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CERAMIC SUSCEPTOR FOR INDUCTION BONDING OF METALS, CERAMICS, AND PLASTICS

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ABSTRACT

A thin (.005) flexible ceramic susceptor (carbon) has been discovered. It was developed to join ceramics, plastics, metals, and combinations of these materials using a unique induction heating process. Bonding times for laboratory specimens comparing state of the art technology to induction bonding have been cut by a factor of 10 to 100 times. This novel type of carbon susceptor allows for applying heat directly and only to the bondline without heating the entire structure, supports, and fixtures of a bonding assembly. The ceramic (carbon film) susceptor produces molten adhesive or matrix material at the bond interface. This molten material flows through the perforated susceptor producing a fusion between the two parts to be joined, which in many instances has proven to be stronger than the parent material. Bonding can be accomplished in 2 minutes on areas submitted to the inductive heating. Because a carbon susceptor is used in bonding carbon fiber reinforced plastics and ceramics, there is no radar signature or return making it an ideal process for joining advanced aerospace composite structures.

INTRODUCTION

Induction heated Rapid Adhesive Bonding (RAB) techniques using a non-metallic susceptor for joining plastics, metals, and ceramics have been developed at the Langley Research Center (LaRC) (1). This process permits the heating of thermoset adhesive filled susceptors or the interface of thermoplastics directly at the bondline. Rapid Adhesive Bonding involves an electromagnetic induction heating of thin ceramic material (carbon susceptor) embedded in the bondline of the structure (Figure 1). Because only the bondline and material in the immediate area are heated, thermal distortions are less severe than conventional processes, which simplify and lower the cost of fixturing. Heating rates greater than 600_ F in 30 seconds have been generated employing a recently discovered ceramic (graphite) susceptor using RAB procedures (Figure 2). RAB bonds have been produced in less than 2 minutes, consuming much less power than conventional techniques. The low amount of input electrical power required to heat the bondline can be supplied from various sources (Figure 1).

Current state-of-the-art processes, such as press or autoclave bonding, take hours to accomplish and have very limited heating/cooling rate capabilities. These current processes rely on the conduction of heat from resistance heating elements through tooling, fixtures, caul plates, the structural parts and finally into the bondline to heat the adhesive. Consequently, a heat-up rate of 10_F/min is considered high, and much energy is consumed in bonding structures together. These bonding cycles can often take over 5 hours to execute.

The original objective of this bonding system was to provide low energy, portable, selfcontained, cost-effective apparatus and method for joining thermoplastic matrix composites and other compatible materials. This equipment was developed to fabricate structures to be used in outer space, and secondarily, structures on earth, or in motionless surroundings. As stated above, a recently discovered ceramic (graphite) susceptor material has been used to join pieces of metallic, ceramic, and plastic composites. In a toroid pole piece, magnetic flux remains inside the toroid core when the system is energized. To divert the path of the magnetic flux from the toroid to an adjacent ceramic susceptor, the toroid must be altered. This alteration is accomplished by cutting a segment out of the toroid and placing the air gap in the toroid on the surface of a matrix material composite sandwich consisting of a susceptor positioned between the two composite components to be joined (Figure 1). When using inductive heating to bond a typical plastic composite, a toroid is first energized, flux will flow through the toroid, through the plastic composite (which is transparent to magnetic flux) into the ceramic susceptor back through the plastic composite into the toroid. Alternating current produces inductive heating instantly in the susceptor causing the plastic interfacing on either side of the susceptor to melt and flow into perforations made in the ceramic susceptor forming the joint. Joining is accomplished in minutes.

The objective of this proof of concept study was to demonstrate the thermal efficient quality of a ceramic (graphite) susceptor when used for the induction heating and subsequent joining or bonding of plastic composites, metals, ceramics, and combinations of these materials.

SPECIMEN PREPARATION

Components of the specimens are shown in Figure 3 laid out in the order in which they would be stacked together in the fixture. A susceptor is sandwiched between thermoplastic adherends or in a stack containing adhesive layers placed between a thermoset plastic or between inorganic adherends (metal or ceramic). The surface preparation for all lap shear specimens consisted of a methanol wash followed by a 120 grit sandblast plus a second wash in acetone, methanol, and trichloroethylene. Table 1 shows the materials used in this ceramic susceptor proof of concept study.

BONDING AND TESTING

Shear Specimen Bonding

Overlap shear specimens were bonded in a configuration conforming to the American Society for Testing Materials (ASTM) standards D1002 and D3136. The technique similar to that used for spot welding metallic structures was used for rapid bonding of lap shear specimens made of thermoplastic composites, thermoset composites, metals, ceramics, and combination of these materials (Figure 4).

The rapid bonding equipment for laboratory shear specimens is shown in Figures 5 & 6. The press is identical to that for conventional specimen bonding, as are the load cell and temperature and load indicators. Replacing the conventional heated platens is a toroidal high frequency induction heater and its power controller. The specimen is located in a fixture for ease of alignment. The fixture was fabricated to align the specimen components prior to bonding. It was machined from bakelite with cutouts and location screws for the adherend (Figure 6). Bonding was accomplished by assembling the specimen in the specimen fixture, placing the fixture in the press under the toroid head and applying pressure and the induction field. The power used to energize the induction heater was approximately 300 watts at 60 Hz and 120 volts input into the inductive heater circuit. When power was applied, the induced energy from the toroid rapidly heated a perforated graphite susceptor which had been impregnated with a thermoplastic adhesive or was sandwiched between thermosetting adhesive films. The power was concentrated as heat entirely within the ceramic (graphite) susceptor, concentrating the heat within the bond line and minimizing detrimental thermal effects on the composite shear test specimen. For lap-shear specimens, the ceramic, metallic, or fiber-reinforced plastic composite material adherends were placed above and below the susceptor in the specimen fixture, and bonding pressure was applied (Figure 1). The susceptor heated the adhesive or thermoplastic composite adherend rapidly, usually within a minute, to the bonding temperature. Temperature within the bondline was considered to be an important requirement of this induction bonding process since heating was concentrated in the bondline in all applications in which a susceptor was used. A thermocouple was positioned in the bondline of each test specimen for each of the materials to be bonded (Figure 6). The heat is maintained from one to several minutes to promote adherend joining. When power is turned off, the specimen rapidly cools to a temperature below which the adhesive or thermoplastic composite is sufficiently set, and pressure is removed. Some of the composite materials tested are shown in Table 1. This process is more controllable and more energy conserving than conventional bonding with heated platens or an autoclave. (1,2).

APPARATUS AND TEST PROCEDURES

Tensile tests at room temperature were conducted in a 10 kilo pounds mechanical power screw driven machine at a head speed of .05 inches per minute until fracture. Grips used in the tensile tests were split collar assemblies. Maximum load was recorded from the dial indicator on the test machine, recorded from the dial indicator on the test machine. Specimen shear area used to determine shear strength was accomplished by measuring and taking the sum of all the hole areas in the graphite susceptor sandwiched between the adherend tensile specimen (Figure 7).

DISCUSSION OF RESULTS

Graphite-Peek Adherends

Table 1 and Figure 8 show overlap shear strengths (per ASTM D1002) of graphite fiber polyether etherketone (PEEK) (.004 inches thick) fabricated by rapid adhesive bonding technique using PEEK adhesive and a 0.0005 inch perforated ceramic (carbon) susceptor (Figure 3). Data are shown for specimens bonded at 720^0 F at 32 psi. Hold time under pressure at the bond temperature was 2 minutes. All shear strength data was obtained at room temperature. Figure 8 shows the best shear strength value obtained joining graphite/PEEK to graphite/PEEK with PEEK WAS 4,500 PSI. The bond was cohesive through the perforated carbon susceptors and failure was observed in the adherend part of the tensile test specimen.

Titanium Adherends

Table I and Figure 9 show the overlap shear strengths (per ASTM D1002) of Ti-6AL-4V titanium alloy adherends (0.05 inch thick) fabricated employing RAB using PEEK thermoplastic adhesive and a 0.0005 inch thick perforated ceramic (carbon) susceptor sandwiched with adhesive (similar to Figure 3). The specimens were bonded at a temperature of 720^0 F and 32 psi. Hold time under pressure at the bond temperature was 2 minutes. All shear strength data was obtained at room temperature. The highest shear strength value obtained joining the titanium adherends was 6,500 psi (Figure 9). The bond material was PEEK adhesive joining the two adherend components through a perforated ceramic (carbon) susceptor at the joint interface. The failure of this specimen was in the adhesive bond.

Titanium was also bonded to titanium using Hysol EC934 thermoset adhesive. The titanium adherends were 0.05 inches thick with a .005 inch thick ceramic (carbon) susceptor filled with the Hysol EC934 adhesive and sandwiched between the two adherends that made up the shear specimen. Table 1 and Figure 10 show the shear strength for this combination of material. The specimens were bonded at a temperature of 400^0 F and a bonding pressure of 19.2 psi. Hold time under pressure at the bond temperature was 2 minutes. All shear strength data was obtained at room temperature. The highest adhesive bond strength using Hysol EC934 adhesive was 6,400 psi. The failure of this specimen was in the adhesive.

Graphite/Epoxy Adherends

The applicability of a ceramic (carbon) susceptor used with RAB to bond graphite/epoxy adherends was demonstrated when joining Hercules 350 graphite/epoxy thermoset adherend with Hysol EC934 thermoset adhesive. Specimens were bonded at a temperature of 400^0 F and a pressure of 19. Hold time under pressure at the designated temperature of 2 minutes (Table 1, Figure 11). The highest shear strength value obtained bonding thermoset composite to itself with Hysol EC934 thermoset adhesive was 2,250 psi (Figure 11). It was noted that the bond maintained its integrity, and failure occurred in the adherend.

Adherends of Unlike Materials

The versatility of the rapid bonding concept was again demonstrated by using the process described in the preceeding paragraphs to bond titanium to graphite epoxy, aluminum to graphite epoxy, and aluminum to aluminum oxide ceramic. The adhesive used was Hysol EC934. The bonding temperature was 400^0 F. The average tensile strength of the 4,500 psi as shown in Table 1 and Figures 12, 13, and 14. Figure 12 shows strength data for Titanium bonded to graphite epoxy composite with Hysol EC934. The best shear strength value obtained for these specimens was 2,900 psi. Failure of the specimen was in the composite material. Aluminum 6061-T6 was bonded to graphite epoxy Hercules 3501 with Hysol EC934. The fabrication parameters and procedures for bonding the aluminum to the graphite epoxy was the same as described earlier in the text (Table 1). The average strength of the specimens tested was 432 > psi and the best strength value for the combination of materials was about 5250 psi. The 3501 adherend epoxy is .061 thick and the aluminum is .062 inches thick. The specimens failed in the composite part of the overlap shear joint. The last combination of materials bonded together was aluminum 6061-T6 (.062 inches thick) and aluminum oxide (.062 inches thick). The perforated ceramic (carbon) susceptor (.005 inches thick) was filled with Hysol EC934 thermoset adhesive and sandwiched at the joint between the aluminum and aluminum oxide adherends. Upon completion of the bonding cycle the specimen was tensile tested and found to have an average strength of 4,520 psi. The best shear strength value obtained from the aluminum oxide test was 5,600 psi. Failure occurred in the ceramic portion of the specimen. The low numbers obtained when testing this group of specimens is believed to be due to the lack of mobility in the grips of the pull test machine and the brittle nature of the aluminum oxide ceramic.

CONCLUDING REMARKS

A proof of concept study at the Langley Research Center has been conducted to evaluate a ceramic (carbon) susceptor for use in the induction bonding of structural materials used in aerospace technology. A thin (.005) flexible ceramic susceptor (carbon) has been developed to be used with a toroid bonder inductive heating instrument. Preliminary tests show that this bonding process produces rapid joining of ceramics, plastics, metals, and combinations of these materials. A typical lap-shear specimen placed in the toroid inductive heating press produced a bond in less than 10 minutes from energizing to removal from the heating press. Average lap shear bond strengths varied from about 6,000 psi to 2,000 psi depending on the materials bonded. Some specimens failed in the adherend rather than the bond joint. Bonding times for laboratory specimens comparing state-of-the-art technology to induction bonding have been cut by a factor of 10 to 100 times.

REFERENCES

1. Stein, B. A.; Tyeryar, J. R.; and Hodges, W. I.: Rapid Adhesive Bonding Concepts. NASA TM 86256, June 1980.

2. Buckley, J. D.; Fox, R. L.; and Swaim, R. J.: Toroid Joining Gun SAE Paper 85040T presented at International Congress and Exposition Detroit , MI, February 25- March 1, 1985.

TABLE I

SPECIMEN BONDING PARAMETERS

ADHEREND	[1]GR PEEK TO GR/PEEK	TI to 3501[2]	AL TO 3501[2]	TI TO TI	AL TO AL2O3	TI TO TI	3501[2] 3501[2]
ADHESIVE	PEEK	HYSOL934	HYSOL934	HYSOL934	HYSOL934	HYSOL934	HYSOL934
SUSCEPTOR	CARBON	CARBON	CARBON	CARBON	CARBON	CARBON	CARBON
BONDING TEMP DEGREES F	720	400	400	720	400	400	400
BONDING PRES PSI	32	19.2	19.2	32	19.2	19.2	19.2
SURFACE PREP	A	A	A	A	A	A	A
HOLDING TIME AT TEMP MIN	2	2	2	2	2	2	2
AVG OVERLAP SHEAR STRENGTH PSI	4371	2566	4327	5993	4520	5646	2022

A. METHANOL WASH, 120 GRIT BLAST, ACETONE, METHANOL AND TRICHLOROETHLYENE

1. GRAPHITE - POLYETHERTHER-KEPTON COMPOSITE,
2. HERCULES THERMOSET GRAPHITE EPOXY

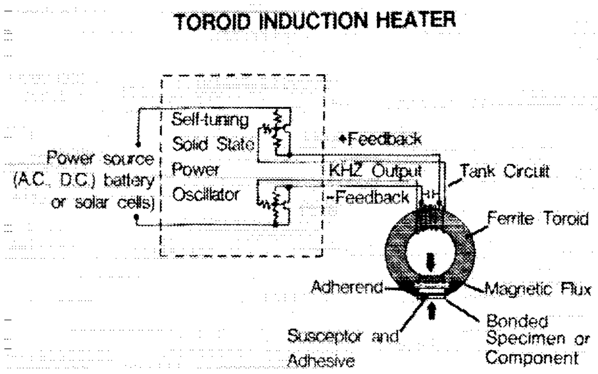

Figure 1 Schematic of toroid induction concept

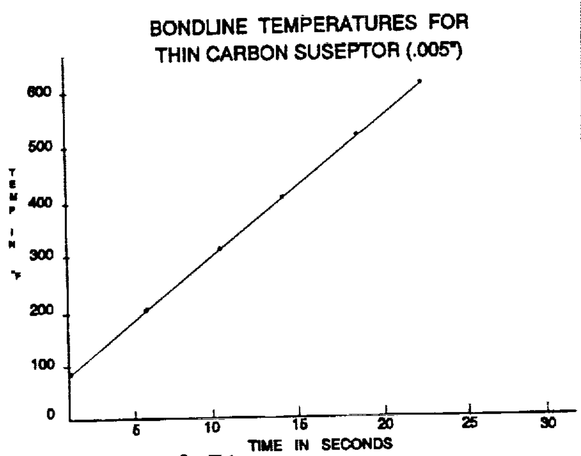

Figure 2 Time temperature curve for inductive heating of a ceramic (graphite) susceptor

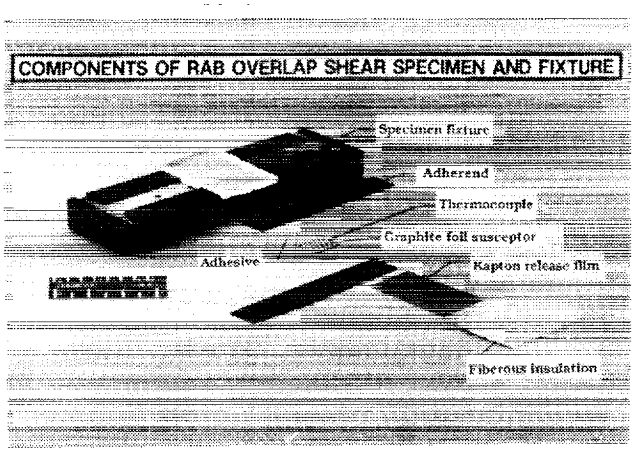

Figure 3 Typical induction bonded overlap shear test specimams

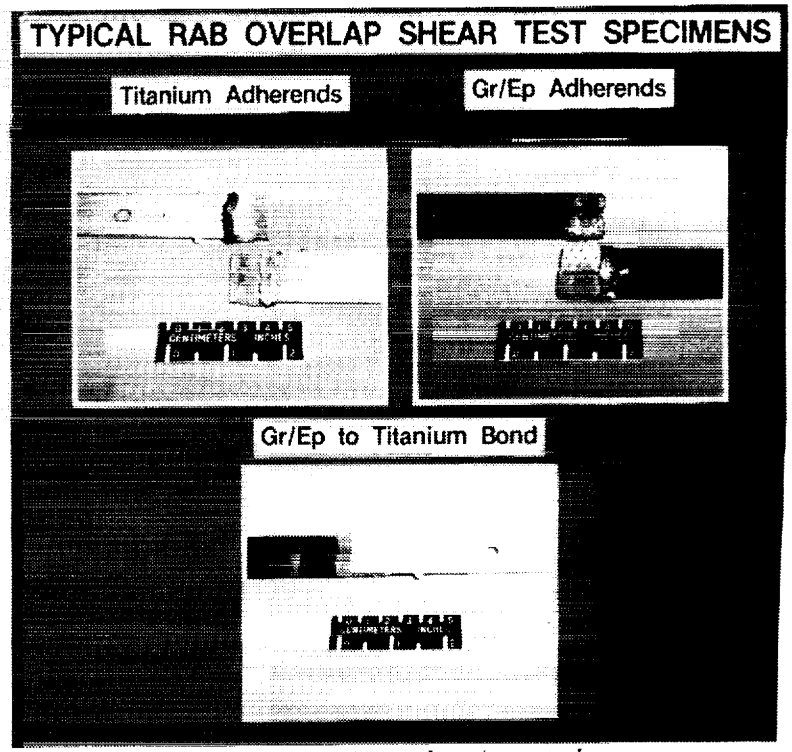

Figure 4 Overlap shear specimans according to ASTM

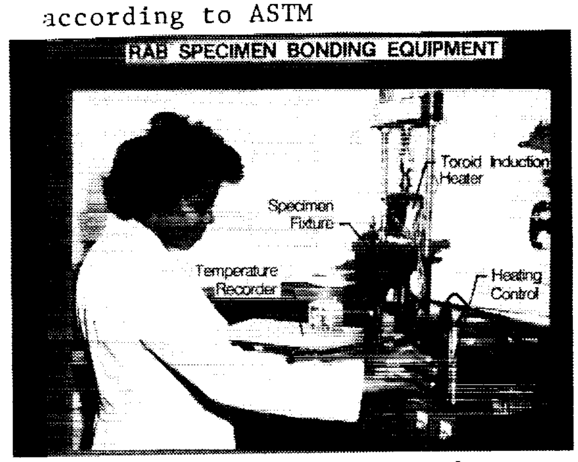

Figure 5 Toroid induction heater speciman bonding equipment

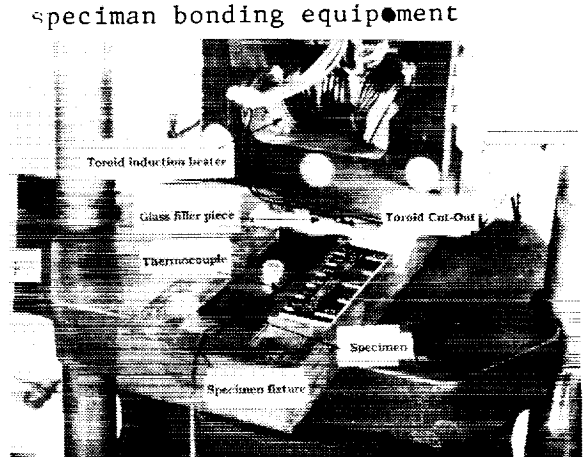

Figure 6 Speciman fixture in press under toroid head

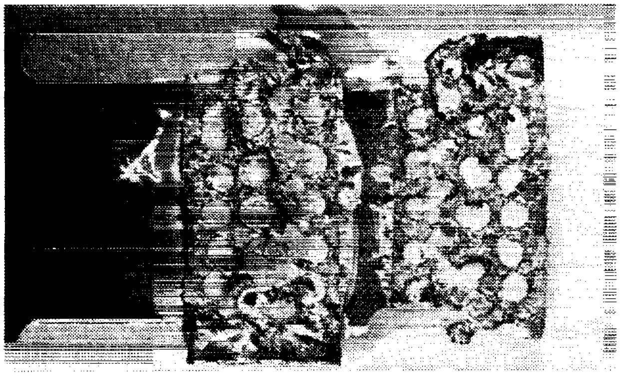

Figure 7 Overlap shear test speciman showing adhesive through preforated susceptor(both sides).

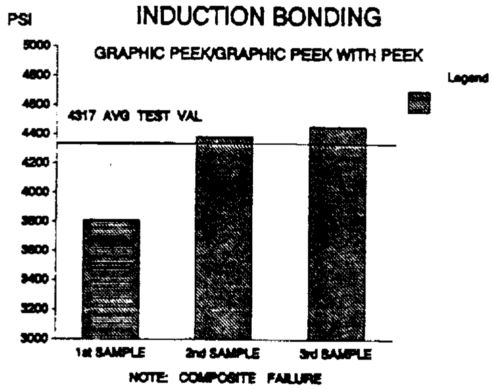

Figure 8

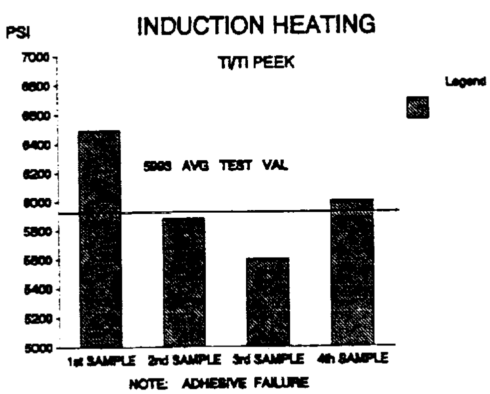

Figure 9

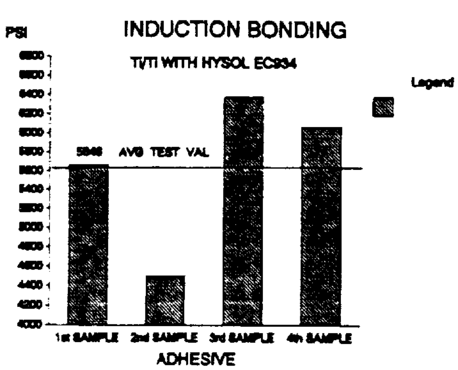

Figure 10

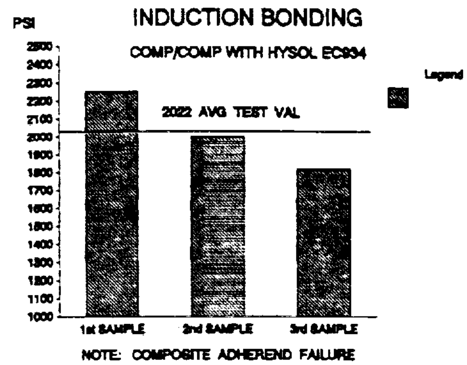

Figure 11

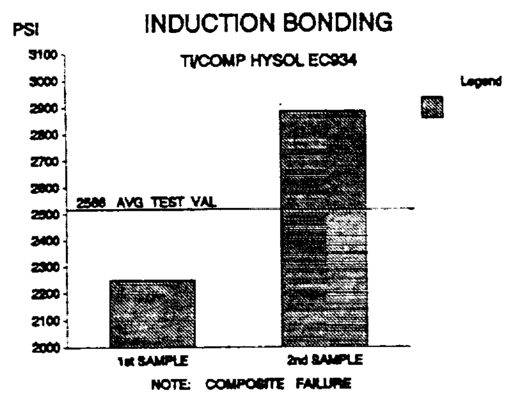

Figure 12

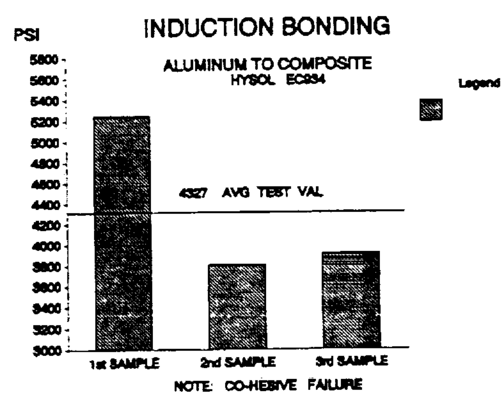

Figure 13

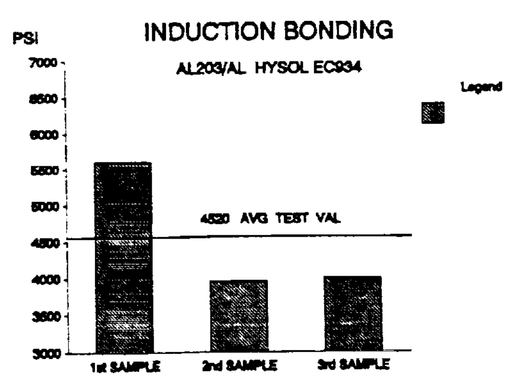

Figure 14