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Experimental investigation of free vibration analysis on fibre metal composite laminates

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ABSTRACT

Fibre-metal laminates (FMLs) offer advanced improvements over current available structural materials due to the excellent mechanical properties. In this work, the dynamic behaviour of the carbon fibre/epoxy, glass fibre/epoxy, aluminium 2024-T0, and fibre metal laminates were carried out. Furthermore, the different type of reinforced composites in FMLs and the effect of the layer sequence of metal layers were investigated. The composite laminates have been manufactured by a hot press machine. The free vibration tests were conducted to determine the dynamic characteristics of the samples. The accuracy of the experimental results was verified by comparing the numerical analysis results. The results indicate that the effect of thickness and the layer sequences of metal layers have a significant effect on the natural frequency of the FMLs.

Keywords: FMLs; natural frequency; free vibration analysis; dynamic characteristics; finite element analysis.

INTRODUCTION

Over the last decade, demand for lightweight materials caused many automakers to find alternative materials to replace the traditional materials like steel and cast iron in order to reduce the weight of the vehicle. By looking of composite materials widely used in aerospace due to high specific properties in term of strength to weight and stiffness to weight ratio, many automakers switching used composite materials in the automotive industry to replaced current materials to manufactured parts such as bulkheads, hood and B-pillar [1-4]. Laminated composites are an advanced class of materials formed by combining one or more materials that having different chemical and physicals properties.

Fibre metal laminates (FML) [5-9] consists of alternating layers of fibre reinforced polymer composites and metal alloys [10, 11]. FMLs have improved resistance to impacts and environmental conditions due to the outer aluminium alloy layers [12-15]. Until now, FML is most popular and it is presently used for manufacturing of most part of aerospace structural component such as the aircraft engine cowlings, cargo floor and containers and seamless tube. In any structural service are frequency subjected to dynamics load. Therefore, FMLs need more sophisticated analysis and experiment to estimate the dynamic behaviour accurately. For the determination of the natural frequency and mode shape, analysis of free vibrations can be applied [16-23]. Nowadays, various experimental methods potentially applicable to determine dynamic behaviour (free vibration, rotating-beam deflection, forced vibration response, continuous wave or pulse propagation technique) have been used [24-27]. The vibration response of the FML annular plate by combining different quadrature method was investigated by Rahimi et al. [28]. However, their focus study is confined to circular plates only. The linear and nonlinear free vibration of FML rectangular plates was investigated by Shooshtari and Razavi [29] using the Galerkin method. They have presented only on analytical results on FML. Another study by Tao et al. [30] analytical method, the author investigated the nonlinear dynamics behaviour of FML beam under moving load subjected to the thermal environment using Euler-Bernoulli beam hypothesis and Von Karman geometric nonlinear theory. It found that most studies on the dynamics behaviour of FML using various analytical studies. For dynamic behaviour of FML plate shows very few studies are available.

The aim of this study is focused on the investigation of the dynamic behaviour of FML materials. In this study, a free vibration test by impact hammer is used to obtain the mode shapes and natural frequency. The different type of reinforced composites in FMLs and the effect of the layer sequence of metal layers are investigated. In addition, the numerical analysis by a three-dimensional finite element model was developed using finite element anaylis (FEA) ABAQUS software. It is used to carry out a comparative study between numerical and experimental results.

MATERIALS AND METHOD

Materials Preparation

Glass fibre/epoxy (GF-E), carbon fibre/epoxy (CF-E) and an aluminium 2024-T0 are used for the fibre metal laminates manufacture. The mechanical properties of composite laminates and aluminium alloy are provided in Table 1 and 2, respectively. The aluminium (Al) surfaces were prepared for adhesive bonding by mechanical treatment using sandblasting to produce a macro-roughened surface, different roughness levels of the surface textures and to remove an undesirable oxide layer, which has been improved bonding durability [31-33].

Table 1. Properties of the materials used to produce fibre metal laminates (a) and (b); (a) Properties of the Glass fibre/epoxy (GF-E) and carbon fibre/epoxy (CF-E)

Property	**GF-E**	**CF-E**
Longitudinal elastic modulus, E_1 (GPa)	7	17.5
Transverse elastic modulus, E_2 (GPa)	7	17.5
Thickness elastic modulus, E_3 (GPa)	1*	5*
In-plane Poisson's ratio, v_{12}	0.22	0.24
Thickness Poisson's ratio, v_{13}, v_{23}	0.22	0.24
In-plane shear modulus, G_{12} (GPa)	1*	2*
Thickness shear modulus, G_{13}, G_{23} (GPa)	2.5	10.5

* Data taken from references

Table 2. Properties of an aluminium 2024-T0 (Al)[34].

Property	Value
Density, ρ (kg/m^3)	2780
Young's modulus, E (GPa)	70.6
Poisson ratio, v	0.3

In the production process, fibre and aluminium alloys were cut in dimensions of 250 mm x 25 mm. Fibre-metal composite laminates were manufactured by application of epoxy resin to fibre layer and aluminium surface. During the experiment, free plate length is kept on 223 mm.

Fibre-Metal Composites Laminate Preparation

The fibre metal composite laminate was prepared by stacking laminae and the aluminium sheet. The sequence lay-up of the composites of 2/1 and 3/2, as shown in Table 3. The hand lay-up of the fibre metal laminates materials was made as shown in Figure 2. After the lay-up process, the compression machines are used to compress and applied pressure 0.4 MPa under room temperature, shown in Figure 3.

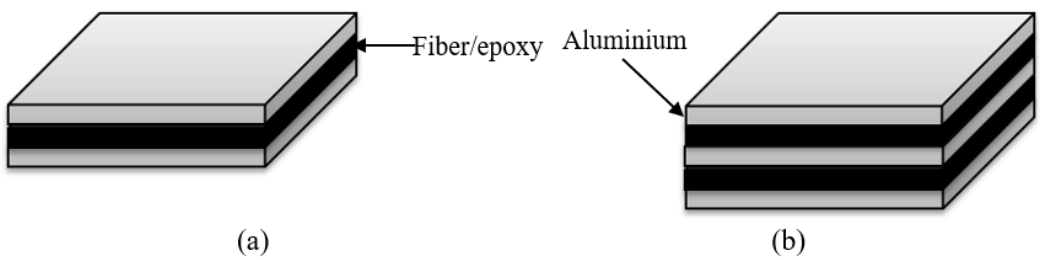


Figure 2. Configuration of the fiber/metal/epoxy composite laminates (a) 2/1, (b) 3/2

Table 3. Stacking sequence of the fibre metal laminates composite (FML).

Naming	Stacking sequence	Configurations
H1	Al/GF-E/Al	2/1
H2	Al/CF-E/Al	2/1
H3	Al/GF-E/AL/GF-E/Al	3/2
H4	Al/CF-E/Al/ CF-E/Al	3/2

AL: Aluminium; GF-E: Glass fiber/epoxy; CF-E: Carbon fiber/epoxy

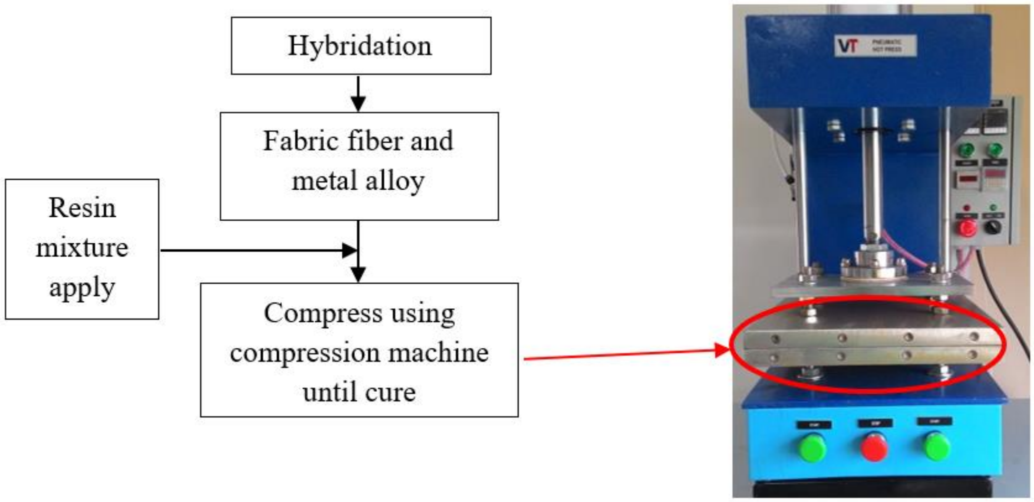


Figure 3. Fiber metal composite laminates preparation process.

Experiment Modal Analysis (EMA) Setup

Dynamic characteristic of fibre metal composites laminates was measured using the free vibration method as per the ASTM standard E756. Figure 4 shows the experiment setup for free vibration test set up. In this experiment, uniaxial accelerometer, Piezotronic hammer and National Instrument and Vibration Data Logger were used for output signal acquisition, stimulus forces signal and data acquisition. To achieve dynamic characteristic, all specimens were excited by an impact hammer. Frequency response properties of the samples were recorded during the dynamic modal analysis test a function of amplitude and frequency (Hz) by using Fast Fourier Transforms (FFT) in order to determine the natural frequency. The test parameters were analyses of 1000 Hz.

Table 4. Dimension and weight of specimens used in the experiment.

Specimen ID	Length (mm)	Width (mm)	Thickness (mm)
CF-E	250	25	1.34
GF-E	250	25	2.56
Al	250	25	0.88
H1	250	25	2.32
H2	250	25	2.04
H3	250	25	3.50
H4	250	25	3.18

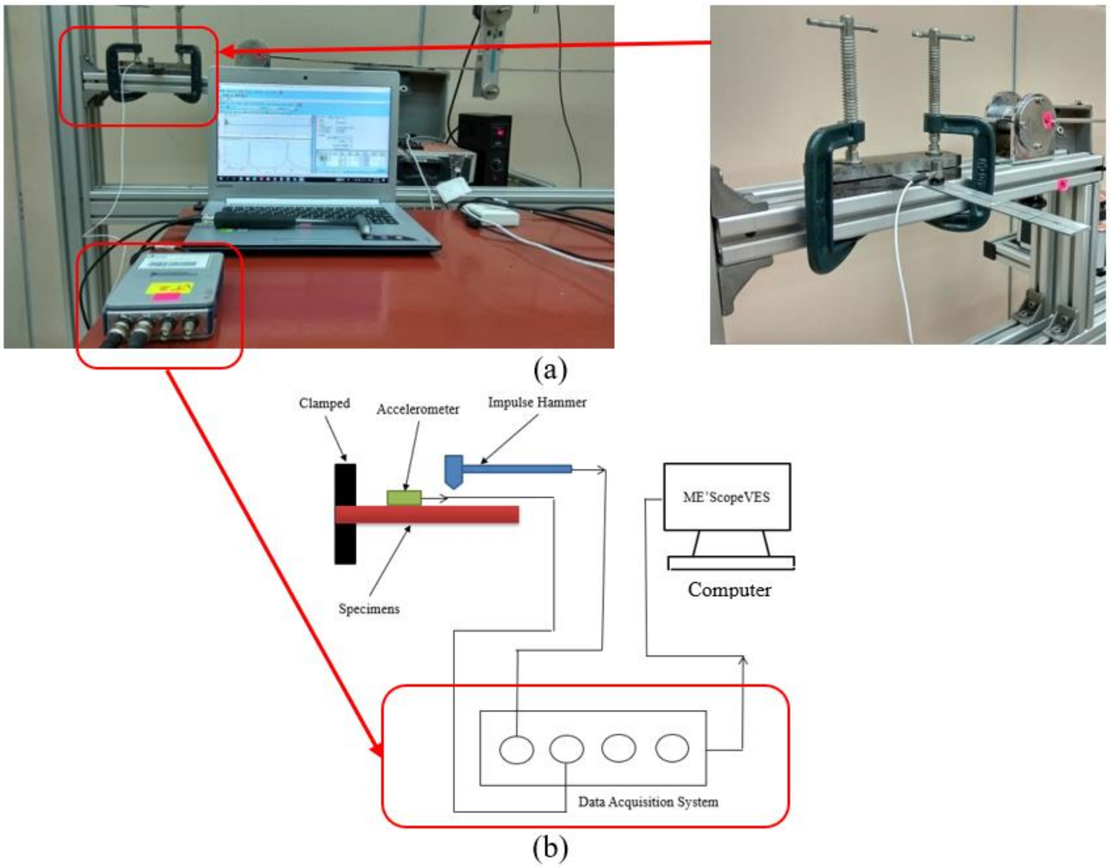


Figure 4. Experimental setup: (a) Experimental overview, (b) Schematic diagram of free vibration testing setup.

Vibration test specimens with a dimension of 250 mm x 25 mm were prepared and specimens were clamped by supports, shown in Figure 5. The specimen dimensions follow ASTM E756. Table 4 shows the dimension of the plate for vibration tests. In this experiment, the uniaxial accelerometer will move to every point while impact hammer will only impact at one point only (point d). The process called roving accelerometer. Fifteen averages data which are obtained from excited location are taken during acquisition for each specimen to prevent experimental errors.

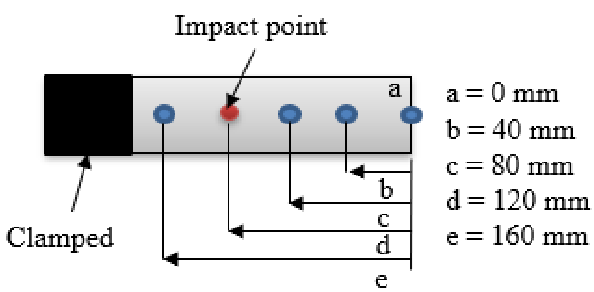


Figure 5. Position of impact and uniaxial accelerometer points.

Finite Element Analysis (FEA) Setup

In the numerical analysis, a solid homogeneous model is used in the modelling of FMLs. The three rotations and displacements are constrained at the FMLs as showed in Figure 6. The FMLs are represented with the 3-D linear solid element (C3D8R) of ABAQUS. C3D8R means an 8-node linear brick and reduced integration. The number of elements used in the analysis was 1992 and the number of nodes is 3024. Linear perturbation and Lanczos method are used to extract Eigenvalues of the first three modes.

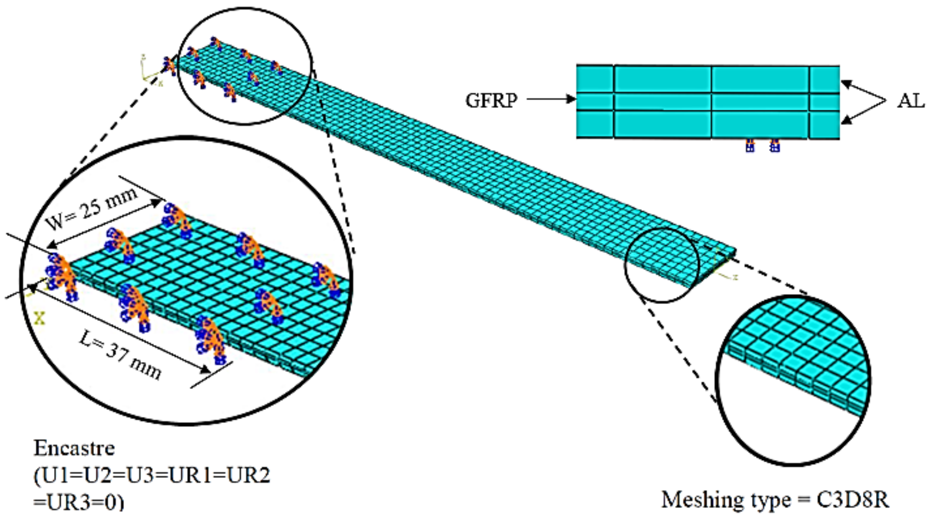


Figure 6. Boundary conditions for frequency analyses in ABAQUS.

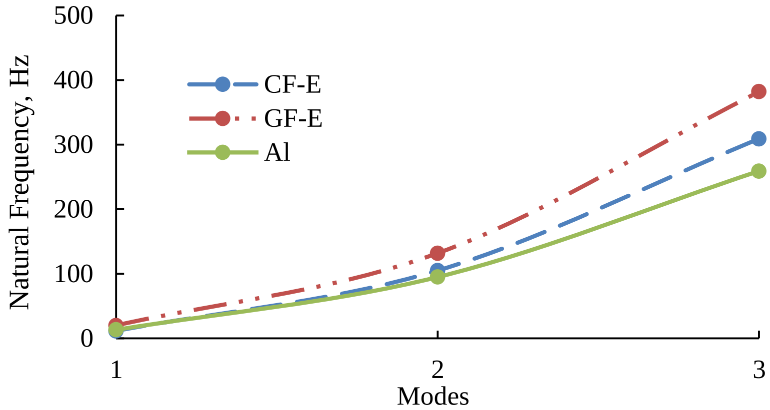
RESULTS AND DISCUSSION

The frequency response values were recorded after the vibration test and then tabulated in Table 5.

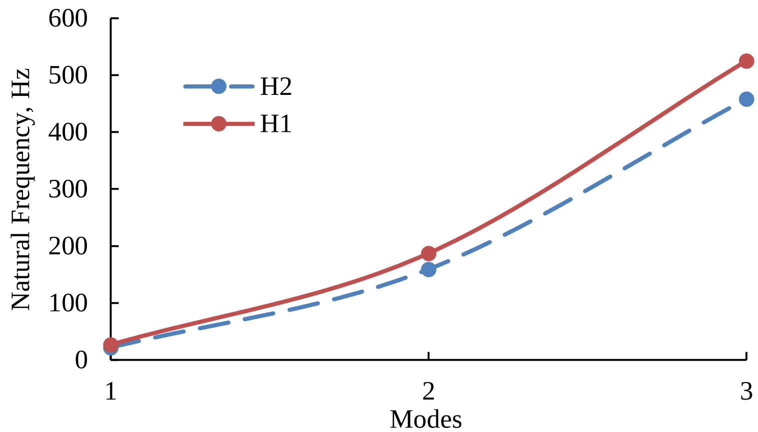
Table 5. Frequency values of materials analysed between experiment and numerical method.

	Mode 1 (Hz)			Mode 2 (Hz)			Mode 3 (Hz)		
Specimens	**Exp**	**Numerical**	**Error (%)**	**Exp**	**Numerical**	**Error (%)**	**Exp**	**Numerical**	**Error (%)**
CF-E	11.70	13.69	17.59	105.00	109.14	3.94	309.00	305.20	1.22
GF-E	20.20	18.25	9.61	132.00	125.11	5.21	382.00	364.33	4.71
Al	13.40	16.21	17.33	95.00	101.62	6.96	259.00	283.03	8.50
H1	29.03	30.42	4.79	187.00	190.28	1.75	525.00	532.25	1.38
H2	21.50	25.64	16.14	159.00	160.63	1.02	458.00	450.01	1.74
H3	48.64	50.78	4.21	298.00	303.66	1.08	871.00	845.58	2.91
H4	41.77	41.59	0.40	266.00	260.35	2.12	716.00	722.84	0.95

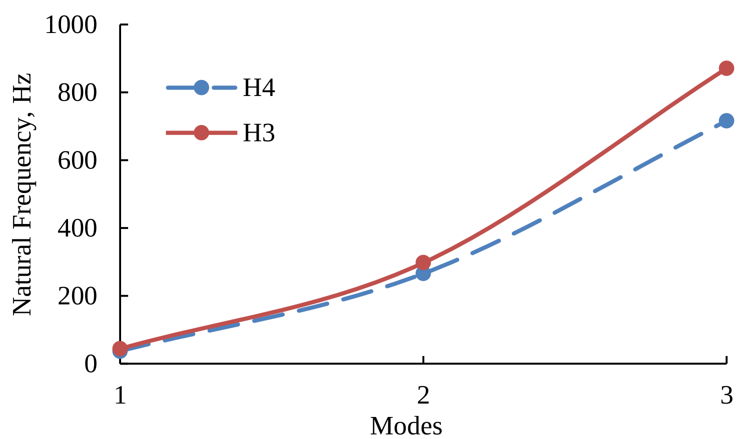
*Exp: Experiment



(a)



(b)

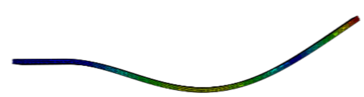
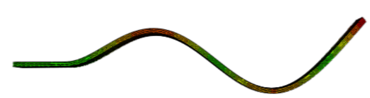


(c)

Figure 7. Variation of the first, second and third mode of natural frequency based on experimental result, (a) GF-E, CF-E, and Al, (b) H1 and H2, and (c) H3 and H4.

Table 5 showed the different results of natural frequency value from the experiment and numerical results. In this experiment, the different type of reinforced composites in FMLs and the effect of the layer sequence of metal layers are investigated. To study the effect of different type reinforced composite in FMLs, two types of reinforced composite materials used which is CF-E and GF-E. The thickness varied between two different types of reinforced composite materials, by keeping the length and wide constant (250 mm x 25 mm), as shown in Table 4. The results showed that natural frequency of GF-E composite was seemingly greater that CF-E composite, showed in Figure 7. The first three modes of natural frequency H1 and H2, are 29.03 Hz, 187 Hz and 525 Hz; and 21.50 Hz, 159 Hz and 458 Hz. The higher first natural frequency value is H1 due to the thickness of GF-E more than others. It observed that dissimilar thickness shows significantly influence the natural frequency of the FMLs.

Table 6. The first three mode shape between EMA and FEA analysis for H1.

	Mode shape	
	EMA	**FEA**
1		
2		
3		

Effect of the layer sequence of metal layers in composite materials plate (CF-E and GF-E) shows the natural frequency increases as more the Al plate embedded in the composite materials plate. Table 4.6 (c) shows the first mode of the natural frequency of H4 and H3 are 41.77 Hz and 50.78 Hz. It can be observed that the when Al plate embedded in the middle composite layer in H4 shows significantly influence the natural frequency which is increase from H2 where 21.50 Hz to 41.77 Hz. The percentage of increment is 42.67%. For H1 to H3 is 40.18%. This was because of the lateral stiffness of Al layers more than composite materials ones. Table 6 shows the first three mode shapes using a between EMA and FEA analysis for H1. Good adaptions could be observed between results.

CONCLUSIONS

The mode shapes and natural frequency of aluminium 2024-TO alloy, glass fibre/epoxy (GF-E), carbon fibre/epoxy (CF-E), and fibre metal laminates (FML) composite were investigated. Vibration characteristic of all samples was determined by free vibration analysis using the exciting impact hammer on the specimen. Two factors are carried out which is the different type of reinforced composites in FMLs and the effect of the layer sequence metal layer. Based on the conducted experiments and numerical analysis, the following conclusions were made. The numerical agree well with their experiment results. The natural frequency shows differ between two types reinforced composite in FML which is CF-E and GF-E. With the thickness of glass fibre ply used in this experiment thicker compares to carbon fibre ply, shows significantly influence the natural frequency. The natural frequency of the FMLs plate increase when more Al layers embedded in the composite layer.

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