Experimental investigation of the crashworthiness performance of laminated composites using CPVC pipe and woven carbon fiber mat

Mr. Abhijeet P.S[1], Prof. Patil S.H[2]

[1]*P.G Student, Government College of engineering, karad*
[2]*Professor, Dept. of mechanical, Government College of engineering, karad*

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Abstract - *Ability to protect its occupants in the event of an accident of vehicle is called as crashworthiness. it play a major role in energy loss and therefore in car accidents, and Crashworthiness is about car safety during a car accident, not accident prevention. In car accidents, the destruction of crashing forces is critical to saving lives and protecting property. Impact type comes in vehicle have different malfunction which are arising in the structure. A number of criteria are used to assess the likelihood of a sudden shock, including patterns of vehicle collapse; acceleration is responsible for the destruction in the vehicles impact, and the potential for injury predicted by human body models. Mechanical parameters such as power, acceleration, or twisting are responsible for injury during the accident. To identify crashworthiness, car manufacturers conduct extensive crash testing on the vehicles, to identify potentially injurious car defects. This research paper will provide the behavior of the specimen under force and compares the experimental results with the structural analysis of the specimen using ANSYS software.*

Key Words: Crashworthiness, FEA analysis, structural analysis, woven carbon fiber matt, plastic tube, laminated composite.

1. INTRODUCTION

Automobile accidents are a few of the primary causes of mortality in current society. Within the automotive industry, protection is one of the important design considerations. When there is a progressive crumble of the automobile shape during a frontal crash, two fundamental necessities must be fulfilled for preventing death or extreme harm to the occupants.

Most of the parts in automobile vehicle are made from plastic fiber material like mudguard, wind shield, mirror case, bonnet, when accident takes place then destruction in plastic parts occurs. Therefore it is necessary to make plastic material enough hard so that it cannot break easily in accidents, by using carbon fiber as reinforcement material, and Whenever accidents happens in vehicle plastics parts gets scratches and easily destructed, so it is necessary to do analysis on plastic parts using carbon fiber mats as laminated reinforcement.

Carbon fiber includes carbon atoms bonded together to shape a prolonged chain. The fibers are rather stiff, strong, and moderate, and are used in plenty of strategies to create remarkable building materials. The houses of a carbon fiber' strength factor are near that of steel and the load is near that of plastic.

This research paper is all about the first requirement of crashworthiness testing parameter i.e. "high inertial force and material" used. Aluminium, steel, rubber, plastics, fiber and are four normally used in automobiles production , this project deals with laminated composites of plastic and carbon fiber.

Fig -1 Woven carbon fiber matt on CPVC pipe

2. CRASHWORTHINESS INDICATORS AND PARAMETERS

Crashworthiness includes crushing load, absorb and dissipate the collision energy, and it is decided by the plastic failures or brittle fracture of the structure when a collision or the accident takes place. It is very necessary to evaluate crashworthiness of the energy absorption components of the components. The crashworthiness indicators include:

1. Energy absorption (EA)
2. Specific energy absorption (SEA)
3. Initial peak force (Fmax)
4. Mean crushing force (F_{Mean})
5. Crushing force efficiency (CFE).

These above crashworthiness indicators decide the failure of the component in tensile test, compressive test of the specimen.

2.1 Energy absorption (EA)

- It is a total energy absorbed by the structures at some point of the whole crushing manner
- It is able to be received by integrating the load–displacement curves.
- Commonly its miles required to be as massive as viable for safe shape. Higher the energy absorption safety is higher.

$$\text{Energy absorption}(EA) = \sum_{0}^{d} F(\delta)d\delta$$

Where,

- $F(\delta)$ =Crushing force
- D=Crushing displacement.

- Since the energy-absorbing up fabric allows taking in (reduce) the effect force, and spreads it over a larger location.

2.2 Specific energy absorption (SEA)

- It is ratio of the EA and mass of the specimen.
- It plays important role to evaluate the crashworthiness calculations.
- It reflects the material utilization during the crushing,.
- SEA is the energy absorbed consistent with the mass of the specimen, and its unit is kJ/kg.
- It can be calculated from the equation and defined as follows:

$$\text{Specific energy absorption (SEA)} = \frac{\text{Energy absorption}(EA)}{M}$$

Where *M*= mass of the specimen.

- Value of the SEA ought to be as big as viable within the design for crashworthiness and lightweight of the energy absorption structures.

2.3 Maximum force/load (F_{max})

The Fmax is having more crushing force during the accident, which is responsible for low energy absorption in the specimen or the structure. Its high value will cause the injury seriousness that comes to passengers while the impact of the accident. Larger F_{max} can give high collision acceleration, which will again bring more injuries to passengers while the impact of the accident.

Therefore, a large Fmax should be avoided in the design process. On this specimen, the relative positions of molecules of the object change in case of compression force.

2.4 Minimum force/load (F_{min})

Energy absorption in the unit displacement during the accident is called as Minimum force/load it gives the overall energy absorption capability or capacity of the specimen, defined as follow:

$$\text{Minimum force/load } (Fmin) = \frac{\text{Energy absorption}(EA)}{d}$$

- Most amount of power from an impulse or surprise loading that a cloth can face up to.
- Due to the fact every type of tool. Metal has precise or exclusive mechanical properties, the.
- Minimum compression force of each additionally differs.
- d= Crushing displacement, and larger the F_{mean} is, the better the energy absorption

2.5 Crushing force efficiency (CFE)

Ratio of the Fmean to the Fmax is called as Crushing force efficiency (CFE), defined as follows:

$$\text{Crushing force efficiency (CFE)} = \frac{F\,mean}{F\,max}$$

3. MANUFACTURING PROCESS AND TESTING

For this project mainly three material are selected the are woven carbon fiber matt, CPVC pipe as base material plastic and Araldite epoxy resin with hardener.

- Dimensions of specimen: Decision of Criteria for manufacturing is as follows,
- CPVC pipe specimen-

- External Diameter (40 mm)
- External Diameter (34 mm)
- Thickness (6 mm)
- Length (100 mm)

- Five reinforced CPVC pipe specimen with increase in number of lamination of carbon fiber matt of thickness of 0.5 mm.Total five types of specimens are created:
  - Non-reinforced tubes (Only CPVC pipe)
  - One layer of carbon fiber on CPVC pipe
  - Two layers of carbon fiber on CPVC pipe
  - Three layers of carbon fiber on CPVC pipe

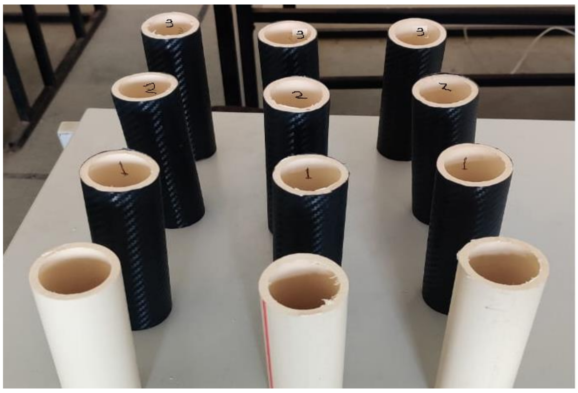

Fig-2 Types of specimens

The experiment of crashworthiness is done with the help of UTM and various 4 reading are get for the analysis for the following specimens and All the load and deformation reading are taken for three times and taking their mean so we will get the near to the exact value.

The crashworthiness indicator will decide whether the structure is safe or it fails, CFE should be increased as much as possible In order to avoid great injuries to passengers or damages to goods, and the better the energy absorption capability of the structures is the larger the F_{mean} is.

Fmax should be less in the design of the energy absorption structures. And SEA should be as large as possible in the design perspective. EA required being as large as possible for safe structure for Higher energy absorption so safety is higher.

But the result will depend on deformation under load and the Crushing force efficiency (CFE) and that is deformation should be less and Crushing force efficiency (CFE) should be higher. Readings of the specimens are taken by using the UTM machine and the deformation and the force at which the specimen is failing at that point readings are taken.

Fig-3 Compression test on non-reinforced tube

A single non laminated trail specimen is tested under the load and that fails at 30 KN, so that for further readings taken nearer to 30 KN because the component/ specimen gets fails at that point of the load.

Fig-4 Compression test on Reinforced tube

4. EXPERIMENTAL RESULTS

Following are the readings of deformation and load which are helpful to find the crashworthiness indicators for the experiment.

Table -1: Experimental results

Type of specimens	L(KN)	M.L(KN)	D(MM)	M.D(MM)
Non-reinforced tubes	30.78	30.48	8.67	8.13
	30.20		7.72	
	30.48		8.00	
One layer of carbon fiber on CPVC pipe	30.24	30.20	6.37	6.98
	30.08		7.87	
	30.28		6.72	

Two layers of carbon fiber on CPVC pipe	30.76	30.58	6.05	6.13
	30.20		5.80	
	30.78		6.55	
Three layers of carbon fiber on CPVC pipe	30.25	30.23	5.39	5.023
	30.23		4.48	
	30.23		5.20	

By using the Mean load (MN) and mean deformation (MD) crashworthiness parameters can be calculated by their formulas mentioned as above.

Table -2: Reading's results

Type of specimens	EA (KJ)	SEA (KJ/KG)	F_{max} (KN)	F_{mean} (KN)	CFE
Non-reinforced ML =30.48 MD=8.13	264.0	54.04g 4.88	30.78	30.4	0.99 0
One layer ML =30.20 MD=6.98	210.7	56.04g 3.76	30.28	30.2	0.99 7
Two layers ML=30.58 MD=6.13	187.4	58.048 g 3.2	30.60	30.5	0.99 9
Three layers ML =30.23 MD=5.023	182.0	60.0 g 3.0	30.2	30.2	0.99 9

For this project the crashworthiness can be determined by the deformation results and the crushing force efficiency (CFE) of the specimens.

Table -3: Mean deformation and Crushing force efficiency CFE readings

Type of specimens	(MD)	(CFE)
Non-reinforced tubes (Only CPVC pipe)	8.13 MM	0.99025
One layer of carbon fiber on CPVC pipe	6.98 MM	0.99735
Two layers of carbon fiber on CPVC pipe	6.13 MM	0.99901
Three layers of carbon fiber on CPVC pipe	5.023 MM	0.99933

The results can be showed by using the graph as follows:

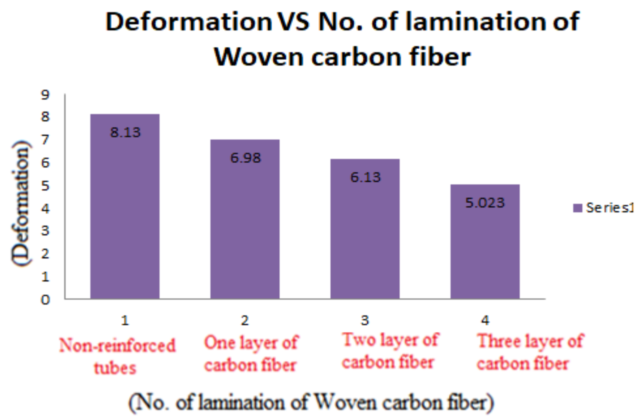

Chart -1: Deformation VS NO. Of woven carbon fiber lamination

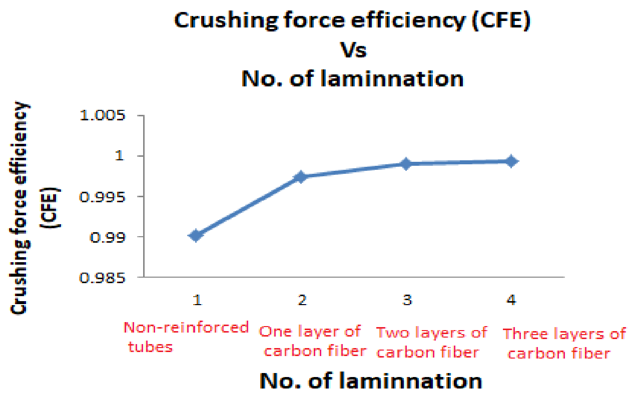

Chart -2: CFE VS NO. Of woven carbon Fiber lamination

5. FINITE ELEMENT ANALYSIS

For this analysis ANSYS software is used, And to perform analysis four types of specimens are used they are Non-reinforced tubes (Only CPVC pipe), single layer of carbon fiber on CPVC pipe, double layers of carbon fiber on CPVC pipe, Three layers of carbon fiber on CPVC pipe. Two types of main materials are used they are Epoxy_Carbon_Woven_395GPa_Prepreg, CPVC pipe. Fine meshing is applied on the specimens. And the force is applied vertically downward direction with bottom is fixed. Four reading results are taken out of total deformation.

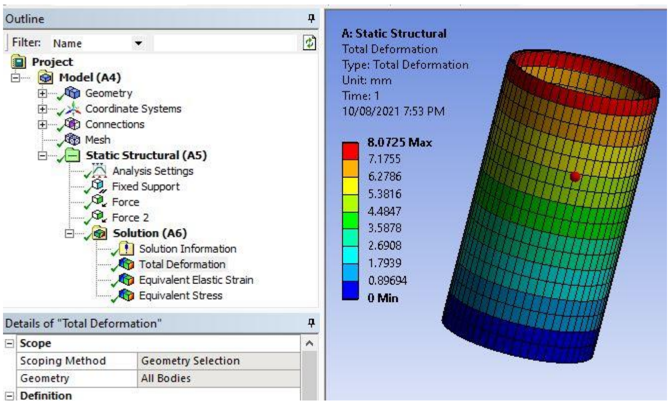

Fig-5 Non-reinforcement pipe

Max. Deformation=8.075MM

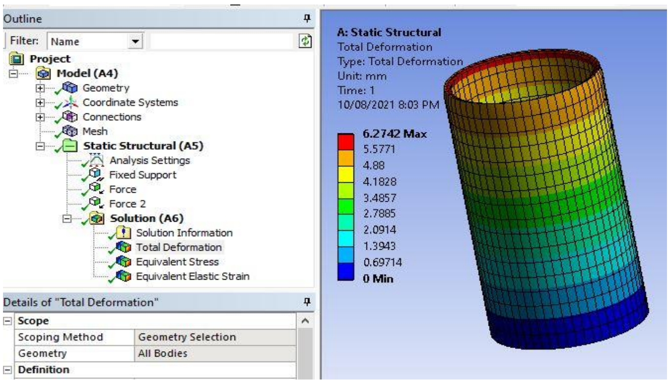

Fig-6 CPVC pipe +1 lamination of woven carbon fiber

Max. Deformation=6.2742 MM

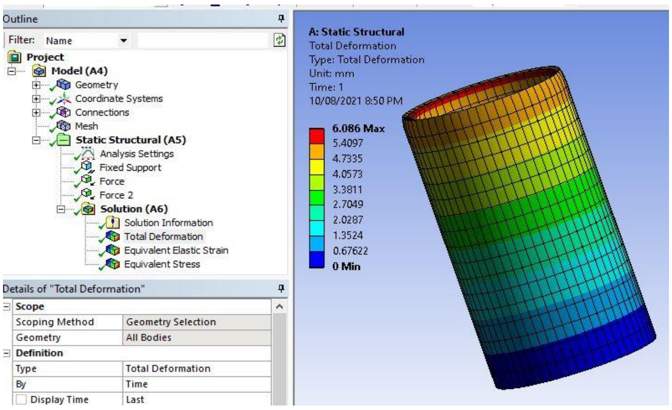

Fig-7 CPVC pipe +2 lamination of woven carbon fiber

Max. Deformation=6.086 MM

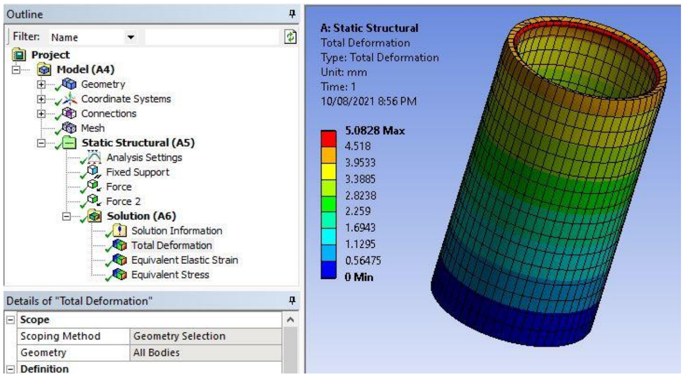

Fig-8 CPVC pipe +3 lamination of woven carbon fiber

Max. Deformation=5.0828

As completion of FEA and analyzing the results of Total deformation, as the number of windings of woven carbon fiber matt on the CPVC tube increases the deformation is decreasing moderately as follows:

Table -4: Deformation results

SR.NO	Type of specimen	Total deformation in MM
1.	Non-reinforcement pipe (CPVC pipe only)	8.075
2.	(CPVC pipe +1 lamination of woven carbon fiber)	6.274
3.	(CPVC pipe +2 lamination of woven carbon fiber)	6.086
4.	(CPVC pipe +3 lamination of woven carbon fiber)	5.082

By analyzing the above data we can plot the graph between Total deformations VS number of woven carbon fiber lamination is as follows:

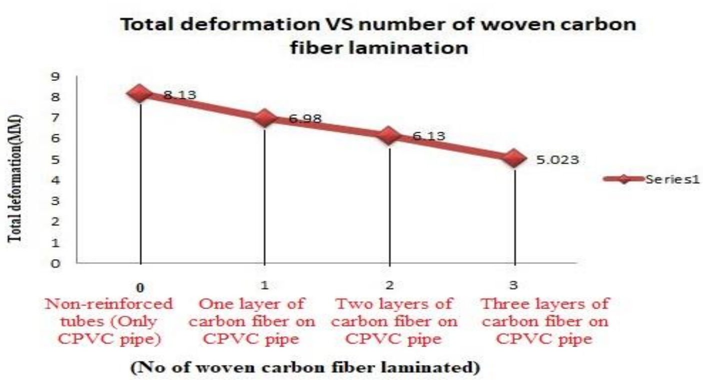

Chart -3: Total deformation VS No. of woven carbon fiber lamination

6. FINAL RESULTS

6.1 Results

For final conclusion need to study the comparison between the deformation results between and experimental the crushing force efficiency (CFE). Comparison analysis between Experimental results and ANSYS (Analysis) software results for deformation. After completing the experimentation and software analysis the results of deformation for all the specimens we got, they are as follows and When the same amount of load is applied on all the specimens i.e. One Non-reinforced tubes (Only CPVC pipe), single layer of carbon fiber on CPVC pipe, double layers of carbon fiber on CPVC pipe, Three layers of carbon fiber on CPVC pipe and The results of deformation get they are as follows:

Table -5: Deformation results

SR. NO	Type of specimen	Experimental results	ANSYS Result
		Total deformation in MM	Total deformation in MM
1.	Non-reinforcement pipe	8.13	8.075
2.	(CPVC pipe +1 lamination C.F)	6.98	6.274
3.	(CPVC pipe +2 lamination C.F)	6.13	6.086
4.	(CPVC pipe +3 lamination C.F)	5.024	5.082

From the above data of deformation for Experimental results and ANSYS Result we can plot the comparison chart:

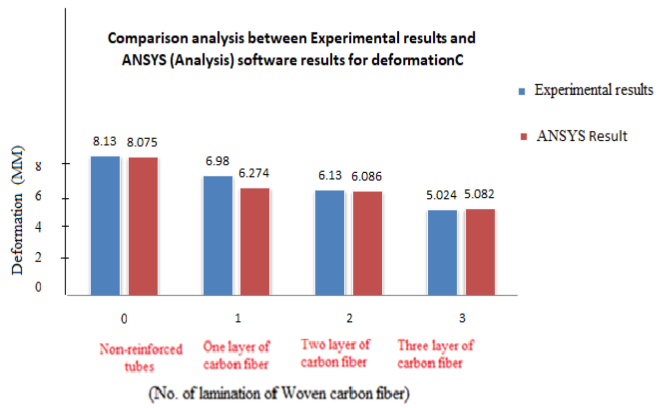

Chart -4 Experimental and FEA analysis results)

And experimental the crushing forces efficiency (CFE) results are as follows:

Table -6: Experimental the crushing forces efficiency (CFE) results

Type of specimens	Mean load (KN)	Mean Deformation (d) (MM)	EA (KJ)	SEA (KJ/KG)	F_{max} (KN)	F_{mean} (KN)	CFE
Non-reinforced tubes (Only CPVC pipe)	30.4	8.13	264.0	54.0g 4.88	30.7	30.4	0.99025
One layer of carbon fiber on CPVC pipe	30.2	6.98	210.7	56.0g 3.76	30.2	30.2	0.99735
Two layers of carbon fiber on CPVC pipe	30.5	6.13	187.4	58.0g 3.22	30.6	30.5	0.99901
Three layers of carbon fiber on CPVC pipe	30.2	5.023	182.0	60.0g 3.032	30.2	30.2	0.99933

From the above data of crushing forces efficiency (CFE) for Experimental we can plot the chart:

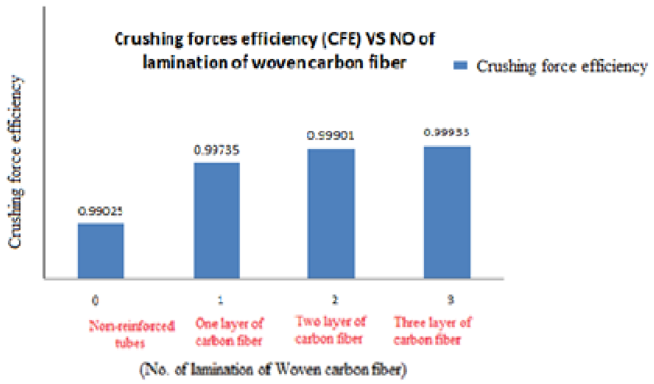

Chart -5 Crushing force efficiency

7. CONCLUSION

By studying the specimens under load condition as deformation gets reduced when the number of Windings of woven carbon fiber lamination increases on the surface of CPVC pipe. The crushing force efficiency (CFE) depends on the F_{max} and Fmean which is eventually depends on the EA (Energy absorption) and SEA (Specific Energy absorption).

The crushing force of efficiency tends to increases gradually when the same amount of the load is applied on all specimens one by one. So the EA (Energy absorption) and SEA (Specific Energy absorption) will also increase as lamination increases on surface of CPVC pipe increases.

Also the results of total elastic strain get increases as the number of windings of woven carbon fiber lamination increases on the surface of CPVC pipe. The stress produced in the specimen also gets reduced under the loading condition when the number of winding increase on CPVC pipe surface.

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