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Effect of Nano Filler on Mechanical Properties of Stainless Steel Glass Fibre Reinforced Fibre Metal Laminate

[1] Satnam Singh, [2] Surjit Angra
[1] Assitant Professor, Department of Mechanical Engineering, National Institute of Technology Kurukshetra-136119, Haryana, India.
[2] Professor, Department of Mechanical Engineering, National Institute of Technology Kurukshetra-136119, Haryana, India

***Abstract:* -- Recent advancements in the field of fibre-metal laminates (FML's) proved the superiority of fibre metal laminates over monolithic aluminium alloys in aerospace and aircraft structures. In this research flexural strength and Izod impact, energy absorption of stainless steel based fibre metal laminate (SS FML) with and without nano-clay was compared for the different orientations of glass fibre layers. Three point bend test and Izod impact test were performed on the universal testing machine and pendulum type Izod impact testing machine respectively. SS FML sheets were prepared using hand layup process. Standard size flexural and impact test specimens were cut from the prepared sheets according to ASTM standards. It was found that flexural and impact properties of SS FML were improved drastically after the addition of nano-clay into the composite matrix due to the dispersion of nano-clay particles in the composite matrix. The flexural and impact properties of SS FML were decreased as the angle of orientation of fibres was increased from 0° to 90°.**

***Keywords* - Fibre orientation; Flexural strength; Izod impact energy absorption; Nano-clay; Hand layup.**

I. INTRODUCTION

Fibre metal laminates are the laminated composites of metallic sheets and fibre reinforced plastics. These materials are very much popular for aerospace and aircraft structures due to their superior mechanical properties over monolithic aluminium alloys. FML's merge the excellent characteristics of metals like ductility, high impact strength with high specific strength, high specific stiffness and good corrosion and fatigue resistance of composites [1]. Fibre metal laminate was initially designed and tested for its fatigue characteristics at the National Aerospace Laboratory, Netherlands. Tests performed on the centre wings of a Fokker F-27, and the laminate showed superior fatigue resistance [2]. ARALL (Aramid Fibre Reinforced Aluminium Laminate) was the first commercial fibre metal laminate designed, developed and tested by Faculty of Aerospace Engineering at the Delft University of Technology in Netherland in 1978. ARALL laminates consists of high strength aramid fibres as reinforcement in central FRP (fibre reinforced plastic) layers (0.22 mm). A structural adhesive was used to join the alternative layers of FRP and thin aluminium alloy sheets (0.3 mm). Four kinds of ARALL were developed as per the needs with variation in the metal type. After the commercial success of ARALL laminate, two more FML's named as GLARE (Glass fibre reinforced aluminium laminate) and CARALL (Carbon fibre reinforced aluminium laminate) were developed by using glass fibres and carbon fibres respectively as the reinforcement phase [3].

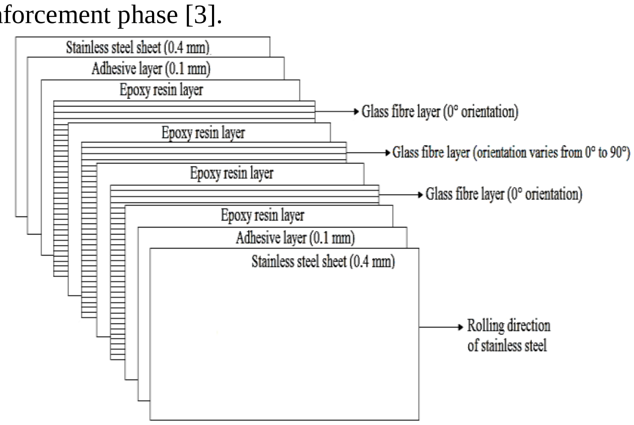

Figure 1: - Stacking sequence of SS FML

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Various studies have been performed to investigate mechanical properties of FML's. No studies have been reported on the effect of nano filler on the mechanical properties of stainless steel based fibre metal laminates. In this research paper the effect of nano-clay addition on flexural strength and Izod impact energy absorption of stainless steel fibre metal laminate has been evaluated with the variation in the fibre orientation.

II. MATERIALS AND METHODS OF PREPARATION

A. Materials used

Unidirectional E-glass fibre (SikaWrap-430 G) with fabric thickness of 0.172 mm, fibre density of 2.56 g/cm3 (supplied by Sika India Pvt. Ltd.) and MasterBrace 4500, a two part epoxy (provided by BASF India Limited) were used to prepare the GFRP sheets. Stainless steel AISI 304 sheet of thickness 0.4 mm has been used as the outer skin of fibre metal laminate. A nano clay powder (Closite 15 A) is used as the nano filler in the epoxy resin during GF/E composite preparation. An epoxy-based structural adhesive was used to join metal and the composite parts (Cured Thickness 0.1mm).

B. Method of specimen preparation

Hand layup process was used for the preparation of three layers glass fibre laminate. The mould (50 cm x 25 cm) was cleaned and releasing agent was applied on the surface of mould for the easy removal of GFRP composite sheet. The Glass fibre sheet was laid down into the mould. Two parts of epoxy resin were mixed by weight in the ratio of 100 : 40. Pour this mixture over the glass fibre sheet and spread it uniformly by using a steel scraper. Allow it to cure for at least 24 hrs. When the layer was cured, then mixture was applied on the other side of glass fibre sheet and add two more layers of glass fibre using the mixture of epoxy resin. To remove the excess resin, a roller was used. The fibres in first and third layer are oriented in the same direction i.e. at 0°. Orientation of fibres of middle layer varies as 0°, 30°, 45°, 60° and 90° w.r.t top and bottom layer of GF/E composite sheet as shown in figure 1. After curing for 24 hours at room temperature, GFRP sheet was removed from the mould and let it fully cured for 7 days. Remove the waste edges of sheet using Treadle shear machine. Stainless steel sheets were cut as per the size of GFRP sheet. To increase the surface roughness and adhesion quality, stainless steel sheets are subjected to sand blasting. Prepared GFRP sheet was stacked between two layers of SS in picture frame mould (50 cm x 25 cm) on a hot press. An epoxy-based adhesive (mixing ratio 100 : 80 by weight) was used to join the stainless steel sheets with GFRP sheet. Cured SS FML sheet was removed from mould after 24 hours. A nano clay powder (closite-15 A) was mixed in different proportions i.e. 0%, 1%, 2 %, 3%, 4% and 5% in to the epoxy resin to study its effect on the mechanical properties of epoxy resin. Standard size specimens of plain epoxy were prepared using ASTM standards and it is found that the epoxy matrix with 2 % nano-clay content gives maximum flexural strength and Izod impact energy absorption. After that SS FML sheets with the addition of 2 % nano clay powder by weight of epoxy resin were prepared. A mechanical stirrer and an oil bath were used for proper mixing of nano-clay. High speed shear homogenizer (20000 rpm for 20 minutes) was used to break the lumps of clay particles and to disperse the clay particles throughout the epoxy resin. Entrapped air bubbles were removed by putting the epoxy jar in to a vacuum chamber for 15 minutes. After that the jar containing epoxy and nano clay mixture was put under ultrasonic probe for at least 15 minutes. Sonication was done to break intermolecular interactions and for evenly dispersing nano-particles in epoxy resin. After preparation of epoxy resin, the pre-described procedure was adopted to produce SS FML with nano clay. The SEM images of epoxy matrix without nano-clay and with 2 % nano-clay powder are shown in figure 2 and 3.

III. EXPERIMENTATION

A. Flexural test

Flexural test specimens of SS FML were cut from the prepared sheets and tested on 50KN (Model name - EZ50) universal testing machine (UTM), manufactured by Lloyd Instruments Ltd, UK according to the ASTM D790-15e2 standard [4], [5]. Three point bend test was used with standard fixture dimensions. Five specimens for each orientation (i.e. 0°, 30°, 45°, 60° and 90°) with dimensions 127 mm x 12.7 x 3.5 were tested flat-wise with a rate of cross head motion of 1.5 mm / min.

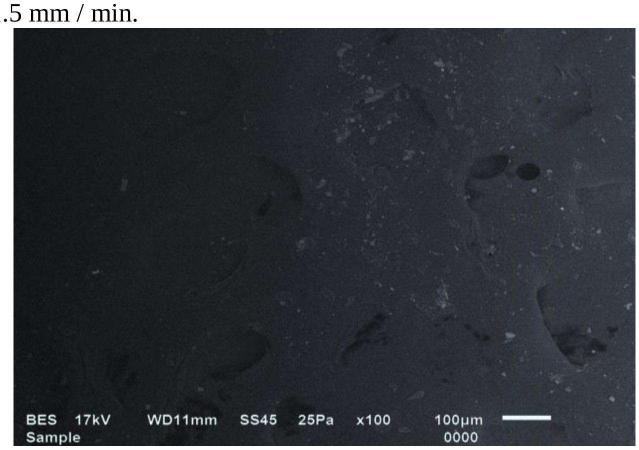

Figure 2: - SEM image of Epoxy matrix without nano-clay powder

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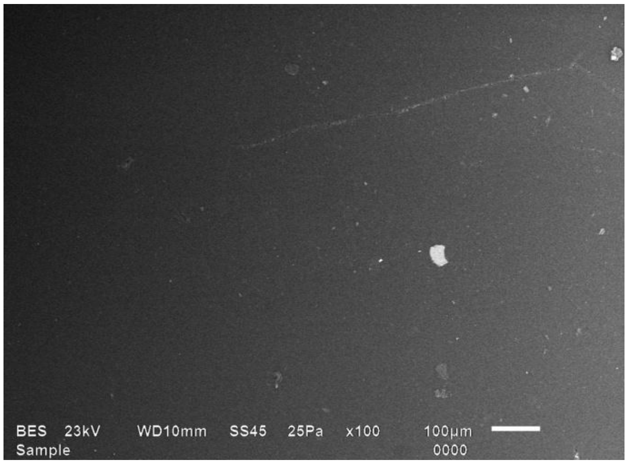

Figure 3: - SEM image of Epoxy matrix with 2 % nano-clay powder

B. Izod impact test

Izod impact test was conducted on Izod impact testing machine (Model IT-30-D made by fuel instrument & engineers pvt. ltd.) having an electronic system consisting of a digital indicator and sensor to record the impact energy of the specimen. The capacity and least count of the impact testing machine were 0.5–300 J and 0.5 J respectively. Specimens were cut from the prepared sheets of GF/E and SS FML according to the ASTM D256–10e1 standard [5]. Specimens with dimensions 63.5 mm x 12.7 mm x 3.5 mm were tested edge wise with the lower part fixed in the fixture. Notch in the specimen was cut using a single tooth notch cutter. The other dimensions of the notch like included angle and the radius of curvature at the apex was 45° and 0.25 mm respectively. The standard size flexural and Izod impact test specimens are shown in figure 4.

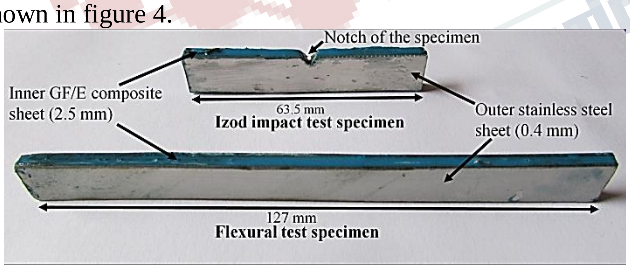

Figure 4- Flexural and Izod impact specimens

IV. RESULTS AND DISCUSSION

Figure 5 shows behaviour of SS FML after Izod impact test. It is clear from the figure that the Impact energy absorption of SS FML was maximum (29.4 Joule) for specimens in which the glass fibres in central layer of GFRP oriented at 0° and minimum (17.1 Joule) for 90°. The results when analysed revealed that with the increase in fibre orientation from 0° to 90°, the impact energy absorption was found to be decreased. The specimens with nano clay perform better in impact test with maximum and minimum impact energy absorption of 39.6 Joule and 18.9 Joule respectively for 0° and 90° oriented specimens

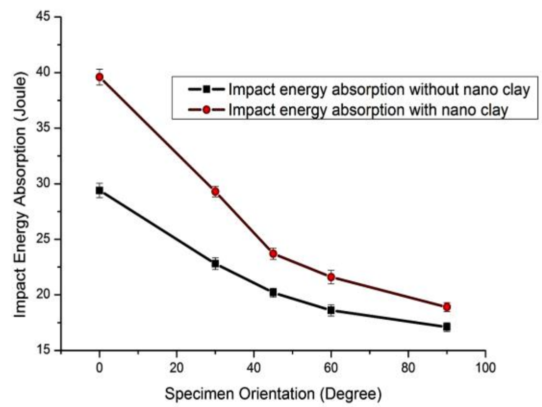

Figure 5- Impact energy absorption vs fibre orientation

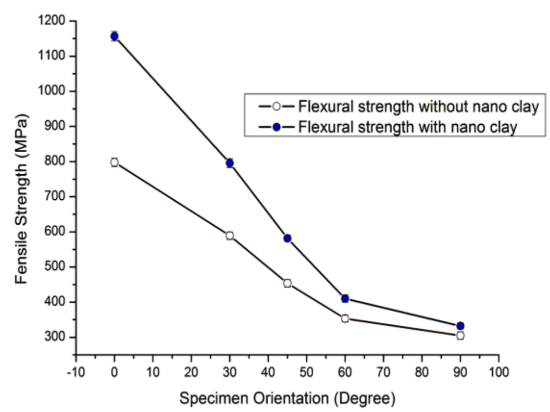

Figure 6- Flexural strength vs fibre orientation

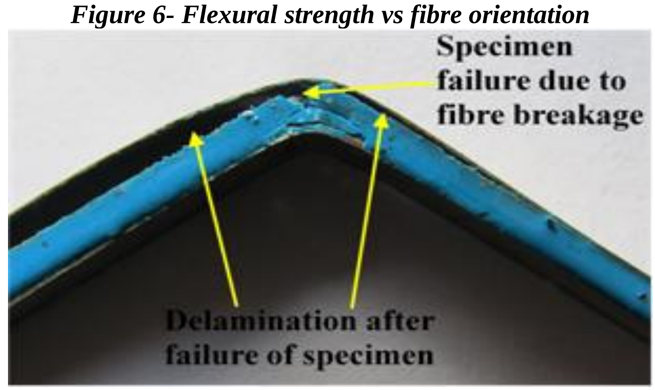

Figure 7- Failed flexural specimen

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It is clear from figure 6 that the flexural strength was maximum 797.72 MPa for specimens in which the fibres oriented at 0°. This is due to the fact that fibres in all three layers of inner GFRP sheet are oriented in the same direction. Due to this the applied flexural load is evenly carried by the three GFRP layers. After that, there was a sudden decrease in the flexural strength for 30o, 45°, 60o and 90o specimens having an average value of 589.27 MPa, 453.68 MPa, 353.13 MPa and 304.81 MPa respectively. The reason behind this decreasing trend was that as the angle of orientation of middle layer glass fibres was increased from 0o to 90o, the load carrying capacity was reduced. Because the fibres oriented at higher angles (other than 0o) don't have any support to carry the load. Flexural strength was minimum for the 90° specimens. Because in 90° specimens, fibres of middle layer of GFRP are perpendicular to first and third layer fibres. Due to this, the middle layer fibres don't carry any load. The flexural specimens with nano-clay illustrated improved flexural properties due to the even dispersion of nano–clay particles in to the epoxy matrix. The dispersed nano-clay particles in to the epoxy matrix creates the microscopic bonds with in epoxy layers and improves the mechanical properties of FML's significantly.

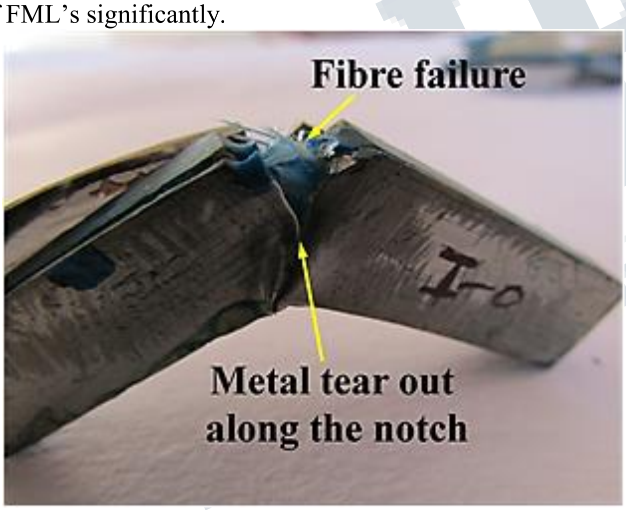

Figure 8- Failed impact specimen

V. CONCLUSION

In this work, the flexural and impact properties of fibre metal laminate consisting of AISI 304 Stainless steel sheet and GFRP were evaluated along with the variation in fibre orientation from 0° to 90° and concluded that flexural and impact properties were maximum for the specimens in which fibres oriented at 0° and along the rolling direction of stainless steel sheet. Flexural and impact properties showed a decreasing trend as the fibre orientation increased from 0° to 90°. Flexural strength and izod impact energy absorption were minimum for 90° FML specimens. The effect of nano-clay addition in to the epoxy matrix was also evaluated. It is concluded that the flexural strength and Izod impact energy absorption of fibre metal laminate with the addition of nano-clay was drastically improved.

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