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EVOLUTION OF FILLING SYSTEM DESIGN FOR AN A356-T6 ALUMINUM HOUSING CASTING

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Abstract

The results of a student project to produce two housing halves for an engine dynamometer are presented in this paper. The filling systems were designed to minimize turbulence and damage to the metal. The results of small changes in the filling system design are discussed. A new method of using different parts of the filling system (rigging) to evaluate the results of quality improvement efforts is introduced.

Introduction

The Osprey Racing team at the University of North Florida designed a water brake engine dynamometer. The design involves two identical housings, as presented in Figure 1. A decision was made to produce the housings by the sand casting process. A356 cast aluminum alloy was chosen based on its castability and mechanical properties. Patterns for the housing were prepared by the fused deposition modeling rapid prototyping process. Although the initial intent was to produce a pair of housings, the project scope was later expanded to examine how changes in the filling and feeding system would affect the quality of the casting. There were three trials with slightly different filling system designs. This paper summarizes the methods used in the project to assess the quality of the casting nondestructively and final results and recommendations.

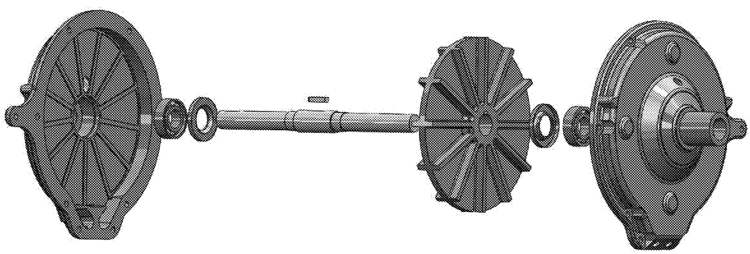


Figure 1. Exploded view of the engine dynamometer assembly.

Experimental Details

The dimensions for the filling system of the castings were calculated based on the practice recommended by Campbell [1]. The dimensions of the filling system, presented in Figure 2, were calculated based on a flow rate of 0.5 kg/s and a velocity of the melt entering the casting of 0.25 m/s. This velocity is well below the critical velocity of 0.5 m/s for aluminum [2]. The dimensions of the feeder were calculated based on (i) expected volumetric shrinkage of the casting, (ii) feeder (riser) efficiency (~14% [1]) and (iii) an expected solidification time that is 20% longer than that of the casting. Due to the shape of the part, the feeder was located below the casting during filling. After the completion of filling, a lid was placed over the mold which was then rotated 180° to relocate the feeder above the casting. The dimensions of the sprue and the feeder were not changed between the three filling system iterations. The runner design incorporated a flow-off volume by extending the runner past the feeder. The end of this extension was tapered to a point to help prevent a back wave. A no-bake binder (Lino-Cure™) was used for all sand molds. In all three trials, virgin A356 ingots were used and castings were poured at 720°C (100°C superheat). In Trials 1 and 2, a powder flux was added to the melt for degassing and the melt was subsequently stirred. No flux was used in Trial 3.

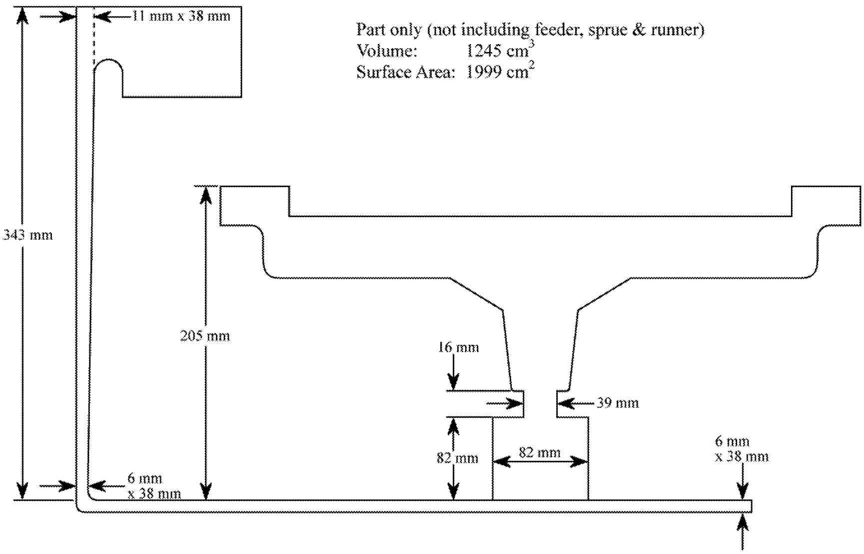


Figure 2. Details of the filling system used in this study.

Trial 1:
The pouring basin in Trial 1 was approximately 38 mm deep and included a radiused weir to control the flow into the sprue, Figure 3.a. The filling system did not include a vent and there was no mechanism to determine whether the mold was completely filled. The runner was arranged to pass under the center of the feeder.
Trial 2:
In Trial 2, the pouring basin kept the same basic dimensions and radiused weir – only the depth was increased to 89 mm, as shown in Figure 3.b. In addition, a vent was added to the mold, both to eliminate any possible back pressure and to allow a visual indication of when filling is completed.

Trial 3:
The only change between Trials 2 and 3 was the runner design; the runner joined the feeder tangentially (vortex gate), Figure 3.c. Moreover the runner was not extended past the feeder.

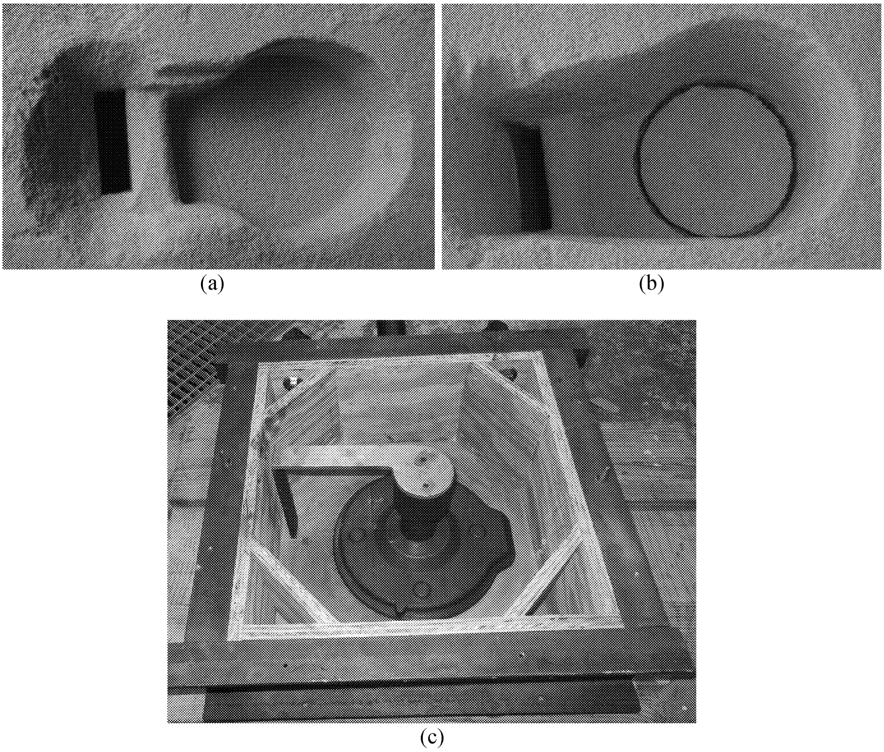


Figure 3. The pouring basins in Trial 1 (a) and Trial 2 (b) and the vortex gate in Trial 3 (c).

The sprues and feeders from the three trials were heat treated to T6 condition along with the castings for improved machinability. Parts of the sprues, approximately 20 mm downstream from the pouring basin and the cross section of the feeders were machined by using a 76.2 mm (3 in.) face mill tool with six inserts. The machined surfaces were ground and finally polished to expose all internal pores. Subsequently, all surfaces were scanned with 600 dpi resolution and images were analyzed by using the ImageJ software [3] from the National Institutes of Health.

Results and Discussion

Initial Observations:

The castings after they were taken out of the sand mold are shown in Figure 4. In Trial 1, it was determined that the shallow depth of the pouring basin did not allow sufficient flow into the sprue to keep it completely full. Subsequently, a minor misrun was detected in Trial 1, as indicated by the arrow in Figure 4.a. In Trials 2 and 3, the deeper pouring basin allowed for a much faster filling rate and the sprue was completely full during the pour. Initial observation of surface finish indicated that the casting in Trial 1 had the roughest surface of the three and castings in the other two trials had almost the same surface roughness.

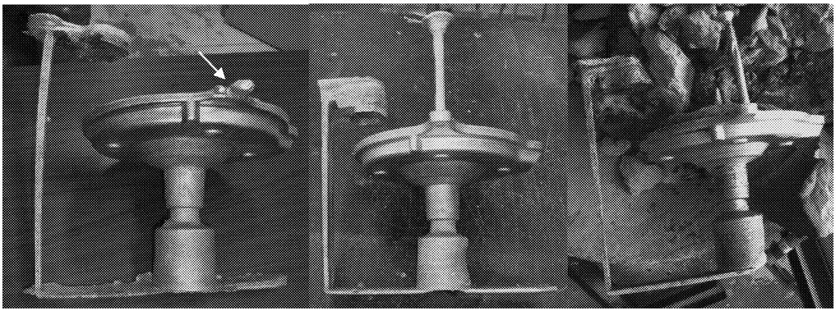
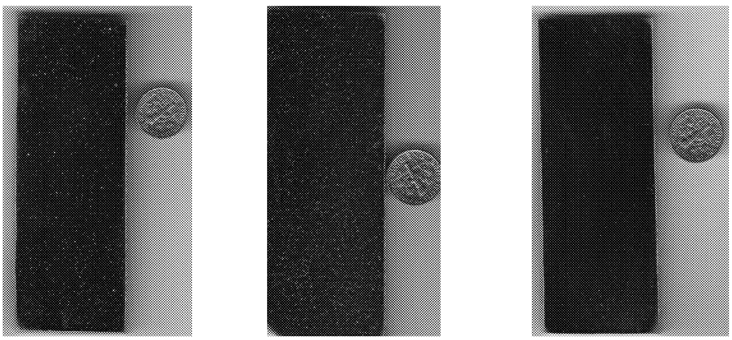


Figure 4. Castings with filling systems attached: (a) Trial 1 (b) Trial 2, and (c) Trial 3.

<u>Nondestructive Evaluation of Internal Defects</u>

The sections of the sprues are presented in Figure 5. Note that sprues for Trials 1 and 2 contain many pores, whereas that for Trial 3 has only a few pores compared to the first two. The same observation can be made for feeders, presented in Figure 6. Note that there is significant external shrinkage in the feeder



(a) (b) (c)

Figure 5. Sections of the sprues: (a) Trial 1, (b) Trial 2, and (c) Trial 3.

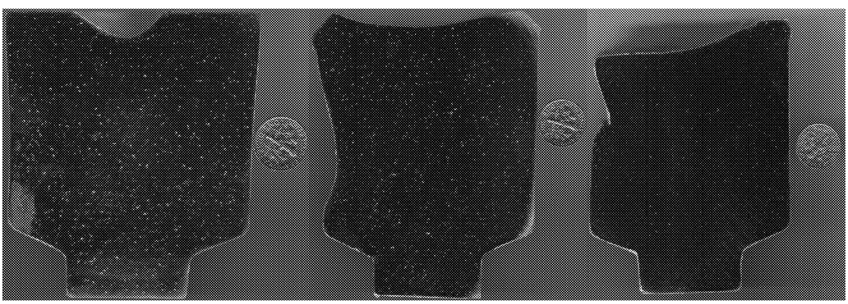
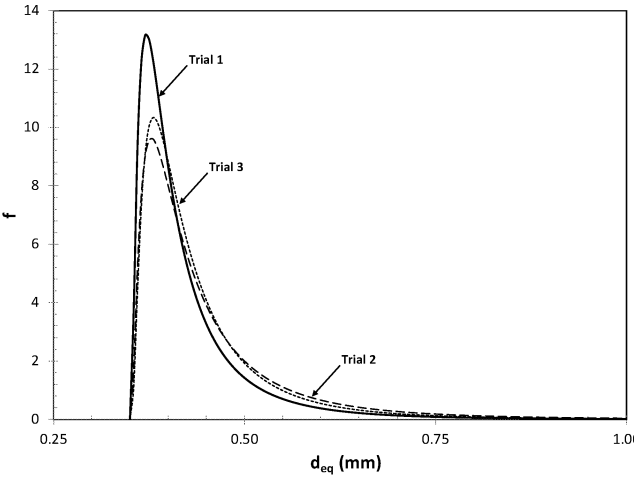
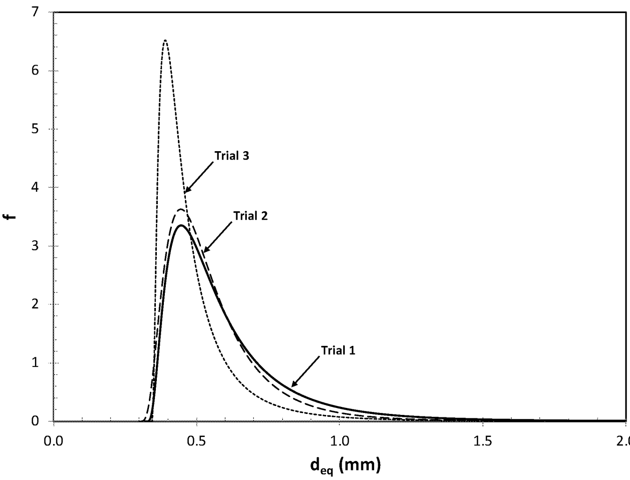


Figure 6. Feeders sectioned for the three trials: (a) Trial 1, (b) Trial 2, and (c) Trial 3.

Areas of pores shown in Figures 5 and 6 were measured by the ImageJ software. Equivalent diameters, d_{eq}, were calculated ($=\sqrt{4A/\pi}$) after excluding any pore with an area of less than 0.1 mm^2, as recommended by Dispinar and Campbell [4]. Analysis of d_{eq} results showed that three-parameter lognormal distribution provided the best fit to all datasets, consistent with results on pore sizes in Mg die castings [5]. The probability density functions, f, for pore sizes in sprues and feeders in all trials are presented in Figure 7.



(a)



(b)

Figure 7. Lognormal distributions for equivalent diameters of pores in (a) sprues and (b) feeders.

It is noteworthy that the size distribution of pores in the sprues of three trials is very similar with those for Trials 2 and 3 being almost identical. Because the depth of the pouring basin was the same in Trials 2 and 3, it can be expected that sprues from Trials 2 and 3 have similar pore size distributions. The main difference between the results from these two trials is the number of defects per unit area, as can be seen in Table 1, in which numbers of pores per $100mm^2$ area are presented. Although the size distribution of pores in sprues in Trials 2 and 3 are similar, there are almost 30 times more pores in Trial 2 than in Trial 3. This result is a clear indication that the powder flux added for degassing severely degraded the melt quality in Trials 1 and 2. The powder particles entrained surface oxides which led to the unintended consequence of higher number of defects than what would be possible without the flux addition as in Trial 3.

Table 1. The number of defects per 100 mm^2 in sprues and feeders for all trials.

	Sprue	Feeder
Trial 1	10.39	19.08
Trial 2	11.38	18.76
Trial 3	0.35	4.53

The number of pores in feeders given in Table 1 is consistent with the results for pores in sprues. The size distribution of pores in Figure 7.b., however, clearly shows that the tangential runner design in Trail 3 has resulted in smaller pores, as evidenced by the pronounced peak at lower d_{eq} values. In contrast, Trials 1 and 2 produce almost identical pore size distributions.

It is noteworthy that Trials 1 and 2 gave similar results in which the numbers of defects arriving in the feeder were approximately doubled when compared to those at the sprue. It can be expected that the melt suffered a modest amount of damage during its passage through these filling systems because all gravity filling systems are ultimately merely damage limitation systems [6]. For Trial 3, Table 3 indicates that the number of defects was increased by over 10 times between the sprue and the feeder. However taking the ratios of the number of defects at the sprue and the feeder may be misleading. The damage given to the metal while flowing through a gravity filling system is expected to be additive. Therefore the three trials need to be evaluated based on the increase in the number of defects between the sprue and the feeder, which was 8.69, 7.38 and 4.18 for Trials 1, 2 and 3, respectively. These numbers indicate the beneficial effects of the deeper pouring basin (Trial 2) and the vortex gate (Trial 3).

The method of sectioning parts of the filling and feeding system presented in this study is of potential value to foundries. The 'rigging', which would be normally be discarded and remelted, should be heat treated and the macrostructure should be analyzed. The results of any quality improvement effort, such as changes in the filling system and/or melt treatments, can be easily quantified and documented. Although the effects of filling system design can be isolated to some extent from the erratic and large variability of melt quality from melt to melt, there seems no substitute for the accuracy in comparison which can be made by pouring all three castings at the same time from the same melt.

Conclusions

1. Using powder flux for degassing degraded the melt quality significantly by entraining surface oxides. The melt quality was significantly better when no flux was used.
2. The increase in the number of defects between the sprue and feeder was smallest when a vortex gate was incorporated.
3. A new method of analyzing the defects in different parts of the 'rigging', which is normally discarded and remelted, is introduced. The new method can be used to quantify and document the results of any improvement effort, such as changes in the filling system and/or melt treatments.

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