Effect of HTT on Bending and Tensile Properties of 2D C/C Composites

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Abstract

Bending and tensile properties of 2D cross-ply C/C composites with processing heat treatment temperature (HTT) are evaluated. C/C composites used are made from two types of PAN based T700 and M40 carbon fibers with phenolic resin as carbon matrix precursor. Both the types of composites are heat treated at different temperatures (ranging from 750 to 2800°C) and characterized for bending and tensile properties. It is observed that, real density and open porosity increases with HTT, however, bulk density does show remarkable change. The real density and open porosity are higher in case T-700 carbon fiber composites at 2800°C, even though the density of M40 carbon fiber is higher. Bending strength is considerably greater than tensile strength through out the processing HTT due to the different mode of fracture. The bending and tensile strength decreases in both composites at 1000°C which attributed to decrease in bulk density, thereafter with increase in HTT, bending and tensile strength increases. The maximum strength is in T700 fiber based composites at HTT 1500°C and in M40 fiber based composites at HTT 2500°C. After attaining the maximum value of strength in both types of composite at deflection HTT, after that strength decreases continuously. Decrease in strength is due to the degradation of fiber properties and in-situ fiber damages in the composite. The maximum carbon fiber strength realization in C/C composites is possible at a temperature that is same of fiber HTT. It has been found first time that the bending strength more or less 1.55 times higher in T700 fiber composites and in M40 fiber composites bending strength is 1.2 times higher than tensile strength of C/C composites.

Keywords: Carbon/Carbon composites. Heat treatment. Mechanical properties

1. Introduction

Carbon-Carbon (C/C) composites are made from brittle matrix as well as brittle fibers can exhibit high strength and stiffness [1, 2]. They possess low density, superior thermo-mechanical properties as well as remarkable damage tolerance that makes them promising materials for high temperature structural applications as compared to monolithic ceramics [2, 3]. Also a number of these composites receiving more attention as an ideal material for reciprocating component of intermittent combustion engines [4]. The performance of C/C composite is known to depend on the type of carbon fibers, matrix precursors, weave geometry, nature of bonding between the fibers and matrix (fiber-matrix interactions) and processing conditions [5, 6]. In particular, mechanical properties of C/C composites are very sensitive to the bonding between fibers and the matrix. The C/C composites does not obey the rule of mixture, because of difference in the properties of individual constituent [7] and low strength of carbon derived from polymeric matrix [1]. But at high temperature carbon matrix properties play an important role in the realization of fiber properties in C/C composites at high temperature [1]. There are only few studies are reported on the problem addressing the effect of heat treatment temperature on mechanical properties of C/C composites [8-11] but these studies are limited to bending strength and some of them for tensile strength. Manocha et al. [9] reported that, flexural strength of (surface treated and non surface treated carbon fiber reinforced polyfurfuryl alcohol matrix based) C/C composite increases with heat treatment up to temperature 2000°C. Thereafter with increase in HTT of composite, strength decreases which is related to decrease in interlaminar shear strength due to graphitization of matrix. On the other hand, Zaldivar et al. [10] reported tensile strength of polypyrrole (PAA) based carbon matrix composites after heat treatment at 1800°C increases because weakening of fiber-matrix interface owing to more graphitic matrix structure. Baxter et al. [11] reported the flexural strength of (unidirectional furf resin based) C/C composites decreases after heat treatment at on 2200°C, which is attributed to the structural development of carbon matrix. But no one study addresses the effect of HTT on both tensile and bending properties of 2D C/C composites and relationship between them.

Therefore, in present investigation systematic approach is adapted to study both bending and tensile properties of 2D cross-ply C/C composites made from two types of PAN based carbon fibers with processing HTT. Also examine if
there is any relationship between bending and tensile strength of C/C composites, because the fracture mechanism is different in both the test. In this direction, two types of carbon fibers possessing different properties are used. The high strength carbon fiber T700 heat treated to temperature ~1500°C and M40 carbon fiber heat treated to temperature >2200°C. Therefore, these fibers have different surface characteristics and mechanical properties. How these different fibers affect on the ultimate bending and tensile properties, fracture behavior of 2D C/C composites with processing HTT are investigated.

2. Experimental

In the present study two types of 2D cross-ply (0°/90°) C/C composites were used (supplied by Across company Ltd., Japan). These composites were made from polyacrylonitrile (PAN) based T700 high strength and M40 high modulus carbon fibers (produced by Toray Industries Inc., Japan) as reinforcements and resole type phenolic resin as matrix precursor. In both the type of composites fiber volume fraction was 50% at polymer stage. The two type of carbon fibers possess different properties were listed in Table 1. These composites were heat treated at 750, 2000 and 2500°C in inert atmosphere (supplied by Across company, Japan), additional heat treatment was performed on 750°C heat treated composites to at 1000, 1500 and 2800°C in Institute of Space and Astronautical Science (ISAS, JAXA) Kanagawa, Tokyo. The composites heat treated in vacuum and inert atmosphere at the heating rate of 10°C/min and cooled down at same rate. These composites are made by preformed yarn method. In this method, bundles of carbon fibers and matrix are placed in nylon sheaths. These sheathed bundles are arranged unidirectionally and stitched together with thin nylon filament to produce a unidirectionally reinforced preform sheets. Then these sheets are laminated in to a symmetric cross-ply stacking sequence to form polymer cross-ply. The polymer bodies are hot-pressed in a mold and cured under pressure. These cured composites are heat treated at initially up to 750°C and further heat heated at different temperatures. The heat treated composites (at 750, 1000, 1500, 2000, 2500 and 2800°C) were characterized for bulk density, open porosity and real density by using Archimedes principle as per JIS R-1634. Distilled water was used as a liquid medium for the measurement. Bending strength of composites were measured by four point bending method with span length 100 mm and cross head speed 0.5 mm/min with specimen dimensions (120 mm x 9 mm x 3 to 3.5 mm) on Instron testing machine (Model 4482). The load was applied perpendicularly on one of the 0° oriented plies. Tensile strength was measured at room temperature on servo-hydraulic testing machine (Model 8502, Instron Corporation, USA). The dog-bone type specimens were used for tensile test. The tensile specimen with gauge length of 30 mm, thickness ~3 to 3.5 mm, and width 6 mm and over all length was 180 mm. The gripping regions of test specimens were protected by thick paper tabs. The tension was applied at constant speed 0.5 mm/min. The tensile strain is measured using strain gages adhered to both surfaces of each specimen; the average of the measured strains was used as representative value. The measurements were taken for the studied direction, two types of carbon fiber based composites. These composites were studied for micro-structural investigation to see how the fibers morphology changes in composites with HTT using the field emission scanning electron microscope (Model S-4700, Hitachi Ltd., Japan). The interlayer spacing of different heat treated C/C composites were measured by XRD with a Cu-Kα radiation under conditions of 40 kV and 200 mA and scan speed 0.1/min. (Model RINT2500, Rigaku Co., Tokyo, Japan).

3. Results and Discussion

3.1. Variation in bulk and real density with HTT

Table 1. Properties of fibers

<table>
<thead>
<tr>
<th>Fiber type</th>
<th>T700</th>
<th>M40</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tensile strength (MPa)</td>
<td>4900</td>
<td>2740</td>
</tr>
<tr>
<td>Tensile Modulus (GPa)</td>
<td>200</td>
<td>392</td>
</tr>
<tr>
<td>Density (gm/cm³)</td>
<td>1.80</td>
<td>1.81</td>
</tr>
<tr>
<td>Strain to failure (%)</td>
<td>2.1</td>
<td>0.6</td>
</tr>
<tr>
<td>HTT of fibers (°C)</td>
<td>~1500</td>
<td>&gt;2200</td>
</tr>
</tbody>
</table>

Fig. 1 (a and b) shows the variation in bulk density (BD), real density (RD) and open porosity (OP) with processing HTT of T700 and M40 carbon fiber based composites. These three parameters are related to each other. Initially the bulk density of as received (HTT 750°C) T700 fiber based composite is (1.687 g/cm³) higher than that of M40 carbon fiber based composites (1.64 g/cm³). This is due to the compactness and strong fiber-matrix interactions in T700 fiber composites. With increase in processing HTT, bulk density continuously increases more or less but decreases at 1000°C in both composites. This is related to shrinkage due to evolution of volatile by-product from the matrix phase, because up to 750°C, carbonization of matrix is not completed. After that bulk density increases continuously up to HTT 2800°C in both the cases and maximum density is 1.695 g/cm³ of T700 fiber based composite. However, lower value of bulk density of composites heat treated at 2000 and 2500°C is because of we have received these composites already heat treated from (Across company Ltd., Japan), may they have to different processing parameter during HTT.

The real density and open porosity increases with processing HTT in both the types of composites are measured by using Archimedes principle. In both the composites real
density decreases at 1000°C and open porosity increases suddenly. Further, with increasing the HTT, real density and open porosity increases moderately up to HTT 2800°C. The maximum real density and open porosity is noticed in T700 fiber based composites even though the density of M40 fiber is higher than T700 carbon fibers used in the study. The maximum real density and open porosity in T700 fiber composite is due to strong fiber-matrix interactions. Stronger is the fiber-matrix interactions, higher is degree of stress graphitization, as a consequence structural reorganization and opening of close porosity [8] this resulted into higher real density and open porosity. However, lower value of open porosity and real density is a cause of weak fiber-matrix interactions and as a consequence lower degree of stress graphitization in M40 fiber based composites [8]. In case of carbon fiber, with increasing the HTT, carbon fiber density, preferred orientation and degree of crystallinity increases and tensile strength decrease [12]. But on the other hand, in C/C composites bulk density does not show remarkable change because opening of closed porosity and as a result increase in open porosity and real density due to the orientation of graphitic plane parallel to the fiber axis at high temperatures.

3.2. Bending and Tensile strength with HTT

Fig. 2 (a and b) shows the variation in bending and tensile strength with processing HTT of C/C composites. Initially at 750°C the bending strength is (273 MPa) maximum in T700 fiber composite as compared to (136 MPa) M40 fiber composites which might be due to the strength of fibers itself is high and strong fiber-matrix interaction yielded in to high strength composites and weak fiber-matrix interaction yielded in to lower value of strength. This observation also confirms from open porosity data (Fig. 1), for T700 fiber based composite it is 3.83% and for M40 fiber based composite it is 5.16%. On HTT at 1000°C the bending strength decreases suddenly in both the composites are attributing to decrease in bulk density and increase in open porosity due to the matrix shrinkage is a cause of evolution of volatile by product, as a consequence increases in stress concentration.
centers. The strength of carbon-carbon composites is also dependent on the bulk density; composites possessing lower value of density yielded into low strength composite [13, 14]. Also, the decrease in strength is due to the conversion of the matrix from relatively compliant polymer to a low strain to failure carbon, since the matrix is well bonded and brittle in nature after heat treatment to 1000°C, a flaw or crack initiated in the matrix can propagate through the fibers, resulting more or less catastrophic failure because of crack tips are highly concentrated by stresses [15].

Fig. 4 load-displacement curve, composites fail catastrophically up to maximum value of load, thereafter load decreases subsequently at constant displacement in T700 fiber composites (Fig. 4a curve b). However, in M40 fiber composites, after catastrophic failure up to maximum value of load, after that displacement increases with decrease in the load (Fig. 4b, curve b). Further with increasing HTT, the bending strength increases with processing HTT in both the type composites. The maximum value of strength in T-700 carbon fiber composites at HTT 1500°C, after that the strength decreases slightly. The maximum value of strength at 1500°C is might be due to both the fiber and carbon matrix experience same temperature in composites. This observation is confirmed by taking the X-ray diffraction profile of T700 composites HTT 1500°C (Fig. 9a). Fig. 9 shows the symmetric peak of 002 and 100 fraction at 2θ = 22-28° and 40-45°, suggest that both the fiber and the matrix behave in same manner. As a result composites fracture at strain level at which both fiber and matrix reaches the maximum obtainable load [7]. Again further on heat treatment, bending strength of T700 fiber based composite decreases continuously up to 2800°C. Fig. 4a (d-e), load-displacement curve shows the pattern of fracture behavior after HTT 1500°C changes. This change in the load –displacement curve is due to the change in the microstructure. Micro-structural change with heat treatment facilitates graphitization in the composites. The graphitization reduces interfacial bonding strength between the fiber and the matrix with increasing HTT [16, 17]. The lower is the interfacial bond strength between the fiber and the matrix, higher is the bending or tensile strength [18, 19]. In the present study, phenolic resin is used as matrix and phenolic resin derived carbon is hard non-graphitizeable [1, 20]. Thus the fiber-matrix interactions are not to be sufficiently weak. But in the present investigation above 1500°C, strength of T700 fiber based composite decreases continuously up to 2800°C. This seems that the strength degradation with heat treatment is not related to the interfacial properties. In case of PAN based carbon fibers, with increasing the processing HTT above 1500°C, fiber diameter decreases and tensile strength also decreases [12]. There fore, in the present investigation, decrease in strength is attributed to the degradation of the fiber properties because T700 fiber heat-treated only up to 1500°C. In composites above 1500°C, fibers cross section is being started to distort with increasing HTT. This is due to the shrinkage in the fiber diameter and deviation in circular cross section. The deviation in circular cross section of fibers is due stresses exerting on fiber surface, stress concentration around the whole cross section of fibers because of irregular fiber surface. Overall effect is fiber damage with HTT above 1500°C. This effect is more pronounced at 2800°C is shown in Fig. 5 (SEM micrographs with HTT). Thus, decrease in strength above the HTT 1500°C is due to the degradation of fiber properties [21]. On the other hand, bending strength of M40 fiber based composite increases continuously after HTT 1000°C up to 2500°C. This continuous increase in bending strength is attributed to two factors (i) M40 carbon fibers used are heat treated to > 2200°C i.e., retention of strength of the fibers in composites and (ii) conversion of the matrix from amorphous carbon to a higher strain to failure graphitic type structure and as a result weakening of fiber-matrix interactions. It results the fracture of composite being less matrix dominated. Therefore, permits higher strain to failure of fiber, which ultimately contributes in fracture failure strain of composites. After 2500°C, bending strength of M40 fiber composite decreases, decrease in strength is related to degradation of fiber properties in composites as explain above. Because M40 fibers are heat treated at temperature > 2200°C and above this temperature the fiber morphology changes due to the shrinkage in fiber diameter and some deviation in cross section due the graphitization of the fibers (Figure 5, SEM M40-2800°C). In both the composites modulus of decrease is same from temperature 2500°C to 2800°C. This indicates that T700 fiber is behave like M40 fibers at high temperature in composites during bending test. But again one question arises here why the bending strength is highest at only 2500°C. As argued above for T-700 fiber based composites, maximum strength at HTT 1500°C same reasoning may applicable that both the fiber and the matrix experience same HTT 2500°C. This observation is confirmed by taking the X-ray diffraction profile of M40 composites HTT 2500°C (Fig. 9b). Fig. 9b shows the nearly symmetric peak of 002 diffraction at 2θ between 22-29°, suggest that both the fiber and the matrix behave in same manner. This resulted into composites fracture at strain level at which both fiber and matrix reaches the maximum obtainable stress.

Fig. 2b shows the variation in tensile strength with processing temperature of composites. The tensile strength is lower as compared to the bending strength. The change in tensile strength with processing temperature is same as that of bending strength. Only difference in the ultimate value of strength is due to the loading direction and mode of fracture. During tensile test fibers oriented in loading direction are under homogenous stress. On the application of stress, stress concentrations are induced at the tips of matrix micro-cracks and when the interface is strong, microcracks immediately cut the fibers and propagate straightly through the whole cross section of composites. On the other hand, fiber-matrix
interactions are weak, then the matrix during the tensile test get delaminated on the application of stress and ultimate fracture stress contributed from fibers. However, during bending test, upper most ply of 2D composites are under direct contact of load, micro-cracking take place from tensile loading direction and cracks travel from tensile to compressive loading side if the cracks are not change the propagation path.

The tensile strength is decreases from HTT 1500 to 2800 °C by 16.5% as compared bending strength 19% in case of T700 fiber composites. The extent of strength decrease is higher during bending test as compared to tensile test. Versa the increases in strength from HTT 1500 to 2800°C during tensile test are higher as compared to bending test in M40 fiber composites. This suggests that micro-structural changes occur above 1500°C in composites is responsible in lower increase of bending strength as compared to tensile strength.

Fig. 3 shows the relationship between bending and tensile strength of C/C composites with HTT. From the figure it observed that, above 1500°C there is direct relation ship between bending and tensile strength. Up to 1500°C, the strength is controlled very much by fiber-matrix interactions because different fibers have different magnitude fiber-matrix interactions with the matrix; hence it is very difficult to correlate the relation between bending and tensile strength. Above the 1500°C, in both the composites matrix phase is started to convert from amorphous carbon to graphitic type structure. Therefore, above HTT 1500°C, fracture of composites is less matrix dominated because the graphitic matrix fail in shear mode and as a result in both the composites above the 1500°C ratio of bending to tensile strength is almost constant. The bending strength is more or less 1.55 times higher than that of tensile strength in T700 fiber composites and in M40 fiber composites bending strength more or less 1.2 times higher than that of tensile strength.

This shows that ratio of the bending to tensile strength depends upon type of reinforcements.

3.3. Fracture behaviors after bending test with HTT

Fig. 4 (a and b) shows change in load-displacement curve of C/C composites with processing HTT. During the bending test on the application of load, micro-cracking in the composites specimen began on the side subjected to tensile load and progressed gradually towards the compressive side. If, the bonding between laminates interfaces (0° and 90°) is not week. As a result composites fracture in more or less catastrophically. Initially in composites heat treated at 750°C, micro-cracking initiated from tensile side and cracks passes towards compressive loading side by connecting the failure cracks to thermal or shrinkage cracks. As a result instead of laminate delamination, the crack passes toward the compressive side and hence, T700 fiber based composites fracture in brittle manner with catastrophic failure (Fig. 4a curve a, and Fig. 6, micrograph T750). While the M40 fiber composites also more or less fracture in brittle manner (Fig. 4b curve a
and Fig. 6, micrograph M750). With increasing the HTT to 1000°C, due to increase in the open porosity and decreases in the bulk density, fracture behavior of both the composites changes. The T700 fiber composites fracture in mix mode while M40 fiber composites more or less fracture in shear mode (Fig. 4a and b curves b and Figure 6 {T1000 and M1000}). Further with increasing HTT to 1500°C, the T700 fiber composites fracture in brittle manner with laminate deformation (Fig. 4a, curve c) however, M40 fiber based composites fracture in mix mode (Fig. 4b, curve c).

At and above 2000°C, graphitization process is initiated in composites [22]. The residual stresses at the fiber-matrix interface are going to be relaxed in the process of graphitization and as a result the fiber-matrix interactions in both the type of composites becomes comparatively weak. The stresses at the matrix crack tips also get relaxed. As a result both the composites fracture in mix mode by laminate deformation (Fig. 4 and b curve d). At and above 2500°C, the fracture behavior of composites is influence by the failure mechanism of the matrix in addition to the fiber-matrix interactions. At this temperature, due to the graphitization of carbon matrix, carbon matrix fails in shear mode. Therefore, at 2500 and 2800°C in both type of composite, fiber-matrix interactions are going to weaker and composites fracture in mix mode of failure i.e., tensile cum shear. If we see the fracture surface of composites HTT 2500 and 2800°C after bend test, it shows that fracture occur by multiple cracking with laminate deformation. At and above 2500°C, the fracture behavior of composites is influence by the failure mechanism of the matrix in addition to the fiber-matrix interactions. At this temperature, due to the graphitization of carbon matrix, carbon matrix fails in shear mode. Therefore, at 2500 and 2800°C in both type of composites, less or more fracture in mix mode by laminate deformation (Fig. 6, T2500,T2800, M2500 and M2800). This also reflected from the load-displacement curve shown in figure Fig. 4a and b (curve e & f). However, during tensile test, stress concentrations are induced at tips of matrix microcracks and microcracks immediately propagate from composite cross section by cutting the fibers. Thus, during the tensile test it is observed that all the heat treated composites fracture catastrophically brittle manner with progressing stress-strain curve linearly except the composites HTT at 750°C.

3.4. SEM micrograph C/C composites after HTT

Fig. 5, shows SEM of T700 and M40 carbon fiber based C/C composites after the heat treatment at temperatures 1500, 2000, 2500 and 2800°C. These cross sections are observed after cutting and polishing by diamond slurry, therefore, some new damages might have been added. In case T700 fiber composites heat treated at 1500°C (Fig. 5, T1500), the matrix around the carbon fiber well bonded and some gap around the carbon fiber is due to shrinkage of matrix and mismatch between coefficients of thermal expansion between the carbon fibers and the matrix. With increasing HTT of composites above 1500°C, the carbon matrix oriented parallel to fiber axis and due to shrinkage of carbon fibers; fiber diameter decreases, and deviation from a circular cross section (Fig. 5, T2000, T2500 and T2800). Above 1500°C the structural changes occur in the matrix and the fiber, because fiber heat treated only ~1500°C, therefore, above this temperature structural change in the matrix is associated with fiber damage in the composites [23]. The distortion in fiber cross section in composites is depends upon fiber type, fiber-matrix interaction and HTT. In case of M40 fiber composites, deviation in fiber cross section and diameter of fiber decreases after HTT of composites 2500°C (Fig. 5, M2800) before this HTT more or less no change in fiber morphology (Fig. 5, M1500, M2000 and M2500) only change in carbon matrix morphology. The extent of distortion in fiber cross section and fiber diameter is less in M40 as compared to T700 fiber based composites at same HTT 2500°C. In T700 fiber composites, the core (non graphitic portion) diameter in the fiber cross section decreases with increasing HTT. The extent of distortion in cross section is higher in T700 fiber composites at HTT 2800°C.
Hence, the degradation of C/C composites properties above the HTT of fibers is due to the change in fiber properties.

3.5. Tensile strain with HTT during tensile and bending test

Fig. 7 shows the change in tensile strain with HTT during bending and tensile test of composites. It is observed that, tensile strain during either the test increases or decreases in same manner, difference in ultimate value of fracture tensile strain is due to the different mode of fracture mechanism. The higher value of strain during tensile test is due to fracture of composites more or less dominated by tensile failure; on the other hand, during bending test, fracture is dominated by both compressive and tensile. Hence the tensile strain during bending test is lower.

Tensile strain is also directly related to the fiber properties. In both the test, tensile strain is higher in case of T-700 carbon fiber composites. The fiber properties more or less do not change up to its processing temperature (fiber HTT) in composites. Some change occurs is due to the fiber-matrix interactions and shrinkage stresses. In case of T700 fiber based composites after the HTT 750°C tensile strain decreases this is related to decrease in bulk density of composites. Lower is the density, lower value of shear strength and as a result low fracture stress and strain due to the insufficient load transfer capacity from the outer plies to the inside plies of the C/C composites [26, 27]. Further with increasing the HTT, maximum strain at 1500°C and after that strain continuously decreases up to 2800°C. With increasing HTT, fiber-matrix interfacial bonding strength decreases [9, 17]. Decreases in interfacial strength as a result increase in tensile fracture strain but above the HTT 1500°C, fracture strain decrease in the present investigation. Thus decrease in tensile strain is related to in-situ degradation of fiber properties. However, in case of M40 fiber composites tensile strain increases continuously up to 2500°C. Continues increase in tensile strain is attributed to conversion of the matrix from amorphous carbon to graphitic carbon type structure and also due to the weak fiber-matrix interactions. It resulted in to the fracture of the composite being less matrix dominated and, therefore, permits higher strain to failure of fiber which ultimately contributes in fracture failure strain of composites. Also retention of fiber properties up to 2200°C and above this temperature is due to degradation of the carbon fiber properties, and as a result decreases in tensile strain of composites as shown in Fig. 7. But if we see the Fig. 8, shows the change in modulus and interlayer spacing of C/C composites with the HTT. The modulus continuously increases and interlayer spacing continuously decreases with HTT. So that modulus and interlayer spacing does not a affected by morphological change occur with the HTT. These continuous increases in modulus are related to change in microstructure with HTT of composites. At the HTT 2800°C, the interlayer spacing of T700 fiber based composites is lower.
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than M40 fibers based composites is due to the higher extent of stress graphitization as cause of strong fiber-matrix interactions. This brings that even the tensile strength and fracture strain influence by the HTT of C/C composites but modulus does not. Thus, the properties of composites changes as like the fiber properties vary with HTT.

4. Conclusions

From the above study following conclusions are drawn:

1. The real density and real porosity increases with processing HTT, however, bulk density does show much change with HTT.

2. The bending strength is considerably greater than tensile strength through out the processing temperature. After attending the maximum value of bending and tensile strength, strength decreases in both types of composites at one deflection temperature.

3. The maximum fiber strength realization in C/C composites is at temperature same that of processing HTT of carbon fibers.

4. The principle factor in the degradation of bending and tensile strength of C/C composites after deflection temperature is the degradation of fiber properties and in-situ fiber damages.

5. Same as the tensile and bending strength, tensile strain also increases and decreases with the HTT. But the modulus increases and interlayer spacing decreases continuously with the HTT. This shows that the bending and tensile properties of C/C composites changes as like the fiber properties vary with the HTT.

6. It is very interesting note that, bending strength more or less 1.55 times higher in T700 fiber composites and in M40 fiber composites it is 1.2 times higher than that of tensile strength of C/C composites.

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References


