Hybridization analysis of ramie-glass fiber reinforced metal composite laminates tensile and fatigue strengths

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ABSTRACT
Fiber metal matrix composite laminates are the contemporary materials which are employed in engineering applications. Owing to their lightweight and excellent fatigue resistance, these materials are gaining a wide interest in automotive and aeronautic sectors. In this study, fiber metal matrix laminates were fabricated through a hot press compression moulding process. The effects of different ramie-glass fiber stacking configurations on the tensile and fatigue properties of laminates are investigated. The results demonstrated that hybrid metal matrix laminates with glass fibers in the outermost layers attested comparable tensile properties with only 2.38 % lower than non-hybrid glass fiber reinforced metal matrix laminates and had better fatigue strength with 3.41 % higher than non-hybrid glass fiber reinforced metal matrix laminates.

Keywords: Fiber metal matrix laminates; hybrid composites; tensile strengths: fatigue strengths.

1. INTRODUCTION

Fiber Metal Laminates (FMLs) are the contemporary materials which consist of metallic alloys and composite materials. The intention of developing FMLs is to improve the fatigue resistance of aerospace materials. However, due to their excellent impact properties, they are gaining attention in the automotive industries. The most commercially available FMLs include glass fiber reinforced aluminum laminates (GLARE), which consist of synthetic fibers and epoxy polymer. The trend has inclined towards the use of thermoplastic instead of thermoset matrices as thermoplastics are environmental friendly[1].

Several works have been reported on the tensile and fatigue properties of FMLs. Gonzalez-Canche *et al.,*[2] revealed the tensile strength of aramid fiber reinforced polypropylene metal laminates is between their respective composites and aluminum. Vieira *et al*[3]., studied the tensile properties of woven sisal fiber reinforced metal laminates and their respective composites. They noticed the tensile strength of FMLs was 186 % higher than their respective composites. Reyes and Kang[4] conducted tensile and fatigue tests on the self-reinforced polypropylene (Curv) and glass fiber (Twintex) reinforced metal laminates. The finding showed the tensile and fatigue properties of Twintex based FMLs is higher than Curv based FMLs.

To date, the tensile and fatigue properties of hybrid ramie-glass fiber reinforced aluminum laminates still remain unexplored. Thus, this study focuses on the tensile and fatigue properties of FMLs.

2. METHODOLOGY

In this investigation, plain weave woven ramie and glass with the areal weight of 285 g/m^2 and 600 g/m^2 respectively were employed. Hybrid composites and their associated FMLs were fabricated through a hot compression process. Four fiber stacking configurations were fixed. [GRG] refers to the replacement of middle glass fibers with ramiefibers whereas [RGR] indicates the replacement of outer glass fibers with ramiefibers in FMLs. [GGG] and [RRR] represent the non-hybrid glass and ramiefibers reinforced metal composite laminates, respectively.

FMLs were fabricated by stacking two aluminium sheets with a thickness of 0.5 mm to the composite laminates with a thickness of 3 mm where the adhesives agents were incorporated at the aluminium-composite interfaces. FMLs were then hot compressed at a temperature of 170 ºC and pressure of 1 MPa which was followed by rapid cooling. The nominal thickness of FMLs is 4 mm.

The tensile test was conducted in accordance with ASTM E8 at a cross-head displacement rate of 2 mm/min. Constant amplitude fatigue test was carried out with reference to ASTM E466 at a frequency of 10 Hz and a stress ratio of 0.1. Fatigue test was stopped once the specimens fail or the run-out cycles of 1 million were reached.

3. RESULTS AND DISCUSSION

Figure 1 shows the absolute and specific tensile strength of FMLs. As shown in Figure 2, [GGG] FMLs demonstrate the highest tensile strength of 91.92 N/mm² which is 32.90 % higher than the [RRR] FMLs. The partial substitution of glass fibers with ramiefibers reduces the tensile strength of FMLs. Nevertheless, it was noticed that [GRG] FMLs possess a comparable tensile strength to [GGG] FMLs. The tensile strength of [GRG] FMLs is only 2.38 % less than [GGG] FMLs. This is due to the fact that the outer layers of fiber are the main load carrier in the tensile measurement.

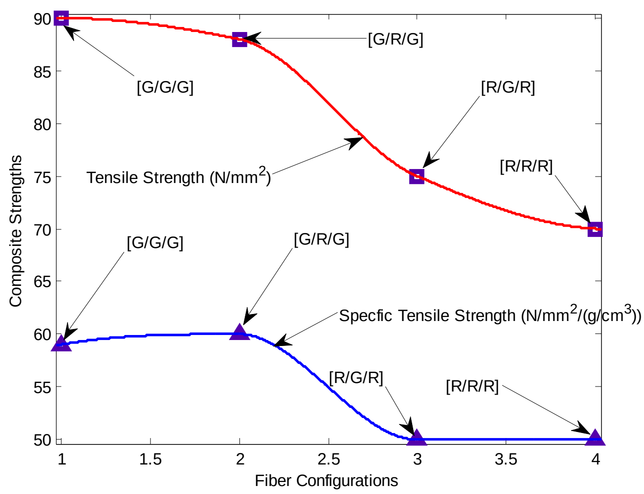

Figure 1: Absolute and specific tensile strength of FMLs.

Table 1: Analysis table for Absolute and specific tensile strength of FMLs

Xi	$df(Xi)/dX$	$d^2f(Xi)/dX^2$	$integral\ f(Xi)$
1	0	-5.06667	0
1.3	-1.376	-4.10667	26.9783
1.6	-2.464	-3.14667	53.8349
1.9	-3.264	-2.18667	80.4719
2.2	-11.5671	-31.3156	106.759
2.5	-16.8278	-3.75556	132.06
2.8	-13.8204	23.8044	155.907
3.1	-7.08	1.95556	178.566
3.4	-6.01333	5.15556	200.545
3.7	-3.98667	8.35556	221.99
4	-1	11.5556	243.083

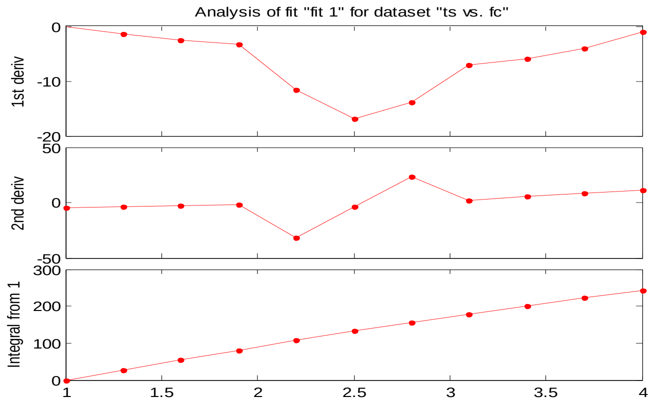

Figure 2: Analysis fit for Absolute and specific tensile strength of FMLs

Lightweight properties are one of the advantages in natural fibers, thus the density characteristic is taken into account. It is noticeable that the specific tensile strength of hybrid [GRG] FMLs outperformed non-hybrid [GGG] FMLs when the density is taken into consideration. The specific tensile strength of hybrid [GRG] FMLs was observed to be 2.27 % higher than the non-hybrid [GGG] FMLs. Moreover, it is motivating to note that the difference between the specific tensile strength of ramie dominated FMLs and [GGG] FMLs was reduced when the density was considered.

Figure 3 demonstrates the Stress-Life (S-N) linear approximation of FMLs with different fiber stacking configurations. In overall, the fatigue life cycles of each composite laminate increase with the decreasing of fatigue stress levels. In spite of higher fatigue strength of [GGG] FMLs observed at low fatigue cycle, hybrid [GRG] and [RGR] FMLs outperformed [GGG] FMLs at high fatigue cycle. The stiffening effect of natural fibers enhances the fatigue performance of FMLs during fatigue loading.

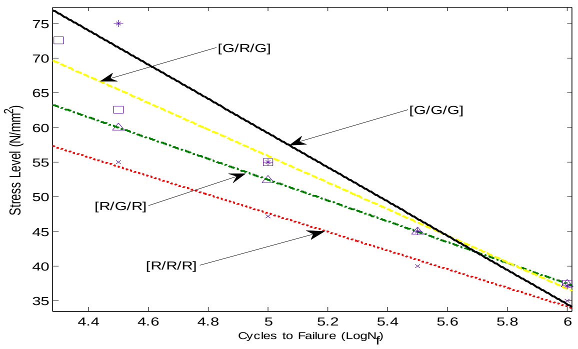

Figure 3: S-N linear fits of FMLs.

Table 2: Analysis table for S-N linear fits of FMLs.

Xi	$df\,(Xi)/dX$	$d^2f(Xi)/dX^2$	$integral\,f(Xi)$
4.5	-13.44	0	0
4.65	-13.44	0	8.0058
4.8	-13.44	0	15.7092
4.95	-13.44	0	23.1102
5.1	-13.44	0	30.2088
5.25	-13.44	0	37.005
5.4	-13.44	0	43.4988
5.55	-13.44	0	49.6902
5.7	-13.44	0	55.5792
5.85	-13.44	0	61.1658
6	-13.44	0	66.45

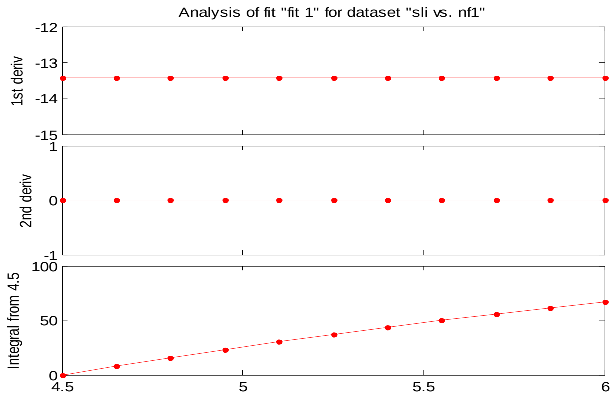

Figure 4: Analysis fit for S-N linear fits of FMLs.

Figure 5 elucidates the modulus degradation of FMLs with different fiber stacking configurations. Modulus degradation is the progressive damage from fatigue loading. A sharp decrease of the modulus was observed in the glass dominated FMLs compared to ramie dominated FMLs. These results support the fact that the fatigue strength degradation of glass dominated FMLs is higher than ramie dominated FMLs. Sivakumar *et al*[5]., obtained similar results where the natural fiber dominated hybrid composites showed better fatigue performance than synthetic fiber dominated hybrid composites.

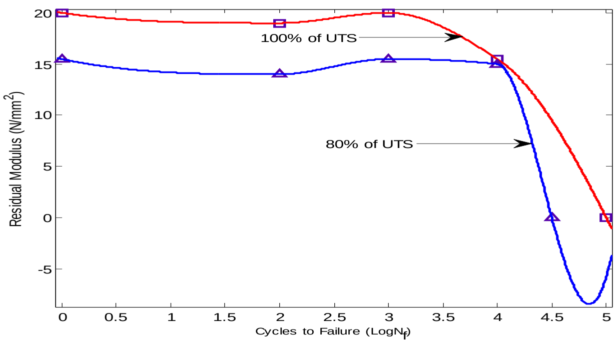

Figure 5: Modulus degradation of FMLs for [GGG]

Table 3: Analysis table for Modulus degradation of FMLs for [GGG]

Xi	$df\,(Xi)/dX$	$d^2f(Xi)/dX^2$	$integral\,f(Xi)$
0	-1.5	1.5	0
0.5	-0.84375	1.125	9.8418
1	-0.375	0.75	19.4688
1.5	-0.09375	0.375	28.998
2	0	6	38.5
2.5	1.5	0	48.0937
3	0	-13.05	58
3.5	-5.00625	-6.975	67.7598
4	-6.975	-23.1	76.3312
4.5	-16.2562	-14.025	82.7754
5	-21	-4.95	85.25

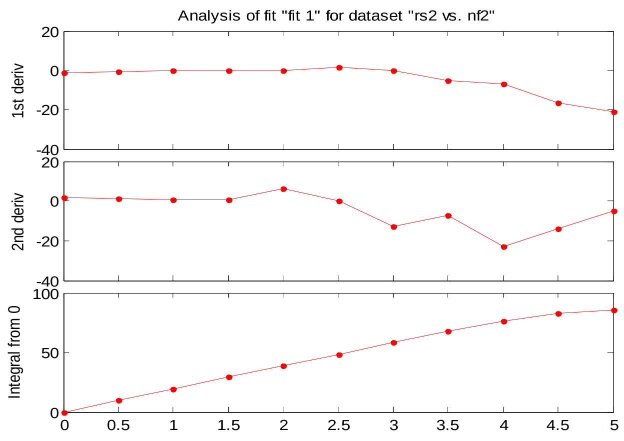

Figure 6: Analysis fit for Modulus degradation of FMLs for [GGG]

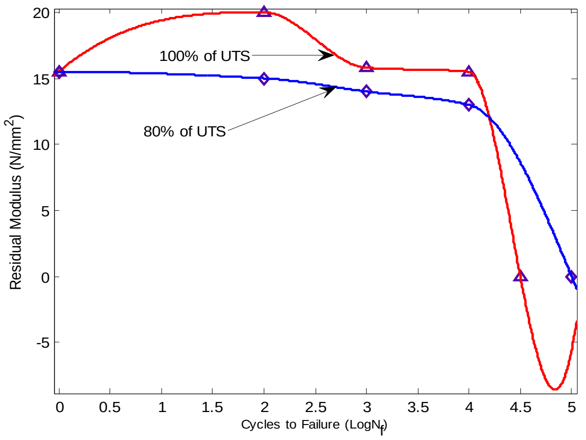

Figure 7: Modulus degradation of FMLs for [GRG]

Table 4: Analysis table for Modulus degradation of FMLs for [RGR]

Xi	$df\ (Xi)/dX$	$d^2f(Xi)/dX^2$	$integral\ f(Xi)$
0	6.55	-6.35	0
0.45	4.00384	-4.96625	7.547
0.9	2.08038	-3.5825	15.9153
1.35	0.779594	-2.19875	24.7154
1.8	0.1015	-0.815	33.6838
2.25	-4.55	-12.32	42.6283
2.7	-5.3312	8.848	50.7774
3.15	-0.336238	1.20963	57.9946
3.6	-0.172768	-0.483092	65.0527
4.05	-10.1505	-177.612	72.059
4.5	-41.2333	39.4656	76.009

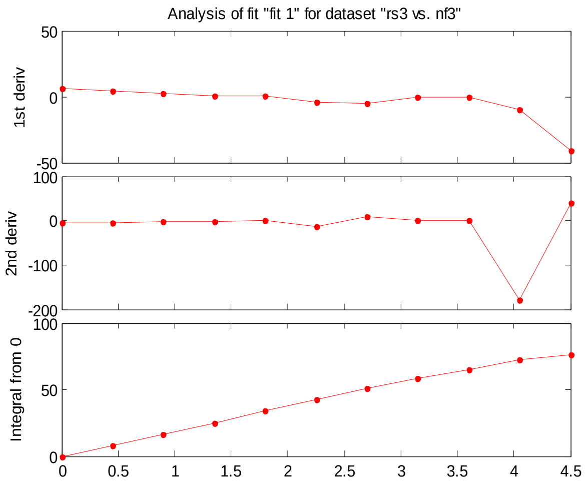

Figure 8: Analysis fit for Modulus degradation of FMLs for [RGR]

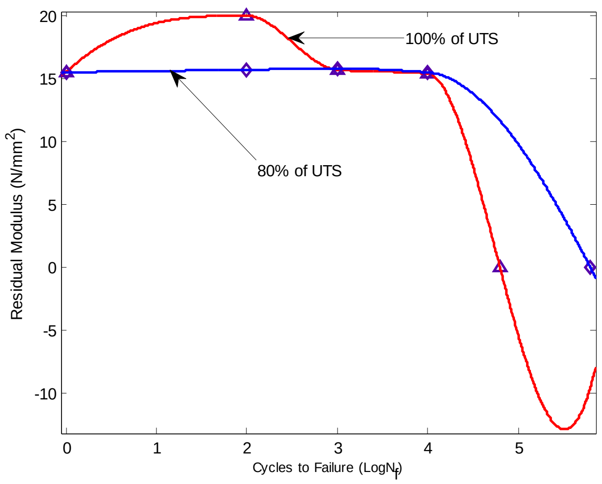

Figure 9: Modulus degradation of FMLs for [RGR]

Table 5: Analysis table for Modulus degradation of FMLs for [RGR]

Xi	$df\ (Xi)/dX$	$d^2f(Xi)/dX^2$	$integralf(Xi)$
0	6.61667	-6.48333	0
0.48	3.87043	-4.95933	8.08976
0.96	1.85571	-3.43533	17.0853
1.44	0.572507	-1.91133	26.5225
1.92	0.0208267	-0.387333	36.1056
2.4	-6.01252	-5.38435	45.4938
2.88	-3.04036	17.7683	53.7079
3.36	-0.183047	0.429953	61.2285
3.84	-0.373184	-1.22219	68.6859
4.32	-18.7914	-41.4855	75.7012
4.8	-27.6722	4.48191	78.7598

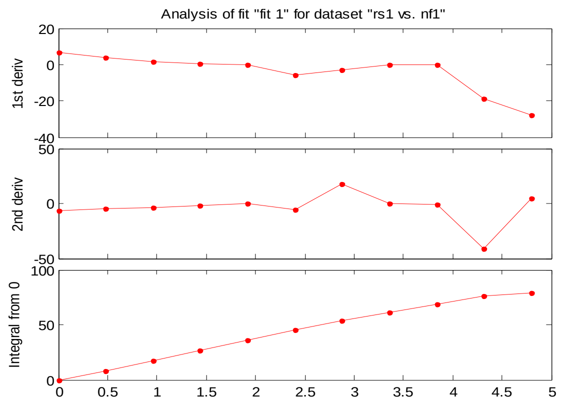

Figure 10: Analysis fit for Modulus degradation of FMLs for [RGR]

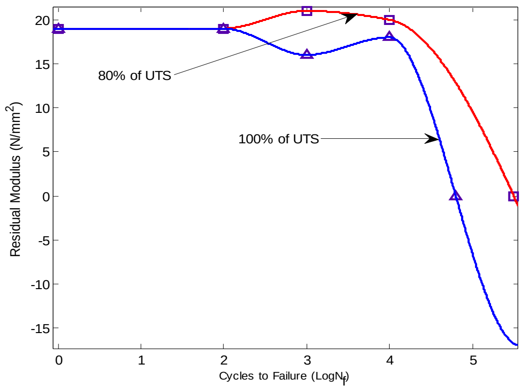

Figure 11: Modulus degradation of FMLs for [RRR].

Table 6: Analysis table for Modulus degradation of FMLs for[RRR]

Xi	$df\ (Xi)/dX$	$d^2f(Xi)/dX^2$	$integral\ f(Xi)$
0	0	0	0
0.55	0	0	10.45
1.1	0	0	20.9
1.65	0	0	31.35
2.2	1.92	7.2	41.8144
2.75	2.25	-6	52.7773
3.3	-0.679355	-2.04809	64.2893
3.85	-1.58758	-1.25455	75.6274
4.4	-9.26784	-16.5448	86.2938
4.95	-16.684	-10.4232	94.23
5.5	-20.7333	-4.3016	97.2042

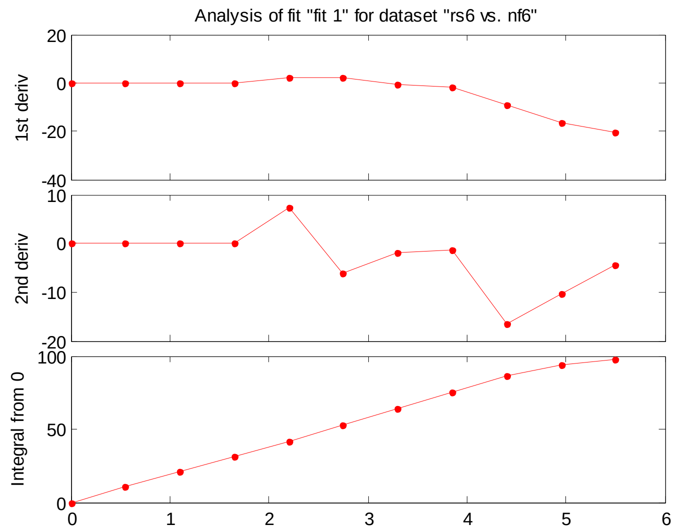

Figure 12: Analysis fit for Modulus degradation of FMLs for [RRR].

4. CONCLUSIONS

The tensile and fatigue responses of ramie-glass FMLs are investigated in this study. The results revealed that the ramie-glass FMLs show superior tensile and fatigue characteristics over non-hybrid glass fiber FMLs. The [GRG] showed higher specific tensile strength over [GGG] FMLs. In terms of fatigue responses, [GRG] and [RGR] FMLs are less sensitive towards fatigue loading and thus their endurance strengths are higher than [GGG] FMLs. The findings contribute to the research communities to explore the potential of using environmentally friendly materials.

REFERENCES

[1] Sivakumar, D., Ng, L. F., Chew, R. M. and Bapokutty, O. (2017). Investigation on failure strength of bolted joints woven fabric reinforced hybrid composite. *International Review of Mechanical Engineering*, 11 (2), 138–143.

[2] Gonzalez-Canche, N. G., Flores-Johnson, E. A. and Carrillo, J. G. (2017). Mechanical characterization of fiber metal laminate based on aramid fiber reinforced polypropylene. *Composite Structures*, 172, 259–266.

[3] Vieira, L. M. G., Santos, J. C., Panzera, T. H., Rubio, J. C. C., and Scarpa, F. (2017). Novel fibre metal laminate sandwich composite structure with sisal woven core. *Industrial Crops and products*, 99, 189–195.

[4] Reyes, G., and Kang, H. (2007). Mechanical behavior of lightweight thermoplastic fiber-metal laminates. *Journal of Materials Processing Technology*, 186, 284–290.

[5] Sivakumar, D., Ng, L. F., Lau, S. M., and Lim, K. T. (2018). Fatigue life behavior of glass/kenaf woven-ply polymer hybrid biocomposites. *Journal of Polymers and the Environment*, 26, 499–507.