Design and Development of Automotive Interior Plastic Map Pocket For Multi-Material 3D Printing

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Abstract- *The present scenario demanding increase of Additive Manufacturing products for various application in different fields has gained new demands through various industries. The parts manufactured by additive manufacturing are used in various fields, though the mechanical characteristic properties of the parts produced tend to be less than the parts manufactured by conventional manufacturing processes like injection molding.The most dominating and crucial factor that can largely kick in the additive manufacturing industry is heightening the mechanical properties of fused deposition modelling printed products; most likely the strength of printed products. A map pocket (automobile interior door part)was used for the study. The map pocket which was to be manufactured by conventional process of injection molding attributed to undercut arising due to placement of fixation feature (doghouse); which requires specific space for operation of lifter. No strengthening features can be placed over this place ultimately making it weak over that area. The changes in fixation demanded major design changes.In order to avoid this; map pocket which was to be manufactured by conventional process of injection molding was instead manufactured by fused deposition modelling (FDM). The map pocket was successfully printed with multi nozzle 3D printer for combination of ABS and PLA material for a single part and further it was tested on UTM*

Keywords- 3D printing, injection molding,multi-material.

I. INTRODUCTION

Additive manufacturing is growing rapidly over the past years widely in manufacturing industry. Three-dimensional (3D) printing is one of the method of additive manufacturing process. In 3D printing the required product is manufactured by addition of material layer by layer until the required form and shape is achieved. Unlike conventional processes this is done without any special tool or forming operation. [1]Additive manufacturing produces less waste compared to other conventional processes certainly having less impact on the environment. One of the additive manufacturing technology widely used for rapid prototyping is fused deposition modelling (FDM). It is suitable for manufacturing of components with complex structure and geometries. Fused deposition modelling uses the principle of layer by layer manufacturing. The polymer is melted and extruded in the form of filament from the heated nozzle and deposited in the required pattern on the bed. As soon as the material is deposited it starts to cool and bonds to the adjoining layer. The bed simultaneously moves downward after each layer is deposited with the same value as of filament thickness and then another layer is deposited. This is repeated till the whole part is built up.

Initially additive manufacturing was used for prototyping widely in various fields; but nowadays with continuous innovation and advances in manufacturing processes additive manufacturing has found wide application in the manufacturing industry for the production of various tools and end user components. It is very important to imply considerable improvements which has to be done to develop the additive manufacturing process fully for manufacturing process instead using it only for prototyping. One of the important improvements is the limited mechanical properties of the 3D-printed plastic parts compared to injected material.
Considering the challenges in the plastic injection molding like design of the tool, design of the mold, duration to completely develop and manufacture the product which result in high cost production. Various considerations are used in plastic injection molding design procedure such as use of uniform wall thicknesses throughout the part is preferred, this minimizes sinking, warping, residual stresses, and improve mold fill and cycle times. Unlike plastic injection molding 3D printing is simple and easy. The only difficult task is to design the product and it can be directly printed from the CAD model. Various steps present in plastic injection molding are eliminated which saves time and cost involved in production.
Recent growth in FDM technologies has given boom to innovative developments like multi-material 3D printing. Multi-material 3D printing uses two or more materials to print the part in which the 3D printer uses multiple filaments linked to the nozzles to control the materials to be deposited. Though it does not look like a major improvement but these improvements can largely contribute to improvement of mechanical properties of the 3D printed parts as two or more materials are used. Much research regarding the enhancement of the mechanical properties for FDM processes by adjusting

the printing orientation angle or material composition has been actively conducted. Furthermore, multiple-material printing can be used to enhance specific parts of the printed-product with low mechanical properties due to geometric structure issues [2].

II. PROBLEM STATEMENT

The presence of the strengthening or fixation features on the automotive plastic interior map pocket leads to the undercut due to which the tool cannot be cleared in the main tooling direction. Due to specific space requirements for lifter operations there is no provision to place strengthening features around the periphery of the dog houses ultimately weakening the part around that region. There has to be an alternative for lifter operation so it does not hinder the strengthening or the strengthening features has to be manufactured differently as in separately or by different method.

III. LITERATURE SURVEY

Michael Dawoud et. al. studied the mechanical properties of ABS part comparatively prepared by injection moulding and 3D printing. From the results obtained by conducted tests it was observed that injection molded parts exhibited better mechanical properties compared to that of 3D printing. The characteristic features such as material compaction and crystalline structure of injection molding lead to increase in the mechanical properties. The study reports that parts with acceptable properties can be produced by fused deposition modelling with accurate parameter selection. The raster gap being a vital factor, almost the density of injected parts can be achieved at a negative gap of−0.05 mm. Printed parts are able to reach 91 percent and 86 percent of the tensile strength and flexural strength of injection moulded parts respectively. A negative raster gap in combination with a 45◦raster angle is recommended if a high density part with enhanced mechanical properties is desired [4].

Divyathej M V et. al. conducted an experimental study for ABS material parts which were manufactured by both injection moulding and 3D printing. Injection molded samples exhibited maximum flexural strength compared to FDM which was 57.937 MPa. The molecular orientation in the specimen has a significant influence on the results. Sample with high degree of molecular orientation normal to applied load exhibited high flexural results. Bond and molecular orientations were high in injection moulded parts to that of FDM. Maximum flexural strength of 53.505 MPa was obtained for the sample of FDM with 0.2 mm of layer thickness. Bond strength between layers was lower than that inside a strip. Loaded in Z direction, flexural strength depends on bond strength inside a strip, at the same time when loaded in X direction, it depends on interlayer bond strength [5].

Heechang Kim et. al, printed multiple-material printed specimen as one body part extruded partially with ABS and PLA to verify the effect of a percentage of each material by using FDM 3D printer which can extrude dual filaments. Parameters like orientation angle: *x*-direction, infill rate: 100% were fixed except for proportion of materials. All the samples were designed as symmetric structure. The middle portion of the sample was extruded with different material. Percentages of specimen were differed as 20%:80%, 40%:60% and 50%:50% (ABS:PLA). The sample with 20% ABS to 80% PLA exhibited maximum average ultimate tensile stress among all extruded samples with respect to different proportion of materials[6].

Y. Song et.al. measured the orthotropic mechanical response of 3D-printed PLA in different directions manufactured using the FDM. This study highlights the features related to mechanical response of 3D-printed products, showing that the fracture behaviour is direction dependent these are anisotropic and asymmetric. By optimising the extrusion speed and temperature the porosity of the material can be minimised which improves mechanical response of the part. The fracture response of the material is tougher when this is tested in the axial direction then in the transverse direction. It is observed that 3D-printed PLA is tougher than injection-moulded PLA; this is due to the layered and filamentous nature of the 3D-printed material and the complexity that this induces in the microscopic mechanisms of fracture [7].

L.R. Lopes et. al. addressed the most critical issue of boundary layer interface in multi-material 3D printing which is the geometrical boundary separating two different materials. By using multi-material 3D printing it became feasible not only to have multi coloured parts but also to produce multi-functional objects by the use of multi filament extrusion. Manufacturing of components with multi-material 3D printing gives rise to boundary layer interfaces for different materials. The effect of the boundary interface was analysed for two cases: first, the boundary interface between the same material was evaluated, to quantify the performance change when the active extrusion head switches; second, the interface between different materials, to demonstrate the performance dependence on the chemical affinity between the materials [8].

IV. ISSUE ARISING DUE TO LIFTER OPERATION FOR DOGHOUSE

Considering the CAD model of the map pocket of automobile interior door panel shown in the fig., there are 3 doghouses located on the part which account for undercut in injection moulding. The presence of the doghouse on the automotive plastic interior map pocket leads to the undercut due to which the tool cannot be cleared in the main tooling direction. Considering this lifter has to be used for the easy removal of undercut of the doghouse; but due to specific space requirements for lifter operations there is no provision to place strengthening ribs around the periphery of the dog houses ultimately weakening the part around that region.

$$\text{Space for lifter operation} = 2 \times \; undercut + lifter\ size + \; 5mm(clearance)$$

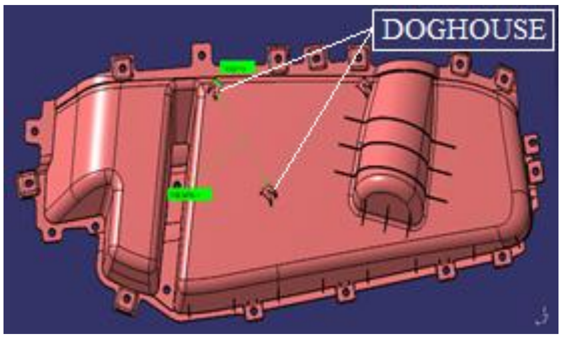

Figure.1. CAD Model of MAP POCKET

The distance between the two doghouses as shown in figure is 118.34 mm. The length of the dog house is 18 mm. According to design consideration for operation of lifter a total of 60 mm space is required. The consideration for this space is (2*undercut +lifter travel+ 5mm clearance). There are no strengthening features around these doghouses near about 284 mm. This makes the portion weak over there. Also it is not possible to place any features about 60 mm around the periphery of the doghouse as it will interfere in the operation of lifter for doghouse. The remaining space left around the doghouse is about 58 mm only. This space can hardly accommodate the strengthening features effectively for strengthening. As there are no other strengthening features placed over the portion there is no support for the component. As a large area is involved without any support the component gets weakened. Also there is no provision to change the location of the doghouse as the substrate is already designed. Therefore, whole design has to be changed accordingly the substrate parts and its surrounding parts.

V. MULTI-MATERIAL 3D PRINTING

The occurrence of undercut due to the presence of doghouse weakens the part around the area of doghouse. To avoid this, considerable changes in design has to be made. Instead without changing the fixation, it is possible to manufacture the map pocket by using fused deposition modelling. There is no complication like undercut involved in 3D printing, so the stiffeners can be designed and placed accordingly and manufactured easily without any complexity with additive manufacturing; so that strength over that portion can be increased. The major issue in FDM is of the mechanical properties of the material used for manufacturing of a component. In order to cope with the mechanical properties of the component, multi-material 3D printing is used. Multi-material printing allows printing single object with two or more materials. The materials to be used can be varied according to the properties required. Here as more strength is required around the doghouse where the strengthening ribs are placed are manufactured by high strength material than the material used for base parts. This gives more strength to the portion where it is possibly going to fail unlike for single material printing. This leads to increase in mechanical properties of the component compared to the component manufactured by single material. Multi-material printing allows objects to be composed of complex and heterogeneous arrangements of materials.

VI. MODELLING AND SIMULATION

In order to optimize the design for strengthening purpose, two other CAD models were developed with different design configurations for rib structures around the periphery of doghouses.

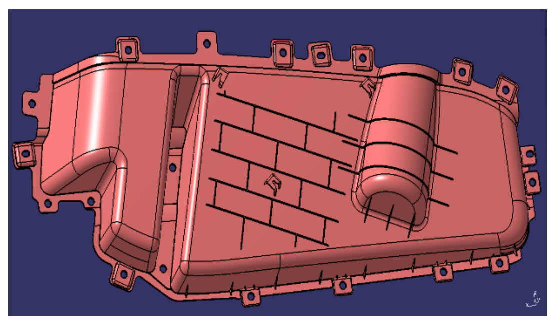

Figure.2. CAD model of map pocket with brick rib structure.

One of the design developed was with the brick rib structure. The strengthening features were added to the part. The ribs were placed in the form of the brick arrangement.

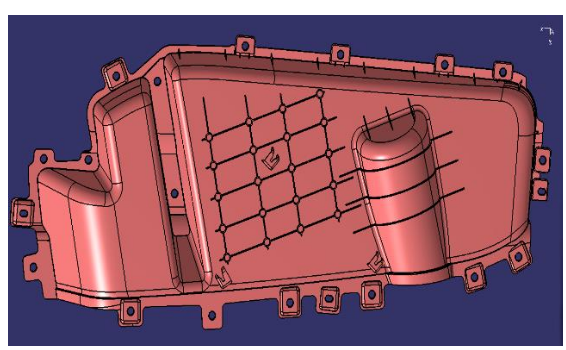

Figure.3. CAD model of map pocket with cylindrical rib structure.

Other design developed was with the cylindrical rib structure. The strengthening features were added to the part. The ribs were placed in the form of the square structure with cylinders at the intersection of the square ribs.

The CAD models developed were used to develop the mesh models for different material properties. After preparation of mesh models, they were analyzed for deformation, stress concentration and force reaction. For the base part the material defined was ABS whereas for the strengthening ribs the material defined was PLA.

Table 1. Results for total deformation, equivalent stress and force reaction for different structures with different materials.

Rib Structure With Material	Total Deformation (mm)	Equivalent Stress (MPa)	Force Reaction (N)
Brick rib structure for ABS material	5.019	53.964	205.05
Brick rib structure for ABS and PLA material	5.02	39.885	112.34
Cylindrical rib structure for ABS and PLA material	5.044	42.621	105.67

The results from the simulation model were obtained for the total deformation, equivalent stress and force reaction for map pocket brick rib structure with material ABS and combination of material ABS and PLA whereas for map pocket with cylindrical rib structure material used was combination of ABS and PLA. From the results obtained for simulated models the deformation was almost same therefore the selection of the model was mainly dependent on equivalent stress and force reaction. The brick rib structure for single material had more force reaction than that of brick rib structure for multi material; but the equivalent stress arising in the brick rib structure for multi material was least compared to other models. So the brick rib structure with multi material is recommended for the manufacturing.

VII. MANUFACTURING

Two types of materials, PLA and ABS filaments were used to print the component. The diameter of the filaments used is 1.75 mm. The FDM 3D printer used for the experiment was Zortrax M300 Dual printer with two (dual) nozzles. The diameters of 0.4 mm were used for the both nozzles and the temperature was configured as 210° Cand 230° Cfor both the PLA and ABS filaments. The temperature of the heating bed was set as 80° C.

The component was manufactured by using two materials ABS and PLA. The base part along with the features was manufactured by using ABS material, whereas the strengthening ribs were manufactured by using PLA material.

Table 2. Material properties of ABS and PLA material.

Property	ABS	PLA
Density	1200 kg/m^3	2470 kg/m^3
Tensile Strength	49.0 MPa	114 MPa
Flexural Modulus	5500 MPa	1380 MPa
Hardness Rockwell	113 R	85 R
Youngs Modulus	3500 MPa	2900 MPa

The CAD model designed in modelling software was then converted to the .stl file to print it on 3D printer. Pre-processing required for the model to make it easily printable was done. The model was sliced into pieces to make layer by layer distribution to simplify it. The G codes required for the extruder were generated so as the extruder can trace the path required for printing. Then the Z-SUITE was used to send the file which is already pre-processed model to the 3D printer for printing.

Figure 4. 3D Printed Map Pocket

The main parameters considered were the nozzle temperature (defines the filament melting), the temperature of the printing surface (for adhesion enhancement) and the printing speed. The component was printed with a layer thickness of 0.2 mm. There is a rule of thumb within the 3D printing process stating that the layer thickness should not be above 80% of the nozzle diameter. Moreover, the value 0.2 mm is currently a standard value among most of all 3D printers. Although it would have been possible to have a lower thickness as 0.1 mm, the printer would have been working close to its layer resolution, which could have introduced defects on the parts. The map pocket was printed with 100 % infill rate, which represents a full part with no intentional voids in its inner section. The component was oriented along the x-axis of the print, and located at the middle of the printing surface. The extruder was directed along the x direction to print the map pocket.

The base part of the map pocket which was printed by using ABS material was manufactured in 14 hours and 57 minutes, while the strengthening ribs which were manufactured by using PLA material required a total time of 3 hours and 54 minutes accounting to a total time of 17 hours and 51 minutes.

VIII. EXPERIMENTAL TESTING

The map pocket manufactured by the 3D printing was put to test on the universal testing machine. The head of the UTM was loaded on the map pocket and starting force of 1 N was applied on the map pocket under controlled conditions. The force on the map pocket was increased continuously by 1 N.The map pocket sustained the force effectively until a force of 102.97 N where crack was initiated at the central portion of the map pocket where the strengthening ribs are located. The plot of the cross head travel of the UTM head and load (KN) was generated through the computer connected to the UTM. From the plot in figure the total cross head travelled is 5mm for which the load was 102.97 N.

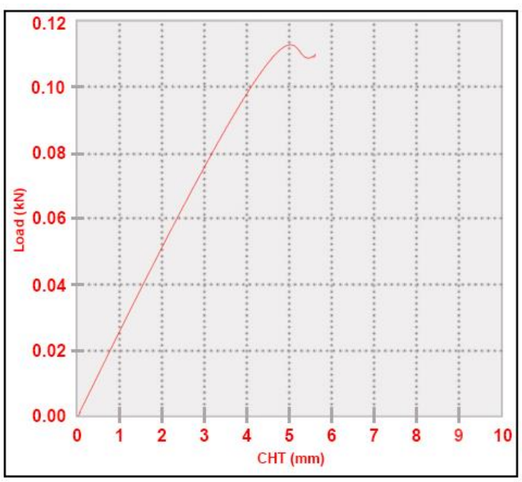

Figure 5. Plot of Load (KN) Vs Cross Head travel (mm).

IX. RESULTS AND DISCUSSION

- The limitation arising in manufacturing for injection molding due to the presence of undercut in map pocket was eradicated by using 3D printing process for manufacturing of the map pocket.
- The existing design of the map pocket for strengthening features was analyzed for strengthening by adding different rib structures such as brick rib structure and cylindrical rib structure; where the design was finally optimized by brick rib structure as it showed more strength in comparison to the cylindrical rib structure.
- The map pocket was manufactured by 3D printing under controlled conditions by using combination of ABS and PLA material. The interface between the boundary of two different materials was observed and found to be intact. No gaps were observed between inter layer of ABS and PLA. Both the materials were found to be fused with each other effectively.
- The same component manufactured was tested on the UTM for load Vs deformation. The test result obtained was, a crack was initiated for the load of 102.97 N which was expected to occur for the load of 112.34 N according to the results obtained from the simulation.
- It was observed that part which is to be designed for plastic injection moulding can also be manufactured by using 3D printing without compromising on the strength of the component.
- Also the component can be manufactured by using one or more materials with different properties so that the strength of the component can be increased compared to that of with single material.

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