Recycling of RP Models by Solution – Casting Technique

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Abstract

Most of the Rapid Prototyping systems process polymeric materials for model making. Increased environmental concerns and waste minimization demands the recycle of these polymeric models. One way is to melt the models and cast it. However, in this method polymer degradation may occur leading to diminished functionality. In the present work a preliminary attempt has been made to reuse the polymer components by dissolving in a suitable solvent and casting the same into the required shape using soft tooling. Acrylonitrile Butadiene Styrene (ABS) polymer components, made by Fused Deposition Modeling (FDM) process were taken for the present study

1. Introduction

Rapid Prototyping is key prototyping technology for producing accurate parts directly from CAD models with little need for human intervention. With the introduction of RP, designers have the freedom of realizing all the instances of the conceptual design. Further, this allows unlimited checking as required of form, fit and assembly of the design [1]. In the total product development cycle, there will be a lot of design iterations before the design is freezed. During each cycle, prototypes will be made for checking. The end products of the most of the RP systems are polymeric models. Plastics are so versatile in use that their impact on the environment is extremely wide ranging. However, they are difficult to destroy and are classified as non-biodegradable materials. The each design iteration will produce a prototype which will accumulate to significant solid waste. With increased environmental concerns, strict legislations with further emphasis on material recovery there is a requirement for recycle of RP solid waste. One way is to reuse these polymers by melting and casting the same to required shape through proper tooling. Polymeric materials are mostly thermo – dynamically incompatible. Often during recycling, a decline in the quality of the material properties is observed. The properties of secondary products may be worse than the properties of products made from virgin plastics.

In the present work, a preliminary attempt has been made to recycle the RP polymeric materials. A solid based RP method FDM (Fused Deposition Modeling) was chosen for the present study. The basic material for the FDM is ABS (Acrylonitrile Butadiene Styrene). ABS is copolymer composed of two copolymers and is one of the most common polymer materials. Styrene and Acrylonitrile form a linear copolymer (SAN) that serves as a matrix. Butadiene and styrene also form a linear copolymer (BS rubber) which acts as the filler material. The combination of the two copolymers gives ABS an excellent combination of strength, rigidity and toughness. The main objective of the present work is to get a component from a solid waste. For this purpose ABS polymer, a used FDM (Fused Deposition Method) component was taken and dissolved in suitable solvent and casted through proper tooling.

2. Methodology

The procedure of solution-casting technique for recycle of RP polymeric waste is depicted in Fig. 1 and described subsequently.

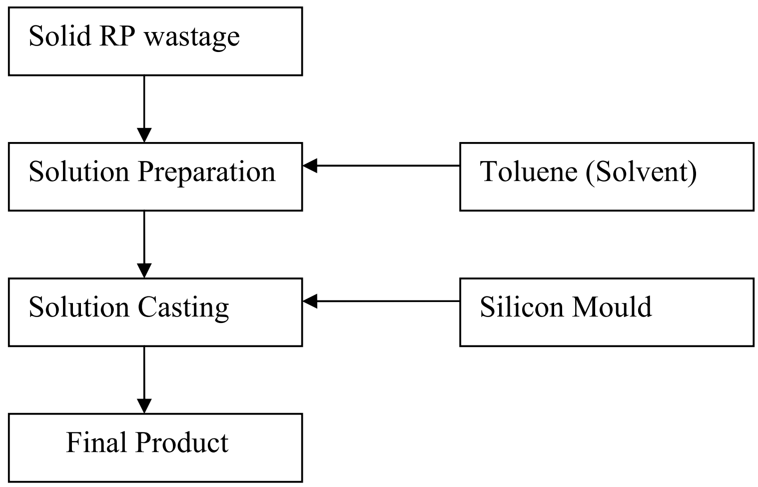

Fig. 1. Sequential Steps of the Proposed Methodology

2.1 Materials

Acrylonitrile Butadiene Styrene (Stratasys & Co, USA), Analytical grade toluene (Ranbaxy, India), Silicone (HEK, Germany), release agents (HEK, Germany) were used for the work.

2.2 Polymer Solution Preparation

The solubility of a given polymer in a solvent depends on the chemical structure**.** One way to measure the solubility is by finding the difference between solubility parameters of the polymer and solvent [2]. If the difference between these two is small, then the polymer is completely soluble in solvent. Solubility parameter is defined as the square root of cohesive energy density. The cohesive energy density is defined as the cohesive force (heat of vaporization) to the molar volume. The cohesive energy density as well as solubility parameters of various polymers and solvents are listed in the Van Krevelen [3]. For unknown polymers group contribution method is used.

The first step in estimating the solubility parameter for the present specification of ABS is to measure the butadiene content. Butadiene is estimated by dispersed fixed quantity of ABS in acetone solvent and centrifuged. The supernatant contains copolymer of Acrylonitrile and Styrene and is decanted from the grafted phase of Butadiene. The butadiene content is 14% and further, it is assumed that Acrylonitrile and Styrene are present in equal molar ratio. Therefore, solubility parameter of ABS estimated is 17 $J^{0.5}/m^{1.5}$. This value is compared to solubility parameters of various solvents given in the Van Kreyelen [3] and toluene is selected (solubility parameter 18-18.5 $J^{0.5}/m^{1.5}$) as solvent.

ABS polymer in 1:4 was added to toluene in a conical flask. The mixture was kept on magnetic shaker for two days to get homogenous solution. The obtained solution was centrifuged (REMI model -R 24) at 10000 rpm for 30 minutes for the removal of un-dissolved polymer and dust particles. The supernatant homogeneous solution was transferred to a conical flask (air tight) and kept for overnight for the removal of entrapped air bubbles.

2.3 Silicon Mould Preparation

The Master model is examined thoroughly for its dimensions and cleanliness. Further, parting line and position of the gate are decided. Clear taping along the parting line and coloring the edge of the tape is done to assist in cutting the mould along parting line. The master model is hanged in a casting frame (laminated chip board/ wooden board) whose dimensions allow for sufficient clearance from the model. Degasified silicon resin and catalyst (HEK, Germany) are mixed in proper ratio (10:1). This semi solid mixture is poured slowly and steadily into the casting frame. For secondary degasification, the casting frame is kept in vacuum chamber (10 – 25 minutes). The actual time of degasification depends on volume of the rubber. To get extreme dimensional accuracy in the castings, the resin mixture is cured in oven (40^0C for 6-8 hours). The cured mould is then cut along the parting line with a help of sharp scalpel and mould openers. Cutting is made along undulating path to allow for perfect alignment of male and female halves.

2.4 Casting Models

Figure 2. Silicon Mould for Cube

Fig. 3 Silicon Mould for Aerofoil wing

The prepared silicon mould is ready for casting is shown in Figure 2 & 3 for aerofoil wing and cube subsequently. Release agents are applied on the cavity of the silicon mould for easy detachment of cast component. The mould parts are held together by proper fixturing so as to prevent deformation in silicon mould due to excessive swelling as toluene diffuses during evaporation. The solution is poured into the mould and left to cure by exposing the same to atmosphere 10 to 12 hours. The mould is further kept in vacuum oven for removal of residual solvent.

3. RESULTS AND DISCUSSION

Aerofoil wing model is chosen to demonstrate the applicability of the proposed methodology. Aerofoil wing is a typical shape which has variation in thickness from head to tail. The obtained aerofoil wing model is satisfactory from the shape and smoothness point of view which is shown in Figure 4. However, the strength is varying from the head to tail because part of head is strong and part of it is hollow. This is because of improper casting and it can be rectified by pouring the polymer solution in regular time intervals. The main objective of the present work is to answer the following questions

- How many steps it will take for complete casting?
- Exactly, how many days it will take to complete the model?
- What is the dimensionality of the end product?
- What more conditions are required for the present process?

Aerofoil model is too ambitious to answer the above questions because of its complex shape. So, a simple cube 5 x 5 x 5 (cm^3) has been taken for experimentation. Approximately 25 steps and 15 full days were taken to complete the component. The dimensionality is satisfactory and is shown Fig. 5. The present casting is carried out in atmospheric conditions. The silicon mould after detaching the model is thoroughly checked and there is no surface damage. It indicates that there will not be any severe destructive chemical reaction between silicon, toluene and ABS.

4. CONCLUSIONS

The present work is an attempt to prepare the prototype/products from the solid wastage of FDM (ABS) components using solution-casting method. Aerofoil wing and cube are chosen to demonstrate the present work. The obtained shape (dimensions) and smoothness is satisfactory for chosen model. However, more studies are required to understand the role of various properties and/or conditions required to get the final product. This preliminary study underlines the potential of application solution-casting technique to recycle of FDM (ABS) components.

5. REFERENCES

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Fig. 4. Final Aerofoil wing model

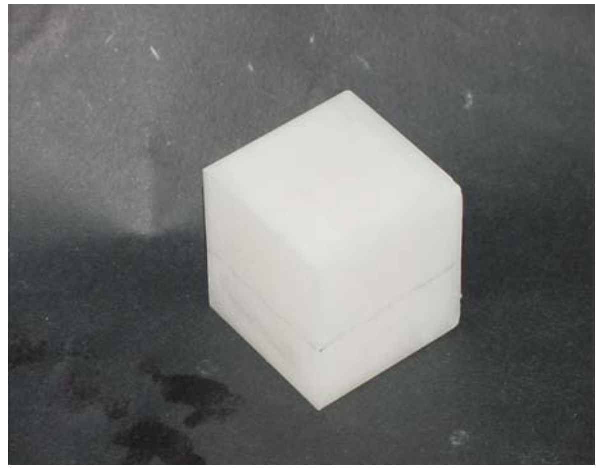

Fig. 5. Final Aerofoil wing model