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WELD-BRAZING - A NEW JOINING PROCESS

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SUMMARY

A joining process designated weld-brazing which combines resistance spot welding and brazing has been developed. Resistance spot welding is used to position and align the parts as well as to establish a suitable faying surface gap for brazing. Fabrication is then completed by capillary flow of the braze alloy into the joint. The process has been used successfully to fabricate Ti-6Al-4V titanium alloy joints using 3003 aluminum braze alloy and should be applicable to other metal-braze systems.

Test results obtained on single overlap and hat-stiffened structural specimens show that weld-brazed joints are superior in tensile shear, stress rupture, fatigue, and buckling than joints fabricated by spotwelding or brazing. Another attractive feature of the process is that the brazed joint is hermetically sealed by the braze material which should eliminate many of the sealing problems encountered in riveted or spotwelded structures. The ease of fabrication associated with the weld-brazing process could well make it cost effective on a production basis compared with more conventional techniques in addition to the improved joint characteristics observed.

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INTRODUCTION

Recent interest has been generated in the combined use of resistance spotwelding and epoxy bonding (weld-bonding) as an effective means of fabricating aerospace structures. In a study sponsored by the Air Force Materials Laboratory (ref. 1), weld-bonding was used to fabricate aluminum alloy structures having mechanical properties vastly superior to similar panels fabricated by conventional methods. The interest in weld-bonding as an effective manufacturing process prompted NASA-Langley to investigate its applicability to some of their current and future programs. A study was undertaken at NASA-Langley to investigate weld-bonding as a potential joining method in the fabrication of titanium structures. However, since titanium structures are considered for use at temperatures which exceed the capability of current epoxy systems, a higher temperature adhesive was desired. The idea of substituting a braze alloy for the adhesive to extend the temperature capabilities was conceived and a program was therefore initiated to evaluate the process designated as WELD-BRAZING. The material used in the study was mill annealed Ti-6Al-4V titanium alloy sheet and the braze alloy was 3003 aluminum. The study consisted of the fabrication of single overlap specimens which were tested at room and elevated temperatures, and the fabrication of hat-stiffened panels which were tested in compression at room temperature.

Weld-brazed joints were examined metallurgically to verify adequate flow of the braze and absence of porosity. This paper reports the results obtained in this study.

PROCESS DEVELOPMENT

In the development of the weld-brazing process, which combined the use of resistance spotwelding and brazing, two primary approaches were investigated. One was designated the prepunched foil approach (figure 1) and the other the capillary flow approach (figure 2). Both of these approaches were developed together and both proved to be successful joining methods.

In the prepunched foil approach, the foil was punched (see Figure 1) so that the diameter of the holes was larger than the diameter of the intended spotweld nugget. This was done in order to prevent excessive reaction of the parent material with the braze alloy in the vicinity of the spotweld. Single overlap specimens fabricated in this manner showed that expansion of the weld nugget caused the faying surface gap to be approximately 0.002-inch greater than the thickness of the braze foils being used. It was therefore necessary that the width of the braze foil be greater than the overlap in order to have a sufficient volume of braze alloy to adequately fill the gap resulting from welding. Specimens were heated to 1250°F in vacuum to accomplish the brazing cycle.

In the capillary flow approach (see figure 2) the titanium strips are first chemically cleaned and then joined by conventional spot-welding techniques. Nugget expansion during welding produced a faying surface gap which could be varied from 0.002-inch to 0.006-inch by varying the welding parameters. Following welding, the braze foil was positioned at the edge of the overlap and the assembly was heated to the brazing temperature of 1250°F in vacuum as in the prepunched approach. Upon melting the braze alloy was drawn into the gap by capillary action. Ultrasonic and metallographic inspection of the joint indicated that the gap was filled completely.

Both approaches produced satisfactory joints that were hermetically sealed. In the prepunched foil approach, the positioning of the punched foil and the welding electrodes, without the aid of precise positioning equipment made the process somewhat difficult for application to the fabrication of structural parts. However, there could be certain applications where the braze would not flow into the faying surface gap and the prepunched foil approach would be the better joining method. Weld-brazed joints were fabricated with relative ease by the capillary flow approach, and it was for this reason that this approach was used to fabricate the test specimens used in the test program.

SPECIMENS AND TEST PROCEDURES

The weld-brazing process, using the capillary flow approach, was used to fabricate single overlap specimens and hat-stiffened panels. These specimens were then tested to evaluate the mechanical properties of weld-brazed joints. The parent material used was annealed 0.050-inch thick Ti-6Al-4V titanium alloy and the braze alloy employed throughout the study was 0.004-inch thick 3003 aluminum alloy. The Ti-6Al-4V parts were thoroughly cleaned before weld-brazing as outlined in reference 2.

Specimens

Single overlap specimens. - The configurations of the single overlap specimens are shown on figure 3. Specimens were fabricated by spotwelding, brazing, and weld-brazing. The overlap on all specimens was approximately 3/8-inch and was selected to insure determination of joint characteristics. The specimen on the right of the figure was used for determining the tensile shear and stress rupture properties of the joints. End tabs were spotwelded to the specimens to prevent end failure during testing. The longer specimen shown in the figure was used for determining the fatigue properties of the joints. The weld spacing on the spotwelded only and weld-brazed specimens was 1 inch. All brazing operations were accomplished in a vacuum furnace at a temperature of 1250°F and a pressure of 10^{-5} torr for 10 minutes

Hat-stiffened panels. - The panel configuration used in the program is shown on figure 4. Panels having a maximum width to thickness ratio of 25 were fabricated by brazing only, riveting only, spotwelding only, and weld brazing. The panels fabricated by brazing only were first spotwelded at the ends and in the center to eliminate fixturing. The riveted panels were fabricated using 0.16-inch diameter flush-head stainless steel rivets and a rivet spacing of 1/2-inch. For comparative purposes, the spacing of the spotwelds in the spotwelded only and weld-brazed panels were also 1/2-inch. The weld-brazed and brazed only panels were fabricated using the same brazing parameters as for the single overlap specimens.

The need for spotwelding the brazed panels, as mentioned above, resulted from difficulties associated with attempts to fabricate specimens by brazing alone. Attempts to maintain alinement of the hat stringer on the face sheet and to establish the optimum gap for brazing were found to be very difficult unless elaborate fixtures were used. A slight twist in the stiffener during fabrication resulted in braze thicknesses ranging from 0.003 to 0.020-inch. Therefore, to eliminate the need for fixturing, the brazed only panels were fabricated by spotwelding the stiffener to the face sheet at each end and in the center. The braze alloy was then placed along the edge of the overlap and fabrication was completed in the same manner as the weld-brazed panels. Thus, the brazed only panels were actually fabricated by weld-brazing using widely spaced spotwelds.

Test Procedures

<u>Tensile shear test</u>. - The tensile shear tests of single overlap specimens were conducted at ambient temperature, 350°F and 550°F at a constant load rate of 2000 lb/min using a 100 kip capacity hydraulic testing machine. Heating of the specimens tested at elevated temperature was accomplished using a resistance-wound furnace mounted in the testing machine.

<u>Stress-rupture tests</u>. - Stress rupture tests were conducted using single overlap specimens. The specimens were loaded in conventional creep testing machines, equipped with tube furnaces, to various percentages of

the elevated temperature static tensile shear strength. The loading was applied shortly after reaching test temperature and the times to rupture were obtained from digital elapsed-test-time indicators that stopped automatically when the specimens ruptured.

Fatigue tests. - Constant-amplitude fatigue tests (R=0.05) were conducted in subresonant-type axial load fatigue machines (reference 3). Load was sensed by a weigh-bar in series with the specimen and grips. A wire strain-gage bridge cemented to the weigh-bar supplied a load signal to an oscilloscope which was used to monitor cyclic loading. Operating frequency was 1800 cycles per minute.

Panel tests. - the hat-stiffened structural panels were tested in compression using a 300-kip-capacity hydraulic testing machine. The edges of the specimens were supported with knife edges positioned 1/4 of an inch from the edge. Foil strain gages were attached at the centers of the stiffener and face sheet and were used to measure local strains. Relative motion between the upper and lower heads of the testing machine was measured using linear variable differential transformers. Data were recorded every 10 seconds to local instability and at an increased rate of every second from local instability to maximum load. All tests were conducted at a load rate of 12,000 lbs/min.

RESULTS AND DISCUSSION

Single Overlap Specimens

Tensile-shear. - The tensile shear results obtained at room temperature, 350°F and 550°F are presented on figure 5 for specimens fabricated by spotwelding, brazing, and weld-brazing where maximum load is plotted against test temperature. The data points are the average of 6 tests with the data spread indicated. The tensile shear properties of the weld-brazed specimens are shown to be greater than those of the brazed or spotwelded specimens and are approximately equal to the sum of the values shown for the spotwelded and brazed specimens. The strength of the weld-brazed specimens apparently decrease linearly with increasing temperature, and at 550°F the specimens were capable of carrying a load which was 85 percent of the value obtained at room temperature. The strength of the brazed specimens decreases in a similar fashion, and the spread in the data indicates that the brazing process was much more difficult to control. At a temperature of 550°F, the average strength of the brazed specimens was equal to approximately 80 percent of the room temperature strength. Although both the weld-brazed and brazed specimens experienced a decrease in strength at 550°F, the decrease compared to room temperature strength was proportionally less for the weld-brazed specimens. The differences in the percentages noted for the weld-brazed specimens might be attributed to the fact that the strength of the spotwelds were not temperature dependent.

Stress-rupture. - The stress-rupture properties at 350°F and 550°F for single overlap specimens fabricated by spotwelding, brazing, and weld-brazing are shown on figure 6. At 550°F for a 500-hour life, the weld-brazed specimens appear capable of carrying more than twice as much load as the brazed specimens and approximately 15 percent more load than the spotwelded specimens. Although both the weld-brazed and brazed specimens exhibited substantial decreases in load carrying ability at 550°F compared to 350°F, the decrease noted for the weld-brazed specimens was proportinally less, probably because of the contribution from the spotwelds. Based on these results and those obtained from the tensile shear test, it would seem possible to tailor the elevated temperature properties of a weld-brazed joint by varying the number of spotwelds present. Although the strength contribution of the braze decreases with increasing temperature, it should be sufficient to redistribute the stress in the joint so that the stresses in the spotwelds are reduced.

Fatigue. - The room temperature fatigue data obtained from the single overlap specimens are shown on figure 7. Note that the fatigue strengths of the brazed and weld-brazed specimens are approximately equal and that the strengths are approximately three times as great as the strength of the spotwelded specimens for a life of 200,000 cycles. Failure of the brazed and weld-brazed specimens occurred in the joint for stress levels resulting in failure in less than about 50,000 cycles while failure of the gross section occurred for the specimens having a fatigue life greater than about 50,000 cycles. The reason for the change in failure mode was attributed to specimen configuration.

Hat-Stiffened Panels

The hat-stiffened panels fabricated by the various methods were tested in compression, and the results obtained are presented on figure 8. Data are shown for three panels tested for each joining process. The load carrying ability of the brazed and weld-brazed panels are shown to be similar and substantially greater than that of the panels fabricated by spotwelding or riveting. The maximum load of the weld-brazed panels was approximately 59 kips compared to 38 kips for the riveted panel or an increase in load carrying capability of 55 percent. A similar increase was also noted for the loads at which face sheet wrinkling or buckling occurred for the weld-brazed panels compared to the riveted specimens. The increase in load carrying ability of the weld-brazed and brazed panels is attributed to an increased panel stiffeness resulting from the continuous bond between the stiffener and face sheet as compared to the point attachment inherent with spotwelded and riveted specimens. However, since the specimens were of the same configuration, a structure fabricated by weld-brazing should provide a reasonable weight savings for buckling design considerations.

Metallographic Investigation

Metallographic specimens were prepared using conventional polishing and etching techniques. Typical cross-sections of a weld-brazed joint taken from a compression panel are shown on figure 9. The upper portion of the figure depicts the joint and provides evidence that the faying surface gap is adequately filled by brazing. The braze alloy which was placed adjacent to the flange of the stiffener is shown to have penetrated completely through the joint to form a generous fillet between the inner surface of the stiffener and the face sheet.

The photomicrograph on the lower portion of figure 9 provides further verification of adequate braze penetration, at least to the weld nugget. A good metallurgical bond is shown to exist between the braze and all adjoining titanium surfaces although there is some evidence of the formation of titanium aluminide. However, the formation of the intermetallic to the extent shown was not detrimental to the properties studied.

CONCLUDING REMARKS

The results obtained indicate that weld-brazing is a fabrication process capable of producing joints having superior ambient and elevated temperature properties compared to similar joints produced by brazing only or spotwelding only. Tailoring of the properties may also be possible by varying the extent of the overlap and the number of spotwelds. Weld-brazing may also eliminate many of the sealing problems encountered in spotwelded and riveted structures because the process results in a hermetically sealed joint. The ease of fabrication associated with the weld-brazing process could well make it cost effective on a production basis compared with more conventional techniques in addition to the improved joint characteristics observed. Although the process has only been used to join Ti-6Al-4V titanium alloy 3003 aluminum braze, weld-brazing should also be adaptable to any material system where both brazing and spotwelding techniques are viable methods for joining. Candidate systems include nickel-base superalloy and refractory metal structures as well as the fabrication of structures using more conventional material such as mild steel.

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3. Grover, H. J.; Hyler, W. S.; Kuhn, Paul; Landers, Charles B.; and Howell, F. M.: Axial-Load Fatigue Properties of 245-T and 755-T Aluminum Alloy as Determined in Several Laboratories. NACA Report 1190, 1954. (Supersedes NACA TN 2928.)

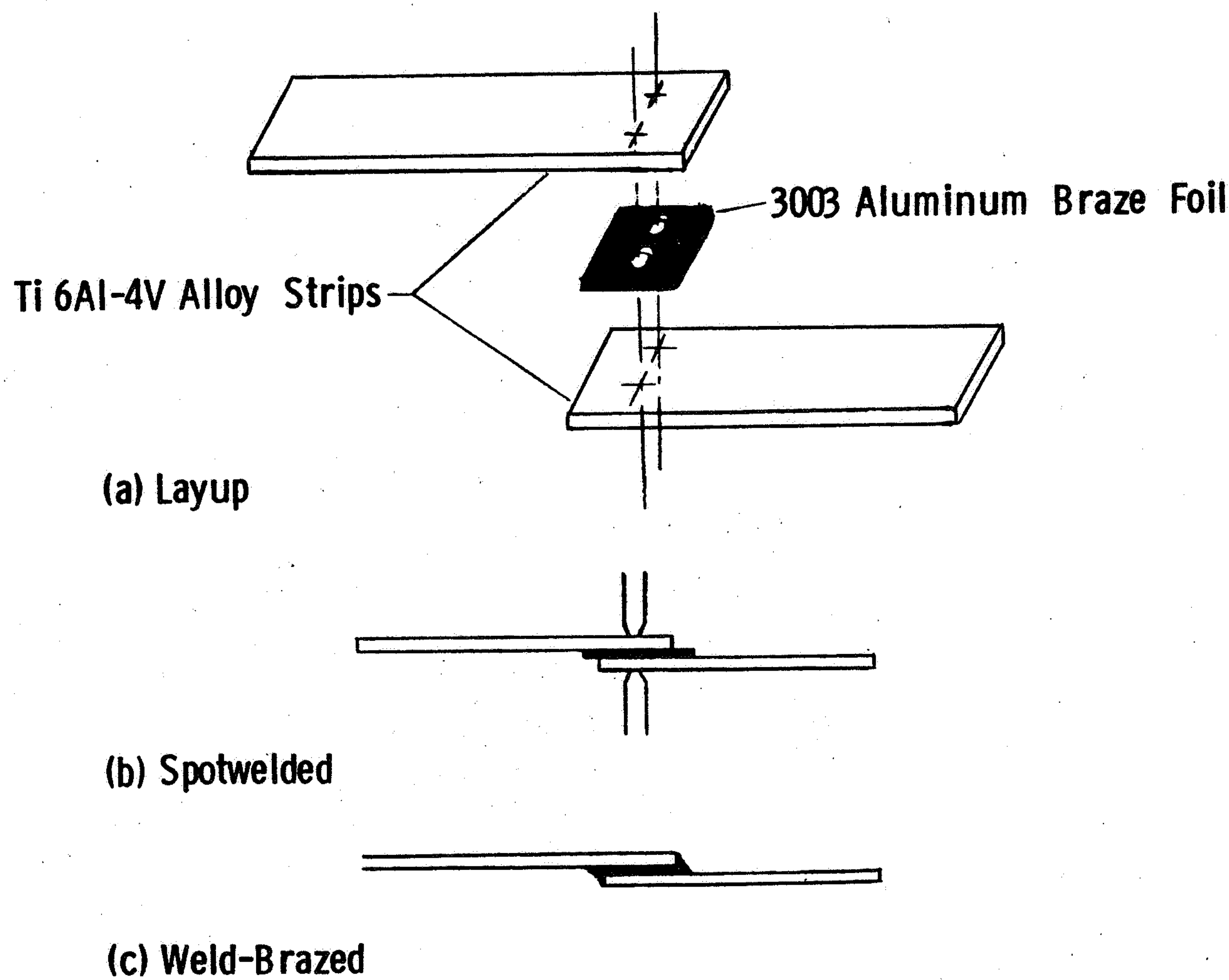


FIGURE 1. WELD-BRAZING WITH PRE-PUNCHED FOIL.

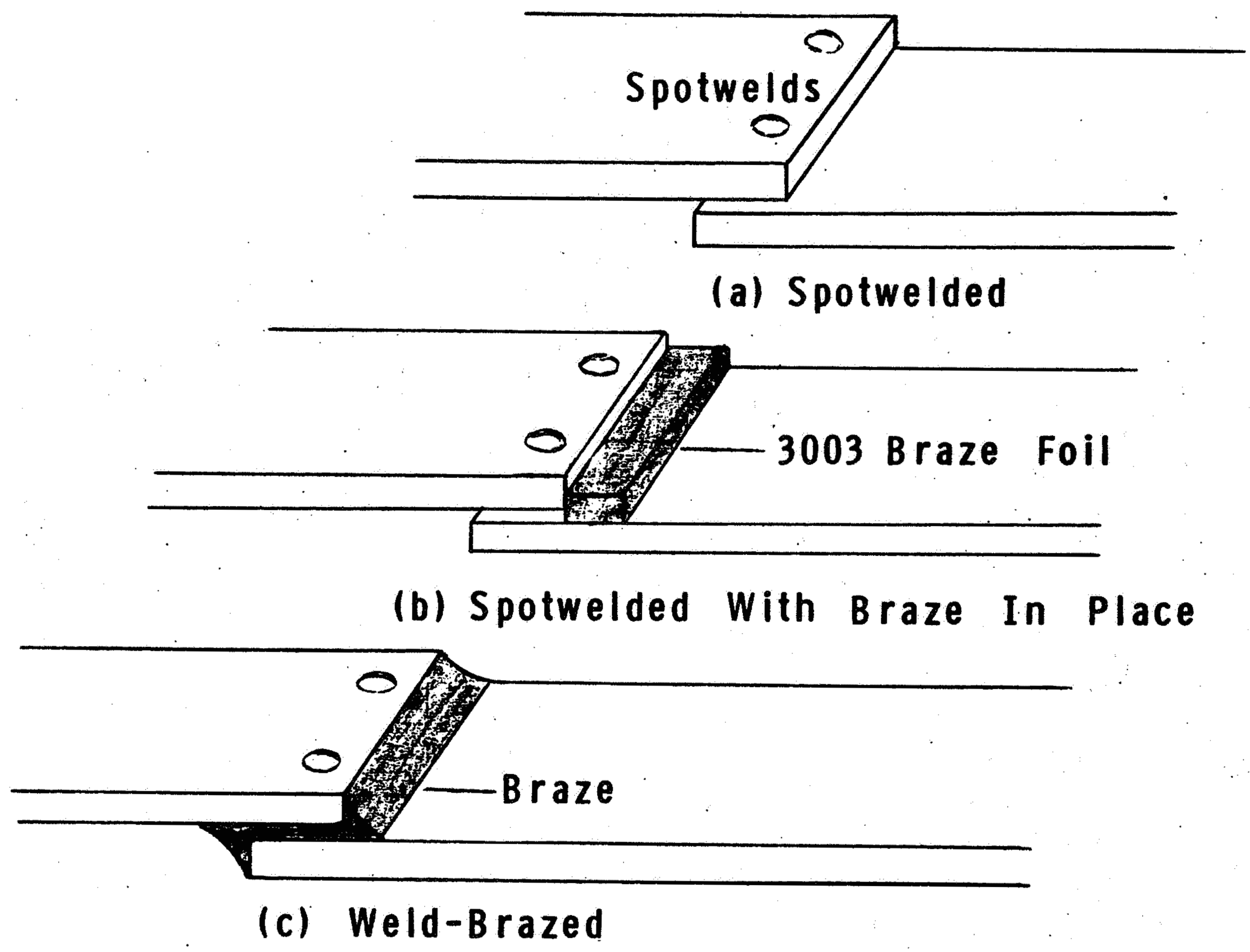


FIGURE 2. - WELD-BRAZING WITH CAPILLARY FLOW.

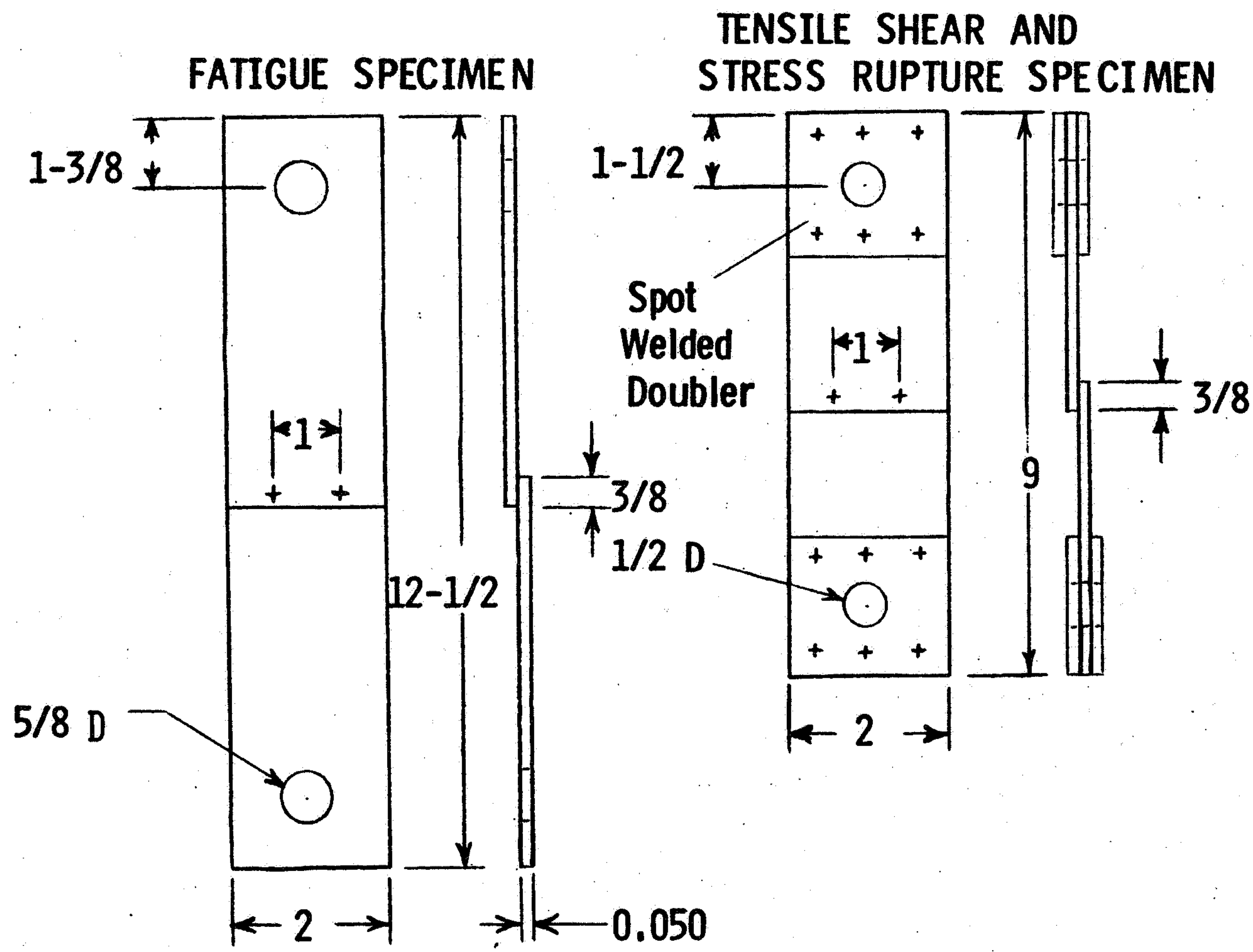


FIGURE 3. - SINGLE-OVERLAP TEST SPECIMENS; DIMENSIONS IN INCHES.

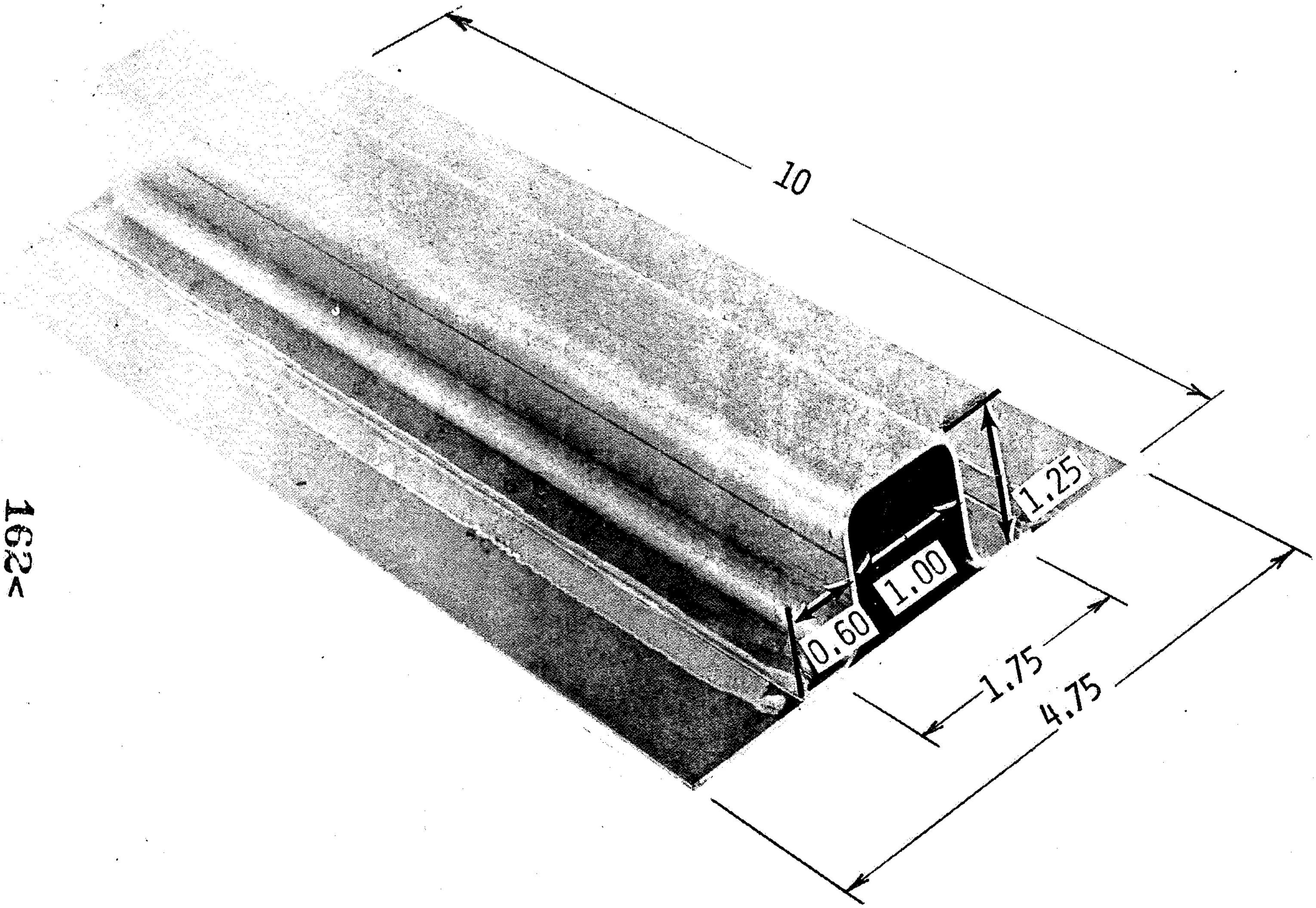


FIGURE 4. - HAT-STIFFENED COMPRESSION PANEL; DIMENSIONS IN INCHES.

163<

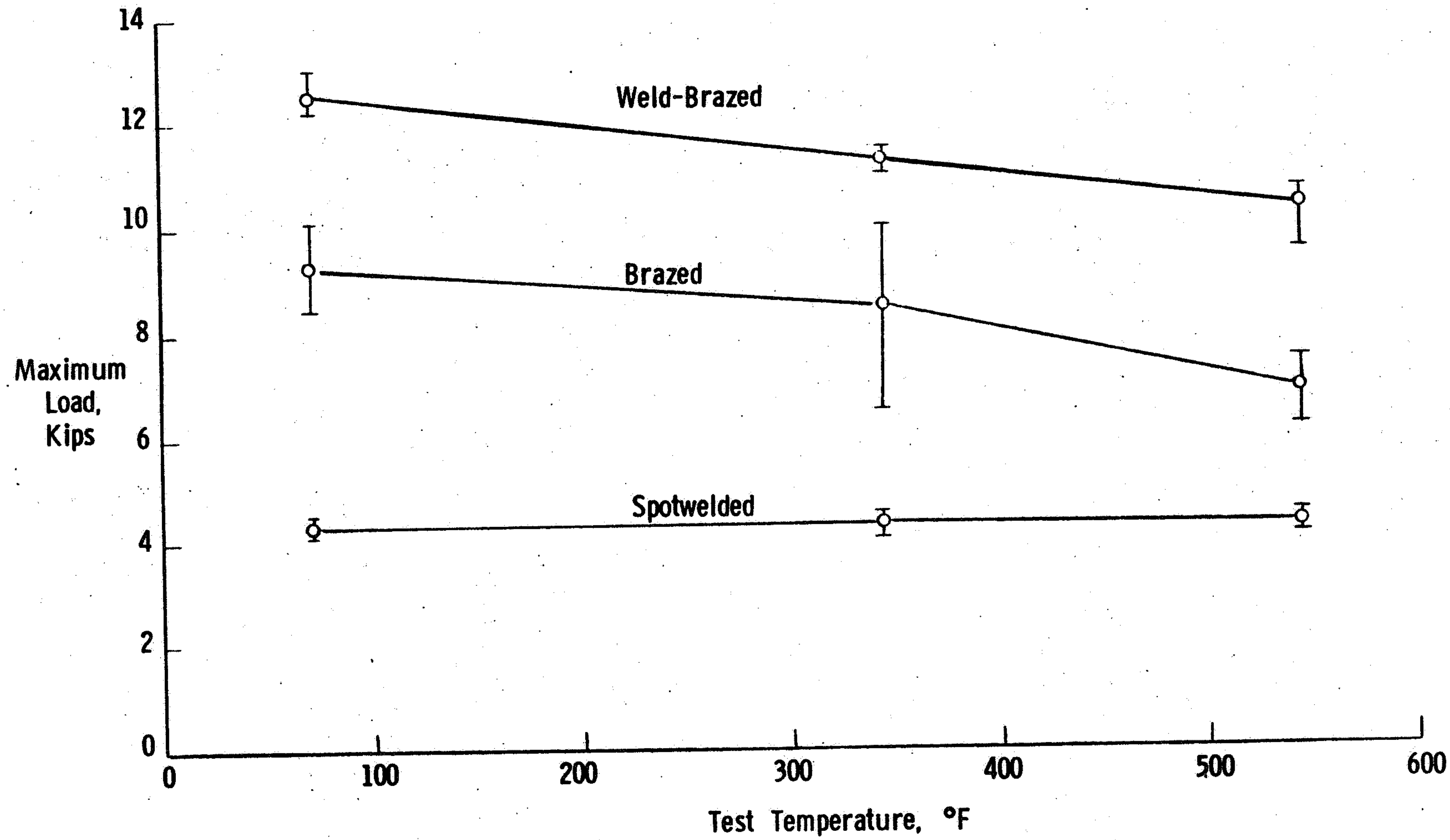


FIGURE 5. - SINGLE-OVERLAP TENSILE-SHEAR DATA.

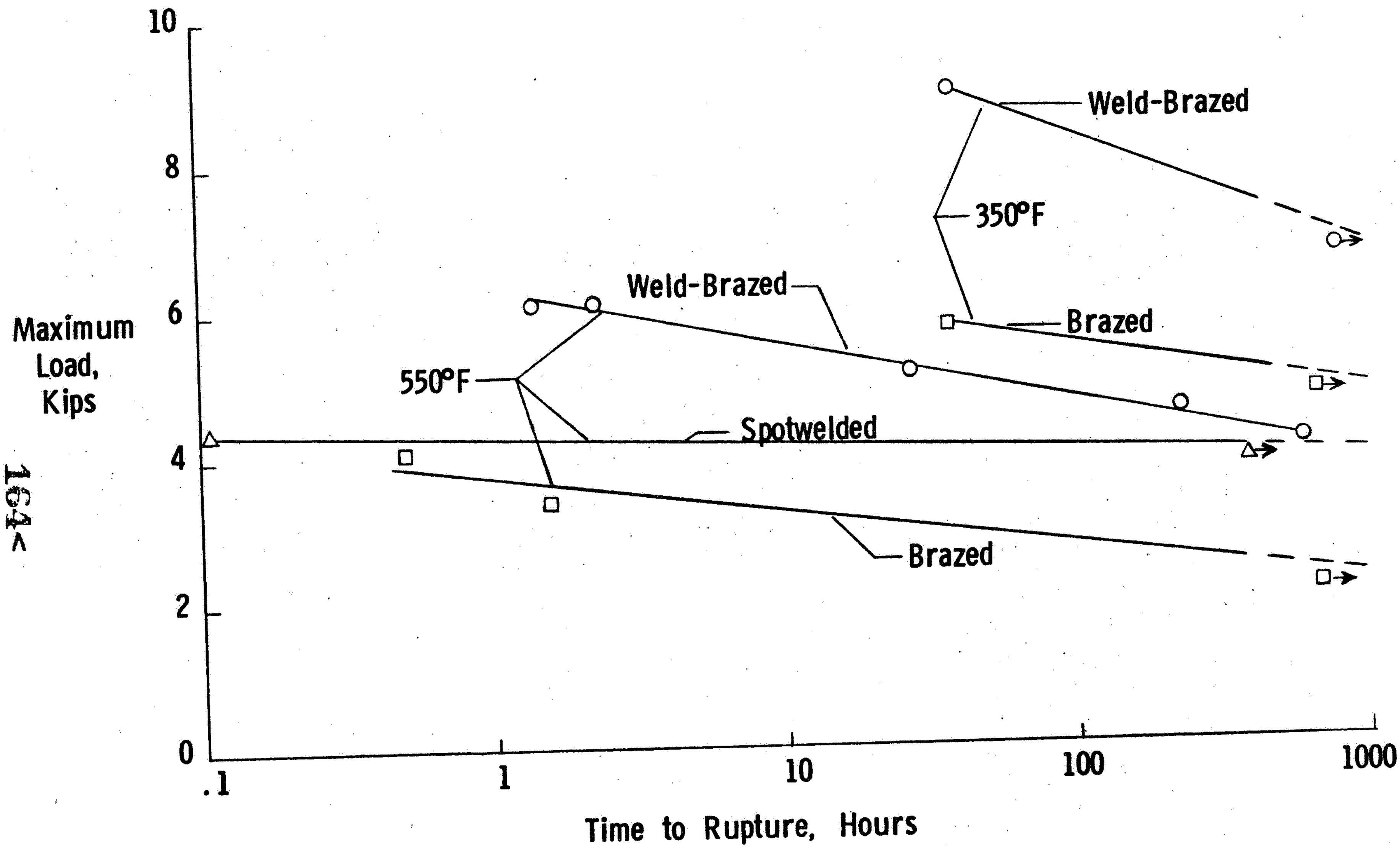


FIGURE 6. - TIME TO STRESS RUPTURE OF SINGLE-OVERLAP SPECIMENS.

164<

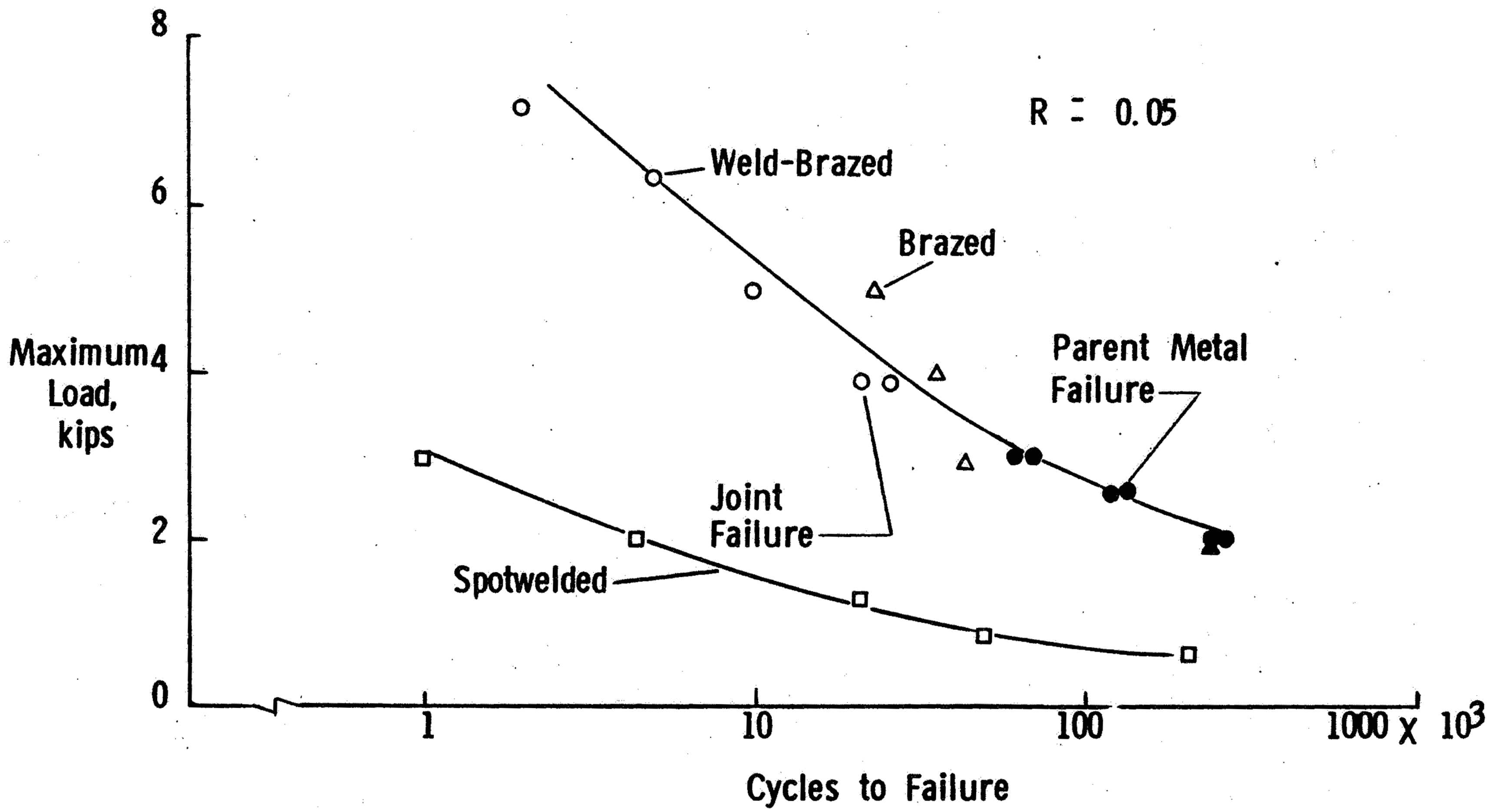


FIGURE 7. - RESULTS OF FATIGUE TESTS ON SINGLE-OVERLAP SPECIMENS.

165<

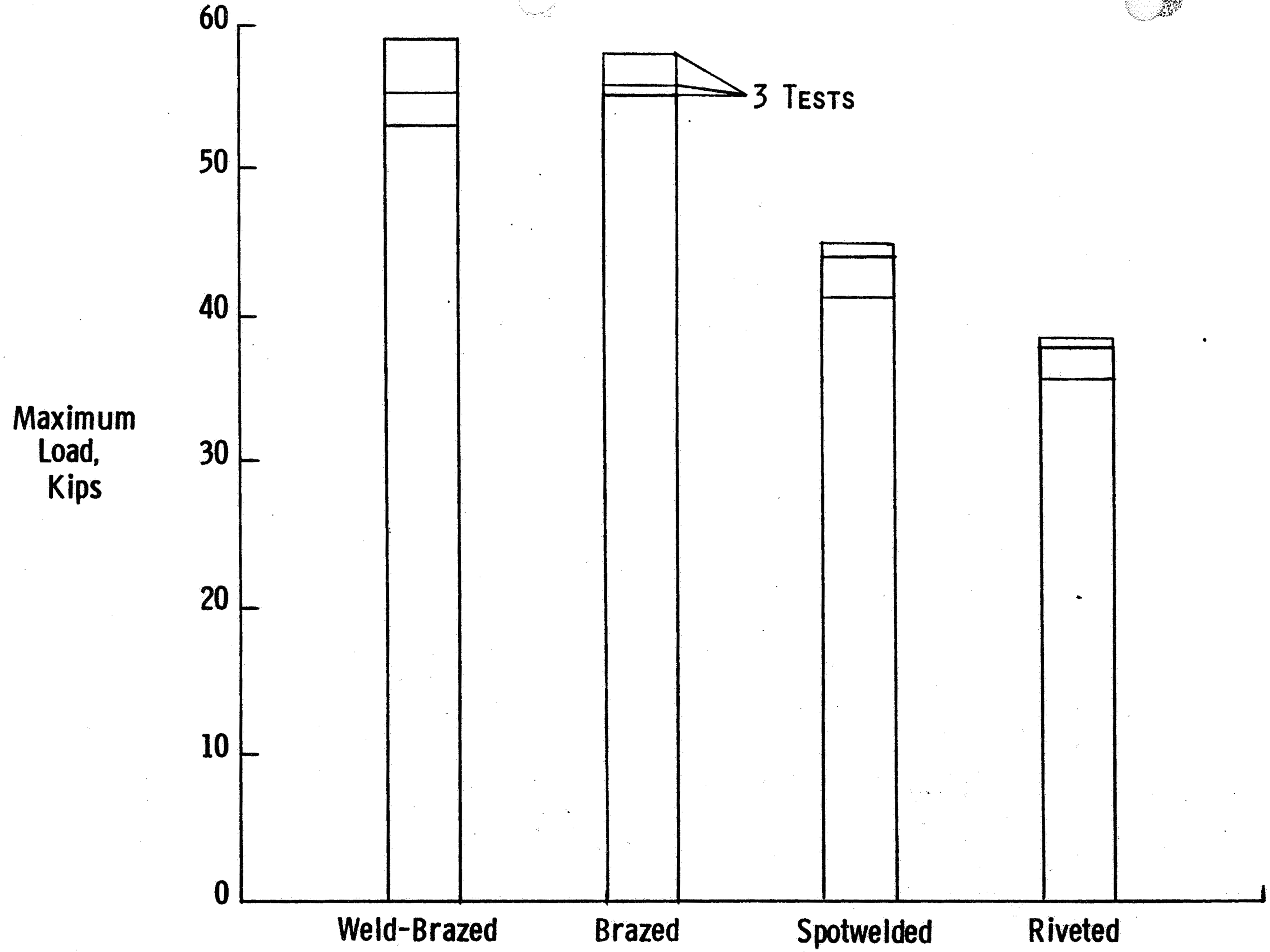
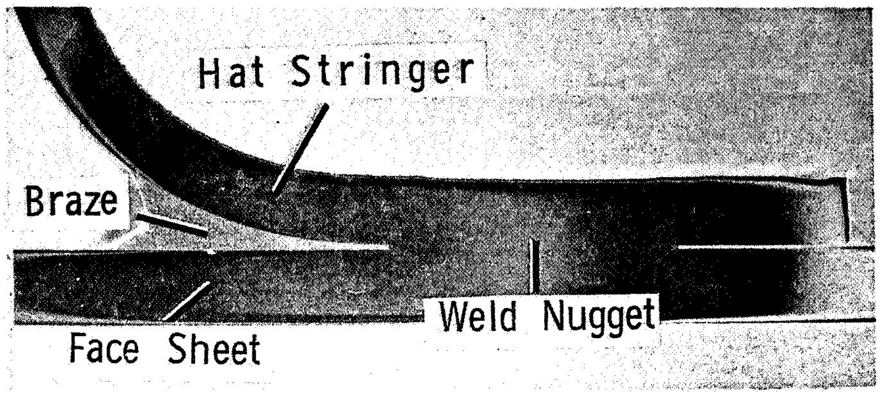
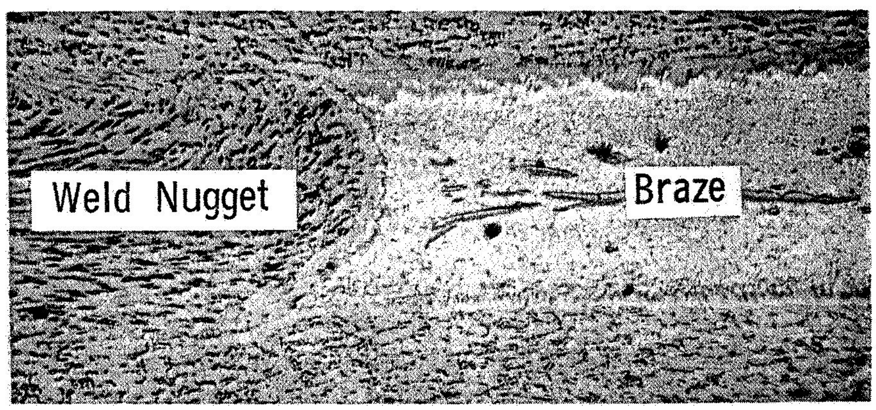


Figure 8. - Maximum load to failure for compression panel tests.



(A) WELD-BRAZED JOINT (10X)



(B) WELD NUGGET-BRAZE INTERFACE (400X)

FIGURE 9. - CROSS-SECTIONS OF A WELD-BRAZED JOINT

NASA-Langley, 1972