Journal of Mechanical Engineering Research Vol. 3(5), pp. 162-167, May 2011
Available online at http://www.academicjournals.org/jmer
ISSN 2141-2383 ©2011 Academic Journals

Full Length Research Paper

Adhesive bonded single lap and over-lap joints of C/C, C/C-SiC composites and titanium alloy

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Accepted 28 March, 2011

Carbon-carbon (C/C), carbon-carbon-silicon carbide (C/C-SiC) composites and titanium alloy substrates were bonded in single lap and overlap joints with phenolic resin to study the differences in joint strength of two similar and dissimilar materials under shear load. The results indicate that the bonding strength of single lap joint of C/C, C/C-SiC is more than the other ceramic and titanium alloy, whereas Ti-Ti bonded over lap joints show remarkable improvement in similar and dissimilar substrates. Scanning electron microscope (SEM) describes the surface morphology and indicates the bonded zone fractured in the form of thin film which shows strong interaction in between two surfaces.

Key words: C/C composite, C/C-SiC composite, titanium alloy, adhesive joints, bonding strength.

INTRODUCTION

Generally, ceramic matrix composites have been developed to combine the advantageous properties of monolithic ceramics with a high damage tolerance, which is known for example from the reinforcing of fibres reinforced polymers. However, the mechanisms, which cause high damage tolerance, are completely different for both classes of materials. Polymers are reinforced with strong and stiff fibres, whereas the matrix is weak and of low strength stiffness with thermal stability as well.

To achieve the minimum saving in weight without sacrificing strength, scientists and engineers face the problem of developing methods for joining structural ceramic composite components with metallic components without weakening or damaging them. It is impossible to use conventional fastening techniques without drastically affecting the strength of fibre-reinforced composites. Adhesive bonding is a desirable alternative to mechanical fastening in composite/metallic structures. Even with all the potential advantages and encouraging experience with adhesive bonding, manufacturers still hesitate to use this technology especially for the application at high-temperature structural components. For high-temperature industrial application, a large number of alternative materials are available in the market. High-temperature plastic instability, thermal activation of secondary slip systems, inadequate corrosion and oxidation resistance, cracking during thermal cycling and high inherent density limit the use of metallic materials in weight sensitive applications (Kleefisch, 1981).

Carbon–carbon composite is essentially composed of only graphite and carbon materials. It is not possible to use graphite and carbon materials separately for critical applications unless and until the introduction of carbon–carbon composite materials with higher toughness. A typical carbon–carbon composite consists of pitch-based carbon fibre composite in a carbon matrix made by chemical vapour infiltration and/or impregnation of organic binders. Carbon–carbon composites are lightweight and high strength and are expected to be used as heatproof materials in the field of spacecraft and nuclear fusion. However, the practical application of these composites is markedly restricted when used in an oxidative atmosphere at high temperature because of low oxidation protection (Taylor et al., 1983). To provide oxidation resistance for reuse capability, the outer layers of the reinforced carbon–carbon composites are converted to silicon carbide. Sometimes, additional oxidation protection is required to make full use of carbon-carbon composites at high-temperature

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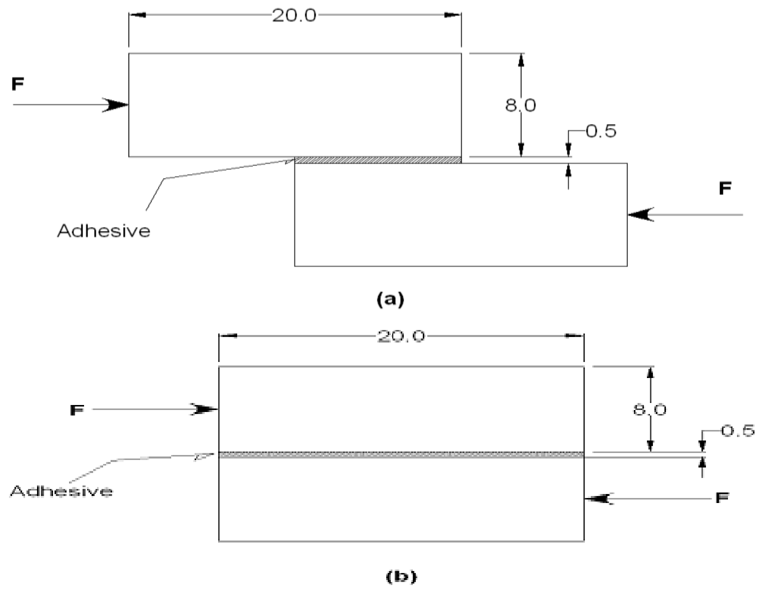

Figure 1. (a) Single lap joint and (b) overlap joint under shear force (F). All dimensions are in mm.

applications (Konstadimidis et al., 1993; Arendts et al., 1995; Srivastava et al., 1999; Krenkel et al., 2002). On the other hand, titanium metal is also one of the useful materials for the aerospace industries due to better mechanical properties than many alloy steel. Ti–6Al–4V alloy has a high specific heat and stability up to 400°C and good corrosion resistance (Dasilva et al., 2007). Titanium (Ti) is allotropic in nature and changes in α-phase at temperature below 800°C and in β-phase at temperature above 800°C.

Adhesive joints are increasingly being used due to their improved mechanical performance and better understanding of the interface strength. High temperature bonding technique between C/C composite has been reported by several authors (Koyama et al., 2005; Dasilva et al., 2007; Hatta et al., 2009). Koyama et al. (2005) studied that the bonding strength is enhanced by minimizing bonding thickness, in that bonding strength became higher than interlaminar shear strength of the substrate C/C composite. C/C, C/C–SiC composites and Ti–6Al–4V alloy are prime materials for structural use at high temperature. The stability and long-term reliability of a metal/composite interface are key objectives in the design and manufacturing of joints and this totally depends on the surface chemistry (Dasilva et al., 2007). Konstadinidis et al. (1993) have stated that the Ti adsorption is greatly affected by oxygen in the polymer film that is either present in the polymer, during metal deposition or quickly diffuses into the polymer.

The main objective of this study is to see the performance of single lap and overlap joints of two similar and dissimilar substrates like C/C, C/C-SiC composites and Ti–6Al–4V alloy. The surface morphology was obtained by the scanning electron microscope (SEM) method.

EXPERIMENTATION

The adherent materials, Ti–6Al–4V alloy, carbon-carbon composite (C/C) and carbon–carbon–silicon carbide composite (C/C–SiC), were used as substrates. Thickness of C/C and C/C–SiC composite sheet was 3 mm for the single lap and overlap bonded joints. C/C-SiC composite was manufactured by liquid siliconising infiltration (LSI) method in the form of rectangular plates, 3 mm of nominal thickness. C/C-SiC is tough ceramics when the fibre matrix bonding is properly optimized usually through a thin layer of an interfacial material referred to as the interphase. The investigations refer to cross-woven ($0^o/90^o$) C/C-SiC composites with HTA carbon fibre (ϕ=7 μm) as reinforcement, and the matrix is silicon carbide. The volume fractions are 60% carbon fibre, 38% silicon carbide and 2% silicon.

A processing route of performed yarn method produced the carbon-carbon (C/C) rectangular plates of 3 mm thickness at the orientation of $0^o/90^o$ and volume fraction 50% with PAN based high modulus carbon fibre Trayca M40. However, dense population of fibres and matrices were formed. The alloy Ti–6Al–4V was obtained from M/S Midhani, Hyderabad, India. Due to outstanding properties over other materials in different environments, Ti-alloys are used in airframe structure, although Ti–6Al–4V alloy sheets are also available with the thickness of 3 mm.

The specimens (20 mm long, 8 mm wide and 3 mm thick) for adhesive single lap and overlap joints (Figure 1a and b) were prepared with a water-cooled diamond cutting wheel and dried for a few hours at room temperature. The flat surfaces of the Ti–6Al–4V alloy, C/C and C/C–SiC composites were properly degreased and cleaned. The cleaned surface was etched for 30 s followed by distilled water cleaning and acetone rinsing. The abraded area was cleaned with vacuum cleaner. After proper cleaning of adherent surface, phenolic resin was selected as adhesive on the basis of good quality for high-temperature applications.

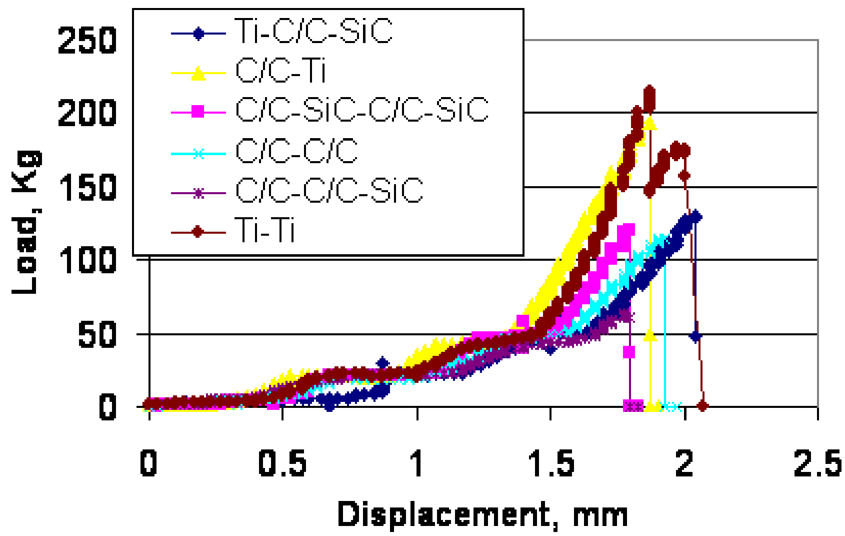

Figure 2. Variation of load with the displacement of over lap joint with phenolic resin adhesive.

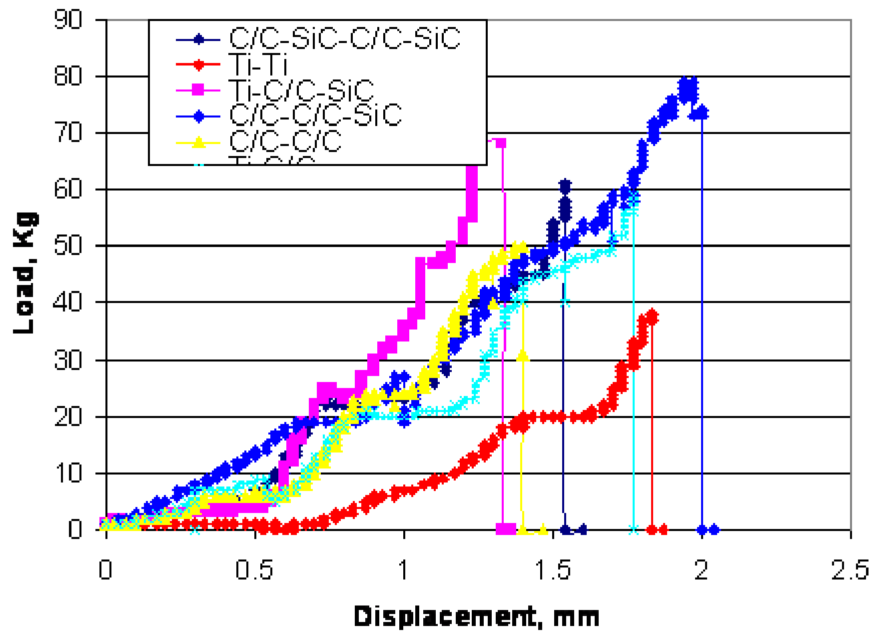

Figure 3. Variation of load with the displacement of single lap joint with phenolic resin adhesive.

A thin layer of adhesive mixture of phenolic resin (glue thickness of 0.5 mm) was applied onto the surface of composites and Ti–6Al–4V alloy sheets. To ensure the perfect bonding, an optimized curing time was used. For the conditioning, samples were preserved for few days in a moisture-free container. Single lap and overlap joints specimens were prepared for the experimental observations. A typical combination of friction-based shear grips for Ti, C/C and C/C–SiC adherents, compression press type fixture were used for the shear loading of bonded joints. All results were obtained on Universal Testing Machine with the cross-head speed of 10 mm/min. Finally, the morphology of fractured surfaces was obtained by the use of SEM to investigate the behaviour of the crack pattern.

RESULTS AND DISCUSSION

It can be seen in Figures 2 and 3 that the fracture load of adhesive bonded single lap and overlap joints of C/C, C/C-SiC composites and Titanium specimens shows

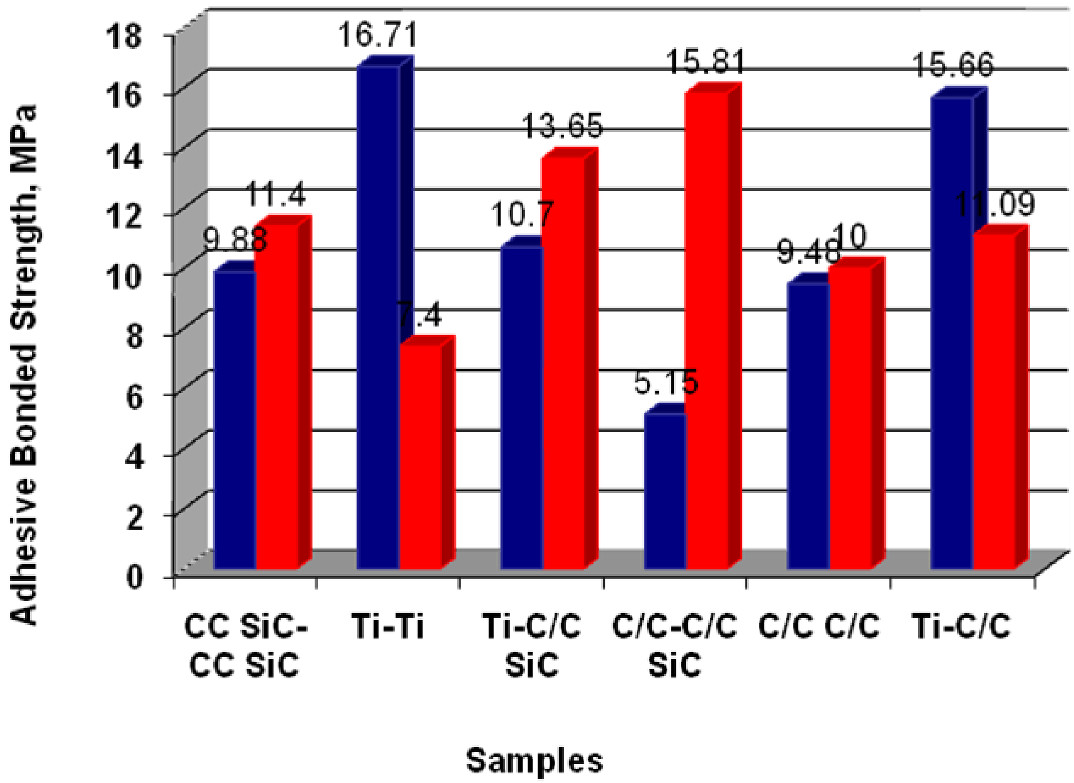

Figure 4. Variation of adhesive bonded strength with the different joints amid phenolic resin (Blue - over lap; Red - single lap).

increments with the increase of displacement. Single lap joint of C/C and C/C-SiC substrate gives higher bonding strength than the other similar and dissimilar substrates, whereas overlap joint of Ti and Ti substrates show very high strength when compared to the other substrates and single lap joints as shown in Figure 4.

Single lap and overlap joints of C/C-SiC-C/C-SiC, C/C-SiC-C/C, C/C-C/C, C/C-SiC-titanium, C/C-titanium and titanium-titanium specimens bonded with phenolic resin were fractured under the action of shear stress, as can be seen in Figures 5 and 6. Also, it is clear that both surfaces are fractured in different planes, because the phenolic resin is used to increase the interface bond strength in between two surfaces. However, the main advantages of phenolic resin are that its adhesive properties increased with the increase of temperature as reported by several authors (Dasilva et al., 2007). It is widely known that the fundamental reason behind the success of the joints over the basic geometry is the gentle and gradual stiffness blending between one adherent and another adherent. The improvement of strength may be caused by an increased ability to accommodate the applied strain upon loading through increased flexibility of the adhesive layer. This clearly involves a different crack pattern of titanium alloy substrate, where C/C and C/C–SiC composite substrates cracks were initiated at the phenolic resin / carbon fibre / silicon carbide interfaces.

The surfaces of C/C–SiC and Ti–6Al–4V substrates indicate that the surface feature of C/C and C/C–SiC substrate is very rough than the Ti–6Al–4V substrate, as can be identified from Figures 5 and 6. When these surfaces are coated by adhesive and exposed in the environment, the interface surfaces degraded and lost the bonding strength (Hatta et al., 2009). It can be seen in general that this thermodynamic criterion for discussion at the interface leads to debonding between adhesives and high-energy substrates such as Ti–6Al–4V metal, but not between adhesives and low-energy surfaces such as C/C and C/C–SiC composites. This clearly provides a valid explanation for the observed reductions of bond strengths in Ti–6Al–4V/phenolic resin interface and C/C–SiC/phenolic resin interface. For the fact that the oxygen found within the polymer plays an important role in the interfacial region forming an oxide with Ti, and also the oxygen reacts with carbon and forms carbon dioxide within the adherent side, this weakens the adhesive bond strengths of Ti–6Al–4V and C/C–SiC composites.

Conclusions

Based on the experimental observation, the results can

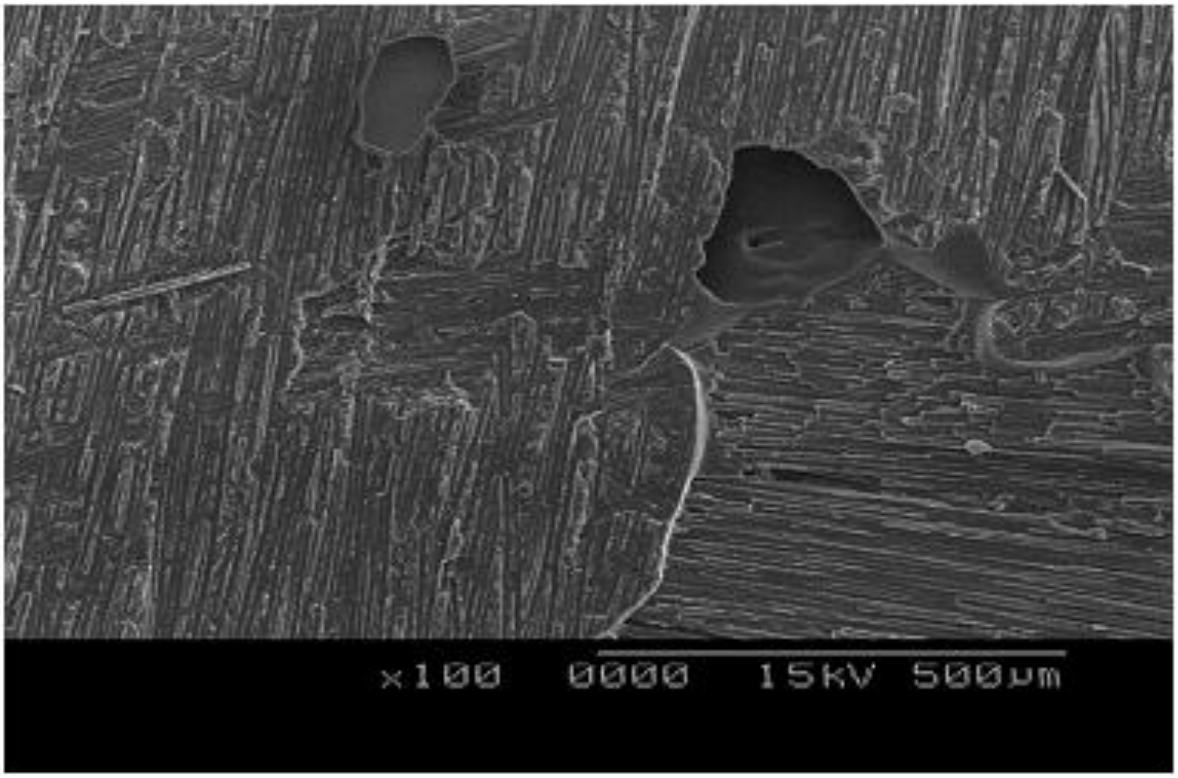

Figure 5. SEM micrograph showing the different planes of C/C-C/C composite, bonded with phenolic resin (500 µm).

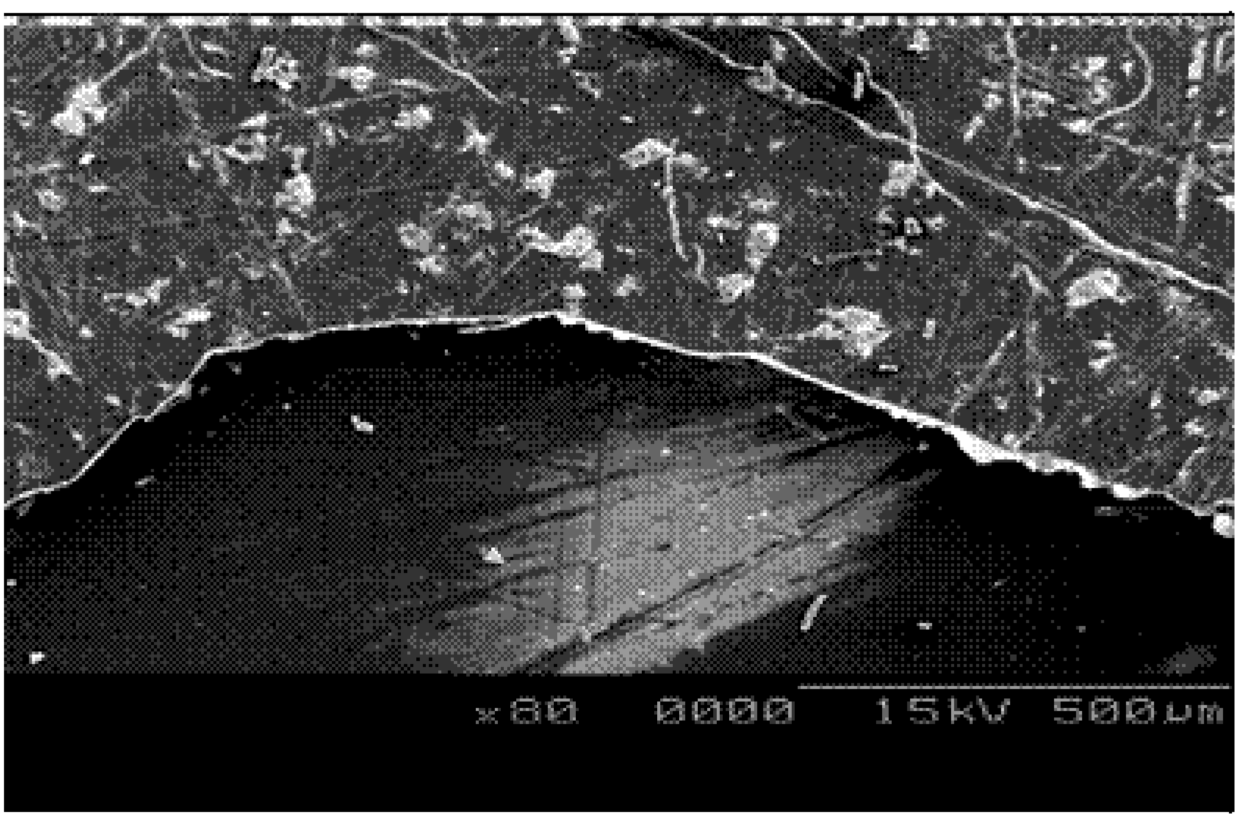

Figure 6. SEM micrograph showing the different layers of Ti-C/C-SiC composite, bonded with phenolic resin (500 µm).

be concluded that the single lap joint of C/C and C/C-SiC substrates give higher value than the other substrates under shear load like C/C-SiC-C/C-SiC, C/C-SiC-C/C, C/C-C/C, C/C-SiC-titanium, C/C-titanium and titanium-titanium. On the other hand, the overlap joint of Ti-Ti substrate gives another very high strength than the other substrates and single lap joint strength. However, adhesive bonded joints of metal to metal and metal to composite resulted to higher value than similar substrates due to unbalance stiffness.

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