Rapid Adhesive Bonding of Thermoplastic Composites and Titanium with Thermoplastic Adhesives

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Abstract

ADHESIVE bonding processes are often used in the aerospace industry for joining structural elements. Fiber-reinforced polymeric composite materials are particularly amenable to adhesive bonding because of load transfer uniformity. However, certain drawbacks in current adhesive bonding technology, including relatively long heating and bonding cycles, have limited its application. Advanced thermoplastic adhesives are candidates for adhesive bonding of titanium or composite structures. These thermoplastics do not require long processing times, but usually require processing temperatures above 600°F to achieve strong bonds. However, because of the thermal inertia of fixtures and equipment, at least several hours in presses or autoclaves are required.

Rapid adhesive bonding (RAB) concepts have been developed at NASA Langley Research Center (LARC) to utilize a toroid induction technique to provide heat directly to the bondline and/or adherends, without heating the entire structure, tooling, and support fixtures of a bonding assembly. Bonding times for specimens can be decreased by a factor of 10 to 100 compared to standard press or autoclave bonding.[1] This paper focuses on rapid adhesive bonding of titanium and an advanced composite material (graphite-fiber-reinforced PEEK) using advanced thermoplastic adhesives. Bonding parameters, bond strengths at room and elevated temperatures, and the effect of thermal cycling or water boil exposures on bond strength are described. A promising nondestructive technique for evaluation of bond strength is also described.

Contents

The rapid adhesive bonding equipment for overlap shear specimens was previously described in considerable detail.[1] The adherends in this study were graphite-fiber-reinforced PEEK composites and titanium alloy (Ti-6Al-4V) sheet. Perforated, 0.005-in.-thick stainless steel (Type 410) or flattened steel screen susceptors were used to concentrate the heat in the bondline of the RAB specimens. A number of specimens were also fabricated in a conventional laboratory press with heated platens which typically required several hours. The complete RAB cycle, from initiation of heating to removal of the specimen from the equipment, required only 5-10 min.

Certain RAB specimens were subjected to 1000 thermal cycles from −100 to +450°F in ambient pressure air to determine whether the thermal expansion mismatches between susceptor, adhesive, and adherend would degrade strength. Other RAB specimens were subjected to 72-h exposures in boiling, deionized water to determine whether rapidly bonded specimens were particularly sensitive to wet environments, considering that corrosion of susceptors would be accelerated. Specimens were tested for overlap shear strength by application of tensile loads at room temperature (RT) and elevated temperature in an Instron universal testing machine, in accordance with ASTM D1002 or D3163.

The adherend/adhesive combinations used in this study are listed in Table 1. The metallic adherends were Ti-6Al-4V titanium alloy sheets, nominally 0.05 in. thick. The composite adherends investigated were quasi-isotropic graphite-fiber-reinforced PEEK (Gr/PEEK) composites, supplied by ICI Americas Inc., designated Aromatic Polymer Composite APC-2.[2] The surface treatments for the polyimide-bonded titanium specimens included a 120-mesh aluminum oxide grit blast and Pasa Gel 107 surface treatment, followed by surface priming. The composite adherends were simply methanol-wiped and grit-blasted prior to bonding. The adhesives investigated were all thermoplastics. Two polyimide adhesives were evaluated, LARC-TPI and polyimide-sulfone, both developed at LARC.[3,4] They were impregnated onto fiberglass carrier cloth. Layers of this "scrim cloth" were used in specimen preparation. PEEK film, 0.01 in. thick, was used to bond the APC-2 composite. Bonding conditions for the various specimens evaluated are indicated in Table 1. The data presented subsequently are the averages of three or four specimens at each test condition.

A comparison of bonding processes for titanium adherends bonded with the polyimide-sulfone adhesive is shown in Fig. 1. In the as-bonded condition, overlap shear strengths of RAB and press-bonded specimens are equivalent at room temperature. At 450°F, RAB strengths were much higher. After thermal cycling, both press and RAB specimens retained 70-85% of RT strengths and demonstrated increased 450°F strengths. The effect of the 72-h water boil was to lower RT strength of the press-bonded specimen by 26% and of the RAB specimens by 50%. The latter result may be due to susceptor corrosion. In the room-temperature tests of as-bonded specimens, failures were cohesive. After the water-boil exposure, the failure modes of the RAB

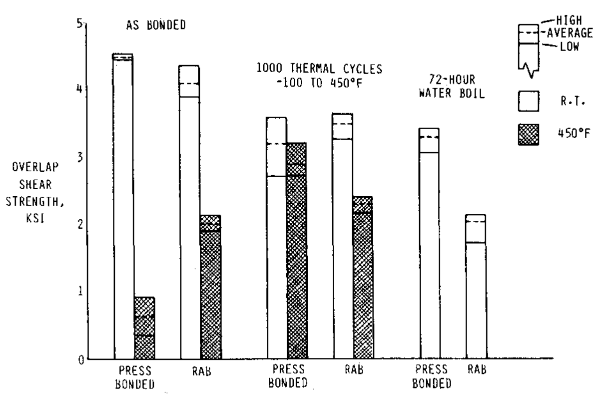

Fig. 1 Effect of bonding process, temperature, and environmental exposure on overlap shear strengths of titanium adherends bonded with polyimide-sulfone adhesive.

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Table 1 Bonding conditions for overlap shear specimens

				Bonding conditions			
Adhesive	Method	Susceptor	Surface priming	Temperature, °F	Pressure, psi	Hold time, min	Heating rate, °F/min
			Ti-6Al-4V titanium alloy adherends				
Polyimide-sulfone[a]	Press[b]	None	Yes	650	200	10	10
	RAB[c]	Steel screen	Yes	635	50	2	20-500
LARC-TPI[a]	Press	None	Yes	650	300	30	10
	RAB	Steel screen	Yes	650	50	2	500
	RAB	Perforated stainless-steel foil	Yes	650	50	2	800
			Quasi-isotropic APC-2 (graphite/PEEK composite)				
PEEK film	RAB	Steel screen	No	750	10	2	300

[a]Impregnated on fiberglass carrier cloth. [b]Laboratory hydraulic press with heated platens. [c]Rapid adhesive bonding.

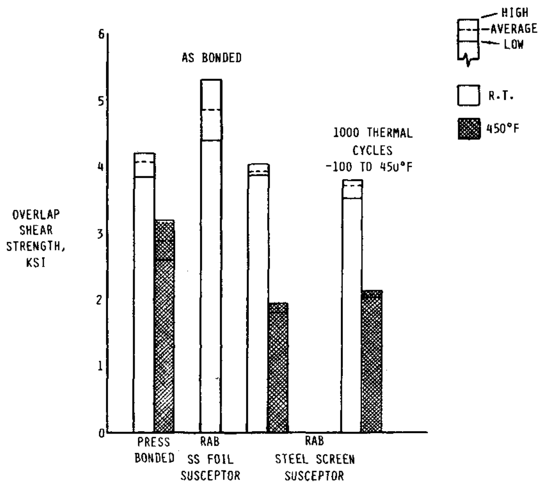

Fig. 2 Effect of bonding process, temperature, and thermal cycling on overlap shear strengths of titanium adherends bonded with LARC-TPI.

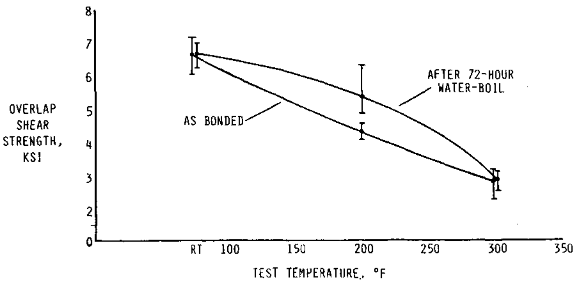

Fig. 3 Effect of test temperature and water-boil exposures on overlap shear strengths of APC-2 composite adherends bonded with PEEK.

specimens changed to adhesive failure between the scrim and the susceptor.

Results of bonding process comparisons and thermal cycling exposures on the overlap shear strengths of titanium alloy adherends bonded with LARC-TPI are shown in Fig. 2. In this case the RAB specimens were equivalent in room-temperature strength to the press-bonded specimens when the steel screen susceptor was used and 20% higher with the perforated stainless-steel foil susceptor. The 450°F strengths of the RAB specimens were 36% lower than those for the press-bonded specimens. The shorter heating times of RAB may be contributing to this behavior in the LARC-TPI adhesive due to lowering of Tg (glass transition temperature) by trapped solvent. Comparing the data in Fig. 2 for the RAB (steel screen susceptor) specimens as-bonded and after 1000 thermal cycles, a 6% degradation in RT overlap shear strength and no degradation at 450°F resulted from the thermal cycling. These results indicated that the susceptor/adhesive/adherend mismatches in thermal expansion coefficients are not a significant detriment to environmental stability of adhesive bonds in the materials investigated.

An examination of the data in Figs. 1 and 2 indicates that the variability in overlap shear strengths at any test condition is not significantly different when they are bonded by standard press procedures or by RAB—a positive indication of the viability of RAB. The data show that RAB provides different challenges than standard press-bonding procedures. Adhesive bonds of equivalent (and structurally significant) strength with reasonable environmental resistance can be produced by rapid adhesive bonding in much shorter times than conventional bonding processes require.

Bonding of the APC-2 (Gr/PEEK) composites with PEEK film was only possible by RAB when the bonding temperature was above 700°F, about 100°F above the crystalline melting temperature of both the PEEK film and the PEEK matrix in the adherends. To produce strong adhesive bonds with the least possible "squeeze out" of molten matrix from the adherends, very low bonding pressures were evaluated. Bonding conditions of 10 psi and 750°F for 2 min were arrived at a reasonable tradeoff. The shear data are shown in Fig. 3. RT and 300°F shear strengths exceeded 7000 and 3000 psi, respectively, with cohesive failures in the PEEK adhesive film layer.

The effects of 72-h water-boil exposures on the RAB APC-2/PEEK/APC-2 specimens are also shown in Fig. 3. No degradation was noted in the room-temperature and 300°F tests and an increase of 22% in 200°F strength (over the 200°F as-bonded strengths) was recorded. These results testify to the excellent moisture resistance and hot-wet strength of PEEK and Gr/PEEK composites.

Rapid adhesive bonding (RAB) techniques were evaluated for bonding of titanium and Gr/PEEK composite adherend overlap shear specimens with three advanced thermoplastic adhesives.

RAB produced Ti/LARC-TPI/Ti and Ti/polyimide-sulfone/Ti bonds of equivalent strengths to conventional heated platen press samples, while reducing process times by 1-2 orders of magnitude. Very strong bonds (>6000 psi at RT) were produced in Gr/PEEK composite specimens.

Thermal cycling exposures had little effect on overlap shear strengths of Ti/LARC-TPI/Ti and Ti/polyimide-sulfone/Ti specimens, although steel susceptors are in the bondlines of RAB specimens. Water-boil exposures did not degrade PEEK bond strengths.

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