FEM Simulation of Impact of Round Tool on Composite Laminated Block

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Abstract

Many industries like Aviation sector, War and general purpose Helmet making industries, War equipment industries use high velocity impact analysis for design purposes .It is very difficult to analyze by experimental set up because of high costing of experimentation and technical limitations of experiments like high velocity cameras, velocity measurement instruments etc, while the use of computer simulation software like Ansys help researchers to analyze these type of problems very easily.The failure of an alloy of AL6061-T6 with composite laminated plates Kevlar-29 and E-Glass are analyzed under high-velocity impact of round tool of structural Steel using the FEM software, ANSYS Workbench 14.5.Two impact velocities of 500 m/s and 700 m/s were analyzed by FEM simulation . It was analyzed that metal alloy of AL6061-T6 is more resistant than various combination of layers of composite plates, only use of combination of composite materials can not be sufficient for overall strength of laminated plate so use of metal alloy is good approach to increase the strength. It was also observed that mass of tool and overall tool dimension play an important role to failure of composite laminated block plate. In this analysis plate thickness was kept constant but combination of plate layer were changed.
Keywords: Ansys Workbench 14.5, FEM Analysis, AL6061-T6, Kevlar-29, E-Glass

I. INTRODUCTION

High velocity impact is of concern to many different field of researches. Over this period of time, the techniques used to analyze high velocity impact have changed naturally, as have the researchers are still trying to get a clear cut picture of the impact performance. Mainly this phenomenon applies to the various important industries like defense and aviation industries. Armor flexibility and impact resistance are extremely important in many applications.

Finite element analysis is based on the method of domain and boundary dissertation which reduces the infinite number of unknowns defined at element nodes. It has two primary subdivisions. The first utilizes discrete element to obtain the joint displacements and member forces of a structural framework. The second uses the continuum elements to obtain approximate solutions to heat transfer, fluid mechanics and solid mechanics problems. The response of composite materials during ballistic impact can also be determined by using finite element analysis apart from experimental testing.

II. FINITE ELEMENT ANALYSIS

FEM techniques are useful to get solution of differential and integral equations having complex geometries of real world. With the help of this technique real complex problems are now solvable without any experimental work. The method essentially consists of assuming the piecewise continuous functions for the problem solution and obtaining the final parameters of the functions in a manner that reduces the error in the analytical solution. Although this method has become a popular trend in characterizing composite materials, it must be used with a precaution and be always validated by experimental work. It is also doubtful that experimental testing can be replaced totally by finite element analysis; rather it is probably a compliment to each other.

III. PROBLEM DESCRIPTION

In general, to determine the deformation of composite plates for two different materials; (1) E-Glass and (2) KEVLAR-29 for various different velocities like 500 m/s and 700 m/s. Thick composite material made plate was investigated using FEM technique to know high velocity impact analysis of plate. Meanwhile, finite element analysis software used in this study was Ansys Autodyn. In Ansys data modeling, composite material was modeled as an orthotropic material.

Due to limitation of experimental results from previous research papers limited results were obtained from FEM modeling. In addition, no ballistic experiment was carried out in this study. Therefore, the validation of finite element modeling was based on the published research papers. Apart from that, this research emphasizes on the structural integrity of the composite plate when impacted at high velocity. Finite element analysis can be used as a method to characterize the response of composite ballistic material and to obtain valuable information on parameters affecting impact phenomena.

IV. OBJECTIVE OF RESEARCH

The main focus of this research work is to study the response of thick plate made of composite materials when impacted at high velocity by using finite element analysis. The objectives of this research are:

- To determine the effect of high velocity impacts on thick plates made of composite materials.
- Three materials are simulated to find high velocity impact on their structure. First material is alloy of Aluminium named AL6061-T6, second and third are composite materials used in Aviation industry and war industry etc.
- To analyze the deformation as well as residual velocity distribution of the thick plate when struck by a bullet at velocity of 500 m/s and 700 m/s .
- To evaluate the deformation mechanism occurred on thick plate after the impact.

V. LITERATURE REVIEW

In few literatures the definition of ballistic impact can be found. It is called ballistic for an impact resulting in complete penetration of the laminate plate while non-penetrating impact is low velocity impact. As the projectile contacts the target plate, outward the impact point compressive and shear waves propagate and reach the back face and then reflects back. If the contact period of the impactor is longer than the time period of the lowest mode of vibration of the structure then impact phenomenon is considered as low velocity impact. Other than that, the support condition is also critical since the stress waves generated during the impact have enough time to reach the edges of the structure and causes full vibrational response. Where the ballistic impact or high velocity impact involves smaller contact period between impactor and the structure plate. Most composite materials are anisotropic and heterogeneous in nature. These two properties applied to the composite materials since these material properties are different in all directions and locations in the body. In general, there are three fundamental laws used in analyzing the impact phenomenon either assuming stress wave propagation or ballistics modeling or numerical simulation. These fundamental laws are conservation of mass, conservation of momentum and conservation of energy.

VI. DESIGN OF EXPERIMENT

In this study main focus was on impact of various shape of projectile tools on laminated test specimen plate made of composite materials and metal alloy combination. Velocity range was selected from previous research work. Combinations of composite materials with Alloy AL6061-T6 material in test specimen plate were shown in figure. A, B and C represent material type which was shown in figure are Al6061-T6, E-Glass and Kevlar-29 respectively

1) Combinations:

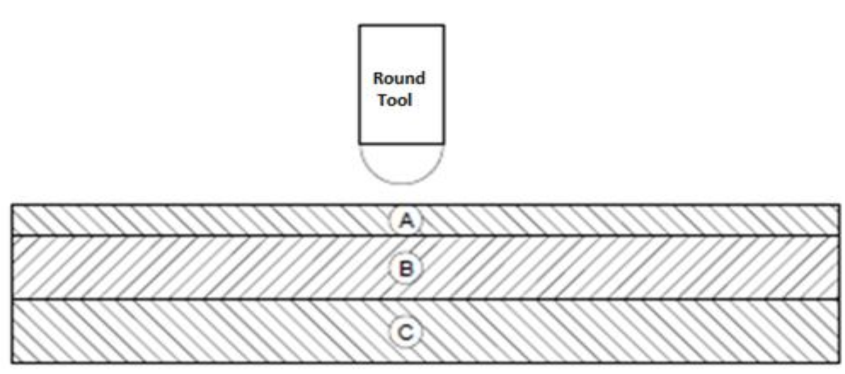


Fig. 1: Schematic Diagram of All Combinations of Cases

A. Boundary Conditions for Study:

Test specimens for all cases were maintained same boundary conditions as shown in Figure.

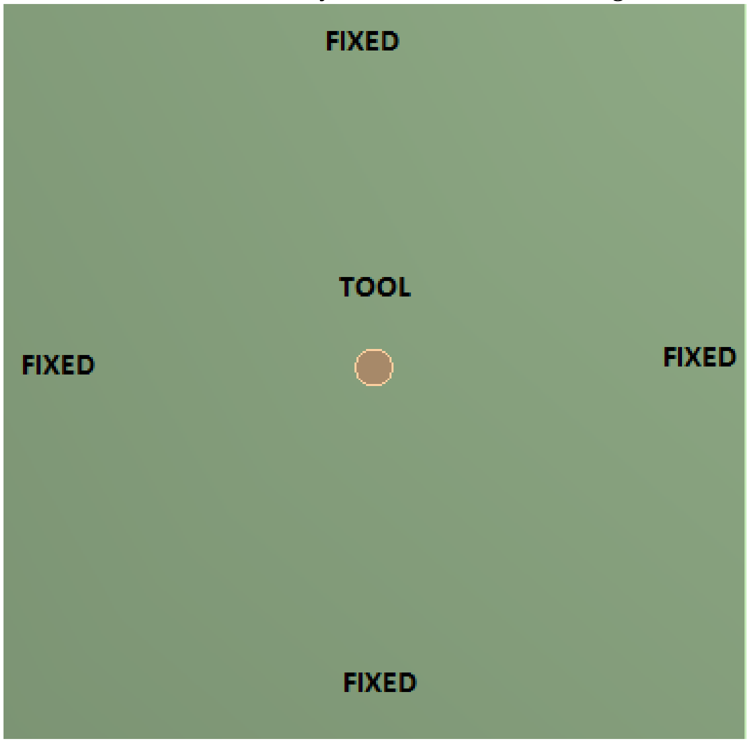


Fig. 2: Boundary Conditions for Test Specimen

Initial velocity was given to tool itself and it was shown in Figure below.

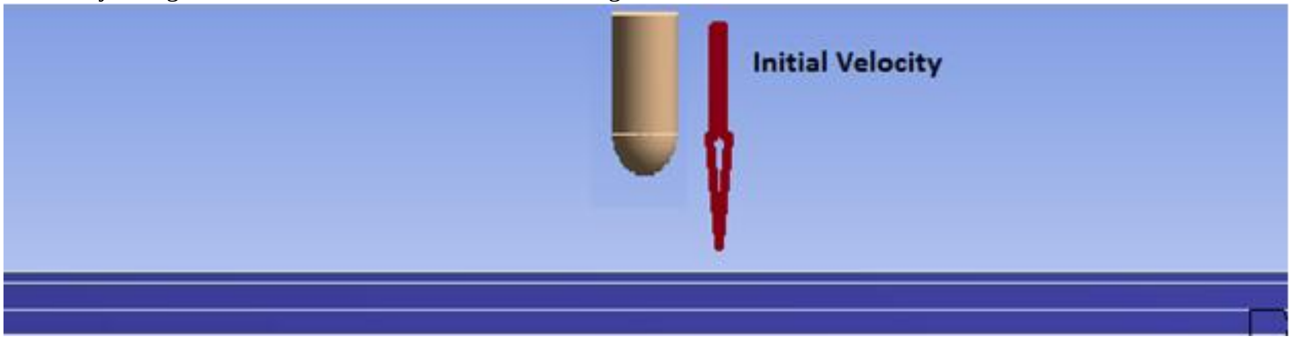


Fig. 3: Boundary Conditions for Tool Projectile

VII. RESULT DISCUSSION

Total 18 cases were studied in this study having cylindrical tool shapes .All materials used in this study were selected from literature review basis and their material properties were taken from Ansys data book.

Table-1
Total test specimens used in study

Tool Projectile	*Test Specimen*			*Initial Velocity (m/s)*
Height (mm)	*Front Layer*	*Middle Layer*	*Back Layer*	
10	*Al6061*	*E-Glass*	*Epoxy*	*500, 700*
10	*E-Glass*	*Al6061*	*Epoxy*	*500, 700*
10	*E-Glass*	*Epoxy*	*Al6061*	*500, 700*
15	*Al6061*	*E-Glass*	*Epoxy*	*500, 700*
15	*E-Glass*	*Al6061*	*Epoxy*	*500, 700*
15	*E-Glass*	*Epoxy*	*Al6061*	*500, 700*
20	*Al6061*	*E-Glass*	*Epoxy*	*500, 700*
20	*E-Glass*	*Al6061*	*Epoxy*	*500, 700*

20	*E-Glass*	*Epoxy*	*Al6061*	*500, 700*

In this study total 18 cases were simulated using Ansys WB 14.5. Results of all cases were shown in graphical form and all outcomes were converted into tabular format and were shown in following sections. Comparison between initial velocity and final residual velocity was important part of this study because it was very important to know how metal plate can change impact of projectile to composite plate.

Table -2
Summary Table of Simulation of Round Shape Tool Impact for Various Variables

Sr. no.	*Tool*		*Test Specimen*		*Initial Velocity (m/s)*	*Residual Velocity (m/s)*	*Strain Rate (m/m)*
	Shape	*Dimension (Dia, length) (mm)*	*Layer*	*Thickness (mm)*			
1	*Round-A*	*(5, 7.5)*	*A-B-C*	*5*	*500*	*5.3807*	*0.64693*
2	*Round-A*	*(5, 7.5)*	*A-B-C*	*5*	*700*	*11.61*	*1.0528*
3	*Round-B*	*(5, 7.5)*	*B-A-C*	*5*	*500*	*3.8143*	*0.90961*
4	*Round-B*	*(5, 7.5)*	*B-A-C*	*5*	*700*	*2.7854*	*1.0363*
5	*Round-C*	*(5, 7.5)*	*B-C-A*	*5*	*500*	*34.12*	*0.67737*
6	*Round-C*	*(5, 7.5)*	*B-C-A*	*5*	*700*	*38.237*	*0.85903*
7	*Round-D*	*(5, 12.5)*	*A-B-C*	*5*	*500*	*12.336*	*0.6255*
8	*Round-D*	*(5, 12.5)*	*A-B-C*	*5*	*700*	*58.133*	*0.89791*
9	*Round-E*	*(5, 12.5)*	*B-A-C*	*5*	*500*	*15.316*	*0.84739*
10	*Round-E*	*(5, 12.5)*	*B-A-C*	*5*	*700*	*15.017*	*1.3939*
11	*Round-F*	*(5, 12.5)*	*B-C-A*	*5*	*500*	*20.141*	*0.98212*
12	*Round-F*	*(5, 12.5)*	*B-C-A*	*5*	*700*	*28.04*	*1.5562*
13	*Round-G*	*(5, 17.5)*	*A-B-C*	*5*	*500*	*140.55*	*1.053*
14	*Round-G*	*(5, 17.5)*	*A-B-C*	*5*	*700*	*293.29*	*1.0694*
15	*Round-H*	*(5, 17.5)*	*B-A-C*	*5*	*500*	*4.0569*	*0.4739*
16	*Round-H*	*(5, 17.5)*	*B-A-C*	*5*	*700*	*210.41*	*1.3075*
17	*Round-I*	*(5, 17.5)*	*B-C-A*	*5*	*500*	*11.618*	*0.52873*
18	*Round-I*	*(5, 17.5)*	*B-C-A*	*5*	*700*	*13.319*	*0.81875*

In this table all 18 cases for different layer combinations of plate with various velocities and overall tool thickness of round shaped tool is given in tabular form. There is also a graphical comparison of initial velocity and residual velocity of round tool is discussed for all three cases of tool length.

Notation in layer column was following: A represents Al6061, B represent E Glass and C represents Kevlar-29. Like that Shape column notation was following: A, B, C, D…… represents group combinations of velocity range (500 and 700 m/s).

A. Graph between Initial Velocity And Residual Velocity:

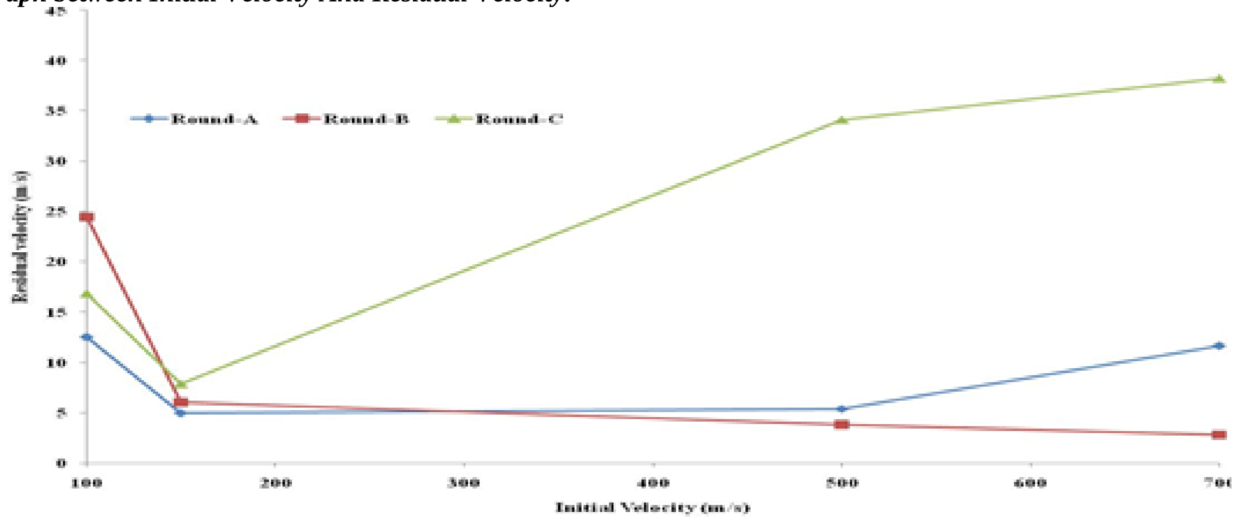


Fig. 4: Test Specimen (Round Tool) Velocity Results at Various Laminated Plate Combination at Tool Height 10 Mm

From Table 2 it was shown that when tool dimension was changed it was found that residual velocities of tool facing large change comparing with initial velocity. When this dimensional effect was perform with laminated plate combinations, changing results again found out.

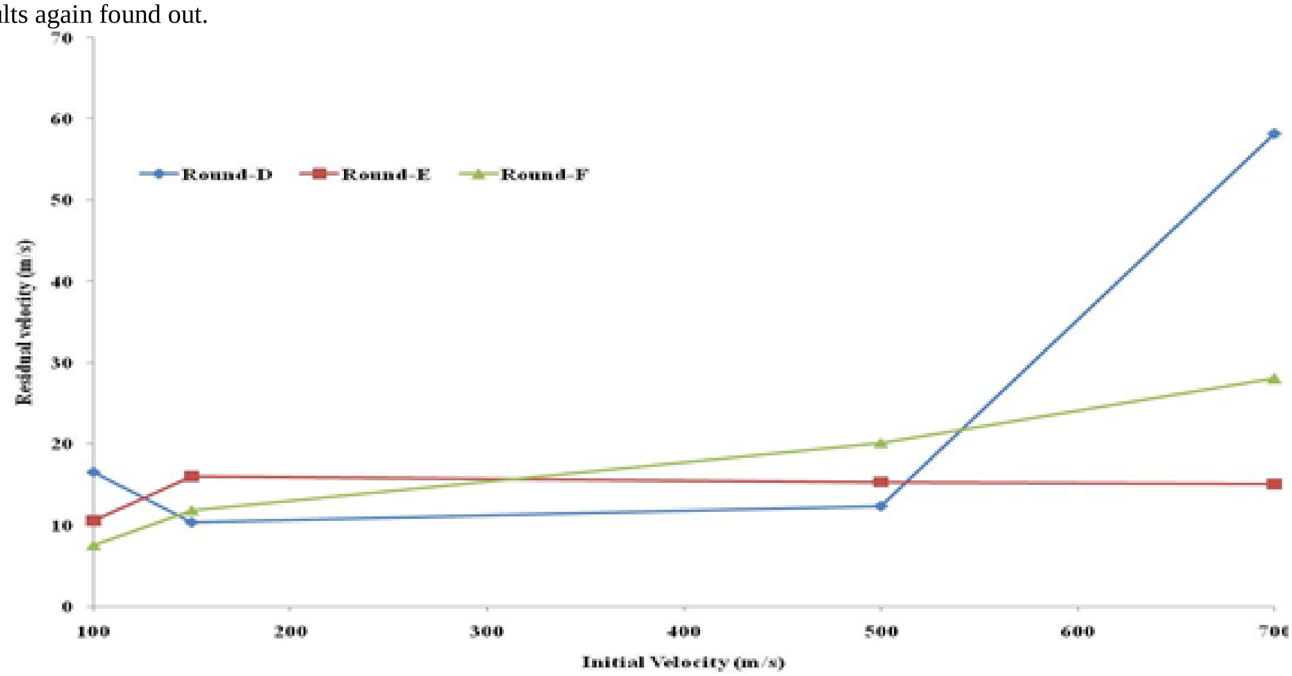


Fig. 5: Test Specimen (Round Tool) Velocity Results at Various Laminated Plate Combinations at Tool Height 15 Mm

When tool length was changed to 15 mm (overall length) by previous tool length 10 mm, it was found that residual velocity for all cases were changed from 10 mm length tool results, but also approaching high magnitude than previous case. In this study the effect of mass of tool was show high changes in impact results of composite laminated plates.

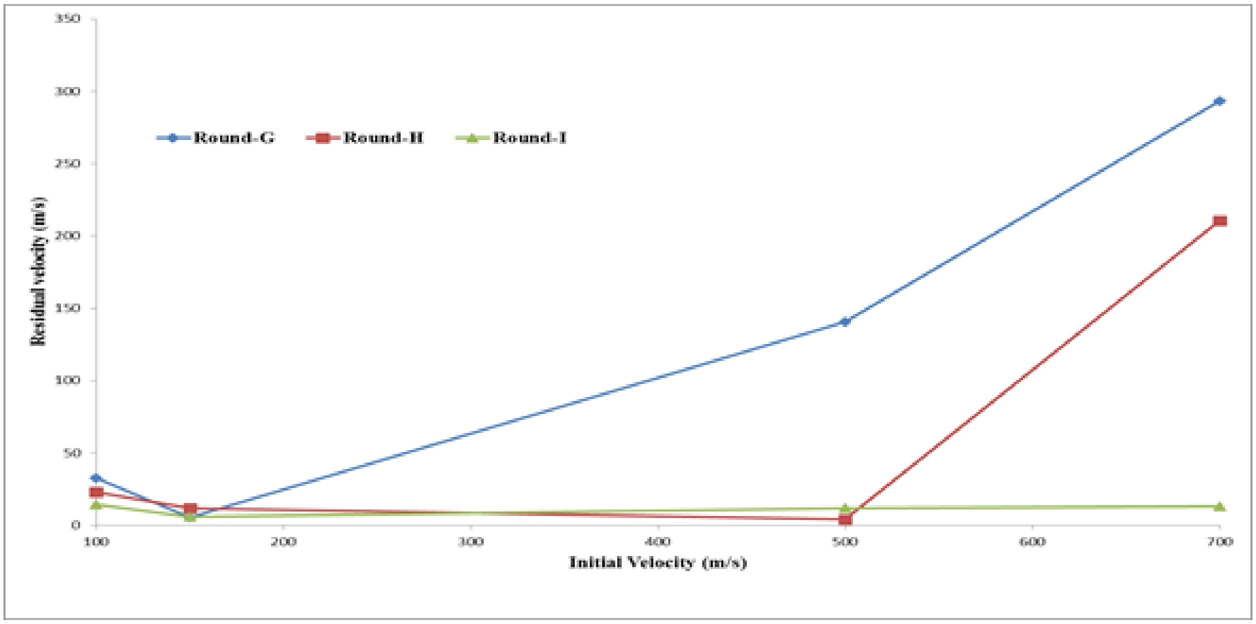
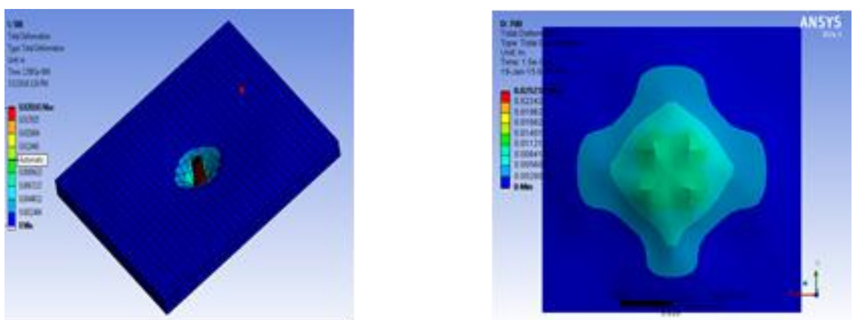


Fig. 6: Test Specimen (Round Tool) Velocity Results at Various Laminated Plate Combinations at Tool Height 20 Mm

B. Total Deformation Of Tools And Layer Plate:

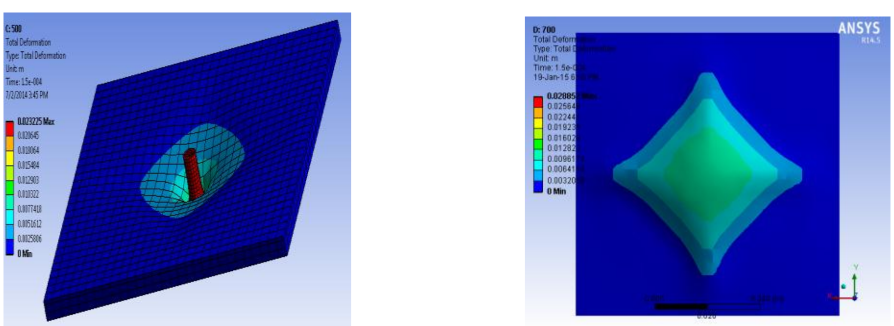
500 Design1 (Round) 700 Design 2 (Round)



(a) (b)

Fig. 7: Impact of Tool On Composite Plate at Velocity 500 M/S And 700 M/S for Layer Combination ABC For 10 Mm Tool

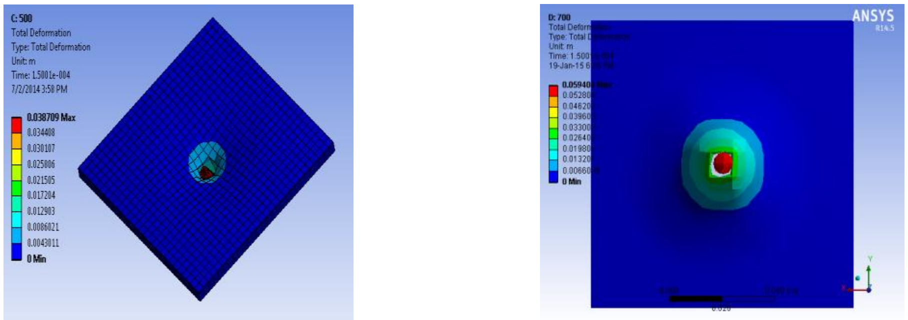
500 Design1 (Round) 700 Design 2 (Round)



(a) (b)

Fig. 8: Impact of Tool on Composite Plate at Velocity 500 M/S and 700 M/S For Layer Combination ABC for 15 Mm Tool

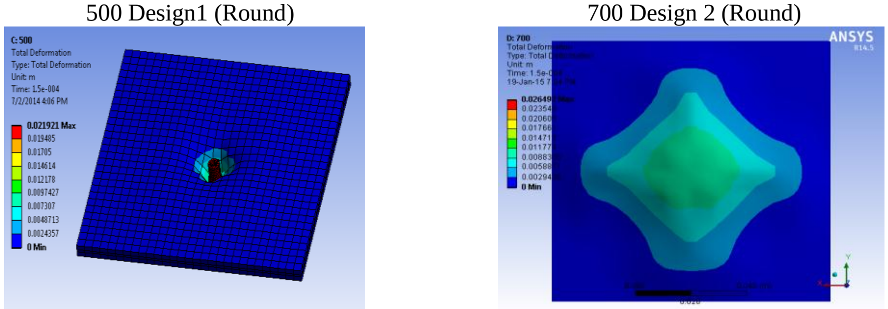
500 Design1 (Round) 700 Design 2 (Round)



(a) (b)

Fig. 9: Impact of Tool on Composite Plate at Velocity 500 M/S And 700 M/S for Layer Combination ABC for 20 Mm Tool

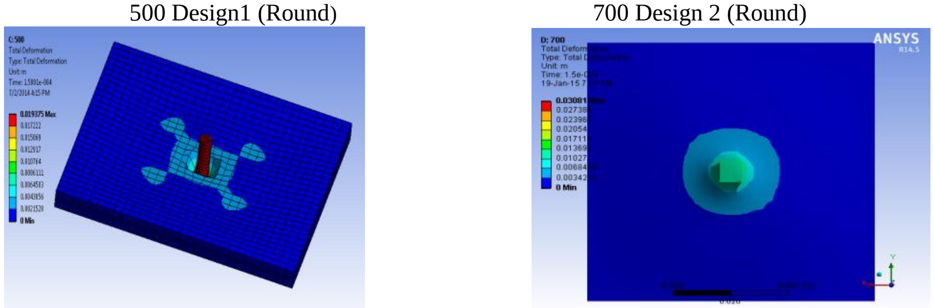
500 Design1 (Round) 700 Design 2 (Round)



(a) (b)

Fig. 10: Impact of Tool on Composite Plate at Velocity 500 M/S and 700 M/S for Layer Combination BAC for 10 Mm Tool

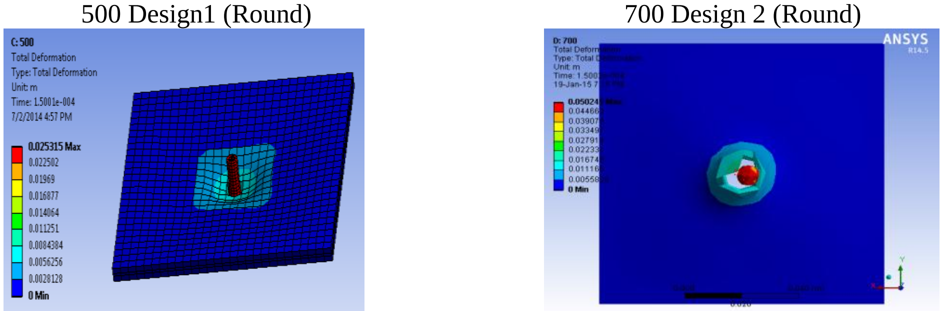
500 Design1 (Round) 700 Design 2 (Round)



(a) (b)

Fig. 11: Impact of Tool on Composite Plate at Velocity 500 M/S and 700 M/S for Layer Combination BAC for 15 Mm Tool

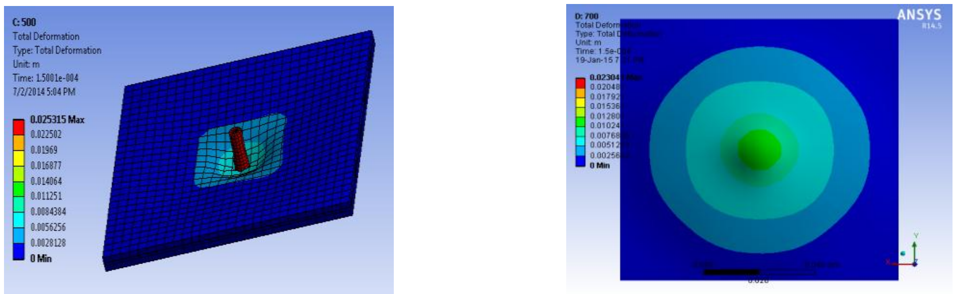
500 Design1 (Round) 700 Design 2 (Round)



(a) (b)

Fig. 12: Impact of Tool on Composite Plate at Velocity 500 M/S and 700 M/S for Layer Combination BAC for 20 Mm Tool

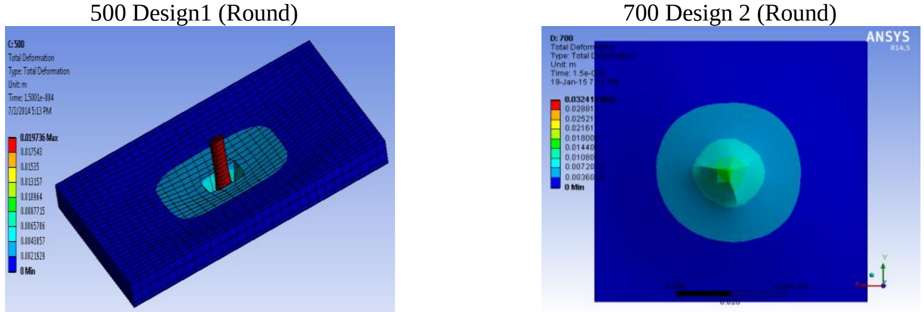
500 Design1 (Round) 700 Design 2 (Round)



(a) (b)

Fig. 13: Impact of Tool on Composite Plate at Velocity 500 M/S and 700 M/S for Layer Combination BCA for 10 Mm Tool

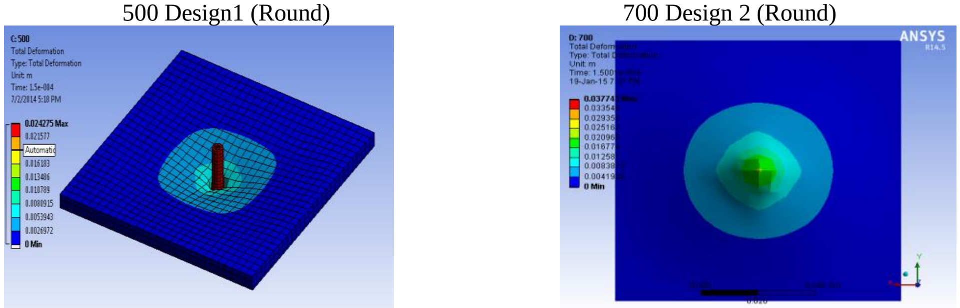
500 Design1 (Round) 700 Design 2 (Round)



(a) (b)

Fig. 14: Impact of Tool on Composite Plate at Velocity 500 M/S and 700 M/S for Layer Combination BCA for 15 Mm Tool

500 Design1 (Round) 700 Design 2 (Round)



(a) (b)

Fig. 15: Impact of Tool on Composite Plate at Velocity 500 M/S and 700 M/S for Layer Combination BCA for 20 Mm Tool

Figure 7 to Figure 15 show deformation effects at various conditions opt during simulation of composite plate. All 18 cases were shown in this section. It was clear that when impact velocity was increased from 500 m/s to 700 m/s, most of the cases show full three layer deformation.

It was also shown from figures that metal layer play important role to reduce damage of composite plate. In this study tool was also opt as flexible material and it means simulation show effect of impact on tool also.On the basis of simulation study, the shape of tool can also increases or decreases the impact effect on composite plates.

VIII. Conclusion

A finite element model using Ansys Autodyn 14.5 was developed to simulate the high-velocity impact reaction of an AL6061-T6, E-Glass and Kevlar-29 composite plate combination.The interaction between the impactor tool and the laminate was simulated using a minimum length contact theory.Numerical analyses were conducted at two impact velocities of 500 m/s and 700 m/s of a structural steel impactor.

Main conclusions from this study were shown in tabular form as following:

Table-3
Effect of Round Tool Shape on Composite Plate at Different Velocity for 20 Mm Tool Length

Tool	*Plate Combination*	*Initial Velocity*	*Conclusion Remark*	
			Plate Survive	*Plate Not Survive*
Round Tool	*ABC*	*500,700*		*500,700*
	BAC		*500*	*700*

	BCA		*500,700*	

From Table 3 it was concluded that best results from simulation for 20 mm tool length is achieved for plate combination BAC and BCA.It was also concluded that shape of tool may increase damage in composite plate combination.General conclusion is that metal layer position play important role to increase impact strength of composite plates.

Table-4
Impactor Mass Effect on Composite Plate at Constant Velocity 500 M/S

Tool	*Plate Combination*	*Tool overall length*	*Mass of Tool (gm)*	*Conclusion Remark*
Round Tool	*ABC*	*10*	*1.41*	*Damage layer A & B*
	ABC	*15*	*2.18*	*Damage layer A & B*
	ABC	*20*	*2.95*	*Damage layer A, B & C*
	BAC	*10*	*1.41*	*Damage layer A*
	BAC	*15*	*2.18*	*Damage layer A*
	BAC	*20*	*2.95*	*Damage layer A & B*
	BCA	*10*	*1.41*	*Damage layer A*
	BCA	*15*	*2.18*	*Damage layer A*
	BCA	*20*	*2.95*	*Damage layer A & B*

Mass of impactor tool also play important role on deformation of composite plate.It is concluded that if mass of tool was increased than damage of composite plate was also increased. Maximum deformation on composite plate on the basis of tool mass was observed at layer combination ABC. Both BAC and BCA show better result than ABC layer combination.

In this study residual velocity of all simulated cases were also carried out and it predict some important results for composite laminate plate. It was predict that residual velocity was increased or decreased with composite layer combinations.Effect of residual velocity on laminate layers of composite plate at initial velocity 500 m/s, 20 mm length of tool was shown in tabular form as below:

Table-5
Summary of residual velocity

Tool	*Plate Combination*	*Residual Velocity*
Round Tool	*ABC*	*140.55*
	BAC	*4.06*
	BCA	*11.68*

It is observed from the table that minimum residual velocity represents best layer combination of composite plate and for this study it was BAC.

IX. FUTURE SCOPE

- Although FEM simulations were done in this study with experimental validation but in-house (laboratory tests) experiments were not performed for actual simulation cases.
- Effect of thermal aspects on composite plate at high velocity impacts.
- Application of Nano and micro mechanics for composite laminate layer.
- Application of Advanced optimization techniques like Ant colony optimization, generic algorithm etc.

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