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AN EXPERIMENTAL STUDY ON CAR SAFETY THROUGH ROLL CAGE SPRING, BUMPER

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ABSTRACT

It is important to know their mechanical properties and their failure mechanism during the impact in order to increased the safety of any vehicle. This thesis focuses on the design of bumper, spring and roll cage for lesser weight and better performance. Also it describes about the stress analysis on a car frontal protection system (bumper) simulations. Research concentrates on composite material. It is considering their function, geometry, and other parameters that influence the compatibility of the bumper and roller cage In future research, these parts will face the static test and analysis will be done on their load distributions by applying the variation of load and locations.

We analyze the basic concepts for improving the safety on the car by doing analysis on the car bumper and roller cage.. This analysis was carried out by using ANSYS for structural physics that could simulate static (stationary), dynamic (moving) and thermal (heat transfer) problems to evaluate the behaviour of bumper system and roller cage. Another additional innovative step for improving crashworthiness is the use of material to produces the part to absorb energy during the process of a crash and that part is spring. Here we will use spring on the front side of the vehicle to absorb the energy of sudden impact and this will secure the driver as well as produce less injury to the person outside. How the load applied effect the stress distribution.

I. INTRODUCTION

Nowadays, in development of technology especially in engineering field make among the engineers more creative and competitive in designing or creating new product. They must be precise and showing careful attentions on what they produce. Here, we concentrate on automotive industry. The greatest demand facing the automotive industry has been to provide safer vehicles with high fuel efficiency at minimum cost. Current automotive vehicle structures have one fundamental handicap, a short crumple zone for crash energy absorption. One of the options to reduce energy consumption is weight reduction. However, the designer should be aware that in order to reduce the weight, the safety of the car passenger must not be sacrificed. A new invention in technology material was introduced with polymeric based composite materials, which offer high specific stiffness, low weight, erosion free, and ability to produce complex shapes, high specific strength, and high impact energy absorption. Substitution of polymer based composite material in car components was successfully implemented in the quest for weight and fuel reduction. Among the components, in the automobile industry substituted by polymer based composite materials are the spoiler, bumper fascia, bumper beam, pedal box system, connecting rod and door inner panel. The bumper system consists of three main components, namely energy absorber, bumper beam and energy fascia. The automotive body is one of the critical subsystems of an automobile, and it carries out multiple functions. It should hold the parts of the vehicle together and serve to filter vibration and noise. Additionally, it should be able to protect its occupants when accidents happen. To do this, the automotive body designer should design a structure with significant levels of stiffness, strength and energy absorption. Here we will take a step to modify and implement our idea of using spring on the front side of the car to take the load , to absorb the energy and as we all know spring is a good shock absorber so using spring on front side will keep the occupants of car as well as driver safe or will reduce the risk of serious crash and accidents. Analysis on the structure of roll cage is also being done here by using ANSYS.

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II. METHODOLOGY

A. Bumper design for vehicle safety

During a frontal crash, the front side member is expected to fold progressively, so as to absorb more energy and to ensure enough passenger space. To do so, various cross sections and shapes have been investigated for the front rail of the automotive body to maximize crashworthiness and weight efficiency. Their design included reinforcing the cross-section.Because of these limitations, the fatality rate increases dramatically in high speed impacts. In order to design a successful lightweight vehicle and significantly improve the crash performance of current cars, technological development is still needed. If the automotive body can extend its front end during or right before a crash, the mechanism of absorbing the crash energy would be totally different from that of the passive structure.

B. Material Selection Criterion

The choice of materials for a vehicle is the first and most important factor for automotive design. There is a variety of materials that can be used in the automotive body and chassis, but the purpose of design is the main challenge here. The most important criteria that a material should meet are lightweight, economic effectiveness, safety, recyclability and life cycle considerations. Some of these criteria are the result of legislation and regulation and some are the requirements of the customers. However, some of these criteria may be conflicting and therefore the optimization comes into business here.

In the beginning we start with explaining each criterion and then continue to introducing several materials and where they can be used.

➢ **Lightweight**

As there is a high emphasis on greenhouse gas reductions, reduction of emission and improving fuel efficiency this criterion is most important one for an automotive company. Lightweight materials can improve fuel efficiency more than other factors. Experiments reveal that 10 percent of weight reduction can lead to 6 to 8 percent improvement in fuel usage. Weight reduction can be obtained by three ways:

- Replacing materials of high specific weight with lower density materials without reducing rigidity and durability. For example replacement of steel with aluminium, magnesium, composites and foams.
- Optimizing the design of load-carrying elements and exterior attachments so as to reduce their weight without any loss in rigidity or functionality.
- Optimizing the production process, such as reducing spot welding and replacing new joining techniques.

But the single main obstacle in application of lightweight materials is their high cost. Yet the weight reduction is still the most cost-effective means to reduce fuel consumption.

The weight reduction versus the price increase by replacing steel by Aluminium or Magnesium for some of the parts is shown in Table 1

Table1 : Weight Reduction due to replacement of Steel to Aluminium & Magnesium

	Steel (kg)	Aluminium (kg)	Magnesium (kg)	% weight reduction (part)	% weight reduction(vehicle)
Body in white	285	218	N/A	23.5	3.90
Bonnet	14.8	8.3	N/A	44	0.48
Door	15.7	9.5	N/A	39	0.40

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IP Beam	11.4	N/A	6.3	45	0.33

C. Selection of a car model

Model is randomly selected for simulation of crash test, i.e, Tata Indica Vista. All Specifications are studied and considered for calculation of impact force, velocity of impact.

Table 2. Tata Indica Vista Technical Specifications

Length	3795mm
Width	1695 mm
Height	1550 mm
Seating Capacity	5 Person
Displacement	1248 cc
Fuel Type	Diesel
Max Power	75 bhp @ 4000 RPM

D. Helical spring design

The design of a new spring involves the following considerations:

- Space into which the spring must fit and operate.
- Values of working forces and deflections.
- Accuracy and reliability needed.
- Tolerances and permissible variations in specifications.
- Environmental conditions such as temperature, presence of a corrosive atmosphere.

Calculation of stresses in the helical spring wire

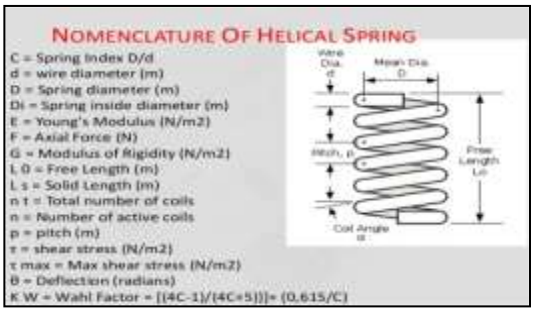

Figure 2.1: Helical Spring

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CODEN: IJESS7

Figure 2.2: Actual view of spring

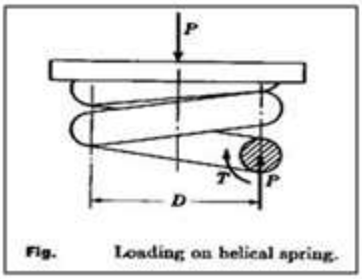

Figure 2.3: Loading on helical spring

From the free body diagram, we have found out the direction of the internal torsion T and internal shear force F at the section due to the external load F acting at the centre of the coil.

The cut sections of the spring, subjected to tensile and compressive loads respectively and the shear stresses (τT) arising due to the torsion T and the shear stresses (τF)due to the force F. It is observed that for both tensile load as well as compressive load on the spring, maximum shear stress ($\tau T + \tau F$) always occurs at the inner side of the spring. Hence, failure of the spring, in the form of crake, is always initiated from the inner radius of the spring.

The radius of the spring is given by D/2. Note that D is the mean diameter of the spring as 0.15m
The torque T acting on the spring is
T = F x D/2
Mass of car (m): 1135
Let the car is running at 50 km/hr = 13.889 m/sec, car stops at 0.05 seconds when obstruction appears.
Acceleration (a): 13.889/ 0.05 = 277. 78 m/s^2
Force acting impact (F) = m*a
= 1135 * 277.78
= 315280 N
Torque (T) = 315280 * 0.15/2
= 23646 Nm
Using $T= \pi/16 * \tau * d^3$
$23646 = \pi/16 * \tau * 0.15^3$
$\tau = 35700495.48$ N/m^2
$\tau = 35.7$ MPa

Stiffness
For an elastic body, with single degree of freedom (DOF) for example, compression or stretching of a rod, the stiffness is defined as,
The stiffness 'k' of a body is a measure of the resistance offered by an elastic body to deformation.
k = F/ ∂
F is the force on the body, ∂ isthe displacement produced by the force along the same degree of freedom (for instance, the change in length of a stretched spring)

Rotational stiffness
A body may also have rotational stiffness 'K'given by,
K = M / Θ

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Where, M is the applied moment and ϴ is the rotation. In the SI system, rotational stiffness is typically measured in Nm per radian.

E. Roll cage design

A roll cage is a specially-constructed tubular frame built in or around the cab of a vehicle to protect its occupants from injury in the case of a rollover or accidents. A standard features in race cars and stunt cars, roll cages are made of steel tubes and include a geometric design to increase strength and stability. The development and design process of roll cage involves various factors, namely material selection, roll cage elements, finite element analysis and frame design.

As the Roll cage was developed by plotting key points, so every member of the roll cage is considered to be properly constrained at each joint. For boundary conditions for Frontal Impact test, the roll cage is to be fixed from the rear side and the front member will come across the applied load. In the same way, for side impact test, one side of the roll cage element is fixed while the other side will be applied with load. For Rollover Impact test, the lower elements of the roll cage are fixed.

F. Experimental Results And Discussion

Explicit Analysis is done to identify the stresses in the bumper for better design and performed to find the best material for the Bumper design .In the explicit dynamics, Car is given velocity and made to impinge to a concrete wall.

Dynamic analysis can be done via the explicit solver or the implicit solver. . In nonlinear implicit analysis, solution of each step requires a series of trial solutions (iterations) to establish equilibrium within a certain tolerance.

G. Material Selection for Car Bumper Design

Looking into design and processing aspect, bumpers are big in size so they are processed by techniques like injection molding, blow molding and roto-molding. Considering the above processing techniques plastics are suitable material of choice. Considering the above said processing methods, most commonly ABS, PC/ABS is injection molded and blow molded ABS are used in cars like Hyundai, Ford. When processed by roto-molding pulverized HDPE is processed easily and is used in making bumpers.We have considered Stainless Steel and Aluminium Alloy as substitute and continued further for analysis.

- **Stainless Steel 304 L**

Steel consists mainly of iron with a small amount -- between 0.2 and 2.1 percent -- of carbon. Steel is very hard and strong. Steel has a very high strength to weight ratio. All these properties make it suitable as a material for car bodies. Steel is often alloyed with small quantities of manganese, chromium, tungsten and vanadium to make it even stronger.

Table 3: Stainless Steel Properties

Properties	Values
Density	8000 kg/m^3
Poisson Ratio	0.3
Young's Modulus	210000 Mpa
Shear Modulus	81000 Mpa
Yield Strength	240 Mpa

- **Aluminium Alloy**

Aluminium 1100 and Aluminium 6061 both have same density. But Aluminium 6061-T6 is used mainly for Bicycle Frames.

Table 4: Aluminium Alloy 6061-T6 Properties

Properties	Values
Density	2720 kg/m^3
Poisson Ratio	0.33
Young's Modulus	68900 Mpa
Shear Modulus	26000 Mpa
Yield Strength	386 Mpa

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- **Concrete Properties**

Table 5 Concrete material properties

Characteristics	Value
Density	2300 kg m^-3
Coefficient of Thermal Expansion	1.4e-005 C^-1
Specific Heat	780 J kg^-1 C^-1
Thermal Conductivity	0.72 W m^-1 C^-1
Young's Modulus	3.e+010
Poisson's Ratio	0.18
Bulk Modulus	1.5625e+010
Shear Modulus	1.2712e+010
Tensile Ultimate Strength	5.e+006
Tensile Ultimate Strength	4.1e+007

Analysis for Aluminium Alloy

Table 6 : Moment of Inertia in X, Y & Z directions

Moment of Inertia Ip1	520.21 kg·m²	325.02 kg·m²
Moment of Inertia Ip2	374.81 kg·m²	969.48 kg·m²
Moment of Inertia Ip3	854.6 kg·m²	677.32 kg·m²

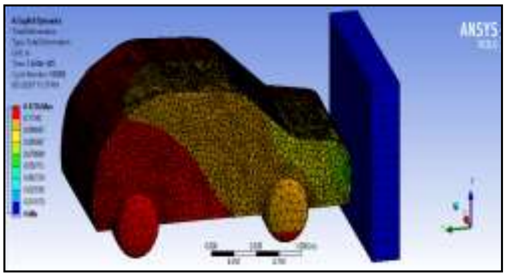

Fig 2.4: Total Deformation of Car for Aluminium Alloy

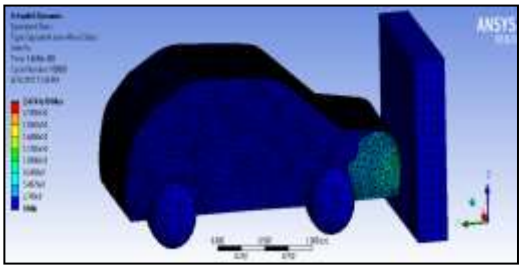

Figure 2.5 : Equivalent Stress for Aluminium Alloy

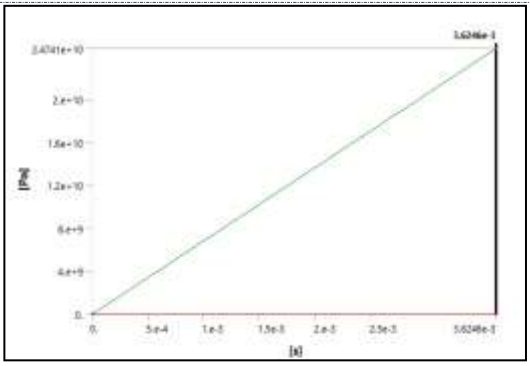

Figure 2.6 : Equivalent Stress Vs Time for Aluminium Alloy

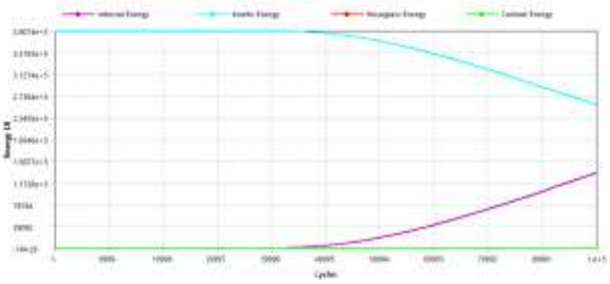

Figure 2.7 : Energy Summary

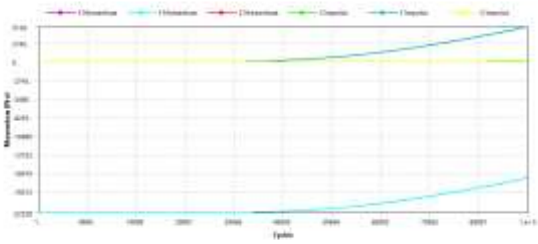

Figure 2.8 : Momentum Summary

Table 7: Combined Result for Aluminium Alloy

Results		
Minimum	0. m	0. Pa
Maximum	0.1276 m	2.4741e+010 Pa
Minimum Occurs On	Solid	
Maximum Occurs On	Part Body	

H. Calculation of Force

According to Newton's Second Law of Motion, In an inertial reference frame, the vector sum of the forces **F** on an object is equal to the mass 'm' of that object multiplied by the acceleration '**a**' of the object

F =m*a

F =(Weight / acceleration due to gravity) * (Change in Velocity/Time)

Assumptions:
1. Initial Velocity = 0 m/s
2. Time = 1 s

Therefore,
F = (1135 kg/9.81m/s2) *(35 m/s / 1 s)
F = 115.8 * 35 **F = 4053 N**

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Figure 2.9 : Equivalent Elastic Strain in Spring

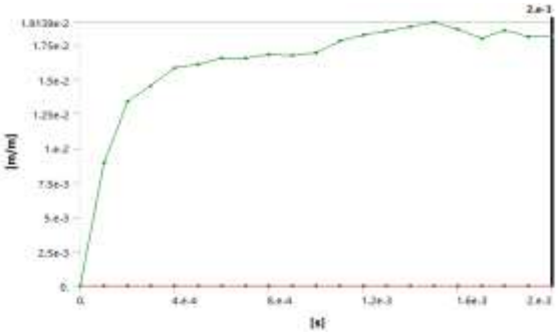

Figure 2.10: Equivalent elastic Strain Vs Time

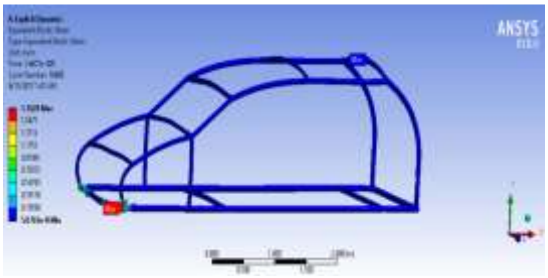

Figure 2.11 : Equivalent Elastic Strain for Copper Alloy Roll Cage2

III. RESULT & DISCUSSIONS

Results of Analysis are generated in the form of graphs. Graphs are plotted to compare material with total deformation (in m) and equivalent stress at 35 m/s for bumper shown in Fig 5.1 and 5.2

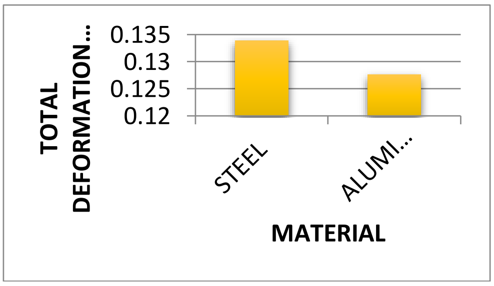

Fig 3.1: Total Deformation Vs Material of Bumper for 35m/s

ISSN: 2277-9655
Impact Factor: 4.116
CODEN: IJESS7

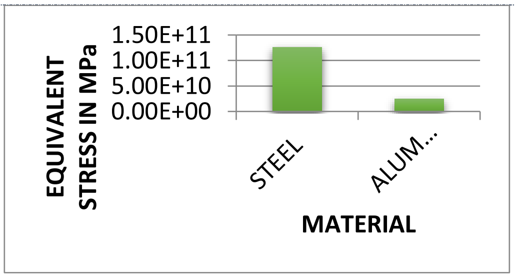

Fig 3.2: Equivalent stress Vs Material of Bumper for 35 m/s

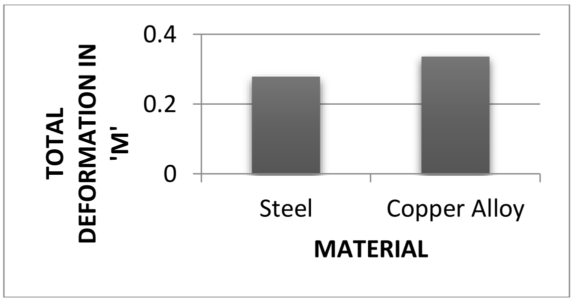

Fig 3.3: Total Deformation Vs Material for Roll Cage at 35 m/s

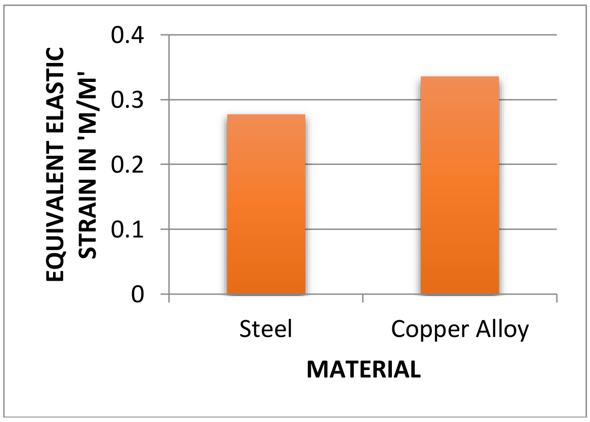

Fig 3.4: Equivalent Elastic Strain Vs Material for Roll Cage at 35 m/s

IV. CONCLUSION

1. For the Bumper, Aluminium Alloy 6061-T6 has the lesser Total Deformation and Equivalent von-mises Stress than the Stainless Steel. Therefore, Alumnium Alloy is selected for best material for the bumper design.
2. For the spring, Stresses for Stainless steel calculated at 35 m/s are under safe limit.
3. For the Roll Cage, Copper Alloy suits the best as per analysis. Copper Alloy has lesser Total Deformation and Equivalent Elastic Strain at 35 m/s and 50 m/s both.
4. Hence, we take Aluminium Alloy 6061-T6 for Bumper, Stainless steel for Spring and Copper Alloy for Roll Cage Design.
5. It was found that the use of helical spring and roller cage leads to lesser deformation in the bumper as compared to the roller cage without springs.
6. The crash test undergone implies that the use of heavy helical spring (take up axial load) and roll cage with better load carrying capacity is the best way to use it as shock absorber during crash.

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