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TECHNICAL NOTE

No. 1415

THE EFFECT OF PREHEATING AND POSTHEATING ON THE QUALITY OF SPOT WELDS IN ALUMINUM ALLOYS

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THE EFFECT OF PREHEATING AND POSTHEATING ON THE QUALITY OF SPOT WELDS IN ALUMINUM ALLOYS

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SUMMARY

This report is the result of further work in the course of studies to improve the quality of spot welds in aluminum alloys. The present investigation was performed to determine the effect of preheating and postheating cycles on the quality and strength of spot welds in aluminum alloys. The welds for the preheating study were made by discharging two banks of condensers in sequence through a condenser-discharge welding machine, the first discharge serving to preheat the material and the second to make the weld. Postheating of spot welds was accomplished in an alternating-current welding machine by using a sequence timer to control the welding cycle, cool time, and postheat cycle.

The results of the investigation showed that the combination of a slowly rising condenser-discharge preheat current with a rapidly rising welding current afforded no more freedom from expulsion than was obtained with the rapidly rising welding current alone. A double waveform combination of this type was in all cases inferior to a single, slowly rising welding current. With 0.040-inch Alclad 24S-T, the addition of a slowly rising preheat current to a slowly rising welding current produced some beneficial results with regard to decreasing expulsion, but this combination was less effective with the bare 24S-T and 61S-T alloys. In most cases, however, it is more practicable to decrease expulsion by raising the electrode force for welding, although with some alloys this, too, has a definite limitation because of the introduction of excessive sheet separation. Condenser-discharge preheating has no apparent effect on the occurrence of cracks in the welds.

Postheating of spot welds in 0.040-inch Alclad 24S-T made with alternating current had no effect on their shear strength until the magnitude of postheating current was sufficient to cause remelting of the welds, which greatly increased the weld diameter and the shear strength. Radiographic examination, however, showed no increase in the magnitude of cracks in those welds in which remelting occurred.

INTRODUCTION

This report describes the results of an investigation to determine the effects of preheating and postheating on the quality of spot welds in aluminum alloys. The welds for the preheating study were made with a condenser-discharge welder by discharging two banks of condensers in sequence. The purpose of the first discharge was to preheat the stock between the welding electrodes, and the second current pulse, which was of higher magnitude, produced the weld. The welds for the study of postheating were made with a conventional alternating-current welder using a Thyratron control panel and a sequence timer. The current-time program was such as to produce a 6-cycle weld with a 2-cycle cool time, followed by a 30-cycle postheat.

A previous investigation in which condenser-discharge welding equipment was used, indicated that a steep or rapidly rising welding current was slightly superior to a shallow-wave-form current for welding 0.020-inch Alclad 24S-T. (See reference 1.) With the steep wave form the weld strength was less affected by changes in the welding current. Because of the flatness of the strength-current characteristic in this case, somewhat more freedom could be allowed in setting a machine to produce sound welds of a given strength. Attempts which have been made to incorporate this desirable feature into the welding of heavier gages of Alclad 24S-T and also other aluminum alloys by using steep-wave-form welding currents have been unsuccessful. This is due to the greater tendency for expulsion and surface flashing when thicker or harder-surface materials are welded with rapidly rising currents. The same difficulty is encountered in welding alloys which are difficult to treat chemically to produce low and consistent surface resistances.

The purpose of the investigation of condenser-discharge preheating, therefore, was to determine whether the addition of a shallow-wave-form preheat to a steep-wave-form welding current would permit a realization of the benefits of the steep-wave-form current by eliminating its undesirable effects with regard to expulsion and surface flashing.

The material used for this phase of the investigation consisted of Alclad 24S-T and 61S-T alloys in the 0.40-inch gage, and bare 24S-T in the 0.040 and 0.064-inch gages. Alclad 24S-T may be chemically treated in a hydrofluosilicic acid solution at room temperature to produce a low consistent surface resistance. Because of its low surface resistance and soft surface cladding, this alloy gives less trouble with regard to expulsion than most aluminum alloys. (See reference 2.) It has been observed that, when the other welding conditions are optimum, an increase in the thickness of Alclad 24S-T requires a decrease in the rate of current rise in order to produce maximum freedom from expulsion. (See reference 3.) This would indicate that the expulsion tendency is definitely related to the material thickness. The 61S-T and bare 24S-T alloys have relatively high surface hardnesses and are difficult to treat in hydrofluosilicic acid or other solutions operated at room temperature to produce low, consistent surface resistances. These two factors are believed to be largely responsible for the difficulty in obtaining freedom from expulsion when welding these alloys.

The second phase of this investigation dealt with the use of an alternating-current welding and postheating program for spot-welding 0.040-inch Alclad 24S-T. A previous study in which an alternating-current postheat was added to a condenser-discharge welding current failed to reveal any significant changes in the weld properties. (See reference 4.) This was believed to be due to the insufficient magnitude of postheat current. It was intended in the present investigation to continue that earlier limited study on the postheating of spot welds after modifying the electronic control circuit of the welding equipment. The results of additional work indicated, however, that an extensive redesign of the equipment would be required in order to synchronize properly the condenser-discharge wave with the alternating-current postheat cycle.

Because of the difficulties encountered in combining the alternating-current postheat with the condenser-discharge-welding current, this procedure was abandoned, and a brief study was made with an alternating-current program consisting of a 6-cycle weld with a 2-cycle cool time, followed by a 30-cycle postheat.

These investigations have been performed at the Rensselaer Polytechnic Institute under the sponsorship and with the financial assistance of the National Advisory Committee for Aeronautics.

EQUIPMENT

The welding equipment for the condenser-discharge preheat studies consisted of a Federal condenser-discharge welding machine and a Raytheon flexible weld power control unit. The electronic control equipment was designed to permit the firing of two banks of condensers in sequence. The first discharge served to preheat the stock and the second actually to make the weld. The design permitted considerable flexibility in the selection of different transformer-turns ratios for preheating and welding. In order to simplify the circuit as much as possible, the preheat condenser bank was charged from the rectifier to the same voltage as the welding condenser bank. Therefore, as the voltage was raised to increase the welding current, the preheat current was also increased proportionally. The initiation of the preheat current was accomplished when a microswitch on the head of the welder energized a relay in the ignition circuit of the ignitron tube which passed the preheat current. At a preselected point on the preheat wave the discharge of the welding condenser bank was initiated.

The welding for the study of the effect of postheat on the strength of alternating-current spot welds in Alclad 24S-T was performed with a Thomson-Gibb, 200-kilovolt-ampere press-type spot welder, using a General Electric Thyratron control panel and sequence timer. The welding program consisted of a 6-cycle welding current, a 2-cycle cool time, and a 30-cycle postheat. The magnitude of the welding current was held constant for all welds, and the magnitude of the postheat current was varied for different series of welds by means of a phase-shift control on the sequence timer.

PROCEDURE AND RESULTS

Condenser-Discharge Preheating of Spot Welds

in 0.040-Inch Alclad 24S-T

The Alclad 24S-T used for this phase of the investigation was chemically treated at room temperature in a solution of hydrofluosilicic acid, 1½ percent by volume, prior to spot welding. This treatment produced a consistently low surface resistance. All welds were made with a constant electrode force of 600 pounds, since it was desired to determine whether the preheating would have any effect on the occurrence of cracks at this low value of electrode force. Normally, cracks are best avoided by the application of a forging force of sufficient magnitude and properly timed with respect to the peak welding current. The use of a forging force might be resorted to for the prevention of cracks in the event that preheating should not eliminate cracks and yet should prove desirable for some other reason, such as decreasing the expulsion. Electrode tips, of Elkaloy A or SMS-101 alloy having a spherical radius of 2½ inches were used for the welding. The welding conditions are listed in table I.

Figure 1, consisting of a series of strength-current characteristics made with 0.040-inch Alclad 24S-T, gives a comparison of results obtained with this material both with and without preheat. As the welding current was increased to make larger welds, the preheat current was increased proportionately, because of the manner in which the electronic control equipment was designed.

The strength-current characteristic shown in figure 1(a) was obtained without any preheat and with a welding current having a steep wave form. The numbers above each point on the strength-current characteristic refer to the number of welds which expelled, out of the total of eight welds made at that point. This number gives a quantitative indication of the expulsion tendency for the different types of current wave form. This tendency toward expulsion is to be expected with such a steep wave from in combination with the low electrode force. Oscillographic measurements of the current wave form for figure 1(a), together with corresponding measurements of the other types of wave form for figures 1(b) to 1(d), are presented in table II.

Figure 1(b) shows the results obtained with a shallow wave form, or a slowly rising welding current without any preheat. From this, it is evident that the shallow wave form is to be preferred to the steep wave form of figure 1(a) because of the larger welds which were made without expulsion. The maximum shear strength of welds having freedom from expulsion was about 600 pounds for the shallow-current wave form as compared with the value of less than 400 pounds for the steep-current wave form. Both figures 1(a) and 1(b) show that cracks occurred in welds of relatively small size in each case, owing to the low electrode force. In a further comparison of figures 1(a) and 1(b) it may be seen that the peak welding current required to produce a weld of the same size is much lower for the shallow current wave form than for the steep wave form. This is due to the longer available heating time before the peak value of current is reached with the shallow wave form. A slightly higher energy discharge from the condensers is also required to make a weld of the same size with a steep current wave form than with a shallow wave from.

The characteristic obtained with a shallow-wave-form preheat plus a steep-wave-form welding current is shown in figure 1(c). In this case, the peak current for preheating was approximately 47 percent of that for welding, although the energy ($1/2\ CE^2$, where C is the condenser capacitance and E is the difference of potential) was only 20 percent as great for preheating as for welding. Oscillographic measurements of this current wave form are shown in table II. The curve of figure 1(c) indicates that little or no improvement in results over those obtained with the steep-wave-form welding current alone (fig. 1(a)) was effected by the addition of the condenser-discharge preheat. These data would indicate that the expulsion due to the steep wave form was so severe that, even with the preheat that was used, the results were still worse than with the shallow-wave-form welding current alone. Another strength-current characteristic was made after the condenser capacitance for preheating was raised from 150 to 300 microfarads. In this case, the energy for preheating was 40 percent of that for welding. Up to the point at which fusion began to occur from the high value of preheat, however, the results were no better than those shown in figure 1(c).

The next wave-form combination tried was that of a shallow-wave-form preheat plus a shallow-wave-form welding current. The results are shown in figure 1(d). In this case the peak current for preheating was 64 percent of that for welding, and the energy for preheating was 20 percent of that for welding. The oscillographic measurements of the current wave form are presented in table II. The curve of figure 1(d) shows a considerable improvement over any of the other results shown in figure 1. With this wave form, the maximum-size welds which were obtained without expulsion had an average shear strength of about 800 pounds as compared with a corresponding strength of 600 pounds obtained with a shallow-wave-form welding current alone, as shown in figure 1(b). Another series of welds was made in which the condenser capacitance for preheating was raised from 150 to 300 microfarads, thus increasing the preheating-to-welding energy ratio from 20 to 40 percent. No improvement in results over those shown in figure 1(d) was obtained with this wave form, however.

A comparison of all the curves in figure 1, shows that the preheating had no effect on the occurrence of cracks in the welds.

The use of a shallow-wave-form preheat in combination with a shallow-wave-form welding current effectively lengthens the total time of current flow and produces the same effect with regard to decreasing the expulsion, as would be expected from a single-current discharge through a sufficiently high turns ratio to give the same total time of current flow. Expulsion can also be decreased by increasing the electrode force, although at the expense of increasing the sheet separation somewhat. From the results of the work with condenser-discharge preheating on Alclad 24S-T it would appear that the use of higher transformer-turns ratios and higher electrode forces are a much more effective and economical means of reducing expulsion than the use of condenser-discharge preheating.

Condenser-Discharge Preheating of Spot Welds

in 0.040-Inch and 0.064-Inch Bare 24S-T

It was considered advisable to study the effects of preheating on bare 24S-T because of its high tendency toward expulsion even when very-shallow-current wave forms are used for welding. This tendency has been attributed to the high surface hardness of the material and also to the difficulty of obtaining a uniformly low surface resistance with room-temperature etching solutions. (See reference 2.) It is known that the expulsion can be minimized by using the highest available turns ratio together with relatively high values of electrode force as compared with those found to be adequate for alloys having soft surfaces. Even with these considerations, expulsion is still very often the limiting defect in the production of large welds in the hard materials and the use of a preheat to decrease the expulsion further might prove advantageous.

Series of welds were made in 0.040-and 0.064-inch thicknesses of this material similar to those made in the study using 0.040-inch Alclad 24S-T material. In the 0.040-inch bare 24S-T, however, no welds were made with a steep wave form alone, since the results with Alclad 24S-T showed such a procedure to be undesirable and the higher surface hardness of the bare alloy would be expected to cause even further trouble than was encountered with the clad material. The welding conditions that were used are shown in table III. The various strength-current characteristics obtained with 0.040-inch bare 24S-T treated in hydrofluosilicic acid are presented in figure 2. The electrode force was 600 pounds, and the radius of the dome tips was $2\frac{1}{2}$ inches for each series of welds. The curve obtained for welds made with a shallow-wave-form welding current without any preheat (fig. 2(a)) shows that expulsion occurred with welds having shear strengths greater than 500 pounds. Figure 2(b), for a shallow-wave-form preheat plus a steep-wave-form welding current, shows these particular conditions to be worse than a shallow-wave-form welding current alone, since expulsion occurred in this case when the weld strength was greater than 400 pounds. The results for a shallow-wave-form preheat plus a shallow-wave-form welding current, shown in figure 2(c), appear to be slightly inferior to those of figure 2(a) for the shallow-wave-form welding current alone.

These data indicated that a condenser-discharge preheat was of no benefit from the standpoint of decreasing expulsion in this material with a welding force of only 600 pounds. It was believed that any slight improvement which might have resulted from preheating was completely masked by the high expulsion tendency for the welds at such a low welding force. The logical step was to continue the investigation, using a higher electrode force for welding. The force selected was 1200 pounds. The new welding conditions are shown in table III. The results, with this higher electrode force, for a shallow-wave-form welding current and no preheat as compared with a shallow-wave-form preheat plus a shallow-wave-form welding current, are shown in figure 3. From this, it may be seen that slightly improved results are obtained with the preheat. Without preheat, expulsion occurred in welds with shear strengths slightly greater than 600 pounds. With the preheat, the weld strengths approached 700 pounds before expulsion occurred. This small improvement would economically hardly justify the use of a double condenser-discharge wave form for welding this material, since the same decrease in expulsion could be obtained by a slight increase in weld force, which would be a much more practicable solution to the problem.

A series of welds was also made in the 0.064-inch thickness of this alloy, using a shallow-wave-form preheat plus a shallow-wave-form welding current. This double wave form, however, produced a slight but hardly significant improvement in results over those obtained with a shallow-wave-form welding current alone, as shown in figure 4.

In comparing the occurrence of cracking in welds made with preheat and without it in figures 2, 3, and 4, it may be seen that preheating did not lessen the cracking tendency of spot welds in this alloy.

Effect of Condenser-Discharge Preheating on 0.40-Inch 61S-T

A limited study of the effects of condenser-discharge preheating was also made with the 61S-T alloy in the 0.40-inch thickness. This alloy, like bare 24S-T, has a relatively high surface hardness and does not treat well in a room-temperature etching solution. (See reference 2.) As with bare 24S-T, these factors combine to give 61S-T a rather high expulsion tendency when spot-welded with low electrode forces.

The welding conditions used for this material are shown in table IV. The results obtained in welding this alloy at an electrode force of 600 pounds, using various current wave forms, are very similar to those obtained with the bare 24S-T alloy. Figure 5(a) is the strength-current characteristic obtained with a shallow-wave-form welding current alone. The maximum-size weld with freedom from expulsion had an average shear strength of about 450 pounds in this case. Figure 5(b) shows the results of combining a shallow-wave-form preheat with a steep-wave-form welding current. It is apparent that such a step is in the wrong direction, since expulsion occurred with welds having shear strengths greater than 350 pounds. A shallow-wave-form preheat plus a shallow-wave-form welding current (fig. 5(c)) give roughly the same results as a shallow-wave-form welding current alone (fig. 5(a)). A previous investigation (reference 2) has shown that a welding force of 1200 pounds will produce much more freedom from expulsion than was obtained in these characteristics with an electrode force of 600 pounds. As was the case for bare 24S-T, it may be concluded that an increase in the welding force is much more effective in decreasing expulsion from welds in this alloy than is the use of a condenser-discharge preheat. The preheat had no effect on the occurrence of cracks, as was the case with the other alloys.

Alternating Current Welds with Postheat in 0.040-Inch Alclad 24S-T

The welding for this part of the investigation was performed with a Thomson-Gibb, 200 kilovolt-ampere spot welder and a General Electric Thryatron control panel and sequence timer. The material was chemically treated in hydrofluosilicic acid solution, $1\frac{1}{2}$ percent by volume, at room temperature. The welding was performed with 4-inch-radius dome tips, by using a constant electrode force of 750 pounds and a transformer-turns ratio of 36:1. The welding program consisted of a 6-cycle welding current, a 2-cycle cool time, and a 30-cycle postheat. The magnitude of the postheat current was varied for different series of welds by means of a phase-shift control. The welding conditions are tabulated in table V.

The welds of series 1 may be considered equivalent to welds made without any postheat, since the postheating time was only 2 cycles with a low phase setting. Series 7 represents about the maximum postheating current output which can be obtained with the present equipment.

The results of the shear tests of the welds are presented in table VI. The data indicate that no improvement in shear strength was obtained by postheating until the phase was set at 100 percent, in which case remelting occurred in some of the welds and effectively increased the weld diameter. The radiographic examination revealed that the welding conditions were such as to produce incipient cracking in the welds, some of the cracks being radiographically detectable. With this in mind it is of interest that the remelting of some of the welds in series 7, although it produced larger welds, did not result in any detectable increase in the extent of cracking.

CONCLUSIONS

As a result of the investigation of the effect of preheating and postheating on the quality of welds in aluminum alloys, it is concluded that:

1. A slight reduction in the tendency for expulsion with large welds in 0.040-inch Alclad 24S-T was obtained by using a double condenser-discharge wave form consisting of a slowly rising preheat current and a slowly rising welding current.

2. A double condenser-discharge wave form effectively increased the total time of current flow so that the heating and cooling was much more gradual than could have been obtained with a single condenser-discharge wave from, using the maximum transformer-turns ratio of the machine.

3. Steep-current wave forms increased the tendency toward expulsion in Alclad 24S-T, bare 24S-T, and 61S-T alloys, and this is probably also true of other aluminum alloys. Expulsion with steep-current wave forms was more pronounced in those alloys having high surface hardnesses and also in those which were difficult to treat chemically to produce a low, consistent surface resistance.

4. The combination of a shallow-wave-form preheating current plus a steep-wave-form welding current was inferior to a single shallow-wave-form welding-current discharge from the standpoint of expulsion.

5. Shallow-wave-form preheating and welding currents were ineffective in decreasing the expulsion of welds in hard alloys, such as bare

24S-T and 61S-T, when the electrode force for welding was low. At higher electrode forces the double wave form decreased the expulsion slightly. Increasing the electrode force, however, is a much more effective means of decreasing expulsion in these alloys.

6. Condenser-discharge preheating had no apparent effect on the occurrence of cracks in welds in 0.040-inch Alclad 24S-T, 0.040- and 0.064-inch bare 24S-T, and 0.040-inch 61S-T.

7. Postheating of spot welds made with alternating current had no effect on their shear strength until the magnitude of the postheating current was sufficient to cause remelting of the welds which greatly increased the weld diameter and the shear strength.

8. Radiographic examination showed no increase in the magnitude of cracks in those welds in which remelting occurred because of a very high postheating current, although the diameter and the strength of the remelted welds were much greater than the others.

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Rensselaer Polytechnic Institute
Troy, N. Y., June 29, 1945

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TABLE I. – WELDING CONDITIONS FOR INVESTIGATION OF CONDENSER-DISCHARGE PREHEAT ON 0.040-INCH ALCLAD 24S-T

[Electrode dome-tip radius, $2\frac{1}{2}$ in; electrode force, 600 lb ; material vapor degreased, treated 8 min at 75° F in hydroflusosilicic acid solution ($1\frac{1}{2}$ percent by volume); surface resistance, 5 to 10 microhms]

Type of wave form	Condenser voltage range (volts)	Preheat		Weld		Remarks
		Turns ratio	Condenser capacitance (microfarads)	Turns ratio	Condenser capacitance (microfarads)	
No preheat, steep-wave-form welding current (rapid current rise)	1800-2300	– – –	– –	103:1	750	See fig. 1(a)
No preheat, shallow-wave-form welding current (slow current rise)	2000-2800	– – –	– –	398:1	750	See fig. 1(b)
Shallow-wave-form preheat, steep-wave-form welding current	1800-2400	398:1	150	103:1	750	See fig. 1(c)
Shallow-wave-form preheat, shallow-wave-form welding current	2000-2800	398:1	150	398:1	750	See fig. 1(d)

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TABLE II.– OSCILLOGRAPHIC MEASUREMENTS OF CURRENT WAVE FORMS FOR SPOT WELDING 0.040–INCH ALCLAD 24S–T

Type of wave form	Transformer-turns ratio		Condenser voltage (volts)	Condenser capacitance (microfarads)		Peak current (amperes)		I_p'/I_p	Time (milliseconds) to –			I_1/I_p' (x 100)	Total time of current flow to 10 percent I_p (milliseconds) (4)
	Preheat	Weld		Preheat	Weld	I_p'	I_p		I_p' (1)	I_1 (2)	I_p (3)		
No preheat, steep-wave-form welding current		103.1	1800		750		37,000				4.5		17.4
			2000				41,100				4.3		17.7
			2100				42,200				4.5		17.6
			2200				45,100				4.5		17.9
			2300				47,400				4.6		18.2
No preheat, shallow-wave-form welding current		398:1	2000		750		30,700				12.5		50.3
			2200				34,000				12.9		51.5
			2400				37,400				13.6		51.0
			2600				40,700				13.1		51.8
			2800				44,800				14.0		51.4
Shallow-wave-form preheat, steep-wave-form welding current	398:1	103:1	1800	150	750	16,700	35,200	0.474	6.8	13.2	16.5	60.0	30.3
			2000			18,900	40,000	.472	6.8	12.4	16.5	62.7	29.4
			2200			20,000	43,700	.458	6.8	13.0	17.0	61.1	30.9
			2300			21,500	44,800	.480	6.6	12.9	16.7	62.1	30.4
			2400			22,600	47,400	.477	6.6	12.5	16.5	62.3	29.7
Shallow-wave-form preheat, shallow-wave-form welding current	398:1	398:1	2000	150	750	20,000	30,800	0.651	6.8	11.6	21.7	70.4	57.8
			2200			21,500	33,700	.637	7.1	11.3	21.8	72.8	58.0
			2400			23,000	35,500	.646	6.9	11.7	21.9	69.4	60.0
			2600			24,800	38,500	.644	7.0	11.9	22.2	67.2	59.3
			2800			27,400	42,900	.638	6.9	11.6	21.9	67.6	60.0

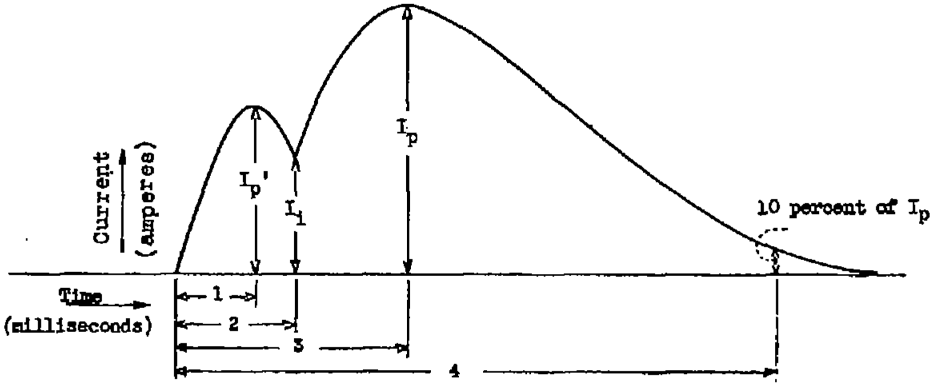

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TABLE III. – WELDING CONDITIONS FOR INVESTIGATION OF CONDENSER-DISCHARGE PREHEAT ON BARE 24S-T

[Material vapor degreased, treated 8 min at 75° F in hydrofluosilicic acid solution (1½ percent by volume)]

Material thickness (in.)	Type of wave form	Condenser voltage range (volts)	Preheat		Weld		Electrode force (lb.)	Radius of dome tips (in.)
			Turns ratio	Condenser capacitance (microfarads)	Turns ratio	Condenser capacitance (microfarads)		
[a]0.040	No preheat, shallow-wave-form welding current	1400–1900	–––	–––	398:1	750	[b]600	2½
0.040	Shallow-wave-form preheat, steep-wave-form welding current	1400–1800	398:1	150	103:1	750		
0.040	Shallow-wave-form preheat, shallow-wave-form welding current	1400–2000	398:1	150	398:1	750		
0.040	No preheat, shallow-wave-form welding current	1800–2600	–––	–––	398:1	750	[c]1200	2½
0.040	Shallow-wave-form preheat, shallow-wave-form welding current	1800–2600	398:1	150	398:1	750		
[d]0.064	No preheat, shallow-wave-form welding current	1800–3000	–––	–––	398:1	1200	2000	4
	Shallow-wave-form preheat, shallow-wave-form welding current	1800–3000	398:1	450	398:1	1200		

[a] Surface resistance, 26 to 185 microhms.
[b] See figure 2.
[c] See figure 3.
[d] Surface resistance, 24 to 160 microhms.

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TABLE IV. - WELDING CONDITIONS FOR INVESTIGATION OF CONDENSER-DISCHARGE PREHEAT ON 0.040-INCH 61S-T

[Electrode dome-tip radius, $2\frac{1}{2}$ in.; electrode force, 600 lb; material vapor degreased, treated 8 min at 75° F in hydrofluosilicic acid solution ($1\frac{1}{2}$ percent by volume); surface resistance, 75 to 1050 microhms]

Type of wave form	Condenser voltage range (volts)	Preheat		Weld		Remarks
		Turns ratio	Condenser capacitance (microfarads)	Turns ratio	Condenser capacitance (microfarads)	
No preheat, shallow-wave-form welding current	1400-2200	- - -	- -	398:1	750	See fig. 5(a)
Shallow wave-form preheat, steep-wave-form welding current	1400-2100	398:1	150	103:1	750	See fig. 5(b)
Shallow-wave-form preheat, shallow-wave-form welding current	1600-2400	398:1	150	398:1	750	See fig. 5(c)

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TABLE V. – WELDING CONDITIONS FOR STUDY OF EFFECT OF POSTHEATING ON ALTERNATING-CURRENT WELDS IN 0.040-INCH ALCLAD 24S-T

[Turns ratio, 36:1; electrode force, 750 lb; electrode dome-tip radius, 4 in.; surface resistance, 5 microhms (1½ percent by volume H_2SiF_6, room temperature)]

Weld series	Generator terminal voltage (volts)	Weld		Cool time (cycles)	Postheat	
		Time (cycles)	Phase (percent)		Time (cycles)	Phase (percent)
1	575	6	92.5	2	2	22.5
2	575	6	92.5	2	30	50
3	575	6	92.5	2	30	70
4	575	6	92.5	2	30	80
5	575	6	92.5	2	30	90
6	575	6	92.5	2	30	95
7	575	6	92.5	2	30	100

TABLE VI.– RESULTS OF SHEAR TESTS OF POSTHEATED SPOT WELDS IN 0.040-INCH ALCLAD 24S-T

Weld	Postheat		Shear strength (lb)
	Time (cycles)	Phase (percent)	
1a	2	22.5	505
b			455
c			445
			Av. 468
2a	30	50	455
b			450
c			480
			Av. 462
3a	30	70	485
b			425
c			470
			Av. 460
4a	30	80	430
b			455
c			440
			Av. 442
5a	30	90	445
b			465
c			525
			Av. 478
7a	30	100	485
b			455
			Av. 470
c			[a]1105
d			[a]1045
			Av. 1075

[a] Remelted.

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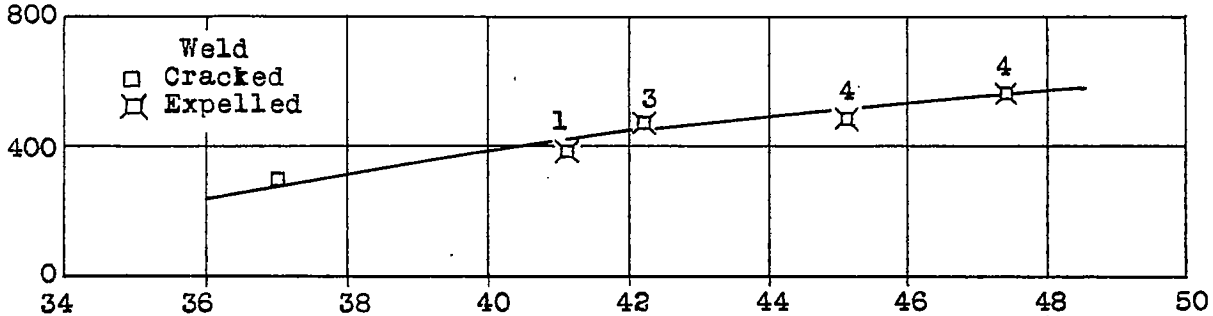
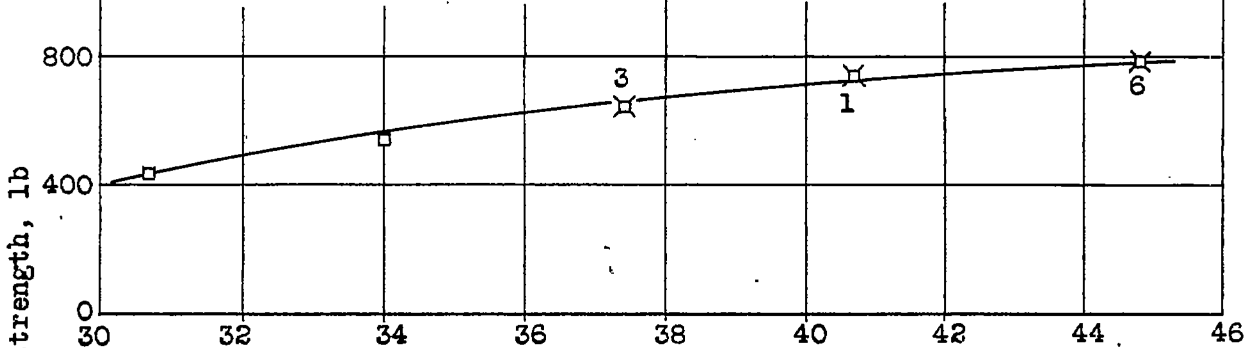
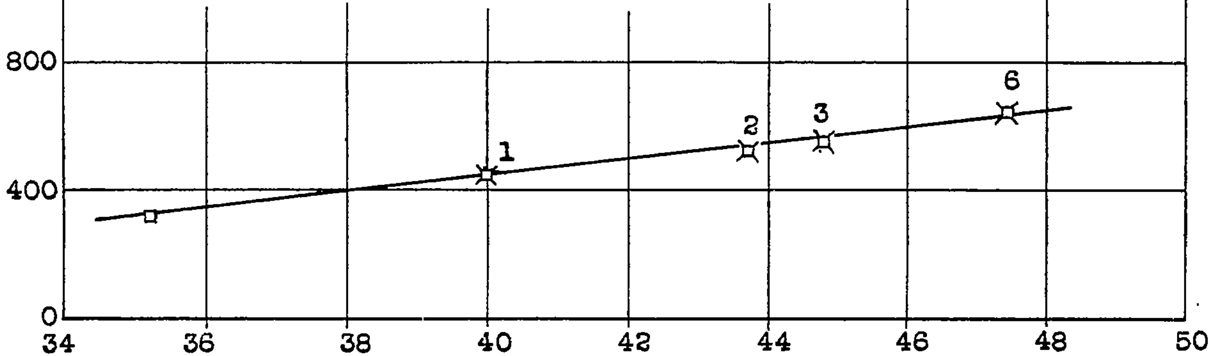


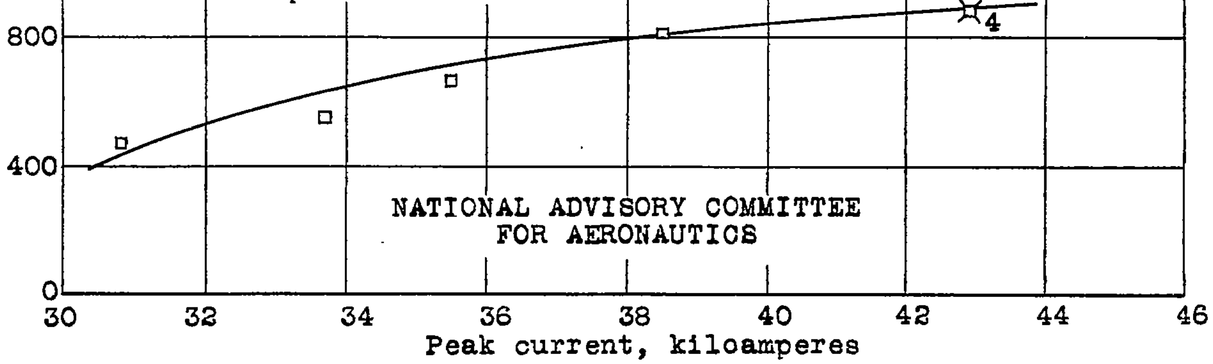
(a) No preheat; welding current, steep wave form.



(b) No preheat; welding current, shallow wave form.



(c) Preheating current, shallow wave form; welding current, steep wave form.



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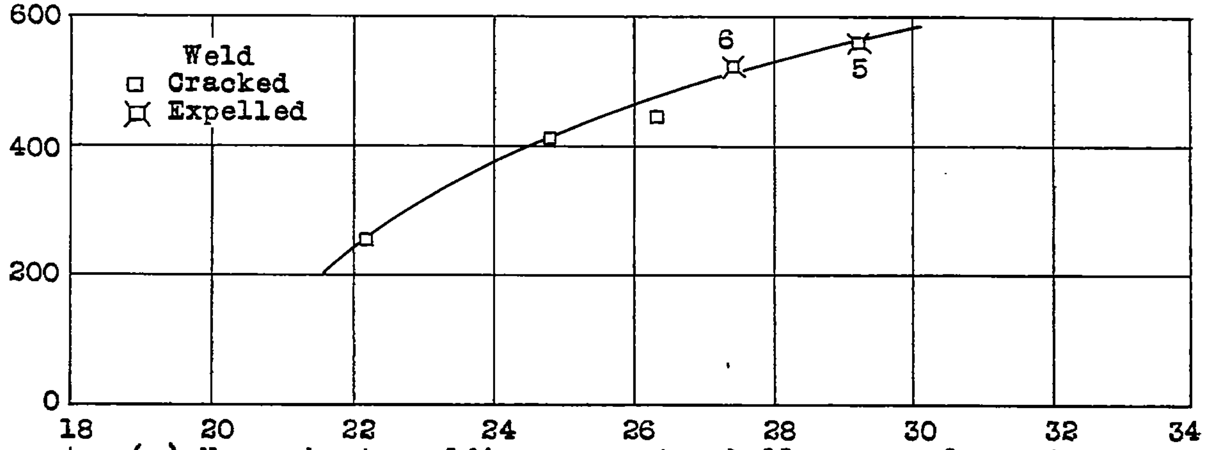
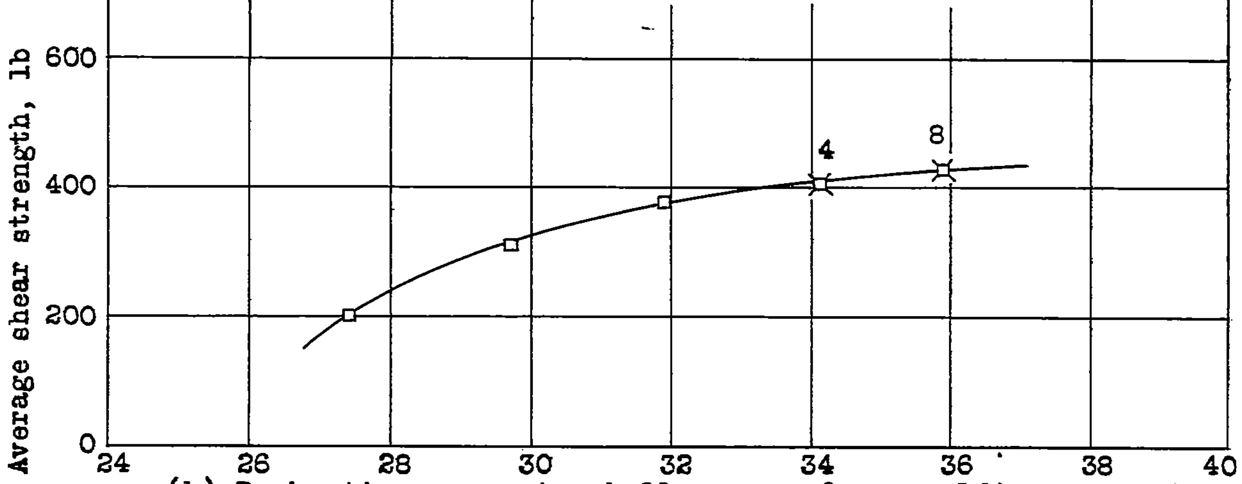
(d) Preheating current, shallow wave form; welding current, shallow wave form.

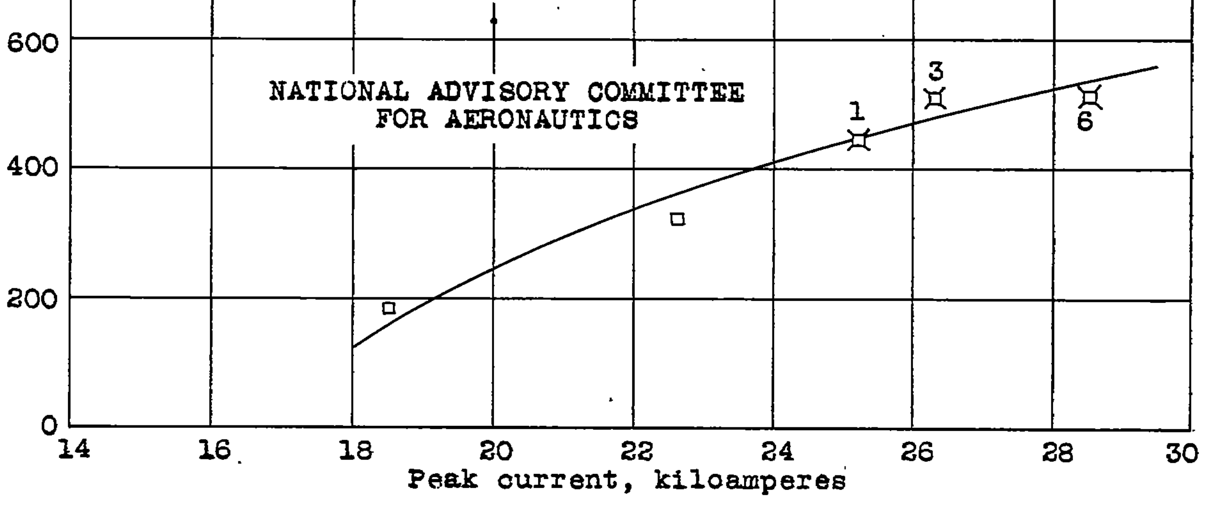
Figure 1.- Strength-current characteristic of Alclad 24S-T. Thickness, 0.040 inch; electrode dome-tip radius, 2-1/2 inches; electrode force, 600 pounds; chemically treated.



(a) No preheat; welding current, shallow wave form.

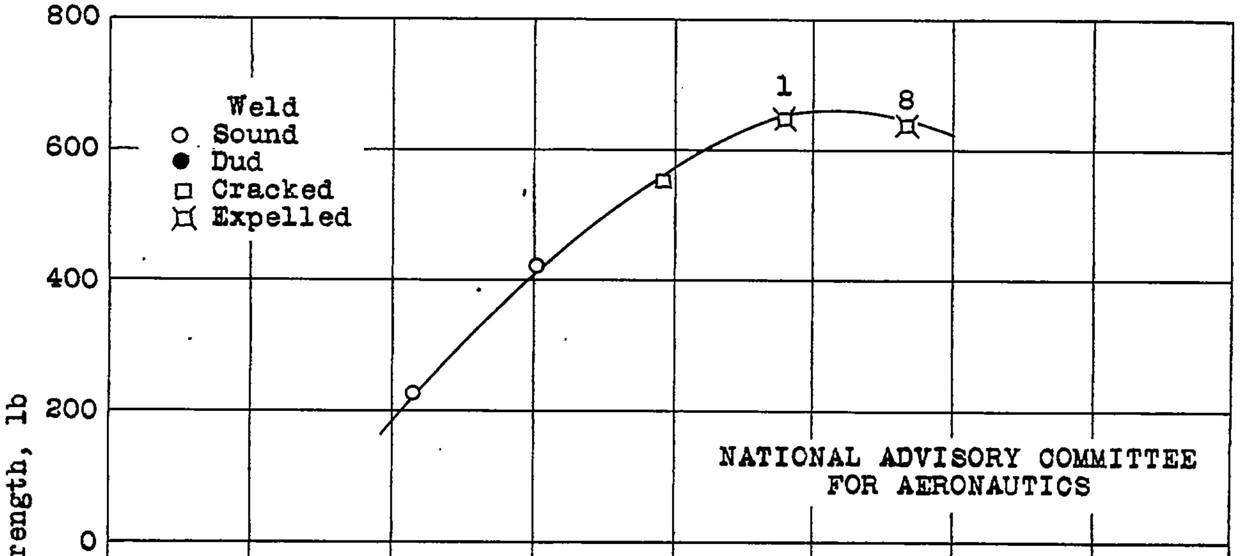


(b) Preheating current, shallow wave form; welding current, steep wave form.

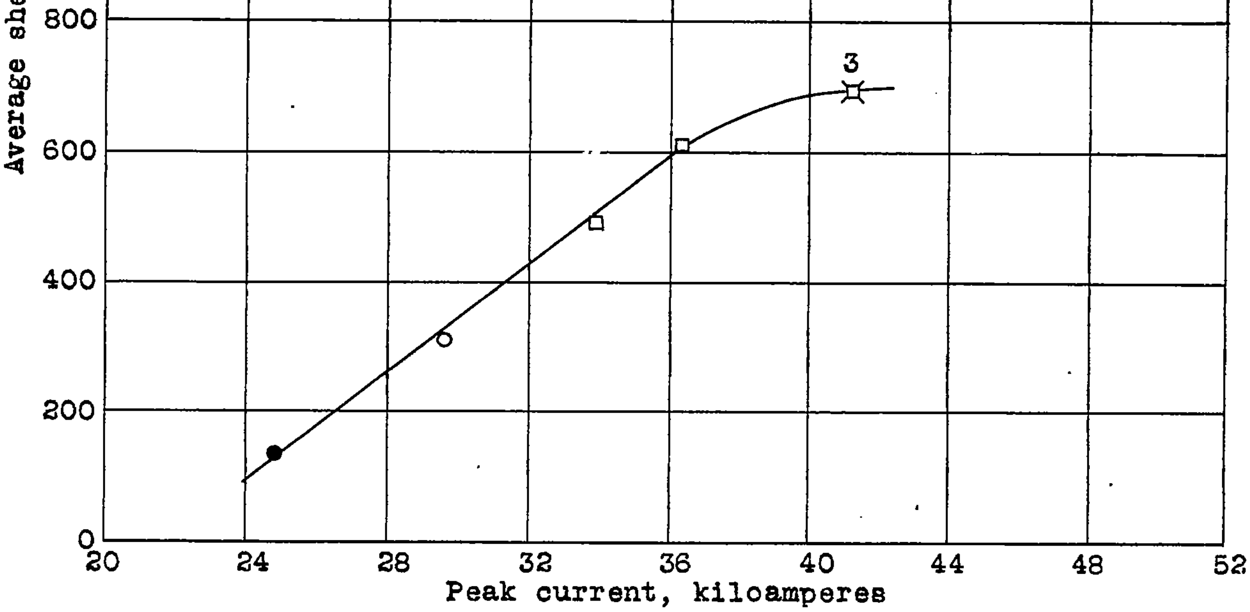


(c) Preheating current, shallow wave form; welding current, shallow wave form.

Figuer 2.- Strength-current characteristic of bare 24S-T. Thickness, 0.040 inch; electrode dome-tip radius, 2-1/2 inches; electrode force, 600 pounds; chemically treated.



(a) No preheat; welding current, shallow wave form.



(b) Preheating current, shallow wave form; welding current, shallow wave form.

Figure 3.- Strength-current characteristic of bare 24S-T. Thickness, 0.040 inch; electrode dome-tip radius, 2-1/2 inches; electrode force, 1200 pounds; chemically treated.

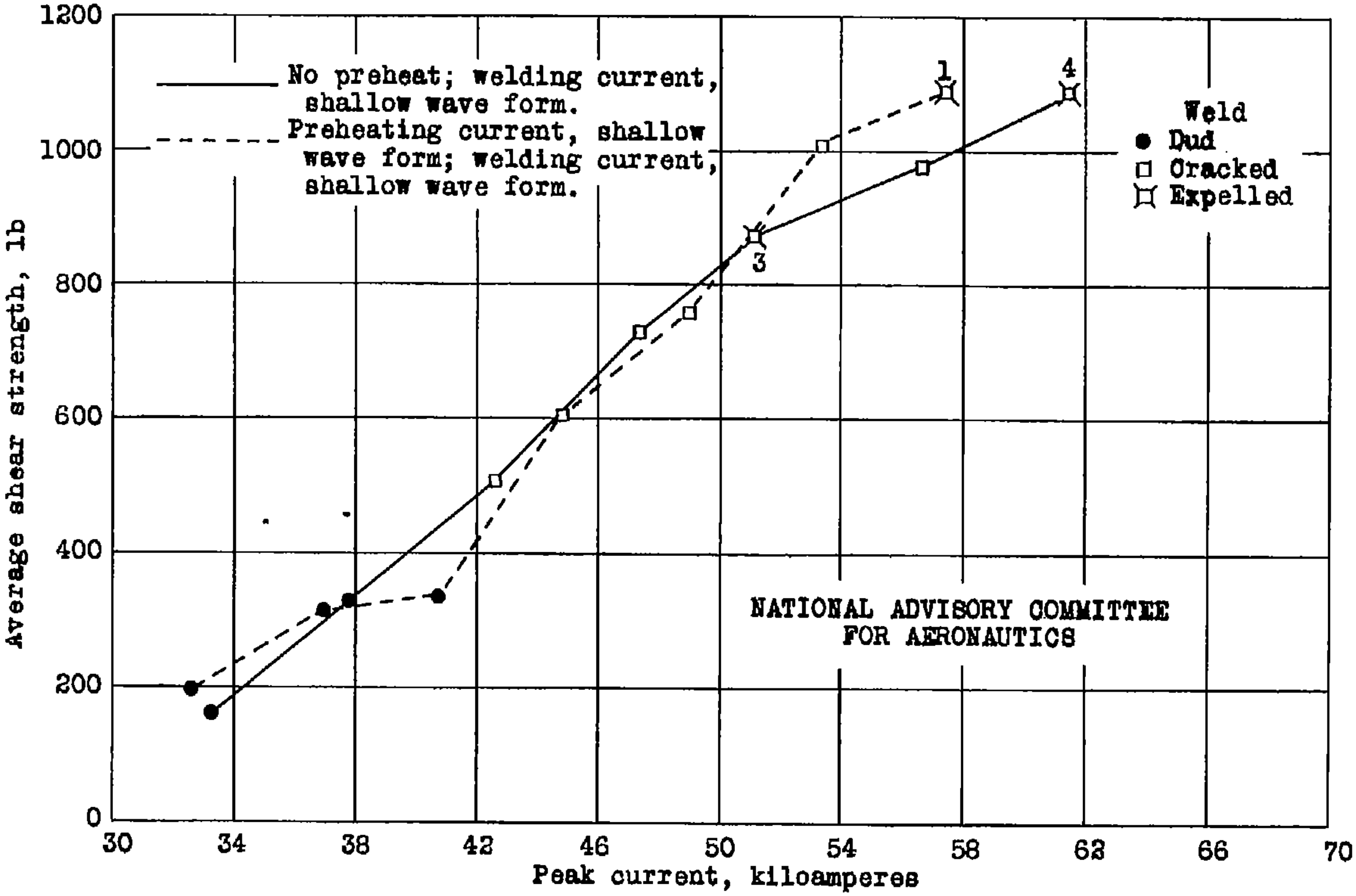
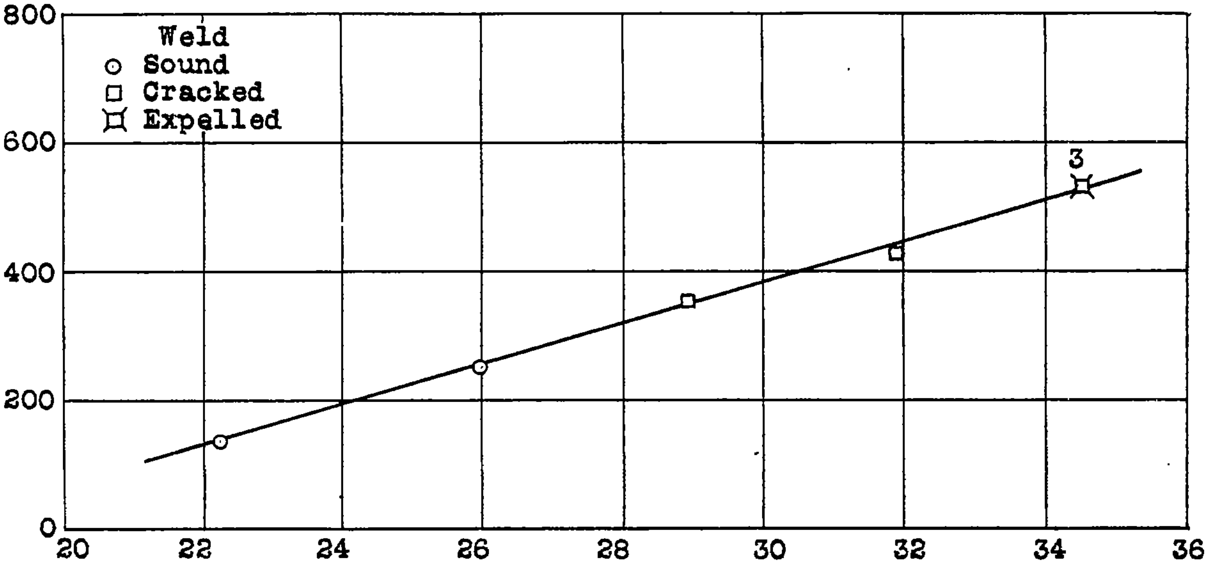
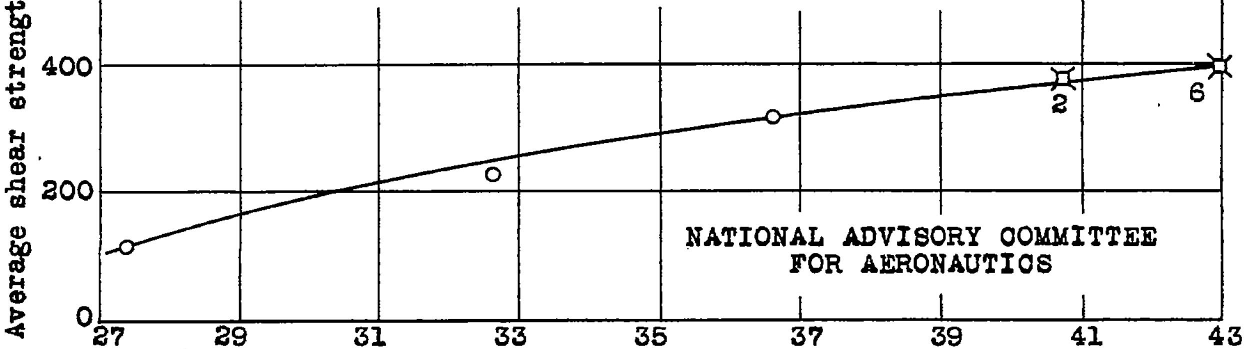


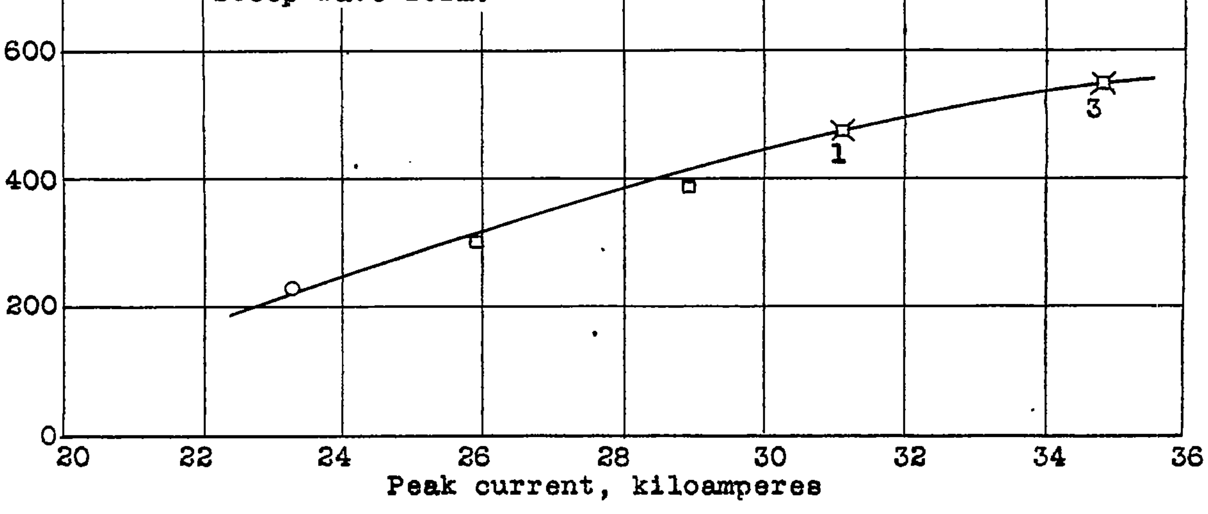
Figure 4.- Strength-current characteristic of bare 24S-T. Thickness, 0.064 inch; electrode dome-tip radius, 4 inches; electrode force, 2000 pounds; chemically treated.



(a) No preheat; welding current, shallow wave form.



(b) Preheating current, shallow wave form; welding current, steep wave form.



(c) Preheating current, shallow wave form; welding current, shallow wave form.

Figure 5.- Strength-current characteristic of 61S-T. Thickness, 0.040 inch; electrode dome-tip radius, 2-1/2 inches; electrode force, 600 pounds; chemically treated.