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Effect of Dry Carbon Fibers on the Mechanical Properties of G801 Carbon Fiber Reinforced Composites

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Abstract
The field of fiber-reinforced composite materials has progressed quickly in the last two decades, mainly due to the extreme lightness and superior properties of it, when compared to conventional materials. These materials are progressively being utilized as a part of aviation, automotive, electronics, sporting goods, and numerous other modern applications. In this work, we have fabricated carbon fiber reinforced composites by lay-up procedure in different sequences. This work aims to optimize the production cost by sandwiching dry fibers alongside the pre-pregs without trading off on the performance of the composite. It is additionally seen to have no resin-rich, resin-starvation or other defects.

Keywords: *Carbon-fiber-reinforced polymer (CFRP), composites, laminates, lay-up, materials, aviation*

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INTRODUCTION
A composite material is a combination of two or more chemically different materials with a distinct interface between them. The constituent materials maintain their separate identities in the composites, yet their combination produces properties and characteristics that are different from those of constituents [1]. Composites consist of one or more discontinuous phases embedded in a continuous phase. Discontinuous phase is usually harder and stronger than continuous phase and is called the ‘reinforcement’ or ‘reinforcing material’. The continuous phase is called the ‘matrix’ [2, 3]. The reinforcement in a composite material is essentially used to improve the mechanical properties whereas the matrix plays a multi-faceted role such as holding the reinforcement, a path of stress transfer between fibers, protecting the reinforcement from environmental damage and so on.

One such composite material is the carbon-fiber-reinforced-polymer (CFRP). It is an extremely strong and light FRP containing carbon. It is commonly used in places that demand lightness and high specific strength. But, the major drawback of CFRPs is that it is expensive to produce.

In this paper, we propose an alternative way to produce CFRP structures to bring down the cost of manufacturing without much effect on its performance. The methodology followed was sandwiching dry fibers in between pre-preg layers. To evaluate the level of reinforcement, the dry fibers were laid-up in different sequences and were tested for their mechanical properties. A computerized ultra-sonic C-scan was conducted on the specimens in order to analyze the attenuation in turn to analyze the defects present in the composites if any.

EXPERIMENTAL
Materials and Methods
The pre-preg layer used was carbon G801 woven fabric of thickness 0.115 mm. Carbon CC206 dry fibers with thickness 0.25 mm were used as alternative reinforcement. Laminates were fabricated according to DIN standards. A master laminate (Sample 1) was made entirely out of the pre-pregs. Samples 2, 3 and 4 were made out of G801 pre-pregs and sandwiching layers of CC206 dry fibers between two, three and five layers of the pre-pregs. The fibers were fabricated by wet lay-up process in alternating 0 and 90° laying up angle. The laying up was stopped when the

laminates attained the thickness of 2 mm. The lay-up details are given in Table 1. All the samples after lay-up were sealed in a vacuum bag and were cured in an auto-clave. Cured structures were then machined to get the required specimens.

Shear Test

Inter-laminar shear strength (ILSS) test was conducted on a universal testing machine to determine the shear strength between the layers of pre-pegs in the laminate. The ILSS specimens were fabricated according to DIN 29971 standards. The specimens had dimensions of 20 mm length, 10 mm width and 2.2 mm thickness. A minimum of six trials were carried out for each sample. The mean values and standard deviations were found out.

Tensile Test

The specimens used for tensile test were fabricated as per DIN LN 53292 and had dimensions of 50 mm×50 mm thickness. The tests were conducted on the UTM at a crosshead speed of 5 mm/min. A load of 5000 kg was gradually applied to the specimen until fracture. A minimum of six trials were carried out for each sample. The mean values and standard deviations were determined. A similar procedure was followed for tensile properties of short-glass-fiber-and short-carbon-fiber-reinforced polypropylene composites [4].

Flexural Test

Flexural test was done to assess the bonding strength of the composites. The specimens were machined according to DIN EN 14125 standards and had dimensions 20 mm×10 mm×2 mm. The test was carried out on the UTM with the cross head speed set at 2 mm/min. A minimum of six trials were carried out for each sample. The mean values and standard deviations were determined.

Ultrasonic C-Scan Test

An ultrasonic C-scan test was conducted to get a plane view of the defect, projected on a plane at right angle to the axis of the ultrasonic beam. In the test, the specimen having dimension 150 mm×150 mm was placed between the sender and receiver and scanned at normal incidence in through transmission mode by means of a focused broadband transducer (9.5 mm in diameter) with a probe frequency of 2.25 MHz and a scan index of 2 mm. The scan speed was 200 mm/sec. The reference was taken as 21 dB. Attenuation maps of the specimens were captured [5].

Cost Analysis

A raw material cost analysis of the samples was carried out by comparing it with the master laminate (Table 2).

RESULTS AND DISCUSSIONS

The variation of mechanical properties of the samples can be seen in Figures 1a–1c.

Table 1: *Lay-up Sequence of the Specimens.*

Layer No.	Sample 1	Sample 2	Sample 3	Sample 4
1	G801 Carbon	G801 Carbon	G801 Carbon	G801 Carbon
2	G801 Carbon	G801 Carbon	G801 Carbon	G801 Carbon
3	G801 Carbon	**CC 206 Carbon**	G801 Carbon	G801 Carbon
4	G801 Carbon	G801 Carbon	**CC 206 Carbon**	G801 Carbon
5	G801 Carbon	G801 Carbon	G801 Carbon	G801 Carbon
6	G801 Carbon	**CC 206 Carbon**	G801 Carbon	**CC 206 Carbon**
7	G801 Carbon	G801 Carbon	G801 Carbon	G801 Carbon
8	G801 Carbon	G801 Carbon	**CC 206 Carbon**	G801 Carbon
9	G801 Carbon	**CC 206 Carbon**	G801 Carbon	G801 Carbon
10	G801 Carbon	G801 Carbon	G801 Carbon	G801 Carbon
11	G801 Carbon	G801 Carbon	G801 Carbon	G801 Carbon
12	G801 Carbon	**CC 206 Carbon**	**CC 206 Carbon**	**CC 206 Carbon**
13	G801 Carbon	G801 Carbon	G801 Carbon	G801 Carbon
14	G801 Carbon		G801 Carbon	G801 Carbon
15	G801 Carbon			G801 Carbon
16	G801 Carbon			
17	G801 Carbon			
18	G801 Carbon			

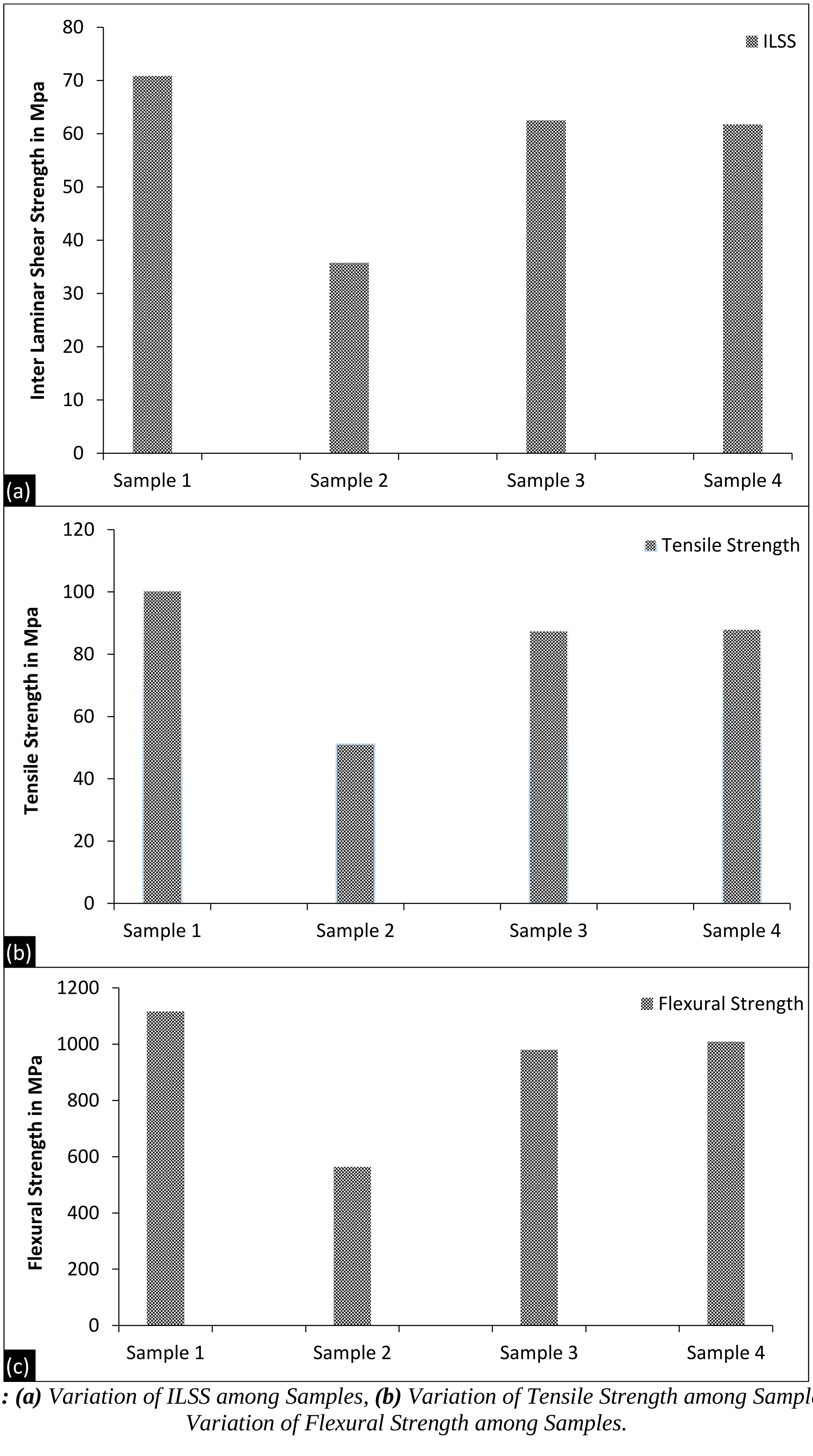
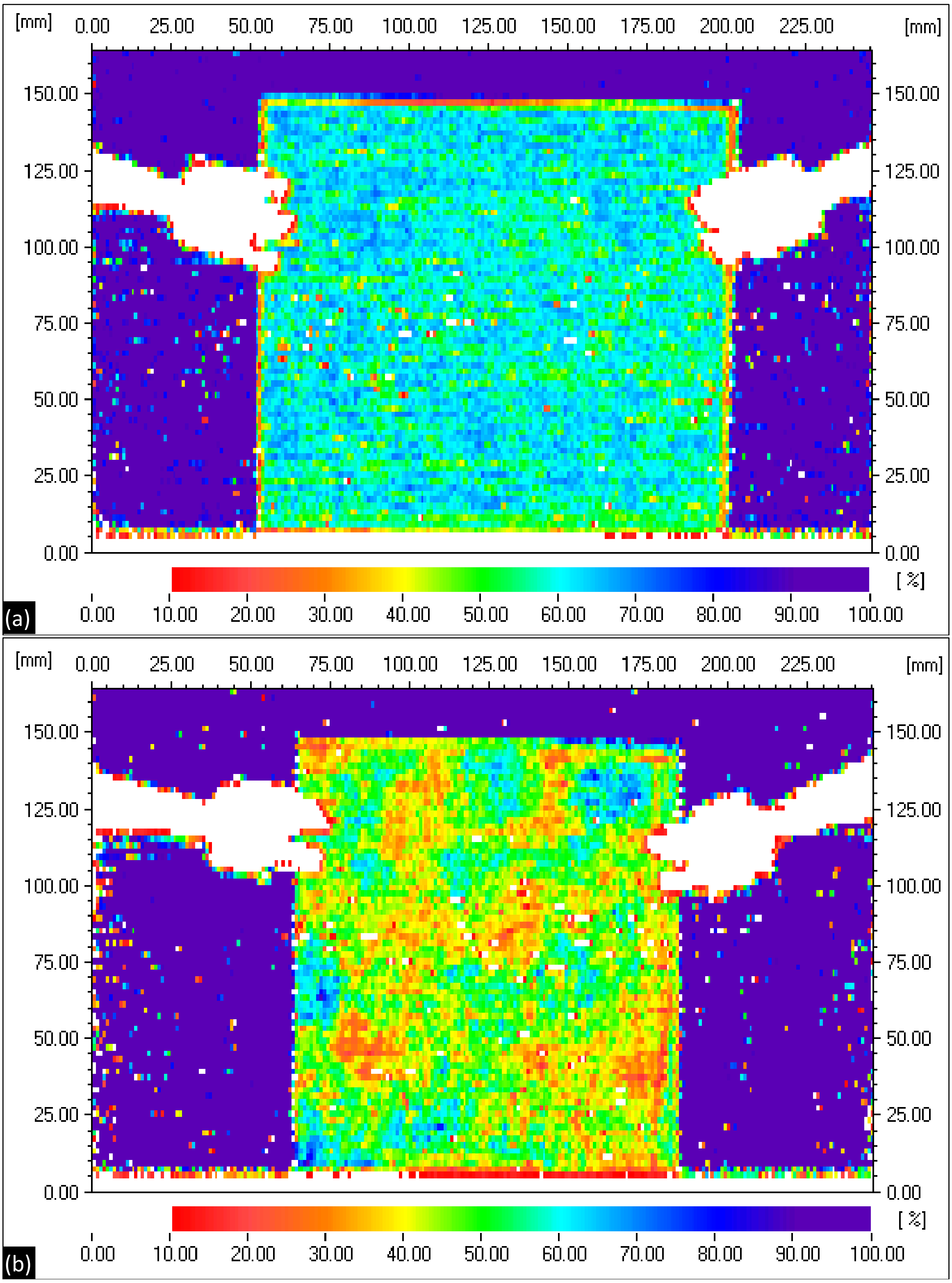


Fig. 1:* *(a) *Variation of ILSS among Samples,* ***(b)*** *Variation of Tensile Strength among Samples,* ***(c)*** *Variation of Flexural Strength among Samples.*

Usually, ILSS in the range of 56–62 MPa is considered optimum for the usage according to DIN standards. It is observed that the ILSS values are within limits for the Sample 3 and Sample 4 whereas Sample 2 does not comply with the acceptable limit. Similar trend was observed in the case of tensile and flexural properties of the samples [6, 7]. It could be attributed to the presence of voids as could be seen from the C-scan image shown in Figure 2(b). This highlights when a part is fabricated with alternate dry layers, the fiber volume ratio increases and there is a resin starvation that results in voids.



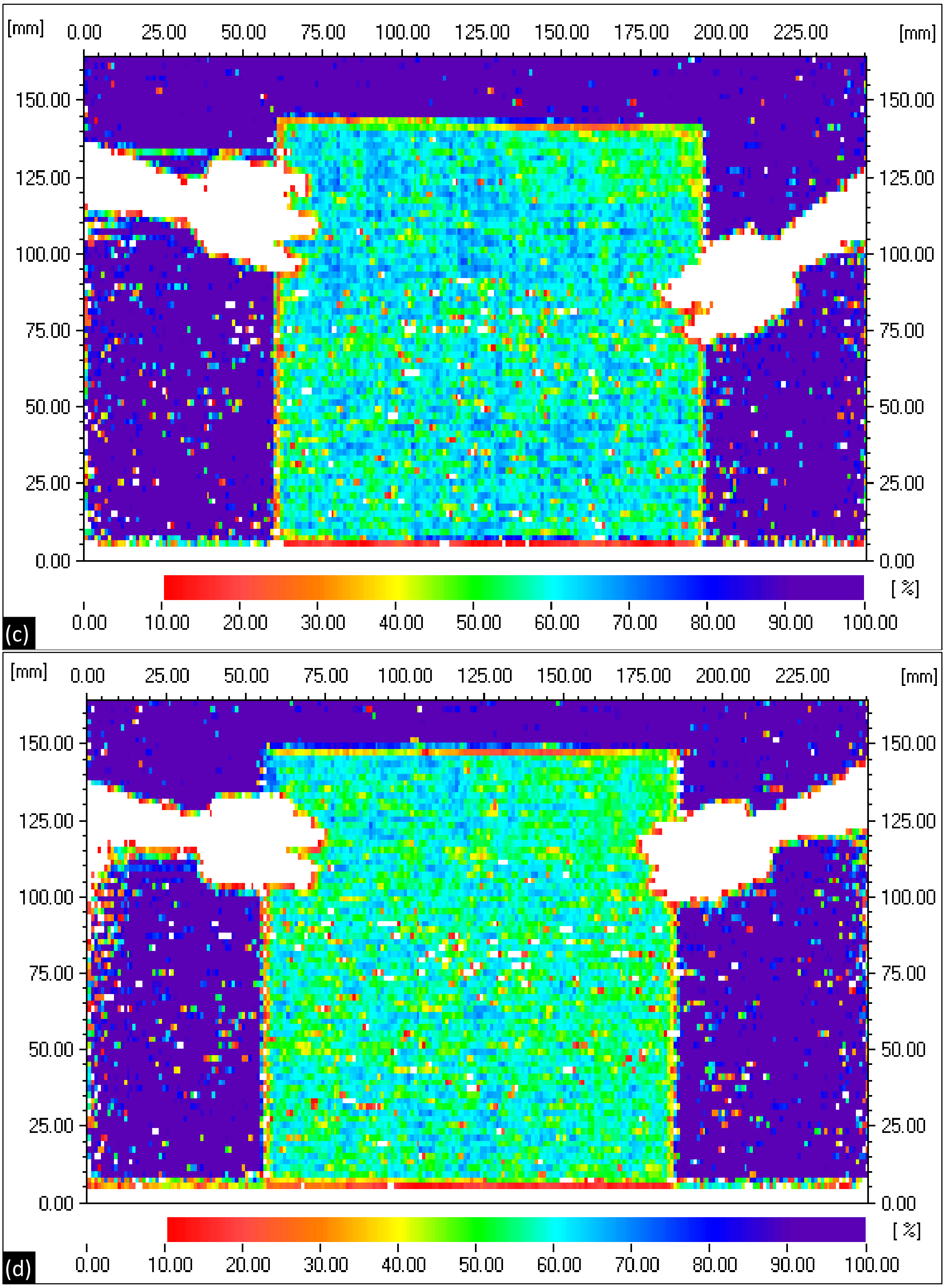


***Fig. 2**: **(a)** Ultrasonic Image of Sample 1; **(b)** Ultrasonic Image of Sample 2; **(c)** Ultrasonic Image of Sample 3; **(d)** Ultrasonic Image of Sample 4.*

The attenuation map gives a clear indication that there are no internal defects or voids even after the dry fibers are sandwiched with the pre-pregs in Sample 3 and Sample 4. But, a significant amount of voids is seen in Sample 2 which makes it unfit for use [8].

The ultrasonic attenuation values of the master laminate correlate with Sample 3 and Sample 4 as can be seen in Figure 3.

The cost-analysis for production of the laminates is shown in Tables 2 and 3. The cost per layer of material for fabricating the laminates is taken in to account and is used as the standard to find out the total raw material cost for each sample. The variation in the total raw material cost of the samples can be seen in Figure 4.

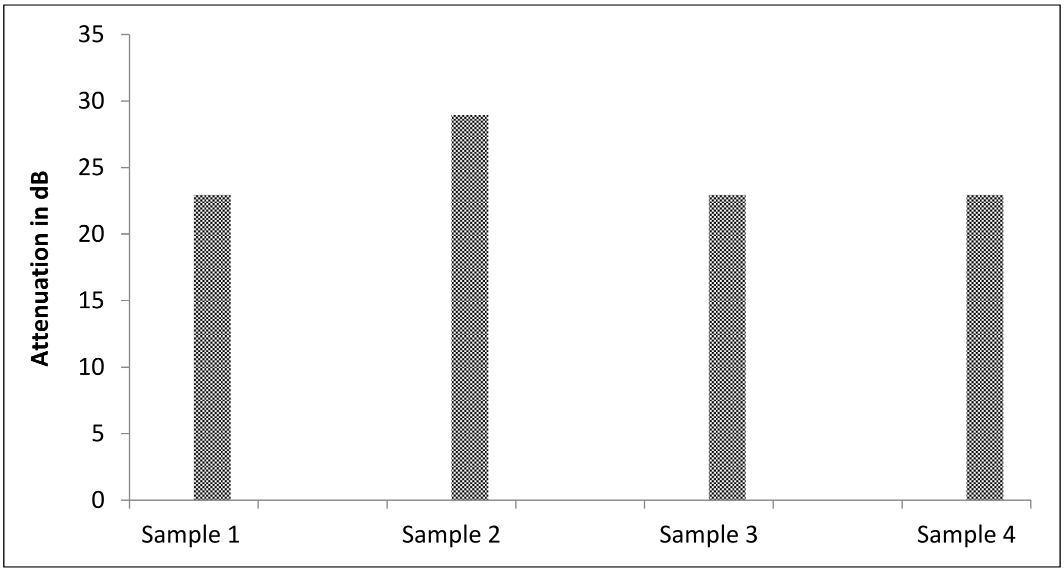


Fig. 3: *Attenuation Values of Samples as Obtained from C-Scan.*

Table 2: *Individual Raw Material Cost (in ₹).*

Material	Cost/sq. m (₹)	Cost/Layer (₹)
G801 Carbon Pre-preg	3,647.7	91.04
CC 206 Carbon dry fibers	591.46	15.06

Table 3: *Total Raw Material Cost for Each Sample (in ₹).*

Material	Sample 1	Sample 2	Sample 3	Sample 4
	Cost for Total No. of Layers (₹)	Cost for Total No. of Layers (₹)	Cost for Total No. of Layers (₹)	Cost for Total No. of Layers (₹)
G801	1,638.31	819.4	1,001.49	1,183.59
CC 206	N/A	60.26	45.2	30.13
Total Cost	1,638.31	879.66	1,046.69	1,213.71

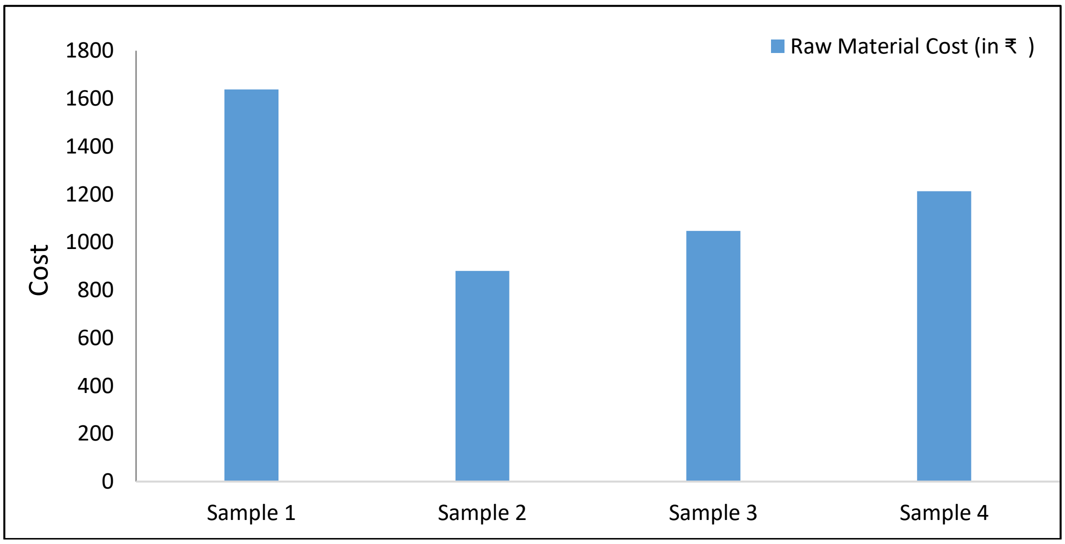


Fig. 4: *Variation in Total Raw Material Costs among Samples.*

It is evident from the table that the cost of production of the laminates fabricated by sandwiching dry fibers with the pre-preg layers was reduced up to 25% when compared to the master laminate.

CONCLUSION

Fabrication of CFRP structures by sandwiching dry carbon fibers between pre-preg layers resulted in competitive mechanical properties compared to master laminates laid up using only pre-pregs. The C-scan results showed the absence of internal defects in the laminates produced by this method of fabrication. Cost analysis indicated that laminates could be manufactured at lower costs without significant loss in performance. Hence it is proposed that these types of laminates can be a replacement for their existing counterparts.

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