Experimental Investigation on the Impact of Presence of Natural Fibre on the Mechanical Performance of a Light Weight Hybrid Bonded Laminate

M.Vasumathi [#1], Vela Murali [*2]

[#] Engineering Design Division, Department of Mechanical Engineering, College of Engineering, Guindy, Anna University, Chennai – 25, Tamil Nadu, India

[1] vasumathi@annauniv.edu

[2] velamurali@gmail.com

Abstract—Natural fibres play a vital role in the area of composites and have found wide acceptance in this area. In this work, two kinds of hybrid laminates are studied, one with carbon, jute and aluminium termed as CAJRAL and the other, CARAL, with carbon and aluminium only. The purpose of this study is to analyse the effect of addition of natural fibre jute in the fibre metal laminate on its mechanical behavior. Experimental studies are undertaken on tensile, flexure and impact properties of both CARAL and CAJRAL. It is observed that, CAJRAL's mechanical performance deviates from that of CARAL by only a maximum of 24%, with respect to axial and impact loadings. As far as the bending behaviour is concerned, CAJRAL performs even better than CARAL, due to the presence of jute fibre. Moreover the experimental findings are compared with analytical simulation and are found to be in close agreement.

Keyword-CARAL, CAJRAL, Tensile, Bending, Impact

I. INTRODUCTION

Pollution is becoming a big threat to life in today's world. There exist measures to control pollution but then it is difficult to eliminate it completely. In the early days, people were leading peaceful life free from harmful diseases. But nowadays, people have to live with diseases that turn out to be fatal in some cases and are not able to pin-point the root cause for such diseases. The materials that have to come to be used by mankind are mostly man-made and are made up of chemicals and other toxic substances. This is because man's lifestyle has switched over from nature to man-made due to his eagerness to lead a luxurious life. If this situation persists, then that would be the end of mankind and other organisms on this earth. Hence research is going on, in a large scale, in inventing materials such as composites incorporating natural fibres [1]–[5]. Natural fibres are the ones that are found naturally on this earth and hence have no ill-effects on the living beings.

Laminated composites are gaining wider use in mechanical and aerospace applications due to their high specific stiffness and strength. Due to the excellent stiffness and weight characteristics, composites have been receiving more attention of engineers, scientists, and designers. The use of fibre reinforced polymer based composite has been increasing in various applications. Fuel tanks, rocket motor cases, pipes, pressure vessels, etc are made of composite materials. The idea of making fibre reinforcement in the adhesive bond lines between aluminium alloys has been researched at many laboratories over the past three decades. These researches made it possible to develop first hybrid laminate incorporating metal alloy called fibre metal laminate. A reinforcement of aramid fibre with aluminium named as ARALL (ARamid reinforced ALuminium Laminate) emerged during the year 1978 and its commercial product came out in 1982 [6]. Later as an improvement of ARALL, GLARE (GLAss Reinforced aluminium Epoxy laminate) was developed for aeronautical use with advanced glass fibre, in the year 1990 and its commercial product came out in 1991 [6]. Aramid fibre has good specific strength and high impact resistance, however its poor compressive strength is a major limitation for these hybrid laminates. In this point of view, CARAL laminates have been developed as an improvement of ARALL laminates. They contain different amount of carbon/epoxy prepegs instead of aramid/epoxy prepegs and have been proving their ability in aeronautical applications [7]-[9].

TABLE 1
Properties of Fibres and Metal Used in the Hybrid Laminates

Property	Aluminium	Carbon	Jute Fibre
Density (Kg/m^3)	2800	1750	1460
Tensile Strength (MPa)	248-483	2200-3100	393-773
Young's Modulus (GPa)	69	180-214	13-26.5
Elongation (%)	40	1.2	1.16-1.8

In the present work, an attempt is made to study the influence of addition of a natural fibre to a hybrid laminate CARAL (CARbon Reinforced ALuminium), in its mechanical properties, after replacing a portion of carbon fibre in CARAL by the natural fibre jute. The resulting Fibre Metal Laminate (FML) is named as CAJRAL (CArbon-Jute Reinforced ALuminium). The idea of using jute in partial replacement of carbon has occurred due to its low density. The behavior of CAJRAL is examined when it is subjected to tensile, flexure and impact tests. The experimental findings are validated with finite element simulation. Moreover, theoretical evaluation of tensile parameters is done and is compared with experimental and simulated results. The mechanical properties of carbon and jute fibres and aluminium are tabulated in Table. 1.

II. MATERIALS AND METHODOLOGY

A. *Materials used for hybrid laminate preparation*

The materials utilized for the preparation of the FML samples are carbon (300 gsm) and jute (200 gsm) fibres, aluminium 2024 T3 sheet with thickness of 0.19 mm, epoxy resin of grade LY 556 and Araldite hardener of grade HY 951.

B. *Fabrication of CAJRAL and CARAL*

The laminates to be tested for different behaviors such as tensile, flexure and impact are prepared with varying stacking orders of fibres and metal, based on the direction of loading. The CAJRAL specimens considered for tensile loading are oriented with stacking sequences of ($Al/Ca_{0°}/Al/Ju_{0°}/Ju_{90°}/Al/Ca_{0°}/Al$) and ($Al/ Ca_{0°}/Al/Ju_{0°}/Ju_{90°}/Al/Ca_{90°})_S$ whereas the specimens to be subjected to Flexure loading are stacked in the orders of ($Ca_{0°}/Al/ Ca_{0°}/Ju_{0°}/Ju_{90°}/Ca_{0°}/Al/Ca_{0°}$) and ($Ca_{0°}/Al/ Ca_{0°}/Al/Ju_{0°}/Ju_{90°}/Al/Ca_{0°}/Al/Ca_{0°}$). Here the carbon fibre is placed in the top and bottom layers of the laminate, as it has high bending resistance when compared to other materials in the laminate. The specimens taken for Impact loading are arranged in quasi-isotropic stacking sequence of ($Ca_{0°}/Al/Ca_{45°}/Al/Ju_{0°}/Ju_{90°}/Al/Ca_{-45°}/Al/Ca_{0°}/Al/Ca_{-45°}/Al/Ju_{0°}/Ju_{90°}/Al/Ca_{-45°}$) and a general sequence of ($Ca_{0°}/Al/Ca_{90°}/Al/Ju_{0°}/Ju_{90°}/Al/Ca_{90°}Al/Ca_{0°}/Al/Ca_{90°}/Al/Ju_{0°}/Ju_{90°}/Al/Ca_{90°}/Al$). Further, CARAL specimens to be subjected to the above mentioned loadings are stacked in the same order as that of CAJRAL, with carbon fibre taken in the directions of 0° and 90°. The laminates arranged as above are blended with epoxy resin through hand lay-up technique. The epoxy is mixed with the hardener in 10:1 ratio. Then they are cured at room temperature and compressed for ten minutes in the compression molding machine at a pressure of 70 kg cm^2 and at temperature of 80 °C and thus the final FML is obtained [10].

III. BEHAVIOUR OF THE HYBRID LAMINATES UNDER AXIAL, FLEXURE AND IMPACT LOADINGS

A. *Tensile loading:*

The CAJRAL and CARAL hybrid laminates fabricated as above for the tensile loading are cut and tested according to ASTM D 3039 standard in the INSTRON 3369 Universal Testing Machine. The test specimen is positioned vertically in the grips of the testing machine and the speed of the crosshead is 1.27mm/min. The grips are tightened evenly and firmly to prevent any slippage. The test findings are shown in Fig. 1.

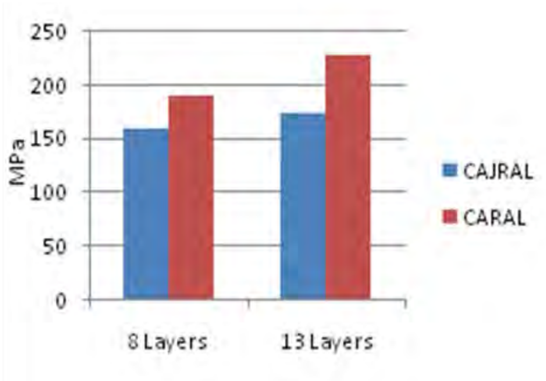
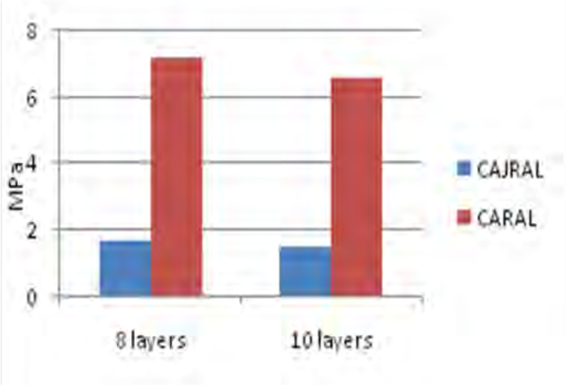


Fig. 1. Tensile strength of CAJRAL and CARAL hybrid laminates

B. *Flexure loading:*

The CAJRAL and CARAL specimens fabricated as above for the flexure loading are cut and tested according to ASTM D790 standard in the three point bending test set-up and the test findings are given in Fig. 2. (a) and (b).

a



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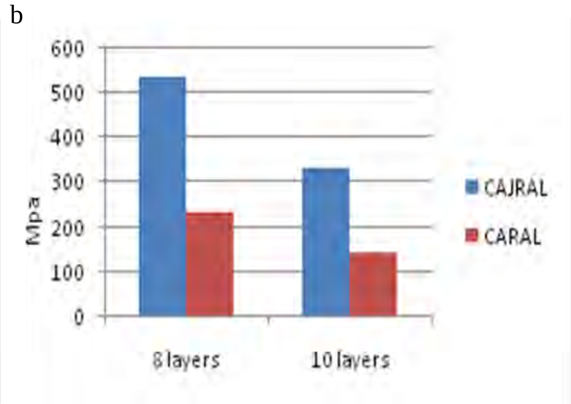

Fig. 2. (a) Flexure modulus and; (b) Flexure strength of CAJRAL and CARAL hybrid laminates

C. *Impact loading:*

The CAJRAL and CARAL specimens fabricated as above for the impact loading are cut and tested according to ASTM D 7136 standard in the Izod impact test set-up and the test findings are shown in Fig. 3.

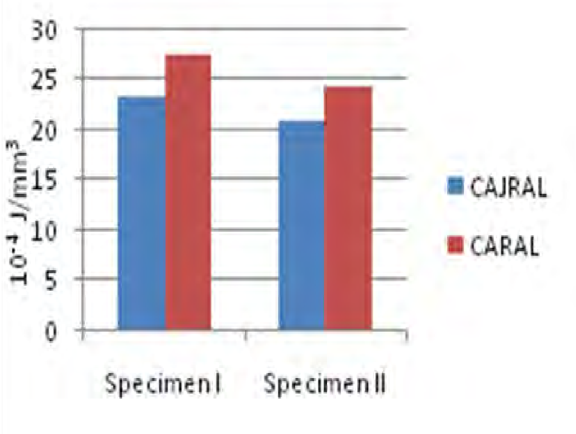

Fig. 3. Impact toughness of CAJRAL and CARAL hybrid laminates

D. *Mechanical properties of individual lamina in CAJRAL and CARAL laminates***.**

In order to determine theoretical values of stress in individual layers of carbon, jute and aluminium in CAJRAL and CARAL hybrid laminates as well as for simulating the above experimental results , the tensile properties such as Young's Modulus and Poisson's ratio of carbon and jute layers in different orientations are to be made use of. These parameters are determined for carbon-epoxy and jute-epoxy laminates, with carbon and jute fibres oriented separately in 0° and 90° directions and are tabulated in Table 2. The stress values in the individual layers obtained using Eq. 1 and Eq. 2, are outlined in Fig. 4.

TABLE 2
Mechanical Properties of Independent Laminae in the Hybrid Laminates

Property	Carbon 0°	Carbon 90°	Jute 0°	Jute 90°
E11(GPa)	166.8	193.6	10.69	13.01
E12(GPa)	5.2	7.724	34.03	10.10
μ_{11}	0.465	0.336	0.318	0.3227
μ_{12}	0.09	0.0399	0.103	0.249
G (GPa)	12.23	12.23	2.15	4.44

The strain matrix is given by

$$\begin{Bmatrix} \varepsilon_x \\ \varepsilon_y \\ \gamma_{xy} \end{Bmatrix} = [A]^{-1}[N] \ \ N/mm^2 \quad (1)$$

where $[A] = \sum [Q] \times t$, is the extensional stiffness matrix, t is the thickness of the laminate and $[Q]$ is the reduced stiffness matrix.

$$[N] = \begin{bmatrix} N_x \\ N_y \\ N_{xy} \end{bmatrix} \ N/mm \quad (2)$$

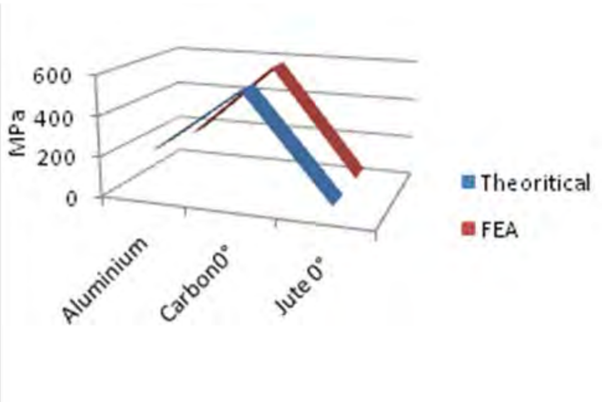

Fig. 4. Comparison of axial stress values of different stacked plies of CAJRAL hybrid laminate

IV. SIMULATION OF THE TEST RESULTS USING FEM

The CAJRAL and CARAL hybrid laminates are modeled in ANSYS software to simulate tensile and flexure performances. The results of tensile analysis of CAJRAL and CARAL are shown in Fig. 5. and Fig. 6. respectively. The tensile stress for 8 layered and 13 layered CAJRAL laminates are observed as 158 MPa and 194 MPa respectively and that of CARAL are 209 MPa and 245.7 MPa respectively. On the other hand, the bending resistances of the 8 layered and 10 layered CAJRAL specimens are found to be 525 MPa and 315 MPa respectively and that of CARAL specimens are 214.59 MPa and 164.77 MPa respectively.

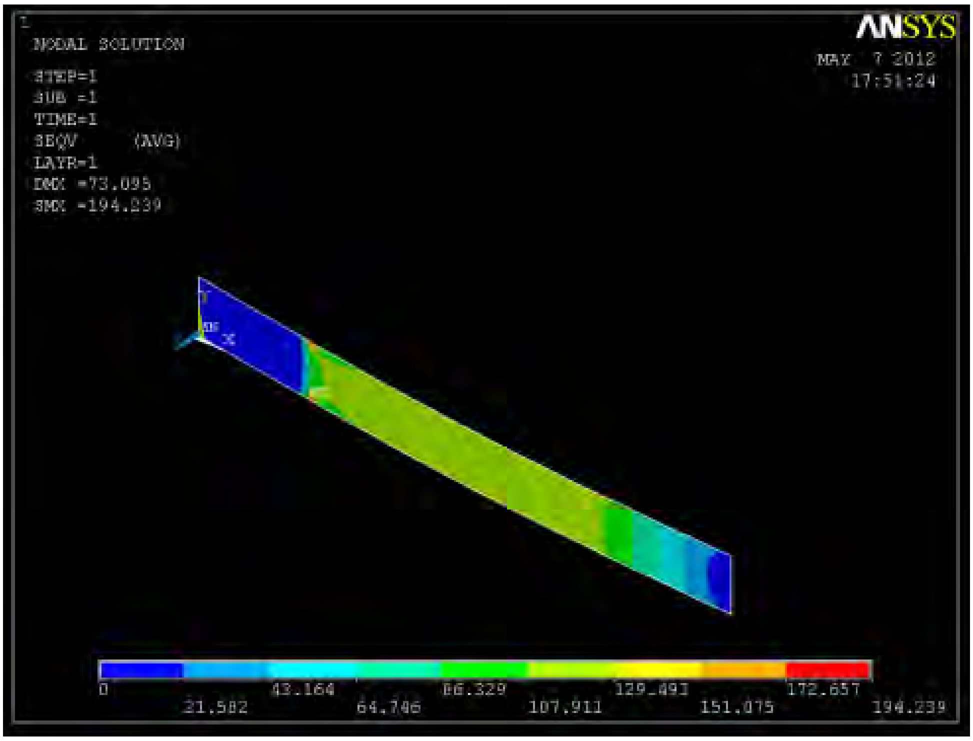

Fig. 5. Simulation of Axial loading of CAJRALL

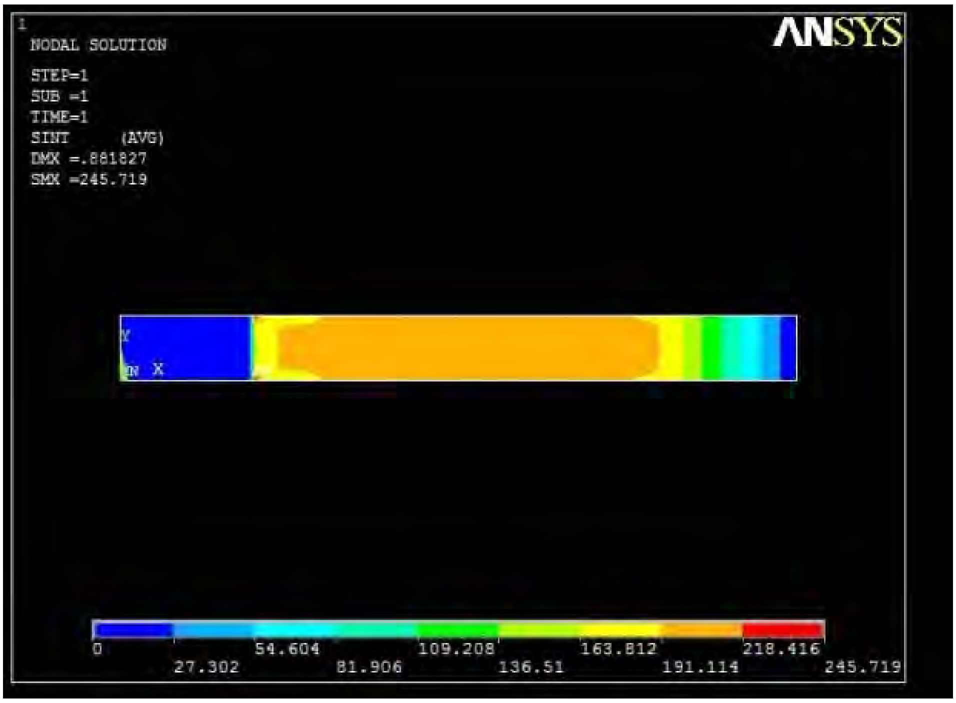

Fig. 6. Simulation of Axial loading of CARAL

V. RESULTS

The experimental results of axially loaded CAJRAL and CARAL hybrid laminates are demonstrated Fig. 1. The tensile stress for 8 and 13 layered CAJRAL are found to be 160.5 MPa and 170.4 MPa respectively and that of CARAL are 191.12 MPa and 228.98 MPa respectively. Fig. 2. (a) and (b) illustrates the flexure behavior of the CAJRAL and CARAL hybrid laminates. The flexure strength of the 8 and 10 layered CAJRAL are found to be 537.5 MPa and 334.2 MPa respectively and that of CARAL are 236.53 MPa and 146.45 MPa respectively. Further the flexure modulus of the 8 and 10 layered CAJRAL are observed as 1.71 MPa and 1.54 MPa respectively and that of CARAL are 7.23 MPa and 6.59 MPa respectively. The experimental results of CAJRAL and CARAL hybrid laminates when subjected to sudden impact loads are shown in Fig. 3. The resulting impact toughness of the quasi-isotropic oriented CAJRAL and CARAL laminates are 23.42 $x10^{-4}$ J/mm^3 and 24.34 $x10^{-4}$ J/mm^3 respectively and that of generally stacked CAJRAL and CARAL laminates are 20.04 $x10^{-4}$ J/mm^3 and 27.68 $x10^{-4}$ J/mm^3 respectively.

VI. DISCUSSIONS

From Fig. 1, it is clear that the tensile strength of the CAJRAL and CARAL hybrid laminates increase with the thickness of the laminates. Moreover, as the number of layers increase, the flexure resistance of the CAJRAL and CARAL hybrid laminates decrease and this is evident from Fig. 2. (a) and (b). It can be seen from Fig. 3 that, quasi-isotropic arrangement of the CAJRAL and CARAL hybrid laminates perform better under impact loads. Further, it may be noted that the experiment results of the CAJRAL closely match with the analytical and theoretical results with a maximum variation of 11% and 13 % respectively.

VII. CONCLUSIONS

The CArbon Reinforced ALuminium (CARAL) laminate is considered and a portion of carbon in it is replaced by natural fibre jute. This is done because of the high cost of carbon and also to provide pollution-free environment to an extent possible. The effect of the addition of jute in CARAL on its mechanical properties is studied both experimentally and analytically. A comparison of the experimental findings with finite element simulation and theoretical evaluation is made. It is observed that, thicker the CAJRALL and CARAL hybrid laminates, more is their tensile strength and flexure modulus but lesser is their flexure strength. Moreover, the CAJRAL with ($Ca_{0°}/Al/Ca_{45°}/Al/Ju_{0°}/Ju_{90°}/Al/Ca_{-45°}/Al/Ca_{0°}/Al/Ca_{-45°}/Al/Ju_{0°}/Ju_{90°}/Al/Ca_{-45°}$) arrangement and CARAL with the same arrangement exhibit good resistance to impact/sudden loads. Also the experiment findings for CAJRAL are in close agreement with analytical and theoretical results with a maximum variation of 11% and 13% respectively. It is observed that, despite a fraction of carbon is replaced with jute fibre in CARAL hybrid laminate, not much difference has been noted in the case of axial and impact loadings. Hence it can be concluded that, it is beneficial to use CAJRAL in place of CARAL in applications where the laminate is exposed to axial pull and sudden impact conditions. By doing so, not only the weight as well as cost of the laminate get reduced because of low density and lower cost of jute but also the environmental pollution is controlled to a considerable extent as carbon content of the laminate is decreased.

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