EXPERIMENTAL INVESTIGATION OF HEAT TRANSFER COEFFICIENT OF ALUMINIUM 6061 CASTING SHAPES USING GREEN-SAND MOULD

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ABSTRACT

It is necessary to produce shapes such as plate and bar using casting process for developing indigenous technology of green sand mould. To have the knowledge of solidification time and temperature gradient which are governed by Heat transfer coefficient (HTC) will help to understand required temperature for achieving desired cast shape. The shapes employed for the study includes rectangular plate, square bar and cylindrical bar. Experiment was conducted and values of various temperatures were obtained using electronic temperature recorder. The solidification time of the cast shows that solidification rate is faster in plate when comparing to other shapes. The casting of shapes that involves using aluminium alloy 6061 solidified within 105 seconds after pouring of the molten metal into mould cavity and also plate was the first to solidify. The mould constant obtained for the sand mould was 3. The experimental result shows that thermal conductivity of the alloy was 102.3 WmK and the value was within range of stated value (85 - 173 W/mK) by ASTM. Heat transfer coefficient (HTC) in the cast objects was 101.1 W/m2K.

Keywords: Aluminium Alloy, Heat transfer coefficient, green sand mould.

1.0 INTRODUCTION

During solidification and casting in permanent moulds, the heat flow is controlled by the thermal resistance at the casting-mould interface. Thus Heat Transfer Coefficient (HTC) at the aluminium alloy-mould interface has a predominant effect on the rate of heat transfer (Ilkhchy, Varahraam and Davami, 2012),(Machuta, J. and Nova, I,(2015). In casting process, the effect of pressure on molten aluminium alloy will affect the rate of heat transfer at least at initial steps of solidification. The method of calculating HTC is based on the knowledge of known temperature histories at the interior points of the casting or mould together with the numerical models of heat flow during solidification (Santos, Quaresma and Garcia, 2001;(Machuta,J. and Nova, I.(2016) Maleki, Niroumandand Shafyei, 2006). These temperatures are difficult to measure due to the difficulty in locating accurate position of thermocouple at the interface. Solidification process of casting is governed by HTC which is a function of the heat flux and the temperature gradient. Since the HTC is the critical factor for achieving desired material properties of the cast metal and also cooling rate is governed by HTC, and this can be found experimentally for small geometries (Bylund, Cruz, Kalach and Tsoi, 2008).The temperature variations induced in a cast product have a direct influence on its final microstructure, and therefore play a critical role in determining its quality. According to Ayoola, Adeosun, Sanni and Oyetunji (2012), aluminium alloy could be formed into semi-finished or finished products using casting technique. Heat transfer between the solidifying casting and mould is critical for high quality casting. In addition, heat transfer between the casting and the mould is primarily controlled by conditions at the mould-metal interface.

In the present study, the casting mould is green sand. Therefore, the quality of castings in a green sand mould are influenced significantly by its properties, such as green compression strength, permeability, mould hardness and others which depend on input parameters like sand grain size and shape, binder and water (Mahesh, Pratihar, and Datta, 2008).According to Khan (2005), green sand moulding is the most commonly used casting process throughout the entire casting industry, worldwide. Green sand moulding may be defined as mixture of sand grains, clay (as a binder), water (as activator) and other materials (as additive) which can be used for moulding and casting purposes

(Khan, 2005). The sand is called ‘green’ because of the moisture content and to distinguish it from dry sand. The sand used for green sand moulding is critical to the soundness of casting produced. Green sand has characteristics of flowability, plastics deformation, green strength and permeability (Tiwani et. al, 2016).Hence, analysing the heat transfer characteristics of the casting shapes of aluminium alloy is of crucial importance to foundry technology. The study determined heat transfer coefficient (HTC) of aluminium 6061 casting in a green sand-mould experimentally.

3.1 Materials and Methods

The following materials are required.

i. Aluminium alloy 6061 ingot
ii. Casting equipment includes mould box, pattern, pliers and scissors, pouring cup and furnance
iii. Thermocouple (Electronic paperless recorder)

Table 1 indicates the composition of the Aluminium Alloy used for the study.

Table 1: Composition of Aluminium 6061

Aluminium alloy 6061 Component	Weight %
Aluminium	96.20
Magnesium	1.20
Silicon	0.75
Iron	0.70
Copper	0.40
Zinc	0.25
Titanium	0.15
Manganese	0.15
Chromium	0.20

Table 2 indicates the specification of the Aluminium Alloy used for the study.

Table 2: Specification for aluminium 6061 (ASTM)

Specification	**Unit**
Liquid Density (kg/m^3)	2400
Solid Density (kg/m^3)	2700
Solid Thermal conductivity (W/mK)	173
Liquid Thermal conductivity (W/mK)	85

Fusion Temperature (°C)	585	
Solid Specific Heat (J/kgK)	1050	2.1
Liquid Specific Heat (J/kgK)	1090	
Latent Heat of Fusion (J/kg)	381900	

3.1 Experimental methods

The mass of ten kilogram's (10 kg) of aluminium alloy 6061 ingot was used for the experiment. The ingot was heated and melted using gas furnace to obtain hot liquid metal. The melting process was done with aid of gas furnace. The molten alloy was poured into the cavities of the various prepared moulds at temperature of 700°C. The steps of the casting:

i. Pattern making: rectangular plate of 250 mm by length, 60mm by width and 10mm by thickness. Square bar of 250 mm by length, 24.5 mm for both width and thickness respectively cylindrical bar of 250 mm by length and 27.6mm by diameter
i. Moulding
ii. Core-making
iii. Melting and pouring
iv. Cleaning and inspection

Figure 1 shows the positioning of thermocouple in cast plate. The blue pigment in Figure 1 was one-quarter of the plate pattern in which thermocouple mounted onto for measuring the readings of temperature points. The measuring points of temperature in the cast include T_{if}, T_{lc}, T_{uf}, and T_{uc} and these measured using thermocouple through electronic paperless recorder. The sand mould temperature (T_s) measuring point was located 50 mm from the wooden or mould box. Four points were used for positioning the thermocouple within the one quarter of the cast. The thermocouple used for measuring the temperature within the cast was positioned at 30mm ($h/2$) from the edge of both width faces (60mm) of the cast. The thermocouple helps to measure temperature at four different points within cast. The thermocouple that measured sand mould temperature was positioned at centre point between pattern and core box within the mould.

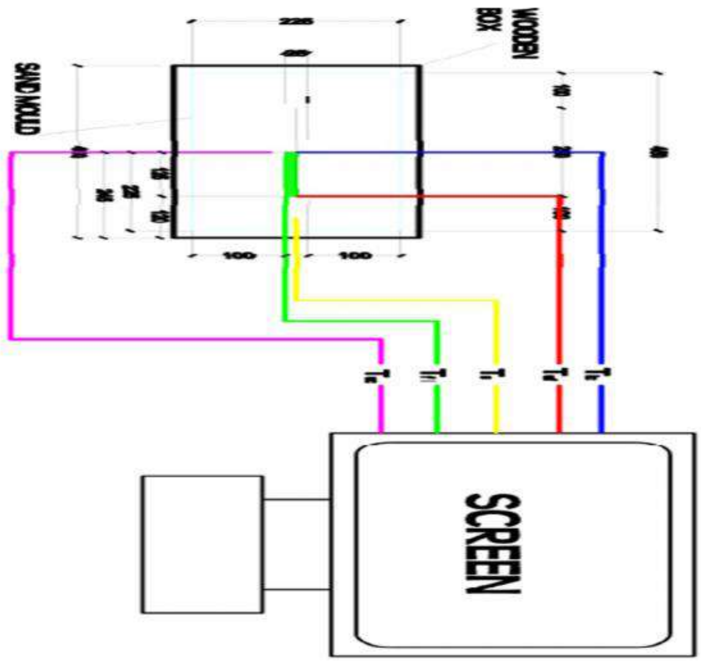

Figure 1: Positioning of thermocouple in the Casting

2.2 Determination of casting modulus

The temperature drop per unit time or cooling of the casting depends on modulus of the casting and it is defined as ratio of volume to effective cooling surface area is:

$M = V_m/A_m$(3.24)

$M_p = t/2$(3.25)

$M_s = w/2$(3.26)

$M_c = d/4$(3.27)

Condition I (equation 3.24) holds if $L > 5t$

Condition II (equation 3.25) holds if $L > 5w$

Condition III (equation 3.25) holds if $L > 5d$

3.5 Determination of solidification time

The solidification time (t_s) is the time required to complete solidification process in casting and depends on heat transfer across the casting surface and mould of the casting and given by (Stefanescu, 2008; Bala and Khan, 2013; Rundman, 2013) and stated as follow:

$$t_s = B\left(\frac{V_r}{A_m}\right)^n \quad (1)$$

$$t_s = \frac{\rho \quad (Q_f + c_m(T_p - T_m))}{HTC_v(T_m - T_o)}\left(\frac{V_m}{A_m}\right) \quad (2)$$

$$B = \left[\frac{\rho_m L}{(T_m - T_0)}\right]^2 \left[\frac{\pi}{4k\rho c}\right]\left[1 + \left(\frac{c_m(T_p - T_m)}{L}\right)^2\right] \quad (3)$$

3.0 Results

The study boundary condition is in Table 3

Table 3: Boundary condition of aluminium 6061

Parameters meter	**Quantity**
Volume per workpiece	0.00015m^3 (150,000 mm^3)
Length of Cast Alloy	0.25m (250mm)
Pouring Temperature	700 ^{O}C
Time interval	10 seconds

The cooling of the casting depends on modulus of the casting (M) and it was calculated for different cast shapes based on same length (L) 125mm.

i. Plate modulus, $M_p = \frac{t}{2} = \frac{10mm}{2} = 5mm$

$$L > 5t = 5(10) = 50mm$$

$$A_m = \frac{V_m}{M} = \frac{150{,}000}{5} = 30{,}000\ mm^2$$

ii. Square bar modulus, $M_s = \frac{width}{4} = \frac{24.5}{4} = 6.1\ mm$

$$L > 5w = 5(24.5) = 122.5mm$$

$$A_m = \frac{V_m}{M} = \frac{150{,}000}{6.1} = 24{,}590\ mm^2$$

iii. Cylindrical bar, $M_c = \frac{diameter\ (d)}{4} = \frac{27.6}{4} = 6.9mm$

$$L > 5(d) = 5(27.6) = 138mm$$

$$A_m = \frac{V_m}{M} = \frac{150{,}000}{6.9} = 21{,}739\ mm^2$$

The plate has lowest casting modulus of 5mm and this mean it has high cooling surface area of $30{,}000\ mm^2$ in comparing to other shapes used for the experiment. The heat transfer coefficient (HTC) of aluminium alloy was determined using experimental records of temperature distribution in the cast. Figure 2 shows the temperature gradient in plate cast and the pouring of molten metal was at 700^{o}C.

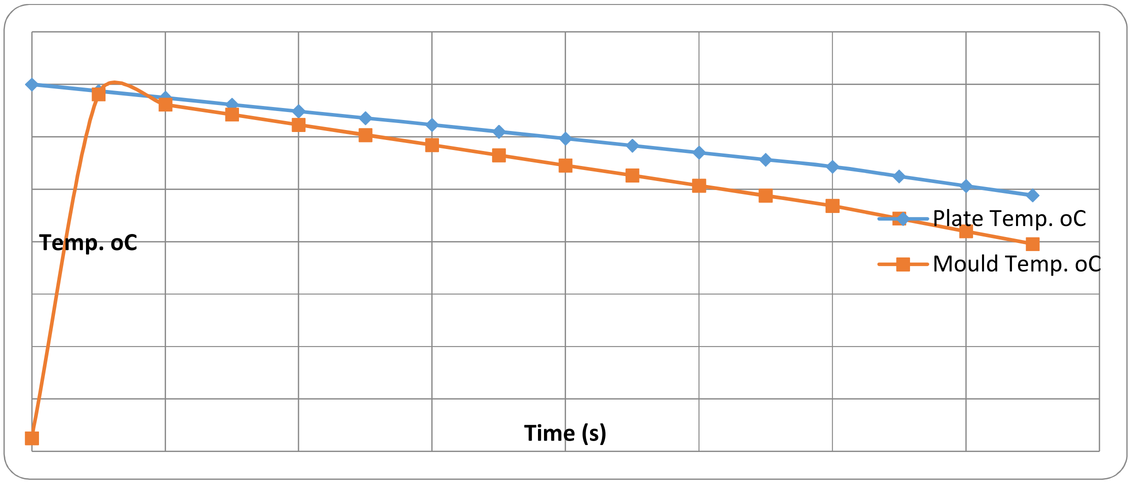

Figure 2: Temperature profile of rectangular plate

Table 4 presents heat transfer coefficient (HTC) of the alloy determined from the experimental result obtained for rectangular plate.

Table 4: HTC of rectangular plate.

Time (s)	**T** (°C)	**Ts**(°C)	**T- Ts** (°C)	**Ts - Tf** (°C)	**HTC** (W/m^2K)
10	687.2	680.7	6.00	655.4	6.2
20	674.3	661.4	12.9	636.1	13.8
30	661.4	642.1	19.3	616.8	21.3
40	648.6	622.8	25.8	597.5	29.4
50	635.7	603.5	32.2	578.2	37.9
60	622.9	584.1	38.8	558.8	47.2
70	609.6	564.8	44.8	539.5	56.5
80	596.3	545.5	50.8	520.2	66.4
90	583.0	526.2	56.8	500.9	156.9
100	569.7	506.9	62.8	481.6	180.9
110	556.4	487.6	68.8	462.3	206.0
120	543.0	468.2	74.8	442.9	233.7
130	524.7	444.0	80.7	418.7	266.8
140	506.4	419.7	86.7	394.4	304.2
150	488.2	395.5	92.7	370.2	346.6

The room/fluid temperature (T_f) used for the study was at 25.3 °C during the experiment. The length of cast plate was 0.125m (half of the cast length) and heat energy was expected to transfer across the cast for solidification to complete. The expected HTC of the cast rectangular plate after 90 seconds was 48.4 W/m^2K. It implies 48.4 W/m^2K was the HTC of molten stage of the plate. The liquid thermal conductivity of the plate was at 111.8 W/mK. The ASTM-liquid thermal conductivity of the alloy in Table 3.2 was at 85 W/mK therefore efficiency of obtained HTC was at 68.5 % in plate.

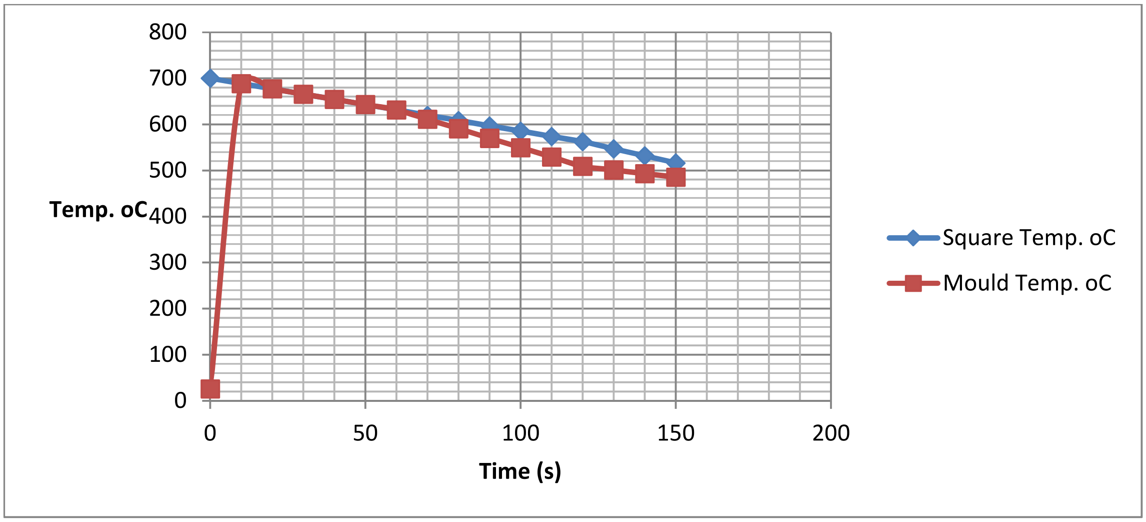

Figure 3: Temperature-profile of square bar

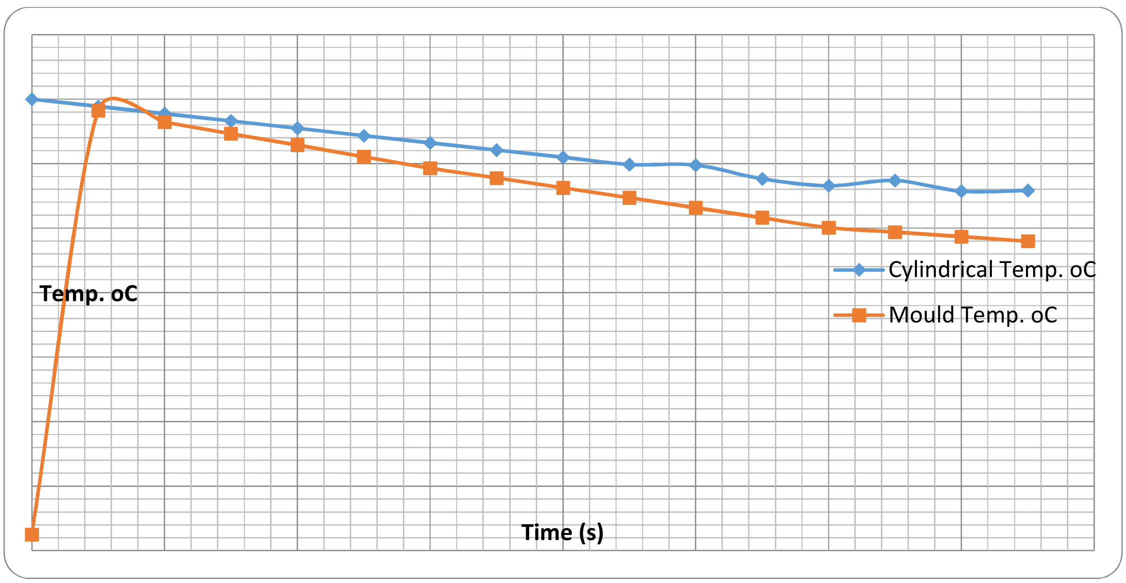

Figure 4: Temperature profile of cylindrical bar

Table 4.18 presents summary of HTC in aluminium alloy cast and therefore it was observed that plate has high value of HTC in the casting with 131.6 W/m^{2}K for the experiment. The HTC of cast square bar was at 73.6 W/m^{2}Kand HTC of cast cylindrical bar was at 98 W/m^{2}K after 150 seconds. Rectangular plate solidified faster than other cast object due high HTC across its surface

Table 5: HTC of the Aluminium Alloy

Time (s)	**HTC-plate** (W/m^2K)	**HTC-square** (W/m^2K)	**HTC-cylindrical (axial)** (W/m^2K)
10	6.2	6.9	6.7
20	13.8	13.3	13.9
30	21.3	18.3	21.4
40	29.4	44.5	29.4
50	37.9	31.3	37.9
60	47.2	49.2	46.9
70	56.5	91.0	53.3
80	66.4	76.2	60.2
90	156.9	91.4	67.5
100	180.9	75.8	88.8
110	206.0	22.8	169.9
120	233.7	153.2	188.4
130	266.8	134.2	236.1
140	304.2	113.9	211.2
150	346.6	183.6	238.8
Average	131.6	73.7	98

Considering the average of HTC presented in Table 4.18 the HTC required for casting of aluminium alloy was at 101.1 W/m^2K after 150 seconds. However, the liquid thermal conductivity (k) obtained of the material used was at 111.8, 90.1 and 105 W/mK for plate, square and cylindrical bar respectively. The average of liquid thermal conductivity was at 102.3 W/mK within the range of 85 to 173 W/mK of ASTM Table.

The following plates were the cast of rectangular plate, square bar and cylindrical bar obtained during the experiment.

Plate I: Cast Rectangular Plate.

Plate II: Cast Square Bar

Plate III: Cast Cylindrical Bar

4.0 CONCLUSSIONS

The aluminium alloys 6061 are cast-able using green sand mould. Heat transfer coefficient (HTC) in the cast objects was 101.1 W/m^2K. The study shows that plate has higher effective cooling surface in comparing to shapes such as square and cylindrical mode. However, it was observed that solidification process is faster in shape with lower modulus based on the use of same volume of material for casting of different shapes. However, the solidification process is obtained in higher rate with lower modulus in casting of different shapes due to high rate of heat transfer coefficient.

References

Ayoola, W. A., Adeosun, S. O., Oyetunji, A. and Oladoye, A. M. (2010). Suitability of Oshogbo Sand Deposit As Moulding Sand. Kenya Journal of Mechanical Engineering, 6(1), 1- 3, 33.

Ayoola, W. A., Adeosun, S. O., Sanni, O. S. and Oyetunji, A. (2012). Effect of Casting Mould on Mechanical Properties of 6063 Aluminium Alloy. Journal of Engineering Science and Technology, 7(1), 88-96.

Bala, K. C. and Khan, R. H. (2013). Experimental Determination of the Effect of Mould Thickness on the Solidification time of Aluminium Alloy (Al-Mn-Ni-Si) Casting in Rectangular Metallic Moulds. International Journal of Engineering Research and Technology (IJERT), (March), 2(3), 3.

Bylund, D., Cruz, R., Kalach, S. and Tsoi, M. (2008). Air Quenching of Aluminium: The effect of Quench Orientation and Air Velocity. Unpublished B.Sc Project, Worcester Polytechnic Institute, p.2.

Ilkhchy, A. F., Varahraam, N. and Davami, P. (2012). Evaluation of Pressure Effect on Heat Transfer Coefficient at The Metal- Mold Interface for Casting of A356 Al Alloy. Iranian Journal of Materials Science & Engineering, 9(1), 239.

Khan, R. H. (2005). Metal Casting Technology in Nigeria-Present Status and Future Prospects. Inaugural Lecture, Federal University of Technology, Minna (Dec. 29), Series 8, p. 10.

Machuta, J. and Nova, I. (2016). Analysis of Heat transfer conditions in sand and metal moulds and their effect on the solidifications of the casting. Journal for Science Research and Production. 16(2), 12-17.

Machuta, J. and Nova, I. (2015). Simulation of calculations of solidification and cooling of Copper alloys casts. . Journal Manufacturing Technology, 15(4), 591-596.

Mahesh, B. P., Pratihar, D. K. And Datta, G. L. (2008). Forward and reverse mapping in green sand mould system using neutral networks. Applied Soft Computing, 8(1), 239-260.

Singh, R. (2006). Introduction to Basic Manufacturing Processes and Workshop Technology, (1st ed.). New Delhi: New Age International Ltd., pp.179- 250.

Santos, C. A., Quaresma, J. M. V. and Garcia, A. (2001). Determination of Transient Heat Transfer Coefficients in Chill Mold Castings. Journal of Alloys and Compounds, 139, 174-186.

Tiwani, S.K, Singh, R.K and Srivastawa, S.C.(2016). Optimisation of green Sand Casting process parameters for enhancing quality of mild steel Casting. International Journal of productivity and Quality Management. 17(2), 127-130.