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Numerical Simulation of Low Velocity Impact Analysis of Fiber Metal Laminates

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A Fiber Metal Laminate (FML) consists of a laminate of several thin metal layers bonded with fiber–reinforced layers of composite materials. In this paper, the response of a fiber metal laminate is analysed on the basis of the residual velocity of the impactor. With the help of Design of Experiments (DOE) the data sets are generated and the residual velocity of the impactor was obtained by using Finite Element Analysis (FEA) software ABAQUS/Explicit. The FEA results are compared with experimental results available in the literature. Analysis of Variance (ANOVA) is used to understand the influence of process parameters on the response of FMLs. Results show that impactor geometry and thickness of the FML plate were the significant process parameters related to the response of low velocity impact analysis of FML and fiber configurations were found to be insignificant with regard to low velocity impact analysis performance. Finally the results show that aluminium based Aramid fibers (ARALL) and aluminium based glass fibers (GLARE) have higher impact strength when compared to other kinds of FMLs such as aluminium based carbon fibers (CARALL). Stress distribution in glass epoxy based FMLs are also studied.

Keywords: Fiber Metal Laminate, ARALL, GLARE, CARALL, low velocity Impact, Design of Experiments, S/N Ratio, ANOVA.

1. Introduction

Fiber Metal Laminate (FML) can be defined as "a family of hybrid composite structure formed from the combination of metal layers sandwiching a fiber–reinforced plastic layer" (Chai and Manikandan, 2014). The high performance of fiber metal laminates occurs due to the principal advantages of long fatigue life,high impact resistance, low weight density, moisture and corrosion resistance, and high resistance to fire and blast loading (Tsamasphyros and Bikakis, 2013). FMLs have found immense applications in the aerospace industry in the development of primary and secondary aerospace structures and in other aircraft applications (Yarmohammad Tooski et al., 2013; Tsamasphyros and Bikakis, 2013). This paper focuses on predicting the low velocity impact response on aluminum, steel and titanium–based fiber metal laminates.

1.1. *Background/Prior research*

The impact response of composite laminates in general has been investigated by a number of researchers. The effect of composite design and other process and material variables on the impact response of composites is a very common theme among these research works. The final objective of such studies is to arrive at important relationships and generalizations that can lead to the design of efficient laminates with least time and expense. For example Lee and Lin (2003) have used regression along with genetic algorithm to accurately estimate the response surface of laminated composite structures. This eliminates the arduous task of running thousands of numerical simulations needed to predict the response of the entire surface. Impact response studies can be distinguished based on impact process data like the velocity of impactor or impact energy; the choice of impactor and target; the composite material behaviour model used for the composite laminates; the input variables the effects of which on the impact response are to be studied; and lastly the performance parameters measured as response to input parameters.

Fig. 1 proposes a classification basis of impact response studies for composite laminates.

In an early study on FMLs, Vlot (1996) experimentally investigated low and high velocity impact response of Aramid and carbon reinforced FMLs (ARALL and CARALL), R–glass reinforced FML (GLARE) and compared them with the responses of monolithic aluminium grades and fiber reinforced composites. The author concluded that on impact the damaged zone for FMLs were smaller compared to the damage zone in fiber reinforced composite materials.

In recent years, much research has been done on low velocity impact response of FMLs. Payeganeh, AshenaiGhasemi and Malekzadeh (2010) analytically studied the dynamic response of FMLs to low velocity impact based on the first order shear deformation theory. They concluded that layer sequence, mass and velocity of impactor and aspect ratio of the plate are significant factors affecting the response.

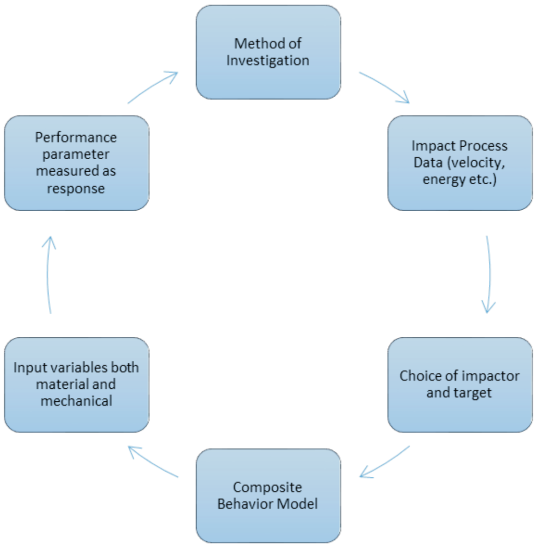

Figure 1 Framework for classification of studies on impact response of composite laminates

The use of Aluminium plates in FMLs improves the global response to low velocity impact and closer the aluminium plate to the impact zone better is the impact resistance. Fan, Guan and Cantwell (2011) developed an experimentally verified numerical model based on FEA simulations to predict the low velocity impact behaviour of aluminium alloy 2024-O and the woven glass fiber Laminate FML. Varying stacking sequences, layer geometries and impact velocities have been considered in the model. The behaviour of aluminium alloy 2024-O has been modelled as an isotropic elasto-plastic material with strain hardening with both shear failure and tensile failure considered for the alloy. Woven glass fiber is modelled as "orthotropic material with critical tensile, compressive and shear strengths corresponding to the on-set of the brittle failure", whereas damage evolution is modelled based on Hashin criterion which allows simulation of brittle failure. Zhu and Chai (2012) conducted quasi-static indentation tests and low velocity impact tests on FMLs with unidirectional and woven layers of glass fiber. They concluded that low velocity impact test is similar to quasi-static indentation when the mass of the impactor is much larger than mass of the FML targets. Further FMLs with unidirectional fibers offer higher failure loads during perforation and consequently higher impact resistance compared to FML with woven fibers. Sadighi et al., (2012) conducted an experimental analysis and proposed a numerical model to investigate the effect of metal type and metal thickness on the low velocity impact response of GLARE. Morinière et al., (2013) developed a generic quasi-static analytical model to accurately predict the low velocity impact response of GLARE FML in terms of contact time, impact force, maximum displacement, perforation energy, and impact velocity. The authors approach has allowed them to bring out the role of individual material constituent in GLARE on the energy absorption, plate flexure, and damage progression upon impact. In one analytical study, Tsamasphyros and Bikakis (2013) chalked expressions for predicting the dynamic response to low velocity impact of thin circular GLARE plates, taking into account internal damages due to delamination. The model is able to calculate critical impact parameters like maximum plate deflection and maximum impact load; and can be used to compare impact response of different grades of GLARE FML. Yarmohammad Tooski et al., (2013) experimentally studied the effects of distance between multiple low velocity impacts at different locations on the plate response, damage behaviour and energy absorbed in GLARE FML. The authors arrived at the result that before cracks appear, plate stiffness increases with decrease in distance between impacted locations, whereas in presence of cracks, plate stiffness decreases with decreasing distance between impacted locations.

Sadighi, Alderliesten and Benedictus (2012) have conducted a comprehensive review on impact properties of FMLS. They have highlighted that despite the availability of many articles studying the impact properties of FMLs, the research is still in the nascent stage and requires further study and consideration. One way to expand the present body of research on FMLs could be by looking at impact studies on miscellaneous targets like Fiber Reinforced Polymers (FRPs), ductile targets etc.

Iqbal et al., (2010) studied the effect on ballistic limit, perforation and damage behaviour upon varying the degree of obliquity of projectile impacted on single layered ductile targets- Weldox 460 E steel and 1100-H12 aluminum. Bobbili et al., 2014 sought to understand ballistic performance as affected by impact velocity and target thickness of Weldox 700E targets.

Shokuhfar et al., 2008 and Kim et al., 2011 have worked on smart composite structures where shape memory alloy (SMA) wires or strips are embedded within the laminates to improve the global impact resistance. While Shokuhfar et al., 2008 studied and concluded that the effect of the volume fraction, the through thickness location and the orientation of the SMA wires are significant factors affecting dynamic response of hybrid plate, Kim et al., 2011 studied the effect of SMA pre-strain, SMA position and SMA temperature on impact behaviours

Lee, Kang and Park (1997) carried out a numerical analysis based on finite element method for studying the low velocity impact response of hybrid laminated composite plate's viz. graphite/epoxy-glass/epoxy and graphite/epoxy-Kevlar/epoxy and compared their performance with single laminated plates (graphite/epoxy). They confirmed that stacking sequence is an important parameter affecting fractional energy loss and a material with higher impact resistance must be placed on the impacted surface. In another work on hybrid composites by Pérez-Martín et al., 2013, the authors have studied the high velocity impact performance of composite plates with combined glass and carbon fibers. They have concluded that these hybrid composites are capable of absorbing greater amounts of energy as compared to single carbon fiber composites.

Reis et al., 2012 performed an experimental impact analysis to understand if composite matrix fillers like cork powder and nanoclays Cloisite 30B improve the impact properties of Kevlar/epoxy composites. It is evident from their research that addition of fillers in composite matrices can lead to benefits like lower displacements, elastic recuperation, lower damage area and increased residual strength.

Three studies (Mitrevski et al., (2005), Mitrevski, Marshall and Thomson (2006) and Mitrevski et al., (2006)) have investigated the effect of impactor shape on the low velocity impact response of composite laminates considering ogival, hemispherical and conical impactors.

Several studies adopt a damage focused approach in their methods for impact analysis. De Moura and Marques (2002) performed an experimental analysis and proposed a numerical damage prediction model to predict damage in carbon/epoxy laminates. In another work on carbon/epoxy laminates, Shi, Swait and Soutis (2012) developed a composite damage model taking into account damage initiation, damage evolution, delamination and non-linear shear behaviour for low velocity. Batra, Gopinath and Zheng (2012) have formulated a problem for analyzing the damage initiation, damage progression and failure during three dimensional (3D) plastic deformations of a fiber reinforced polymeric AS4/PEEK laminate. Amaro et al., 2013 studied the damage evolution in Glass Fiber Reinforced Composite (GFRP) for three impact cases–sole impact energy of 3J, two multiple impacts of (1J+2J) and three multiple impacts (1J+1J+1J), the total energy being same in all cases. A numerical procedure involving mixed mode damage model was employed. The result was more damage occurred during sole impact when compared to cumulative damage occurred during multiple impacts. Yang, Yan and Kuang (2013) conducted an experimental analysis and proposed a numerical model that predicts both intralaminar and inter-laminar damage

Chandrashekhara, Okafor and Jiang (1998) put forth a neural network method for estimating the contact force based from impact-induced strain pattern upon low velocity impact on laminated composite plates. The neural network proposed is trained using data obtained from finite element analysis and can potentially be applied to on-line systems for monitoring structural health. Malik and Arif (2013) proposed an artificial neural network to predict the impact energy absorbed for varying configurations of input variables viz. thickness, stacking sequence and number of layers. The neural network was trained using data sets generated from numerical simulations designed using Design of Experiments (DoE).

In this paper, we numerically perform low velocity impact analysis on FML targets based on finite element method. The main objective of the paper is to understand the influence of test parameters on the residual velocity of the impactor. The parameters (both design and process) considered are impactor shapes, target thickness, stacking sequence, fiber type and metal type. DoE is used to design several impact tests with varying input parameters. Malik and Arif (2013) have indicated that "ability to solve a large number of simulations using FEA gives an advantage in the design optimization with the help of DOE". The results of simulations are used as data sets for Analysis of Variance (ANOVA) in order to arrive at a quantitative realization for the significance of test parameters on the residual velocity of impactor. The resultant values would prove useful for design of optimal FMLs. The recent study by Bobbili et al., 2014 is similar to our study in its use of DoE in conjunction with ANOVA to assess the influence of input parameters. Malik et al., 2013 have also attempted to study the degree of influence of input parameters on impact resistance of composite plates but they have employed a parametric sensitivity analysis approach to achieve this. Lastly, due to the presence of a large number of parameters that influence low velocity impact response, Chai and Manikandan (2014) have indicated the need to pursue further studies on finding parameters which are significant and can be used to develop optimal FML species.

They have highlighted the use of DoE with ANOVA as a possible way to achieve this.Lastly, the stress distribution of each layer on the FML plate with different impactor shapes is studied.

2. Finite element modelling and validation

Finite element simulations were carried out by using finite element software ABAQUS/Explicit. The finite element modelling of the impact system with details of a typical FML lay-up is shown in Figure 2 (a). The finite element analysis results are validated with the results available in (Zhu and Chai,2012). For validation, a hemispherical impactor with a diameter of 13.1 mm and a mass of 2.735 kg was used. The FML plate has diameter of 76.4 mm and is clamped at the outer surface. To save computational time, the impactor was placed just above the FML plate. Since aluminium alloy and glass–fiber laminate have different mechanical properties, different constitutive relations were used to model their respective mechanical behaviour. Johnson–Cook flow stress model is used for aluminium alloy and is expressed as

$$\sigma = (A + B\varepsilon^n)\left(1 + C\ln\frac{\dot{\varepsilon}}{\dot{\varepsilon}_o}\right)\left(1 - \left(\frac{T - T_R}{T_m - T_R}\right)^m\right) \tag{1}$$

Several models have been developed to represent the rate and temperature dependence of metallic materials during deformation. The Johnson–Cook material model is perhaps one of the most widely used models because it takes on a simple, yet effective form that predicts the material behaviour in static and dynamic modes equally well. For damage initiation the Johnson–Cook criterion is used in the present contribution, which reads

$$\bar{\varepsilon}^f = \left(D_1 + D_2 \exp D_3 \frac{\sigma_m}{\bar{\sigma}}\right)\left(1 + D_4 \ln\frac{\dot{\varepsilon}}{\dot{\varepsilon}_o}\right)\left[1 - D_5\left(\frac{T - T_R}{T_m - T_R}\right)^m\right] \tag{2}$$

This is followed up by the damage evolution to model the progressive damage and failure of elements. The damage evolution capability for a ductile material assumes that the damage is characterized by the progressive degradation of the material stiffness. The material properties of various metals and composite fibers are listed in Tab. 1 and 2.

In the finite element model, the nodes between the aluminium layer and GFRP layer were tied together. Contact interaction properties for interactions of the projectile and the aluminium alloy layer; projectile with the glass fiber laminates layer; alloy layer with the glass fiber laminated layers; glass fiber laminated layer were defined and referred relevant type of interaction. For validation purpose, the friction coefficient between impactor and FML plate is to be 0.2 and initial velocity of the impactor is as 2.206 m/s. The impactor modelled as an analytical rigid body and FML plate modelled as three dimensional deformable bodies and plate were meshed with C3D8R element which is an 8–noded linear brick element with reduced integration. There are two elements in each layer thus there are six elements in thickness direction. In this simulation the impactor was allowed to strike the FML plate only once. The impactor would fall and strike the centre of FML plate. The mesh convergence studies are carried out and results are validated with experimental results which are available in the literature. The present numerical results, compared with experimental results available in the literature are well matched and shown in Fig. 2c.

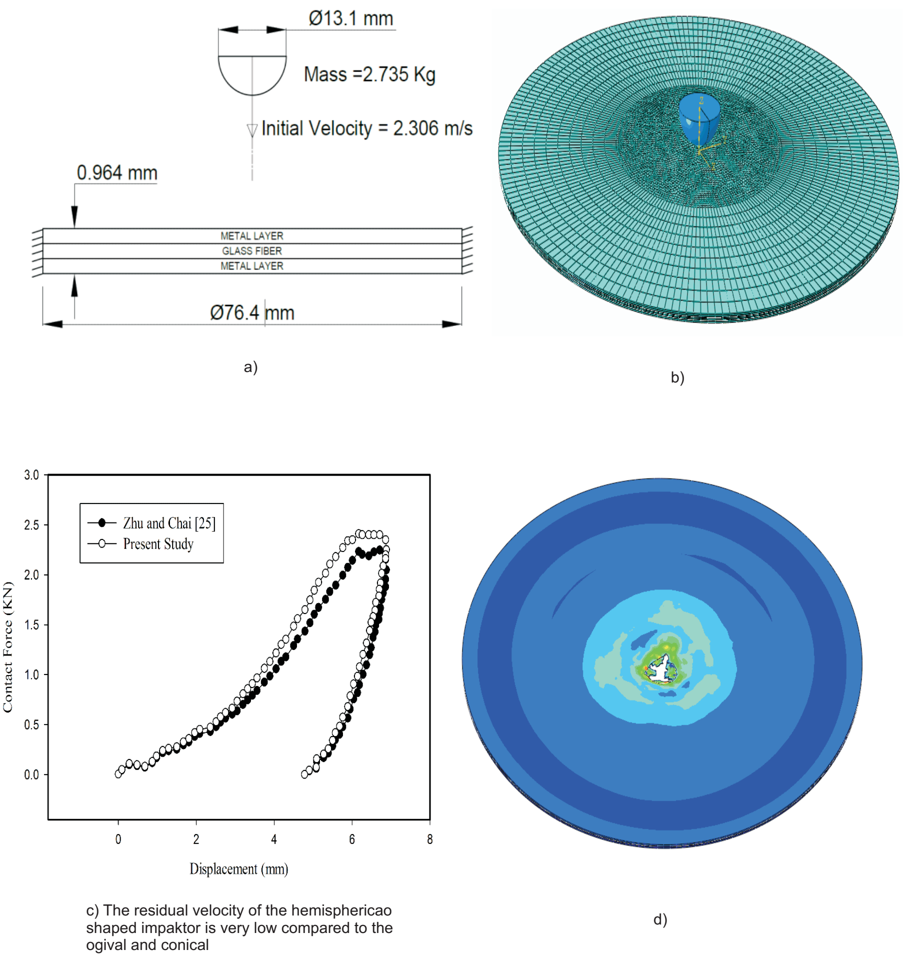

Figure 2 Finite element modelling and validation of (a) experimental specimen and (b) Meshed model of experimental specimen and (c) Validation of present results with literature Zhu and Chai (2012), and (d) Damage progression for FML plate of experimental specimen Zhu and Chai (2012)

Table 1 Johnson–cook material and damage constant

Material	A (MPa)	B (MPa)	C	n	m	D1	D2	D3	D4	D5
Al 2024-T3	252	426	0.015	0.34	1	0.13	0.13	1.5	0.011	0
Ti-6Al-4V	1098	1092	0.014	0.93	1.1	-0.09	0.25	-0.5	0.014	3.87
AISI 4340	490	600	0.015	0.21	0.6	0.05	-2.12	0.002	0.61	0.61

Table 2 Material properties of orthotropic materials

Properties	Glass/Epoxy	Aramid/Epoxy	Carbon/Epoxy
Density (Kg/m3)	1800	1440	1560
E1(GPa)	26	67	60.8
E2 (GPa)	26	47	58.25
E3 (GPa)	8	47	58.25
G_{12} (GPa)	3.8	2	4.55
G_{13} (GPa)	2.8	2	4.55
G_{23}(GPa)	2.8	1.586	5
ν_{12}	0.1	0.34	0.07
ν_{13}	0.25	0.34	0.07
ν_{23}	0.25	0.45	0.4
X_t (MPa)	414	1420	621
X_c (MPa)	458	312	760
Y_t (MPa)	414	36	594
Y_c (MPa)	458	145	707
S_{12} (MPa)	105	53	125
S_{13} (MPa)	65	53	125
G_{ft}(KJ/m2)	10	81.5	160
G_{fc} (KJ/m2)	1.562	106.3	25
G_{mt} (KJ/m2)	0.625	0.28	10
G_{mc}(KJ/m2)	0.14	1.31	2.25

3. Results and discussions

To assess the influence of process parameters on the residual velocity of the impactor and identify the optimal combination of FML parameters that gives the minimum residual velocity, a specifically designed trial plan is needed. Conventional experimental design procedures are too complicated and difficult to apply. A large number of numerical simulations have to be performed when the number of process variables increase. In the present investigation, the Taguchi technique was adopted and implemented in Minitab 17 statistical software to arrive at optimum values of process variables that minimum residual velocity. In this study, five process variables were chosen as input factors and residual velocity was taken as the response to be minimized. The values of operational levels for each process parameter are given in Tab. 3. Trials were planned using a full factorial L27 orthogonal array with 27 distinct combinations of process parameters, each combination giving a corresponding response as shown in Tab. 4. ANOVA (Analysis of Variance) is used to determine the sum of squares and F-value in order to assess the level of significance of individual process parameters.

Table 3 Input process parameters and their levels

Parameters	Level 1	Level 2	Level 3
FML Thickness (mm)	0.9	1.2	1.5
Stacking Sequence	0/30/60/90	45/-45/0/90	45/30/-30/-45
Type of Fibers	Glass/Epoxy	Aramid/Epoxy	Carbon/Epoxy
Type of Metals	Al -2024-T3	Ti-6Al-4V	AISI 4340
Impactor Geometry	Ogival	Conical	Hemispherical

In the present finite element modelling method too, the impactor is modelled as an analytical rigid body and the FML plate is modelled as a three dimensional deformable body. The FML plates were meshed with C3D8R element which is an 8–noded linear brick element with reduced integration. There are two elements in each layer thus a total of six elements in the thickness direction. In the present finite element modelling, the friction coefficient between the impactor and the FML plate is assumed to be 0.2 and the initial velocity of the impactor was assumed to be 5 m/s. The present simulation allows the impactor to strike the FML plate only once. Fig. 3 shows the detailed draft modelling of the FML plate and Fig. 4 shows the residual velocity variation for different impactor shapes viz. ogival, conical and hemispherical for the glass epoxy based Aluminium FML having a stacking sequence of (0/30/60/90) and a friction coefficient of 0.2. The residual velocity of the hemispherical shaped impactor is very low compared to the ogival and conical impactor shapes.

The finite element simulation of 27 cases was carried out. The residual velocity was converted into signal to noise ratio by using analysis of Taguchi method. The smaller value of responses / residual velocity, the better is the result. ANOVA was performed to designate the most effective statistically significant parameters in the low velocity impact analysis of the FML plate. The individual contributions of the process parameters that have the most and the least net effect can be calculated. Fig. 5 shows that FML species of thickness 1.5mm, layer stacking orientation of 45/30/-30/-45, fiber type as Glass / Epoxy, isotropic metal type as steel, and impactor geometry as hemisphere gives the minimum residual velocity. For the S/N ratio of residual velocity, the results explained that all the parameters had an influence on response measure. The results of ANOVA for the process parameters are furnished in Table 5. Larger value of F–value has maximum influence in the process parameter; larger is the influence of the process parameter on the response. The impactor geometry was found to be the most influencing factor with an F-Vale of 658.3 followed by the thickness of the FML plate with F-Value of 87.31.

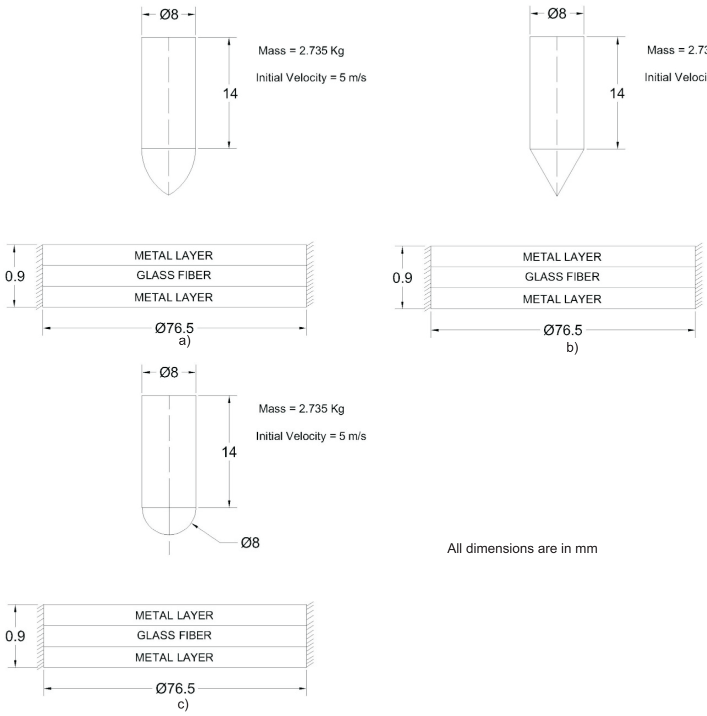

Figure 3 Detailed modelling of fiber metal laminates (a) ogival and (b) conical, and (c) hemispherical shape

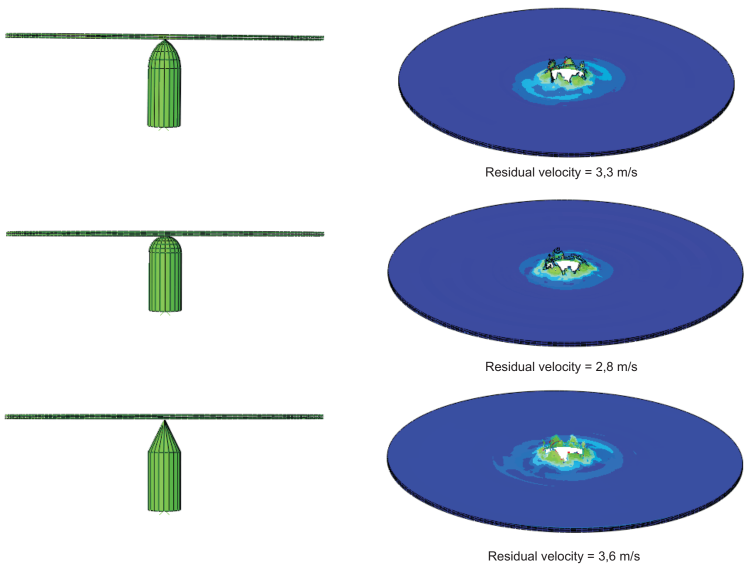

Figure 4 Residual velocity of a glass epoxy based FML with different impactor shape for a stacking sequence of (0/30/60/90) and a friction coefficient of 0.2

Table 4 Experimental design using L 27 standard orthogonal array

S No	FML Thickness (mm)	Stacking Sequence	Type of Fibers	Metals	Impactor shape	Residual Velocity (m/s)
1	0.9	0/30/60/90	Glass	Al -2024-T3	Ogival	3.3
2	0.9	0/30/60/90	Glass	Al -2024-T3	Conical	3.6
3	0.9	0/30/60/90	Glass	Al -2024-T3	Hemisphere	2.8
4	0.9	45/-45/0/90	Carbon	Ti-6Al-4V	Ogival	3.43
5	0.9	45/-45/0/90	Carbon	Ti-6Al-4V	Conical	3.74
6	0.9	45/-45/0/90	Carbon	Ti-6Al-4V	Hemisphere	2.9
7	0.9	45/30/-30/-45	Aramid	AISI 4340	Ogival	3.04
8	0.9	45/30/-30/-45	Aramid	AISI 4340	Conical	3.31
9	0.9	45/30/-30/-45	Aramid	AISI 4340	Hemisphere	2.57
10	1.2	0/30/60/90	Carbon	AISI 4340	Ogival	3.14
11	1.2	0/30/60/90	Carbon	AISI 4340	Conical	3.45
12	1.2	0/30/60/90	Carbon	AISI 4340	Hemisphere	2.6
13	1.2	45/-45/0/90	Aramid	Al -2024-T3	Ogival	3.07
14	1.2	45/-45/0/90	Aramid	Al -2024-T3	Conical	3.24
15	1.2	45/-45/0/90	Aramid	Al -2024-T3	Hemisphere	2.6
16	1.2	45/30/-30/-45	Glass	Ti-6Al-4V	Ogival	3.14
17	1.2	45/30/-30/-45	Glass	Ti-6Al-4V	Conical	3.35
18	1.2	45/30/-30/-45	Glass	Ti-6Al-4V	Hemisphere	2.66
19	1.5	0/30/60/90	Aramid	Ti-6Al-4V	Ogival	3.13
20	1.5	0/30/60/90	Aramid	Ti-6Al-4V	Conical	3.51
21	1.5	0/30/60/90	Aramid	Ti-6Al-4V	Hemisphere	2.61
22	1.5	45/-45/0/90	Glass	AISI 4340	Ogival	2.74
23	1.5	45/-45/0/90	Glass	AISI 4340	Conical	3.08
24	1.5	45/-45/0/90	Glass	AISI 4340	Hemisphere	2.28
25	1.5	45/30/-30/-45	Carbon	Al -2024-T3	Ogival	2.95
26	1.5	45/30/-30/-45	Carbon	Al -2024-T3	Conical	3.32
27	1.5	45/30/-30/-45	Carbon	Al -2024-T3	Hemisphere	2.45

4. Effect of process parameters on residual velocity

Fig. 6 shows the stress distribution on each layer in the FMLs panel for different impactor geometries, the friction coefficient taking a value of 0.2, and stacking sequence orientation being (0/30/60/90). The stress distribution is comparatively high in Figure 5c when compared to Figure 6a and Figure 6b since more force is required to damage the FML plate while using a hemisphere type impactor shape.

Fig. 7 plots the variation of residual velocity of an impactor with varying impactor shape, stacking sequence, metals, and fibers, for the case where the impactor im-

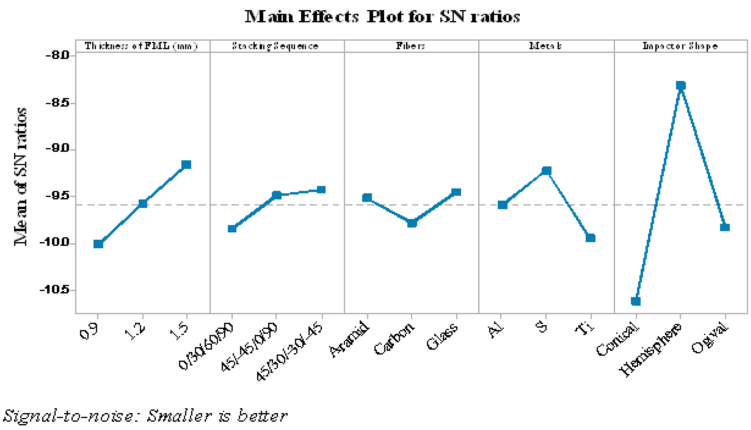

Figure 5 Effect of signal to noise ratio of various process parameters

Table 5 Analysis of variance for residual velocity

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Thickness of FML (mm)	2	0.38261	0.19130	87.31	0.000
Stacking Sequence	2	0.11223	0.05611	25.61	0.000
Fibers	2	0.06992	0.03496	15.95	0.000
Metals	2	0.28376	0.14188	64.75	0.000
Impactor Geometry	2	2.88494	1.44247	658.30	0.000
Error	16	0.03506	0.00219		
Total	26	3.76852			

pacts a glass epoxy based FML plate having a stacking sequence of (0/30/60/90) and a friction coefficient of 0.2. The conical shaped impactor is observed to have the highest residual velocity due to its minimal tip contact area. On the other hand, the hemispherical shaped impactor is found to have the least residual velocity due to its maximum tip contact area as shown in Figure 7a. The FML plate provides the maximum resistance to the impactor only when the tip shape of the impactor is blunt as in the case of a hemispherical shaped impactor. Figure 7b shows that the residual velocity of the impactor is low for a stacking sequence of 45/30/-30/-45. Figure7c shows that the residual velocity of the impactor in a titanium based FML is high because titanium is brittle in nature whereas residual velocities in steel and aluminium based FML plate are very high owing to their ductile nature. Figure 7d shows the variation in residual velocities for different fibers types. The residual velocity is found to be low for Aramid and glass fibers due to their ductile properties and high impact strength.

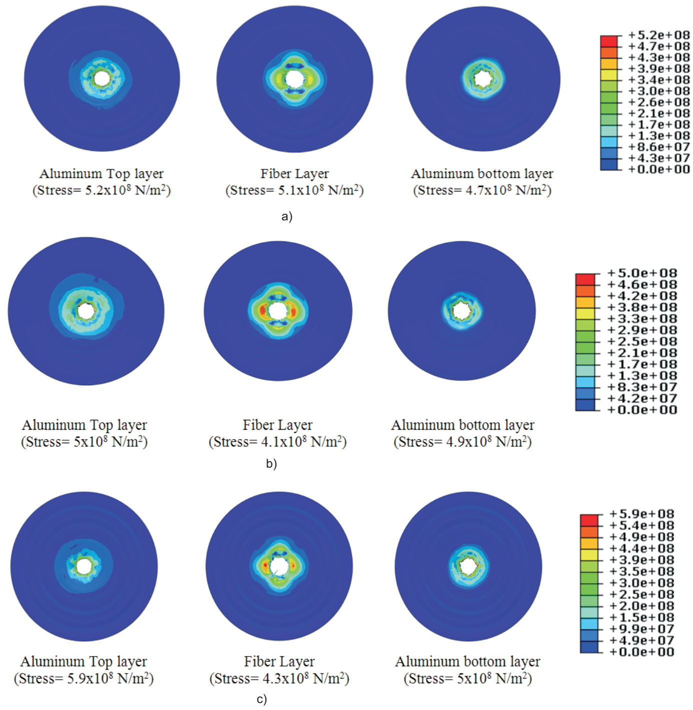

Figure 6 Stress distribution of a glass epoxy based FML with (a) ogival and (b) conical, and (c) hemispherical Impactor shape and a friction coefficient of 0.2, and stacking sequence of (0/30/60/90)

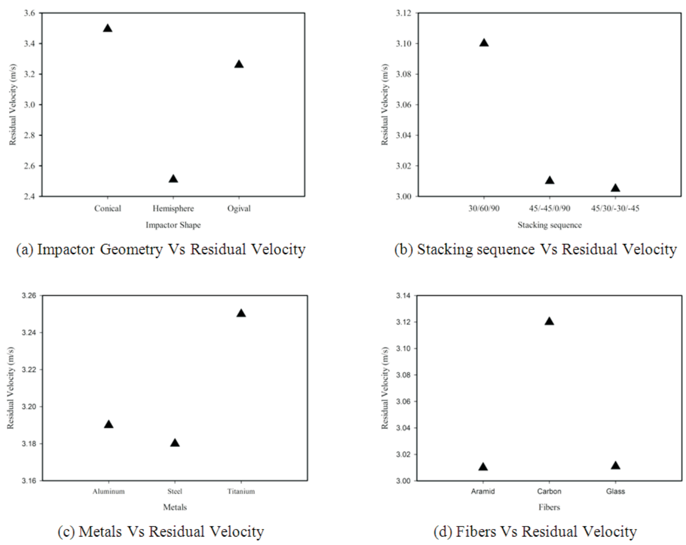

Figure 7 Comparison of the residual velocity of a glass epoxy based FML with: a) different Impactor shape, b) Stacking sequence, c) Metals and d) Fibers of (0/30/60/90) and a friction coefficient of 0.2.

5. Conclusions

The significance of input variables in a low velocity impact analysis performance of FML has been investigated. Design of Experiments was adopted to assess the effect of several input variables on the response characteristics (residual velocity of impactor kind of metal are the significant variables affecting the residual velocity of the impactor. Impactor geometry was found to be the major influencing factor (F-Value-658.3) followed by FML thickness (F-Value-87.31). Fiber configuration was found to be insignificant when compared to fiber orientation relating to low velocity impact analysis performance of the fiber metal laminate plate. The effect of process parameters on the FML has also been studied. The result shows that ARALL, GLARE and steel based fiber metal laminates have higher impact resistance when compared to other FMLs.The stress distribution in each layer metal and fiber layer also studied. Further research can be carried out by including more metals and fibers. Further modifications to variable parameters such as impact velocity and stacking sequence can be explored in order to obtain highly accurate and optimum values for a FML with increased strength and resistance to impact. Thus, there is huge scope for future research in this field, the results of which are highly critical and of utmost relevance to various industries, primarily the aerospace industry.

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