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Full Length Article

Experimental evaluation of hygrothermal degradation of stainless steel fibre metal laminate

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A R T I C L E I N F O

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A B S T R A C T

In this research paper, the tensile and compressive strength degradation of glass fibre/epoxy composite (GF/E composite) and stainless steel glass fibre/epoxy fibre metal laminate (SS FML) due to hygrothermal conditioning have been investigated. The tensile and compression test samples were prepared using hand lay-up process according to ASTM D3039/D3039M – 14 and ASTM D695 – 15 standards respectively. Two aqueous environments, i.e., distilled water and sea water were used at two different temperatures (40 °C and 70 °C) for hygrothermal conditioning up to three months. Tensile and compressive strengths of SS FML were reduced by 23.4% and 32.6% respectively in distilled water at 70 °C. The highest reduction in tensile and compressive strengths of GF/E composite was recorded in distilled water at 70 °C as 29.8% and 36.8% respectively. The maximum weight gain for tensile specimens (0.44% by SS FML and 1.93% by GF/E composite) was lower than those obtained for compression specimens (1.48% – SS FML and 2.97% – GF/E composite) due to the geometrical difference in between them. The failure modes of both tensile and compression samples were investigated using scanning electron microscope (SEM). Unconditioned and hygrothermally conditioned tensile specimens fail due to fibre breakage and delamination respectively, whereas, the compression specimens fail only because of delamination between GF/E layers.

1. Introduction

Fibre-metal laminates (FML's) are the trending materials nowadays for aerospace, aircraft structures, and shipbuilding applications. FML's are hybrid laminates made up of thin metallic sheets along with alternating plies of fibre reinforced epoxy prepregs. These hybrid materials combine the durability of metals with high specific strength and fatigue resistance of fibre reinforced composites [1–3]. Fibre-metal laminates blend the approbative properties of both metals and fibre reinforced composites without sharing their disadvantages [4].

Fibre metal laminate (FML) was initially designed and produced by Faculty of Aerospace Engineering at the Delft University of Technology, Netherland in 1978. First FML was ARALL (Aramid Fibre Reinforced Aluminium Laminate). ARALL laminate includes high strength aramid fibres as reinforcement in intermediate FRP (Fibre Reinforced Plastic) layers (0.22 mm) and thin aluminium alloy sheets (0.3 mm) as outer and inner metallic skins. A structural epoxy adhesive was used to join aramid prepregs with aluminium alloy sheets. Four types of ARALL were developed 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 produced by using glass and carbon fibre prepregs respectively as the reinforcement phase [1,5].

Stainless steel was used by several researcher's as the metal part of fibre metal laminates. Kanerva et al. [6] used stainless steel AISI 304 and glass fibre epoxy composite to produce fibre metal laminate and tested it under tensile loading to determine its young's.modulus. The fracture tests were performed on pre-cracked specimens and concluded that pre-treatment of metallic surfaces had significant effect on interfacial fracture toughness. Sarlin et al. performed peel tests for metal/rubber and composite/rubber interfaces of fibre metal laminate based on either mild steel EN 10,130 DC01 or Stainless steel AISI 304 and E-glass fibre based composite. Five types of metal surface treatments were used to evaluate interface adhesion properties and it was concluded that sandblasted stainless steel surface displayed highest peel strength [7].

Fibre metal laminates were produced by the combination of stainless steel 316 L, aluminium alloy AA1050 and glass fibre reinforced epoxy composite, tested under tensile, bending and

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charpy impact loads. It was found that FML's with outer stainless steel layers displayed a significant increase in damage tolerance limit, stiffness and impact energy absorption as compared to aluminium alloy based FML's [8].

Stainless steel based FML's can become the tempting choice for marine applications due to their excellent corrosion resistance. Sarlin et al. [9] evaluated the corrosion resistance of FML's based on stainless steel AISI 304, mild steel EN 10,130 DC01 and Glass fibre/epoxy composite. The EPDM (ethylene propylene diene monomer) based rubber was used as adhesive to join steel layers with GF/E composite. Peel strength tests were conducted on unconditioned and conditioned specimens in hot and moist environments. It was concluded that FML's based on stainless steel AISI 304 exhibited better corrosion resistance and higher peel strength than mild steel based FML's.

Hygrothermal degradation in tensile and compressive strengths was evaluated for glass fibre/epoxy composite and glass fibre/epoxy/aluminium laminate (Glare). It was concluded that the degradation in tensile strength of glass fibre/epoxy composite was very much higher than Glare laminate, but the compressive strength degradation for both was nearly equal [10]. Botelho et al. [11] performed vibration damping experiments on unconditioned and hygrothermally conditioned specimens of glass fibre/epoxy composite, aluminium 2024-T3 alloy and glass fibre/epoxy/aluminium laminate (Glare) to investigate their viscoelastic properties. The storage modulus of glass fibre/epoxy composite was decreased during hygrothermal conditioning. But the degradation in viscoelastic properties of Glare laminate was negligible due to the resistance of outer metallic skins to moisture absorption. Ning et al. [12] concluded that delamination is the primary failure criterion in compression tests of hybrid composites, which results in a reduction of overall structural strength and stiffness.

Various studies have been performed to evaluate the mechanical properties and their hygrothermal degradation for both FRP's and FML's based on glass fibre and aluminium alloys. But the degradation in mechanical properties of stainless steel and glass fibre epoxy based FML's due to hygrothermal conditioning have not been investigated before. Therefore, the objective of the present work is to evaluate the hygrothermal degradation of tensile and compressive strengths of glass fibre/epoxy composite (GF/E composite) and stainless steel glass fibre/epoxy fibre metal laminate (SS FML).

2. Materials and method of preparation

2.1. Materials

The composite part of SS FML was prepared using unidirectional E-glass fibre (SikaWrap-430 G, supplied by Sika India Pvt. Ltd.) and MasterBrace 4500, a two part epoxy resin (supplied by BASF India Limited). Unidirectional glass fibre has areal weight of 445 GSM, fabric thickness of 0.172 mm and fibre density of 2.56 g/cm^3. Due to high corrosion resistance, stainless steel AISI 304 sheet (with 0.08% of C, 18–20% of Cr, 2% of Mn, 8–10.5% of Ni, 0.045% of P, 0.03% of S, 0.75% of Si, 0.10% of N and remaining iron) of thickness 0.4 mm has been used as the outer skin of fibre metal laminate [6,7,9,13–16], which makes the SS FML highly durable and reliable material for shipbuilding applications. A two part epoxy-based structural adhesive (Cured thickness 0.1 mm, supplied by Huntsman advanced materials (India) Pvt. Ltd.) was used to join metal and the composite sheets together.

2.2. Specimen preparation

In this research work, Hand layup method [17–24] was used to produce the GF/E composite sheets. A stainless steel mould (50 cm × 25 cm) was used to layup the glass fibre epoxy sheets. The mould was cleaned using a dry cotton fabric to remove any dust particles. After that, the releasing agent was applied on the surface of mould for the easy removal of cured GF/E composite sheet. Two parts of epoxy, i.e., resin and hardener were mixed by weight in the ratio of 100:40 using a mechanical stirrer (REMI lab stirrer) for two minutes at 500 rpm. The prepared epoxy mixture was put into a vacuum degassing unit of ABBESS (Model 206 with vacuum pump LAV 10) for five minutes to remove any air voids (i.e. air entrapped in between layers of epoxy) developed during mixing. After that the mixture was poured and spread over the glass fibre fabric in mould using a steel scraper. The desired thickness of GF/E composite sheet was prepared by adding more layers of glass fibre fabric using epoxy mixture. Tensile and compression test specimens of GF/E contained four and fifteen layers of glass fibre fabric respectively. Care was taken to maintain the uniform thickness of GF/E composite sheet. A roller was used to remove the excess resin. After curing for 24 h at room temperature, GF/E composite sheet was removed from the mould. After removal, the resin was applied on the reverse side to produce an equivalent surface as on previous side. The prepared sheet of GF/E composite was allowed to cure completely at room temperature for seven days (As per data sheet of epoxy used). The glass fibres in all layers of GF/E sheet (for both tensile and compression specimens) were oriented in same direction (i.e. 0° as shown in Figs. 1 and 2).

For the production of SS FML, stainless steel (SS) sheets were cut as per the size of GF/E sheet. SS sheets were subjected to sand blasting to increase their surface roughness and adhesion quality. Sand blasting was performed with abrasive blasting machine (GEC G7-500R) using 35 grit alumina. Thereafter SS surfaces were degreased in acetone. GF/E sheet for SS FML consists of three glass fibre epoxy layers for tensile specimen and fourteen glass fibre epoxy layers for compression specimen. Two parts (i.e. resin and hardener) of epoxy-based adhesive were mixed manually in the ratio of 100:80 by weight at room temperature and used to join the stainless steel sheets with GF/E sheet. Prepared GF/E sheet was stacked between two layers of SS in picture frame mould (50 cm × 25 cm) on a hot press under the pressure of 0.4 MPa at 50 °C for 3 h [17]. The fibres in GF/E layers of SS FML were in the rolling direction of SS sheet as shown in Fig. 1. Hot pressurized curing was used to maintain a uniform thickness of the adhesive film (0.10 mm) between SS and GF/E sheet. It also increases the rate of curing. After 3 h of hot curing, hot plates were shut off, and the sheet was kept under pressure for next 21 h. Cured SS FML sheet was removed from the mould after 24 h. The stacking sequences

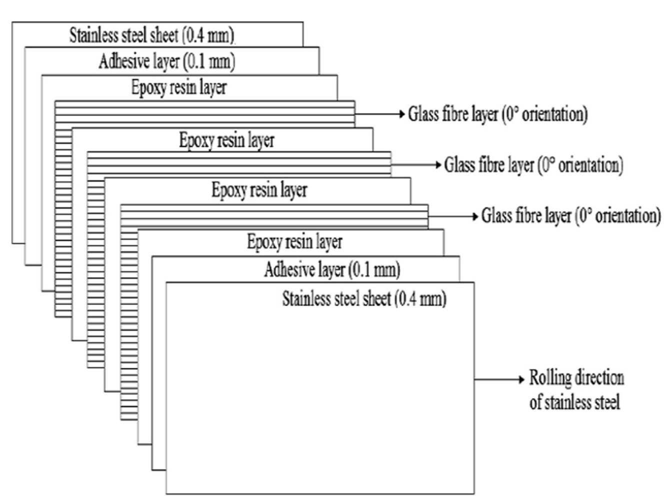

Fig. 1. Stacking sequence of SS FML.