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Improving the Adhesion Bonding Strength for FML Composites by Using an Extremely Thin Mesh Steel

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Abstract

Fiber metal laminate (FML) is an advanced composite material that combines the advantageous of both fiber reinforced composites and metal alloys without sharing their individual disadvantages. When it is compared to commonly known fiber reinforced polymer composites, the FML provides better impact resistance and fatigue strength. But the production of a FML composite is a major problem since the bonding at fiber-metal interface can be poor. For this reason, the adhesion bonding capability at the fiber-metal interface was investigated in this study. Carbon fiber and glass fiber fabrics having both ±45° and 0°-90° orientation were used as fiber layers. And extremely thin stainless steel materials in the mesh form were used as metal layers. The mesh sizes of the layers are 100 and 500 respectively. The produced specimens having 12 different configurations were subjected to single lap shear tests according to ASTM D 5868-01 Standard. The results showed that 500-mesh stainless steel favorably affected the adhesion bonding strength.

Keywords: Fiber metal laminate (FML), composites, mesh steel, single lap shear, adhesion bonding.

1. INTRODUCTION

Fiber-reinforced epoxy composites are widely used in aerospace, automotive, marine, infrastructure, sporting goods and so on. Firstly, military applications in the aircraft industry triggered off the commercial use of composites due to their advantageous properties of low thermal conductivity, fatigue and corrosion resistance. The innovations in the composite area have allowed significant weight reduction in structural design. Composite materials are a good candidate when compared to metallic alloys, especially when high strength and weight ratios are concerned [1-4].

Fiber metal laminates (FMLs) are hybrid structures consist of thin sheets of metal alloy and fiber reinforced polymer composites. The FML composites mainly developed for improving fatigue strength of modern civil aircraft [5-6]. However, it provides additional advantages such as damage tolerance, fire resistance and impact resistance with the aid of different configurations [6]. Two grades of FML are commercially available: ARALL which is based on aramid fibres and GLARE, which is based on high strength glass fibres [2].

Khalili et al. [7] produced FML by using basalt fibers and steel and aluminium for metal layers. They invesitgated the tensile and bending properties of the basalt/epoxy FML. The existing of steel layers improved the bending and tensile strength properties compared to pure basalt fiber reinforced epoxy composites. Gonzalez-Canche et al. [8] showed that the toughness property can be satisfied by producing FML. Carrillo and Cantwell [9] manufactured thermoplastic-matrix FML by using self-reinforced polypropylene (SRPP) composite and an aluminum alloy and investigated the tensile, flexural and impact properties. They concluded that FML provided positive effects on mechanical properites compared to fiber reinforced composites. Also, The strength of adhesion surface between the layers in the composites can be obtained in different geometric shapes. Calik [10] investigated strength of different end part of the adherend geometries in single lap joints and subjected to tensile load by using finite elements method.

The main problem for the production of FML is the adhesion bonding strength between the fiber and metal layers. For this reason, the bonding capability at the fiber-metal interface was investigated in this study. Carbon fiber and glass fiber fabrics having both ±45° and 0°-90° orientation and an extremely thin stainless steel layer in the form of

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mesh were used for the first time in this work. Two different, 100 and 500, mesh sizes were used. Twelve different type of specimens were manufactured with hand lay-up vacuum bagging method. The specimens were subjected to single lap shear tests according to ASTM D 5868-01 Standard in order to investigate the effect of mesh steels on the adhesion bonding capacity.

2. MATERYAL VE METOD

2.1 Materials

AISI 304 stainless steel with 100 and 500 mesh sizes were used for metal layer in FML. The chemical composition and pyhsical properties of the metalic material are given in Table 1 and Table 2. Also, the stereo microscope images of stainless steel mesh are shown in Figure 1.

Table 1. The chemical composition of AISI 304 stainless steel

% C	% Cr	% Fe	% Mn	% Ni	% P	% S	% Si
0-0,08	18-20	65,8-74	0 - 2	8 - 11	0-0,045	0-0,03	0-1

Table 2. The pyhsical properties of 100-mesh and 500-mesh

Thickness, mm	Wire Diameter, mm	Number of Holes/cm^2	Open Area, %	
100 mesh	0,154	0,10	39	37
500 mesh	0,025	0,025	206	25

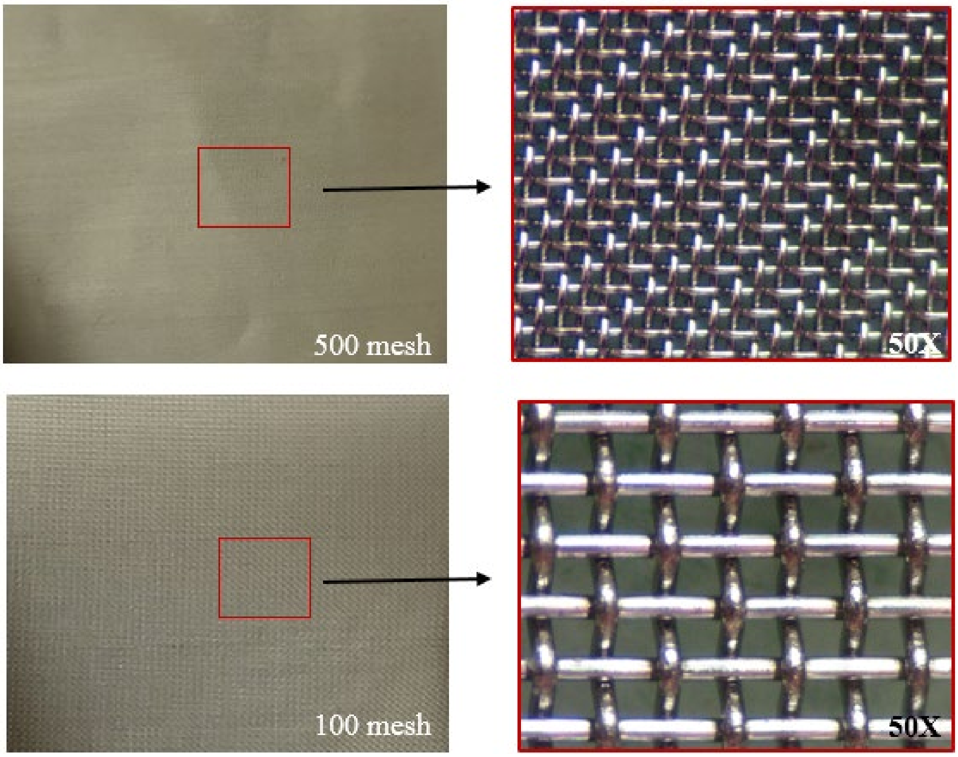

Figure 1. AISI 304 stainless steel having sizes of 100-mesh and 500-mesh

Carbon fiber and glass fiber fabrics having ±45° and 0°-90° orientation were used for the FML production. Table 3 shows the physical properties of fiber fabrics.

Table 3. Properties of fiber fabrics

Areal Density, gr/m^2	Thickness, mm	
Carbon ±45°	300	0,40
Carbon 0-90°	200	0,55
Glass ±45°	468	0,42
Glass 0-90°	200	0,33

2.3 Method

FML production was carried out by stacking metals and fiber fabrics in alternative sequences. In this study, the production was performed by hand lay-up under vacuum bagging method. The test specimens were produced in two stages. Firstly, the fiber reinforced polymer (FRP) test specimens were manufactured, then two FRP specimens were combined by adding a stainless steel mesh layer in between the FRP specimens. Water jet cutting machine was used for cutting both

FRP and mesh steels in order to obtain smooth cut edges.

2.4 FRP Fabrication

The fabrication of FRPs were carried out by using L160 epoxy and its H160 hardener with a mixing ratio of 4:1 in weight. And the total amount of resin set was determined equal to the total amount of fiber fabrics. The prepared resin was applied to each fiber fabric with hand lay-up before vacuum process. Figure 2 shows the FRP laminates under the vacuum atmosphere. The curing process was completed for about 24 hours under vacuum. After curing process, the FRP laminates were cut to standard test dimensions by using water jet cutting machine.

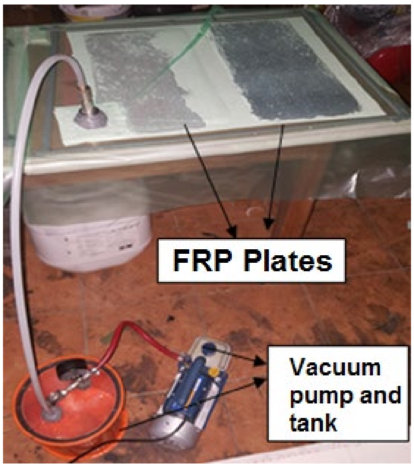

Figure 2. Fabrication with vacuum bagging method

2.4 Water Jet Cutting

The fabricated FRP laminates were cut accurately under the water jet cutting machine according to ASTM D5868-01 “Lap Shear Test” Standard. The dimensions of the plates were schematically represented in Figure 3.

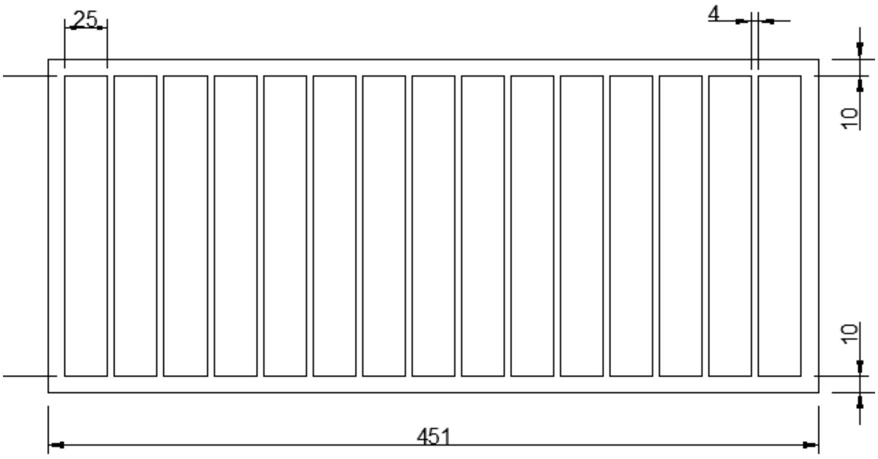

Figure 3. Technical drawing of FRP and metal plates.

The plates were dried with compressed air after water jet cutting. Figure 4 shows the carbon FRP and glass FRP plates. The mesh steels were cut by a hand cutter due to their extremely thin thickness.

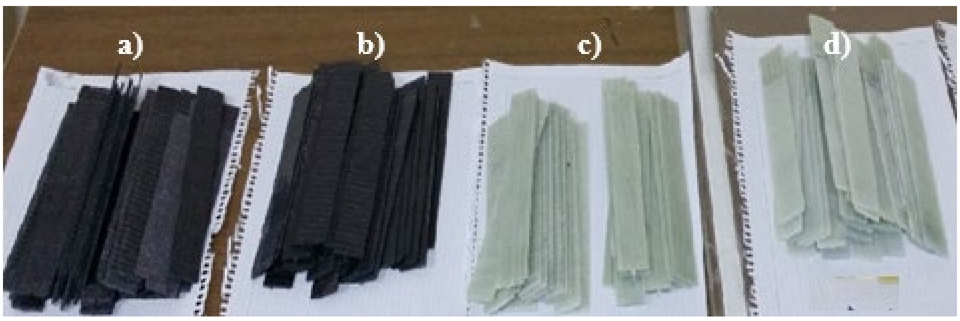

Figure 4. FRP specimens after water jet cutting. a) Carbon FRP, 0°-90°, b) Carbon FRP, ±45°, c) Glass FRP, 0°-90°, d) Glass

FRP ±45°

3. RESULTS AND DISCUSSION

Shear lap test results were given in Tables 4-7 and Figures 5-8 in below. The tests were performed with five replications for each specimen group.

Table 4. Lap shear test results for glass FRP (0°-90°) and mesh steels

GLASS FRP (0°-90°)	P_{max}, N	Lap Shear Strength, Mpa	Average Lap Shear Strength, Mpa	Standard Deviation
Glass - Glass	2503	4,00	3,94	0,25
	2498	3,40		
	2402	3,84		
Glass-500 mesh steel	3093	4,95	4,22	0,53
	2527	4,04		
	2300	3,68		
Glass-100 mesh steel	1230	1,97	1,33	0,45
	633	1,01		
	634	1,01		

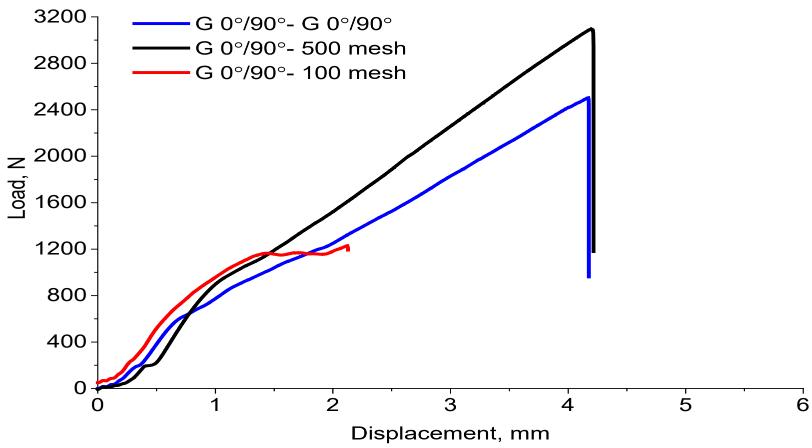

Figure 5. Force Displacement curves for Glass (0°-90°) and mesh steel under lap shear tests

Glass FRP composites having 0-90° orientation laminated with 500 mesh stainless steel yielded maximum lap shear strength (LSS) and the LSS results are minimum when it was laminated with 100 mesh stainless steel.

Table 5. Lap shear test results for glass FRP (±45°) and mesh steels

GLASS FRP (±45°)	P_{max}, N	Lap Shear Strength, Mpa	Average Lap Shear Strength, Mpa	Standard Deviation
Glass - Glass	527	0,84	0,80	0,02
	489	0,78		
	506	0,80		
Glass-500 mesh steel	2095	3,35	3,45	0,07
	2214	3,54		
	2156	3,45		
Glass-100 mesh steel	900	1,44	1,94	0,38
	1477	2,36		
	1263	2,02		

Glass FRP composites having ±45° orientation laminated with 500 mesh stainless steel yielded maximum lap shear strength (LSS) and the results were 4.3 times better than pure glass FRP.

Carbon FRP composites having 0-90° orientation laminated with 500 mesh stainless steel yielded maximum (LSS) but the LSS results are minimum when it was laminated with 100 mesh stainless steel. 500 mesh stainless steel was improved the LSS approximately by 137% when compared to pure carbon FRP (0-90°).

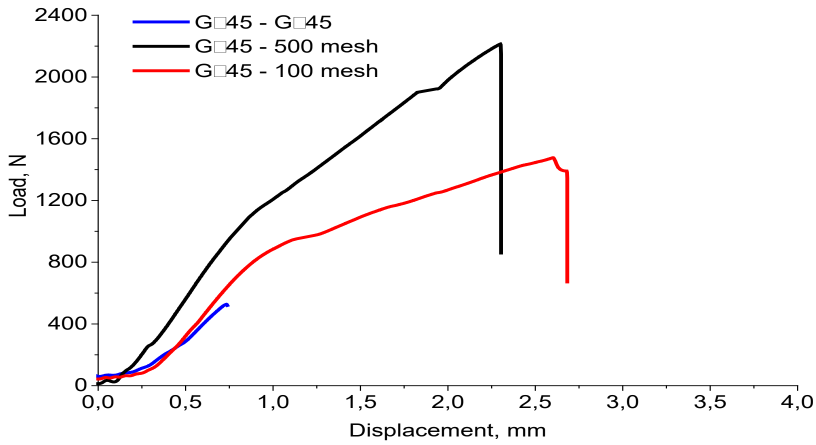

Figure 6. Force Displacement curves for glass (±45°) and mesh steel under lap shear tests

Table 6. Lap shear test results for carbon FRP (0°-90°) and mesh steels

CARBON FRP (0°-90°)	P_{max}, N	Lap Shear Strength, Mpa	Average Lap Shear Strength, Mpa	Standard Deviation
Carbon - Carbon	2030	3,25	3,28	0,1
	1986	3,18		
	2132	3,41		
Carbon-500 mesh steel	5057	8,09	7,78	0,24
	4852	7,76		
	4687	7,50		
Carbon-100 mesh steel	1466	2,34	2,37	0,14
	1596	2,55		
	1385	2,22		

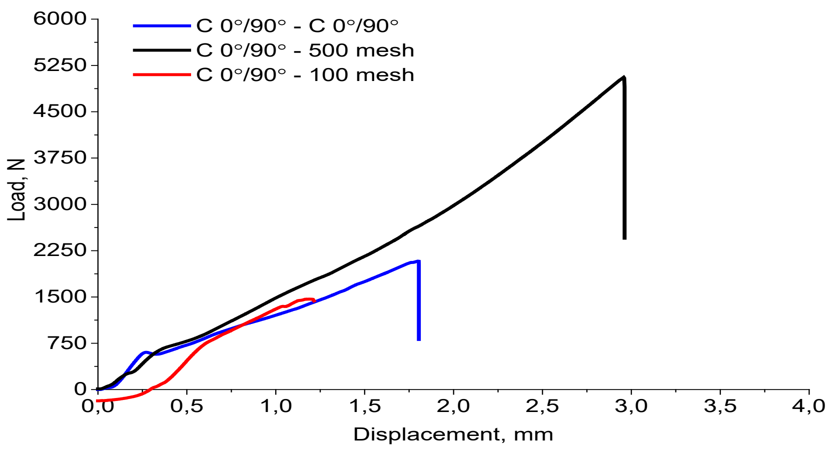

Figure 7. Force Displacement curves for carbon (0°-90°) and mesh steel under lap shear tests

Table 7. Lap shear test results for carbon FRP (±45°) and mesh steels

CARBON (±45°)	P_{max}, N	Lap Shear Strength, Mpa	Average Lap Shear Strength, Mpa	Standard Deviation
Carbon - Carbon	1271	2,03	1,90	0,09
	1123	1,80		
	1179	1,88		
Carbon-500 mesh steel	2140	3,42	3,43	0,06
	2103	3,36		
	2200	3,52		
Carbon-100 mesh steel	1297	2,07	2,05	0,03
	1309	2,09		
	1258	2,01		

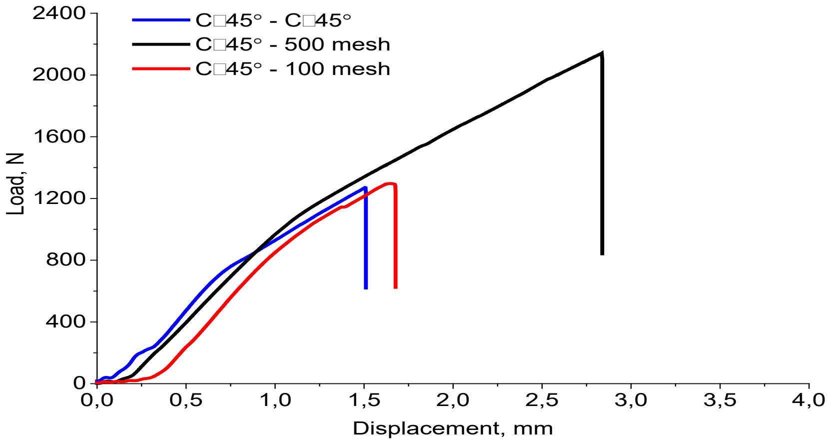

Figure 8. Force Displacement curves for carbon (±45°) and mesh steel under lap shear tests

Carbon FRP composites having ±45º orientation laminated with 500 mesh stainless steel also yielded maximum LSS results. Pure carbon FRP specimens resulted minimum LSS. 100 mesh stainless steel have also positive effect compared to pure carbon FRP.

5. CONCLUSION

When the literature studies were investigated it is commonly seen that the adhesion surface strength at the fiber-metal interface is the most challenging issue. It is mostly affected by physical properties of adhesion bonding between fiber and metal layers, and mechanical properties of composite materials. Researchers have been still investigating to improve the bonding capability of FML composites. Also the previous studies have generally focused to use aluminium and its alloys as a metal layer. However using mesh steels as metal layers have not been investigated yet. This study proved that the mesh size directly affected the lap shear strength results. Coarse mesh sizes generally decreased the LSS values whereas fine mesh sizes favorably influence the lap shear strength for FML applications.

5. ACKNOWLEDGEMENTS

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