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Research Paper

DESIGN AND ANALYSIS OF COMPOSITE BRAKE PEDAL: AN ERGONOMIC APPROACH

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In recent years, the conventional brake, accelerator and clutch pedals of automotive vehicles are replaced by polymeric-based composite pedals. The purpose of replacement from metallic pedal to polymeric-based composite material is to reduce the weight, cost and improve material degradation by corrosion. In this paper four different sections of polymeric based brake pedals are analyzed as per the design parameters received from General motors. The sections are analyzed and arrived at a winning concept based on stiffness comparison. A full scale model is developed from the winning concept, while developing full scale model an ergonomic study has been made on few hatch back and SUVs car's to improve the driver's comfort and reduce fatigue due to breaking operation. The pedal is modelled using CATIA software and analysis is carried out in ANSYS software. The results have shown polymeric-based composite material meets the requirements of manufacturer's specification and can be replaced with present metallic pedal. Weight reduction of 66.7% is achieved by using composite material.

Keywords: Brake pedal, SUVs car (Sport utility vehicles), CATIA, Erogonomics, Composite

INTRODUCTION

With increased competition in automotive industry there is ever increased in efforts to improve the efficiency, reduce cost, increase drivers comfort, reliability, etc., to be competitive. In order to gain competitive advantage a lot of manufacturers are spending millions of dollars in their R&D (http://www.innovationexcellence.com/blog/2012/10/31/booz-company-2012-global) to improve existing material and innovate new materials which are of light weight and less expensive compared to present metallic components. In short plastic and composites meet the challenges of current industry needs (Katarina Szeteova, 2010).

The average vehicle uses about 150kg of plastics and plastic composites versus 1163kg of iron and steel-currently it is moving around 10-15% of the total weight of the car (Figure 1).

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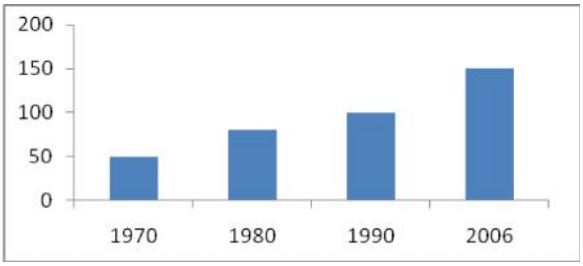
Figure 1: Increase Use of Plastic in Automotive



Source: Atur Cichancki and Mateusz Wirwicki (xxxx)

Sapune (2005) and Pankaj Chhabra (2011) worked on the brake pedal using polymeric based material shows that the use of composite material reduces weight and is equally strong compared to metallic brake pedal. Various concepts presented and analyzed to arrive at the winning concept which is optimized using Finite Element Analysis (FEA) is well appreciated. There are other papers which talked about use of composite materials but all the papers lack in considering drivers comfort and wellbeing. With the recent rising customers' expectations comfort has become a critical quality requirement. This gives vehicle design engineers a significant challenge. Much of the work presented in this paper considers both reducing weight and increasing drivers comfort (ergonomic aspects) considering the work done in the past.

MATERIAL SELECTION

Following factors are considered for material selection

1. Strength to weight ratio
2. Moldability
3. Physical and mechanical properties
4. Availability

As per Mohd Sapuan Salit *et al.* (2005) there are polyamide (nylon) with short glass fibers in varying percentages. The long glass fibers are not suitable because of fiber intermeshes and their corners may be overlapped. Thus, from consideration of material strength and stiffness. The short glass fiber is lightest among materials, which has lowest density. Nylon with short fiber has high impact strength, which is an important factor of brake pedal design. Considering % elongation and other properties nylon with short fibers is chosen as the material of brake pedal.

The material properties are shown in below Table 1.

Table 1: Material Properties (PA66 GF30 %)

% Glass Filled	30%
Tensile Modulus	15000 MPa
Tensile Strength	160 MPa
Poisson Ratio	0.35
Flexural Modulus	3300 Mpa
Density	1130 Kg/m^3
Moisture Absorption	0.35%
Creep Resistance	Good
Corrosion Resistance	Good
Chemical Resistance	Good strength heat resistance

Ergonomic Considerations

This study emphasis on an integration of ergonomics and composite material to reduce weight and increase drivers comfort. As mentioned, drivers comfort is prime concern in design of accessories which are accessible to driver. The ultimate aim of this study is to understand the relationship between the driver's perception of comfort and the engineering design attributes associated with

brake pedal design. It is recognized that in order to achieve this attention needs to focus on two aspects.

- Need to understand the relationship between the drivers actual response, i.e., what the driver actually does in terms of positioning, posture and adjustments to posture, pattern and amplitude of movements required to complete the driving task and the driver's perception of comfort, i.e., the subjective response.
- Need to assess the relationship between the pedal design and other relevant engineering attributes(as inputs) and the drivers actual perceived response.

Following are the ergonomic factor which affects the driver's comfort (Neil Dixon *et al.*, 2009).

- Subject anthropometrics (Leg segments, foot length, stature, soft tissue).
- Driver positioning (Seat position force, seat recline angle).

Figure 2: Position of Brake Pedal

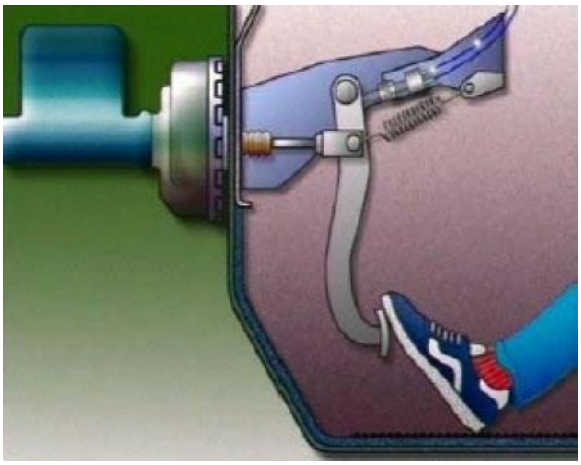


Figure 3: Dimension of Driver Posture

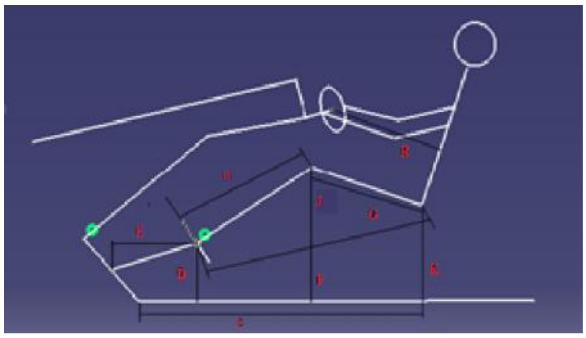
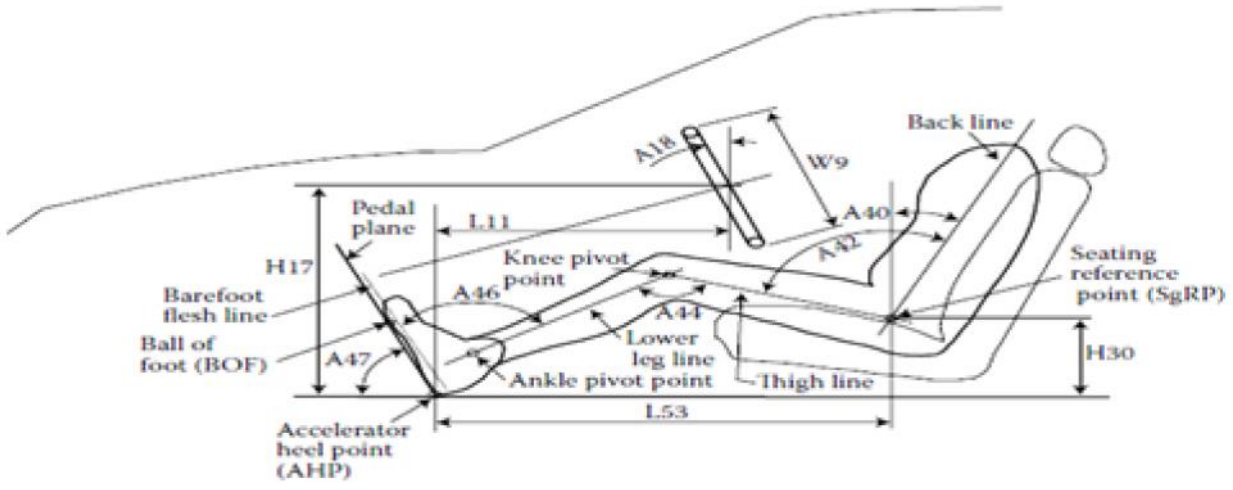


Figure 4: Vehicle Interior Points and Dimensions



Source: Vivek Bhise (xxxx)

- Driver movements (Hip, knee and ankle joint angles)
- Contact surface interaction (buttocks on seat, heel contact location on floor, contact between the foot and pedals)
- Longer term (i.e., over and extended drive task)

To understand the effect of the above mentioned factors various seating parameters are studied for the Sport Utility Vehicles (SUVs) car.

All above data is collected from the different vehicles running in the field (shown in Table 2). Figures 3 and 4 shows various nomenclatures related to driver and brake pedal.

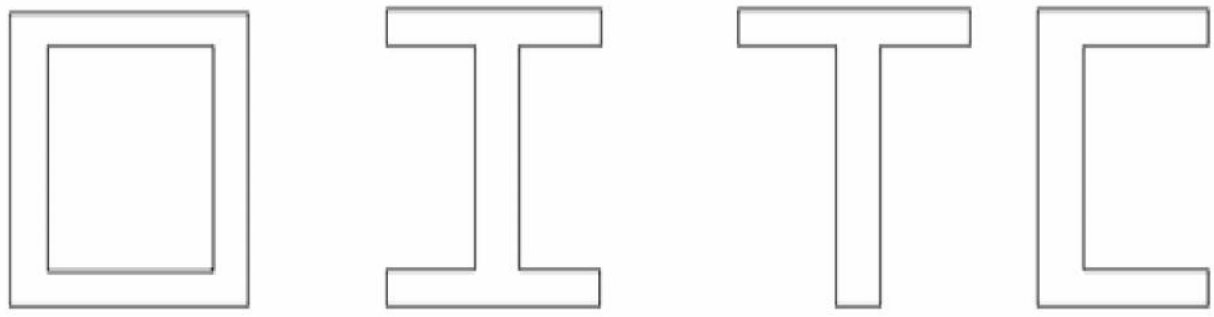
Conceptual Brake Pedal Lever Arm Profile Design

The conceptual design of the polymeric-based composite brake pedal concentrates on beam for the design of the brake pedal lever. There are four concepts of beam. The concepts of the beam generated are shown in Figure 5. The design parameters proposed by General

Table 2: Vehicle Interior Dimensions

Hatch Back for 5 ft Female and 6 ft Male										
Dim.	**GM Beat**		**Maruti Wagnor**		**Tata ind-vista**		**Honda i20**		**Mean Value**	
	Male	**Female**	**Male**	**Female**	**Male**	**Female**	**Male**	**Female**	**Male**	**Female**
C	810	715	820	615	800	708	830	680	815	680
D	140	170	160	180	140	170	130	160	160	170
E	240	240	250	250	260	260	310	310	265	265
F	470	420	480	410	485	410	510	460	490	425
G	890	760	860	740	890	720	895	730	880	735
H	470	460	530	460	588	450	592	510	545	400
J	420	380	430	380	430	390	450	380	450	380
K	280	238	440	360	460	370	480	370	380	334
R	680	450	700	480	680	530	650	480	670	490

Figure 5: The Different Beam Sections



Concept 1 Concept 2 Concept 3 Concept 4

Table 3: Requirement Static Load (Maximum)

Requirement Static Load	Force	Maximum Deflection
Transverse Load	220 N	10 mm
Normal Force	1100 N	10 mm
Maximum Force	2700 N	15 mm

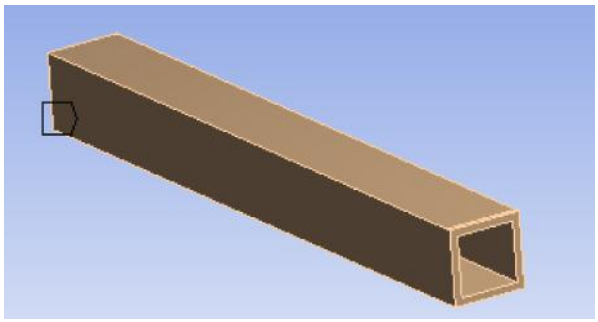
Source: Mohd Sapuan Salit et al. (2005)

Motors are listed in Table 3 (Mohd Sapuan Salit *et al.*, 2005).

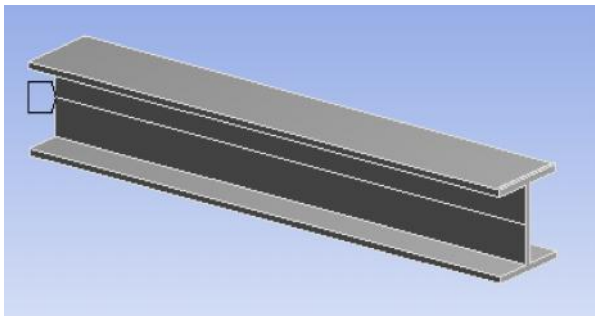
FEA Analysis of Conceptual Brake Pedal Profile

The computational results of analytical and FEA shown in Table 4 they are considered for concept evaluation. Concept 1 chosen as

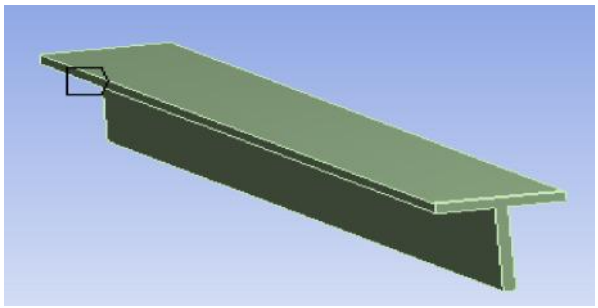
Figure 6: Solid Models of Conceptual Design of Brake Pedal Arm



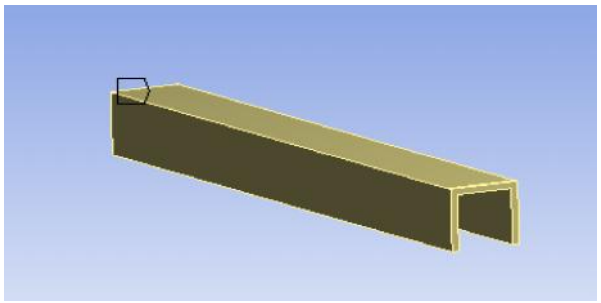
Cad model concept 1



Cad model concept 2

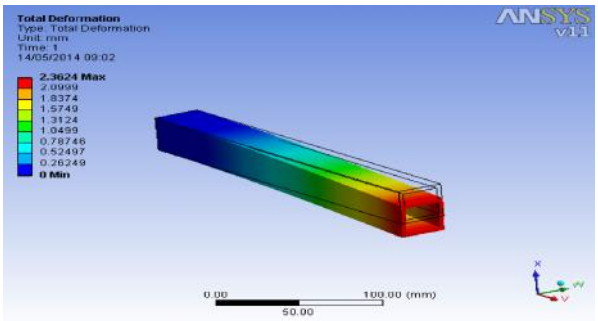


Cad model concept 3

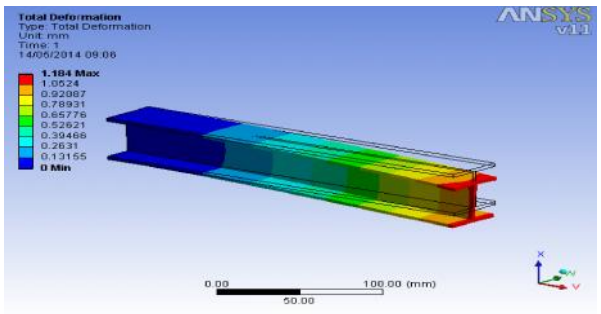


Cad model concept 4

Figure 7: Total Deformation

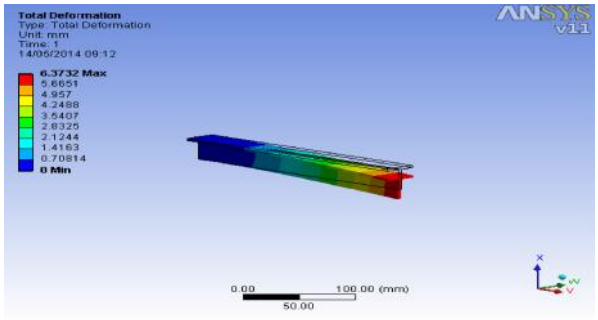


Concept 1, Total deformation

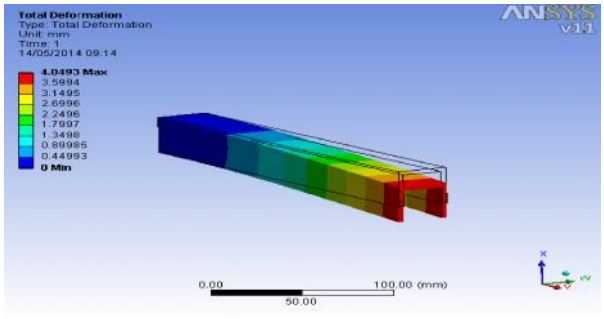


Concept 2, Total deformation

Figure 7 (Cont.)

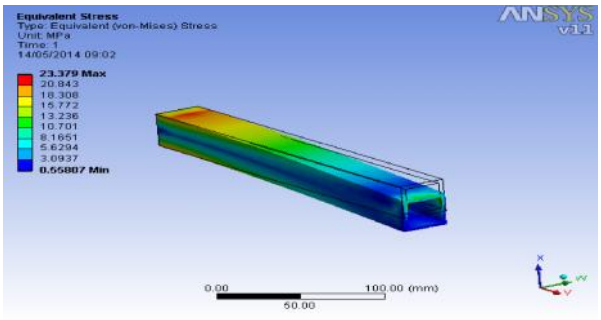


Concept 3, Total deformation

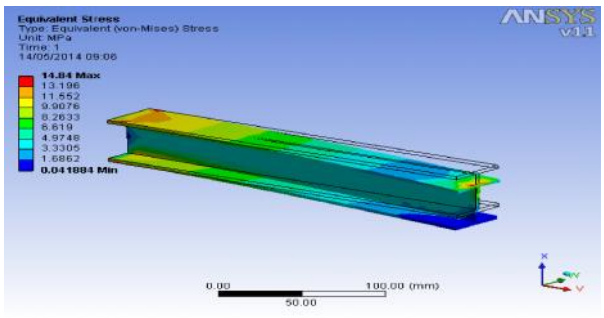


Concept 4, Total deformation

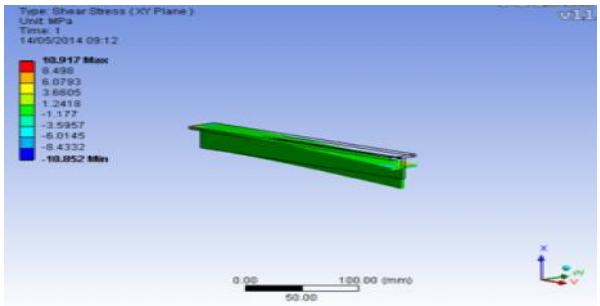
Figure 8: Equivalent Stress



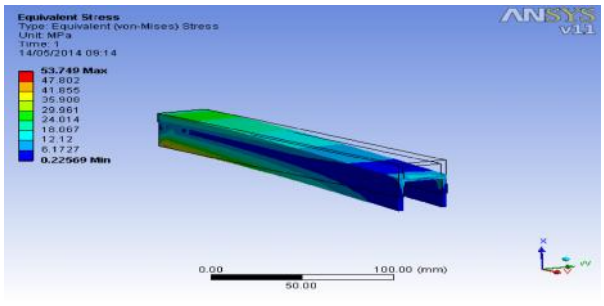
Concept 1, Equivalent stress



Concept 2, Equivalent stress



Concept 3, Equivalent stress



Concept 4, Equivalent stress

Table 4: Total Deformation and Stress Calculated with Computed FEA Results

Calculated with Computed FEA Results for Different Concept with 220 N Traverse Load

Concept	Volume m²	Mass (Kg)	Maximum Deflection "mm"			Maximum Stress (N/mm²)		
			Analytical	FEA	%Error	Analytical	FEA	% Error
1	58	103	2.36	2.27	9	22.9	23.0	10
2	63	109	1.13	1.3	8	13	14	8
3	32	54	0.98	6.3	15	9.478	10.9	9
4	47	80	3.97	4.04	10	28.18	53.6	10

Table 5: Relative Mass, Volume, Deformation, Maximum Stresses are Compared with Concept 1

Concept	Weight Ratio	Maximum Deflection Ratio	Maximum Stress Ratio
Concept 1	1	1	1
Concept 2	0.93	1.8	1.7
Concept 3	1.87	2.8	2.3
Concept 4	1.26	1.6	1.62

Table 6: Matrix Evaluation of the Beam Used to Select the Best Concept

No.	Weight		Rating			Weight Factor X Rating		
	Criteria	Factor	Concept 2	Concept 3	Concept 4	Concept 2	Concept 3	Concep 4
1	Wight	2	2	4	2	4	8	4
2	Maximum Deflection	3	3	1	2	9	3	6
3	Maximum stress	3	3	1	2	9	3	6
						21	19	16

reference for high stiffness. Weight, volume, maximum deflection. The corresponding values for other concepts are calculated and comparison to concept 1. A matrix evaluation is performed to select the best concept among Concept 2, Concept 3, Concept 4 based on the results shown in Table 6. Each concept is rated on the basis of reference score on scale 1 to 4. Weight factor decision matrix is evaluated by multiplying the each concept rating by weight factor assigned for each criterion (Panakaj Chhabra, 2011). The total highest score of 21. There for concept 2 chosen as best profile for design of composite pedal.

Present Concept design and Prototyping of composite accelerator pedal design was selected I-section is the best Profile (Panakaj Chhabra, 2011).

Final Design Brake Pedal (I-Section)

According to general motor specification shown in Table 2 the maximum load of 2700 N applied to pedal, deflection was observed 16 mm shown in Table 7.

Figure 9: Modeling of Complete I Section Brake Pedal

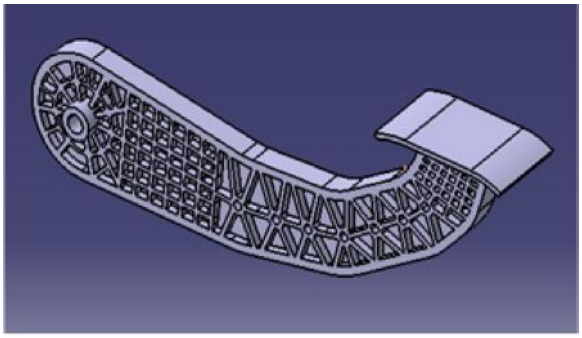


Figure 10: Stress Distribution

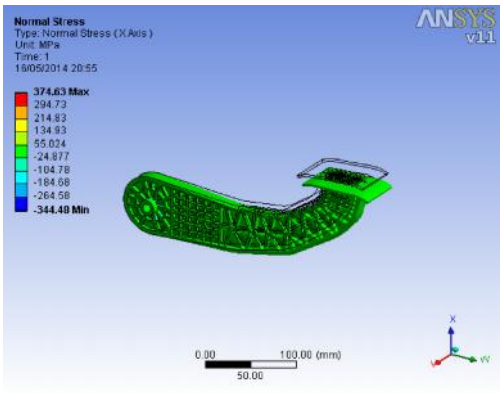


Figure 11: Total Deflection

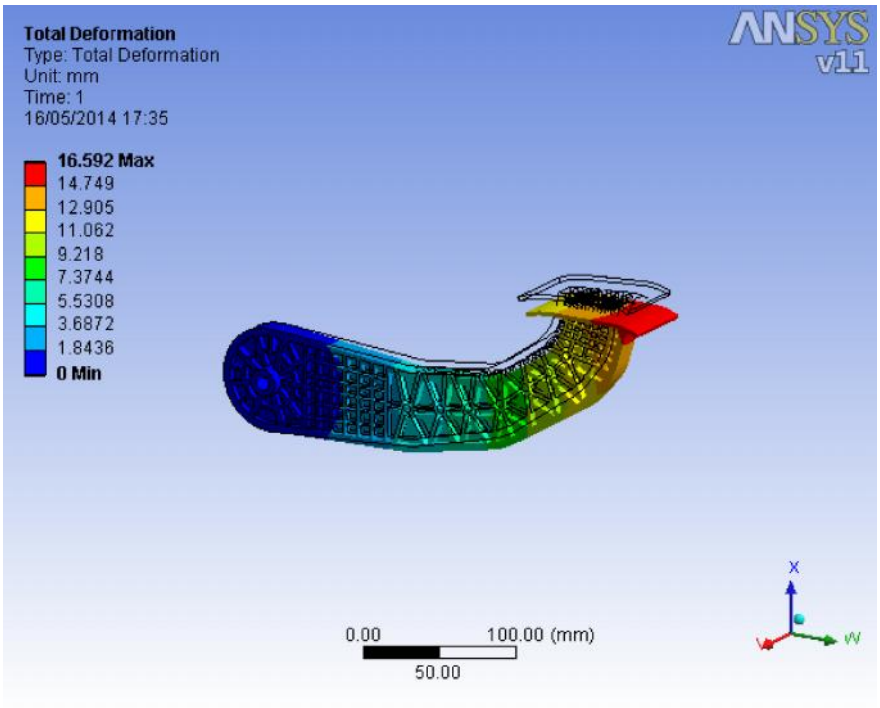


Table 7: Analytically and FEA Analysis Report for Composite Brake Pedal

	Mass (g)	Volume (cm^2)	Deformation (mm)		Stress (N/mm^2)	
			Analytical	FEA	Analytical	FEA
Final Results	219	192.5	16.5	16	315	374.6

RESULTS AND DISCUSSION

- Various sections of brake pedals are analyzed and result a show that the I section is the stiffer among all the pedals under study and hence I section is used for further study.
- The ergonomic parameters are used to model the brake pedal using CATIA and analyzed for the stated load conditions.
- The design is optimized using CATIA and FEA to optimize the section and weight.
- The results show that the deflection and stresses are within the requirements.
- The design and analysis of composite brake pedal weight is 0.219 kg compared to metallic brake pedal weight 0.72 kg. The total weight can be reduced by 66.7%.

CONCLUSION

A detailed analysis and study of the composite brake pedal made from polyamide with short glass fiber material is presented. Various SUVs cars present in the market are studied for the ergonomic aspects and the final model is design based on the dimensions arrived from this study. The results as discussed above shows that there will significant cost saving

from the material and parameters selected for this study.

The actual prototype pedal needs to be studied further for drivers comfort and fatigue by putting it into actual work and compare with the filed pedals.

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