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Evaluation of a thermoplastic polyimide (422) for bonding GR/PI composite

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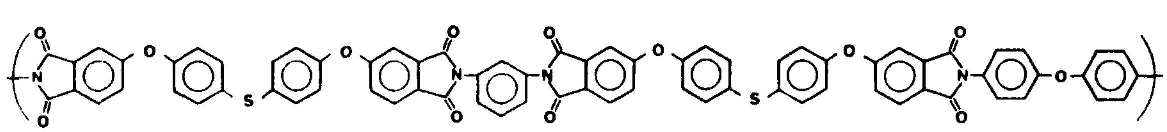
Abstract - A novel hot-melt processable polyimide was synthesized and characterized at NASA Langley Research Center for use as an adhesive for bonding a titanium alloy, Ti-6Al-4V [1]. The present study is a follow on to determine the adhesive's capability for bonding a high temperature, high performance graphite/polyimide (GR/PI) composite. The bonding temperature was different from that previously reported for bonding titanium because of the composite's lower temperature capabilities. Bonded lap shear specimens were tested at RT, 177°C and 204°C both before and after aging in air at 204°C for up to 5000 h. RT and 177°C strengths decreased significantly whereas the strength at 204°C remained unchanged. Bonded specimens were also exposed to boiling water for a 72 h period. Reduced strengths were observed at all temperatures as a result of this exposure. A comparison of the strengths for the bonded composite and the previously reported titanium alloy data is given.

1. INTRODUCTION

A number of polyimides have been developed for potential applications in bonded aerospace structures [2-6]. The novel hot-melt processable polyimide was prepared in our laboratory and designated as 422 in Reference 7 by Burks, St. Clair and Progar. The structure of 422 is shown in Scheme 1.



Scheme 1. Polyimide 422

The structure of the polymer as shown is a copolyimide prepared from a single dianhydride, 4,4'-bis(3,4-dicarboxyphenoxy)diphenylsulfide dianhydride (BDSDA), and equimolar amounts of the flexibilizing units metaphenylene diamine (MPD) and 4,4'-oxydianiline (ODA). This material was shown in the referenced report to have an unusually low melt viscosity when compared with the homopolymers made using only MPD or ODA. The low viscosity of the polymer provides the flow necessary for good wetting of the adherends during bonding. This material because of the low melt viscosity was originally chosen for a study as a structural adhesive for bonding a titanium alloy. The bonding of a high temperature, high performance composite is a follow-on study using the same adhesive material.

2. EXPERIMENTAL

2.1 Synthesis

The synthesis of the 422 material has been reported in Reference 6, however, the general synthesis is reproduced in this paper for the convenience of the reader. A solution of the copolyimide 422 was prepared by reacting 2 moles of BDSDA, 1 mole of 4,4'-ODA, and 1 mole of MPD in diglyme at 20% solids for two hours at RT.

2.2 Characterization

Lap shear strength (LSS) was obtained according to ASTM D-1002 using a Model TT Instron Universal Testing Machine. The average LSS reported represented at least three or more lap shear specimens tested for any one condition. Elevated temperature tests were conducted in a clam-shell, quartz-lamp oven with temperatures controlled to within ±3°C for all tests. Specimens were held 10 min at temperature prior to testing except for the water-boil specimens which were tested upon reaching the test temperature (approximately 1-2 min). LSS range is indicated by dashed lines in the bar graph figures and given in the tables.

Bondline thickness for the titanium bonded specimens was obtained as the difference between the total bondline thickness measured with a micrometer and the sum of the adherend thicknesses. The average bondline thickness for the titanium bonded specimens was 0.20 mm (0.008 in.) with a range of 0.18 mm (0.007 in.) to 0.23 mm (0.009 in.). Because of the composite thickness variability, the bondline thickness was not determined but assumed to be in the same range as the titanium bonded specimens.

Glass transition temperatures (T_g) were determined on the adhesive in the fractured area of the titanium bonded lap shear specimens by thermomechanical analysis (TMA) on a DuPont 943 Analyzer in static air at a heating rate of 5°C/min using a hemispherical probe with a 15 g mass. For the composite bonded test specimens, T_g was measured using the flashing (the material outside the bonded area).

Inherent viscosity (η_{inh}) was determined using a Cannon-Ubbelohde viscometer in a 25°C water bath controlled to within ±0.01°C. A 10 ml solution of 0.5% solids in N,N-DMAC was made and filtered. The average of three runs of the solution was reported.

2.3 Adhesive tape

422 Adhesive tape was prepared by brush-coating a polyamic-acid, 20% solids solution in diglyme onto 112 E-glass cloth with an A-1100 finish (γ-aminopropylsilane). The flow properties of the 422 with 0.789 η_{inh} which was used to prepare adhesive tape to bond the titanium are given in Reference 7. A second solution with a 0.606 η_{inh} was used to prepare adhesive tape for bonding the composites. Prior to coating, the glass cloth (tightly mounted in a metal frame) was oven-dried for 30 min at 100°C. The 0.1 mm (0.004 in.) thick glass cloth served as a carrier for the adhesive as well as for bondline thickness control and an escape channel for solvent. Coatings of the polymer solution were applied to the glass cloth until a thickness of 0.20 mm - 0.25 mm (0.008 in. - 0.010 in.) was obtained. After a primer coat ($\approx$ 4% solids solution) was applied, each coat application thereafter was air-dried 0.5 h, placed in a forced-air oven, and exposed to the following schedule:

(1) RT $\rightarrow$ 100°C, hold 0.5 - 1 h

(2) 100°C $\rightarrow$ 150°C, hold 2 h

(3) 150°C $\rightarrow$ 175°C, hold 3 h

Some foaming of the polymer occurred due to the above treatment. The procedure used to prepare the tapes was required to drive off the solvent and reaction product volatiles when converting the polyamic-acid resin to the polyimide. Imidization of polyamic-acids to polyimides generally occurs in the 160°C range with the degree of conversion being a function of time and temperature.

2.4 Adhesive bonding

The prepared adhesive tapes were used to bond titanium adherends (Ti-6Al-4V, per Mil-T-9046E, Type III Comp. C) with a nominal thickness of 1.27 mm (0.050 in.) or composite with a nominal thickness of 2.15 mm (0.084 in.). The four-fingered Ti-6Al-4V panels were grit blasted with 120 grit aluminum oxide, washed and rinsed with methanol, and surface treated with Pasa-Jell 107* treatment to form a stable oxide on the surface.

The composites were fabricated by Rockwell International from Celion 6000 graphite fibers with a NR 150B2 polyimide finish in a LARC-160 polyimide matrix. The prepreg was supplied by Fiberite. The composite plies were arranged in a $(0,0,0,+30,-30,+30,-30)_s$ layup. Details of the fabrication procedure are given in Reference 8. Maximum temperature during the composite curing process was 329°C (625°F). Table 1 gives the properties of the composite panels used as adherends. C-scans of the composite indicated they were of good quality. The composite adherends were given a light grit blast with 120 grit aluminum oxide in the area to be bonded, washed and spray rinsed with methanol, and dried in a forced-air oven for 24 h at 100°C prior to priming.

*Trade name for a titanium surface treatment available from Semco, Glendale, CA.

Use of trade names or manufacturers does not constitute an official endorsement, either expressed or implied, by the National Aeronautics and Space Administration.

The treated adherends were primed by brushing a thin coat of 20% solids solution approximately 2.5 x 10^2 mm (0.001 in.) thick on the surface area to be bonded. They were air dried for 30 min and then heated in a forced-air oven for 15 min at 100°C and 15 min at 150°C. The primed adherends were placed in a polyethylene bag and stored in a desiccator until needed. Lap shear specimens were prepared by inserting the adhesive tape between the primed adherends using a 12.7 mm (0.5 in.) overlap (ASTM D-1002).

Because the maximum temperature used for bonding titanium with 422 adhesive in the previous study was 343°C (650°F), several temperatures were investigated for bonding the composite with 422 adhesive to determine a bonding process which produced good strengths and did not degrade the composite. The following process cycle was used where the temperatures were 302°C (575°F), 316°C (600°F), 329°C (625°F), and 343°C (650°F) (even though 343°C was higher than the maximum temperature used to fabricate the composite).

(1) Apply 2.07 MPa (300 psi) pressure, heating rate ≈ 8°C/min, RT → temp.

(2) Hold 1 h at temp.

(3) Cool under pressure to ≈ 150°C (302°F) and remove from bonding press.

A bonding cycle was selected which was based on the highest LSS and was used to determine the effects of thermal exposure for up to 5000 h at 204°C on LSS. Thermal exposure was performed in a forced-air oven controlled to within ±1% of exposure temperature. Lap shear tests were conducted at RT, 177°C, and 204°C before (controls) and after exposure.

A rather severe 72 h water boil test was conducted in laboratory glassware containing boiling distilled water. The lap shear specimens were immersed (above the bonded area) during the 72-h period. LSSs were determined at RT, 177°C, and 204°C.

3. RESULTS AND DISCUSSION

3.1 Bonding temperature selection

The chemistry and preparation of this system has been previously discussed in Reference 7. Selection of the bonding temperature for the bonding cycle for the 422 polyimide adhesive bonded composite from those given in Table 2 and Fig. 1 was based on obtaining the highest LSS. Results are expressed in graphical form for those interested in obtaining a quick pictorial summary of the results and in tabular form for those interested in more detail and additional information not included in the graphs. As given in Table 2, the heating rate (8°C/min), bonding pressure (2.07 MPa), and time held at cure temperature were maintained while the temperature was varied (302°C, 316°C, 329°C, and 343°C). Although 343°C was higher than the maximum temperature that the composite experienced, it was nevertheless investigated to determine if the composite was detrimentally affected as well as to determine whether good LSS could be obtained. Although the composite apparently was unaffected visually, the LSSs were slightly lower at 177°C and 204°C than those bonded at 316°C, Fig. 1. The best compromise results were obtained using the 316°C bonding temperature and therefore it was the bonding temperature selected. All bonding cycles produced the same type of failures at the three test temperatures, i.e., RT, composite failure; and 204°C, cohesive failure. The composite failure generally occurs in the plies nearest to the composite/adhesive interface, Fig. 2 and Fig. 3. Because of this type of failure, the LSS value is not very meaningful since the composite is failing rather than the adhesive. However, this is a common occurrence because of the peel stresses developed due to the test method and the composites are generally weak in the direction normal to the surface. No trends were noted for the T_gs which were determined on the adhesive flashing. The T_gs ranged from 206°C (403°F) to 215°C (419°F). The reported T_g for this polymer is 216°C (421°F) [7].

3.2 Thermal exposure

The effects of thermal exposure in a forced-air oven at 204°C for up to 5000 h are given in Table 3 and Fig. 4 for the bonded composite. LSS was determined at RT, 177°C, and 204°C. RT and 177°C strengths decreased significantly, the RT strength for the 5000 h exposure was 57% of the RT control strength and the 177°C strength for the 5000 h exposure was 61% of the 177°C control strength. Failures were primarily in the composite. LSS at 204°C was retained and possibly even increased slightly, 15.5 MPa (2240 psi) compared to the control's strength, 13.4 MPa (1940 psi). However, the failure was in the composite for those aged 5000 h and cohesive for the control tests. An apparent slight increase in T_g was noted for the aged specimens, however, due to the measurement technique, this difference may be within experimental error.

Table 4 and Fig. 5 depict the effects of thermal exposure at 204°C for up to 20000 h for 422 bonded Ti-6Al-4V. The LSS decreases dramatically between 5000 h and 10000 h, i.e., RT, from 21.0 MPa (3040 psi) to 12.0 MPa (1740 psi); 177°C, from 23.1 MPa (3350 psi) to 10.2 MPa (1480 psi); and 204°C, from 17.0 MPa (2470 psi) to 3.0 MPa (430 psi). Although the RT and 177°C strengths retained after 10000 h are still useful for some applications, the strength at 204°C would not be useful. The RT and 177°C strengths are even lower for those aged at 20000 h. The adhesive color which was originally brown became almost black and indicated degradation. Failures were primarily cohesive for most of the tests. Comparing, if permissible, the composite data with that of the titanium data for the 5000 h exposure at 204°C shows the strengths for the bonded titanium to be significantly higher for all aging and test conditions. Since the adhesive apparently degrades significantly for periods longer than 5000 h at 204°C and that the failures were cohesive, indicating that the adhesive and not the titanium surface was at fault, similar results would be expected for long term aging of composite bonded specimens.

3.3 72-h Water boil

Lap shear specimens were given a 72-h water boil to determine adhesive performance when exposed to water (humidity). Test results for the 422 adhesively bonded composite adherend system are given in Table 5 and Fig. 6. LSSs at 177°C and 204°C are significantly reduced due to the water-boil and are 48% and 31% of the control values at those temperatures. Eighty-four percent of the RT control value was retained. The adhesive for the water boil specimens tested at 204°C failed thermoplastically. The T_gs remained in the same range as those of the controls.

Test results reproduced from Reference 1 are given in Table 6 and Fig. 7 for 422 adhesive bonded Ti-6Al-4V. The LSS values were 80%, 59%, and 29% of the RT, 177°C, and 204°C control values respectively. No significant differences in the T_gs were observed between the controls and water boil specimens. Whereas the controls all failed cohesively, the water boil specimens failed adhesively at 177°C and 204°C. Although the control LSS values were significantly higher for the Ti-6Al-4V bonded specimens, the percent retained after water boil for each test temperature was essentially the same for both the bonded Ti-6Al-4V and composite systems. Apparently, the adhesive offers little resistance to water and is probably plasticized due to its presence although this is not reflected in the T_gs determined after water boil. The results of the 72-h water boil showed reduced performance for both adhesive/adherend systems.

4. SUMMARY

A hot-melt processable copolyimide previously synthesized and characterized as an adhesive at NASA Langley Research Center for bonding Ti-6Al-4V has been used to bond Celion 6000/LARC-160 composites. A bonding cycle was determined and lap shear specimens were prepared which were thermally exposed in a forced-air oven for up to 5000 h at 204°C. LSSs were determined at RT, 177°C, and 204°C. After thermal exposure to 5000 h at 204°C, RT and 177°C LSS decreased significantly, however a slight increase was noted for the 204°C test. Useful strengths, > 11.1 MPa (> 1610 psi), were retained for all test temperatures for up to 5000 h exposures. When composite failure occurs, which it did in many cases, the strength values obtained are difficult to interpret because this indicates that the adhesive is stronger than the composite's first surface plies (high peel stresses are introduced in the first few plies due to the testing technique). If the composite were stronger, the strength values would be higher.

Initially the LSS values are higher for the bonded Ti-6Al-4V than for the bonded composite but the LSS decreases dramatically between 5000 h and 10000 h of 204°C thermal exposure. Longer periods of thermal exposure up to 20000 h result in further decreases in LSSs. Although the bonded composite retained useful strengths (> 11.1 MPa) for exposures up to 5000 h, based on the poor results of the bonded Ti-6Al-4V beyond 5000 h, the 422 adhesive bonded composites would most likely also produce poor strengths beyond 5000 h exposure.

Adhesive bonded composite lap shear specimens exposed to boiling water for 72 h exhibited greatly reduced strengths at all test temperatures. Although the control LSS values were significantly higher for the Ti-6Al-4V bonded specimens, the percent retained after water boil for each test temperature was essentially the same for both systems.

Based on the results given here for bonded high temperature, high performance composite and bonded Ti-6Al-4V, the 422 adhesive has limited applications due to its decreasing strength with long term thermal exposure at 204°C and the poor strength after a 72-h water boil.

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Table 1.

Properties of composites

Panel identification	T_g [°C (°F)]	Average thickness [mm (in.)]	Specific gravity	V_f[a] %	Void %
CL14C-25	340 (644)	2.15 (0.085)	1.58	59.3	0.2
CL14C-26	349 (660)	2.18 (0.086)	1.57	58.3	0.8
CL14C-32	324 (615)	2.11 (0.083)	1.58	59.8	--

[a] Based on cure weight.

Table 2.

Cure temperature effect on LSS for 422 adhesive bonded composite

Cure temperature[a] [°C(°F)]	Number of specimens	Test temperature [°C(°F)]	Average LSS [MPa (psi)]	Range of LSS [MPa (psi)]	Primary failure mode[b]	Glass transition temperature, T_g[c] [°C (°F)]
302 (575)	3	RT (RT)	17.0 (2460)	14.8-18.1 (2150-2630)	Comp	212 (414)
	3	177 (350)	19.9 (2890)	19.3-20.3 (2800-2950)	Co/Comp	211 (412)
	4	204 (400)	12.2 (1770)	11.9-12.8 (1730-1850)	Co	214 (417)
316 (600)	4	RT (RT)	19.4 (2820)	18.0-21.4 (2620-3100)	Comp	206 (403)
	4	177 (350)	21.1 (3060)	20.7-22.0 (3000-3200)	Co/Comp	213 (415)
	3	204 (400)	13.4 (1940)	12.7-14.1 (1840-2050)	Co	213 (415)
329 (625)	3	RT (RT)	17.0 (2470)	16.4-17.8 (2380-2590)	Comp	210 (410)
	3	177 (350)	18.6 (2710)	18.3-19.3 (2660-2800)	Co/Comp	210 (410)
	4	204 (400)	10.5 (1520)	8.8-12.0 (1280-1740)	Co	213 (415)
343 (650)	3	RT (RT)	19.9 (2890)	19.0-20.6 (2760-3000)	Comp	215 (419)
	3	177 (350)	17.2 (2490)	16.0-19.1 (2320-2780)	Co/Comp	209 (408)
	4	204 (400)	9.1 (1320)	6.9-11.4 (1000-1650)	Co	213 (415)

[a] Bonding conditions: 2.07 MPa (300 psi) pressure, heating rate of 8°C/min (14°F/min), RT → cure temperature, held 1 h.
[b] Composite-Comp, cohesive-Co.
[c] Single measurement made on adhesive flashing.

Table 3.

LSS test results of thermal exposure for 422 adhesive bonded composite

Time of exposure at 204°C (400°F) [h]	Number of specimens	Test temperature [°C(°F)]	Average LSS [MPa (psi)]	Range of LSS [MPa (psi)]	Primary failure mode[a]	Glass transition temperature, T_g[b] [°C (°F)]
0 (controls)	4	RT (RT)	19.4 (2820)	18.0-21.4 (2620-3100)	Comp	206 (403)
	4	177 (350)	21.1 (3060)	20.7-22.0 (3000-3200)	Co/Comp	213 (415)
	3	204 (400)	13.4 (1940)	12.7-14.1 (1840-2050)	Co	213 (415)
500	4	RT (RT)	14.6 (2120)	12.9-17.8 (1870-2580)	Comp	218 (424)
	4	177 (350)	20.1 (2920)	19.4-21.0 (2820-3040)	Comp	214 (417)
	4	204 (400)	13.4 (1950)	12.4-14.4 (1800-2090)	Co	215 (419)
1000	4	RT (RT)	11.1 (1610)	10.1-11.7 (1460-1700)	Comp	217 (428)
	4	177 (350)	13.6 (1970)	12.0-15.3 (1750-2220)	Comp	220 (428)
	3	204 (400)	15.4 (2230)	14.1-16.5 (2050-2400)	Co	213 (415)
5000	4	RT (RT)	11.1 (1610)	10.2-12.7 (1480-1840)	Comp	220 (428)
	4	177 (350)	12.8 (1860)	10.9-13.6 (1580-1980)	Comp	218 (424)
	4	204 (400)	15.5 (2240)	14.6-16.1 (2120-2330)	Comp	217 (423)

Bonding conditions: 2.07 MPa (300 psi) pressure, heating rate of 8°C/min (14°F/min), RT → 316°C (600°F), held 1 h.

[a] Composite-Comp, cohesive-Co.

[b] Single measurement made on adhesive flashing.

Table 4.

LSS test results of thermal exposure for 422 adhesive bonded Ti-6Al-4V

Time of exposure at 204°C (400°F) [h]	Number of specimens	Test temperature [°C(°F)]	Average LSS [MPa (psi)]	Range of LSS [MPa (psi)]	Primary failure mode[a]	Glass transition temperature, T_g[b] [°C (°F)]
0	10	RT (RT)	36.0 (5220)	30.8-41.6 (4480-6040)	Co	203 (397)
(controls)	10	177 (350)	22.4 (3250)	21.1-23.4 (3060-3400)	Co	-- --
	9	204 (400)	15.6 (2260)	10.4-17.6 (1530-2550)	Co	-- --
1000	4	RT (RT)	34.2 (4960)	31.8-36.9 (4620-5350)	Co	221 (430)[c]
	4	177 (350)	24.0 (3480)	22.5-25.1 (3260-3640)	Co	-- --
	4	204 (400)	19.0 (2760)	18.0-20.3 (2610-2950)	Co	-- --
5000	4	RT (RT)	21.0 (3040)	19.2-23.3 (2790-3380)	Co/Ad	222 (432)
	4	177 (350)	23.1 (3350)	21.9-23.8 (3180-3450)	Co	221 (430)
	4	204 (400)	17.0 (2470)	15.2-18.6 (2200-2700)	Co	216 (421)
10000	4	RT (RT)	12.0 (1740)	5.5-18.3 (800-2660)	Co/Ad	212 (414)
	4	177 (350)	10.2 (1480)	3.2-14.4 (460-2090)	Co/Ad	178 (352)
	4	204 (400)	3.0 (430)	1.9-5.1 (280-740)	Co	168 (334)
20000	4	RT (RT)	4.9 (710)	2.6-11.0 (380-1600)	Co	166 (331)
	4	177 (350)	7.1 (1030)	6.3-7.9 (920-1150)	Co	160 (320)
	4	204 (400)	5.6 (820)	3.8-8.1 (550-1170)	Co	160 (320)

Bonding conditions: 2.07 MPa (300 psi) pressure, heating rate of 8°C/min (14°F/min), RT → 343°C (650°F), held 1 h.

a Cohesive-Co, adhesive-Ad.

b Single measurement made on fractured area of tested lap shear specimen.

c Average of three measurements.

Table 5.

LSS test results of a 72-h water boil for 422 adhesive bonded composite

	Number of specimens	Test temperature [°C(°F)]	Average LSS [MPa (psi)]	Range of LSS [MPa (psi)]	Primary failure mode[a]	Glass transition temperature, T_g[b] [°C (°F)]
controls	4	RT (RT)	19.4 (2820)	18.0-21.4 (2620-3100)	Comp	206 (403)
	4	177 (350)	21.1 (3060)	20.7-22.0 (3000-3200)	Co/Comp	213 (415)
	3	204 (400)	13.4 (1940)	12.7-14.1 (1840-2050)	Co	213 (415)
72-h water boil	4	RT (RT)	16.3 (2360)	14.5-18.6 (2110-2700)	Comp	210 (410)
	4	177 (350)	10.2 (1470)	8.8-11.9 (1270-1730)	Co/Ad	210 (410)
	4	204 (400)	4.2 (610)	2.8-5.5 (400-800)	--[c]	216 (421)

Bonding conditions: 2.07 MPa (300 psi) pressure, heating rate of 8°C/min (14°F/min), RT → 316°C (600°F), held 1 h.

[a] Composite-Comp, cohesive-Co, adhesive-Ad.

[b] Single measurement made on adhesive flashing.

[c] Thermoplastic failure.

Table 6.

LSS test results of a 72-h water boil for 422 adhesive bonded Ti-6Al-4V

	Number of specimens	Test temperature [°C(°F)]	Average LSS [MPa (psi)]	Range of LSS [MPa (psi)]	Primary failure mode[a]	Glass transition temperature, T_g[b] [°C (°F)]
controls	10	RT (RT)	36.0 (5220)	30.8-41.6 (4480-6040)	Co	203 (397)
	10	177 (350)	22.4 (3250)	21.1-23.4 (3060-3400)	Co	-- --
	9	204 (400)	15.6 (2260)	10.4-17.6 (1530-2550)	Co	-- --
72-h water boil	4	RT (RT)	28.8 (4180)	20.7-29.8 (3920-4320)	Co	205 (401)
	4	177 (350)	13.3 (1940)	12.9-13.9 (1870-2020)	Ad	200 (392)
	4	204 (400)	4.6 (670)	3.8-6.5 (550-940)	Ad	202 (396)

Bonding conditions: 2.07 MPa (300 psi) pressure, heating rate of 8°C/min (14°F/min), RT → 343°C (650°F), held 1 h.

[a] Cohesive-Co, adhesive-Ad.

[b] Single measurement made on fractured area of tested lap shear specimen.

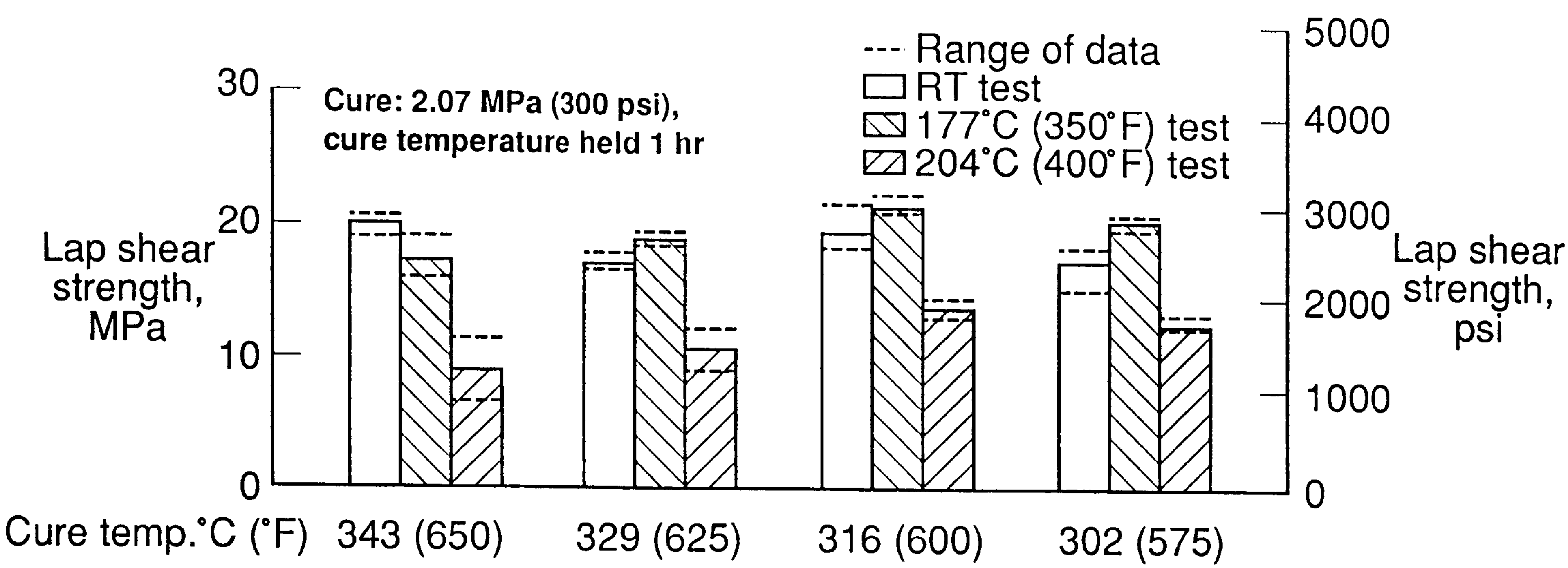
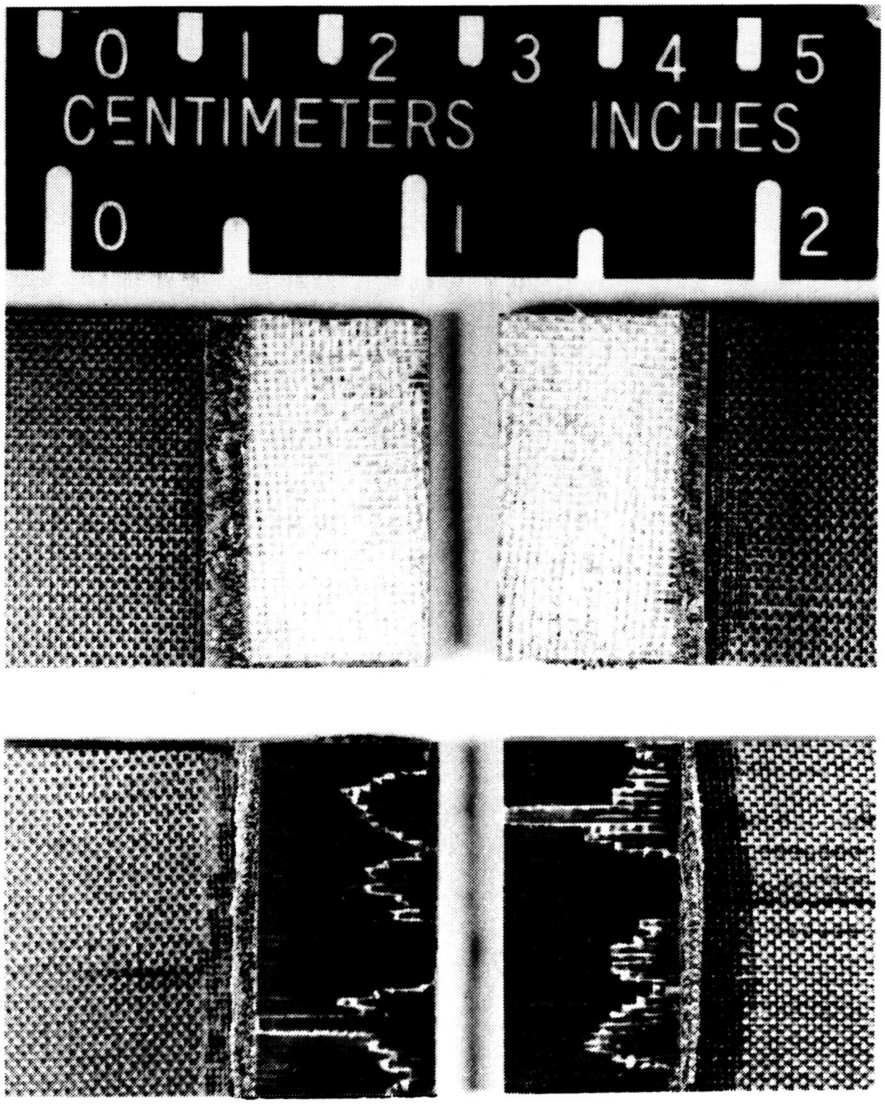


Figure 1. Effect of cure temperature on the LSS for 422 adhesive bonded LARC-160/Celion 6000 composite.



Cohesive failure

Composite failure

Figure 2. Shows cohesive and composite type failure (near the composite/adhesive interface).

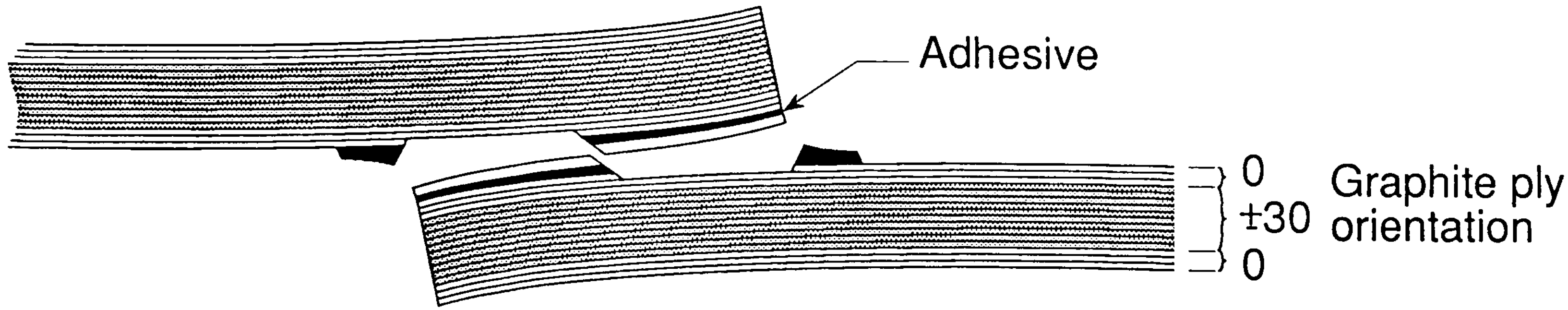


Figure 3. Illustration of composite failure in the "first ply" and the ply orientation $(0,0,0,+30,-30,+30,-30)_s$.

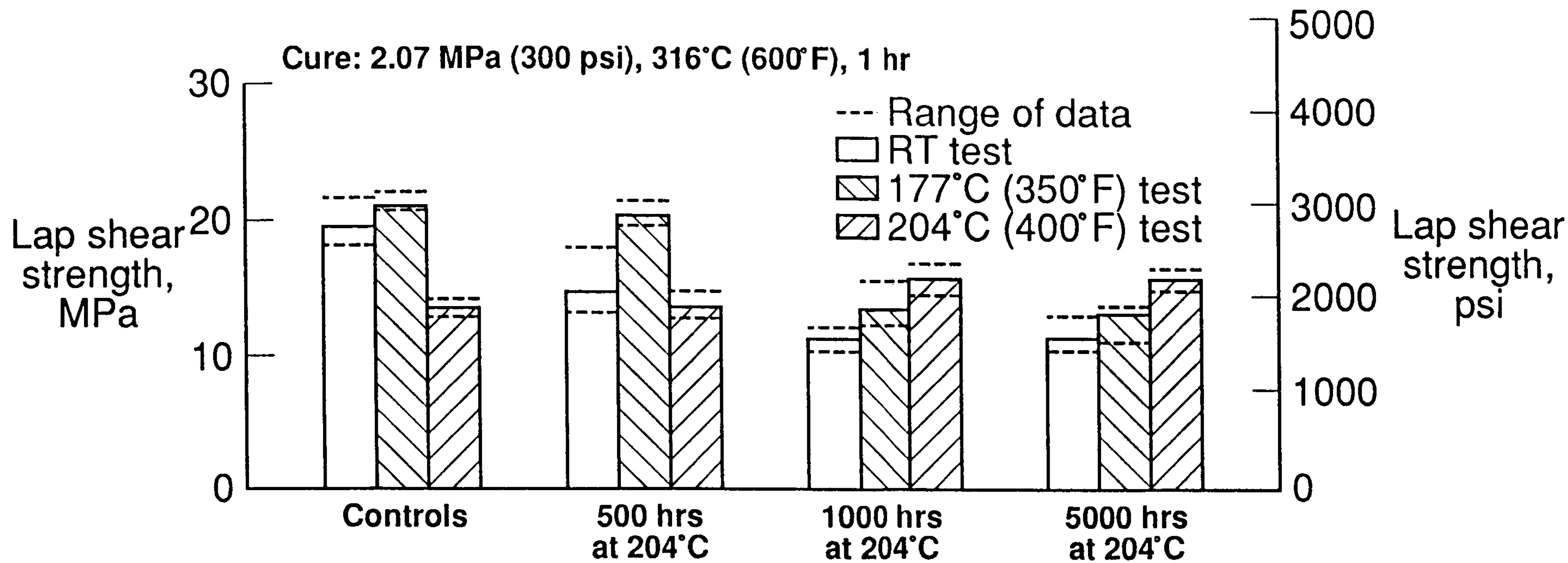


Figure 4. Effect of thermal exposure in air at 204°C (400°F) for 422 adhesive bonded composite.

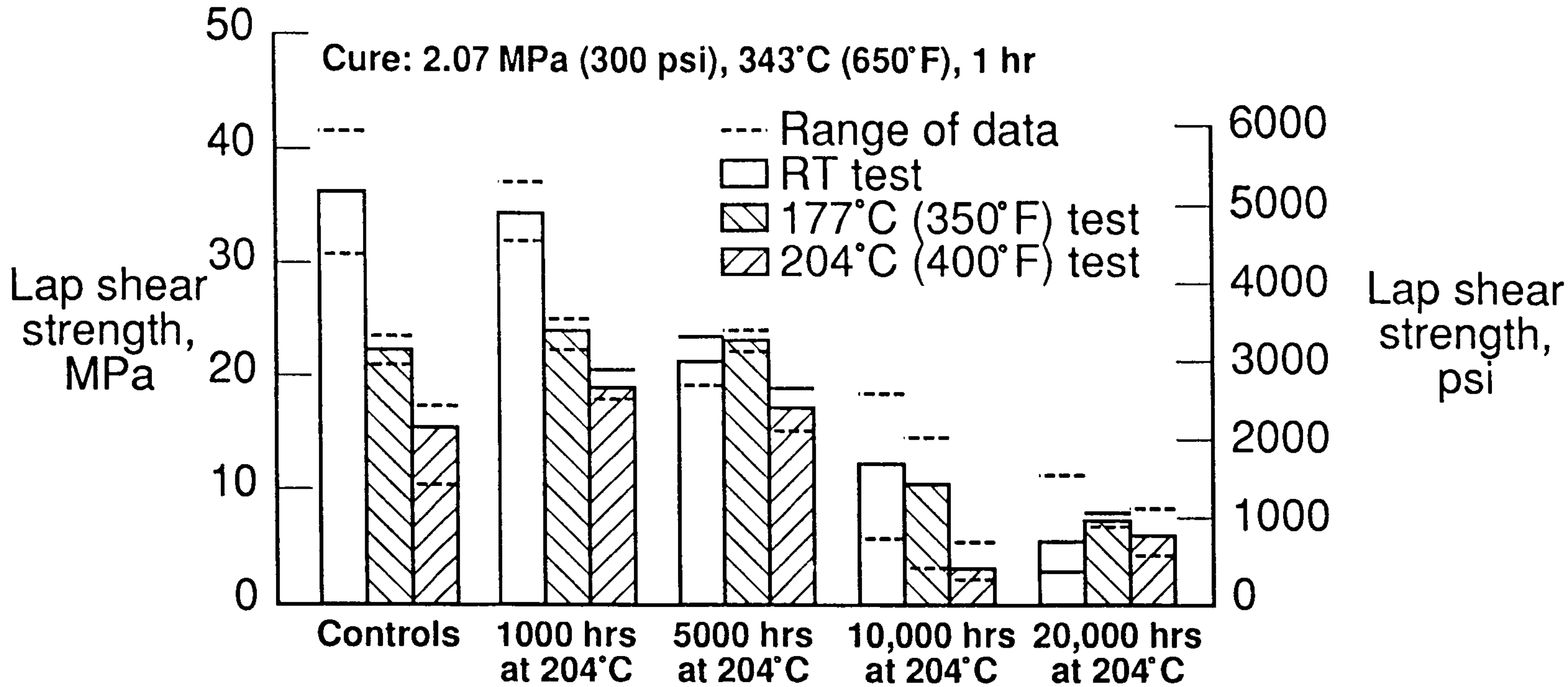


Figure 5. Effect of thermal exposure in air at 204°C (400°F) for 422 adhesive bonded Ti-6Al-4V.

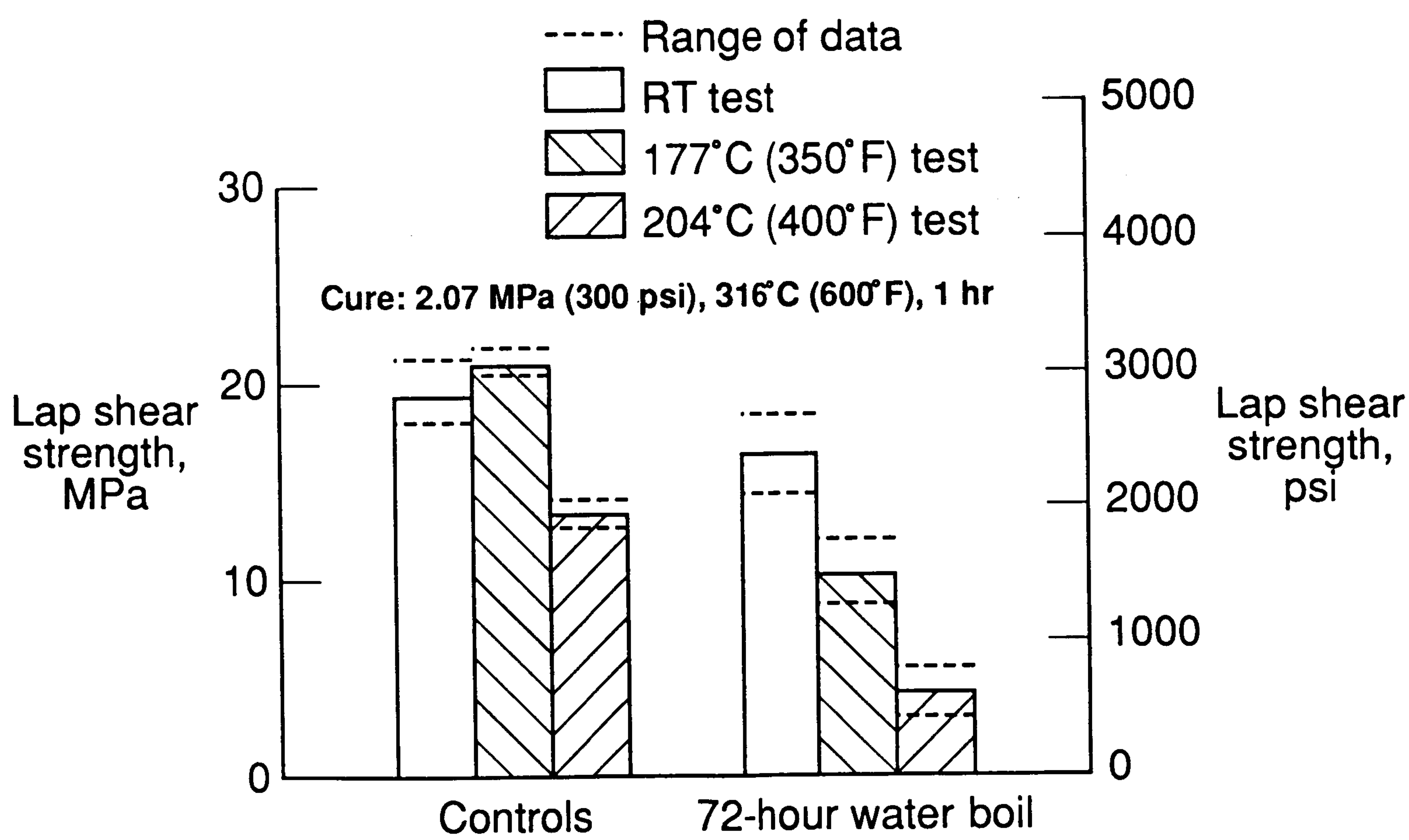


Figure. 6 Effect of a 72–h water boil on the LSS for composite bonded with 422 adhesive.

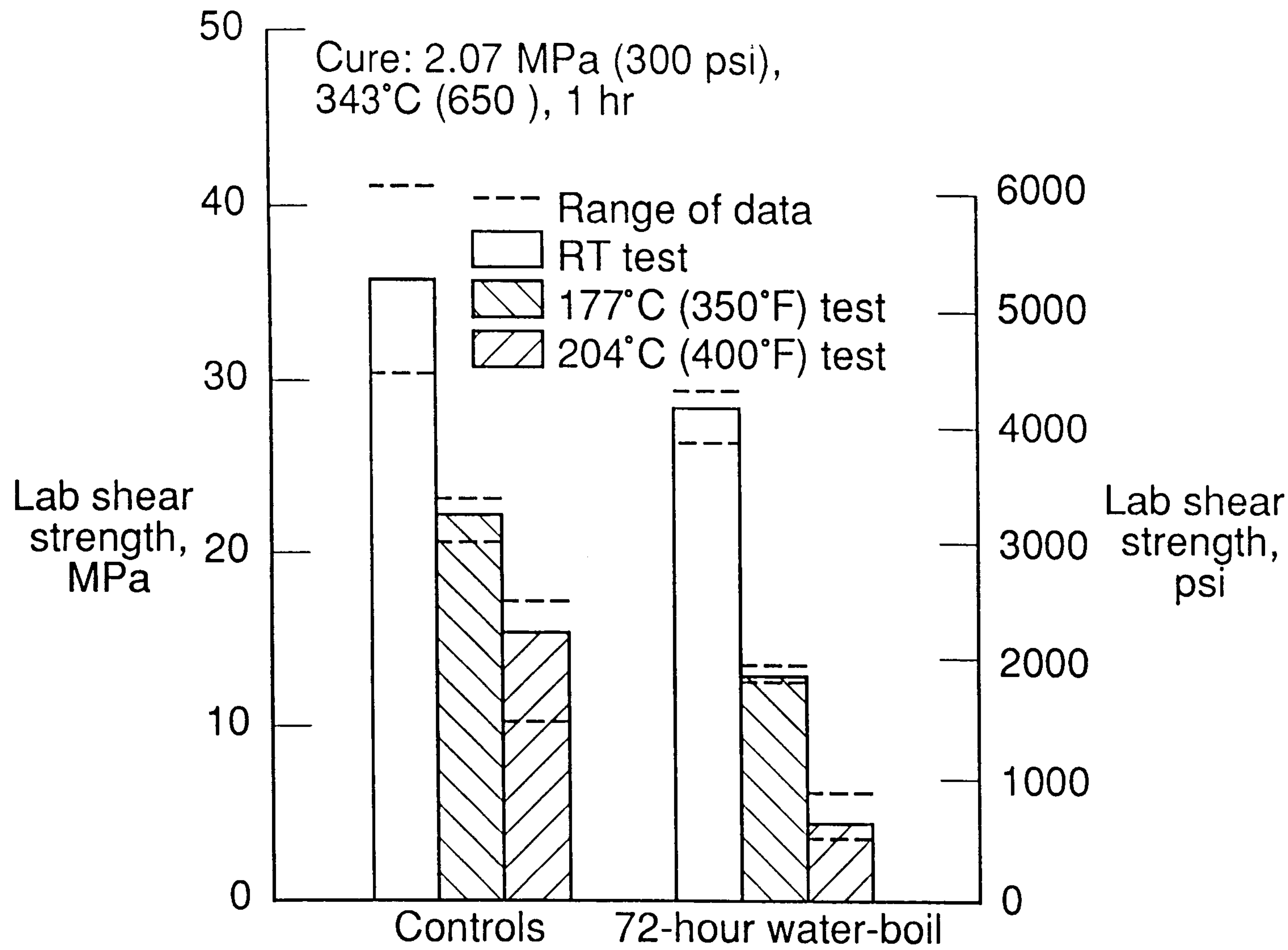


Figure 7. Effect of a 72-h water boil on the LSS for Ti-6Al-4V bonded with 422 adhesive.

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16. Abstract

A hot-melt processable copolyimide previously synthesized and characterized as an adhesive at NASA Langley Research Center for bonding Ti-6Al-4V was used to bond Celion 6000/LARC-160 composite. Comparisons are made for the two adherend systems. A bonding cycle was determined for the composite bonding and lap shear specimens were prepared which were thermally exposed in a forced-air oven for up to 5000 h at 204°C. LSSs were determined at RT, 177°C, and 204°C. After thermal exposure to 5000 h at 204°C, RT and 177°C LSS decreased significantly; however, a slight increase was noted for the 204°C test.

Initially the LSS values are higher for the bonded Ti-6Al-4V than for the bonded composite, however, the LSS decreases dramatically between 5000 h and 10000 h of 204°C thermal exposure. Longer periods of thermal exposure up to 20000 h results in further decreases in LSSs. Although the bonded composite retained useful strengths (> 11.1 MPa) for exposures up to 5000 h, based on the poor results of the bonded Ti-6Al-4V beyond 5000 h, the 422 adhesive bonded composites would most likely also produce poor strengths beyond 5000 h exposure.

Adhesive bonded composite lap shear specimens exposed to boiling water for 72 h exhibited greatly reduced strengths at all test temperatures. The percent retained after water boil for each test temperature was essentially the same for both systems.

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