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Article

Additive Manufacturing Approach to Investment Casting

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ABSTRACT

The use of additive manufacturing has gripped the manufacturing market. The technology which was only restricted to prototyping has now pushed its boundary by being cost effective and rendering endless capability to convert any complex design into tangible outputs. In this paper, a real-time automotive steering mechanism part named "Holder" is produced by investment casting. The customary practice of using a wax pattern in investment casting has been replaced by 3D-printed patterns of polylactic acid [PLA]. "NX" software has been used to design the castings due to its simple synchronous modeling options and "Altair Inspire Cast Student version 2019" has been used for simulation of casting defects and analyzing effective filling. The results focus on choice of effective filling system and effectiveness of 3D-printed PLA patterns in investment casting. This study encourages implementation of additive manufacturing for small volume production in investment casting.

Key words: Investment casting, 3D printing, Polylactic acid patterns, Low-volume production.

1. INTRODUCTION

Investment casting or lost wax process is an ancient metal shaping technique, where wax replica of the component is dipped repeatedly in a ceramic slurry until a shell of required thickness formed around it [1-6]. Once the shell dries, the wax is burnt out leaving behind the shell mold, inside which molten metal is poured to cast the required component. The accuracy of investment casting component depends on the accuracy of wax patterns used. Since the wax patterns are produced by injection molding, they require molds which are expensive to fabricate and hold good only for large volume production. Today's requirement being small volume production such as limited edition products and custom-made products, using investment casting technique is challenging. Hence, wax patterns can be replaced by 3D-printed patterns, which not only avoid the complication of mold making but also reduce turnaround time of casting. Thus, patterns made by additive manufacturing can be potential substitute to traditional molded wax patterns.

2. EXPERIMENTAL

2.1. Pattern Material

Since the pattern material will be burnt in later stages of the process, choice of material becomes a key influencing factor. Polylactic acid (PLA) ($C_3H_4O_2$) is used as pattern material, they are generally composed of sugarcane or corn starch, which makes them degradable. PLA not only has low transition temperature range of about 60–70°C but also produces less toxic fumes during combustion when compared to other polymers. PLA exhibits considerably low rate of warping when compared to other materials after 3D printing. During 3D printing, PLA shows excellent bed adhesion property and has negligible curling up of the first layer.

2.2. Design of Gating System

Since air traps, porosity, and shrinkage and other casting defects have to be eliminated, three different gating systems were designed and analyzed for flow and solidification. Figure 1 shows the specimen (Holder).

2.2.1. Case I

The feeder was placed exactly over the pattern and raisers are placed at point of highest elevation of the specimen, as shown in Figure 2.

2.2.2. Case II

Both feeder and raiser are placed at the topmost point of the specimen and the component is vertically aligned. This arrangement is shown in Figure 3.

2.2.3. Case III

Feed system was placed exactly at the center of the specimen and the raiser was placed at an angle to avoid inconvenience in handling the shell. Figure 4 shows this arrangement.

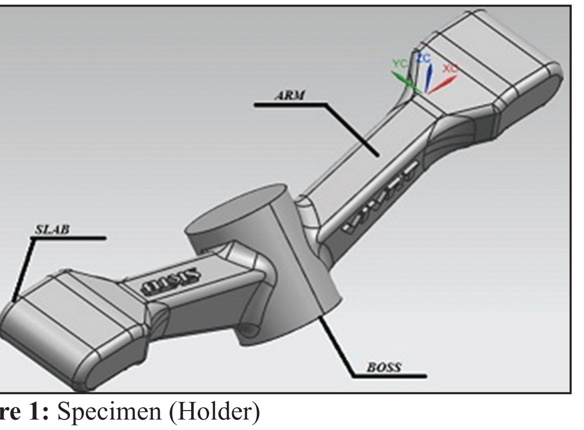

Figure 1: Specimen (Holder)

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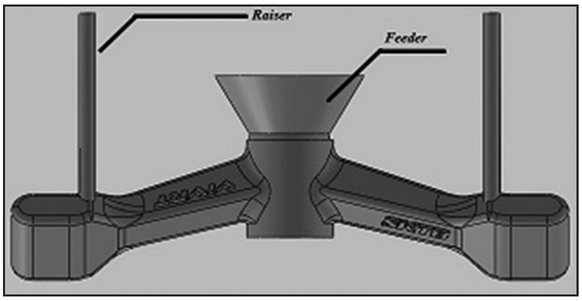

Figure 2: Specimen with the feeder placed exactly over the pattern

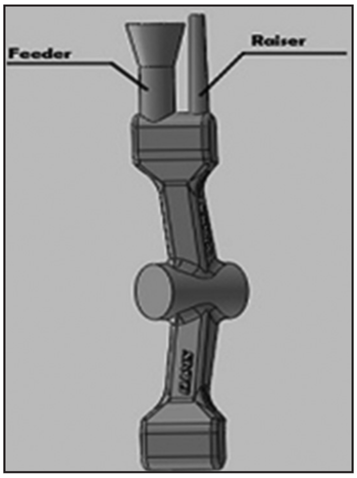

Figure 3: Specimen with feeder and raiser are placed at the top most point

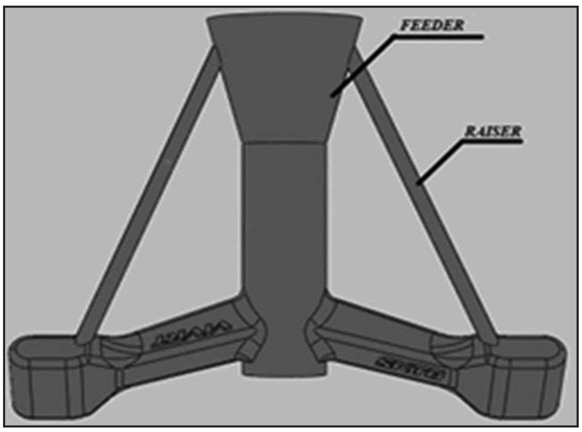

Figure 4: Specimen with feed system placed exactly at the center of the specimen and the raiser were placed at an angle

2.3. Simulation Parameter

The simulation parameters are shown in Table 1.

2.4. Simulations Results

The observations show that when the metal is fed it fills the center boss partially and later raises up to the arm region generating splashes and instability in flow. Further changes in the arm cross-section make the end slab filling uneven and cause turbulence in flow which leads to the formation of air traps.

As seen from the above results, porosity due to air entrapment is absent in the Case III. Hence, Case III casting system was used to proceed with experimental analysis (Figures 5-7).

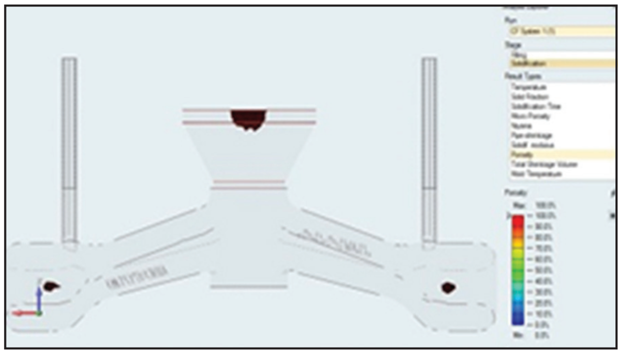

Figure 5: Analysis result for porosity in Case I.

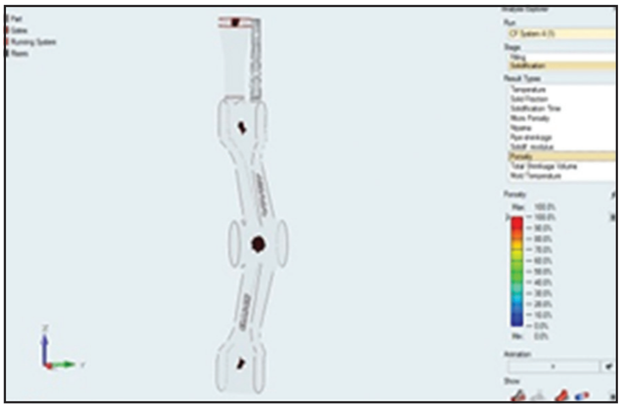

Figure 6: Analysis result for porosity in Case II.

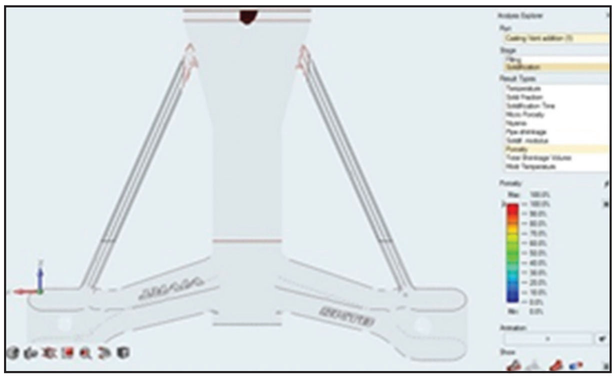

Figure 7: Analysis result for porosity in Case III.

3. EXPERIMENTAL PROCEDURE

3.1. 3D Printing Casting System

To complete 3D print process in short duration, fused deposit modeling process was chosen. Both pattern and feeder were printed separately and attached together with wax. Paper straws were used as raiser to save 3D printing time and material. Figure 8 shows the 3D-printed casting system.

3.2. Shell Building

The 3D-printed casting system was coated with colloidal silica by repeatedly dipping in slurry until a 12 mm thick shell was formed (Tables 2 and 3). Slurry consisted of 30% colloidal silica and 70% water. After complete drying, shell was burnt in electric furnace at 400°C. Once ambient temperature was reached, shell was again pre-heated to 950°C to avoid thermal shock load while pouring metal. EN-8 steel at 1600°C was poured. After cooling, feeder and raiser were cut.

Figure 8: The 3D printed casting system

Table 1: Input data for simulation.

S. No.	Parameter	Data
1.	Pouring material	EN-8 steel
2.	Pouring temperature	1600°C
3.	Pouring time	8 s
4.	Shell material	Colloidal silica
5.	Shell temperature	950°C
6.	Shell thickness	12 mm

Table 2: 3D printing parameter.

Parameter	Pattern	Feeder
In fill	5%	20%
Print speed	40 m/s	60 m/s
Layer height	0.3	0.5

Table 3: EN-8 material chemical analysis.

Material	C	Mn	Si	P	S
Percentage	0.44	0.73	0.23	0.01	0.01

4. RESULTS AND DISCUSSION

The investment casted specimen is shown in Figure 9a. During burning, PLA vapor partially deposited to the shell, caused pit marks on casted specimen (Figure 9b). Piping defect occurred exactly at the center of the boss, due to non-uniform cooling of specimen (Figure 9c). The pit mark defect can be overcome by cleaning shell with water after PLA burning and piping defect can be overcome by burying the shell in sandpit during metal pouring to stimulate slow cooling.

Figure 9: (a) The Investment casted specimen, (b) Deposition of PLA vapor on to the shell and (c) Occurred piping defect exactly at the center of the boss

5. CONCLUSION

PLA-based pattern can reduce lead time, and by 3D printing patterns, any complex shape with deep undercut can be produced. As there are no molds involved, this process is extremely cost effective. However, this method holds good for limited batch of production only. In traditional investment, casting process wax is recycled after burnout, but in lost PLA method, trapping PLA for reuse is not economically viable.

6. ACKNOWLEDGMENT

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***Bibliographical Sketch**

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