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Effects of Pouring Temperature on Solidification Using Energy Profile Analysis on Aluminum Alloy

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Abstract

This work covered the study of energy profiles as influenced by solidification on sand cast 6063 aluminum alloy. Temperature is an important parameter, most especially in foundry technology that influences properties and morphology of cast products. Different pouring temperatures of 680^{o}C, 740^{o}C and 780^{o}C were considered. Mechanical energy expended and the quantity of heat evolved was evaluated from results obtained from tensile test experiments carried on the three samples. Relationship between change in coefficient of thermal expansion and change in applied tensile load were derived; it was observed that the maximum energy expended before fracture for samples decreased with increasing pouring temperature. Increasing pouring temperature decreased the amount of energy to be expended during deformation. This also influenced the change in heat evolved per time.

Key words: *coefficient of thermal expansion, mechanical energy, pouring temperature, quantity of heat, tensile load*

1. Introduction

Products of the aluminum alloy foundry have increased over the years and this can be justified by the increasing number of applications of its products in the areas of aerospace, automobiles, mechanical manufacturing industries ,etc (Bonollo et al., 2005; Ding et al., 2001). The properties of these alloys - high specific strength, light weight, good mechanical behaviour, good corrosion resistance, low density etc., have led to the introduction of new applications and the development of new processing techniques to produce aluminum alloy castings of desired properties. The chemical, physical and mechanical properties of cast and wrought alloys are greatly influenced by their microstructures formed during solidification (Yanwei et al 2010, Bo et al., 2011; Groll,2004).These properties are sensitive to composition, process, shape, size and type of phases evolved during solidification, etc. Aluminum alloys containing silicon as the major alloying element, are majorly used in casting because of the significant effect of silicon on the casting properties, combined with other physical, chemical and mechanical properties such as good weldability, low coefficient of thermal expansion high wear and corrosion resistance (.Mudakappanavar and Radhakrishna, 2012; Kaya et al., 2007). Casting, as a process involves parameters such as charge melting, mould temperature, pouring speed, pouring temperature, composition, microstructure, size of casting, runner size, composition of the alloy and solidification time. The difference in the structure of the casting arises as a result of non-uniform cooling of the molten metal in the mould which later results to low mechanical properties. Studies have shown that the optimum pouring temperature for aluminum alloy is between 700_{o}C and 760^{o}C (.Raji and Khan, 2006; Ndaliman and Pius, 2007) because good quality casts and mechanical properties are produced; the rate of mechanical work and the heat generated as a result of this during tensile loading needs to be studied. In this research, one process parameter and mechanical test are employed. The parameter is pouring temperature while the mechanical test is tensile test from which results obtained were used in calculating mechanical work at deformation.

2. EXPERIMENTAL PROCEDURES

Sample preparation

A cylindrical steel pattern of 50mm diameter and 170mm high was placed in a wider cylindrical

steel container with both ends opened. Moulding sand was added to the container and rammed for easy compact and adherence to the pattern which was finally removed after the rammed mould had reached the required height (pattern's height). This was done for the three specimens needed for the experiment.

Table 1: Aluminum alloy AA 6063 spectrometer analysis

Element	Al	Si	Mg	Fe	Cu	Mn	Ti	Cr
Composition %	95	0.45	0.50	0.22	0.03	0.03	0.02	0.03

The billet was charged in an oil – fired crucible furnace which was initially preheated to 150^{o}C. On heating to the molten state, a pyrometer was brought close to the crucible to measure the melt's temperature. The melt was poured into one of the moulds until the cavity was filled. This was done for the other two samples while the pouring speed and the distance between the crucible and the mould were kept constant for each of the samples. Pouring temperatures recorded for each sample was 680^{o}C, 740^{o}C and 780^{o}C, designated as sample A, B and C respectively.

Mechanical test

Each sample was machined to a tensile test piece of geometry shown in Figure 1.

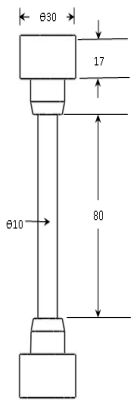

Figure 1: Tensile piece specimen (dimensions in mm)

Tensile test was carried out with the use of universal testing machine (TQSM 1000), which had digital load and displacement meters attached for the measurement of applied tensile loads (in kN) with corresponding specimen longitudinal displacements (mm). Also, the time to attain each elongation at corresponding load was recorded.

Sand casting

The material used 6063 aluminum alloy of composition shown in Table 1.

3. Evaluation equations

Energy expended during deformation

Energy performed during deformation was calculated from the equation

$$E = \frac{1}{2}kx^2 \qquad 1$$

Where k is the spring constant and x is the displacement. Knowing that F=kx, equation (1) becomes

$$E = \frac{1}{2}Fx \qquad 2$$

Quantity of heat given off during deformation

The mechanical equivalent of heat was calculated using the relationship (Kurtus', 2009) expressed as

$$Q = \frac{\text{Work done}}{C_p} \qquad 3$$

Where C_p is the specific heat capacity of 6063 aluminum at constant pressure. given as 0.9kJ/kg^{o}C.

Coefficient of thermal expansion and tensile load relationship

The relationship between coefficients of thermal expansion for the samples was derived resulting to:

$$\frac{d\alpha}{dF} = -\frac{Cp}{Lok^2}\left(\frac{dk}{dQ}\right)_F \qquad (4)$$

where α is the coefficient of thermal expansion, Cp is the specific heat capacity of the alloy, Lo,

the initial gauge length of the specimen, k, the spring constant and Q is the quantity of heat evolved during load application.

4. Results and Discussions

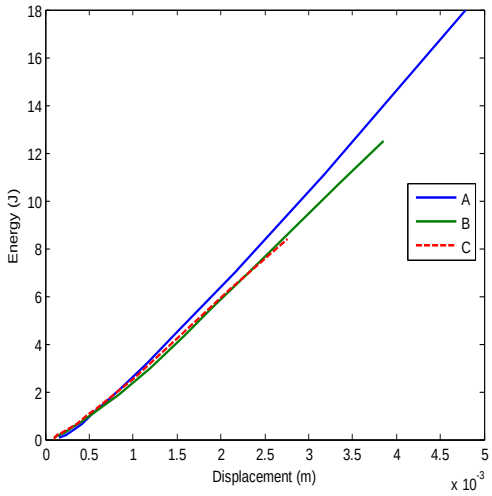

Figure 2: Graph of Energy against Displacement

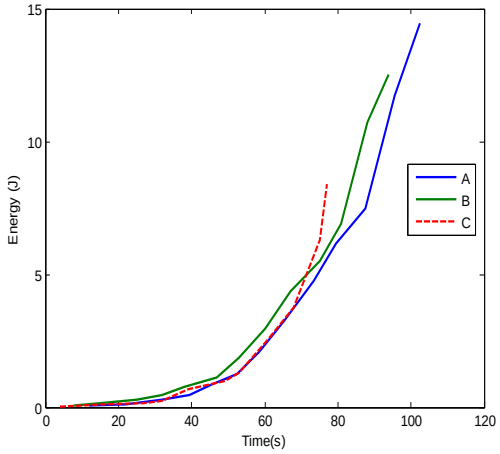

Figure 3: Graph of Energy against Time

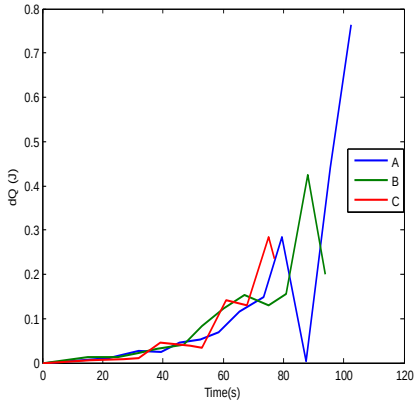

Figure 4: Graph of Heat change against Time

Figure 2 above shows a linear energy – displacement relationship for each specimen. More energy is required to displace each specimen from their instantaneous positions; this is a reflection of the fact that for a specimen to encounter further plastic deformation, higher magnitude of load is required to achieve this. The greatest work is done during deformation of sample A while that of B, though maintains almost similar energy magnitudes with C up to ≈ 2.6mm displacement, follows A. The Figure reveals that increasing pouring temperature lowers the extent to which a cast sample will deform. A non- linear relationship between energy expended and time for each sample is shown in Figure 3 with each curve showing almost similar pattern. A hundred and two seconds is needed for sample A to exhibit ≈4.8mm displacement before fracture. Sample C cannot expend much energy for a long time as compared with the rest.

Wavy curves are observed for the samples shown in Figure 4. The heat evolved during the deformation fluctuates with time. For samples B and C, the quantity dropped to 0.18J and 0.2J within 5s before fracture after attaining maximum values of 0.42J and 0.28J respectively. Minimum heat of ≈0.03J was evolved on the 80th second during deformation of sample A and after 20s, the heat evolved rose to 0.7J. These fluctuations could be as a result of anisotropic effects. The relationship $\left(\frac{d\alpha}{dF}\right)$ for each specimen at maximum load was calculated and values $26.3\mu(N^oC)^{-1}$, $12.2\mu(N^oC)^{-1}$ and

$1.27\mu(N^{0}C)^{-1}$ were recorded for samples A, B and C respectively.

5. Conclusion

Results of pouring temperatures on energy-displacement relationship, rate of energy dissipation and rate of heat evolved by the samples reveal the maximum energy expended before fracture for samples A, B and C are 17.9J, 12.5J and 8.4J respectively. Increasing pouring temperature decreases the amount of energy to be expended during deformation. This also influences the change in heat evolved per time which is seen to increase with decreasing pouring temperature. Furthermore, the maximum load for the system was estimated to be 7.5kN, 6.5kN and 6.1kN for samples A, B and C

Considering the results of this analysis, sample A possessed the highest energy to a maximum displacement of 17.9J at 4.9mm while sample C has the lowest values of 8.4J at 2.8mm. This also accounts for the heat change evolved. From this sudy,It can therefore be concluded that if certain numbers of pouring temperatures are to be considered, the one with the lowest temperature will possess the superlative energy absorbing capacity before fracture.

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