FEM Analysis of Impact of Cylindrical Tool on Composite Laminated Plate
Suman Anand¹, Dr. Pawan Whig², Sharad Shrivastava³
¹Rajasthan Institute of Engineering and Technology, Jaipur, Rajasthan
t2uman.er.mech@gmail.com

ABSTRACT
Aviation sector, War and general purpose Helmet making industries, War equipments making industries uses high velocity impact analysis for design purposes. To analyse high velocity impact conditions, it is very difficult to achieve it by experimental set up because of high costing of experimentation as well as technical limitations of experiment like high velocity cameras, velocity measurement instruments etc. while the use of computer simulation help researchers to conduct these type of studies easily. In this study the failure of an alloy AL6061-T6 with Kevlar-29, and E-Glass composite laminated plates under high-velocity impact from cylindrical projectile tool of structural Steel was investigated using the nonlinear explicit FEM software, ANSYS AUTODYN. Two velocities of 150 m/s and 500 m/s were selected for FEM simulation. It was analyzed that metal alloy AL6061-T6 is more resistant than composite materials at various combination of layers of composite plate, only use of composite material combination can not sufficient for overall strength of laminated plate so use of metal alloy is good approach. It was also observed that tool mass and tool overall dimension play an important role for failure of composite laminated plates. In this study Plate thickness was kept constant but plate layer combinations were changed. Experimental validation was also done in this study by previous published research paper.

KEY WORDS
FEM Analysis, AL 6061-T6, Kevlar-29, E-Glass, Ansys Autodynt.

1. INTRODUCTION
High velocity impact is of concern to many different fields and has been the subject of much research, especially in the last 5 decades. Over this period of time, the techniques used to analyze high velocity impact have changed naturally, as have the disciplines interested in these analyses. Researchers are still trying to get a clear cut picture of the impact performance. Mainly this applies to the various important industries like defense and aviation industries. Armor flexibility and impact resistance are extremely important in warfare applications. Many theories and procedures emerged to study the impact and blast phenomena. Blast phenomena leads to portion progress which in turn leads to impact. In space travel applications impact plays a vital role in designing the sacrificial armor against the debris. Latest innovations like friction stir welding and repair require the data of impact to read the impact event to exactly assess the damage and repair parameters. Low velocity impacts can cause severe damage to soft material like muscle tissue. In early days metals armors were used, now with advent of composites light weight armor materials are introduced which are more portable. Lighter materials increase the flexibility and portability.

2. 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. FEM technique is useful for various fields which are following:

- Mechanical/Aerospace/Civil/Automotive Engineering
- Structural/Stress Analysis
  - Static/Dynamic
  - Linear/Nonlinear
- Fluid Flow
- Heat Transfer
- Electromagnetic Fields
- Soil Mechanics
- Acoustics
- Biomechanics

A general procedure used in FEM technique is shown below:

Pre-processing
- Define the geometric domain of the problem.
- Define the element type(s) to be used.
- Define the material properties of the elements.
- Define the geometric properties of the elements (length, area, and the like).
- Define the element connectivity (mesh the model).
- Define the physical constraints (boundary conditions). Define the loadings.

Solution
- Computes the unknown values of the primary field variable(s)
- Computed values are then used by back substitution to compute additional, derived variables, such as reaction forces, element stresses, and heat flow.

Post processing
- Postprocessor software contains sophisticated routines used for sorting, printing, and plotting selected results from a finite element solution.

3. PROBLEM DESCRIPTION
In general, there are two tests utilized to determine deformation of composite plates for two different materials; (1) E-Glass and (2) KEVLAR-29 for various different velocities like 150 m/s and 500 m/s. The complex response of composite materials coupled with high costs and limited amount of data from ballistic testing has lead to experimental characterization of ballistic helmet becomes expensive and time consuming. In order to address this issue, 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.

4. 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 Al 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 150 m/s and 500 m/s.
- To evaluate the deformation mechanism occurred on thick plate after the impact.

5. EXPERIMENTAL VALIDATION

Various researchers give importance to experimental validation of any analytical or numerical or simulation research work. In this study experimental validation were performed for simulation verification. There are two methods to perform this task, first one is that create a setup for experimental validation, but it was both time and money consuming. Second method is to validate previous published experimental work from any SCI index journal. We opted second method for experimental validation.

**Title of previous research work:** High velocity impact response of Kevlar-29/epoxy and 6061-T6 aluminum laminated panels.

**Journal name:** Materials and Design (2013)

**Geometry and boundary conditions of domain from research Paper**

**Geometry**

![Fig 1: Al plate stacking front side with Epoxy layer](image1)

![Fig 2: Al plate stacking back side with Epoxy layer](image2)

**Boundary Conditions for Experimental validation**

Case 1 Al plate stacked in front of tool having thickness 0.7 mm, tool dia was 7.62 mm and made of steel 4340.

Case 2 Al plate stacked in back relative to impact of tool having thickness 0.7 mm.

**Results**

**Table 1 Comparison between Experimental and Simulated work (Case 2)**

<table>
<thead>
<tr>
<th>Experimental Work (previous)</th>
<th>Simulation Work</th>
<th>% Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial velocity</td>
<td>Residual velocity</td>
<td>Initial velocity</td>
</tr>
</tbody>
</table>
After validation with experimental research work (Fig 1 to Fig 4 with Table 1), it was concluded that simulation work was perform good results with experimental work.

6. DESIGN OF EXPERIMENT
After experimental validation of simulation results, design of final research work was carried forward. In this study main focus was on impact of various shape projectile tool on laminated test specimens made of composite materials and metal combination. Velocity range was selected from previous research work.

Combinations of composite materials with Al 6061 material in test specimen 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.

6.1 Boundary Conditions for study
Test specimens for all cases were maintained same boundary conditions as shown in Figure.

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>
<thead>
<tr>
<th>Tool Projectile</th>
<th>Test Specimen</th>
<th>Initial Velocity (m/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Height (mm)</td>
<td>Front Layer</td>
<td>Middle Layer</td>
</tr>
<tr>
<td>10</td>
<td>Al6061</td>
<td>E-Glass</td>
</tr>
<tr>
<td>10</td>
<td>E-Glass</td>
<td>Al6061</td>
</tr>
<tr>
<td>10</td>
<td>E-Glass</td>
<td>Epoxy</td>
</tr>
<tr>
<td>15</td>
<td>Al6061</td>
<td>E-Glass</td>
</tr>
<tr>
<td>15</td>
<td>E-Glass</td>
<td>Al6061</td>
</tr>
<tr>
<td>15</td>
<td>E-Glass</td>
<td>Epoxy</td>
</tr>
<tr>
<td>20</td>
<td>Al6061</td>
<td>E-Glass</td>
</tr>
<tr>
<td>20</td>
<td>E-Glass</td>
<td>Al6061</td>
</tr>
<tr>
<td>20</td>
<td>E-Glass</td>
<td>Epoxy</td>
</tr>
</tbody>
</table>

Table 3 Summary table of simulation of Cylinder shape tool impact for various variables

<table>
<thead>
<tr>
<th>Sr. no.</th>
<th>Tool</th>
<th>Test Specimen</th>
<th>Initial Velocity (m/s)</th>
<th>Residual Velocity (m/s)</th>
<th>Strain Rate (m/ m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Cylindrical-A</td>
<td>A-B-C</td>
<td>5</td>
<td>150</td>
<td>4.17 84</td>
</tr>
<tr>
<td>2</td>
<td>Cylindrical-A</td>
<td>A-B-C</td>
<td>5</td>
<td>500</td>
<td>11.5 89</td>
</tr>
</tbody>
</table>
In this table all 18 cases for different layer combinations of plate with various velocities and overall tool thickness of conical shaped tool is given in tabular form. There is also a graphical comparison of initial velocity and residual velocity of conical 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 (150 and 500 m/s).

7.2 GRAPH BETWEEN INITIAL VELOCITY AND RESIDUAL VELOCITY

From Table 3 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.

Figure 6 Test Specimen (Cylindrical Tool) velocity results at various laminated plate combination at tool height 10 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.

Figure 8 Test Specimen (Cylindrical Tool) velocity results at various laminated plate combinations at tool height 20 mm

7.3 TOTAL DEFORMATION OF TOOLS AND LAYER PLATE

150 Design1 (Cylinder)
Figure 12: Impact of tool on composite plate at velocity 150 m/s and 500 m/s for layer combination ABC for 10 mm tool.

(a) 500 Design1 (Cylinder)

(b) Figure 13: Impact of tool on composite plate at velocity 150 m/s and 500 m/s for layer combination ABC for 20 mm tool.

(a) 500 Design1 (Cylinder)

(b) Figure 14: Impact of tool on composite plate at velocity 150 m/s and 500 m/s for layer combination BAC for 10 mm tool.

(a) 500 Design1 (Cylinder)
Figure 15 Impact of tool on composite plate at velocity 150 m/s and 500 m/s for layer combination BAC for 20 mm tool

Figure 16 Impact of tool on composite plate at velocity 150 m/s and 500 m/s for layer combination BCA for 10 mm tool

Figure 17 Impact of tool on composite plate at velocity 150 m/s and 500 m/s for layer combination BCA for 20 mm tool

Figure 12 to Figure 17 show deformation effects at various conditions during simulation of composite plate. All 18 cases were shown in this section. It was clear that when impact velocity was increased from 150 m/s to 500 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.

8. 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 150 m/s and 500 m/s of a structural steel impactor.

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

<table>
<thead>
<tr>
<th>Tool</th>
<th>Plate Combinatio n</th>
<th>Initial Velocit y</th>
<th>Conclusion Remark</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cylindrical Tool</td>
<td>ABC</td>
<td>150,500</td>
<td>150,500</td>
</tr>
<tr>
<td></td>
<td>BAC</td>
<td></td>
<td>150,500</td>
</tr>
<tr>
<td></td>
<td>BCA</td>
<td></td>
<td>150,500</td>
</tr>
</tbody>
</table>

Table 5 Effect of cylindrical tool shape on composite plate at different velocity for 20 mm tool length
From Table 5 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 6 Impactor mass effect on composite plate at constant velocity 500 m/s

<table>
<thead>
<tr>
<th>Tool Type</th>
<th>Plate Combination</th>
<th>Tool Overall Length</th>
<th>Mass of Tool (gm)</th>
<th>Conclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cylindrical</td>
<td>ABC</td>
<td>10</td>
<td>1.54</td>
<td>Damage layer A</td>
</tr>
<tr>
<td>Cylindrical</td>
<td>ABC</td>
<td>15</td>
<td>2.31</td>
<td>Damage layer A &amp; B</td>
</tr>
<tr>
<td>Cylindrical</td>
<td>ABC</td>
<td>20</td>
<td>3.07</td>
<td>Damage layer A, B &amp; C</td>
</tr>
<tr>
<td>Cylindrical</td>
<td>BAC</td>
<td>10</td>
<td>1.54</td>
<td>Damage layer A</td>
</tr>
<tr>
<td>Cylindrical</td>
<td>BAC</td>
<td>15</td>
<td>2.31</td>
<td>Damage layer A</td>
</tr>
<tr>
<td>Cylindrical</td>
<td>BAC</td>
<td>20</td>
<td>3.07</td>
<td>Damage layer A &amp; B</td>
</tr>
<tr>
<td>Cylindrical</td>
<td>BCA</td>
<td>10</td>
<td>1.54</td>
<td>Damage layer A</td>
</tr>
<tr>
<td>Cylindrical</td>
<td>BCA</td>
<td>15</td>
<td>2.31</td>
<td>Damage layer A</td>
</tr>
<tr>
<td>Cylindrical</td>
<td>BCA</td>
<td>20</td>
<td>3.07</td>
<td>Damage layer A &amp; B</td>
</tr>
</tbody>
</table>

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 7 Summary of residual velocity

<table>
<thead>
<tr>
<th>Tool Type</th>
<th>Plate Combination</th>
<th>Residual Velocity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cylindrical</td>
<td>ABC</td>
<td>61.70</td>
</tr>
<tr>
<td>Cylindrical</td>
<td>BAC</td>
<td>9.58</td>
</tr>
<tr>
<td>Cylindrical</td>
<td>BCA</td>
<td>24.10</td>
</tr>
</tbody>
</table>

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

Experimental validation was also done for this study to prove FEM validation for this type of work. Simulation work show good result agreement with previous experimental works.

9. 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.

REFERENCES


