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The Use of Plastics in Automotive Industry and Analysis of CFRP on Impact Loads and Energy Levels

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Abstract

Plastics find the major application in automobile components and the interiors and exterior furnishings. There are many applications of plastics in automobile ranging from power trains, under the hood and chassis. Polypropylene (PP) is been widely used in the automobile sector in recent years. Polyurethane (PU), acrylonitrile butadiene styrene (ABS), polyvinyl chloride (PVC), and polyethylene (PE) are the major plastics used that have been great demand in automobile engineering. But after certain period these plastics begin the degradation process, thus the use of the reinforced plastic is been on the large scale. These reinforced plastics are degradable in nature. Its high time need to test the reinforced plastic under impact load and energy levels.
Keywords- Impact, Fibre, Reinforced Plastic

I. INTRODUCTION

The use of plastics in automobile industry is ever growing as new materials and new manufacturing processes become available. New and modern design uses newest way to reduce the weight, improve efficiency and reduce cost respectively. Carbon Fibre Reinforced Plastic (CFRP) gives the freedom to reconsider the use of the thermoplastic composites for both interior and exterior application of the automotive body. CFRP is widely used throughout the aerospace industry and for lightweight racing cars. With the use of the Carbon Fibre Reinforced Plastics (CFRP) the heavy metal parts are been replaced with the light weight plastic parts. As the light weight of the automotive ensure the more efficiency in terms of fuel consumption, thereby increasing the performance of the automotive. The use of the plastic for the bumper can achieve a weight reduction of 2.5 pound i.e. nearly 1.133 kg while eliminating the use of the 13 metal parts respectively. In similar way the use of plastics in case of the engine will reduce the weight of the automotive nearly up to 5 pounds i.e. 2.26 kg, which will consequently increase the horsepower of the engine by 33% respectively.

The use of the plastics in automotive is on higher side, ranging from fuel tank to exterior parts of the automobile. The various types of materials use for the automobile parts are as follows:

A. Fuel Tank

The material used for the manufacturing of the fuel tank is High Density Polyethylene (HDPE).
HDPE is strong light weight material, used to lower the net weight of the automobile.

B. Exteriors

Polymer are used on large scale. For most of the automobile exteriors thermoplastic polymers are used on used on a large scale. They are processed through reaction injection mould (RIM).

Generally for automotive exteriors nylon, polystyrene, polypropylene, polyesters, urethanes are used for manufacturing of the automotive exteriors.

C. Interiors

The large scale plastic is generally utilized for the interiors. The instrument panels consist of Acrylonitrile Butadiene Styrene (ABS) Steering wheels are generally manufactured by vinyl resins or pigmented urethane respectively.

D. Car Engine and Manifold

For car engine and its manifolds high quality Nylon 6 and also Nylon 66 resin arte utilized.

The advantages of the use of the plastics in the automotive are as follows:

1) Weight Reduction

Plastics can weigh 6 to 8 times less than the certain metal parts, using plastics the weight of the automotive is reduced and the efficiency is been achieved to large extent.

2) Easier to Produce

Plastics are generally easier to produce and are easily available. They are more expensive but easier to mould and produce and re-fabricate.

3) Design Flexibility

Plastics allows great freedom of styling, building and placing components respectively.

4) Plastic Consolidation

The plastic parts are usually replaces the function of several metal pieces.

Other competitive materials in plastics are as follows:

1) High Density polyethylene (HDPE).
2) Multi-layer and Barrier HDPE.

This materials have shape flexibility, low tooling coat at low volume, less weight, corrosion resistance.

II. EXPERIMENTAL METHODOLOGY

The experimental analysis was conducted on INSTRON CEAST 9350. The CEAST 9350 is a floor standing impact system designed to deliver 0.59 to 757 J or up to 1,800 J with optional high energy system. The CEAST 9350 works with impact software and data acquisition system. The details of the INSTRON CEAST 9350 is as follows:

Table: The details of the INSTRON CEAST 9350

Sr.No.	*Specifications*	*Range*
1.	*Energy*	*0.59 to 1800 J*
2.	*Speed*	*0.77 to 24 m/s*
3.	*Drop Height (Simulated)*	*0.03 to 29.4 m*

The machine is equipped with weighing system that measures the total weight of the falling mass and tup inserts. Also the specimen feeding system is equipped to perform tests in automatic cycle within the environmental chamber. It also has an environmental chamber that can cool specimen to -70 or heat specimen to + 150 degree Celsius. It is also equipped with high energy configuration setup and an automatic lubrication system eliminates friction effects between the tup insert and the test sample. Also it has the anti-rebound system that can catch the crosshead-preventing it from hitting the sample second time.

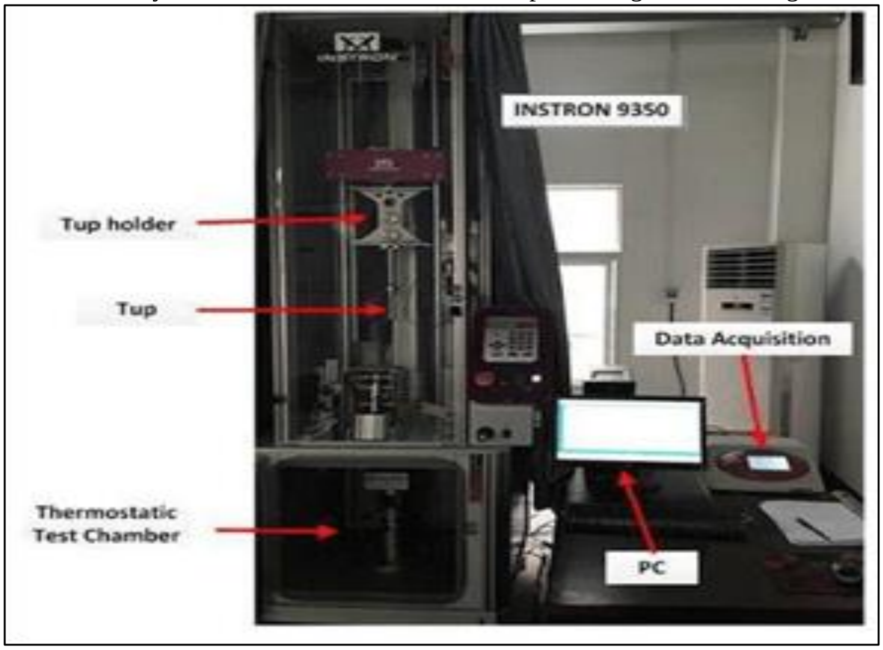


Fig. 1: Setup of INSTRON CEAST 9350

III. THEORIES OF FAILURE

These are five different theories of failures which are generally used
1) Maximum Principal stress theory (Due to Rankine)
2) Maximum shear stress theory (Guest - Tresca)
3) Maximum Principal Strain (Saint - venant) Theory
4) Total strain energy per unit volume (Haigh) Theory
5) Shear strain energy per unit volume Theory (Von – Mises & Hencky)

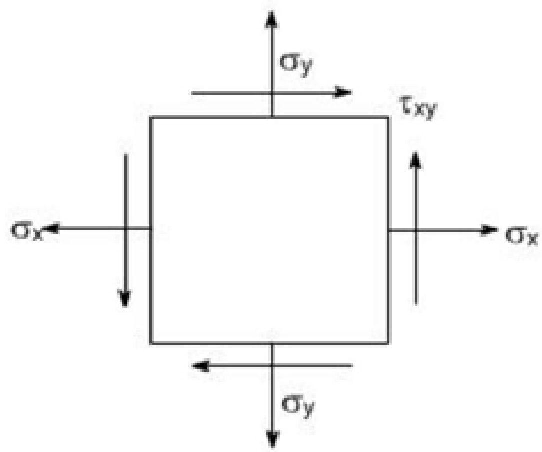
In all these theories we shall assume.
σYp = stress at the yield point in the simple tensile test.
$\sigma 1$, $\sigma 2$, $\sigma 3$ are the three principal stresses in the three dimensional complex state of stress systems in order of magnitude.
1) Maximum Principal Stress Theory

This theory assume that when the maximum principal stress in a complex stress system reaches the elastic limit stress in a simple tension, failure will occur.
Therefore the criterion for failure would be

$$\sigma 1 = \sigma yp$$

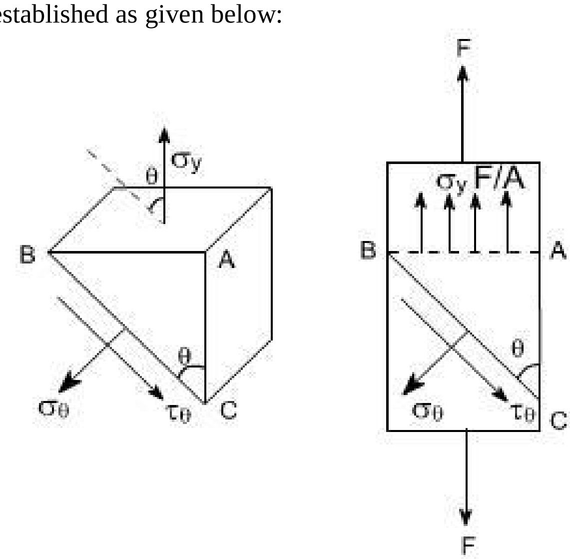
For a two dimensional complex stress system $\sigma 1$ is expressed as

$$\sigma_1 = \frac{\sigma_x + \sigma_y}{2} + \frac{1}{2}\sqrt{(\sigma_x - \sigma_y)^2 + 4.\tau_{xy}^2} = \sigma_{yp}$$



Where σx, σy and σxy are the stresses in the any given complex stress system.
2) Maximum Shear Stress Theory

This theory states that the failure can be assumed to occur when the maximum shear stress in the complex stress system is equal to the value of maximum shear stress in simple tension.
The criterion for the failure may be established as given below:



For Simple Tension Case

$$\sigma_\theta = \sigma_y \sin^2\theta$$

$$\tau_\theta = \frac{1}{2}\sigma_y \sin 2\theta$$

$$\tau_\theta\big|_{max^m} = \frac{1}{2}\sigma_y \quad \text{or}$$

$$\tau_{max^m} = \frac{1}{2}\sigma_{yp}$$

whereas for the two dimentional complex stress system

$$\tau_{max^m} = \left(\frac{\sigma_1 - \sigma_2}{2}\right)$$

where σ_1 = maximum principle stress

σ_2 = minimum principal stress

$$\text{so} \quad \frac{\sigma_1 - \sigma_2}{2} = \frac{1}{2}\sqrt{(\sigma_x - \sigma_y)^2 + 4\tau^2 xy}$$

$$\frac{\sigma_1 - \sigma_2}{2} = \frac{1}{2}\sigma_{yp} \Rightarrow \sigma_1 - \sigma_2 = \sigma_y$$

$$\Rightarrow \sqrt{(\sigma_x - \sigma_y)^2 + 4\tau^2 xy} = \sigma_{yp}$$

becomes the criterion for the failure.

3) Maximum Principal Strain Theory

This Theory assumes that failure occurs when the maximum strain for a complex state of stress system becomes equals to the strain at yield point in the tensile test for the three dimensional complex state of stress system.

For a 3 - dimensional state of stress system the total strain energy Ut per unit volume in equal to the total work done by the system and given by the equation

$$U_t = 1/2\sigma_1 \in_1 + 1/2\sigma_2 \in_2 + 1/2\sigma_3 \in_3$$

substituting the values of $\in_1, \in_2$ and $\in_3$

$$\in_1 = \frac{1}{E}[\sigma_1 - \gamma(\sigma_2 + \sigma_3)]$$

$$\in_2 = \frac{1}{E}[\sigma_2 - \gamma(\sigma_1 + \sigma_3)]$$

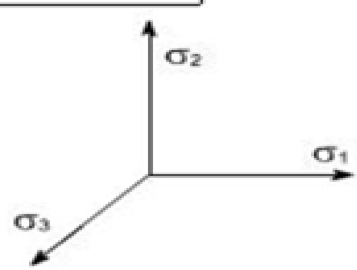
$$\in_3 = \frac{1}{E}[\sigma_3 - \gamma(\sigma_1 + \sigma_2)]$$

Thus, the failure criterion becomes

$$\left(\frac{\sigma_1}{E} - \gamma\frac{\sigma_2}{E} - \gamma\frac{\sigma_3}{E}\right) = \frac{\sigma_{yp}}{E}$$

or

$$\boxed{\sigma_1 - \gamma\sigma_2 - \gamma\sigma_3 = \sigma_{yp}}$$



4) Total Strain Energy Per Unit Volume Theory

The theory assumes that the failure occurs when the total strain energy for a complex state of stress system is equal to that at the yield point a tensile test.

$$\frac{1}{2E}\left[\sigma_1^2 + \sigma_2^2 + \sigma_3^2 - 2\gamma(\sigma_1\sigma_2 + \sigma_2\sigma_3 + \sigma_3\sigma_1)\right] = \frac{\sigma_{yp}^2}{2E}$$

$$\sigma_1^2 + \sigma_2^2 + \sigma_3^2 - 2\gamma(\sigma_1\sigma_2 + \sigma_2\sigma_3 + \sigma_3\sigma_1) = \sigma_{yp}^2$$

It may be noted that this theory gives fair by good results for ductile materials.

5) Maximum Shear Strain Energy Per Unit Volume Theory

This theory states that the failure occurs when the maximum shear strain energy component for the complex state of stress system is equal to that at the yield point in the tensile test.

$$\frac{1}{12G}\left[(\sigma_1-\sigma_2)^2+(\sigma_2-\sigma_3)^2+(\sigma_3-\sigma_1)^2\right]=\frac{\sigma_{yp}^2}{6G}$$

Where G = shear modulus of regidity

$$\left[(\sigma_1-\sigma_2)^2+(\sigma_2-\sigma_3)^2+(\sigma_3-\sigma_1)^2\right]=2\sigma_{yp}^2$$

As we know that a general state of stress can be broken into two components i.e.,

- Hydrostatic state of stress (the strain energy associated with the hydrostatic state of stress is known as the volumetric strain energy)
- Distortional or Deviatoric state of stress (The strain energy due to this is known as the shear strain energy)

As we know that the strain energy due to distortion is given as

$$U_{distortion}=\frac{1}{12G}\left[(\sigma_1-\sigma_2)^2+(\sigma_2-\sigma_3)^2+(\sigma_3-\sigma_1)^2\right]$$

This is the distortion strain energy for a complex state of stress; this is to be equaled to the maximum distortion energy in the simple tension test. In order to get we may assume that one of the principal stress say ($\sigma 1$) reaches the yield point (σyp) of the material. Thus, putting in above equation $\sigma 2 = \sigma 3 = 0$ we get distortion energy for the simple test i.e.

$$U_d=\frac{2\sigma_1^2}{12G}$$

Futher $\sigma_1 - \sigma_{yp}$

Thus, $\boxed{U_d=\frac{\sigma_{yp}^2}{6G}}$ for a simple tension test.

IV. SIMULATION

The material tested was reinforced plastic with reinforcement material as carbon, aramid or basalt. The material tested was carbon fibre reinforced plastics (CFRP) The result of tested reinforced specimen is as below:

Table 2: Tested Reinforced Plastic results

Sr.No.	*Impact Energy (J)*	*Peak Force (N)*	*Peak Energy (J)*	*Total Energy (J)*
1.	*30.00 J*	*3308 N*	*10.53 J*	*26.95 J*

From the above table it is clear that the material is safe within 30 J of impact energy. Beyond 30J of impact energy the material will start plastic deformation and begin to rapture.

Fig. 2: Tested reinforced plastic specimens

The force displacement curve obtained was as follows:

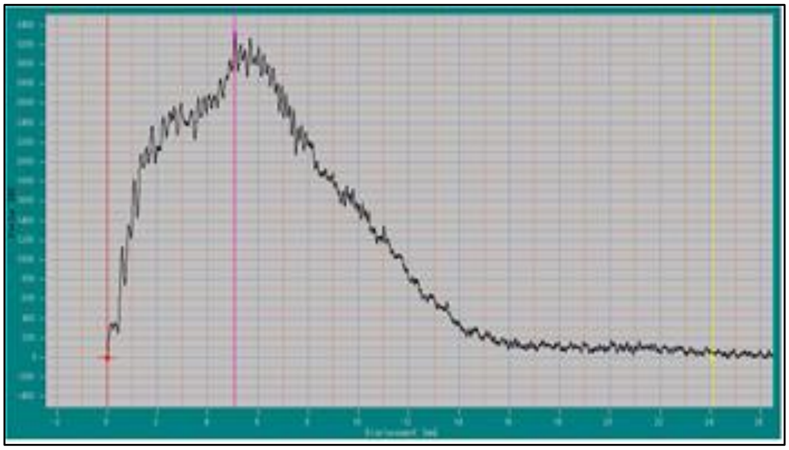


Fig. 3: The force displacement curve

V. RESULT

From the above graph it is clear that the tested specimen is safe within 30J of loading conditions respectively.

VI. CONCLUSION

The automotive industry in India is on of the largest in the world with an annual production of 23.96 million vehicle in fiscal year 2015-16, following a growth of 2.51 % over the last year. The automobile industry accounts for 1.1 % of country gross domestic product (GDP). The two-wheelers. The two wheelers segment, with 81 % market share, and is the leader in the Indian Automobile market.

The tested material shows various elastic and plastic behaviour at each set of points. The comparative analysis will lead to the safer and more reliable material for the automobile industry, which will safer the use of the automobiles for the occupants. The use of plastics will ensure the higher efficiency and thereby with minimum consumption of fuel.

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