

# Experimental Investigation for Characterization of Formability of Epoxy based Fiber Metal Laminates using Erichsen Cupping Test Method

K. Logesh<sup>1\*</sup>, V. K. Bupesh Raja<sup>2</sup> and R. Velu<sup>3</sup>

<sup>1</sup>Department of Mechanical Engineering, Sathyabama University, Chennai-600119, Tamil Nadu, India; klogesh7@gmail.com

<sup>2</sup>Department of Automobile Engineering, Sathyabama University, Chennai-600119, Tamil Nadu, India; bupeshvk@gmail.com

<sup>3</sup>Department of Mechanical Engineering, Vel Tech University, Chennai-600062, Tamil Nadu, India; veluramasamy@gmail.com

## Abstract

Fiber Metal Laminates are now-a-days a dominant material for applications such as automobile body panels, aircrafts cabins and railway wagons, because of reasons such as superior mechanical properties such as high strength and less weight. Hand Lay-up technique was used to fabricate four fiber metals laminates comprising of aluminium alloy 5052-H32 as the skin material and E-glass fiber as the core. The formability behavior of the laminate was found using Erichsen cupping test using an indigenously developed test setup. The Erichsen cupping index on the specimen varied from 5.95 to 7.28 respectively. The test specimens were investigated through microscope and macroscopic approach. Macroscopic examination revealed that the laminate was ductile in nature, which was backed by the aluminium skin. The defect created on the specimen during the test was smaller than the diameter of the ball used during the test. Microscopic examination through Scanning Electron Microscope revealed that the laminates had microscopic defects such as fiber pullout and surface cracks in the skin materials. The fibers were subjected to brittle failure while the skin material sustained ductile fractures. The Erichsen cupping index value depended upon the factors such as complexity of composite sheet forming operations, simple mechanical property measurements made from the tension test area of tested value. Ductile fracture was observed in the specimen due to the influence of progressive loading through Erichsen cupping test. There was non-uniform distribution of reinforcement in material, Microstructure revealed fiber cracks which were oriented in line to the crack growth on the skin material. Hence, it can be concluded that the proposed material can be safely applied for automotive, aeronautical and locomotive body panels or as a skin material.

**Keywords:** Erichsen Cupping Index, Erichsen Cupping Test, Fiber Metal Laminate, Formability Behavior

## 1. Introduction

Fiber-Metal Laminates (FMLs) are lightweight hybrid composite materials that consist of aluminium layer on both the sides laid to fiber reinforced Epoxy layers. GLARE (GLASS-Reinforced) FML demonstrates outstanding damage tolerance capabilities Alderliesten RC and Homan JJ<sup>1</sup>. In addition to its excellent impact resistance when compared to composites or metals and their alloys Vlot A and Gunnink JW<sup>2</sup>. The lightweight materials such as fiber reinforced

composite materials and metal composite structures significant due to their reduction in specific weight find its place in various applications such as automobiles. The challenge in using these advanced light weight material systems in using it in automobiles is a suitable manufacturing technique. Though many researches of Fiber Metal Laminates (FML) have been carried on the stamp forming behaviour of thermoplastic composites, some of the sandwich structures are not purely classified or based on thermoplastic composites. Wrinkle formation is a major issue and it is influenced

\*Author for correspondence

by Fiber orientation, blank size, matrix viscosity and forming speed T. A. Martin et al<sup>3</sup>. Study on stretch and draw behaviour in forming of thermoplastic composite sheets with a knitted-fabric structure concluded that blank forming could be optimised through variation in blank holder force, blank size and punch shape. Thus the amount of stretch and draw present in the forming are varied. The commonly used continuous woven glass fabric reinforced polypropylene materials, the self reinforced polypropylene composites have an additional mode of deformation, as in the case the fiber can still be deformed N.O. Cabrera et al<sup>4</sup>.

The dominant mechanism in woven-composite forming is the intra-ply shear phenomenon. The surface strain results from channel forming of aluminium and pre-heated FML. It was shown that the major strain in the bent regions are much low on the FML channel rather than that on the plain aluminium channel. The magnitude of the bend radius does not affect the surface strain of the FML in a significant manner P. Compston et al<sup>5</sup>. To study the stamp forming behaviour of FML system, its design of experiments was undertaken to find the major effects of the process parameters that include blank holder force and temperature S. Kalyanasundaram et al<sup>6</sup>. Weight reduction is still one of the prime design objectives in automotive, aeronautical, marine and other structural application since they result in continuous savings. The sandwich panels have proved their superiority in aerospace applications because of its superior mechanical properties K. Logesh and V.K.Bupesh Raja<sup>7</sup>.

Sandwich sheets with polymer cores cannot be welded, and hence their use in automotive applications is mostly limited to few structural components of the car body "Final Report to the Ultra Light Sheet Auto Body (USLAB) Consortium. Porsche Engineering Services Inc"<sup>8</sup>. Metal laminates with thickness 1 to 2 mm are highly researched to determine its feasibility in applications such as automotives and aeronautics Gustafsson, R.N.G. Ultralight stainless steel sandwich materials-HSSA<sup>9</sup>. Hybrid stainless steel abbreviated as HSSA with a stainless steel fiber core as new material is aimed for future vehicles industrial applications. The optimally adaptable design structures of sandwich composite materials have excellent mechanical properties Grenestedt JL<sup>10</sup>, Vinson JR<sup>11</sup>. They are special hybrid materials consisting of alternate layers of metal and polymers bonded together with an adhesive layer Karlsson KF<sup>12</sup>. The mono materials are not able to meet high demands of multi functionality and presenting requirements Harris B<sup>13</sup>.

But hybrids can combine the advantages of different mono materials such as density, high bending resistance Kim KJ et al<sup>14</sup>, energy absorption and high load capacity at less weight Librescu L et al<sup>15</sup>. Sandwich laminates and conventional composite materials are used in automotive field and the development of thin sandwich sheets will make them suitable to be used in various engineering applications. However, lack of formability and weldability of these special sandwich composites prevent their wide spread use in the automotive industry Mohr D, Straza G<sup>16</sup>, ship building as well as in aerospace industries Beumler Th et al<sup>17</sup>.

The wide range of investigations on the forming behaviour of sandwich composite materials will ensure their place in future sandwich composites that are to be used in various fields Kim KJ et al<sup>14</sup>. The formability of sandwich composites with different embedded solid and mesh steel inlays was investigated with an aim to gain information about their forming behaviour by shaping, deep drawing and bending Olga A. Sokolova et al<sup>18</sup>. Evaluating the formability of sheet metal was initially proposed by Erichsen<sup>19</sup>, in which a sheet specimen is stretched by means of a hemispherical punch until fracture occurs and this test is called as Erichsen cupping test. Erichsen cupping test is to find the ductility of a given sheet, where the depth of the punch indentation in the specimen is expressed in millimetres. This is called as Erichsen Index (IE), which is the most commonly used parameter for expressing the formability of any sheet metal. Various researchers have analyzed the limits of applicability and their accuracy, the factors influencing the Erichsen test results Pearce R<sup>20</sup>, Yokai M and Alexander JM<sup>21</sup>. Like in the Erichsen test, Olsen test also expresses the formability in terms depth of the punch indentation at the beginning of fracture Animesh Talapatra et al.<sup>22</sup>

## 2. Materials

### 2.1 Aluminium Alloy 5052-H32 (AA5052-H32)

Aluminium alloy 5-series (Al-Mg) are the strongest non heat treatable aluminium alloys. Compared to most of the products made of different alloys, they are more economical. Alloys of the 5-series have resistance to general corrosion as other non-heat-treatable alloys in most of the environments. Aluminium alloy 5052 in H32 temper has very good corrosion resistance to marine and industrial

atmosphere. It has very good weldability and good cold formability. The chemical composition of the alloy used in the present study is shown in Table 1.

## 2.2 Glass fiber

The glass fabric reinforcement used for fabrication of FMLs composite was E-glass woven fabric having a real density of 610 g/m<sup>2</sup>. The most common reinforcement for the polymer matrix composites is glass fiber. The E-Glass fibre chosen for the FMLs, in this work is in the form of mat, so that the FML has high extensibility and toughness. The glass fibre is a lightweight, extremely strong and high strength material Hawtin, L.R et al.<sup>23</sup> This material is less brittle than most of its counterparts and are less costly. Its bulk strength and density are very favourable when compared to metals. It can be easily made using moulding processes. Glass fibre finds its applications in aircraft, automobiles and marine industry Datsko, J<sup>24</sup>.

## 2.3 Epoxy Resin

Epoxy or Poly-Epoxy is a thermosetting Epoxide polymer that cures (polymerizes and cross links) when mixed with a catalyzing agent or hardener. Epoxy resins are produced from a reaction between Bisphenol-A and Epichlorohydrin. The epoxy based materials have many applications which include coatings, adhesives and composite materials with fibre glass reinforcements. The composition and the range of epoxies of commercially available variations allow to curing of polymers with a very broad range of properties. In general, epoxies are known for their excellent adhesion, heat resistance, good mechanical and chemical properties and useful electrical insulating properties. Almost any property can be modified in an epoxy. For example silver-filled epoxies with good electrical conductivity are widely available, though epoxies are electrically insulating. Epoxy resin is used as the binder in counter-tops or coatings for floors. The use of epoxy grows many folds. A good number of varieties of epoxies are constantly being developed to suit the industries and products requirements. The

**Table 1.** Chemical Composition of AA5052-H32

AA 5052-H32	Mg	Cr	Si	Fe	Cu	Mn	Zn	Al
%	2.292	0.162	0.066	0.341	0.009	0.050	0.007	Balance

resin used in this research work is AV138/HV998 that is cure at room Temperature. The mixing ratio is given in Table 2.

## 3. Fabrication Methods of FMLs Sandwich Material

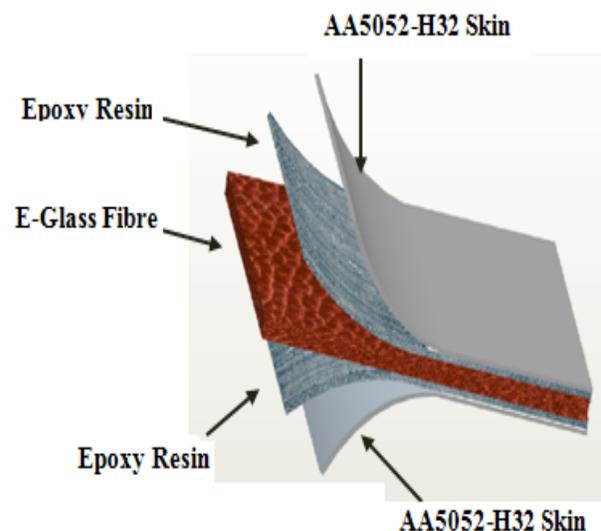
The sandwich sheet was prepared by hand layup technique of two 5052-H32 aluminium alloy skins with a woven roving e-glass fibre between epoxy resins in room temperature curing. The AV138 and HV998 mixing is in the ratio of 5:2. An adhesive mixing is carried out by using hand stirrer uniformly. The fabrication of FMLs includes the curing temperature of 19 hours. Figure 1 show the various segments and materials which make up a FML.

### 3.1 Specimen Preparation

The lamination of FMLs sandwich materials are made by hand Lay-up technique. The dimensions of samples were prepared as per standards. IS 10175, a standard test method for Erichsen cupping test method was followed while testing of sandwich materials for shear properties.

**Table 2.** Mixing ratio for epoxy

Mixing Ratio	Part by Weight
Araldite, AV138	5 parts
Hardener, HV998	2parts



**Figure 1.** Sectional view of the AA5052-H32/GF/AA5052-H32 sandwich sheet.

The samples of FMLs sandwich Sheet are shown in Figure 2.

## 4. Experimental Procedure

### 4.1 Erichsen Cupping Test

The FMLs combination of AA 5052/Glass fibre/ AA5052 epoxy based laminates sandwich sheet was investigated under Erichsen cupping test to find the strength, hardness, anisotropic characteristics and stretch formability. The FMLs sandwich sheet of dimension 90 x 90 mm was prepared and clamped between two ring dies of Erichsen tester and the ball was forced against the sheet until FML fracture occurred. The schematic of Erichsen cupping test is shown in Figure 3. The depth of the bulge before



Figure 2. Erichsen Cupping Test samples of FMLs sandwich sheet.

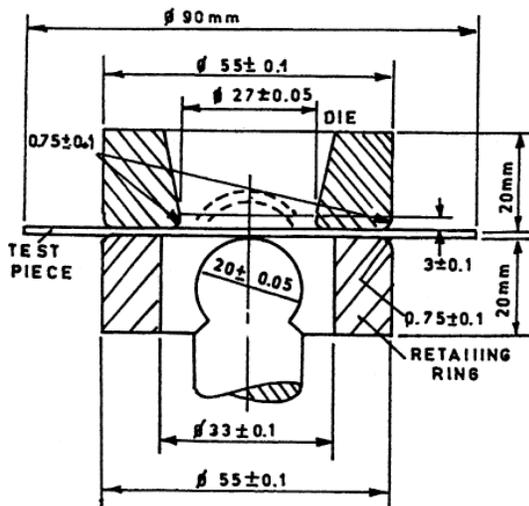


Figure 3. Schematic of the Erichsen cupping test <sup>26</sup>.

fracture was measured using vernier scale. The Erichsen number is the difference between initial reading and final reading measured by the vernier caliper. After rupture, the crack appeared through the full thickness of the test piece. The height of the cup is used as formability index W.F. Hosford and R.M. Caddell<sup>25</sup> and Banabic D<sup>26</sup>.

## 5. Result and Discussion

### 5.1. Macrostructure Investigation

In the FML macrographs the fracture zone are distinctly visible in Figure 4. FML was investigated under Erichsen cupping test to check nature of strength, harness, anisotropy and rate hardening of material considering drawing, redrawing phenomenon of the specimen. The epoxy based FML showed the ductile fracture growth using hemispherical punch. The upper skin affected zone was broad in FML due to the high drawing force input. This caused significant change in the material shape and size. In the fracture section of FML, fiber and aluminium crack orientation were observed. The Erichsen cupping index of the specimen are shown in Table 3. K. Logesh and V. K. Bupesh Raja<sup>27</sup>, revealed that the Erichsen cupping test on AA8011/PP/AA1100 sandwich material showed better Erichsen index because of the influence of the core material and skin material combined together. Similarly many authors have reported improvement in forming index values of FMLs



Figure 4. Macrostructure picture of the Erichsen Cup Test specimen surface of an AA5052-H32/GF/AA5052-H32 Epoxy based FMLs sandwich sheet.

Table 3. Erichsen Cupping Value of FML Sandwich sheet

Nature of Specimen	Trial-1	Trial-2	Trial-3	Trial-4
Square specimen	5.95	6.46	7.28	6.52

such as R. Velu and Moses Raja Cecil<sup>28</sup>, K. Logesh et al.<sup>29</sup> and Aray Zhanys Saule Nurkasymova<sup>30</sup>.

## 5.2. Microstructure Analysis for characterization of Damage

Scanning Electron Microscope (SEM) images were taken for the samples to observe the microstructure. The images were taken for epoxy based FML composites and the images were analyzed for ductility fracture in the Erichsen cupping specimen. The FML composites, ductility fractured during Erichsen cupping test in fracture condition were subjected to observation under scanning electron microscope.

The fibre pull out is clearly visible in the SEM images as shown in the Figure 5a. The fibres are visible in which the

fibre crack can also be seen in Figure 5b. The aluminium skin initial are clearly visible as indicated in the image. The composite sandwich structures of the fibre are visible Figure 5a, 5b and 5c. The extensive fibre pullout at the at the punch tension side of the ductile fracture is visible in Figure 5d and the fibre damage is shown in Figure 5e.

## 5.3 Erichsen Cupping Test

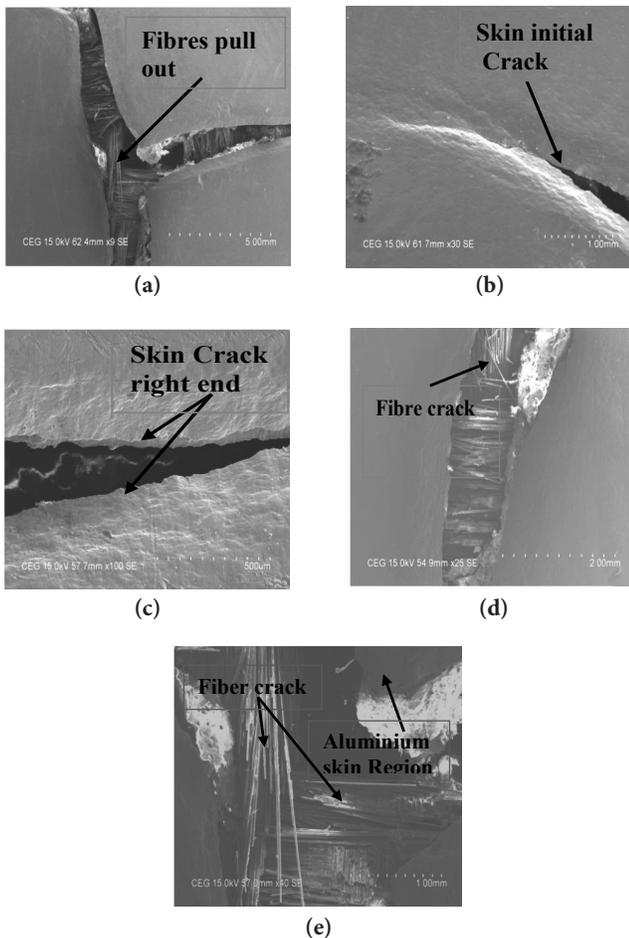
The complexity of composite sheet forming operations, simple mechanical property measurements made from the tension test area of tested value. In that cupping test the Erichsen no of highest value of epoxy based FML composite Sheet (7.28), so the formability is good and also good ductility and good formability from this observed value of Erichsen index.

## 6. Conclusion

Ductile fracture was observed in the specimen due to the influence of progressive loading through Erichsen cupping test. A specimen with (7.28) Erichsen index revealed that, there was slight increase in the thickness of the reinforcement materials. There was non-uniform distribution of reinforcement in material, Microstructure revealed fibre cracks which were oriented in line to the crack growth on the skin material. No other defects were observed. Test results indicated that the Erichsen index was in line with the results as observed in the literature. Hence, it can be concluded that the proposed material can be safely applied for automotive, aeronautical and locomotive body panels or as a skin material.

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**Figure 5.** SEM photographs of fractured FMLs specimens under Erichsen cupping test. (a) Appearances of Fibres pull out. (b) Initial crack with skin scattered debris formation in aluminium skin. (c) Aluminium skin crack at right end. (d) SEM photograph core of fibers crack in FML. (e) Appearance of fibers cracks with ductile fracture formation of aluminium skin.

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