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An Exploration of Natural Fiber Based Composites for Improving Automotive Side Impact Crash Safety

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***Abstract*—In worldwide, maximum of all vehicle accidents (frontal, side, roll-over and rear impact), side impact is one of the major aspect which made the vehicle and human safety the major research criteria in automotive engineering. During the past decades so many developments has been evolved and integrated for the simulation of vehicle & occupant safety protection. By adopting these improvements in vehicle design more than 35% roads accidents were reduced. The present work focused on improving the side impact safety of dodge neon model car using numerical simulation tool. The design of B-pillar plays a significant role to reduce the severity for side impact crash injuries. For the application of side impact, fiber reinforced polymer based composites is more effective as the mechanical behavior is dependent on strain rate. The present work mainly deals with the material properties and geometry of A-Pillar, B-Pillar & door beams. The data results of 4 ply & 6 ply hemp epoxy and 5 ply hemp-glass epoxy based composites with tensile testing of quasi-static rate & high speed strain rate (100mm/min and 200mm/min). From the obtained results of the tensile tests i.e. the maximum values of yield strength obtained are chosen from 200mm/min rate for 4 ply-22.424MPa, 6ply-13.36MPa and for 5 ply hybrid 66.05MPa with failure time of less than 1 sec[1] .These properties are explored for the design of B-Pillar, A-Pillar & Door beams using an efficient numerical modeling methodology in order to meet the vehicle crash safety targets and g-level of the occupant.**

***Index Terms*—side impact, B-pillar, strength, energy absorption.**

I. INTRODUCTION

Worldwide side impact is one among the major aspect of harmful crashes which cause injuries and death per annum. In automotive sector, improving the occupant's safety remains the most significant and challenging task while considering the design criteria. The Statistical analyses from National High-Way Traffic Safety Administrations (NHTSA) figure out that, 5 million vehicle crashes occurred in the United States in the year 2009,where more than 2 million people were injured and claimed more than 33,808 lives

Global statics of accidents shows, more than one-third of all traffic accidents occurs due to the side impact crash, which may be by poles/trees or direct vehicle to vehicle interaction. Same while these accidents can be studied by rigid pole and a movable deformable barrier. At the time of development period of automotive car, it is very significant task in the automotive industry to forecast the side impact crashworthiness with the help of CAE modeling and analysis methods. To reduce injury potential during the time of crash, it is essential to understand the factors affecting injury potential and the mechanism of occupant's injury. The utmost sections of the occupant to be injured in side impact crash are chest and pelvis &the other injuries of side impact crash may be skin injuries with shattered tampered glass, head, neck, thoracic etc….

II. OBJECTIVE

There are many zones in the field of crash-impact dynamics which is necessary to study for the improvement of crashworthy design of the side-door (B-Pillar, A-Pillar & Door Beams). To date, there are many contributions to understand and investigate the character of absorbing energy. In present study FEM is used as an alternate technique for determining the energy absorbing capacity of a structure. In addition it can also be used to analyze the physical performance of vehicle by accompanying full scale crash simulation test. FEM is one of the finest technique but it has a drawback of being expensive method comparing to other and it can able to provide information only for few limited design conditions.

In the present work main objective is to design and make analysis of Natural fiber (hemp) and glass fiber Based Composite beam as a replacement for present steel & aluminum beam and thus reducing the potential injuries sustainable by the vehicle occupant during the side impact crash. More over the work is concentrated in reducing the weight of structure without compromising the safety of occupant. In this work manufacturing and studying the characterization of the hemp epoxy fiber based composites and hemp glass fiber epoxy hybrid composite is done with different ply's and thickness.

Accordingly to the crashworthiness standards, with having the advantage of minimum displacement & more energy absorbing ability, the application of natural fiber based composite material is proposed & efficiency of the structures (B-Pillar, A-Pillar and cross beams) designed studied.

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III. DESIGN

A-Pillar: It has two layers i.e. inner and outer layer. Which are made up of steel and welded to each other and a reinforcement of composite is placed in between the two layers. In this study we are exploring the composite material to these components. The generated catia model of A-Pillar and 2D drafting of A-Pillar is as shown in fig 3.1 and 3. 2respectively.

Fig3.1: A-Pillar model

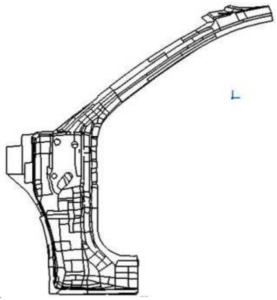


Fig3.2: A-Pillar draft model

B-pillars structures: As this component has to meet many requirements and specifications in automotive structure, so it is one of the most delicate parts of automotive vehicle. B-Pillar has mainly 3 layers, first one is the inner layer and the other is the outer. These layers are made up of steel and are welded together. The reinforcement is placed in between these two layers fig 3.3 shows the component of B-Pillar.

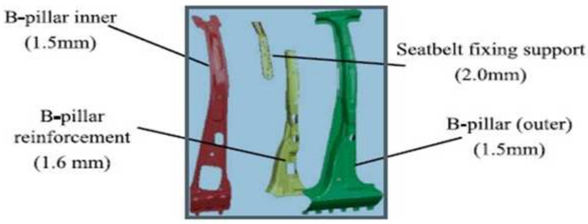
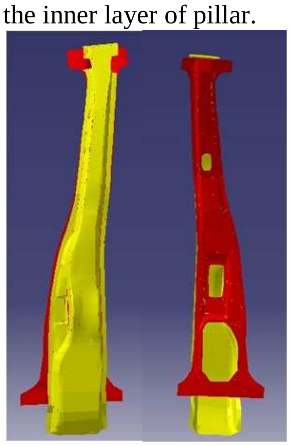


Fig 3.3: Components of B-Pillar

Fig 3.4 shows the geometrical model of the B-Pillar the yellow colour indicates the outer layer of the pillar and the red colour indicates the inner layer of pillar.



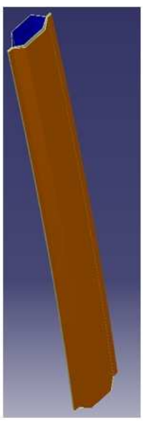


Fig 3.4 B-Pillar models Fig 3.5Generated B-Pillar

Fig 3.5 shows the 3D diagram for the generated model of B-Pillar in CATIA V5 in the present work a similar model is generated comparing with the base model to avoid full car crash. The length is 1000mm and width 138mm with three layers of thickness 1.5mm for inner and outer layer and 1.6mm for mid layer i.e. hemp-glass-epoxy composite.

IV. FINITE ELEMENT ANALYSIS OF A-PILLAR AND B-PILLAR

1. Finite element modeling

In the present work dodge neon model is used with a dummy inside for the analysis. It is developed by NHTSA and the below Fig 10 shows the finite element model of Dodge Neon used for validating the design automotive structure for side impact safety.

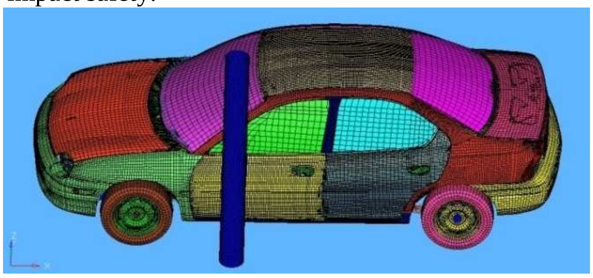


Fig 4.1:Full dodge neon car model

The dodge neon model of car is downloaded from the link http://www.ncac.gwv.edu/vml/model.html. It has 462 components, which represent various parts of vehicle and these are joined together by spot-weld and rigid body constrained options.

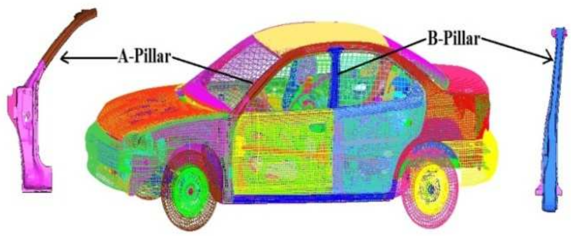


Fig 4.2 Model showing A-Pillar & B-Pillar

In present work full car model of dodge neon car meshed is used for the simulation of A-Pillar with a pole used from NCAC as the A-Pillar supports the roof &front car as shown in fig 4.2.

2.Loads and Boundary conditions

Main study is concentrated on B-Pillar; in present work B-Pillar is generated using approximate dimensions in modeling tool (CATIA V5) with the impactors (Ball>Rectangle). B-Pillar is meshed with Quad and the Impactor such as ball and rectangle shaped meshed with tetra and quad meshing respectively shown in fig 7.2 and fig 7.3.

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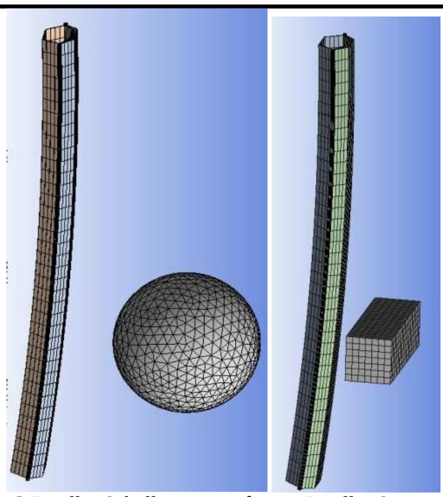


Fig 4.3:B-pillar & ball impactor fig 4.4:B-pillar & rectangle

B-Pillar consists of three layers inner layer, mid layer (reinforcement) and outer layer, in present work alternate materials combination such as Al-alloy, structural steel, hemp-glass epoxy is selected with different impactors such as ball and rectangle shown in fig 4.3 and fig 4.4.

Table 1: summary of nodes and elements used in B-Pillar and Impactor

Group	Types Of Elements		Nodes
	Tetra	Quad	
Ball Impactor	8053	-	1746
Rectangle Impactor	-	1029	1408
B-Pillar Inner	-	666	1444
Middle	-	666	1444
Outer	-	666	1444

After the completion of the meshing of A-Pillar, B-Pillar and impactor (Ball and Rectangle), load and boundary conditions are applied to each component i.e. fixed end and fitted parts comes in boundary conditions and other side load is defined for dynamic stress analysis.

In present work dynamic analysis for A-Pillar is done in LS-DYNA Explicit as solver and post-processor followed by HYPERMESH 8.0 as pre-processor. Whereas for B-Pillar ANSYS Workbench-Explicit dynamics (ANSYS AUTODYN) is used in dynamic analysis.

1. For A-Pillar: - Pole is fixed and the whole car body impacts with a velocity of 30kph (8.33 m/s) with pole made of steel.

2. For B-Pillar:- Top & bottom edges of the B-Pillar are fixed and the impactor strike the B-Pillar with a velocity of 50kph(13.89 m/s) as per FMVSS.

3. Material Properties

In the present work, tests are done on 4 ply and 6 ply of Hemp-Epoxy and 5 ply of Hemp-Glass-Epoxy composites as in this work 4ply and 6ply Hemp-Epoxy composites is explored to the A-Pillar and 5 ply hybrid composites is explored to the B-Pillar[1].

In present work 4 ply material properties are assigned to cross beams and 6 ply material properties are assigned to A-Pillar in dodge neon model of car.

5 ply hybrid material properties are used to alternate materials combination of B-Pillar. Rigid structural steel pole is used for A-Pillar analysis andstructural steel impactor is used for B-Pillar analysis[1].

Table 2: Mechanical properties of materials used[1]

Material/Properties	Young'sModulus "E"(Mpa)	Density "ρ" (Kg/M^3)	Poisson Ratio "υ"	Yielding Stress (Mpa)	Tangent Modulus (Mpa)
Hemp-Epoxy 4 Ply	4130	1200	0.3	22.424	79.53
Hemp-Epoxy 6 Ply	1620	1480	0.3	13.36	211.96
Hybrid 5 Ply	5059	1630	0.3	66.05	2747.53
Structural Steel	200000	7850	0.3	186	-
Aluminium Alloy	71000	2770	0.33	125	-

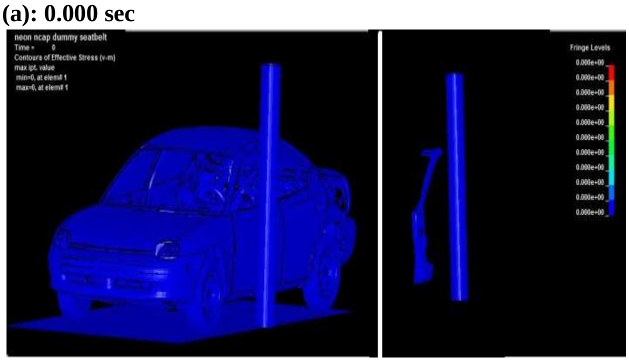
4. Dynamic Stress Analysis

The understanding of results for the separate group component is possible by using LS DYNA for A-Pillar analysis results and ANSYS AUTODYN for B-Pillar analysis results both software is used as a solver and post processor and exact distribution of stress and deformation analysis. The stress values are verified for each separate component by hiding all other components to check maximum stress concentration part of separate component and also maximum deformation is calculated. The maximum stress theory (von-mises stress theory) result mode is selected to review the analysis results.

5. A-Pillar Stress Analysis

Below fig 4.5 (a,b,c,d) shows the simulation for A-pillar for each instant of time with fringe values.

(a): 0.000 sec



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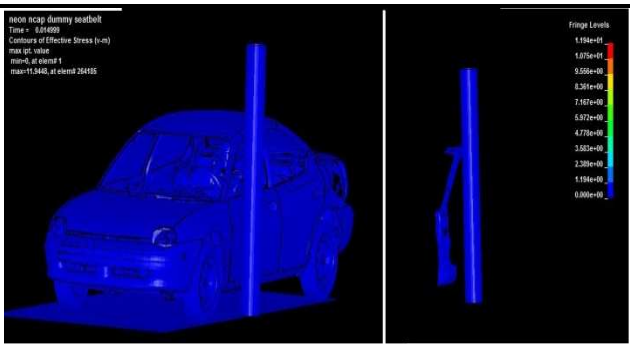
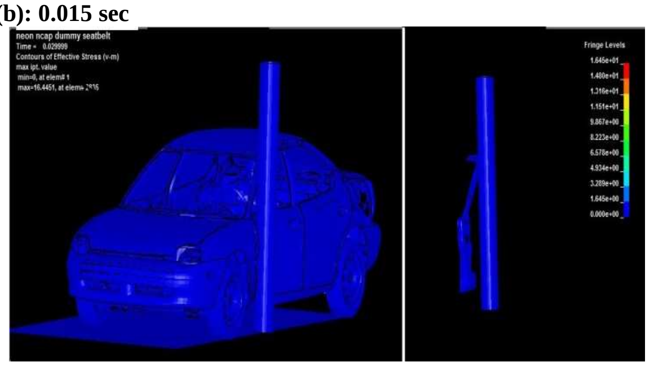
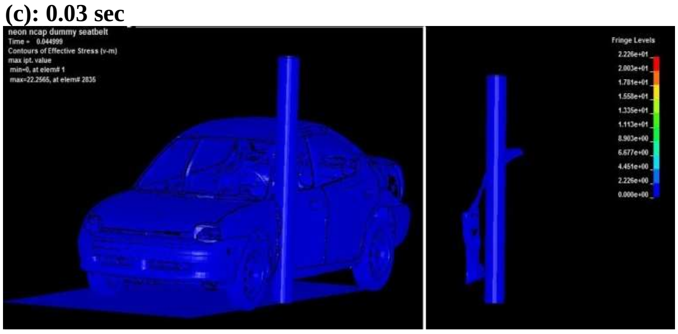


(b): 0.015 sec



(c): 0.03 sec



(d): 0.045 sec

Fig 4.5(a,b,c,d): Simulation results of A-Pillar with respect to time

By using the properties of 4 ply hemp epoxy in A-Pillar, the post processing is done in the LS DYNA manager, from above fig 7.6 we noted all the stress values obtained during the strike of whole car body to the rigid pole at each instant of time at an interval of 0.015 sec. The maximum stress obtained is11.94MPa at the strike time of 0.015sec. In next instant of time at 0.03sec maximum stress were found to be increased to 16.44MPa. Finally for 0.045sec stresses were about 22.256MPa, Fig 8.6 clearly shows the simulation with whole car body and separately pole and A-Pillar.

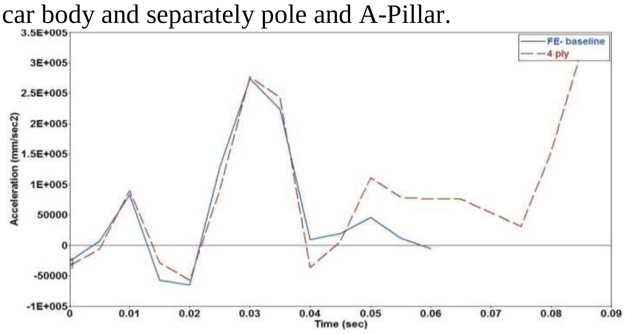


Fig 4.6: Acceleration vs time for 4 ply Hemp-Epoxy in cross beams

In the present work evaluating the chest acceleration is the main objective as at what circumstances the occupant can resist the acceleration occurring on the body, as for the base line during the side impact crash with rigid pole is found to be 28g's.

Fig 4.6 shows the plot of acceleration vs time for the 4 ply Hemp-Epoxy composite comparing with the base line curve. For each instant of time the acceleration is noted when the body comes in contact with the pole. From the above figure, it is noted that the g- level of the 4-ply composite when applied to the cross beams of car are found to be 28 g which is equalto the base line FE-model g-level acceleration.

G-level $=\frac{275}{9.81}= 27.9$

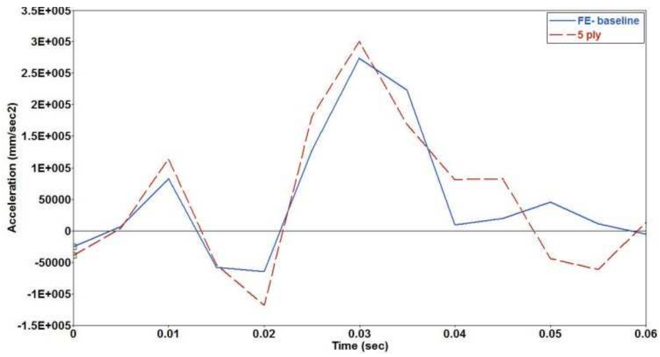


Fig 4.7: Acceleration vs time for 5 ply Hemp-Glass-Epoxy in B-Pillar

Fig 4.7 shows the plot of acceleration vs time for the 5 ply Hemp-Glass-Epoxy composite comparing with the base line curve. For each instant of time the acceleration is noted when the body comes in contact with the pole. From the above figure, it is noted that the g- level of the 5-ply composite when applied to the B-Pillar of car are found to be 29 g which is quite more than base line FE-model g-level acceleration. Here in this case slight increase in thickness gives the less g-level acceleration.

G-level $=\frac{289}{9.81}= 29.45$

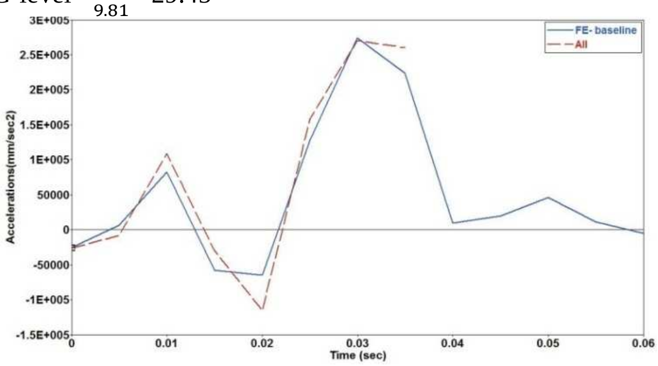


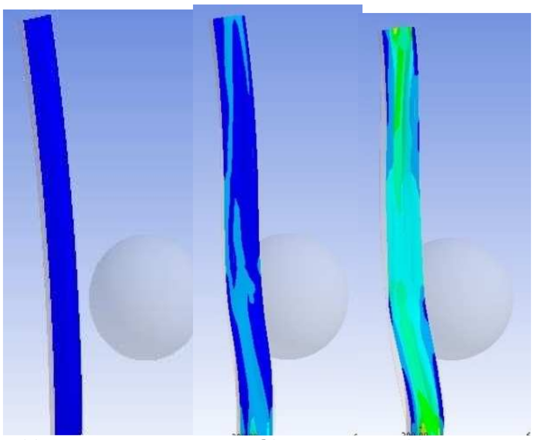
Fig 4.8: Acceleration vs time for 6 ply Hemp-Epoxy in A-Pillar

Fig 4.8 shows the plot of acceleration vs time for the 6 ply Hemp-Epoxy composite comparing with the base line curve. For each instant of time the acceleration is noted when the body comes in contact with the pole. From the above figure, it is noted that the g- level of the 6-ply composite when applied to the A-Pillar of car are found to be 27.5 g which is less than base line FE-model g-level acceleration.

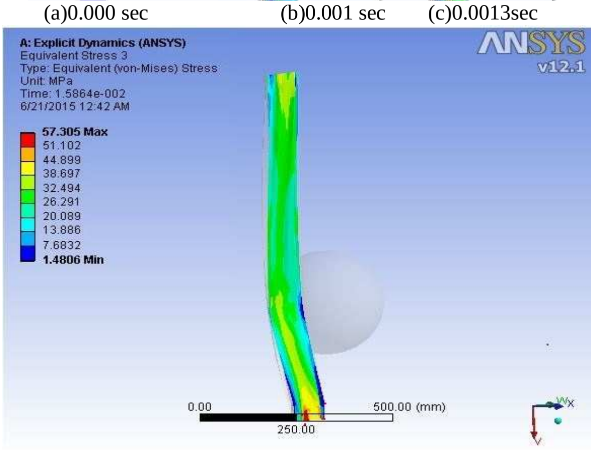
G-level $=\frac{270}{9.81}= 27.5$

6. B-Pillar Stress Analysis (ANSYS Explicit Dynamics)

The analysis of B-Pillar is carried out with two different impactor (ball and rectangle). Thus alternate materials combination with hybrid (H) 5 ply composites is used for B-Pillar such as structural steel (S) and aluminium alloy (Al). Four alternate material combination analysis were done. Best results were found for the combination A(S-H-S) shown in fig 4.9(a,b,c,d) stress distribution with respect to time.



(a)0.000 sec (b)0.001 sec (c)0.0013sec



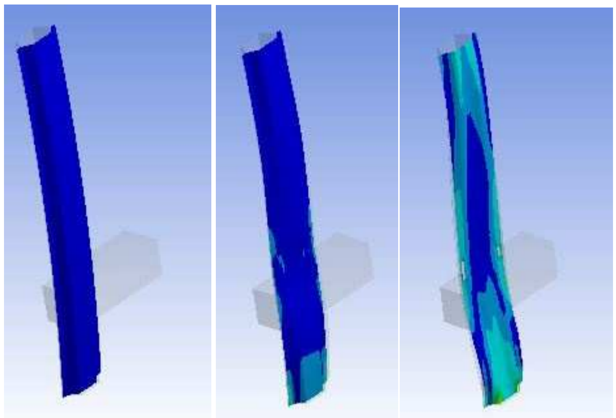
(d) 0.00158 sec

Fig 4.9(a,b,c,d): Stress distribution of B-Pillar with respect to time for combination A (S-H-S) with ball impactor

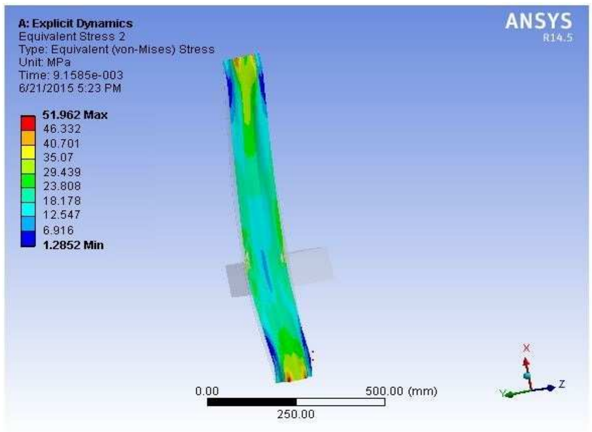
The model of B-Pillar is imported to the Ansys Work bench. Fig 4.9 shows the stress distribution of B-Pillar with respect to the instant of times (0.000sec, 0.001sec, 0.0013sec,0.00158 sec) for the analysis of B-Pillar with ball impactor for the material exploration of steel-hemp-steel combinationA.In this work only the reinforcement layer is high-lighted with suppressing all other body, so it is easy to identify how the stress values are distributed over the mid layer. The stress valves obtained are noted in the Fig (d) with a maximum stress value 57.305MPa at the time of 0.0158 sec.

Table 3: Summary details for alternate materials combination stress analysis

Combination	Material Combination	Impactor	Peak Stress (Mpa)	Deformation (mm)
A	S-H-S	Ball	57.30	72.12
B	S-H-S	Rectangle	51.96	80.31
C	H-H-S	Ball	61.49	72.48
D	A-H-A		64.26	79.68
E	H-H-A		89.54	98.21



(a) 0.000 sec (b)0.005 sec (c)0.007 sec



(d) 0.009 sec

Fig 4.10(a,b,c,d): Stress distribution of B-Pillar with respect to time for combination B (S-H-S) with rectangle impactor

fig 4.10 (a,b,c,d) shows the stress distribution of B-Pillar with impactor at the instant of time(0.000, 0.005, 0.007, 0.009 sec) in this figure only the reinforcement layer is displayed supressing all other body, as it will be easy to note the stress valve particularly distributed over the B-Pillar reinforcement. The maximum stress obtained is 51.9682MPa which is shown in fig (d) during the time of 0.009sec.

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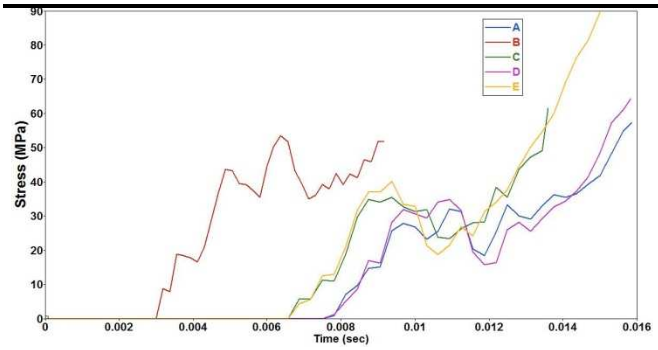

Fig 4.11: Stress vs time for all combinations

Fig 4.11 shows the stress values of each (A,B,C,D and E) combination of materials with respect to time, the minimum stress 51.968MPa obtained is by B combination which is indicated with red colour curve and maximum stress 89.546MPa is by E combination with pink colour curve.

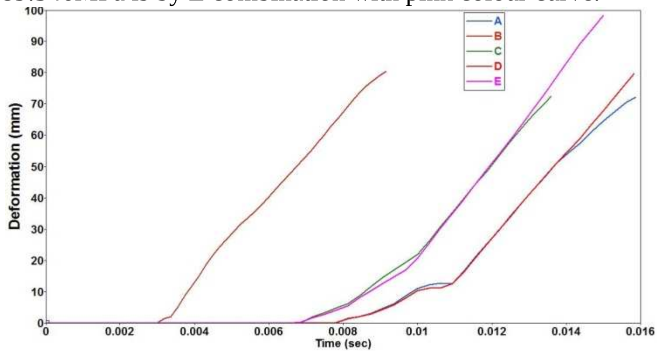

Fig 4.12: Deformation vs time for all combinations

Fig 4.12 shows the relation between deformations of each combination with respect to time, minimum deformation is obtained by A combination and maximum deformation by E combination.

From the graph it is noted that the stress (51.968MPa) combination of B is best suitable as the stress values obtained from the tensile test (66.051MPa) so it is safe to explore the Hemp-Glass-Epoxy composites. Comparatively with ball impactor, rectangle impactor having less stress values which can absorb the more energy and sustain the impact on the B-Pillar.

V. RESULTS AND DISCUSSIONS

In the present work, the obtained results of 4ply & 6ply hemp-epoxy and 5 ply hemp-glass-epoxy are explored to the cross beams, A-Pillar and B-Pillar respectively.The FE model of the dodge neon car is imported to hyper-mesh, where the model is meshed and properties are given with impact velocity of 30kph for the dodge neon car with rigid poleand separately with 50kph impact velocity to B-Pillaras per the FMVSS requirements.

1.Firstly the properties of 6 ply with input of peak stress 22.61MPa, yield stress 13.36MPa, density 1.48X10-6kg/mm3 with thickness C is given and the run is made in the LS-Dyna explicit tool from which the stresses and the accelerations on the A-Pillar is noted.

2.The properties of 4 ply with input of peak stress 26.054MPa, yield stress 22.424MPa, density 1.22X10-6kg/mm3 with thickness of 1.67 mm obtained from 200mm/min rate is given and the run is made in the LS-Dyna explicit tool from which the stresses and the accelerations on the Cross beam is noted.

3.The properties of 5 ply is explored with peak stress 113.33MPa,yield stress 66.051MPa,density 1.63X10-6 kg/mm3with thicknessobtained from 200mm/min rate and the same is simulated in LS-Dyna explicit tool from which stress and accelerations on the B-Pillar is noted.

4.From the LS-DYNA results of von misses it is noted that 22.256MPa stress is maximum obtained after striking with a velocity of 30kph shown in fig 7.6 as, comparatively with the data of tested properties it is suitable to use 4 ply Hemp-Epoxy composite as alternate material.

5.Separately The properties of 5 ply is explored with peak stress 113.33MPa,yield stress 66.051MPa,density 1.63X10-6 kg/mm3with thickness and the same is simulated in the explicit dynamics Ansys workbench, from which stresses distributing on the B-Pillar reinforcement layer is obtained.

6.In present work for B-Pillar different combinations of materials are evolvedand analysis is done using two different impactors (ball and rectangle) detail is shown in table 7.3 of the combinations,among these combination the stress of B-Pillar reinforcement layer has around 51MPa for the combination of B,since the test data results of 5 ply hybrid is 66.05MPa thus the hybrid can be used as alternative material for sustaining the impact with more strength, having less weight comparatively with other materials.

7.The results of stress obtained for the B-Pillar in Ansys work bench of individual component where the stress values are within the test data results values thus if it is adopted with whole car body means it can with stand the impact and the stress value will be minimum since the stresses are distributed all over the car.

VI. CONCLUSIONS AND FUTURE WORK

In the present study, the main objective was to explore the use of composites as an alternative in the vehicle A- pillar , Cross beams and B-Pillar, indeed to reduce the risk of injuries to the occupant during the crash maintaining the g-level acceleration on occupant. The composite were applied and tested in LS-DYNA to find out the maximum stress, acceleration and the energy absorbed by the material.TheB-Pillar component was separately generated in CATIA and tested in Explicit Dynamics with different conditions to find out the maximum stresses absorbing material, orientation and thickness. A side impact B-Pillar was designed and an attempt is made to use this B-Pillar in the vehicle. FMVSS tests are conducted to find out the accelerations and the intrusion sustained by the vehicle before and after the use of composite B-Pillar. Finally, occupant kinematics was studied and discussed in detail.

The hybrid composite designed for B-Pillar is tested with impact velocity in axial direction. Different impactors and materials are used to find out the stresses and deformation. By applying the designed composite B-pillar into the vehicle stresses, acceleration and deformation are reduced.

Conclusions

1.The 4 ply Hemp-Epoxy composites are most suitable to adopt in cross beams of doors as the g-level accelerations is found to be 27.9 g's which equal to the present base line g-level. The overall weight reduction for this component is up to 57% comparatively to the present cross beam.

2.The 6 ply Hemp-Epoxy composites are suitable to adopt in A-Pillar as the g-level accelerations is found to be 27.52 g's which lesser than the present base line g-level. The overall weight reduction for this component is up to 81% comparatively to the present A-Pillar.

3.The use of hemp-glass-Epoxy is best suitable to adopt for the B-Pillar reinforcement as it can sustain the stress up to 66.051MPa which absorbs more energy which reduces the injuries happening in side impact.

4.There is an overall weight reduction 79% by using the hybrid composite for the B-Pillar.

Future Work

1.As the g's for the 5ply Hemp-Glass-Epoxy is beyond the base line g-level so by increasing the thickness of the component we can use this as an alternate material.

2.By increase in ply and thickness alternate combinations of composites can be used as alternate materials.

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