Utilization of Waste Polystyrene Material in Local Foundry Technology for Manufacturing Complex Shapes

Mesay Alemu Tolcha
Mechanical Engineering Department
Jimma Institute of Technology, Jimma University
Jimma, Ethiopia

Getachew Shunki Tibba
Mechanical Engineering Department
Jimma Institute of Technology, Jimma University
Jimma, Ethiopia

***Abstract*—In traditional foundry technologies, casting of complex shapes is very difficult, if not impossible, due to difficulties in pattern removing. Pattern removal affects the mold cavity and gives inaccurate shape of the product. To overcome this difficulty, the pattern is replaced by polystyrene materials. Polystyrene material is used for making a pattern that evaporates when a molten metal is poured into the mold cavity. This technology is also called lost foam casting as the pattern material is lost through evaporation. Lost foam casting is a relatively new advanced technology that helps in manufacturing products of complex shape with better quality.**

The ultimate goal of this task is to utilize wasted polystyrene material in local foundry technology to produce complex shape with minimum labor, shorter production time, no burden of pattern removal. The work also shows the possibility of preventing environmental pollution through recycling waste polystyrene that is imported as a packing material.

In this study, a computational model has been developed to simulate and optimize the filling process of molten aluminum (Al242) and directional solidification of sample pulley for the purpose of predicting the potential defect areas by using commercial Soldcast and 3D flow software. Finally, the optimized model has been used for casting a sample pulley.

***Keywords*— *Polystyrene; Lost foam casting; Directional solidification; Potential defects*.**

I. INTRODUCTION

Casting is manufacturing process by which a liquid metal is usually poured into a mold, which contains a hollow cavity of the desired shape, and then allowed to solidify. The solidified part is ejected or broken out of the mold for direct use or further processing in other manufacturing technologies like machining. Metal casting process is one of the earliest metal shaping techniques but the technology is superior over other processes because of its ability to produce almost all complex shapes. It can be used to produce components of size ranging from few millimeters (teeth of a zipper) to very large ones (propellers of ocean liners).

All casting methods require two basic techniques:-

- A way of creating cavity which is the shape of the desired final shape.
- A way to put molten metal into the cavity.

Among casting technology one is Sand Casting. It is the most common of casting technology and also known as local foundry technology or traditional casting process. Sand casting is suitable for casting of any metallic materials. In sand casting, sand is used for mould making through packing around a wooden or metal pattern. Pattern is a model or replica of the part to be produced. When the sand the packing on the pattern is over, the pattern is removed to obtain the mold cavity. Molten metal is poured in this cavity and is left to solidify. The solidified object will have similar shape as the needed product except the presence of minor additional attachments due to risers and gates. These can be removed machining. Still additional refinements and solidification processes can be conducted. An outline of common sand-casting process is shown in Fig. 1.

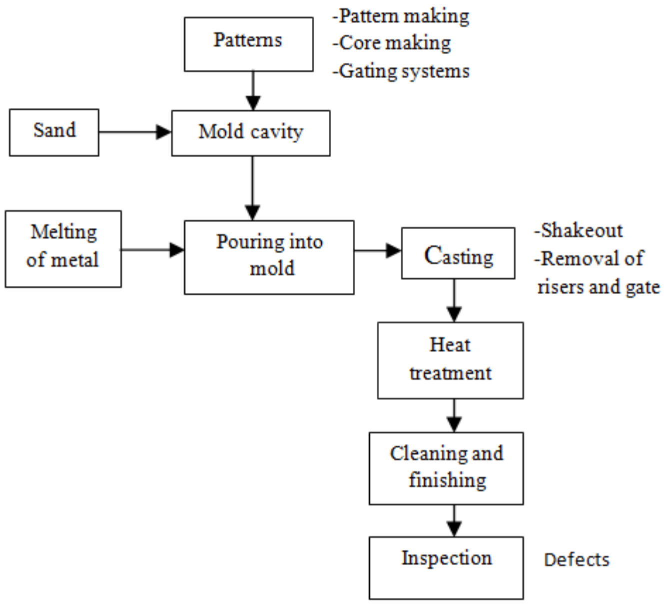

Fig. 1. Steps in sand casting processes.

II. BACKGROUND OF THE PROBLEM

Commonly, in the construction of a mold cavity to obtain desired product all the elements shown in Fig. 2 are incorporated.

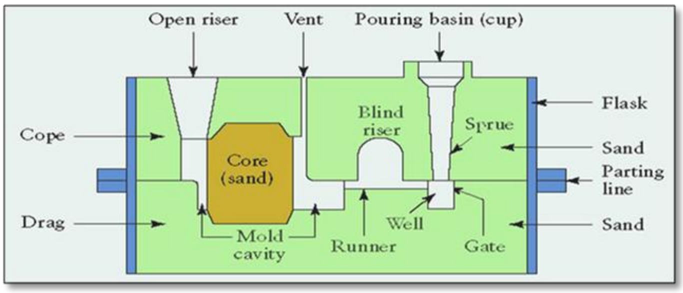

Fig. 2. Section view of sand casting.

The main problem is the traditional sand casting process explained above related to removal of the pattern after sand is compacted around it. As shown in Fig. 3, the mold will be destroyed when a pattern is removed. This results in inaccurate mold cavity, which in turn results in a product with inaccurate and undesired shape.

Fig. 3. Photograph indicating destroyed mold while removing a pattern.

The best solution for this problem is replacing the solid pattern by polystyrene material, which evaporates when approached by a molten metal. The vapor of the polystyrene leaves the cavity through the pores of the mold and there is no pattern removal step. This results in producing a part with more accurate shape. This casting process is known as lost foam casting. The basic procedures of lost foam casting process are shown in the following Fig. 4.

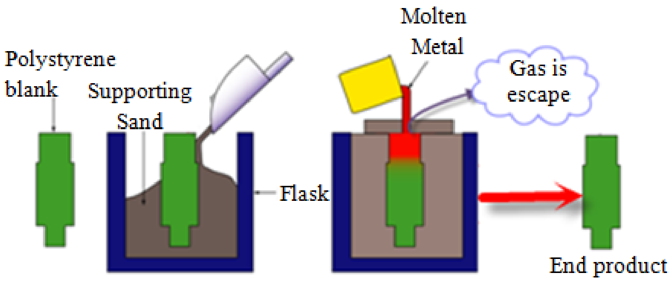

Fig. 4. Outline of lost foam casting process.

One aim of this work is to introduce the utilization of waste polystyrene materials, which come from abroad as a packing material mainly for electronic equipments, in the local foundry technology through the lost foam casting process. At least two benefits can be obtained from recycling waste polystyrene material to use it for casting:

- Reduction of sand casting inaccuracies that come as a result of pattern removal, and
- Environmental protection through utilization of waste material that can stay in the soil up to 500-900 years without degradation.

In this work the lost foam casting process has been introduced in to sand casting process through computational modeling. Successful computational modeling can help to reduce the number of trials, predicting the potential defect areas and cut down the lead time in casting process by better understanding the complex mechanisms and interplay of different process parameters in the mold filling process.

III. OBJECTIVES

The main objective of the research is to reducing casting inaccuracies resulting from pattern removal in sand casting process by using waste polystyrene material.

Specific objectives are:

- Determination of all wasted polystyrene materials suitable for casting process.
- Introducing the lost foam casting technique in local foundry technology.
- Recycling waste polystyrene material in local foundry technology.
- Reducing environmental pollution through recycling solid waste polystyrene materials.

IV. METHODS EMPLOYED

To meet the objectives of the research, the following methods have been employed.

- Pattern was prepared from waste polystyrene materials as shown in the Fig. 5.

Fig. 5. Pattern making steps.

- Computational simulation of lost foam casting process of a pulley has been conducted for analyzing the shrinkage defects and to identify the progress of solidification direction. Shrinkage defects occur when feed metal is not available to compensate for shrinkage as the metal solidifies, as shown in the Fig. 6.

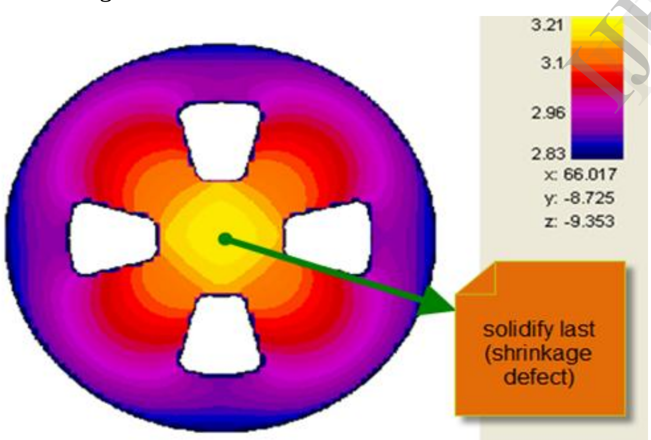

Fig. 6. Shrinkage defect prediction.

- Simulate the filling Aluminum Grade 242 (Al242) on the geometry of pulley for predicating the misruning defect in actual casting metal.
- Based on the result obtained from the computational modeling, testing is made in casting lab with the technical remedy.

V. RESULTS AND DISCUSSION

The purpose of computational modeling was to simulate solidification direction, flow of molten aluminum (Al242), potential defect areas, heat transfer and foam decomposition during the filling of the lost foam casting process.

A. Directional Solidification

Directional solidification indicates that the progression of solidification and the location where defect formed after mold filling was completed. Solidification direction starts from the wall of the mold towards the central portion without chilling effect on geometer of the pulley. Central portion was the point required for the best attachment of the main riser for avoiding the shrinkage defect by considering the point of highest modulus within the casting, shown in the Fig. 7.

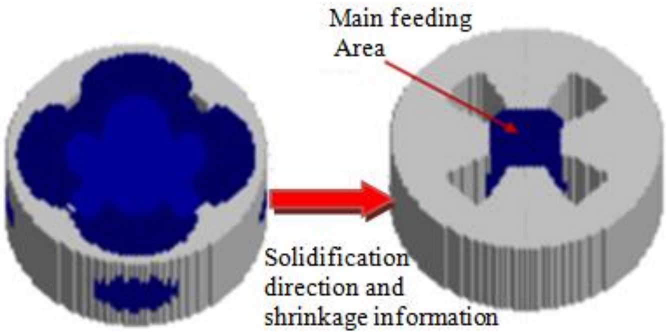

Fig. 7. Three-dimensional view to show the progression of Al242 solidification.

B. Heat Transfer

The temperature distribution and heat transfer throughout the whole body is shown in Fig. 8a and mold only modeled as shown in Fig. 8b. The results indicated that the temperature at the mold wall is equal to that of metal (Al242) casting when 100% solidified. The maximum temperature of the metal is 532.77^{0}C, Fig. 8.

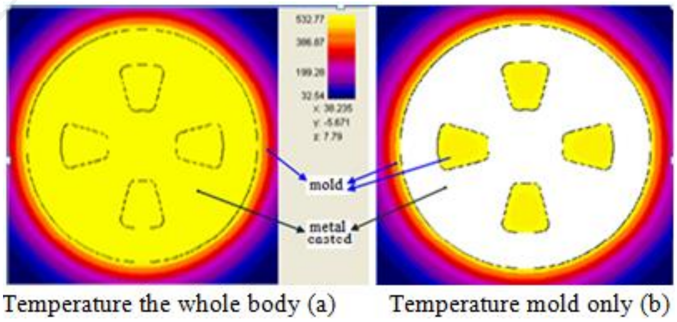

Fig. 8. Sectional view to show (a) distribution of the temperature in the whole body, (b) mold only.

C. Cooling Rate

A cooling curve describes how a single point in a casting behaves as it cools, when its temperature was plotted against time shown in Fig. 9. At initial time, Al242 was liquid with some initial temperature, typically the pouring temperature. This is the initial point on the curve. As the casting loses heat (superheat) to the mold, it cools down, remaining a liquid until it begins to solidify. The results indicate that the maximum shrinkage is formed when 100% solidification process was occurred. Values displayed on the graph are: left side shows temperature and right side shows metal shrinkage rate. Transition phase is analyzed the result indicates:-

- At 635^{0}C phase transition formed from liquid to liquid + solid.

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- At 605^{0}C 29% solidifyied;at point there is no flow of the metal (Al242).
- 100% solidification take place at the temperature is 532^{0}C.

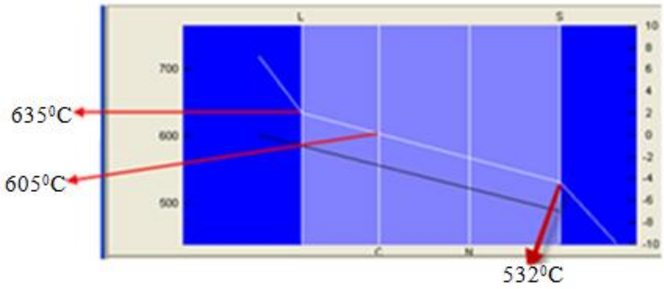

Fig. 9. Two-dimensional solidification and shrinkage curves.

Flow of Al242 with time was analyzed as shown in the Fig. 10. The results indicate that flow of the molten metal stopped at 30 second without chilling application.

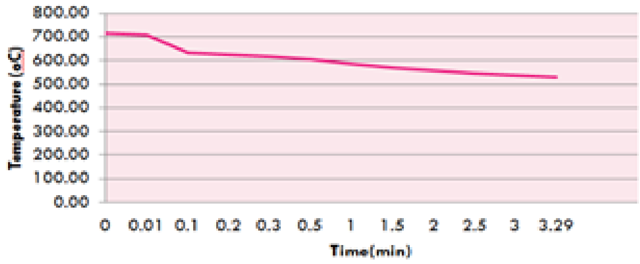

Fig. 10. Effective solidification with time.

D. Potential Defects

1) Gas Porosity

Gas porosity is the formation of bubbles within the casting after it has cooled. This occurs because liquid metal (Al242) can hold a large amount of dissolved gas, but the solid form of the same metal cannot, so the gas forms bubbles within the metal as it cools. This defect is modeled. The results indicated small gas cavities on the surface. Porosity presents itself on the surface of the casting as pore trapped on the metal, which reduces the quality of the products. Carbon monoxide, oxygen and hydrogen are the most encountered gases in cases of gas porosity for this process. In aluminum castings, hydrogen is the only gas that dissolves in significant quantity, which can result in hydrogen gas porosity. As shown in the Fig. 11.

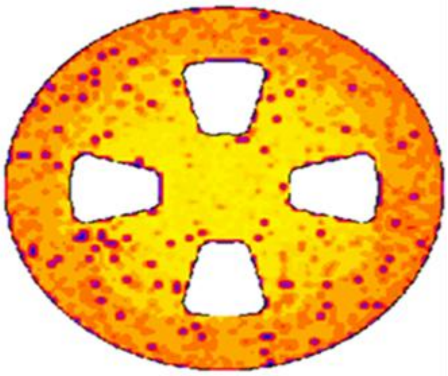

Fig. 11. Porosity defect on the surface.

2) Misrunning

Misrunning is formed when metal freezing before it completely fills the mold cavity. This type of defect is serious because lose the intended shape. Misrunning defect is analyzed on geometry of the pulley as shown in Fig. 12. The result from the lost foam casting is not the same as that obtained from empty sand mold cavity for same shape and size. The mold filling shows time difference of 15.35 seconds.

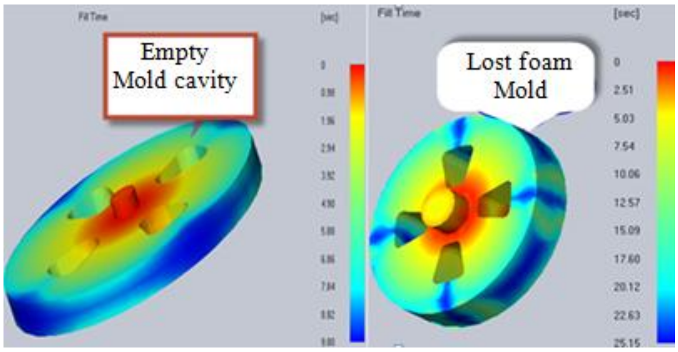

Fig. 12. Misrunning defect prediction vs mold filling time.

3) Metal Replacement of Pattern

As the molten metal flows in the lost foam casting process, the heat it releases evaporates the polystyrene material as shown in Fig. 13. There are different conflicting results on the molten metal replacement of lost foam pattern. These results are contact mode, gap mode and collapse mode. Thickness, metal heat transfer, metal temperature, and foam density have a significant effect on the heat transfer gap length in the lost foam casting process. It occurs more frequently in patterns with thick section is decompose in contact mode.

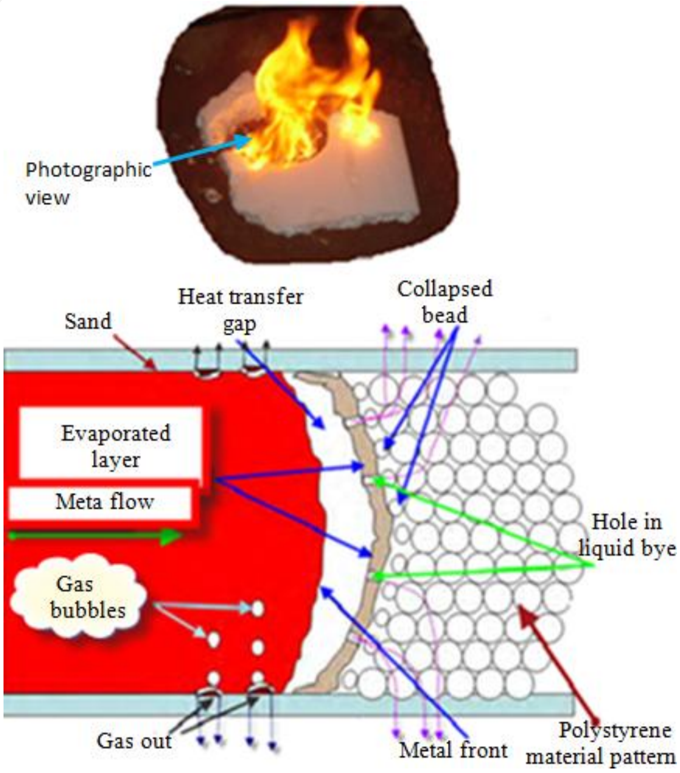

Fig. 13. Physical model of the lost foam metal/pattern replacement practical test.

After analyzing the computational results obtained and utilizing the optimized model, a pulley was produced by the lost casting technique in the mechanical engineering workshop of Jimma University as shown in Fig. 14.

Fig. 14. End product.

The following points indicate some drawback of this casting process and waste polystyrene utilization.

- Economic justification of the process is highly dependent on cost of producing pattern. A new pattern is needed for every casting.
- When the polystyrene burns under insufficient oxygen it releases carbon monoxide that has serious health hazard for technician.
- Pattern making needs long time.
- Polystyrene materials may not be always available.
- Some polystyrene materials are very thin and may easily collapse during compacting and others very hard and may not be easily evaporated.

VI. CONCLUSION

In this work emphasis was made to two points:

- The introduction of lost foam casting in to the local sand casting technology with the aim of reducing casting inaccuracies those results from defect of mold while pattern removal and reusing (recycling) of waste polystyrene material which also reduces environmental pollution.
- Computational modeling of the casting process with aim of optimizing casting parameters to reduce defects related to casting before casting a product in workshop.

In line with this, casting of process of pulley from Aluminum by the lost casting method was simulated and optimized. The optimum model was produced in the mechanical engineering department of Jimma University. The obtained pulley was nearly defecting less and its dimensions were in acceptable limit.

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