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Fabrication and Mechanical Properties of PAN-based Carbon Composite Laminates for High Temperature Applications

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Abstract

The main objective of this work is to study the experimental investigation of thermophysical and mechanical properties of polyacrylonitrile (PAN) based carbon fiber fabric and phenolic resin composites (Cf-PR) for thermal protection system (TPS) for high temperature applications. Composite laminates of Cf-PR were prepared by hand-layup method by considering the curing temperature of 150⁰ C at 100 kg/cm² for 4hrs under hydraulic hot press machine. The mechanical properties of the materials such as the interlaminar shear stress (ILSS), flexural strength, compression strength, bar coal hardness, thermal property such as thermal conductivity and physical property such as density were studied. It was shown that the thermophysical and mechanical properties are responsibility for the higher strength and higher temperature applications for TPS.

Keywords: PAN- based carbon fiber fabric; Phenolic resin; Interlaminar shear stress; Flexural strength; Compression strength; Thermal protection system (TPS).

1. Introduction

The fiber reinforced polymer composites are the materials for high-performance and lightweight structural applications have increased their exploration and usage in many industries such as aerospace, automobile and marine. Thermal protection systems (TPS) are critical in space applications because they shield the spacecraft from the heat generated during hypersonic flight [1]. Carbon-fiber reinforced composite materials have been recognized for their prospective uses in the field of high-temperature ablation resistance [1] for a long period of time. Carbon fiber fabric-phenolic resin (Cf-PR) composites are widely considered as key ablative thermal protection materials [2], particularly in moderate ablation settings [3]. Due to their high carbon output in organic resin systems, phenolics are the preferred resin for thermal applications [3]. Carbonized prepreps created with these components, such as Rayon and Polyacrylonitrile (PAN) [4], depending on the technique, can be thermally produced into a carbon phenolic composite [5]. In aerospace, Carbon fiber fabric-phenolic resin (Cf-PR) shells are used to build re-entry vehicles and are designed to resist extreme temperatures [6]. Phenolic resins can withstand high temperatures for a limited duration [7]. With reference to the literature very limited work is available on usage of PAN- based carbon fiber reinforcement with phenolic matrix [8]. There is a huge scope to work on the PAN-based carbon fiber fabric as a reinforcement and the phenol formaldehyde as a matrix [9] for to form as a composite material used as an ablative materials in thermal protection system (TPS) [10].

The main objective of this study is to fabricate PAN-based carbon-phenolic composite laminates and evaluate their thermo physical & mechanical properties. It is used in the method to prepreg PAN-based carbon fiber that has been treated with phenolic resin and allowed partially to form a prepreg. The Cf-PR composite laminates are

fabricated under hydraulic hot press machine by considering high temperature and pressure [11]. Testing mechanical and thermal properties requires the use of test specimens that are prepared in accordance with ASTM standards.

2. Materials and Methods

The materials used for the preparation of PAN-based carbon fiber fabric [12], reinforced with Ivarez ISRO grade resin matrix for composite laminates is explained in this section.

2.1 Materials

In this investigation, a PAN-based carbon fiber fabric (0-90) weave pattern plain, fiber density 1.80 g/m^3 , thickness 0.30mm , tensile strength 3530MPa and modulus in tension 230GPa . (T300, Torey Co., Japan) was used as a reinforcement. The Ivarez ISRO GRADE resin was employed as a matrix precursor which contains the solid content 65%, viscosity of liquid resin at 30°C is 150CPS , free formaldehyde of NMT 3.0% and free phenol of NMT 6.0% are the properties of the resin.

2.2 Preparation of carbon phenolic composite laminates

Figure 1. Sequence of preparation of prepreg and Cf-PR composite laminate.

Figure 1. shows the step-by-step procedure for the preparation of prepreg and Cf-PR composite laminate fabrication. The prepreg was made by applying the Ivarez ISRO GRADE resin matrix in the warp direction (at equal weight ratios) on PAN-based carbon fiber fabric, followed by 72 to 96 hours of room temperature drying to allow partial cure to obtain prepregs (Cf-PR prepregs) [13]. The Cf-PR prepregs (thickness 0.34mm) were cut into $200 \text{ mm} \times 200 \text{ mm}$ sheets (about 19 layers) and piled up (job) in a hydraulic hot press machine at 150°C and 100 kg/cm^2 with the same load for 4 hours [14] as indicated in figure 1. As a result, the Cf-PR composite were fabricated with a thickness of about 4 mm . To evaluate the thermophysical and mechanical properties of composite laminate, representative specimens were obtained.

2.3 ILSS, flexural and Compression strength

The composite laminate specimens with dimensions of $4 \times 10 \times 35 \text{ mm}$, $4 \times 13 \times 100 \text{ mm}$, and $4 \times 20 \times 20 \text{ mm}$ were collected for ILSS, flexural, and compression testing, with dimensions of $4 \times 20 \times 20 \text{ mm}$. ILSS was

determined using an ASTM D 2344 universal testing machine, while flexural and compression strength [15] were determined using ASTM D 7264 and ASTM D 695, respectively (FIE- Model UTES-40-HGFL, 100 KN, USA). For each property, a minimum of 6 specimens were evaluated, and the average results are provided in table 1.

2.4 Thermal conductivity

The fabricated composites were machined into cylindrical sample with a 12.5 mm diameter and a 2.5 mm thickness. The thermal conductivity was measured using the hot guard method at a temperature of 300⁰ C in the thickness direction under steady state conditions [8] in accordance with ASTM E1225-99. The thermal conductivity of two composite specimens was measured, and the average value is shown in table 1.

Table 1 Thermophysical and mechanical properties of the Cf-PR composite

Specimen description	Density (g/m ³)	Barcol hardness	ILSS (MPa)	flexural (MPa)	Compression (MPa)	Thermal conductivity (W/mk)
Cf-PR composite	1.52	*58.66	*26.14	*27.885	*72.57	*0.59

*Represent the average values of the respective properties.

3. Result and discussion

3.1 Hardness and Density

The Barcol harness method is most used to determine how much a resin or plastic has cured the Cf-PR composite laminates. Barcol harness is measured according to ASTM D 2583. (Average value) and the equivalent weight percent of Cf-PR composite has a low density, as indicated in table 1.

3.2 ILSS, flexural and Compression strength

It is observed that Cf-PR composite have shown good ILSS, compressive strength properties while the flexural strength shows the poor mechanical strength.

According to the Inter Laminar Shear Stress results, the matrix deposited in carbon fiber and an effective interfacial interacting area between the fibers and the matrix in the composite has grown as shown in figure 2. This leads to the better interfacial bond strength resulting enhanced ILSS strength. Figure 3 shows that the flexural strength was increased linearly and significantly decreased due to the variable distribution of matrix and reinforcement The weak addition between the matrix and reinforcement causes main reason for reducing the flexural strength.

Some other study groups have observed that the compression strength increases significantly because of the strengthening of the matrix-fiber interface, which is illustrated in table 1. With the addition of C-fiber reinforcement, the matrix is capable of efficiently resisting the bonding nature.

Figure 2 Inter laminar shear stress vs load

Figure 3 Flexural strength vs load

Figure 4 Compression strength vs load

3.3 Application of PAN-ban based Cf-PR composites

. The fabricated Cf-PR composite materials exhibit excellent insulating with low density, high hard and low thermal conductivity and good mechanical property which would make them attractive candidates for the advanced thermal protection materials in aerospace to protect the hypersonic vehicles in ultra-high temperature environments and other industrial applications.

4.0 Conclusions

- i. PAN-based Cf-PR composite results shows the excellent properties due to the method of manufacturing adopted.
- ii. The ILSS results shows the enhanced interfacial bond strength, the flexural strength decreases due to uneven distribution of matrix and reinforcement and the compression strength increases due to bonding nature between matrix and reinforcement.
- iii. The fabricated PAN-based Cf-PR composites shows the low thermal conductivity, low density, and high hardness material for the wide range of high temperature applications for TPS in space shuttles, automobile, marine and other industries.

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