

Feasibility of Brazing and Welding Aluminum-Graphite Composites

Successful results have been achieved with furnace brazing, using Al-Si-Mg brazing alloys

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ABSTRACT. Furnace brazing, resistance spot welding, and gas tungsten-arc (GTA) welding all appear to have potential as joining processes for aluminum-graphite composites. The most success has been achieved with furnace brazing. An important development in this process was the discovery that aluminum-silicon-magnesium brazing alloys would bond to the composites. Spot welding produced bonding between composites and between a composite and a commercial aluminum alloy sheet. However, metal expulsion and composite crushing were common and much work is needed to prevent these defects. GTA welding requires an automated process and close control over welding temperatures.

Introduction

Recent design trends indicate that increasing use will be made of composite materials in future structural applications. The high stiffness-to-weight ratio of composites makes them attractive as primary members and stiffening supports in weight-critical air frame and aerospace structures.

Metal-matrix composites possess the further advantage of withstanding higher service temperatures than composites with epoxy or phenolic matrices. To use metal-matrix composites effectively, a method must be devised to join these materials to other similar composites and to standard structural metals and alloys in such a way that the elevated temperature capabilities

of the materials are not impaired. Logical choices for joining processes include brazing and welding.

Aluminum-graphite composites, consisting of high strength, high modulus graphite fibers in an aluminum or aluminum alloy matrix, have been successfully produced by the infiltration of graphite yarn with molten aluminum.^{1,2} These composites present a joining problem because any machined surface of the composite will contain exposed graphite fibers. Since molten aluminum (such as would be present in a joint being welded or brazed) does not normally wet graphite, modifications of existing joining techniques may be necessary in order for a sound, strong joint to be made.

Conversely, the aluminum matrix is in the as-cast condition, so heating or melting of the matrix during joining should not be detrimental to the mechanical properties of the composite. This increases the temperature range allowable for joining processes such as brazing and thereby increases flexibility in selecting a suitable joining method.

Some initial results of welding and brazing studies involving aluminum-graphite composites are presented. Our studies to date have been directed only toward estimating the feasibility of several joining processes; thus, no quantitative data are presented. However, the qualitative results obtained may be used as a guideline in selecting promising processes for further investigation. An outline of suggested future work is presented.

Experimental Procedure

Three types of joining processes were studied in this investigation.

Furnace Brazing

Aluminum-graphite composites with matrices of both pure aluminum and Al-7% Zn were brazed to sheets of 6061 alloy. Composites with pure aluminum matrices were also brazed to each other. Brazing was performed in a flowing argon atmosphere without the use of flux. Filler metal was preplaced and the effects of temperature, time and filler metal composition on joint quality were noted.

Resistance Spot Welding

Aluminum-graphite composites were spot welded to each other and to sheets of 2219 alloy. The major variables were electrode force and welding current.

Gas Tungsten-Arc Welding

The feasibility of welding aluminum-graphite composites by the gas tungsten-arc (GTA) process was investigated. A hand held torch deposited 4043 aluminum filler alloy on a composite with a matrix of Al-7% Zn. A butt weld between this composite and 6061 alloy sheet was also attempted with a 4043 filler alloy.

In all of the experiments, the composite samples measured approximately 0.75 by 0.25 by 0.050 in. The unavailability of appreciable quantities of larger size material precluded a comprehensive tensile testing program.

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Results and Discussion

Furnace Brazing

Preliminary experiments were conducted in a reduced pressure argon atmosphere to determine the tendency for commercial 718 braze alloy foil (Al-12% Si) to wet and flow on

machined surfaces of aluminum-graphite composites with matrices of pure aluminum, Al-7% Zn, and Al-13% Si. In the absence of flux, the braze alloy did not wet or bond to the composites; in fact, the foil did not visibly change shape as the result of melting. In the presence of flux (Al-

coa 34), the melted braze alloy tended to form small spheres that were loosely bonded to the composite. This indicated that the flux acted to break down oxide films on the foil and the composites and that, even without oxide, the braze alloy showed little tendency to wet the composite. The lack

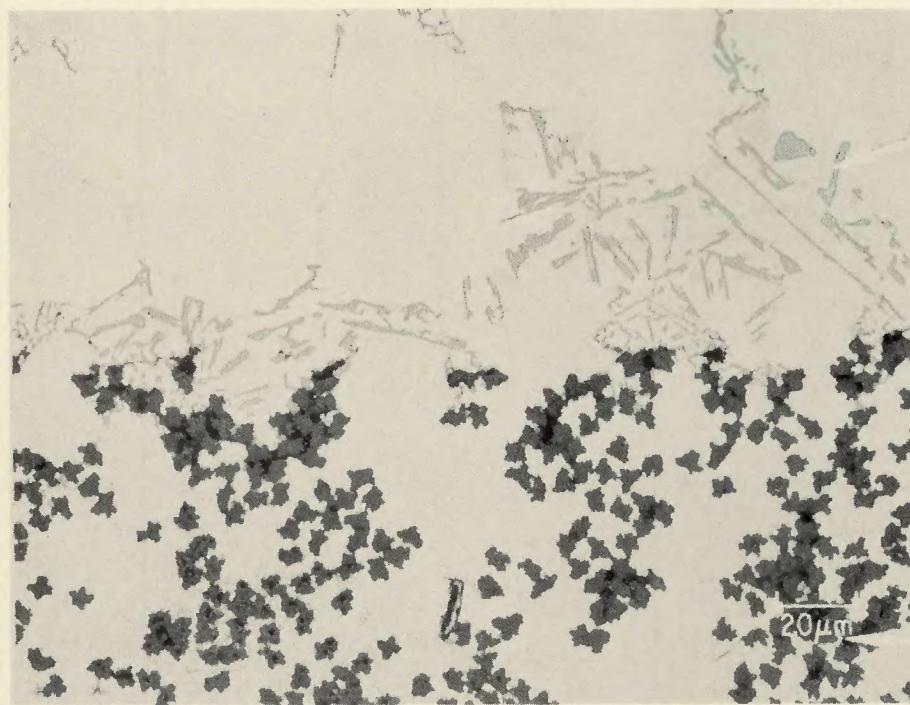


Fig. 1—Furnace brazed joint between 6061 sheet and aluminum-graphite composite. (Composite matrix is Al-7% Zn, braze alloy is 718 and braze temperature is 590C.) Mag: 500X

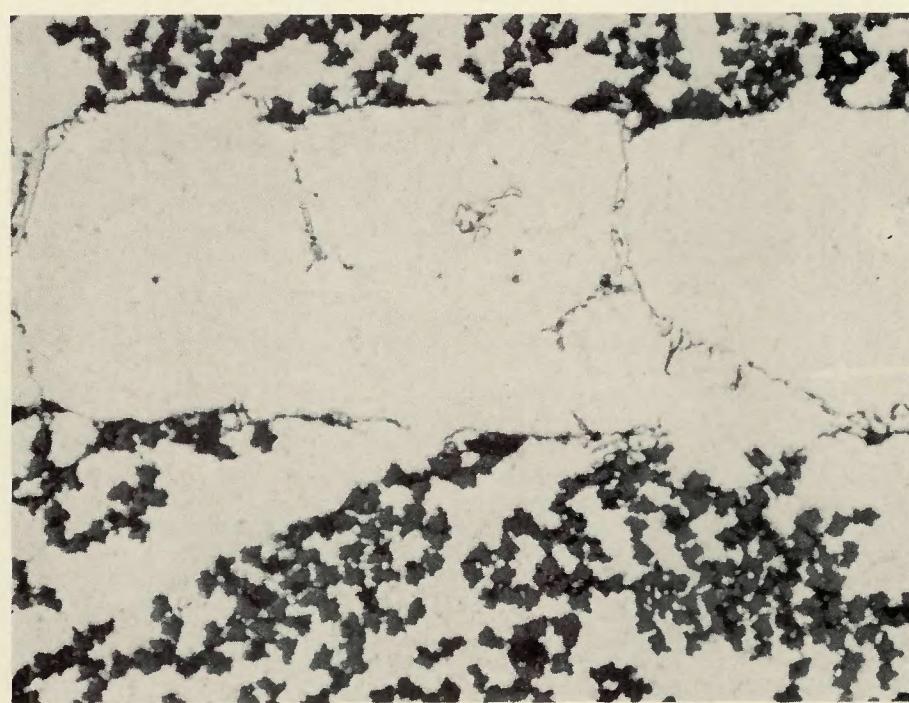


Fig. 2.—Furnace brazed joint between two aluminum-graphite composites. (Composite matrices are pure aluminum, braze alloy is a mixture of 718 and 6061 foils and braze temperature is 590C.) Mag: 500X

} 6061 SHEET
INTERMETALLIC
PARTICLES (GRAY)
BRAZE ALLOY
ORIGINAL
BOND LINE
COMPOSITE
GRAPHITE
FIBERS (DARK)

} COMPOSITE
BRAZE ALLOY
INTERMETALLIC
PARTICLES (GRAY)
COMPOSITE
GRAPHITE
FIBERS (DARK)

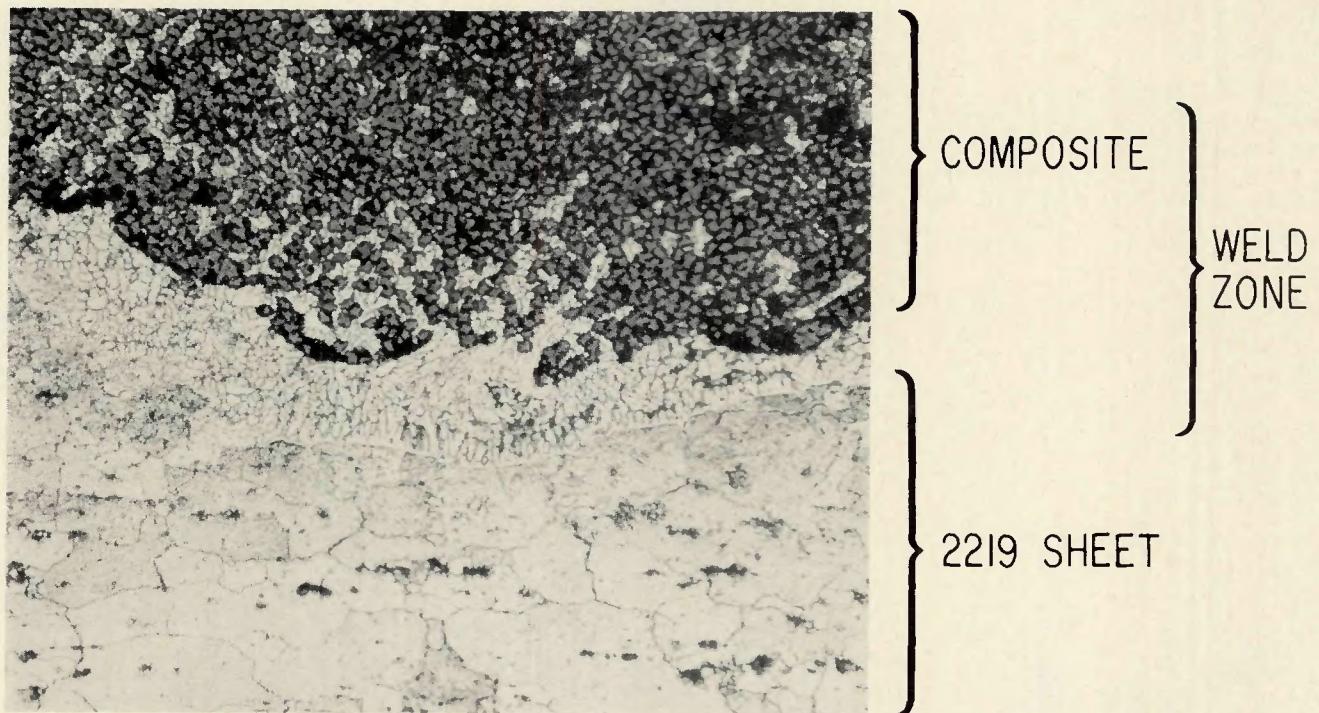


Fig. 3—Spot weld between 2219 sheet and aluminum-graphite composite. (Sheet thicknesses are 0.060 in. each, composite matrix is Al-12% Si, filler alloy is 718, electrode force is 240 lb, weld current is 8900 amp and weld time is 5 cycles.) Mag. 250X

of wetting was quite probably caused by the exposed graphite fibers on the machined surface of the composite.

Other preliminary tests demonstrated that 718 braze alloy, when melted without flux in a flowing argon atmosphere, can be made to wet and to flow satisfactorily on the surface of a 6061 alloy sheet. This result led to experiments in which aluminum-graphite composites were furnace brazed to 6061 sheet with the use of 718 filler alloy. Composites with matrices of pure aluminum and Al-7% Zn were employed. No flux was used and brazing was performed in a flowing argon atmosphere. A typical brazed joint is shown in Fig. 1. Note that the braze alloy has become intimately joined to the composite matrix and that the original bond line has been eliminated. This indicates that the 6061 sheet played a role in the brazing process since results of the earlier wettability studies did not predict bonding between the 718 alloy and the composite.

As a further check on the wettability studies, attempts were made to braze composite to composite by use of the 718 braze alloy. As expected, no bonding occurred. Based on this result and the results of the composite-to-6061 brazing studies, composite-to-composite brazing was attempted with a mixture of 718 and 6061 foils used as the filler alloy. Results have been encouraging.

A typical microstructure of a brazed joint is shown in Fig. 2. Diffusion of silicon from the low melting 718 into the 6061 apparently enabled the entire filler metal to melt at the brazing temperature (590C). Diffusion of magnesium from the 6061 to the 718-composite interface promoted bonding of the composite to the braze alloy. Note that in many places the bond line between the braze metal and the composite is eliminated, although not to as great an extent as in the bonds between composites and 6061 sheets (Fig. 1). Increasing the time and temperature of brazing did not improve the appearance of the brazed joint; the only observable result was an increase in the number of voids present. Optimum brazing conditions therefore appear to be a low temperature (590C) and relatively short times (5 to 10 min).

Experiments have shown that the presence of both magnesium and silicon in the braze alloy is necessary for satisfactory composite-to-composite brazing. Bonding was achieved when a binary aluminum-magnesium braze alloy was used; however, a heavy bond line, possibly indicative of an oxide layer, was visible on both sides of the braze alloy layer. Experiments are presently being conducted to determine the relative effects of a multilayer braze alloy (718 and 6061 foils) and a homogeneous alloy of the same overall composition. These experi-

ments should determine whether the silicon and magnesium act together or consecutively to aid in the wetting and bonding of composites. Other experiments are being performed to determine the optimum magnesium-to-silicon ratios for brazing composites with different matrix alloys. It is evident that the aluminum-silicon-magnesium braze alloy approach represents an important development in the brazing of aluminum-graphite composites.

Resistance Spot Welding

Spot welding was investigated as a process of joining composite to composite and also of joining composites to a difficult-to-braze³ aluminum alloy (2219) sheet. Composite-to-2219 joining is necessary in situations where the composite is being used to stiffen the standard alloy.

Problems were encountered in both composite-to-composite and composite-to-2219 spot welds. Expulsion of metal from the composite was difficult to avoid with the result that composite crushing and marked increases in graphite fiber packing density were common occurrences. The problem was compounded in composite-to-2219 welds, where the apparently higher resistivity of the composite made it difficult to localize melting at the interface. The heat required to cause weld penetration in the 2219 sheet caused excessive melt-

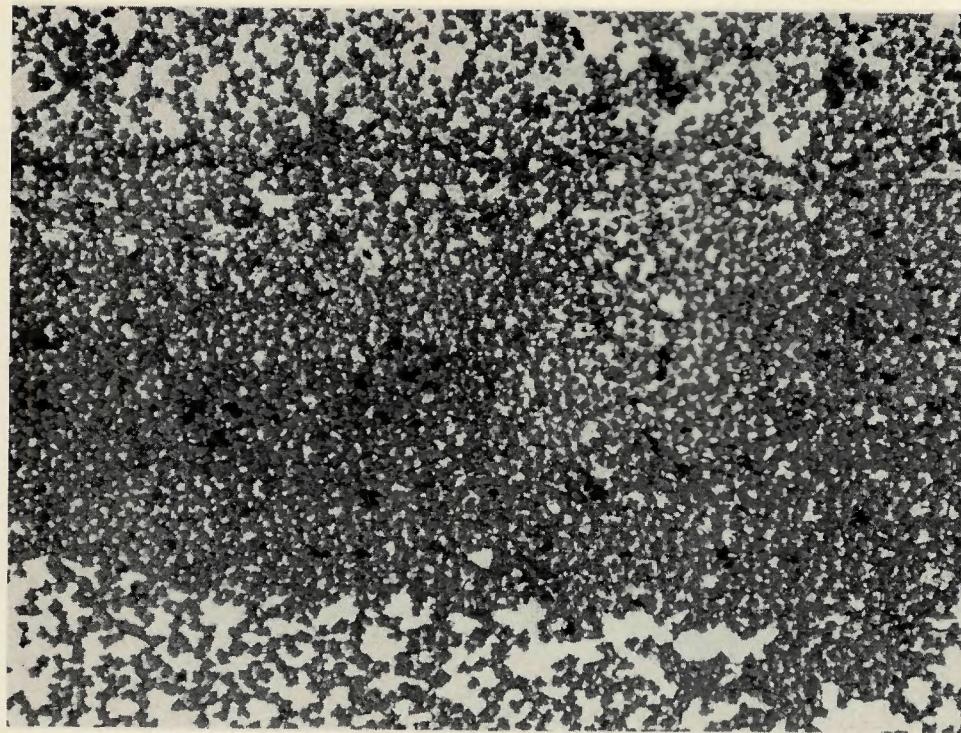


Fig. 4—Spot weld between two aluminum-graphite composites. (Sheet thicknesses are 0.040 in. each, composite matrix is Al-7% Zn, filler alloy is 718, electrode force is 400 lb, weld current is 5000 amp and weld time is 5 cycles.) Mag: 250X

ing in the composite. Welds between thick 2219 and thin composite sheets should be accomplished more easily since the resistances of the materials would be more nearly equal.

Typical spot weld microstructures are shown in Figs. 3 and 4. The voids and increased fiber packing density in the composites (results of expulsion and crushing) are evident. Both welds were made with a 3-mil foil of 718 alloy placed at the interface. The presence of this foil appeared to improve weldability although the necessity of a foil cannot be determined until welding parameters are more nearly optimized. Examples of spot welding parameters used are given in Tables 1 and 2.

In spite of the problems, spot welding of aluminum-graphite composites appears feasible. In neither Fig. 3 nor Fig. 4 does the weld nugget contain a bond line suggestive of the original interface between the composite and the 718 filler metal. Elimination of oxide layers and resultant wetting of the composite surface does not therefore appear to be a problem. Other work has shown that elimination of the original bond line in a joint between two composites is greatly enhanced by increasing the joining pressure from 50 to 100 psi. Since spot welding pressures are typically much greater than 100 psi, complete eradication of the bond line was not surprising.

Future spot welding experiments must be directed toward eliminating crushing and metal expulsion, thereby eliminating regions of high fiber packing density and resultant low shear strength. The most critical variable in the process will probably be pressure; pressures must be high enough to prevent expulsion but low enough to avoid crushing.⁴ Other experiments must be directed toward centralizing the weld nugget in welds between composites and commercial alloys. One possible approach would be the use of several sheets of 718 (or another alloy) foil at the interface. The resulting multiple interfaces would increase the electrical resistance in this region and thus promote localized melting.

GTA Welding

Experiments with GTA welding of aluminum-graphite composites were performed with a hand held torch. For this reason, heat input to the weld could not be controlled. It was found that 4043 filler wire bonded exceptionally well to a transverse section of the composite (a plane perpendicular to the graphite fibers). However, as Fig. 5 reveals, the high temperatures caused by the lack of automated control over the welding parameters resulted in the formation of aluminum carbide on the surfaces of the fibers. The appearance of the carbide phase

UNAFFECTED
COMPOSITE
WELD ZONE
UNAFFECTED
COMPOSITE

is similar to that observed by others.^{2, 5} In the presence of moisture, aluminum carbide decomposes with the release of hydrocarbon gases. The formation of the carbide thus leads to structural degradation and must be avoided during welding.

The use of an automated GTA process should provide adequate temperature control to prevent aluminum carbide formation. Other unpublished work (R. T. Pepper, Aerospace Corp.), has indicated that carbide formation is appreciably rapid only at temperatures above 700C. The presence of the carbide undoubtedly aids in bonding the filler metal to the composite fibers. However, Fig. 5 shows no bond line between the filler metal and the composite matrix so the stirring action of the arc may be sufficient to break up oxide films and promote wetting even in the absence of the undesirable carbide.

During butt welding, difficulty was encountered in bonding 4043 filler metal to a longitudinal surface of the composite (a plane parallel to the graphite fibers). The reason for this difficulty was not determined. However, it may be necessary to use vee joints rather than flat butt joints when welding composites so that the transverse surface is exposed.

Future Work

Future work in the joining of aluminum-graphite composites will be

4043 FILLER ALLOY COMPOSITE

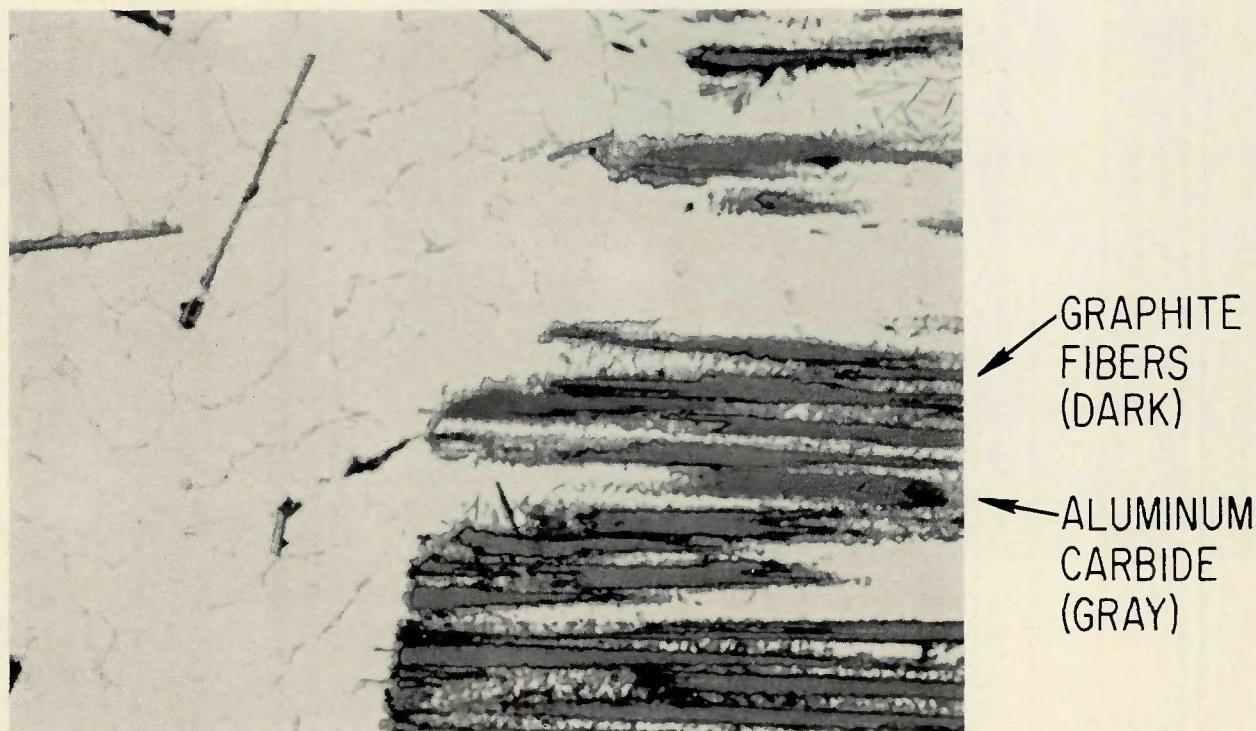


Fig. 5—GTA bead-on-plate deposit: 4043 filler metal on aluminum-graphite composite. Mag: 500X

Table 1—Typical Spot Welding Parameters for Composite-to-2219 Welds

Welding Time cycles	Electrode Force lb	Welding Current amp	Comments
11	700	20,000	Four-cycle forge delay (700 lb added). Composite melted and crushed*
11	500	14,500	Composite bonded but melted and crushed*
11	240	11,500	Better than above but still considerable melting and crushing in composite*
11	300	9700	One sheet 718 braze foil used. Welded, but failed through composite during sectioning*
5	300	8500	One sheet 718 braze foil used. Poor bond but very little crushing or expulsion*
5	240	8900	One sheet 718 braze foil used. Welded, but some spatter and crushing in composite**
5	240	8100	One sheet 718 braze foil used. Welded, less crushing than with preceding welding parameters**

* Electrodes: Class 1, 4-in. radius against composite. Class 3, 2-in. radius against 2219

** Electrodes: Class 1, flat against composite. Class 3, 2-in. radius against 2219

directed into several areas of study. The composition of the braze alloy for brazing the composites will be optimized. Spot welding parameters will be adjusted so that crushing and metal expulsion are eliminated. Studies of automated GTA welding of the composites will be initiated. Other methods such as soldering or diffusion bonding for joining composites to unbrazeable or difficult-to-braze alloys will be investigated. An extensive program for the mechanical testing of joints in composites will be initiated. The results of this program will yield quantitative information on the joint quality obtainable in each of the joining processes under study.

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Table 2—Typical Spot Welding Parameters for Composite-to-Composite Welds

Welding Time cycles	Electrode Force lb	Welding Current amp	Comments*
5	300	3200	Much crushing and metal spatter
5	400	5000	Welded; some expulsion, slight crushing
5	500	5500	Crushing
5	400	4200	Welded
5	450	5400	Welded; very slight metal expulsion

* Electrodes: Class 1, 8-in. radius. One sheet 718 braze foil used in all welds