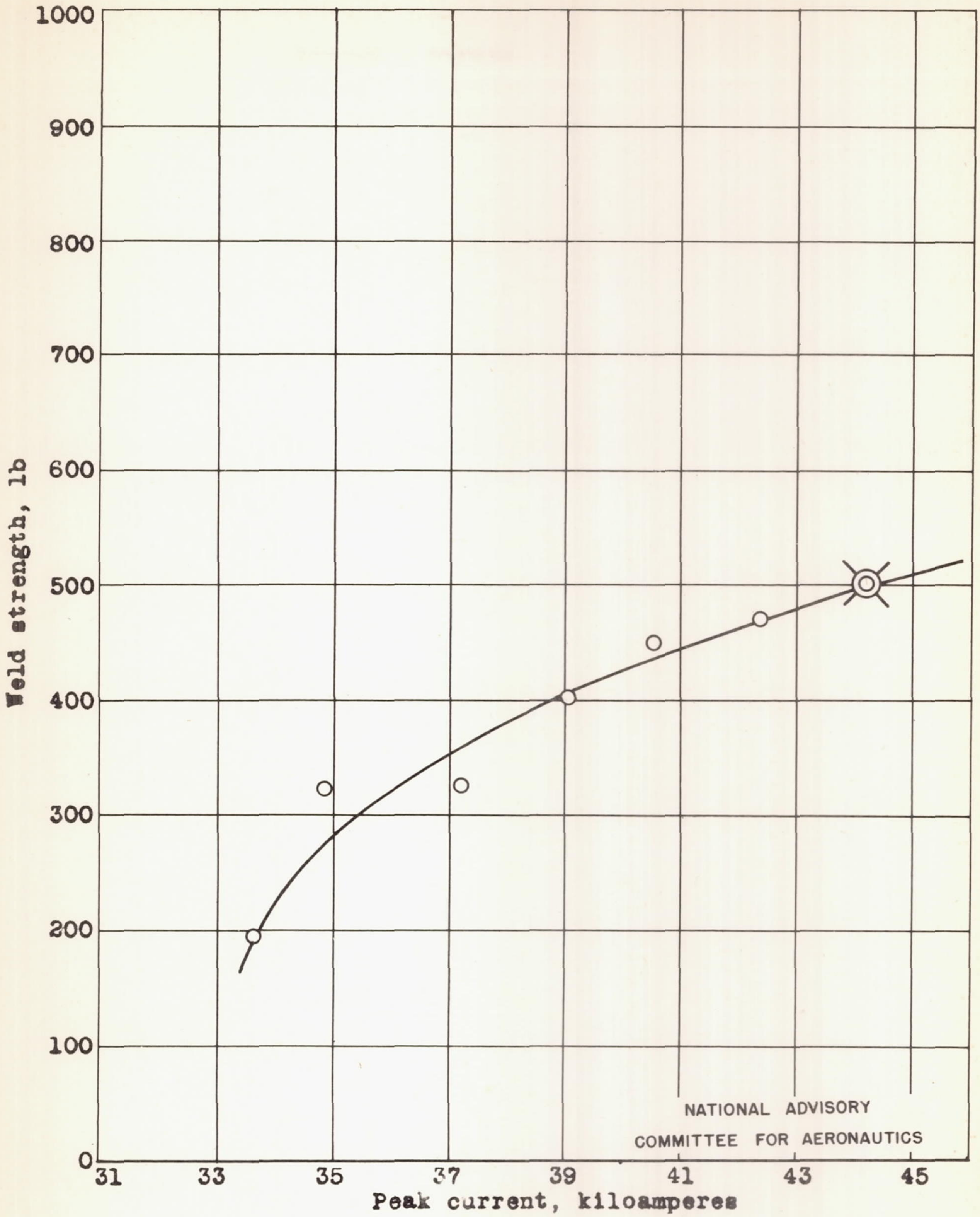
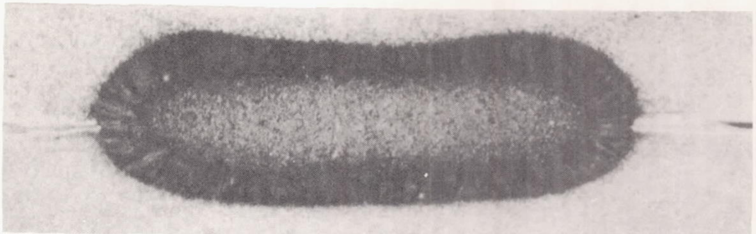


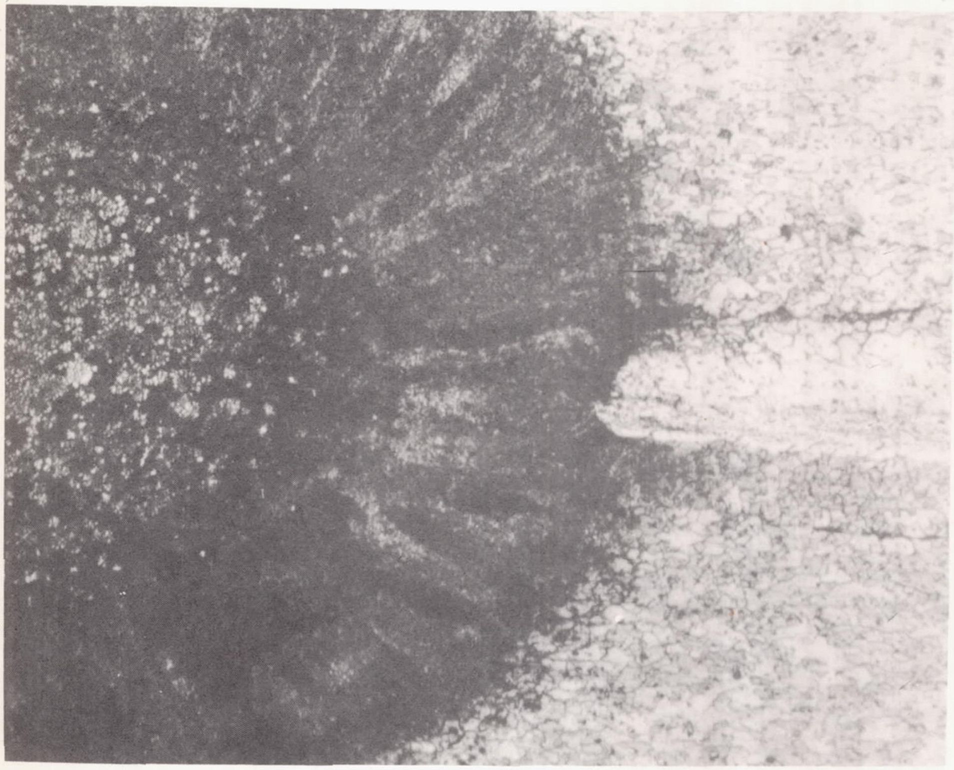
Figure 10.- Strength-current characteristic of Alclad 24S-T to 3S-1/2H. Thickness of both alloys, 0.040 inch; electrode dome-tip radius, 4 inches; electrode force, 800 pounds (weld), 2000 pounds (forge); forge timing, 38 milliseconds; average rate of current rise, 3355 amperes per millisecond.



R-301-T

Alclad 24S-T

15X



R-301-T

Alclad 24S-T

100X

Figure 11.- Photomicrographs of a spot weld in Alclad 24S-T to R-301-T combination, 0.040 inch.

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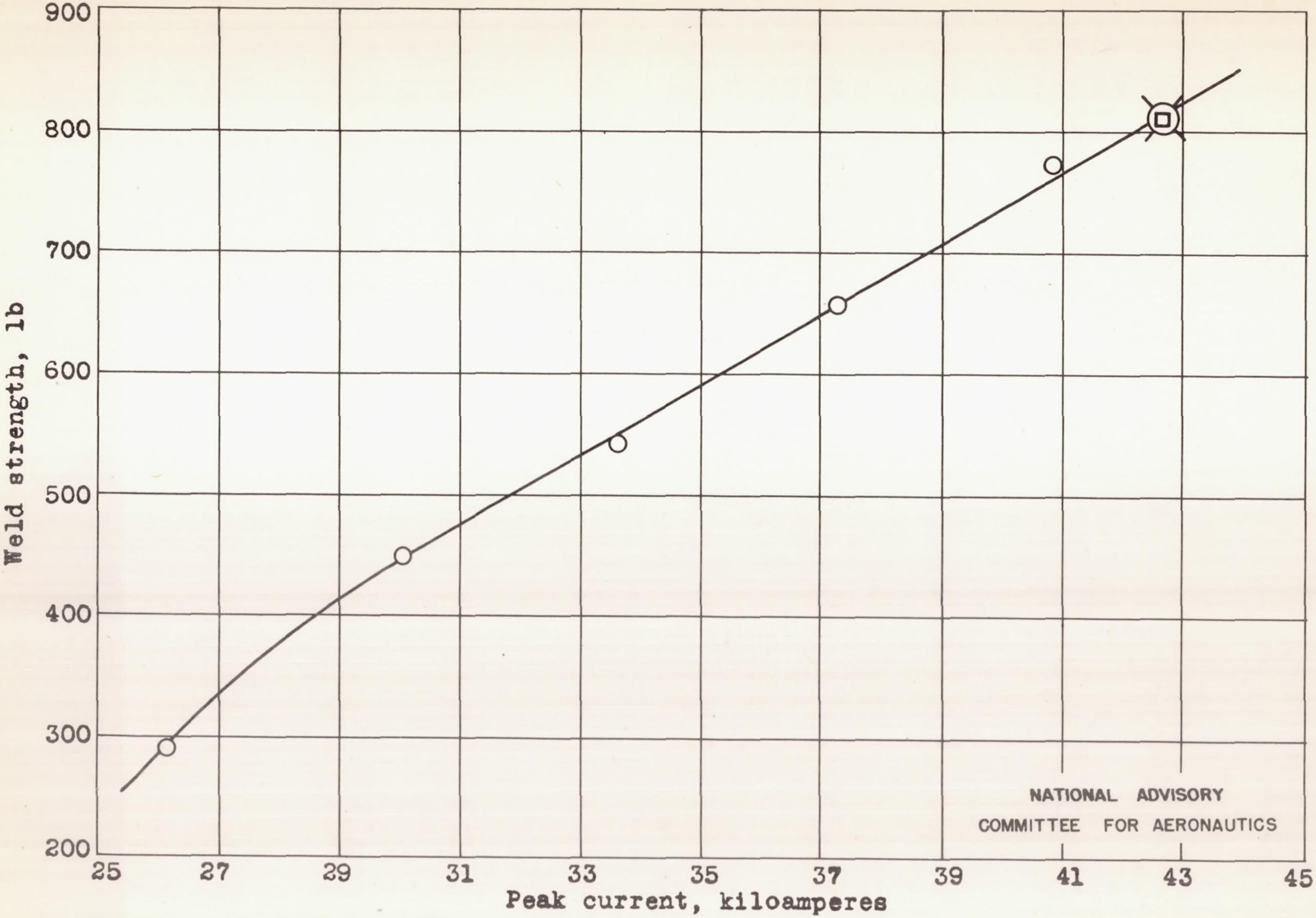
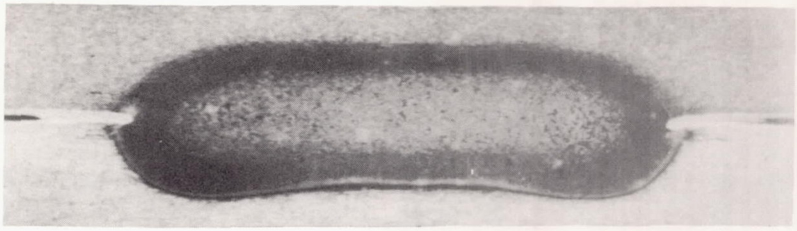


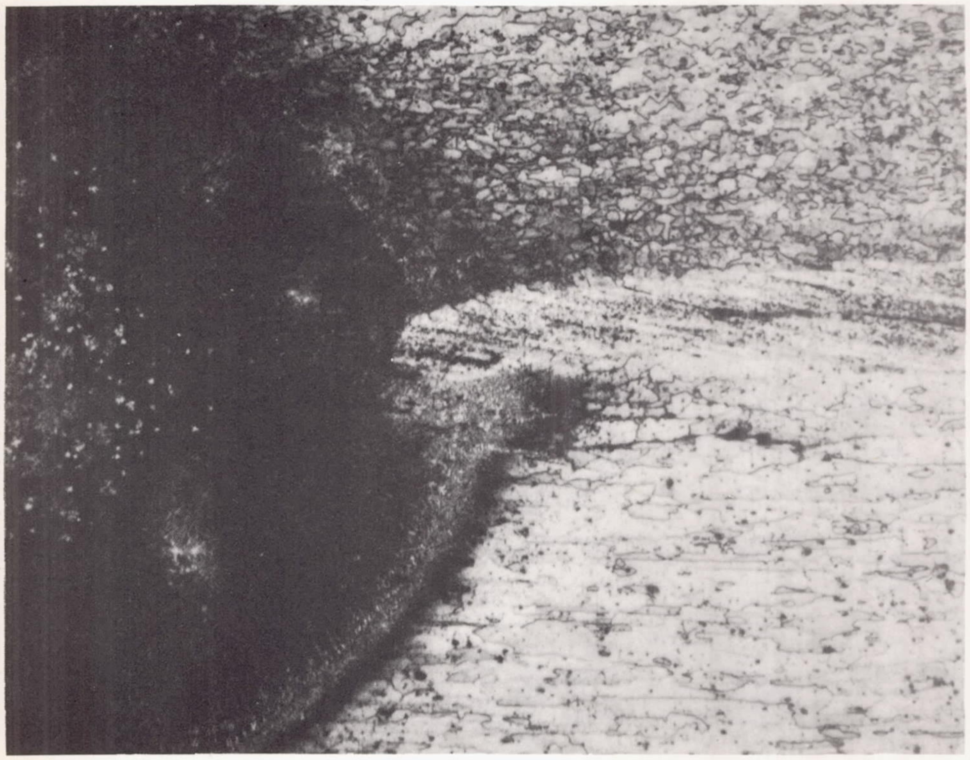
Figure 12.- Strength-current characteristic of Alclad 24S-T to R-301-T. Thickness of both alloys, 0.040 inch; electrode dome-tip radius, 4 inches; electrode force, 1000 pounds (weld), 2000 pounds (forge); forge timing, 38 milliseconds; average rate of current rise, 3040 amperes per millisecond.



Alclad 24S-T

Alclad 75S-T

15X



Alclad 24S-T

Alclad 75S-T

100X

Figure 13.- Photomicrographs of a spot weld in Alclad 24S-T to Alclad 75S-T combination, 0.040 inch.

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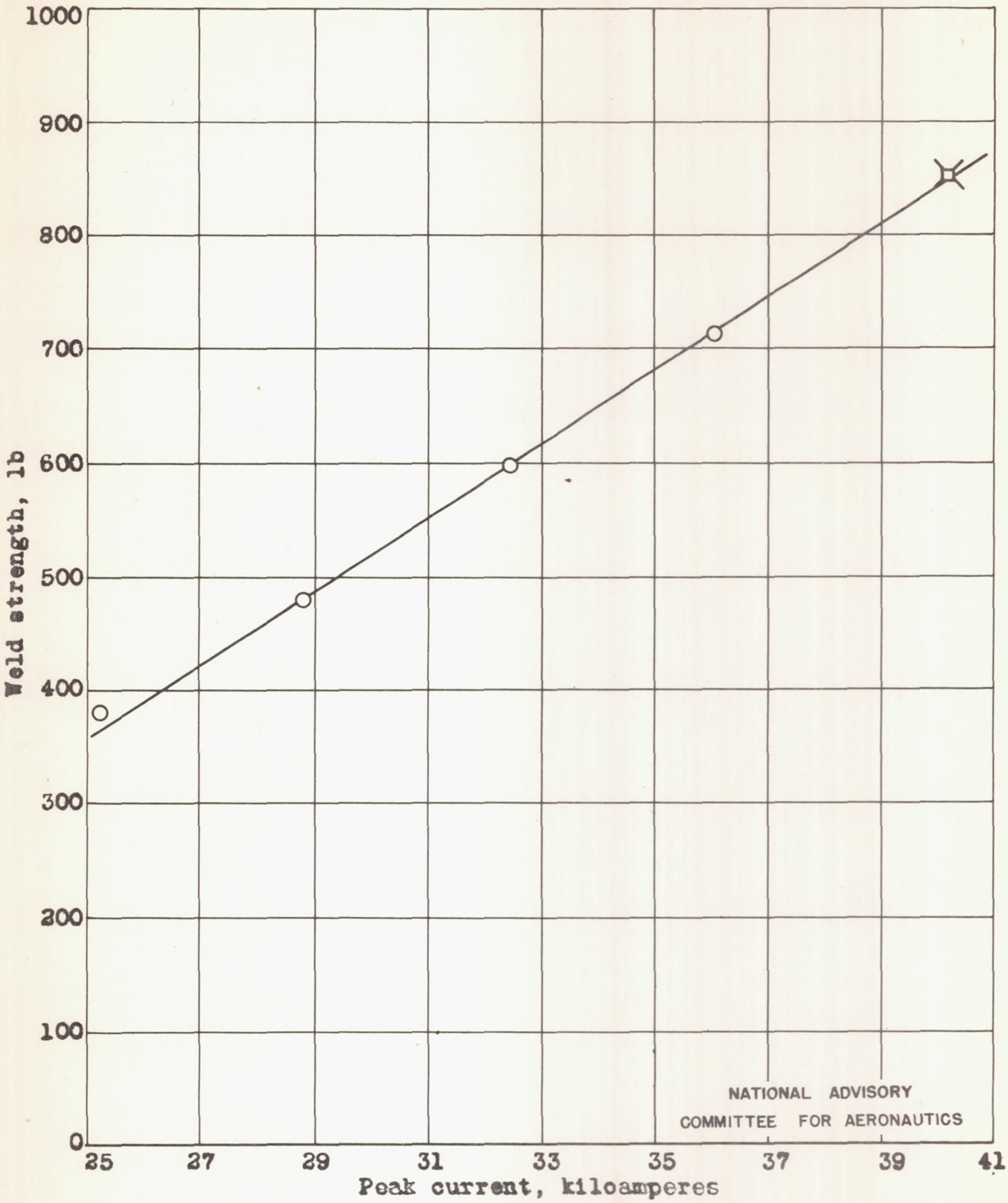
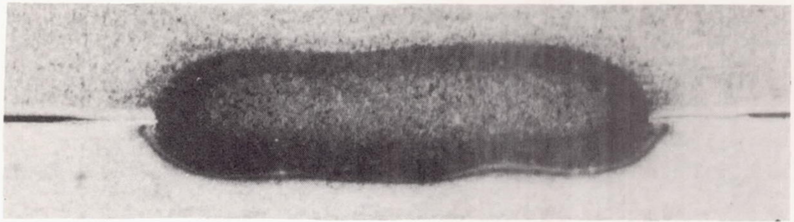


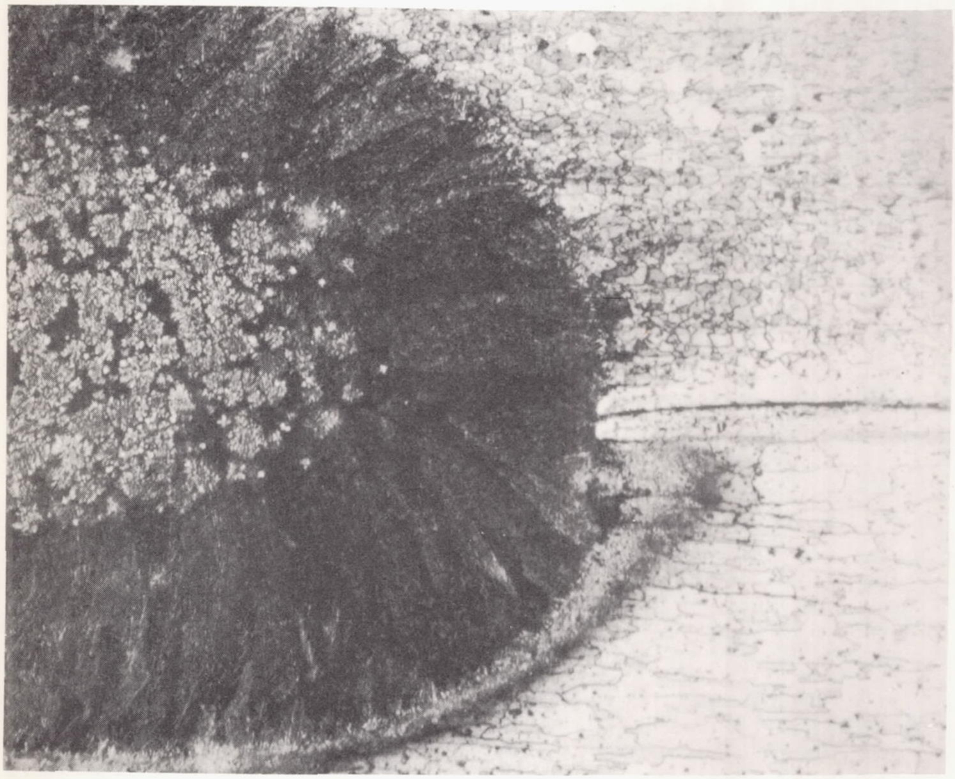
Figure 14.- Strength-current characteristic of Alclad 24S-T to clad XB75S-T. Thickness of both alloys, 0.040 inch; electrode dome-tip radius, 4 inches; electrode force, 800 pounds (weld), 2000 pounds (forge); forge timing, 38 milliseconds; average rate of current rise, 2900 amperes per millisecond.



R-301-T

Alclad 75S-T

15X



R-301-T

Alclad 75S-T

100X

Figure 15.- Photomicrographs of a spot weld in R-301-T to Alclad 75S-T combination, 0.040 inch.

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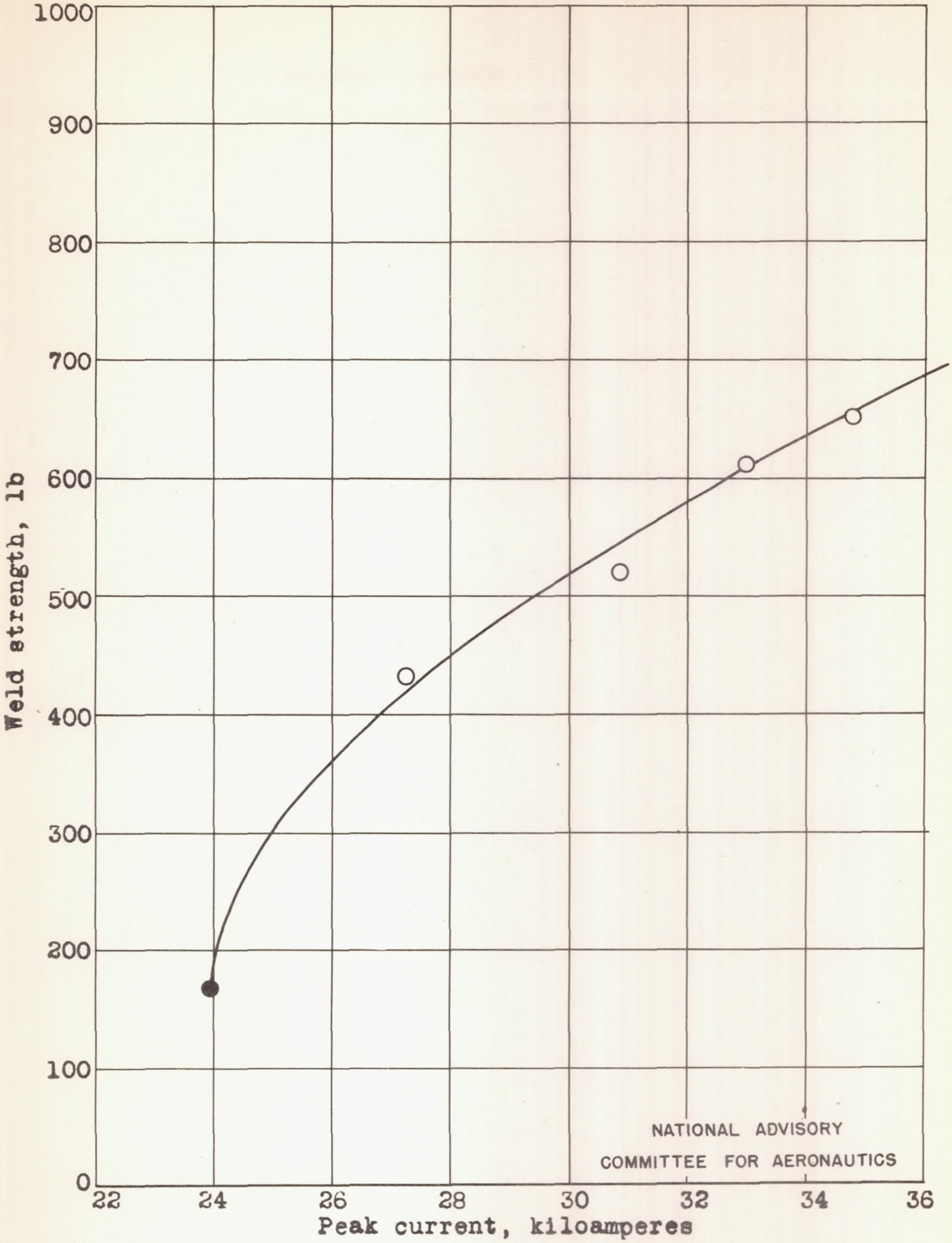
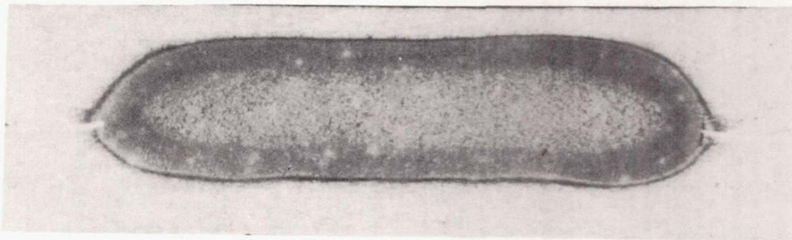


Figure 16.- Strength-current characteristic of R-301-T to clad XB75S-T. Thickness of both alloys, 0.040 inch; electrode dome-tip radius, 4 inches; electrode force, 800 pounds (weld), 2000 pounds (forge); forge timing, 33.4 milliseconds; average rate of current rise, 2630 amperes per millisecond.



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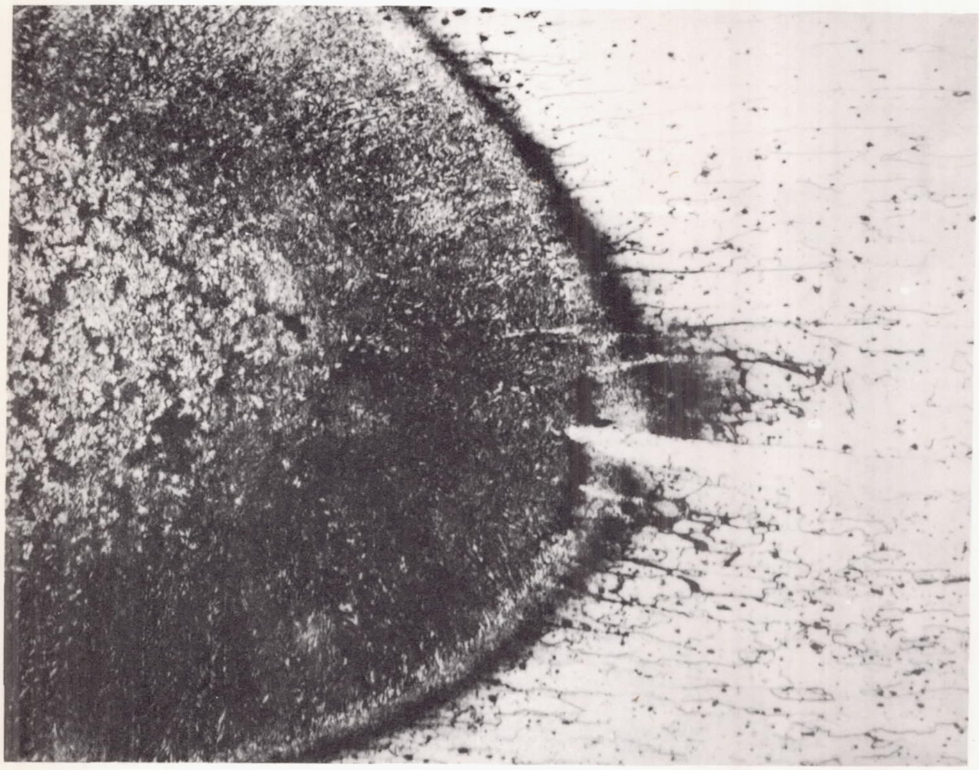

100X

Figure 17.- Photomicrographs of a spot weld in Alclad 75S-T to bare 75S-T combination, 0.040 inch.

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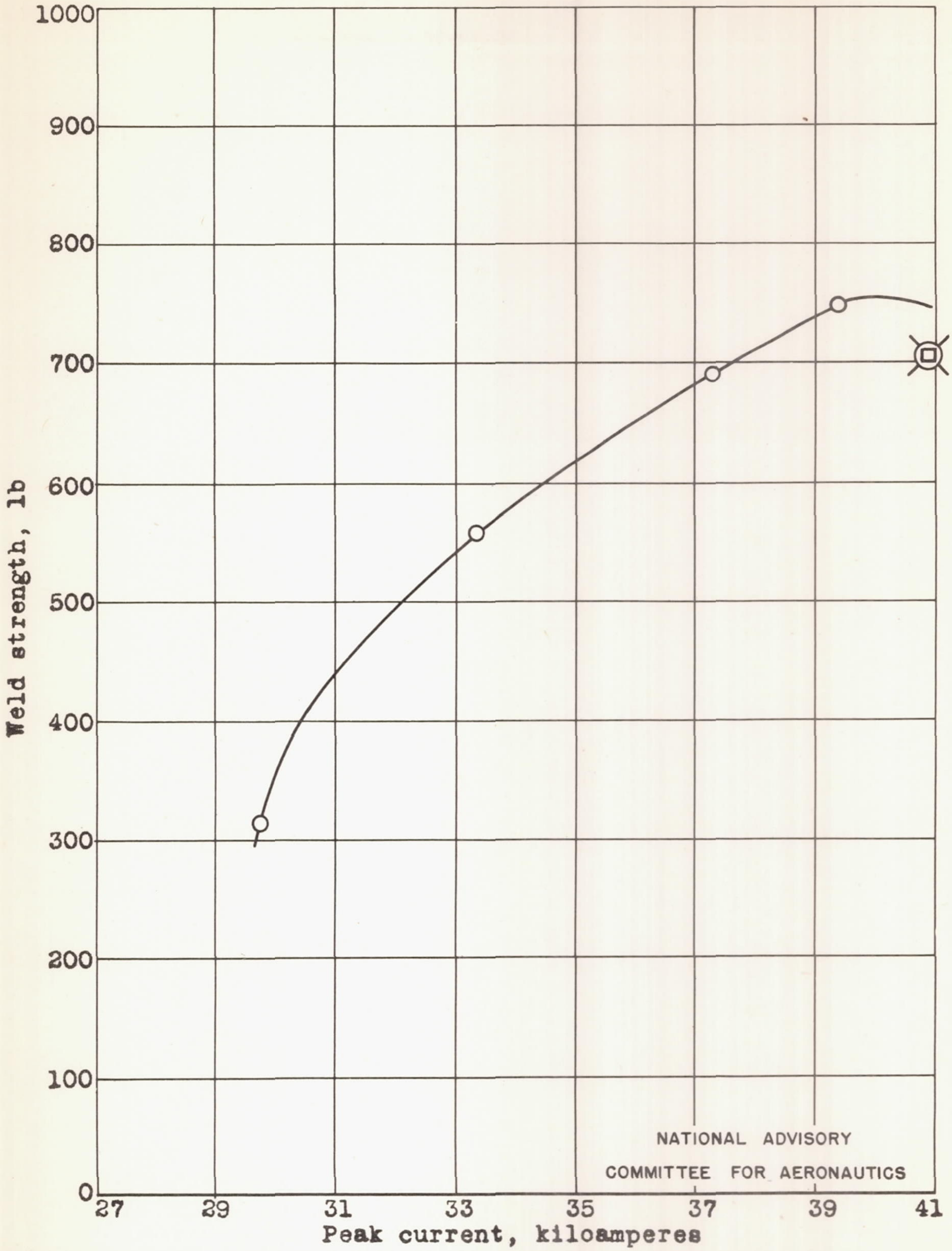

Figure 18.- Strength-current characteristic of clad XB75S-T to bare XB75S-T. Thickness of both alloys, 0.040 inch; electrode dome-tip radius, 4 inches; electrode force, 1200 pounds (weld), 2000 pounds (forge); forge timing, 38 milliseconds; average rate of current rise, 3120 amperes per millisecond.