Concurrent Design and Prototyping of Composite Accelerator Pedal

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Abstract

In this work, Concurrent Engineering (CE) approach has been used to determine the most optimum decision on design concept and material of the composite accelerator pedal at conceptual design stage. Comprehensive studies are carried out to prepare the design specifications of composite accelerator pedal. Various design concepts are generated using the Morphological approach. In particular at design stage, CATIA is used to generate various design concepts followed by analysis on ANSYS. Simultaneously, material selection is done on the basis of past research & specifications. Rating/weighting matrix evaluation method is used to select the best concept for the profile of pedal arm on the basis of mass, volume, stress and deformation results achieved on ANSYS. The composite accelerator pedal is optimized and analyzed for safety parameters and finally prototyped using Selective Laser Sintering. The results reveals the feasibility of composite accelerator pedal with glass filled polyamide providing substantial weight saving and better properties than existing metallic pedal.

Keywords: *Accelerator pedal, Concurrent Engineering, CAD.*

1. Introduction

In recent years, composite materials have been used in interior automotive components because of their properties such as low weight, high specific stiffness, corrosion free, ability to produce complex shapes, high specific strength and high impact energy absorption etc. Therefore, this work is towards the development of an interior automotive component such as composite accelerator pedal for replacing it with the existing metallic one to reduce weight in conformation with safety standards.

Most of the automotive accelerator pedals generally fail due to inappropriate decisions during selection of design concept, material and manufacturing process. In this work, Concurrent Engineering (CE) approach has been used to determine the most optimum decision on design concept and material of the composite accelerator pedal at conceptual design stage.

In this view, development process is carried out under CE environment (Fig. 1). Comprehensive studies are performed to prepare Product Design Specification (PDS). Various design concepts are generated using Morphological approach. In particular at design stage, 3-D solid modeling system is used to generate various design concepts followed by analysis on software package. Simultaneously, material selection is done on the basis of past research & PDS for accelerator pedal. Rating/weighting matrix evaluation method is used to select the best concept for the profile of pedal arm on basis of mass, volume, stress and deformation. Best design concept is selected through morphological chart on logical, conventional design and analysis results. Finally, prototype is prepared using SLS technique. Tab. 1 lists the various methodologies used in the development of composite accelerator pedal.

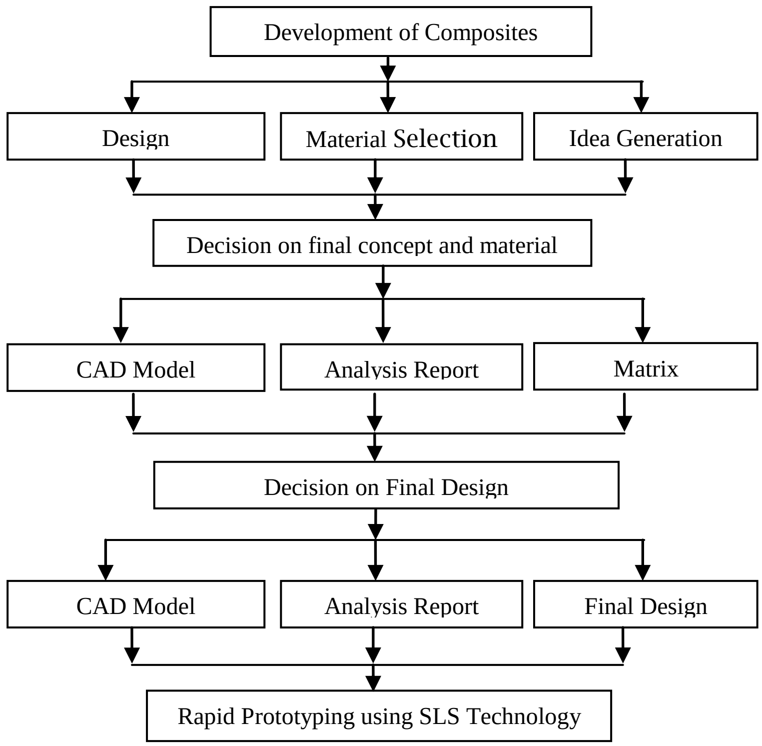


Figure 1: Development Process

Table 1: Summary of Design & Development Methods

Methods	**Used in/as**
Concurrent Engineering	Philosophy throughout the study
PDS	Extensively for specification preparation
Morphological	For design concept generation
Matrix evaluation	For selecting the best concept
Solid modeling	For 3-D modeling of design concepts
FEM	For analysis of concepts
RP	For prototyping

1.1. Background

Accelerator pedal consists of three main parts namely pedal plate, pedal arm and pivot shaft (Figure 2). It is usually close to floor which allows the driver's heel to rest on the floor. It should not sink more than an inch or two, no matter how hard it is pressed with the foot; and the driver should not feel as if he were stepping on a wet spongy pedal spells trouble in maintaining the vehicle speed.

Existing accelerator pedal is made of metal possessing poor weight to strength ratio required for the working condition. It is highly prone to corrosion thus requires paint coating. Its parts are assembled by welding hence increases the number of processing steps, machine requirements. Moreover, pedal plate is needed to be covered with rubber pad for proper foot grip. It also gives poor internal damping.

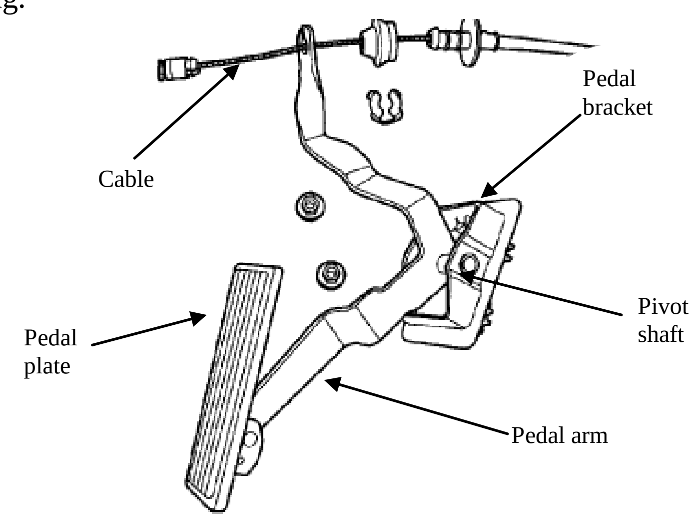


Figure 2: Accelerator Pedal

2. Literature

Composites were introduced in the automotive industry from a quite time and had successfully replaced metallic parts because of increase in fuel efficiency by weight saving and corrosion resistance properties [1][5-6]. Sapuan [11-12] presented conceptual designs for the development of polymeric-based composite automotive bumper and pedal box system by using various methods of creativity, such as mind mapping, PDS, brainstorming, morphology chart, analogy and weighted objective methods. Murat [9] applied fiber reinforced polymers (FRP) for bus exterior and interior components. Gulur [7] presented a low cost fabrication for mono composite leaf spring and mono composite leaf spring with bonded end joints. Gummadi [8] presented a composite drive shaft for the replacement of conventional two-piece steel drive shaft. The design parameters were optimized with the objective of minimizing the weight of composite drive shaft.

Concurrent Engineering, CAE and Rapid Prototyping techniques have also being applied for product development. Alemu [2] presented an approach to see and analyze different product development methods specifically on design for manufacturability and Concurrent Engineering studies. Bowonder [4] illustrated the use of concurrent engineering in an automobile firm Tata Motors.

3. Design Specifications

The following factors are to be evaluated for preparing design specifications.

- **Size:** In view of the limited space available for the driver's feet, the dimensions should be small as possible but must comply with safety and ergonomics standards. For dimensional reference, existing model of Mahindra make accelerator pedal is taken.
- **Weight:** In view of reducing the weight of accelerator pedal, it should have minimum weight.
- **Material:** As per the standards by regularized organizations of the automotive world, modulus of elasticity for the accelerator pedal must be greater than 888.6 MPa. Density of material should be less than density of aluminum i.e. 2700 kg/m3. The material should have high creep resistance, fatigue strength and corrosion resistance. The material should be used in high volume production and should be recyclable.
- **Safety:** The component must be free from sharp edges. The system must comply with all relevant parts of India and international legislation. The maximum force on the accelerator pedal is 40 N with a maximum deflection of 10 mm.
- **Environment:** The accelerator pedal must be capable of use in all weather conditions and should be non corrosive. It must be resistant to fuel slippage, greases and should not degrade by ultra violet radiation. The water absorption percentage of material must be less than 8 %.
- **Ergonomics:** The distance between steering wheel and accelerator pedal are kept approximately 600 mm. The return force should be between 40-60 N. The dimensions of pedal should not be too short so that drivers feel difficult to depress the pedal. The design must provide comfort and enough space installing and removal of the pedal. Design dimension should account factors for easy accessibility and women driving with high heeled shoes.

4. Material Selection

Material selection process is carried out into phases; Selection of matrix and reinforcement composite materials (depicted in Figure 3). Finally, polyamide as matrix composite material and glass as reinforcement composite material are selected for accelerator pedal and its properties are shown in Table 2.

Table 2: Material Properties of Glass Filled Polyamide

Percentage of Glass Filling	20 % by volume
Tensile Modulus	5910 MPa
Tensile strength	38.1 MPa
Possion's ratio	0.314
Flexural modulus	3300 MPA
Density	840 kg/m3
Moisture Absorption	0.30%
Creep resistance	Good
Corrosion resistance	Good
Chemical Resistance	Alkalis, Hydrocarbons , Fuels and Solvents

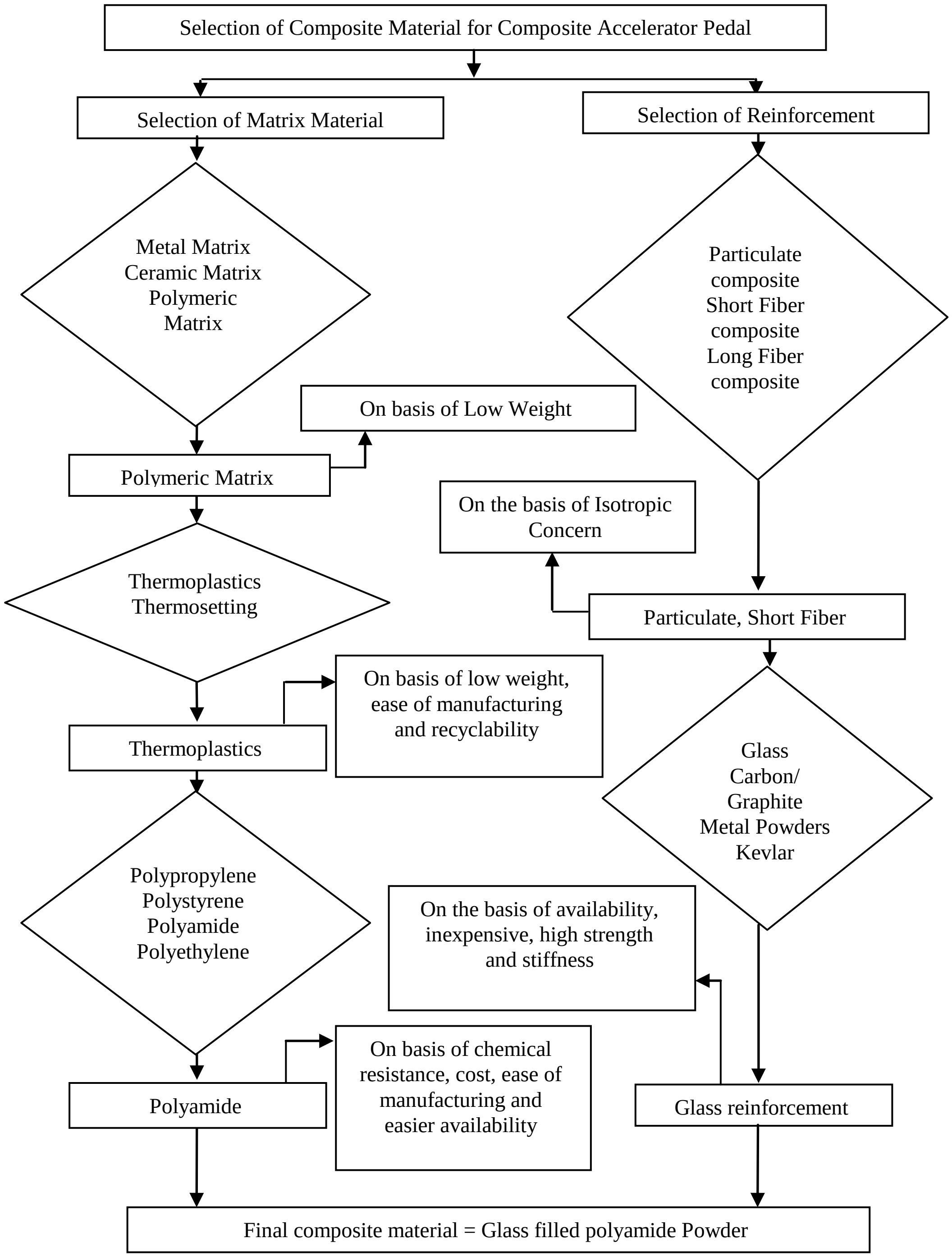


Figure 3: Flowchart for Material Selection

5. Concepts Generation

Concepts generation for the composite accelerator pedal starts with formation of morphological matrix (Table 3). Then, the best pedal arm profile is selected out of six feasible profiles (Figure 4). Further, conceptual designs are modeled on CATIA. Fig. 5 shows the solid models of six concepts having thickness 5 mm and overall profile dimensions of 15 x 15 mm2. The mass and volume of these concepts are found (Table 4).

Table 3: Morphological Matrix for Composite Accelerator Pedal

Sub function \ Solution	1	2	3	4	5
Means of controlling throttle valve	Torsion spring	Hydraulic system	Pneumatic system	Compression spring	Spring in carburetor
Pedal connection to cylinder	Hydraulic cylinder	Pneumatic cylinder	Cable		
Pedal attachment to cable or cylinder	Shaft	Single slot	Double slot	Clevis pin	
Return force on pedal	Torsion spring	Hydraulic force	Pneumatic force	Extension spring	
Pedal pad design	Integral with pedal	Design separately then attached			
Pivot shaft location	End of pedal	Along pedal lever			
Pedal arm profile	I	C	U	O	T
Ribbing pattern	V	X	No ribbing	2 rows of V	2 Rows of X

Table 4: Mass and Volume Matrix

Concepts	**Concept 1**	**Concept 2**	**Concept 3**	**Concept 4**	**Concept 5**	**Concept 6**
Mass (g)	69.071	60.437	60.354	60.437	40.004	54.262
Volume (cm^3)	82.227	71.949	71.851	71.949	51.96	64.579

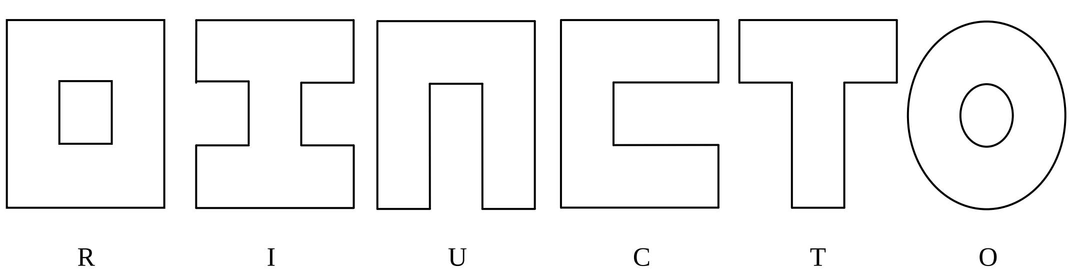
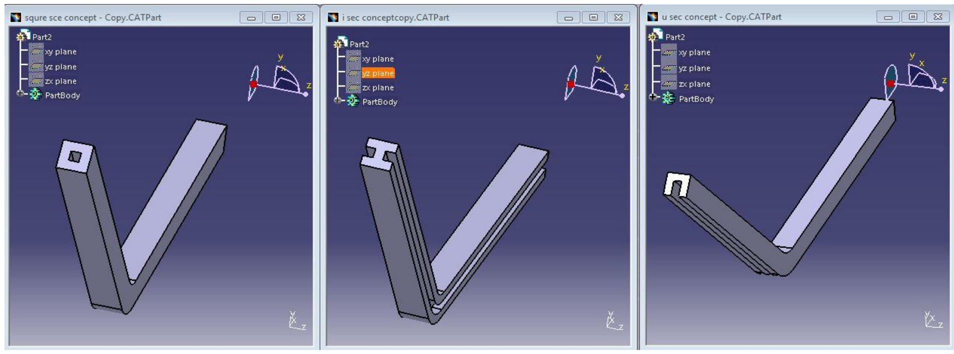
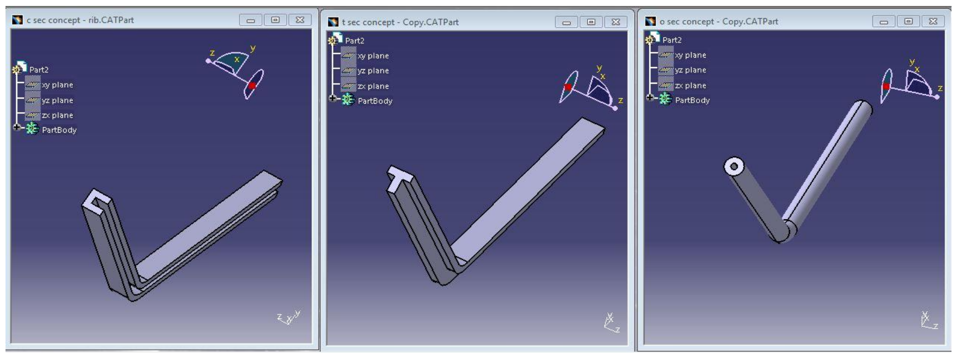


Figure 4: Feasible Pedal Arm Profiles



Concept 1 **Concept 2** **Concept 3**

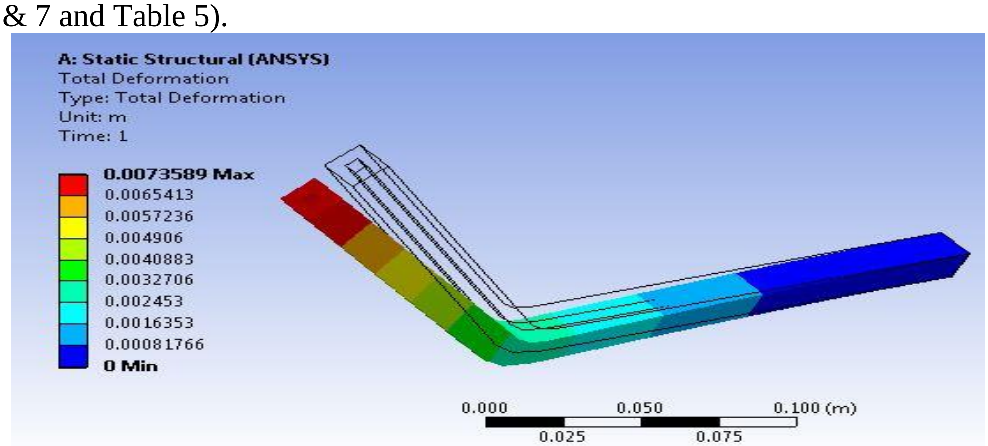


Concept 4 **Concept 5** **Concept 6**

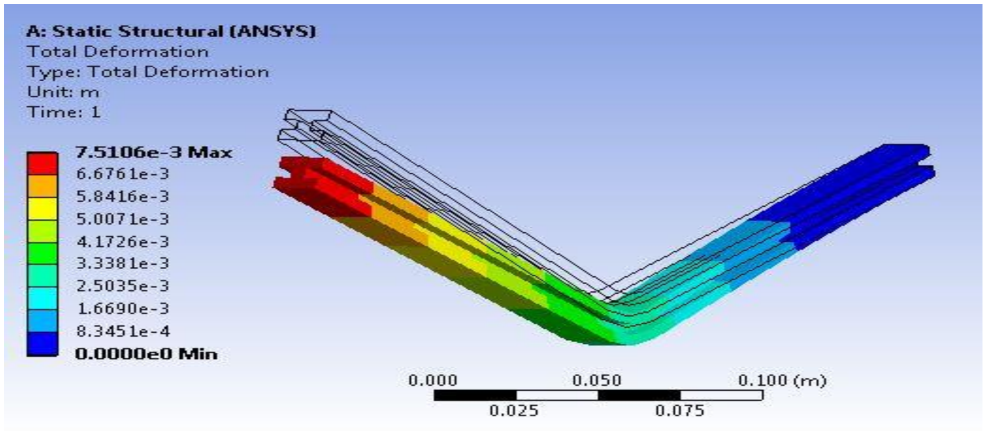
Figure 5: Solid Models of Conceptual Designs of Accelerator Pedal Arm

6. Analysis

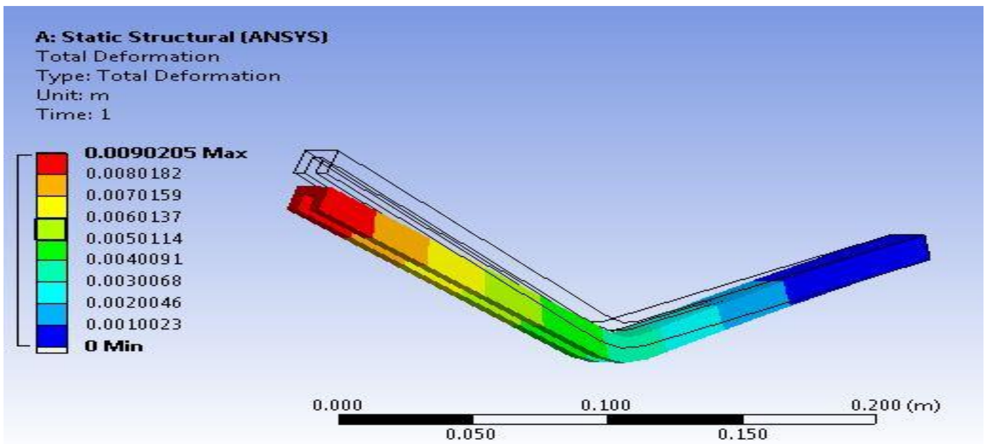
Finite Element Analysis [10] is carried out on all the design concepts using ANSYS work bench for material properties of Glass filled Polyamide i.e. tensile modulus of 5910 MPa, Poisson ratio of 0.314 and density of 840 kg/m3. After fixing at the desired location, force of 40 N is applied and total deformation and equivalent Von-Mises stress for six design concepts are obtained (Figure 6 & 7 and Table 5).



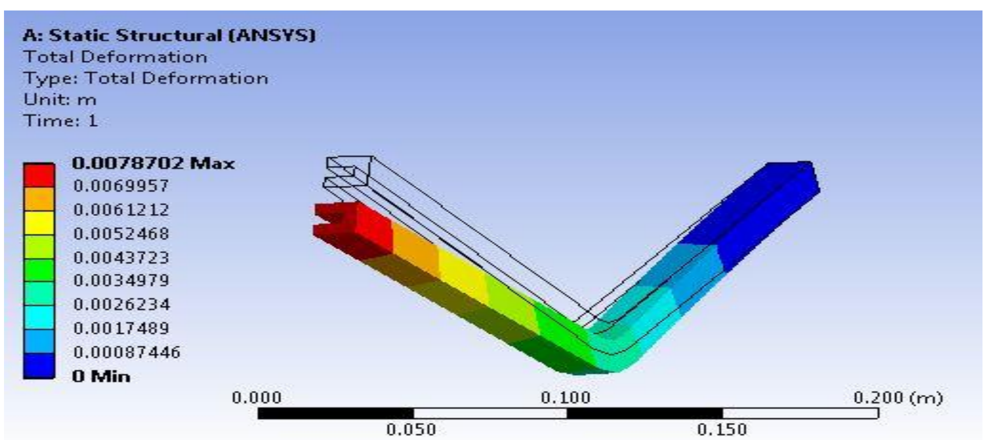
Concept 1



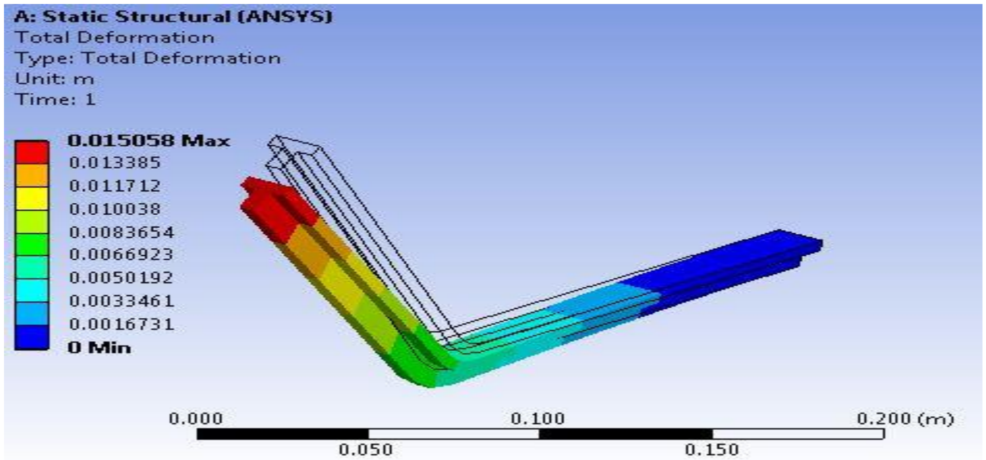
Concept 2



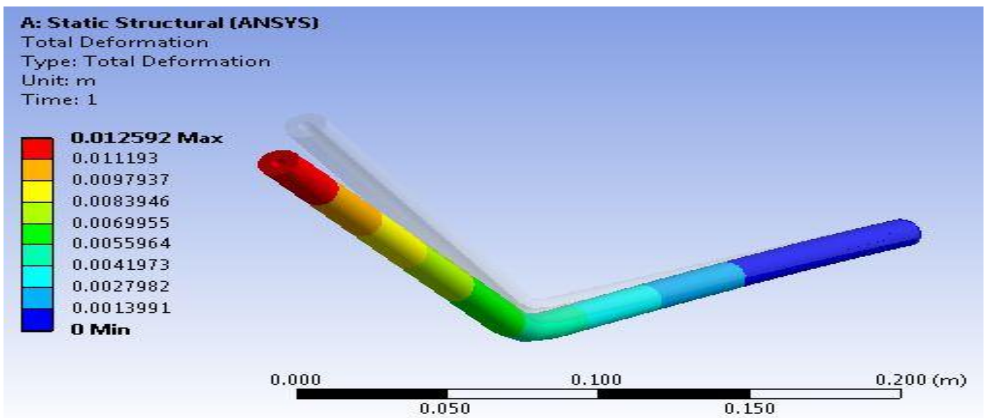
Concept 3



Concept 4

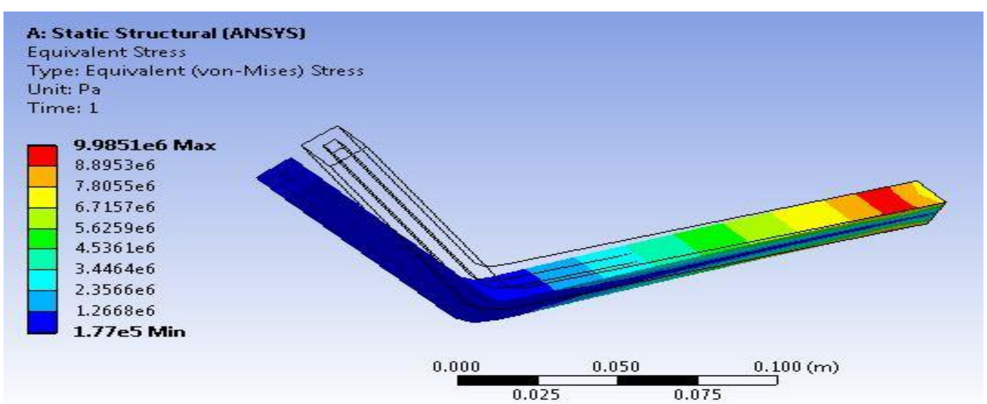


Concept 5

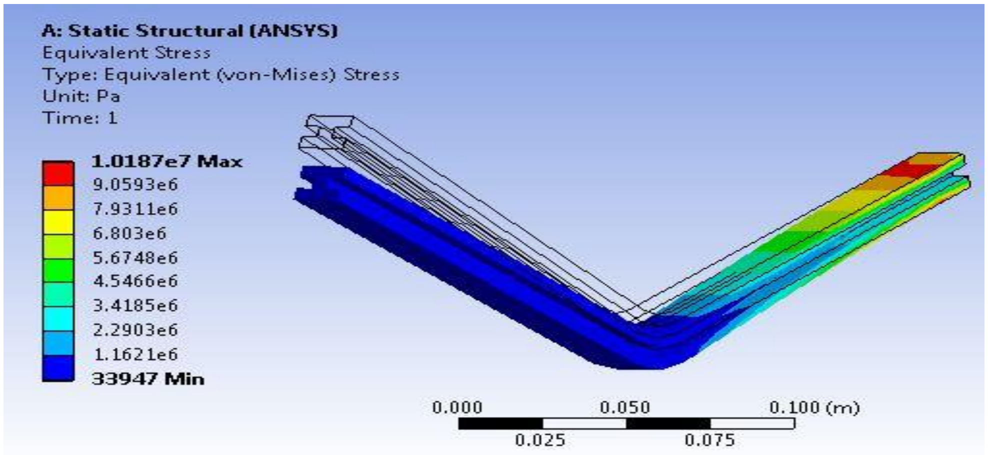


Concept 6

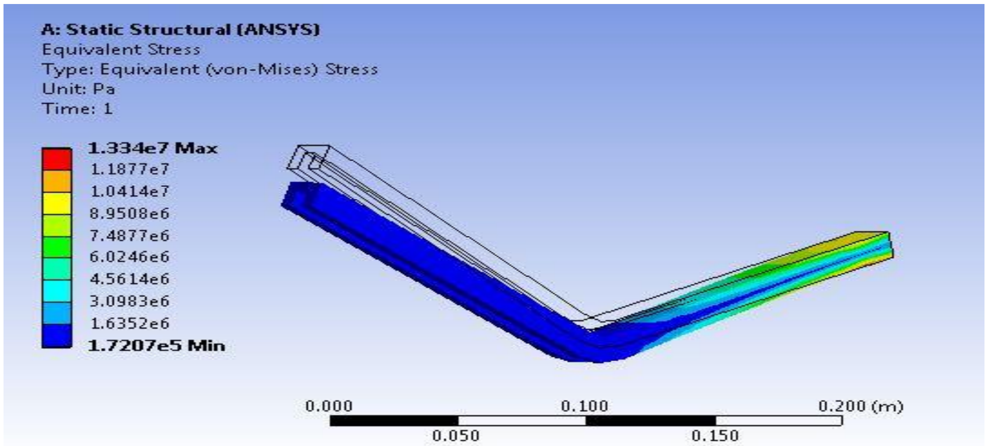
Figure 6: Deformation Distribution for Composite Accelerator Pedal Arm



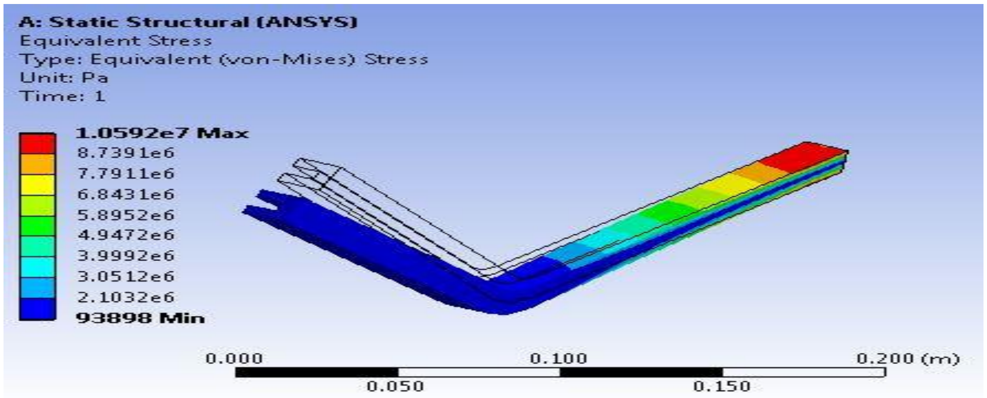
Concept 1



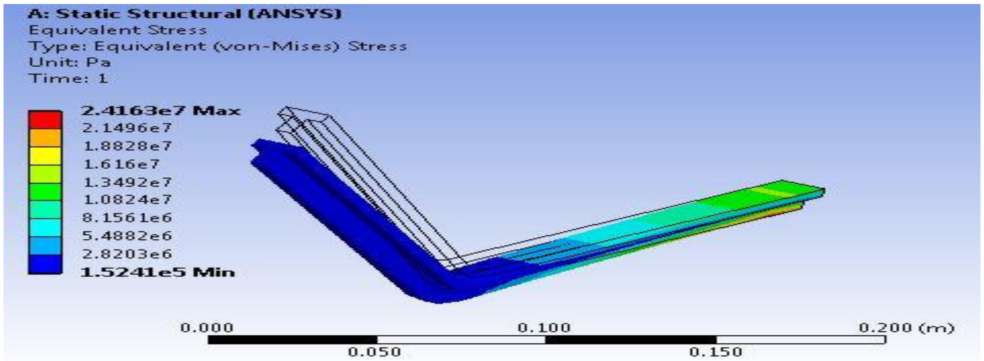
Concept 2



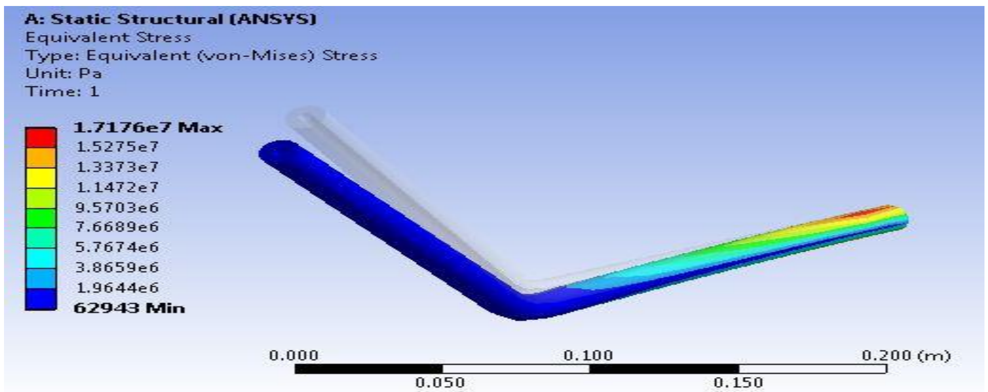
Concept 3



Concept 4



Concept 5



Concept 6

Figure 7: Stress Distribution for Composite Accelerator Pedal Arm

Table 5: Total Deformation and Stress Matrix

Concepts	Concept 1	Concept 2	Concept 3	Concept 4	Concept 5	Concept 6
Deformation (mm)	7.3589	7.5106	9.025	7.8702	15.058	12.58
Von-Mises Stress (N/mm^2)	9.9851	10.187	13.34	10.592	24.163	17.16

7. Best Design Concept

In order to select the best design concept for composite accelerator pedal arm, rating/weighting matrix evaluation method is used. From Tables 4 & 5, all the concepts are compared and concept 1 is selected as the reference on the basis of maximum mass, maximum volume, least deformation and least stresses. The relative mass, volume, deformation and stress to concept 1 are taken as reference parameters and the corresponding values for other concepts are calculated in comparison to concept 1 (shown in Table 6). Further, the weighting factor for each criterion is applied to evaluate the highest ranked design concept as best one. Then, each concept is rated on the basis of reference scores on scale from 1 to 5 by comparing relative values based on the criterions of minimum mass, maximum deformation and maximum stress

Table 6: Relative Mass, Volume, Deformation and Maximum Stress as Compared to Concept 1

Concepts	Mass ratio	Volume ratio	Deformation ratio	Equivalent Von-Mises Stresses
Concept 1	1	1	1	1
Concept 2	0.875	0.875	1.021	1.02
Concept 3	0.874	0.874	1.226	1.336
Concept 4	0.875	0.875	1.069	1.336
Concept 5	0.579	0.632	2.046	2.42
Concept 6	0.786	0.785	1.709	1.719

(Table 7). Lastly, decision matrix is evaluated by multiplying the each concept rating by weight factor assigned for each criterion. The weight factor is on the scale from 1 to 5. Total highest score of 51 for concept 2 (Table 8) is thus selected as the best design concept for the composite accelerator pedal arm [3], [13].

Table 7: Rating Matrix for Design Concepts

Criteria	Rating				
	Concept 2	**Concept 3**	**Concept 4**	**Concept 5**	**Concept 6**
Minimum Mass	2	3	2	5	4
Maximum Deformation	5	3	4	1	2
Maximum Stress	5	3	4	1	2

Table 8: Matrix for Evaluation of Best Concept

Criteria	Weight Factor	Weight Factor x Rating				
		Concept 2	**Concept 3**	**Concept 4**	**Concept 5**	**Concept 6**
Minimum Mass	3	6	9	6	15	12
Maximum Deformation	5	25	15	20	5	10
Maximum Stress	4	20	12	16	4	8
Total		**51**	**36**	**42**	**24**	**30**

Based on logical choice, conventional designs and results for best pedal arm profile, final set of sub function is selected for development of composite accelerator pedal. Further, solid model of the selected accelerator pedal is created using CATIA software package (Fig. 8). Pedal pad and pivot shaft is made integral with pedal arm. ’V’ ribbing is provided to add stiffness and strength. Necessary fillets are also provided for aesthetics and removing sharp edges. Figure 9 shows the total deformation and equivalent stress distribution. Table 9 summarizes the analysis result and it is revealed that stress and deformation are well under safe values on comparison with material properties.

Table 9: Final Morphological Matrix

Sub function \ Solution	1	2	3	4	5
Means of controlling throttle valve	Torsion spring	Hydraulic system	Pneumatic system	Compression spring	Spring in carburetor
Pedal connection to cylinder	Hydraulic cylinder	Pneumatic cylinder	Cable		
Pedal attachment to cable or cylinder	Shaft	Single slot	Double slot	Clevis pin	
Return force on pedal	Torsion spring	Hydraulic force	Pneumatic force	Extension spring	
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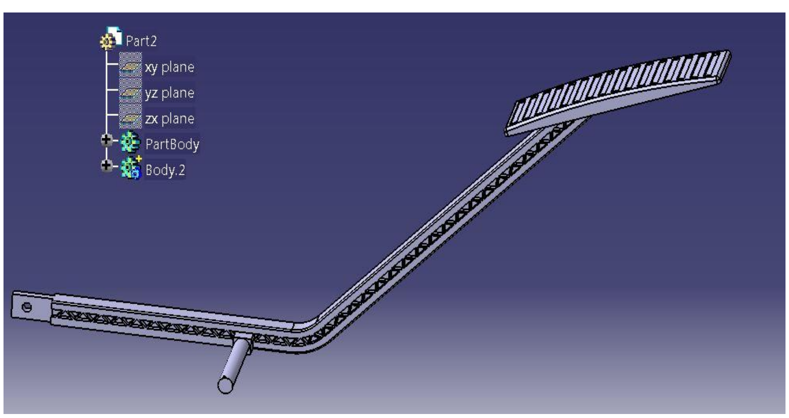
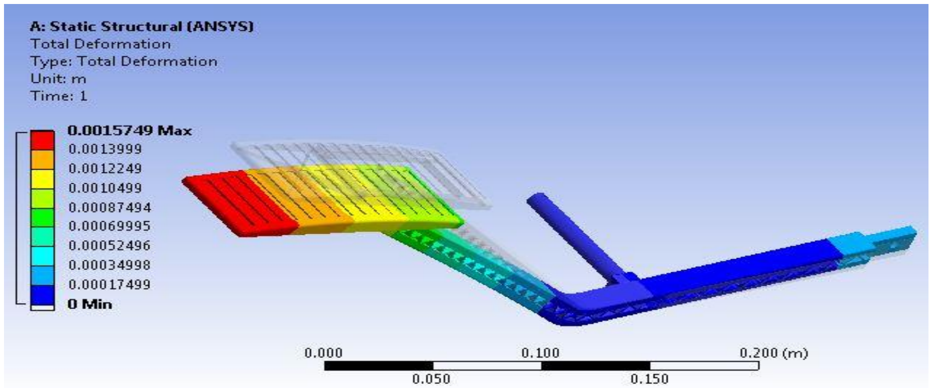


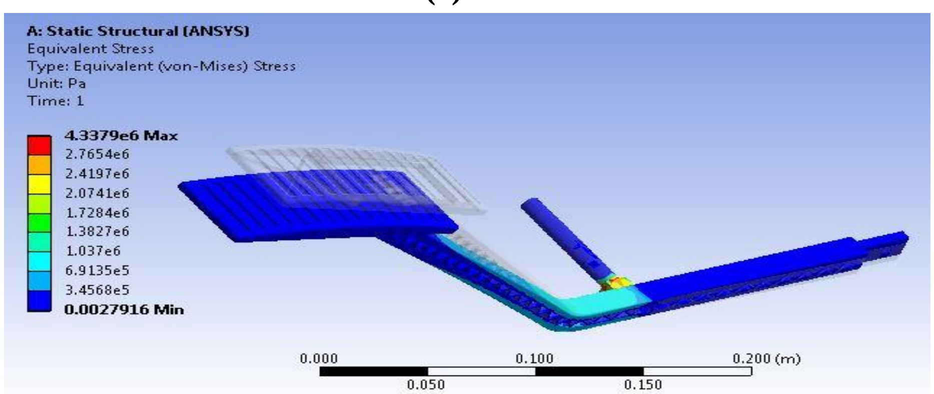
Figure 8: Solid model of Final Composite Accelerator Pedal

8. Prototyping

Prototype of the composite accelerator pedal is created by using SLS machine. Its pictorial view is shown in Figure 9 and characteristics of the prototype developed are summarized in Table 10.



(a)



(b)

Figure 9: Deformation and Equivalent (Von-Mises) Stress Distribution for Composite Accelerator Pedal

Table 10: Analysis Report for Composite Accelerator Pedal

	Mass (g)	Volume (cm^3)	Deformation (mm)	Equivalent (Von-Mises) Stress (N/mm^2)
Final Pedal	100	119.13	1.5749	4.34

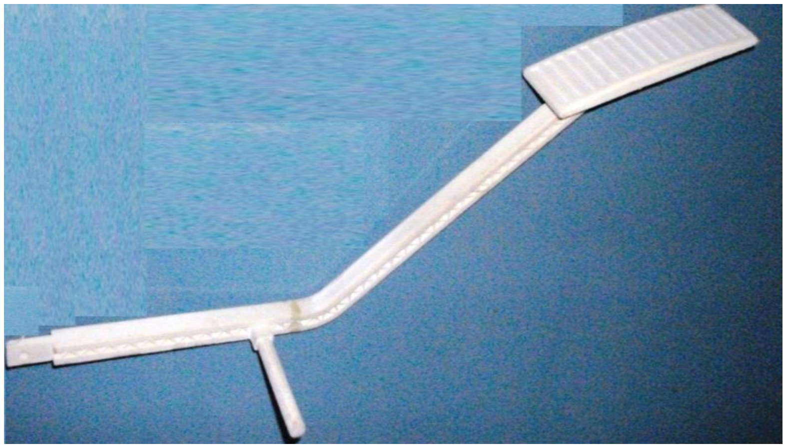


Figure 10: Prototype of the Composite Accelerator Pedal

Table 11: Characteristics of the Prototype Generated by SLS Technology

Characteristics of composite accelerator pedal	
Machine Time	Approx. 9 hours
Surface Finish	1 -6.2 µm
Colour	Yellowish
Weight of Component	100 g
Experience During Handling	Not fragile but thin sections can easily broken

9. Concluding Remarks

The development process of composite accelerator pedal has been carried to replace the existing metallic accelerator for various benefits. It is observed that the composite accelerator pedal weighs 100 g while the reference existing model weighs about 500g, thus gives the weight reduction of 80%. It is produced as a single unit so, gives lower manufacturing complexities, better fit and better finish. Moreover, it is also found to be dimensional stable that makes it suitable for usage in a wide range of temperature. It is non-corrosive and could be worked without requirement paint coatings. It has an inherent resistance to fuel, oil and greases suitable for usage. It is inherently better sound insulator than steel.

There is also further scope of development of other automotive components such as brake and clutch pedals and even the brackets used for mounting the pedals with composite material for higher weight savings and durability on the same context.

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