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Finite Element Analysis of the Crash Tube for an Automotive

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***Abstract*—The crash tube is the structure connected to the bumper of an automobile or to the guard of the vehicle which absorbs the impact energy of the vehicle and gets crushed during the impact.**

The goal of the present work is to design the crash tube with metal and Carbon Fibre Reinforced Polymer (CFRP) and compare the crashworthiness of the composite over the metal crash tube. Since most of the automotives are already implemented the metal/alloys, hence the crash tube made of CFRP could be possible material that could be used as an alternative to the metal crash tubes. Hence in this work, the crash tubes made of metal and composites are being tested and analysed using the Finite Element Analysis (FEA) software to validate the results and the behaviour of the crash tube is observed and CFRP material would be suggested for the crash tube for the occupant and vehicle safety.

***Keywords*—Cad, Crashworthiness, Crash tube, Fea**

I. INTRODUCTION

The modern road transport system provides the utmost care to the life of the occupants in case of accidents and the safety of the occupant is the prime most important issue to be considered in case of an accident and the next thing is to avoid the damage to the vehicle under crash. The modern road transport mainly focuses on the prevention crash than the damage due to crash.

So the preference of the vehicle design and road transport system is to build a safer vehicle in case of accident at least occupants are safe inside a vehicle. Then the concept of the crash bar came into the picture which takes almost all the impact load under the frontal crash and crushes down due to impact without transferring the loads to the next structural member and is almost lifesaver in many heavy vehicles.

Nowadays the automotive industry is concerned based on development of primary car safety equipments. This study focuses in the application of new composite materials in a front car bumper. New composite materials made for the automotive industry every year because they are lighter, high strength and better than the present ones. Euro NCAP company was founded for the first time in 1997 and has two important objectives.

II. LITERATURE REVIEW

[1]The author has worked on the crash safety of the automotive and used LPM and FEA to model crash characteristics of the thin crush tube of the square section made of aluminium an attempt is made in this paper to develop an LPM representation of crash energy absorbing structure for frontal crash. After validating FEA results of axial crushing of a square tube with the experimental results, LPM model for the same tube was created using the stiffness characteristic of the tube obtained from FEA analysis results.[2] This paper investigates the interaction of design factors such as tube thickness, tube length, and tube cross-sectional aspect ratio, along with friction and impacting mass on crashworthiness parameters such as specific energy absorption contact time, peak force and crush distance. The impact velocity is assumed to be constant at 15 m/s. The focus is on rectangular aluminium tubes and the analysis was carried out by using a validated finite element model

[3]The paper investigates the behaviour of the cylindrical steel tubes stiffened with axial rings for the quasi-static axial response. The crash behaviour of the cylindrical tubes has been analysed as nonlinear FEA. [4] The research work focuses on the influence of the cross-section of crush tubes on crash characteristic under the nonlinear dynamic crash analysis. The crash tube is made of the ductile material and having the multicellular structure inside the wall thickness which supports the sudden load under the crash absorbing the kinetic energy to the internal energy and intern crushing the tube to avoid the transfer of the impact to the occupant.

[5] The present papers analyze the impact behavior of a composite car bumper made from new materials. The study is performed using Solidworks software for the design of the new car bumper made from new composite materials and the stress concentration distribution is evaluated by use of finite element analyze with Abaqus software for the impact cases.[6] In this paper mainly discussed on car's side-impact performance of the BIW. The main goal is to co-relate the

performance of the BIW frame under crash with various angles towards the rigid pole and occupant safety after the crash. The analysis is performed according to FMVSS No.214 or EURO NCAP standards.

[7] Crash energy absorbers are important structural elements which plays an important role during accidents. Multi-objective the optimization method is applied for improving the design of crash energy absorbers. It is a case study paper on crash energy absorber. Here mainly discussed on amount of absorbed impact energy and maximum reaction force are developed during accidents, and also nonlinear behaviour.[8] Thin-walled energy absorption tube used as energy absorbers in numerous automotive and aerospace applications. Energy absorption tubes are connecting between the front bumper and the dash toe pan. Here the main influential factor is a dynamic impact, Speed of impact & momentum of impact. The impact velocity is assumed to be constant at 15 m/s. The various section aluminium tubes analysis was carried out by using finite element analysis.

[9]This is based on the prediction variance method to analyse the crash. This method is used to reduce various design models, cost and various methods to solve. Here issues can be addressed by proposing a simple uncertainty quantification method for numerical uncertainty (noise) and surrogate model uncertainty (error) in the optimization process. Methodology and objectives.[10], The article aims to investigate crushing performance under axial and oblique impact performed under 10°, 20° and 30° for different cross-section configurations of S-shaped longitudinal members. Model is designed and analysed using LS DYNA software. The model was validated using experimental data. The complex proportional assessment method is used to provide optimized alternative design by considering two conflicting criteria, energy absorption (EA) and peak crushing force (PCF).

III. METHODOLOGY AND OBJECTIVES

A. Methodology

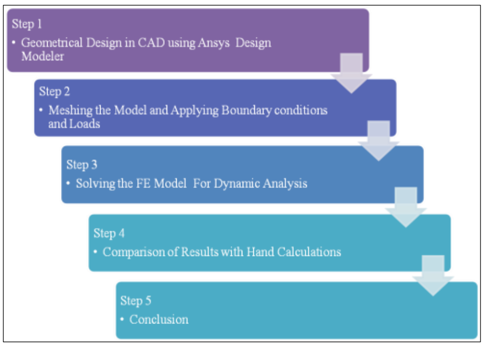

Fig-1: Flow chart for the Methodology steps.

B. Objectives of the work

- Design the crash tube for an automotive.
- Test the crash tube for the frontal impact with both desired materials
- Compare and validation of the results so obtained.
- Optimization of the crash tube by varying the Geometrical design and dimensions.

IV. FINITE ELEMENT ANALYSIS

A. Geometrical Design and FE analysis of crash tubes

The design starts with the standard reference of crash tubes available in the literature and the same parameters are taken as the basic set of dimensions of the crash tubes. Especially the crash tubes are the structures which in turn crushes themselves to absorb the energy under the crash and keep the occupant and other structures safe. From literatures, Most of them used SUV vehicle for testing the crash tubes. crash simulation geometry of crash tube with different shapes are developed using the design modular in ANSYS and also CAD tool SOLIDWORKS is used.

TABLE I. DIMENSION DETAILS OF THE CRASH TUBE

Shape of the crash tube	*Length in mm*	*Diameter/cross section in mm x mm*	*Thickness in mm*
Square Section grooved along the length	200	80 x 80	3

As per the dimensions mentioned in the Table-1 the CAD model developed in the ANSYS design modular. Below in the Fig2 shows the CAD model of the crash tube geometry.

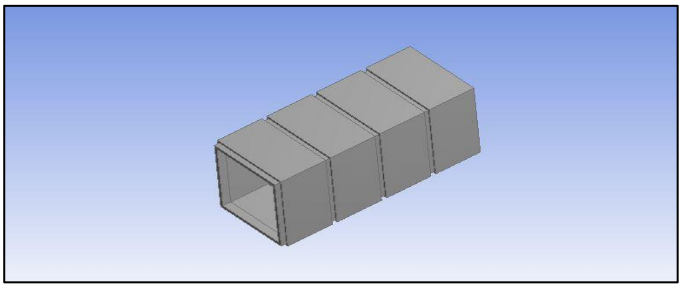

Fig 2. Geometric model of the Crash tube

TABLE -II.MATERIAL PROPERTIES

Aluminium	
Density	2770kg/m^3
Young's Modulus	70gpa
Poisson's Ratio	0.33
Bulk Modulus	77.45gpa
Shear Modulus	29.69gpa

TABLE III.MATERIAL PROPERTIES

CFRP composites	
Density	1580 kg/m^3
Young's Modulus X direction	79gpa
Young's Modulus Y direction	1.22gpa
Young's Modulus Z direction	1.22gpa
Poisson's Ratio XY	0.31
Poisson's Ratio YZ	0.31
Poisson's Ratio XZ	0.31
Shear Modulus XY	5.55gpa
Shear Modulus YZ	5.55gpa
Shear Modulus XZ	5.55gpa

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B. Meshing of the Geometry.

The geometry prepared in the CAD is imported to the ANSYS workbench and is meshed with quadrilateral elements of fine mesh the quality of the mesh has been checked and elements found to around 8000

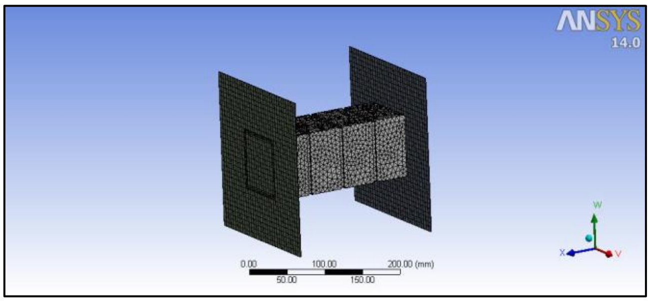

Fig 3. Meshed model of the Geometry

C. Applying boundary conditions and loading the FE model with Load steps.

Once the FE model has been developed the FE has been analysed for the crash behaviour in ANSYS workbench with explicit dynamics tool. The below fig.4 shows the B.C of the analysis where the Crash tube has been supported at one end and was applied with fixed boundary condition and other end was applied with the dynamic load to produce the crash.

Initially the crash of tube has been simulated for the low speed of 18Km/hr considering the first case and later load step two was applied with speed of 36Km/hr and last was analysed with speed of 54Km/hr. All these speed refers to the rules and regulations of crash management systems (CMS) Europe. The load has been calculated based on the weight of the SUV of weight 1400Kg.

TABLE-IV-SPEED AND LOAD VALUES

Velocity in M/s	*Load in N*
5	173750
10	695000
15	1563750

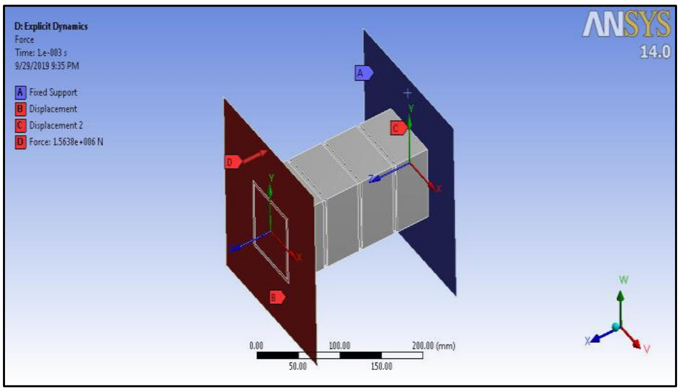

Fig- 4: Shows the boundary conditions applied for the crash tube

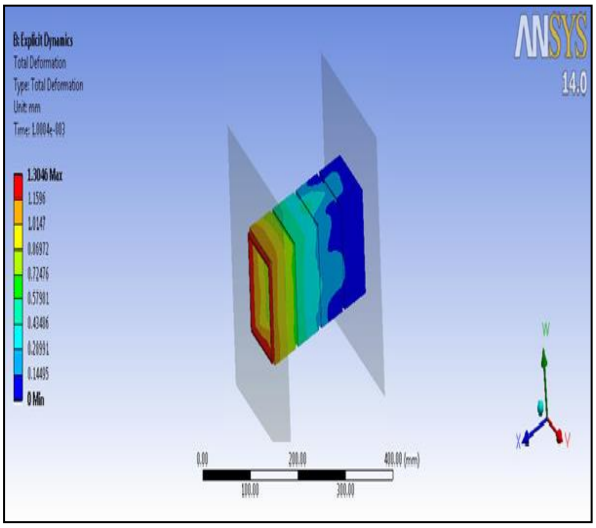

Fig 5: Shows the deformation for load step 1-Al crash tube with grooved square section.

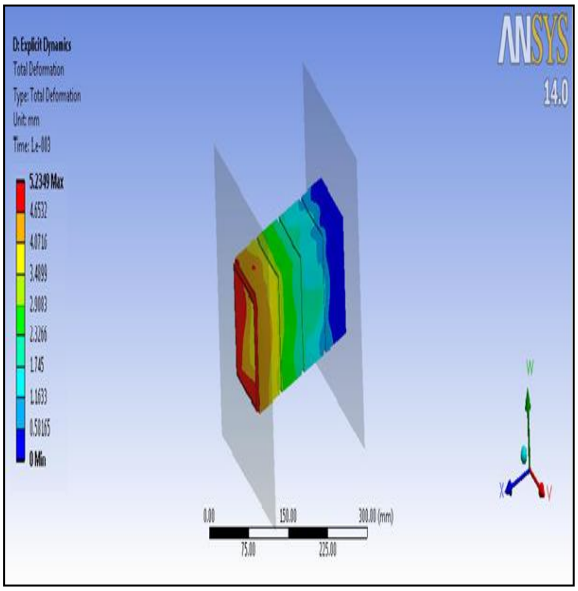

Fig-6: Shows the deformation for load step 2-Al crash tube with grooved square section.

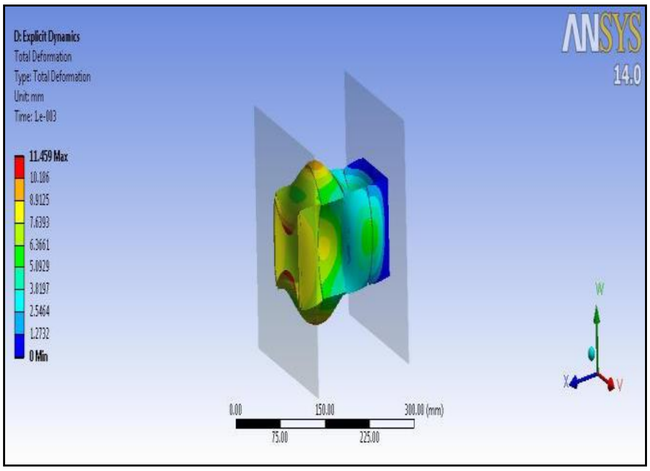

Fig- 7:Shows the deformation for load step 3-Al crash tube with grooved square section

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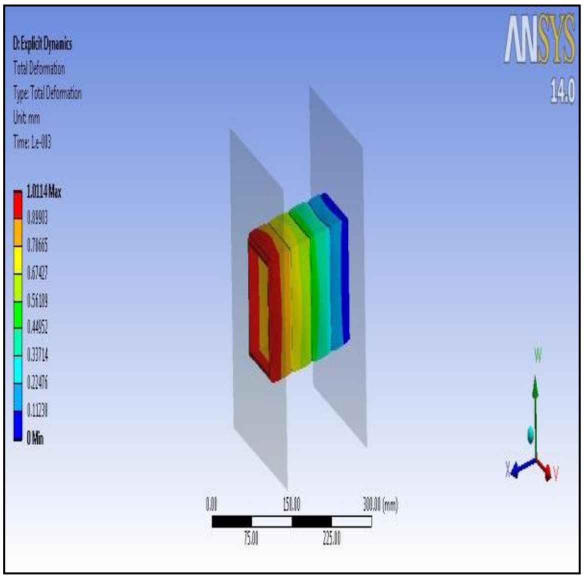

Fig 8:Shows the deformation for load step 1-CFRP crash tube with grooved square section

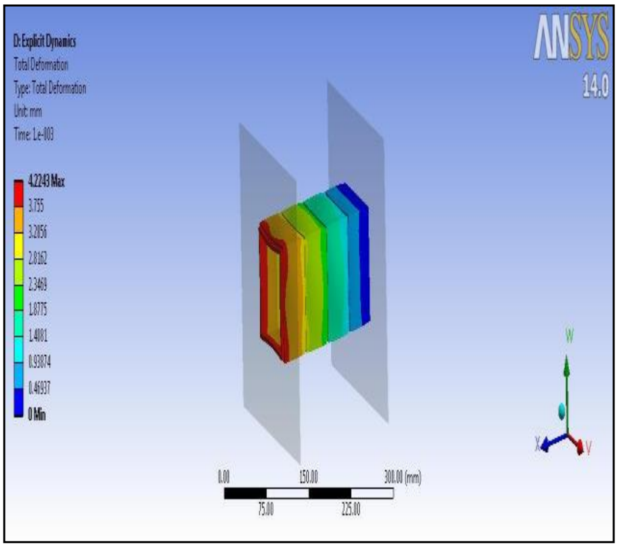

Fig 9:Shows the deformation for load step 2-CFRP crash tube with grooved square section

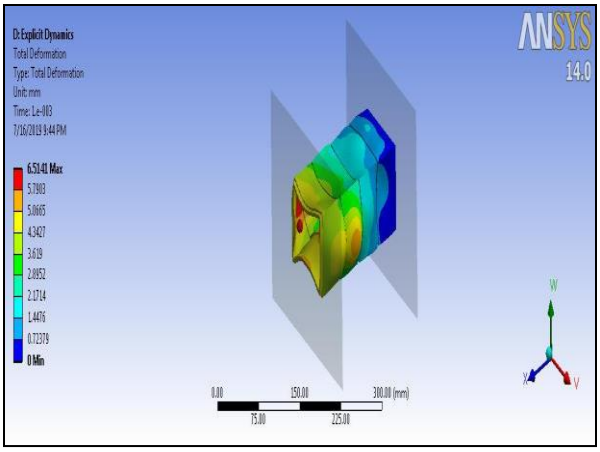

Fig 10: Shows the deformation for load step 3-CFRP crash tube with grooved square section

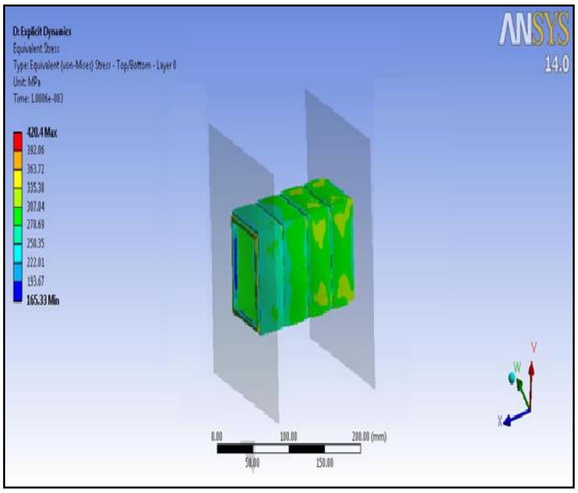

Fig 11:Shows the Von misses stress for load step 1-Al crash tube with grooved square section

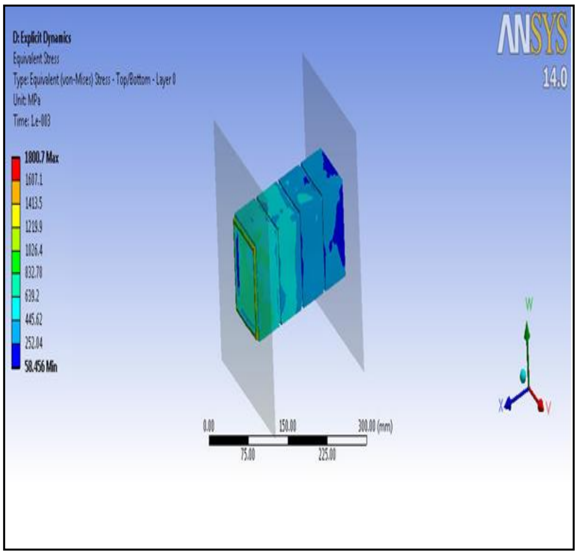

Fig 12:Shows the Von misses stress for load step 2-Al crash tube with grooved square section

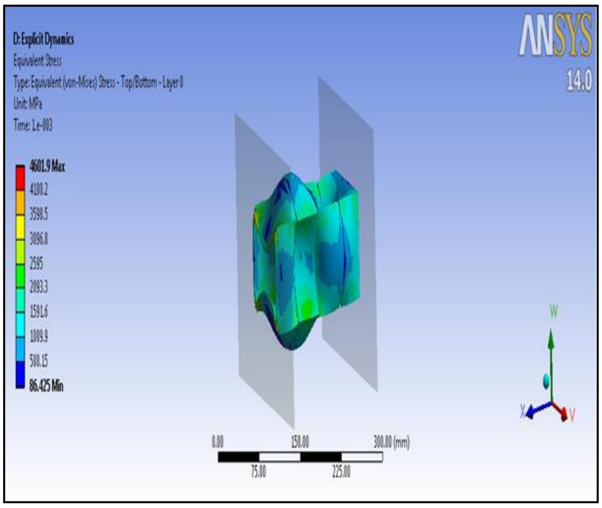

Fig 13: Shows the Von misses stress for load step 3-Al crash tube with grooved square section

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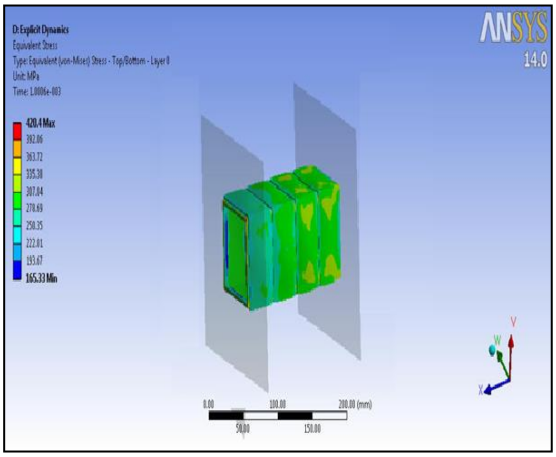


Fig 14 :Shows the Von misses stress for load step 1-CFRP crash tube with grooved square section

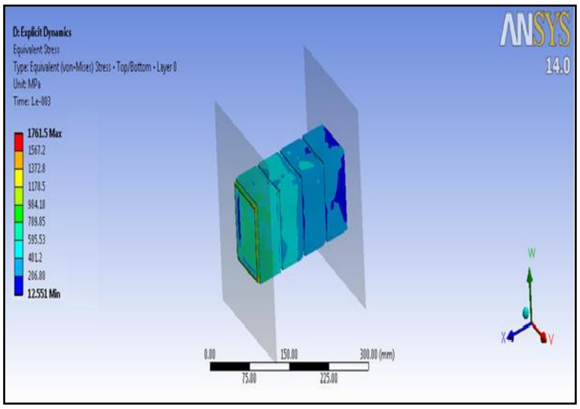


Fig 15: Shows the Von misses stress for load step 2-CFRP crash tube with grooved square section

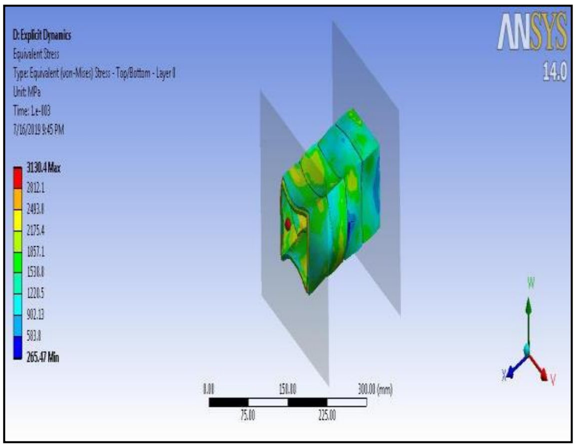


Fig 16: Shows the Von misses stress for load step 3-CFRP crash tube with grooved

V. RESULTS

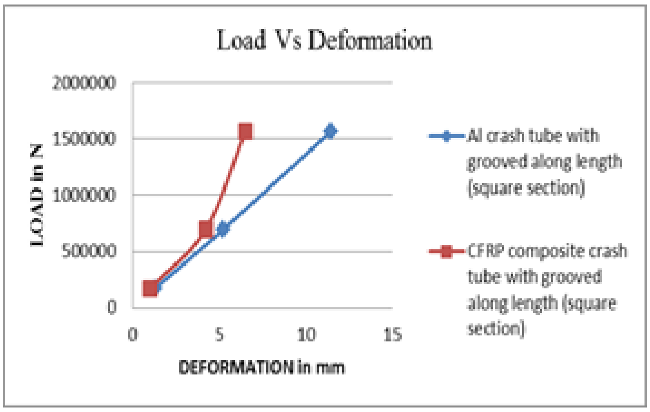
TABLE-V.DEFORMATION RESULTS OF ALUMINUM AND CFRP COMPOSITE MATERIAL

Sl. No	***Load in N***	***Al***	***CFRP***
1	173750	1.3	1.01
2	695000	5.23	4.22
3	1563750	11.45	6.51

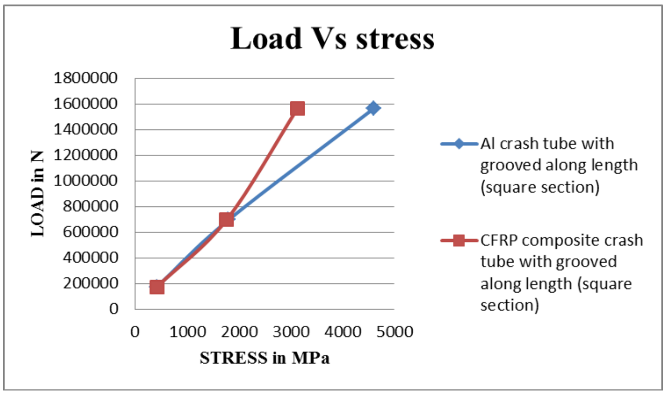
TABLE -VI .STRESS RESULTS OF ALUMINUM AND CFRP COMPOSITE MATERIAL

Sl. No	***Load in N***	***Al***	***CFRP***
1	173750	420.4	420
2	695000	1800	1761.5
3	1563750	4601	3130

The above tables (Table 3 & 4) have been tabulated with deformation and stress behaviour of the crash tube with various configurations. The table values and the graph (Graph 1 &2) in the below shows that the case2 crash tube with square sections shows the better resistance and increased stiffness with the increased deformations when compared with other case. Hence CFRP composites as crash tube material could be suggested.



Graph 1: Load vs Deformation



Graph 2: Load vs Stress

In the above plots (Graph-1 & 2) of load versus deformation and load versus stress shows the crash tube made upof Al alloy with square tube and CFRP with square grooved cross-sections shows the better stiffness and better energy absorption rate as the deformation increases with increase in the stresses. but compared to Al crash tube CFRP crash tube shows better performance hence CFRP material is preferred for crash tube for an automobile.

VI. THEORETICAL CALCULATIONS AND VALIDATION

Theoretical calculations and FEA results are compared and validated.

Theoretical Formulae for crash analysis

Impact stress = $\sigma_{bi} = \sigma_b(1+\sqrt{1+2h/y})$

Where h=0, because of sudden impact load is applied.

Therefore Impact stress= $\sigma_{bi} = \left[\frac{2P}{A}\right]$

Deformation = $\Delta = \sigma_{bi} x \left[\frac{L}{E}\right]$

Where A=cross section Area

σ_{bi} =impact stress

σ_b= normal stress

h=Height of fall or strike height

y=deflection or deformation due to impact

E=Young's Modulus

L=Length of the specimen

using the theoretical formulae impact and deformations have been found assuming the materials behaviour as elastic under crash which gives almost nearby results par with FEA crash analysis.

Formulae To find Area of the crash tube.

Data:

L=80mm, B=80mm, l=74mm, b=74mm

Square shape crash tube area=A= Length x Breadth = (L X B) - (l x b)

(79.7 x 79.7) - (74 x 74) = 876mm^2

Aluminium crash tube

impact stress = $\sigma_{bi} = \sigma_b(1+\sqrt{1+2h/y})$ =2P/A

$\sigma_{bi}=\left[\frac{2\times173750}{876}\right]$ = 396.689 MPa

$\sigma_{bi}=\left[\frac{2\times695000}{876}\right]$= 1586.75 MPa

$\sigma_{bi}=\left[\frac{2\times1563750}{876}\right]$ = 3570.205 MPa

Deformation = $\Delta = \sigma_b$ x (L/E)

Δ = 396.689 x $\left(\frac{200}{70000}\right)$= 1.13 mm

Δ = 1586.75 x $\left(\frac{200}{70000}\right)$ = 4.53 mm

Δ = 3570.205 x $\left(\frac{200}{70000}\right)$ = 10.2 mm

CFRP crash tube

Impact stress

$\sigma_{bi}=\left[\frac{2\times173750}{876}\right]$ = 396.689 MPa

$\sigma_{bi}=\left[\frac{2\times695000}{876}\right]$= 1586.75 MPa

$\sigma_{bi}=\left[\frac{2\times1563750}{876}\right]$ = 3570.205 MPa

Deformation

Δ = 396.689 x $\left(\frac{200}{79000}\right)$= 1.004 mm

Δ = 1586.75 x $\left(\frac{200}{79000}\right)$ = 4.017 mm

Δ = 3570.205 x $\left(\frac{200}{79000}\right)$ = 9.038 mm

TABLE VII: COMPARATIVE STUDY OF THE FEA WITH THEORETICAL CALCULATIONS FOR DEFORMATION OF ALUMINIUM CRASH TUBE

Sl. No	*Load*	*FEA crash analysis*	*Theoretical calculations*	*difference*	*%error*
Load step	*Load in N*	*Deformation in mm*	*Deformation in mm*	*Deformation in mm*	*%*
1	173750	1.3	1.13	0.17	13.10%
2	695000	5.23	4.53	0.7	13.40%
3	1563750	11.45	10.2	1.25	10.90%

TABLE VIII: COMPARATIVE STUDY OF THE FEA WITH THEORETICAL CALCULATIONS FOR DEFORMATION OF CFRP CRASH TUBE

Sl.No	*Load*	*FEA crash analysis*	*Theoretical calculations*	*difference*	*%error*
Load step	*Load in N*	*Deformation in mm*	*Deformation in mm*	*Deformation in mm*	*%*
1	173750	1.01	1	0.01	1.00%
2	695000	4.22	4.02	0.2	4.74%
3	1563750	6.51	9.04	2.53	27.99%

TABLE -IX: COMPARATIVE STUDY OF THE FEA WITH THEORETICAL CALCULATIONS FOR DEFORMATION OF ALUMINIUM CRASH TUBE

Sl.No	*Load*	*FEA crash analysis*	*Theoretical calculations*	*Difference*	*%error*
Load step	*Load in N*	*Stress in MPa*	*Stress in MPa*	*Deformation in mm*	*%*
1	173750	420.4	396.7	23.7	5.60%
2	695000	1800	1586.8	213.2	11.80%
3	1563750	4601	3570.2	1030.8	22.40%

TABLE-X: COMPARATIVE STUDY OF THE FEA WITH THEORETICAL CALCULATIONS FOR STRESS OF CFRP CRASH TUBE

Sl.No	*Load*	*FEA crash analysis*	*Theoretical calculations*	*Difference*	*%error*
Load step	*Load in N*	*Stress in MPa*	*Stress in MPa*	*Deformation in mm*	*%*
1	173750	420	396.7	23.3	5.50%
2	695000	1761.5	1586.8	174.7	9.90%
3	1563750	3130	3570.2	440.2	14.10%

VII. CONCLUSION

The work has been done on the crash simulation of the crash tube made of Aluminum and CFRP composites with various configurations to understand the crash behaviour of both Aluminum and the CFRP composite material to suggest the best material for the crash tube. The simulation shows us in the above case that the crash tube with square grooved cross-sections shows more stiffness and absorbs energy by increasing the stress levels. Both materials almost behave in the same pattern and the especially up to the load step 2, the deformation and stress patterns are symmetric. Then in case of the load step 3, the CFRP composites show better resistance with more crushing. Hence the CFRP shows better crashworthiness than the Aluminum alloy crash tube and also material saving could be achieved. So the CFRP material makes better in the investigation and it suggested as the better material for the crash tubes.

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