

Comparative Analysis and Evaluation of Fuel Injection Inspection 3d Printed Cover Part Design

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Abstract

Automotive industry leaders face a dual challenge of cost management and ensuring optimal comfort, compelling them to continuously pursue innovation. Polymers have gained widespread application in various automotive components due to their lightweight nature and advantageous properties, including corrosion resistance, durability, design flexibility, toughness, resiliency, and high performance at a cost-effective rate.

This research aims to assess the most suitable polymer for the inspection cover part of a diesel fuel injector. The primary role of this component is to prevent diesel spillage from the pump housing during fuel supply to the injectors. Traditionally, the inspection cover part has been manufactured using aluminum through pressure die casting. However, the high cost and weight of aluminum, coupled with its mechanical and thermal properties exceeding the component requirements, necessitate exploration of alternative materials.

Material selection for the inspection cover part is performed employing CES software, aligning with the specific needs and limitations of the component. The chosen material undergoes numerical analysis for stress and strain using a commercial Finite Element Analysis (FEA) package. The component prototype is fabricated using the Fused Deposition Modeling (FDM) method, accompanied by a tensile specimen for evaluating mechanical properties. The results indicate that the selected polymer material is substitute for aluminum, offering potential advantages in terms of cost and weight.

1.0 Introduction

The automotive industry stands at the precipice of a transformative era, with the plastics industry positioned as a key player in this paradigm shift. The inception of the true plastics revolution in the automotive sector traces back to the 1950s when thermoplastics emerged, commencing with ABS and expanding to include polyamide, polyacetal, and

polycarbonate, alongside the introduction of polymer alloys and blends. The continuous evolution of advanced, high-performance polymers has significantly heightened their prevalence. Initially chosen for their commendable mechanical properties and aesthetic appeal, with the added advantage of self-coloring possibilities, plastics have progressively found increased application in the automotive realm over the ensuing decades.

In contemporary automotive manufacturing, plastics play a pivotal role in enhancing energy efficiency by reducing vehicle weight, while concurrently delivering attributes such as durability, corrosion resistance, toughness, design flexibility, resiliency, and high performance at a cost-effective level [1][2].

Engineered polymer composites and plastics rank as the second most prevalent class of materials employed in the automotive industry, following ferrous metals and alloys, which constitute 68% of the total weight. Notably, plastics contribute approximately 50% of all interior components in commercial vehicles, encompassing safety subsystems, door and seat assemblies.

The advantages attributed to the use of plastics in the automotive sector have evolved concomitant with the substantial proliferation of plastic components. The rising costs are effectively addressed by the inherent moldability of plastics, allowing for the creation of components with intricate geometries that often replace multiple parts made from alternative materials. This versatility also facilitates integral fitments, streamlining assembly processes. Various polymer types are now employed in over a thousand distinct parts of diverse shapes and sizes within automobiles. A comprehensive examination of any car model's interior reveals the pervasive integration of plastics in both exterior and interior components, including but not limited to bumpers, doors, safety and windows features, headlight and side-view mirror housings, trunk lids, hoods, grilles, and wheel covers.

1.1 Diesel Fuel Injection System

In a basic diesel fuel system consists of:

- 2 The diesel fuel is stored in a fuel tank.
- 3 A lift pump extracts fuel from the tank, ensuring a consistent supply to keep the injection pump adequately fueled.
- 4 A sedimenter is employed to eliminate water and larger particles present in the fuel.
- 5 A fuel filter is utilized to remove minute particles from the fuel.
- 6 The injection pump plays a crucial role in delivering fuel under high pressure to the injectors through dedicated injector pipes. Precision in delivering the correct amount of fuel at the right time in the engine cycle is imperative for optimal performance.
- 7 Each cylinder is equipped with an injector responsible for spraying fuel into the respective combustion chamber.
- 8 Leak-off pipes serve the dual purpose of channeling fuel used for cooling and lubrication from the injection pump and injectors back to the tank. Additionally, they aid in purging air from the system, contributing to its efficient operation.

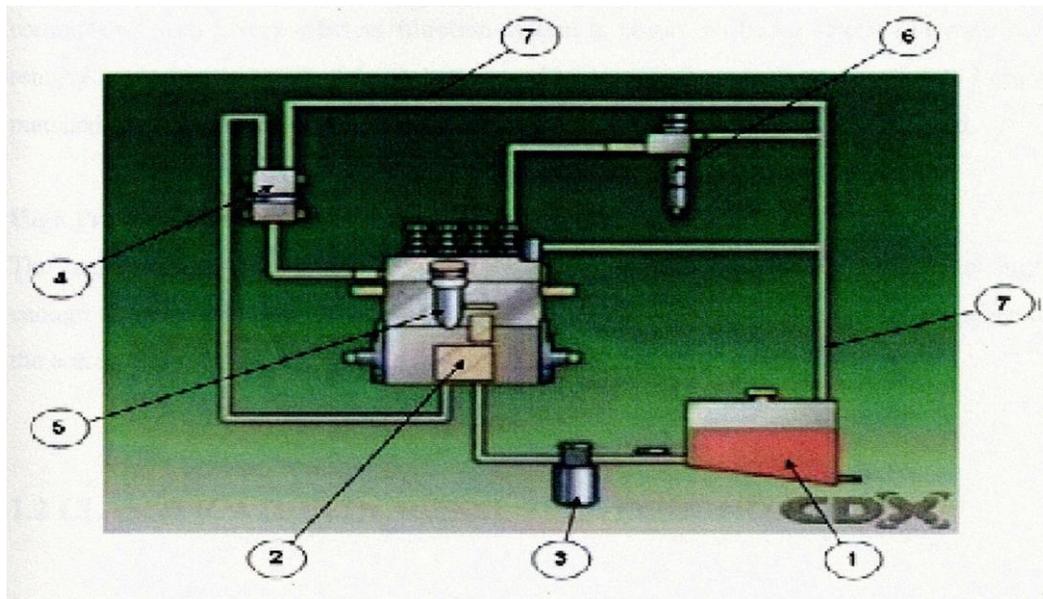


Fig 1: Diesel fuel injection system

The system consists of Low-Pressure Side and the High-Pressure Side. The Low-Pressure Side is responsible for purifying the fuel and conveying it to the high-pressure side or the fuel injection system. It is imperative to safeguard the diesel fuel injection system from potential damage caused by dirt and water. The intricate, highly polished components necessitate an exceptionally efficient filtration system to meticulously eliminate all traces of dirt and water. The attainment of a finely polished finish involves the lapping of two components together to form a precisely matched set. It is crucial to emphasize that once the lapping process is concluded, matched components should not be interchanged.

On the other hand, the High-Pressure Side of the fuel injection system is tasked with elevating the fuel pressure to a level sufficient to initiate the opening of an injector. This pivotal function facilitates the precise injection of fuel into the combustion chamber at the optimal moment. This orchestrated process ensures the seamless and accurate operation of the entire fuel injection system. The following table gives the details of the pump used in the injection system.

Table 1 Classification of diesel fuel injection pumps used in automobiles

In line type pump	The same number of plungers as engine cylinders are aligned in series in the pump
Distributor type pump	One plunger distributes fuel into each cylinder

Literature Review

This survey presents a review of the available published information related to application of polymers in automobiles, material selection, design and analysis of automotive components for polymer material.

Nada Strumberger's paper delves into the diverse array of polymeric materials suitable for manufacturing automotive parts. The utilization of polymeric materials not only provides greater design flexibility but, in many instances, is essential for achieving safe and economically viable solutions for designing various components. Strumberger

proposes specific polymer materials tailored for both internal and external automotive parts, elucidating the manufacturing procedures involved in creating automotive components from polymeric materials [1].

M.F. Ashby and D. Cebon's paper elucidates the role of the Cambridge Engineering Selector Software in identifying suitable polymers for diverse applications. Given the increasing complexity resulting from the growing number of thermoplastics and their varied physical and mechanical properties, Ashby employs a systematic material selection approach using the software. The method involves specifying pairs of material properties, generating graphs, and utilizing user-defined selection criteria to pinpoint suitable materials [2].

Mansor M.R employs the Analytic Hierarchy Process (AHP) method in selecting the most suitable thermoplastic polymer matrix for hybrid natural fiber/glass fiber polymer composites. This selection process is based on specific product design specifications for a parking brake lever, considering operational requirements and sustainability advantages. A four-level AHP structure with four main criteria and seven sub-criteria guides the material selection process, ultimately favoring low-density polyethylene (LDPE) as the most suitable thermoplastic matrix [3].

Pankaj Saini's paper focuses on the design and analysis of composite leaf springs, comparing their stresses and weight savings with conventional steel leaf springs. The study utilizes glass fiber-reinforced polymer (E-glass/epoxy), carbon epoxy, and graphite epoxy as composite materials. The analysis results suggest that E-glass/epoxy composite leaf springs are a favorable alternative to steel, offering significant stress reduction and stiffness benefits [4].

Pradeep Kumar Uddandapu explores the impact of material selection, structure, shape, and impact conditions on the crashworthiness of car bumper beams. The study aims to replace steel with ABS Plastic and Carbon Fiber-Reinforced Poly-Ether-Imide (PEI). Using 3D modeling software, the analysis reveals that ABS Plastic exhibits lower stress values compared to PEI, leading to the conclusion that ABS Plastic is a preferable material for improved crashworthiness [5].

D.V. Pawar's paper focuses on the design of a plastic fuel tank for three-wheeler vehicles to reduce weight and enhance safety. High-Density Polyethylene (HDPE) is chosen as the material, and geometric and finite element modeling is performed in ANSYS software. Comparative analysis between analytical and FEM results supports the conclusion that plastic can replace steel in three-wheeler vehicle fuel tanks [6].

J. Reddaiah's work involves the design and analysis of plastic and aluminum master cylinders for vehicles. Polypropylene is selected as the plastic material, and the results indicate higher stress levels in the plastic master cylinder compared to aluminum. However, the stresses induced in the polypropylene master cylinder remain within acceptable limits [7].

Ravi Lidoriya's paper focuses on reducing wheel weight by replacing aluminum with various plastic materials. The study compares aluminum alloy with PEEK (Polyether ether ketone) and PEEK with glass fiber. ANSYS software is employed for analysis, and the results lead to the conclusion that PEEK 90HMF20 is the most suitable material for replacing aluminum in terms of minimizing deformation and maximizing strength [8].

T. Rangaswamy evaluates the suitability of composite materials, specifically E-Glass/Epoxy and HM-Carbon/Epoxy, for automotive transmission applications. Genetic Algorithm (GA) and ANSYS software aid in optimizing the design of a one-piece composite drive shaft for a rear-wheel-drive automobile. The study concludes that the usage of composite materials and optimization techniques results in substantial weight savings compared to steel [9].

Tulasiram Nasikai's paper explores the design and analysis of a heavy vehicle chassis frame, traditionally constructed from steel and aluminum. Composite materials, including Carbon Epoxy and E-glass epoxy, are considered as

replacements. The study reveals a significant reduction in chassis weight when using composites instead of steel, attributed to the lower density of composite materials [10].

In the context of these diverse studies on material selection and design considerations in automotive applications, the cover part of the diesel fuel injection pump under examination is highlighted. Serving as an enclosure for the pump, this component is typically fabricated from aluminum. Its mechanical and thermal properties exceeding the component requirements. Therefore there is a compelling need to explore alternative materials to reduce both weight and cost while maintaining performance standards.

2.1 Polymers In Automobiles

The utilization of polymeric materials in automobiles is witnessing a continual and increasing application, a trend that is anticipated to persist in the future. The selection of polymeric materials over other traditional materials in automobiles is driven by factors such as the contemporary aesthetics of vehicles, enhanced functionality, more cost-effective manufacturing processes, and the imperative to reduce fuel consumption. While the primary motivation for choosing polymeric materials lies in mass reduction, the ongoing growth in their usage is anticipated to pave the way for novel applications in automobiles, particularly in areas related to comfort, safety, and the integration of components. The use of polymeric materials provides unparalleled design freedom, and, in many instances, only these materials can facilitate safe and economically viable solutions for constructing various automotive components. Consequently, polymer materials are rapidly displacing metals in automotive applications, marking a departure from traditional product design and development approaches.

The key motivations for opting for polymeric materials over other alternatives encompass low mass structures, enhanced comfort, improved safety, cost savings through reduced production costs, greater design flexibility, and the seamless integration of components. Automotive components crafted from polymeric materials are categorized into four main groups: internal parts, external parts, components in the engine compartment, and bodywork and engine parts.

The fuel injection system assumes a critical role in supplying fuel to the diesel engine, with the injection pump generating the necessary pressure for fuel injection. This pressurized fuel is directed through high-pressure fuel injection tubing to the injection nozzle, which subsequently injects it into the combustion chamber.

Specifically focusing on the inspection cover part, its primary function is to protect against the spilling of diesel from the pump housing during fuel injection into the injectors. Acting as an enclosure for the pump housing, the inspection cover contributes to maintaining the integrity and efficiency of the fuel injection system. The utilization of polymeric materials in automobiles is witnessing a continual and increasing application, a trend that is anticipated to persist in the future. The selection of polymeric materials over other traditional materials in automobiles is driven by factors such as the contemporary aesthetics of vehicles, enhanced functionality, more cost-effective manufacturing processes, and the imperative to reduce fuel consumption. While the primary motivation for choosing polymeric materials lies in mass reduction, the ongoing growth in their usage is anticipated to pave the way for novel applications in automobiles, particularly in areas related to comfort, safety, and the integration of components. The use of polymeric materials provides unparalleled design freedom, and, in many instances, only these materials can facilitate safe and economically viable solutions for constructing various

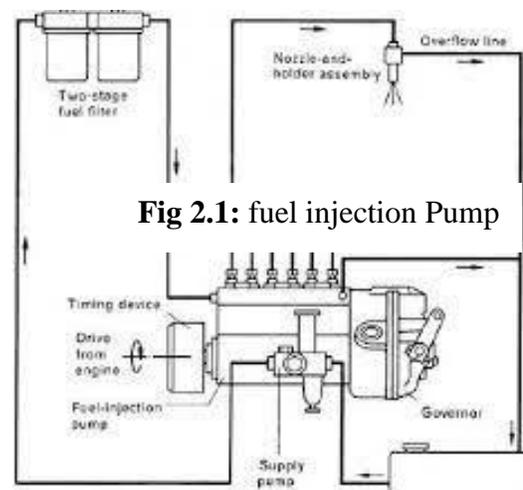


Fig 2.1: fuel injection Pump

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Methodology

Material selection represents a critical step in the design process for any physical object. Within the realm of product design, the primary objective of material selection is to minimize costs while simultaneously achieving the desired product performance goals. As this task becomes increasingly intricate, the integration of computer technology has become indispensable in the material selection process. A notable focus is placed on utilizing computer systems to efficiently store and process data related to material properties. This not only allows designers to access vast amounts of materials data but also facilitates rapid retrieval from a computer database, streamlining the material selection process.

One prominent tool in this domain is the Cambridge Engineering Selector (CES) software, which systematically aids in the selection of the best material for a given application. The CES software, particularly CES EduPack, provides a comprehensive database encompassing materials and process information, coupled with powerful materials software tools. This technology assists designers in searching for materials, visualizing their properties, and aligning them with specific applications.

CES EduPack operates with three distinct levels of database functionality, enhancing its versatility and applicability across various stages of the design process. This multi-level database structure contributes to a more informed and efficient material selection process, ultimately assisting designers and engineers in choosing the most suitable material as the design approaches completion.

	Coverage	Content
Level 1	Around 70 of the most widely used materials drawn from the classes: metals, polymers, ceramics, composites, foams, and natural materials. Around 70 of the most widely used properties, using rankings where processes.	A description, an image of the material in a familiar product, typical applications, and limited data for mechanical, thermal, and electrical properties using rankings where appropriate.
Level 2	Around 100 of the most widely used All materials. Around 110 of the most commonly used processes	All the content of Level 1, supplemented by more extensive numerical data, design guidelines, ecological properties, and technical notes
Level 3	The core database contains more than 3,000 materials, including those in Levels 1 and 2. Specialist editions covering aerospace, polymers, architecture, bio-materials, and eco-design are also available	Extensive numerical data for all materials, allowing the full power of the CES selection system to be deployed.

Selection stages are classified into three types:

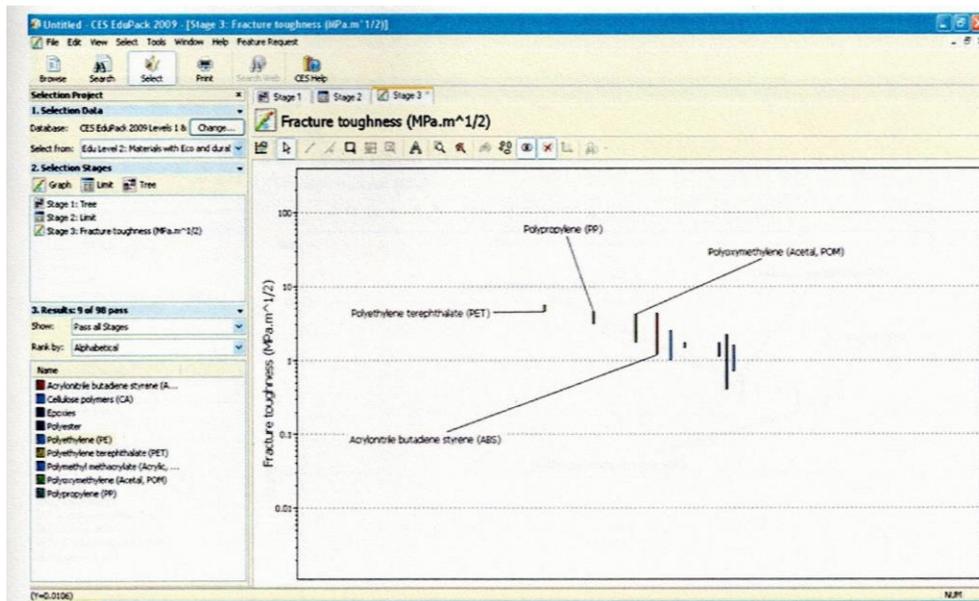
1. Graph: Comparison of materials with their properties;
2. Limit: For selecting a material with constrains;
3. Tree: For selecting a particular type of material like polymers, metals etc.

Stage1: since we are looking forward to replace polymer material, polymers and elastomers are selected from the material university in tree stage. After specifying polymers and elastomers out of 98 materials 29 materials pass in stage one.

Stage2: the inspection cover part should be corrosive resistant to oils and fuel. So excellent durability property is selected in limit stage. The inspection cover part should withstand temperature range of -20 to 140°C, which is entered in stage two along with durability property. After specifying thermal property and durability out of 98 materials 9 material pass in stage.

Stage3: Fracture toughness is a quantitative way of expressing a material's resistance to brittle fracture when a crack is present. Brittle fracture is very characteristic of materials with less fracture toughness. . It is denoted K_{ic} and has the units of $\text{Pa}\cdot\text{m}^{1/2}$ or $\text{Psi}\cdot\text{in}^{1/2}$. In the graph it shows that, all nine materials are below $10\text{MPa}\cdot\text{m}^{1/2}$.

Stage 4: Young's modulus, also known as the tensile modulus or elastic modulus, is a measure of the stiffness of an elastic isotropic material and is a quantity used to characterize materials. Young's modulus measures stiffness and is a material constant, i.e. it is the same whatever the size of the test-piece. 'Stiffness' measures how much something stretches when a load is applied.



Graph shows young's modulus of nine materials, Polyoxymethylene has highest young's modulus than other materials in graph.

Many applications require stiff and low density materials. So in order to find stiff and low density material above graph will helps.

Stage 6: In automobiles introduction of polymer material is to reduce weight and cost of that component. In order to know the cost of nine materials those are passed in previous stage, this graph will help.

STAGE 7: Thermoplastics with fiber reinforced plastics are processed by **Injection molding process** so, in stage 7 from processing university injection molding process is selected.

In this stage 7, out of 9 materials passes and these seven materials can be processed in injection molding for mass production.

STAGE 8: In the previous stage we came to know that seven materials can undergo mass production but we want a prototype model of inspection cover part for validation. So, in rapid prototyping process Deposition based production is selected in stage 8.

In this stage 8, out of 7 materials 1 material passes i.e. Acrylonitrile - Butadiene -Styrene(ABS). So ABS material is selected for inspection cover part. Know we can go for analysis of ABS material to check that it will suite for particular application or not.

Model construction

Multiple ribs were added based on functional requirements in order to withstand torque range of 5 Nm, basically aluminum has more strength than selected ABS polymer material. So to compensate, more number of ribs was added and thickness is given as 2mm on bottom side of the inspection cover part.

Analysis:

The analysis of the inspection cover part is conducted using ANSYS 14.4, a powerful engineering simulation software. In this process, boundary conditions are established to represent the constraints and interactions within the system. Additionally, torque is applied to simulate the forces and stresses acting on the inspection cover during its operational conditions.

To apply the torque, specialized bolts are created and seamlessly integrated into the inspection cover model developed using CATIA V5R20. These bolts are strategically assembled to accurately represent the physical connections and interactions within the inspection cover assembly. By incorporating these bolts into the CATIA model, the simulation in ANSYS can account for the torquing effects on the inspection cover, allowing for a comprehensive analysis of its structural integrity and performance under various loads.

This integrated approach, utilizing both CATIA V5R20 for modeling and ANSYS 14.4 for analysis, ensures a cohesive and efficient workflow in assessing the inspection cover's response to applied forces and torque. The combination of these advanced engineering tools enables a detailed understanding of the structural behavior and performance characteristics of the inspection cover in real-world conditions.

Prototyping A Model Using Fdm:

Prototyping is an approximation of a product (or system) or its components in some form for a definite purpose in its implementation. It is performed using FDM Process which is categorized by three distinct steps: Pre-Processing, Production and Post-Processing.

Pre-Processing: CatalystEX software is used as pre-processing software in Fused Deposition Modeling; it provides a 3D view of the model or models to be printed which can also be scaled to our desired size and can be controlled to orient the model in the build chamber. Following are the steps for Pre-Processing using CatalystEX Software:

1. **Importing STL file:** A CAD model of inspection cover part is converted to STL format and it is imported into Catalyst EX software. After importing STL file it has to orient properly because it will reduce the time required for production and it also reduces the amount of support material required for processing, part quality in terms of surface finish or accuracy and cost as well. Fig shows different icons to orient the STL file.
2. **STL rotation:** Once the STL file is oriented to the required position, it will shows the X, Y and Z coordinates of the inspection cover model in work table of FDM machine for the movement of nozzle to develop the model.
3. **Processing model:** After STL rotation it will slice the STL file layer by layer and it will decide the amount of support material required for processing. Then .cmd file will be created in the local disk so that it can be imported at any time.
4. **Layer resolution:** Layer resolution will decide the time required for processing the model. Layer thickness value is 0.254 or 0.33mm and it is depends on the maximum thickness of the STL file. 0.254 is used when thickness is less than one and 0.33 is used when thickness is more than one. Since the thickness of the inspection cover is 14mm, the layer resolution given is 0.33mm.
5. **Pack and download:** Proper positioning of STL file on the work table is important, because the nozzle movement will decides the time required to produce the component. So, STL file should be as close as FDM machine nozzle.
6. **Model information:** Once all the above steps are completed it will provide the information such as: location of .cmd file, estimated time required for developing prototype model, XYZ co-ordinates of STL file, material name, amount of material required etc.

Production: In the Fused Deposition Modeling (FDM) process, a movable nozzle with x-y movement capability dispenses molten polymeric material onto a substrate in a controlled manner. The build material is heated to a temperature slightly above its melting point, typically around 0.5 degrees Celsius higher. This elevated temperature ensures that the material remains in a molten state during extrusion and is deposited onto the substrate.

As the molten material is laid down by the nozzle, it solidifies rapidly, typically within a very short timeframe of approximately 0.1 seconds after extrusion. This quick solidification is crucial for the material to adhere and cold-weld effectively to the previous layer. The layer-by-layer deposition and rapid solidification enable the gradual buildup of the three-dimensional object with precise control over its geometry and structure.

This process is a hallmark of FDM 3D printing technology, where successive layers of molten thermoplastic material are strategically deposited to form the final object layer by layer. The ability to control the temperature, movement, and deposition of the material allows for the creation of intricate and customized three-dimensional structures. The model is then stripped away followed by finishing and cleaning.

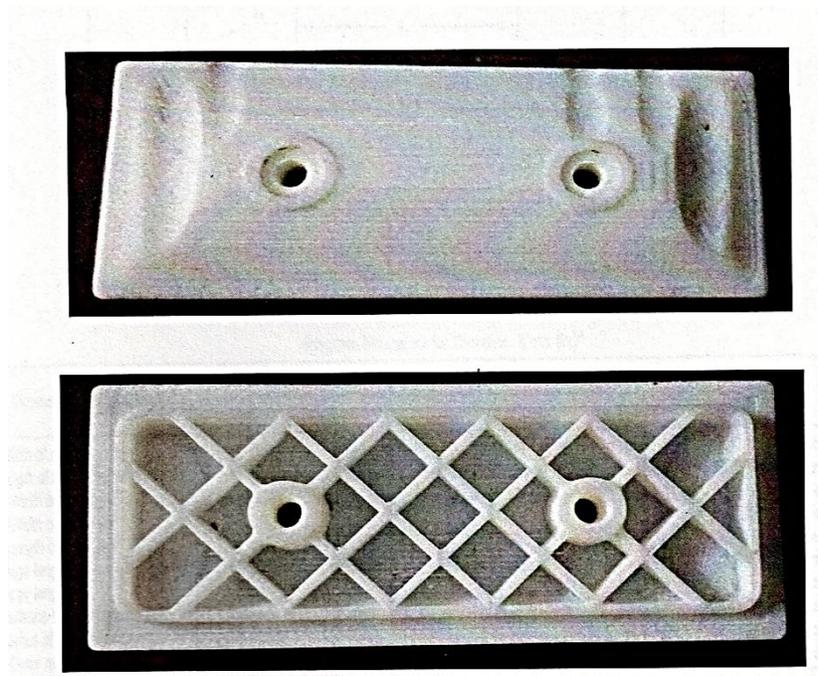


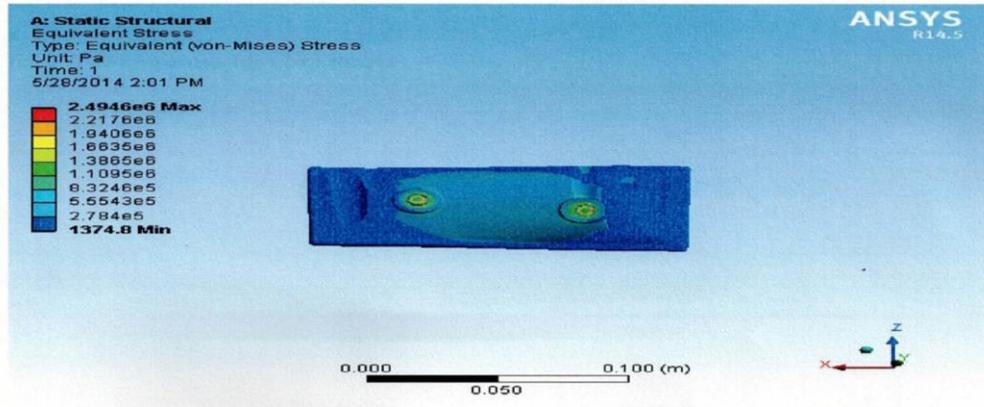
Fig 3: Prototype Model

TENSILE SPECIMEN: For tensile testing we have to create a tensile specimen. Standard test method for tensile property of plastic is ASTM D638-02a. Tensile specimen is modeled in CATIA in order to develop a prototype model.

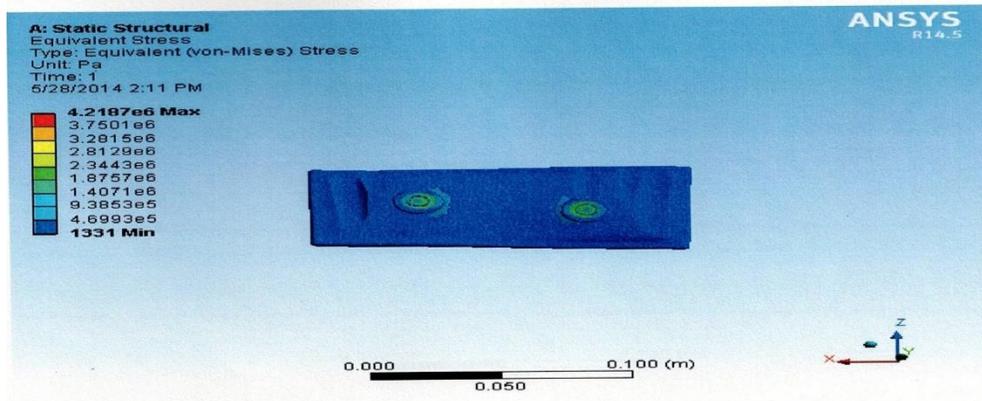
Results And Discussions

The hardness of plastic, specifically ABS material, was assessed using the Rockwell hardness test. This test determines the resistance of the plastic to indentation, and for the ABS material specimen, the Rockwell hardness value obtained was 13. In addition to hardness testing, a tensile test was conducted to measure the force required to break an ABS sample specimen and the extent to which the specimen stretches or elongates to the breaking point. The ABS specimen was created using a Fused Deposition Modeling (FDM) machine, and the maximum load it could withstand was determined to be 4.46 kN. The ultimate tensile strength of the ABS specimen was calculated as 16.05 MPa.

Furthermore, Finite Element Analysis (FEA) was performed to analyze the static behavior of the ABS material under different torque conditions. The results of the FEA analysis, specifically for torque values of 5 Nm and 6 Nm, are depicted in the figure below.



(a)



(b)

Fig: 4(a) and (b) von-Mises for Aluminium and ABS respectively.

These comprehensive analyses provide insights into the mechanical properties of ABS material, covering hardness, tensile strength, and static behavior under varying torque conditions. Such evaluations are essential for understanding the material's performance characteristics and suitability for specific applications in engineering and manufacturing.

The maximum and minimum values of total deformation, directional deformation along applied torque and von-Mises stress for ABS and aluminum materials are given in table below

Torque of 5 Nm for aluminum material			
Type	Total Deformation	Directional Deformation(Z-axis)	Equivalent (von-Mises)Stress
Minimum	9.2341×10^{-7} mm	-4.309×10^{-4} mm	1.3748×10^{-3} MPa
Maximum	8.2754×10^{-4} mm	4.324×10^{-4} mm	2.4946 MPa
Torque of 6 Nm for aluminum material			

Type	Total Deformation	Directional Deformation(Z-axis)	Equivalent (von-Mises)Stress
Minimum	1.1081X10 ⁻⁶ mm	-5.1611X10 ⁻⁴ mm	1.6498X10 ⁻³ MPa
Maximum	9.9305X10 ⁻⁴ mm	5.1888X10 ⁻⁴ mm	2.9935 MPa
Torque of 5 Nm for ABS material			
Type	Total Deformation	Directional Deformation(Z-axis)	Equivalent (von-Mises)Stress
Minimum	1.7103X10 ⁻⁵ mm	-9.3617X10 ⁻³ mm	1.331X10 ⁻³ MPa
Maximum	0.01887 mm	9.3981X10 ⁻³ mm	4.2187 MPa
Torque of 6 Nm for ABS material			
Type	Total Deformation	Directional Deformation(Z-axis)	Equivalent (von-Mises)Stress
Minimum	2.0523X10 ⁻⁵ mm	-0.011234 mm	1.5972 X10 ⁻³ MPa
Maximum	0.0225 mm	0.011278 mm	5.0625 MPa

6.4 Discussions

Creation of prototype model is to check any necessary modifications is required in the design by comparing it with the CAD model. Rapid prototype model of inspection cover in fig 3 shows that no changes are required and it is suite for mass production. An RP part can be given to the production team to enable them to plan how best to manufacture the part for mass production.

Tensile test result shows that the maximum load tensile specimen can withstand are about 40KN. Since the maximum torque acting on the inspection cover part of fuel injection pump is 6Nm, it is well above the functional requirement.

ANSYS Results of Inspection Cover Part: From ANSYS results the total deformation of ABS material for 5Nm torque is 0.0188mm and for 6Nm torque is 0.02257mm, which is well within the acceptable limit of 0.5mm.

Comparison of ANSYS Results with Test Result

The results obtained from analysis is quite encouraging. It was found that Von-Mises stress for ABS material is 4.2187 MPa and 5.0625 MPa at 5Nm and 6Nm torque respectively which is less than yield stress value is 13.13 MPa.

Conclusion

In this work the design and analysis inspection cover part of fuel injection pump made out of ABS and aluminum are performed.

The conclusions drawn from the study are as follows:

- The prototype model of the inspection cover, created through Fused Deposition Modeling (FDM), indicates that design changes are unnecessary, and the model is well-suited for mass production.
- The Rockwell hardness test on the ABS specimen yielded a hardness value of approximately 13 RHN.
- Tensile testing on the ABS specimen provided the following mechanical properties: a tensile strength of 16.05 MPa, a yield stress of 13.13 MPa, and a percentage of elongation of 2.50%.
- The static analysis results revealed maximum displacements of 8.275×10^{-3} mm and 9.930×10^{-3} mm for EN AC 47100 material at 5 Nm and 6 Nm, respectively. For ABS material, the maximum displacements were 0.018 mm and 0.0225 mm at 5 Nm and 6 Nm, respectively.

- In terms of von-Mises stress, the analysis indicated values of 2.4946 MPa and 2.9935 MPa for EN AC 47100 material at 5 Nm and 6 Nm, respectively. For ABS material, the von-Mises stress was 4.2187 MPa and 5.0625 MPa at 5 Nm and 6 Nm, respectively. Importantly, these von-Mises stress values are below the yield stress value of 13.13 MPa obtained from the tensile test results. As per the failure criteria, ABS material is deemed suitable for the inspection cover part compared to the conventional aluminium alloy.

In summary, the results from prototype modeling, hardness testing, tensile testing, and static analysis collectively support the suitability of ABS material for the inspection cover part, affirming its potential for mass production.

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