Product Development and its Comparative Analysis by SLA, SLS and FDM Rapid Prototyping Processes

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Abstract. To grab market and meeting deadlines has increased the scope of new methods in product design and development. Industries continuously strive to optimize the development cycles with high quality and cost efficient products to maintain market competitiveness. Thus the need of Rapid Prototyping Techniques (RPT) has started to play pivotal role in rapid product development cycle for complex product. Dimensional accuracy and surface finish are the corner stone of Rapid Prototyping (RP) especially if they are used for mould development. The paper deals with the development of part made with the help of Selective Laser Sintering (SLS), Stereo-lithography (SLA) and Fused Deposition Modelling (FDM) processes to benchmark and investigate on various parameters like material shrinkage rate, dimensional accuracy, time, cost and surface finish. This helps to conclude which processes can be proved to be effective and efficient in mould development. In this research work the emphasis was also given to the design stage of a product development to obtain an optimum design solution for an existing product.

1. Introduction
The competition in the world market due to globalization for manufacturing products has intensified tremendously in recent year. The enormous competition forces the manufacturing company to produce product in good quality, more quickly, and at lower cost. In contrast to the larger batch size requirements, the market demands are now becoming customer centric needing smaller batch sizes with shorter life cycle. This also increases the burden to the production unit during the mould development for satisfying such a dynamic requirement [1,2]. The overall time- to- market becomes a key factor in remaining competitive. Rapid Prototyping (RP) process can reduce the time to market of the products [3]. In the last 30 years, the demand for products of increasingly high quality and lower cost has brought about substantial changes in the industrial. An increase in productivity has been attempted through with technical innovation and automation in manufacturing. Rapid Prototyping Technologies, otherwise also known as Solid Freeform Fabrication, Desktop Manufacturing or Layer Manufacturing Technologies have shown significant progress over the past two decades. The term rapid prototyping (RP) refers to a class of technologies that can automatically construct physical models from Computer – Aided Design (CAD) data [4-5, 6]. Classification of RP systems can be broadly done by the initial form of its material used i.e. the material with which the component or prototype is built. In the present scenario, the commonly used forms of material in all the RP systems are Liquid-Based, Solid-Based, and Powder-Based [5, 7-8]. RP is widely used in the automotive,
aerospace, medical and consumer product industries. They can be widely used for prototyping, rapid tooling and rapid manufacturing [9-13]. Nowadays, RP is emerging as a rapid manufacturing technique, which produces the functional parts in practically all the applications ranging from Dies and Molds, Aerospace, Marine, Biomedical to Fashion and Jewelry. This demands a higher accuracy in RP parts. Hence, the objective of this study is to compare and comment on dimensional accuracy, shrinkage, surface finish, building time and cost involved for different RP technologies such as SLA, SLS and FDM.

2. Experimental Study- Product Design and Development

In this study an industrial part Fluid Premixer is considered for re-design and re-development since it was subjected to premature failure due to the application of pressure load at the centre. Figure 1 shows the 3D CAD model developed using Solid Works software. Modifications in the existing design model were carried out based on its deformation pattern and stress analysis.

![Figure 1. 3D CAD model of a Fluid Premixer without stiffener (original component)](image1)

![Figure 2. 3D CAD model of a Fluid Premixer with stiffener (modified component)](image2)

It was observed in Finite Element (FE) simulation that the component (original) as shown in Figure 1, was more susceptible for deformation and hence stresses at the centre. Thus, it was the root cause of failure. However it was overcome by re-designing the component i.e. by providing stiffener member in order to reduce the deformation and stress.

Thus, brainstorming was done to identify the approximate solution so that the deformation and stresses should be safe to accept. The deformation was controlled by providing mass stiffeners and thereby the induced stresses. To implement this solution, two ways were identified such as placing a solid disc equal to the outer diameter of the part (at top) and performing simulation trial for different thickness or placing the stiffeners like ribs in array form as shown in figure 2. Therefore, the attempts were planned to modify the component geometry without affecting its functional use. Initially component was modified by placing 4 numbers of stiffeners of 1, 1.5 and 2 mm at 90° phase. Components with these different values of stiffeners (thickness and depth) were simulated, but still the results were not satisfactory in regards to the induced values of deformation and stress. Further attempts were made to modify the component by placing 5, 6 and 7 numbers of stiffeners of 1, 1.5 and 2 mm at regular phase angle. Yet the results were not satisfactory. Finally by placing 8 stiffeners with 2 mm thickness at 45° phase has helped solving the problem. Thus the deformation value obtained was lesser and acceptable in this trial as compared to original model (without stiffener). Hence, the attempts with 2 mm have shown the effective and optimum utilization of material as compared to solid disc. The simulation results obtained for 2 mm thickness stiffeners at 45° are shown in Figure 3 (a and b) for deformation and Figure 4 (a and b) for stress in component without and with stiffeners:
Deformation Analysis (without stiffener), mm
Max. 8.753e-1
Min. 2.918e-1

Deformation Analysis (with stiffener), mm
Max. 2.722e-1
Min. 1.000e-030

Stress Analysis (without stiffener), MPa
Max. 35.111
Min. 0.098

Stress Analysis (with stiffener), MPa
Max. 22.982
Min. 0.039
3. Comparative Analysis of Different Rapid Prototyping Techniques (RP)

It has been identified that SLA, SLS and FDM are three techniques widely used and hence they have been chosen for the study [2]. Fluid Premixer prototypes were built by using three different rapid prototyping techniques. Figure 5 shows prototype build using fused deposition modelling (FDM) process and material used is ABS (Acrylonitrile Butadiene Styrene), Figure 6 shows prototype build using Selective Laser Sintering (SLS) process in which SLS Duroform PA (polyamide) is the material used and in Figure 7 prototype build using Stereo-Lithography (SLA) process and the material used is Accura 25 (Polypropylene Equivalent). These sets of components were compared based on few major parameters like material shrinkage, dimensional accuracy, surface finish, building time and cost etc.

4. Comparison of Shrinkage Percentage and Dimensional Accuracy

Dimensions of fabricated specimens were measured using vernier calliper (least count 0.02mm). The results of measurement are given in Table 1. Shrinkage Percentage for each of the specimen is calculated by using the following equation:

\[
\text{Shrinkage Percentage} = \frac{A-B}{A} \times 100
\]

Where A is the dimension in original CAD model and B is the measured dimension of prototype. Lesser values of shrinkage percentage is an indication of achieving closer dimension. Thus, the part made with SLA technique has been found to have better dimension accuracy as compared to other two techniques.
Table 1. Measured Dimension of the three different RP part

| RP Process | Parameter Measure | CAD Dimensions, A (mm) | Measured Dimensions, B (mm) | Shrinkage Percentage = (A-B)/A*100 |
|------------|-------------------|------------------------|-----------------------------|----------------------------------|
| SLA        | Outer Diameter    | 54.6                   | 54.5                        | 0.183                            |
| SLA        | Inner Diameter    | 50.6                   | 50.5                        | 0.198                            |
| SLA        | Outer Diameter 1  | 44                     | 43.92                       | 0.182                            |
| SLA        | Inner Diameter 2  | 34                     | 33.88                       | 0.353                            |
| SLA        | Rib thickness     | 1.5                    | 1.498                       | 0.133                            |
| SLA        | Slot length       | 8                      | 7.96                        | 0.500                            |
| SLA        | Slot height       | 10                     | 9.96                        | 0.400                            |
| SLA        | Slot width        | 4                      | 3.98                        | 0.500                            |
| SLA        | Height            | 13.6                   | 13.54                       | 0.441                            |
| SLS        | Outer Diameter    | 54.6                   | 54.3                        | 0.549                            |
| SLS        | Inner Diameter    | 50.6                   | 50.32                       | 0.553                            |
| SLS        | Outer Diameter 1  | 44                     | 43.78                       | 0.682                            |
| SLS        | Inner Diameter 2  | 34                     | 33.78                       | 0.882                            |
| SLS        | Rib thickness     | 1.5                    | 1.49                        | 0.667                            |
| SLS        | Slot length       | 8                      | 7.94                        | 0.750                            |
| SLS        | Slot height       | 10                     | 9.92                        | 0.800                            |
| SLS        | Slot width        | 4                      | 3.98                        | 0.500                            |
| SLS        | Height            | 13.6                   | 13.5                        | 0.735                            |
| FDM        | Outer Diameter    | 54.6                   | 53.8                        | 1.465                            |
| FDM        | Inner Diameter    | 50.6                   | 50                          | 1.186                            |
| FDM        | Outer Diameter 1  | 44                     | 43.7                        | 0.682                            |
| FDM        | Inner Diameter 2  | 34                     | 33.7                        | 0.882                            |
| FDM        | Rib thickness     | 1.5                    | 1.48                        | 1.333                            |
| FDM        | Slot length       | 8                      | 7.88                        | 1.500                            |
| FDM        | Slot height       | 10                     | 9.9                         | 1.000                            |
| FDM        | Slot width        | 4                      | 3.94                        | 1.500                            |
| FDM        | Height            | 13.6                   | 13.42                       | 1.324                            |

5. Comparison of Surface Roughness among the three different Prototypes

To compare the surface roughness of three different prototypes, the surface roughness of each three types of part was measured by using Mitutoyo Surface Roughness Tester mounted on Metzer Optical profile projector as shown in Figure 8. Because of the intricate geometry, only the top surface of Section 1, the periphery surface (Ribs surface) of Section 2 as shown in Figure 9-11 were measured.

The measured surface roughness values are given in Table 2. According to Table 2, prototypes made from the Stereolithography (SLA) process have the smoothest surfaces, ranging from 1.41 µm to 2.28 µm. Prototypes made from FDM have highest surface roughness ranging from 2.28 to 0.92 µm.
Figure 8. Surface roughness measured using Mitutoya Surface Roughness Tester on Meterz Optical Profile Projector.

Figure 9. Surface Roughness measurement (SLA).

Figure 10. Surface Roughness measurement (SLS).

Figure 11. Surface Roughness measurement (FDM).
Table 2. Measured surface roughness of three different RP parts

| RP Process | Parameters       | Section 1 (Top Surface) Ra value in µm | Section 2 (Rib surface i.e. Periphery) Ra value in µm |
|------------|-----------------|----------------------------------------|-------------------------------------------------------|
| SLA        | Readings        | 1.40, 1.40, 1.45                       | 2.21, 2.34, 2.29                                      |
|            | Mean            | 1.41667                                | 2.28                                                 |
|            | Standard Deviation | 0.02887                          | 0.06557                                               |
| SLS        | Readings        | 2.61, 2.34, 2.29                       | 3.21, 2.84, 2.66                                     |
|            | Mean            | 2.41333                                | 2.90333                                               |
|            | Standard Deviation | 0.17214                         | 0.28042                                               |
| FDM        | Readings        | 3.31, 3.64, 2.89                       | 4.61, 3.84, 2.76                                     |
|            | Mean            | 3.28                                   | 3.73667                                               |
|            | Standard Deviation | 0.3759                             | 0.92932                                               |

6. Comparison of other parameters for three different RP parts
Table 3 shows the comparison for the part made by three different RP Process in terms of building time, machine setting time and cost.

Table 3. Comparison of process methods to create RP Fluid Premixer

| RP Process | Time Taken | Machine Setting | Cost in Rupees/part | Material                  |
|------------|------------|-----------------|---------------------|--------------------------|
| FDM        | 2hrs/part  | 10 min          | 733                 | ABS                      |
| SLS        | 5hrs/part  | 13 min          | 1392                | Duraform Polyamide (nylon)|
| SLA        | 4hrs/part  | 17 min          | 2468                | Accura 25(Polypropylene Equivalent)|

Table 3 suggests that in terms of building time and cost, FDM process takes the shortest time and has minimum cost as ABS material is cheaper than the material used in other two RP processes. Whereas SLA ranks second in building time but it is an expensive process as the material cost is high.

7. Conclusion
This paper present the work related to the re-design and re-development of an industrial component Fluid Premixer to reduce the induced stresses and deformation factor at the centre of the component. By addition of mass that is stiffener to the centre of the component the deformation and stresses were brought to the acceptable value. By placing stiffeners the maximum deformation has been drop from 8.753e-1 mm to 2.722e-1 mm and the induced stresses have been drop by 34.54%. This also solved the issue of premature failure of the component by using the material in optimise way. Thus, FE simulation has played a key role in deciding the appropriate thickness and number of stiffening ribs required. This has saved a lot of time and cost as compared to building the physical prototype and testing for all combinations of ribs.

Investigation of the various parameters like the shrinkage percentage, dimensional accuracy, surface roughness, building time, machine setting time and cost for the parts made by SLA, SLS and FDM processes was carried out with the aim of validating the system for mould development. The dimensions of Fluid Premier made by these RP processes were measured and shrinkage percentage was calculated. It was observed that the prototype build by SLA process has lesser shrinkage as compare to SLS and FDM process. This provides closer dimension achievements of RP part. Shrinkage Percentage found to be lower in the range of 0.1 to 0.5 in case of SLA, in the medium range of 0.5 to 0.8 in case of SLS and higher variations are found in the range of 0.6 to 1.5. The results of the study also showed that the surface finish of SLA part was best amongst the three RP process when complexity of the job is to be considered. This is because of fundamental principle on which they work. This is also supported by calculated standard deviation for SLA process. In case of FDM
process, stair casing was observed as compared to other RP processes, thereby affecting the surface finish of part. SLS technique seems to be more mechanically complex than other process of RP. For simple plane surface shape of the part with less intricacy the FDM process gives good surface finish with moderate cost of production. In terms of building time and cost, FDM process takes the shortest time and has minimum cost as ABS material is cheaper than the other two processes. Whereas SLA ranks second in building time but it is an expensive process as the material cost is high. Therefore, there is a trade-off between SLA and FDM on the basis of shrinkage percentage, dimensional accuracy, surface roughness or building time, machine setting time, cost and with average surface finish.

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