Innovative 3D Glass Fiber Metal Laminate

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ABSTRACT

A novel, international patent pending assembled glass fiber metal laminate has been developed, which includes a 3D E-glass fiber fabric and light-weight magnesium alloy sheets. The 3D fabric contains two bidirectional fabrics knitted together by vertical braided glass fiber pillars. Application of resin to core faces and interior fibers creates spaces and voids in the fabric, which are filled by injection of foam to increase strength and stiffness. Thin magnesium alloy sheets comprise the outer layers on the two sides of the core layer. In addition, core and laminate structural strength and stiffness can be increased through the optional step of inserting thin fiberglass cloth layers between the core layer and outer metal alloy layers. Further renditions of this composite material can be attained by bonding together two or more of the abovementioned configuration. The structural panels are suitable for use in automobiles, marine vessels and other applications that particularly require optimal impact resistance and minimal likelihood of occurrence of delamination.

Keywords: 3D composite, glass fiber, magnesium alloy, foam, fabric

I INTRODUCTION

Fiber-reinforced polymer (FRP) composites [1] have been extensively utilized in various industries over recent years. The relatively high specific-strength and stiffness and noteworthy fatigue and corrosion endurance characteristics have made them useful materials for numerous applications, particularly in aerospace and automotive industries. The weakest link in the FRPs has been their inter-laminar shear capacity, which makes them susceptible to impact loading. Thus, researchers [2, 3] have tried to improve the impact resistance of FRPs over the last few decades.

In order to overcome these deficiencies, new hybrid materials called fiber-metal laminates (FMLs) [4] have been developed to combine the best attributes of metal and composites. FMLs offer a considerable weight advantage over other materials, such as metals. Generally, the weight savings are obtaat the sacrifice of other important material properties such as; ductility, toughness, bearing strength and conductivity.

Fiber-metal laminates are obtained by stacking alternating sheets of metallic alloys (most prevalent one being aluminum alloys) and the fiber-reinforced pre-pregs and curing the stack under heat and pressure. Such FMLs have been used mainly in the aerospace and spacecraft industries. They can also be used as sheets and/or a reinforcing element and/or as stiffening agents in structural components, such as; aircraft wings, fuselage and tail panels.

One of the most well-known FMLs is the commercial product GLARE (Glass Laminate Aluminum Reinforced Epoxy) [5], which is composed of several very thin layers of metal (aluminum) interspersed with layers of pre-preg glass-fiber, bonded together with an epoxy resin. GLARE5 FMLs [6] were developed with emphasis upon the effects of FML thickness and impactor mass on the impact response. It was determined that specimen thickness had a significant effect upon the failure modes of FMLs, such that an increase in panel thickness significantly enhanced the energy absorption capacity of these FMLs. Previous studies (1) have found that compared to 2024-T3-based GLARE5, the impact resistance of magnesium-based FMLs was lower, when damage in the form of cracking of magnesium plates was taken as the failure criterion. In addition, when comparing the perforation limit, the specific impact energy of the magnesium-based FMLs was observed to be approximately equal to GLARE5 (6).

The material under the trade name of ARALL [7] is fabricated by putting fiber reinforcement in the adhesive bond lines between aluminum alloys. The main difference between ARALL and GLARE is that ARALL contains aramid fibers instead of the glass fibers in GLARE, and that GLARE exhibits higher tensile, compressive and residual strengths and greater impact resistance than ARALL. It has been observed that in comparison to GLARE, ARALL exhibits poor compressive strength, which represents a major limitation of the product (7).

CARAL [8] materials have exhibited an improvement over ARALL materials, such that they contain different amounts of carbon/epoxy pre-pregs instead of aramid/epoxy pre-pregs. Compared with aramid/epoxy, carbon/epoxy composites possess higher specific modulus, but relatively low values of specific impact strength and strain to failure. In terms of fatigue, it has been recognized that aramid fiber composites exhibit better low-cycle fatigue performance, but worse high-cycle fatigue performance than carbon fiber composites. Moreover, the high stiffness of carbon fibers allows for extremely efficient crack bridging, and therefore, relatively very low crack growth rates (9).

2. NEW ALTERNATIVE MATERIALS FOR FORMATION OF FMLS

2.1 3D E-glass Fabric

A novel generation of truly three-dimensional fiberglass woven fabric, herein referred to as 3D fiberglass fabric (3DFGF), has been recently introduced into the marketplace. The 3DFGF is comprised of two layers of woven bi-directional fiberglass fabrics, knitted together by a series of fiberglass fibers (hereafter referred to as pillars or columns). As illustrated in **Error! Reference source not found.**, the unique structure of 3DFGF fabric provides a series of hollow cores between the two woven fabrics. This unique and complex structure of the fabric significantly enhances the resulting mechanical properties in comparison to those of its conventional 2D counterparts. In other words, the composite made from this 3D fabric offers comparatively a more superior bending stiffness and strength, lighter weight, excellent thermal insulation and acoustic damping, as well as a remarkable energy absorption capacity under impact loading. In order to improve the mechanical response of the fabric, the hollow cores within the fabric can be filled with a foam material, [2, 3].

2.2 Light-weight Alloy

The use of magnesium alloys (Mg, hereafter) in various engineering applications has been increasing steadily [10] and one of the primary reason is due to the low density of magnesium (roughly 25% that of steel and 35% lower than aluminum), which makes the weight of magnesium alloy structural components very comparable to that of FRPs. Magnesium alloy-based fiber metal laminates exhibit several advantages over other metal-base alloys, such as; a high strength to weight ratio, improved electromagnetic shielding capability, relatively lower density and lower cost compared to aluminum and they also display superior corrosion resistance. In addition, it has been found that magnesium-based alloys exhibit higher specific tensile strength than that of 2024-T6 aluminum alloy-based FMLs. It has also been suggested that the relatively lower elastic modulus and fracture properties exhibited by magnesium-based FMLs may be mitigated by selection of an appropriate volume of the composite constituents [2,3].

2.3 A Novel 3D-FML

As briefly mentioned earlier, one of the most common modes of damage for conventional FML configurations subjected to low velocity impact is the delamination that could develop within their FRP layers and/or within FRP/metallic interfaces. The authors have recently demonstrated that superior impact response with minimal delamination can be attained by appropriately configuring layers of the 3D fabric with sheets of Mg. It has been demonstrated that the impact energy in such FMLs is absorbed mainly by crushing the through-thickness fibers and the supporting foam beneath the region of impact.

Figure 1. The 3D fiberglass fabric (3DFGF)

The combination of the 3D fabric mentioned above and Mg alloy sheets has been recently used to develop a new class of FML, referred to as 3DFGF-FML. The static response and low velocity impact response of the 3DFGF-FML were thoroughly investigated experimentally and also simulated computationally (1, 2). In order to obtain a more comprehensive understanding of the performance of the FML, the performance of the 3DFGF-FML was compared against the conventional FMLs, which were fabricated using layers of woven fabrics instead of the 3D fabric. In addition, the effect of the stacking configuration of the materials was examined on the responses of 3DFGF-FML [2,3].

3. PRODUCTION OF THE NEW 3D-FML

The steps involved in production of the new material (3DFGF-FML) are comprised of:

The surfaces of metal alloy sheets are sanded. Compressed air is blown to free the surfaces of dust, and then surfaces are wiped clean with acetone.

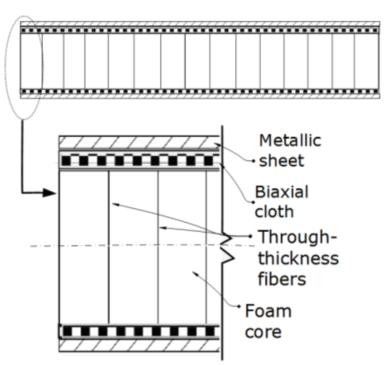
Epoxy resin is applied to the 3D fiber fabric and its core fibers and permitted to cure with addition of a hardener.

A liquid polymer foam (or alike) is injected into the 3D fiber core and permitting to solidify. Resin is applied to the surface of each metal alloy sheet, and the sheet is bonded to the surfaces of the cured foam-filled 3D fiberglass, and let cure under appropriate pressure [2,3].

Table 1: Comparison of the flexural stiffness of the 3D FML and the conventional FMLs

FMLs type	Flexural Stiffness (N-m2)	Specific Flexural Stiffness (N-m2/g.mm-3)
3DFGF-FML	269.28	5729.53
4-layer FML (conventional)	178.23	1916.40
7- layer FML (conventional)	356.96	2189.96
16- layer FML (conventional)	1287.25	3460.34

The appropriate steps from the above procedure can be repeated if more than one layer of the 3D-fabric, or metal alloy sheets are to be used to fabricate thicker and stiffer/stronger 3D-FMLs, as illustrated in Figure 2.



(a)

(b)

Figure 2. Two configurations of the novel 3D-FML

4. TEST RESULTS

Results of laboratory testing relevant to the present invention are summarized in the following Tables. The new FML exhibited an overall bending stiffness greater than conventional FMLs made with four layers of fibers. However, the specific stiffness of the 3DFGF-FML is greater than those exhibited by all the conventional FMLs considered here. Moreover, when comparing the specific stiffness values of the tested FMLs, as reported in Table 1, it can be seen that the 3DFGF-FML produced even higher specific stiffness than the conventionally made FML with 16 layers of glass fabric. These results demonstrate the notable cost-savings one could achieve by using the developed 3DFGF-FML. The details of the FMLs noted in Table 1 are reported in Table 2.

Moreover, the impact characteristics of the newly assembled 3D FMLs were examined by characterizing and comparing; their energy absorption capacities, residual deformation and maximum deformation due to low velocity impact, with the results illustrated in Figure 3. Test results revealed that the proposed FMLs based upon the 3D glass fiber fabric, exhibited outstanding specific impact energy absorption capacity [2,3].

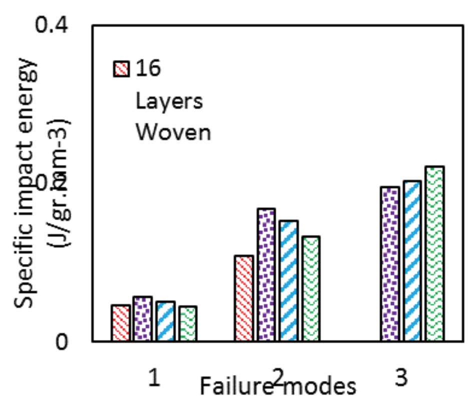


Figure 3. Variation of the specific impact energy absorption capacity of FMLs for the various failure modes

Table 2. Specifics of the different FML types

Specimen ID	Overall Thickness (mm)	Overall Density (g/mm3)	Reinforcement Fabric type	No. of layers of fabrics
3DFGF-FML	14.40	0.047	3DFGF	1
4-layer FML	4.87	0.093	biaxial woven	4
7-layer FML	6.53	0.163	biaxial woven	7
16-layer FML	10.16	0.372	biaxial woven	16

5 SUMMARY AND CONCLUSIONS

A novel 3D structural fiber metal laminate (3D-FML) has been developed, which exhibits outstanding specific stiffness and strength, and impact energy absorption capacity in comparison to conventional FMLs. It has been demonstrated that by combining a recently developed truly 3D E-glass fabric, whose core spaces are filled with a light-weight foam and light-weight metallic alloys sheets (e.g. magnesium alloys), one could produce a cost-effective, lightweight and highly resilient structural material. The resulting composite also provides excellent strength against delamination under both static and impact loading conditions. The

Afore mentioned attributes render the use of this novel 3D-FML as an economical and effective material for use in various impact-prone structural applications (e.g., in automotive and space vehicles).

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