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EFFECTS OF COOLING RATE DURING CASTING ON THE CORROSION RESISTANCE OF 6XXX ALUMINIUM ALLOY

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Abstract

6xxx aluminium alloy, despite its good mechanical properties do undergo corrosion attack thereby reducing the lifespan of the alloy and increasing liability in its application. This study investigates the effects of cooling rate during casting process on microstructure, mechanical properties and corrosion behaviour of 6xxx aluminium alloy. Aluminium ingot was melted in a muffle furnace and cast into rods. The cooling rate was controlled by holding the moulds at different temperatures. Microstructural characteristics were examined by optical microscopy. Mechanical properties such as impact strength, hardness, and tensile strength were analysed using standard methods. Corrosion behaviour was evaluated by potentiodynamic polarization. It was found that increasing cooling rate resulted in a significant improvement in mechanical properties and corrosion resistance of the 6xxx alloy. The findings were explained in terms of microstructural refinement and chemical homogeneity of the alloy.

Keywords: 6xxx-series Aluminium alloy, microstructure, mechanical properties, corrosion.

Introduction.

Most applications of aluminium alloy are dependent on their mechanical properties which are mainly dependent on microstructure (Lui *et al.,* 2014). 6xxx-series aluminum alloy is widely used as structural materials in aircraft and automobile because of its high strength and low density (Wanhil *et al.,* (2014). However, it has been observed that 6xxx aluminium alloy despite its good mechanical properties do undergo some form of corrosion attack, the effects of which results to loss of human lives and other economic consequences (Davis, 2001and Sinyavski, 2004). Zbigniev *et al*., (2017) has attributed Corrosion process in aluminium alloy to heterogeneous microstructure containing intermetallic phases and precipitates that are usually present at the grain boundaries.

Mohandass *et al.,* (2014) investigated the effect of cooling rate on mechanical behaviour of bulk cast of A380 aluminum alloy by using copper as a die material for attaining fast heat transfer during solidification. Their results showed that a faster cooling rate improved the ultimate tensile strength. However, their work did not investigate the effects of cooling rate on corrosion behaviour of the alloy. Akhil *et al.,* (2014) has established that mechanical properties of aluminium alloy increased as the solidification time reduces. Elantia (2013) also showed that castings at faster cooling rate yields high value of yield strength, ultimate tensile strength, ductility, hardness and resistance to impact in the cast. The influence of cooling rate on solidification behaviour of AA2618 aluminium alloy was examined by Lui *et al.,* (2014). They concluded that under slow cooling conditions, the alloy was of complex microstructures with lots of eutectic compounds and that increasing cooling rate suppressed the formation of intermetallic Al_9FeNi.

Despite several efforts that have been made for refining microstructure of aluminium alloy casting to improve mechanical properties suitable for application in automobile industry, research effort on the effect of cooling rate on microstructure and corrosion behaviour of 6xxx alloy is rare. Hence, this study investigates the effect of cooling rate during casting process on microstructure, mechanical properties and corrosion behaviour of 6xxx-series aluminum alloy.

2.0 Materials and Method

6xxx aluminium alloy is melted using muffle furnace. Prior to pouring, the moulds were treated to different temperature conditions in order to control the cooling rate. Table 1 shows specimens according to mould condition.

Table 1: Identification of Cast Specimens

SPECIMEN	COOLING METHOD
A	alloy cooled in mould at room temperature
B	alloy cooled in mould immersed in ice-block
C	alloy cooled at mould temperature of 140 °C
D	alloy cooled at mould temperature of 230 °C

A pyrometer was placed close to the moulds cavity to measure the temperature. The temperature data acquired during cooling was used to plot cooling curve. Cooling rate curves were obtained by taking the slope at each temperature of time versus temperature curves.

The cast specimens were then machined to ASTM standards for tensile, impact and hardness test specimens. Cast specimens for tensile test were machined to ASTM standard E8M with a gauge length of 45mm and gauge diameter of 9mm. Tensile test were performed on universal tensile testing equipment. (The strain rate is 10^{-3}/s,). Impact test was performed on test specimen machined to a 10mm by 10mm cross section with a V notch using a universal impact testing machine model IT30 with maximum capacity of 360J±1 (J). Hardness was measured on HB-3000 Brinell hardness tester. All tests were repeated 3 times and the data from the experiment was obtained by averaging the values. Specimens for microstructural analysis were prepared by polishing on disc polisher followed by etching with diluted hydrofluoric acid while the microstructural analysis was performed by a metallurgical microscope at 200 magnifications.

Corrosion behaviour of the samples was studied by applying the potentiodynamic polarization method using a potentiostat interfaced to a computer and a three-electrode cell with the sample as a working electrode of exposed area 100 mm^2, a saturated calomel reference electrode (SCE) and two graphite rods as the counter electrode (see plate 1).

Plate 1: Gamry potentiostat connected to

an electrode cell.

3.0 Results and Discussion

3.1 Cooling rate evaluation

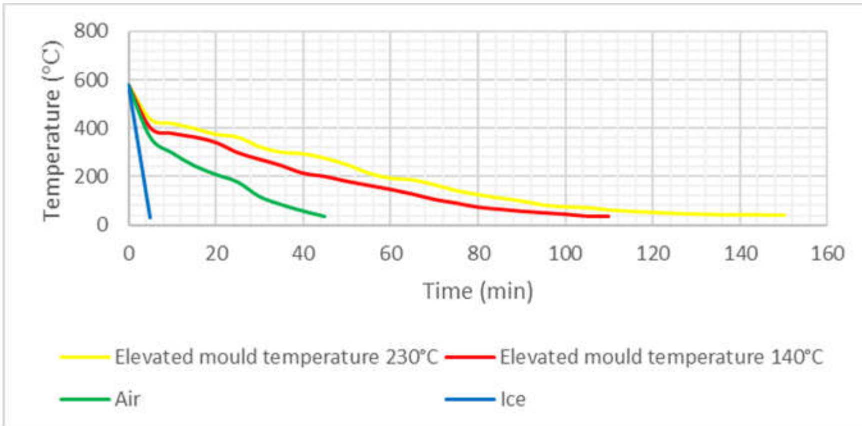

Figure 1: Cooling curves of 6xxx aluminum alloy under different mould temperature.

Figure 1 shows the cooling curves of cast specimen under different mould temperature. Cooling rates are measured from the gradient of the curves in figure 1 and found to be 8.2°C/min, 19.1°C/min, 3.82°C/min, and 2.76°C/min for specimens A, B, C and D respectively.

Figure 2 a-d shows the graphs of cooling rate versus temperature for 6xxx aluminium alloy cooled under different mould temperature. From figure 2a-d, it is found that increasing the temperature lead to reduction of cooling rate.

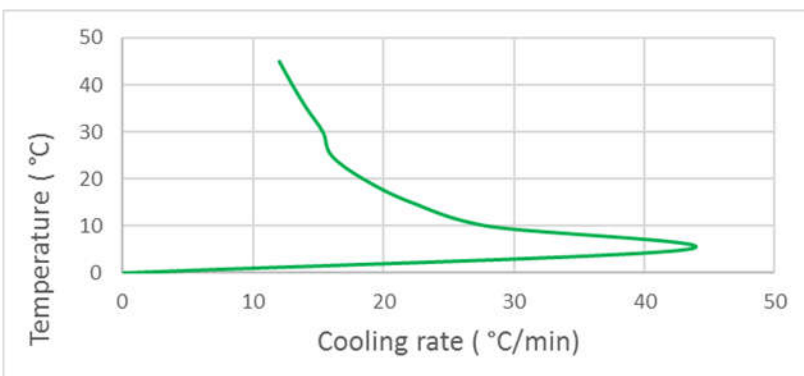

Figure 2a: Cooling rate curve of cast specimen cooled in mould at room temperature.

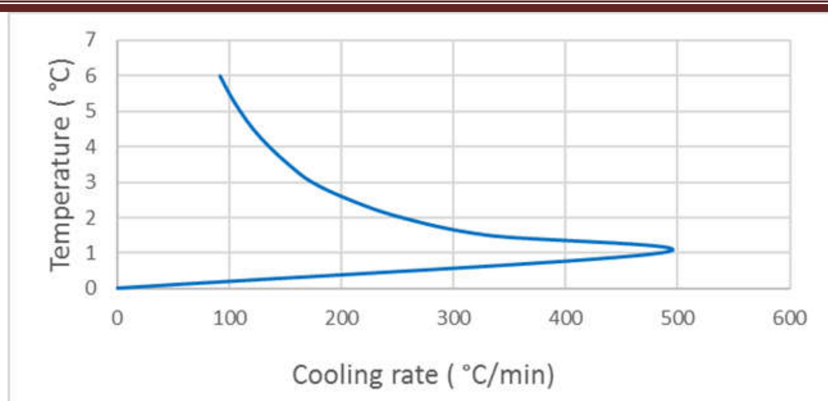

Figure 2b: Cooling rate curve of cast specimen cooled in mould immersed in ice block.

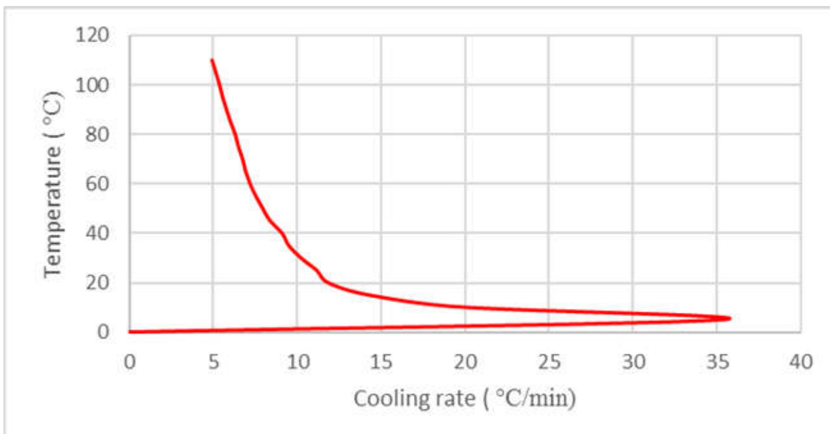

Figure 2c: cooling rate curve of cast specimen cooled in mould at 140 °C

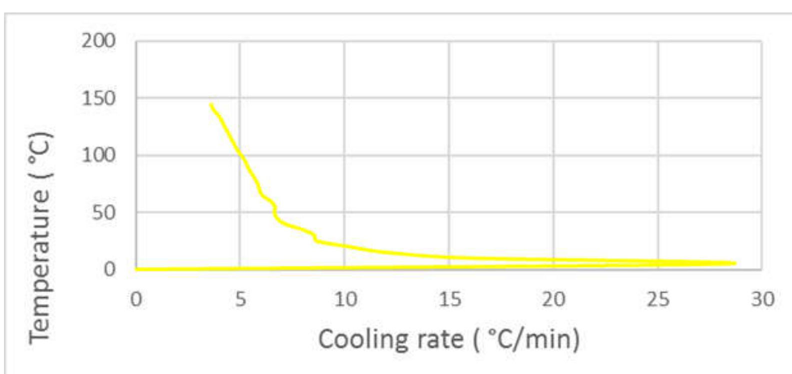

Figure 2d: Cooling rate of cast specimen cooled in mould at 230 °C.

3.2 Microstructure at different cooling rates

Plate II a-d, shows the optical microstructures of 6xxx aluminium alloy solidified at different cooling rates. It can be seen from Plates II (a-d) that the faster the cooling rate, the smaller the grains and the more refined the microstructure.

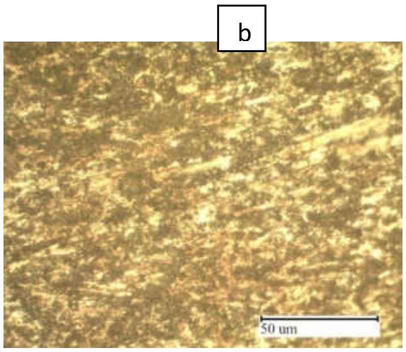

Plate IIa. Micrograph for specimen A

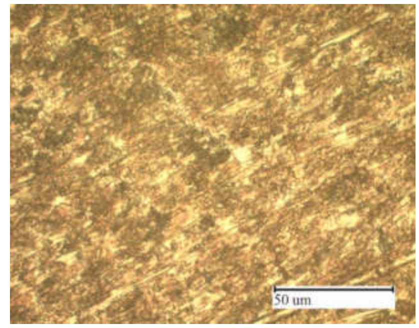

Plate IIb: Micrograph for specimen B

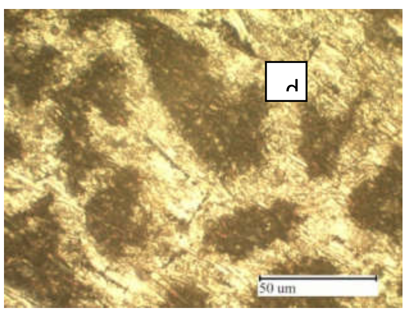

Plate IIc. Micrograph for specimen C

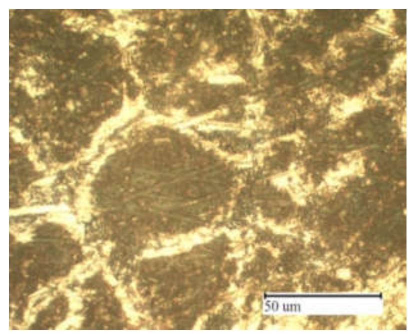

Plate IId. Micrograph for specimen D

Plate II: Microstructure of the 6xxx aluminium alloy under different cooling rates.

3.3 Mechanical Tests Results

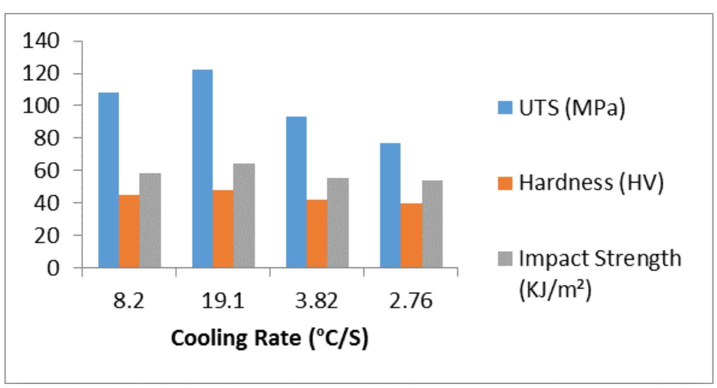

Figure 3: Variation in UTS, Hardness and Impact strength with cooling rate.

Figures 3 shows the effects of cooling rate on UTS, Hardness and Impact strength of 6xxx aluminum alloy

Table 1: Effects of cooling rate on the mechanical properties

Specimen	Cooling rate (°C/min)	UTS (MPa)	Hardness (HV1)	Impact strength (KJ/m²)
A	8.2	108.5	45.3	58
B	19.1	122.6	48	64
C	3.82	93.58	42.3	55.3
D	2.76	76.95	39.6	54

From Figure 3 it can be seen that mechanical properties such as UTS, hardness and impact strength increased with increasing cooling rate. The increase in mechanical properties may be attributed to grain refinement. This observation is in agreement with Elantia (2013) that mechanical properties increased with increase in cooling rate.

4 Electrochemical Results

Figures 4(a-d) shows the potentiodynamic polarization curves in 1.0 % M HCl for 6xxx aluminum alloy cooled under various conditions.

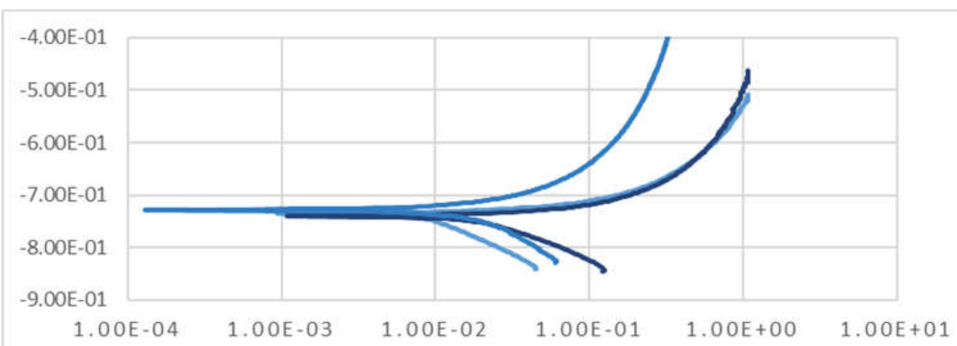

Figure 4a: Polarization curves from electrochemical tests of 6xxx aluminum alloy cooled in mould at room temperature.

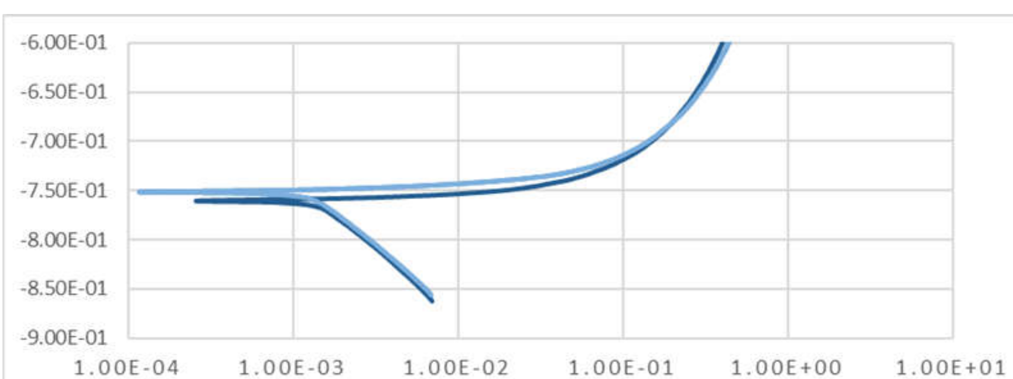

Figure 4b: Polarization curves from electrochemical tests of 6xxx aluminum alloy cooled in mould immersed in Ice block.

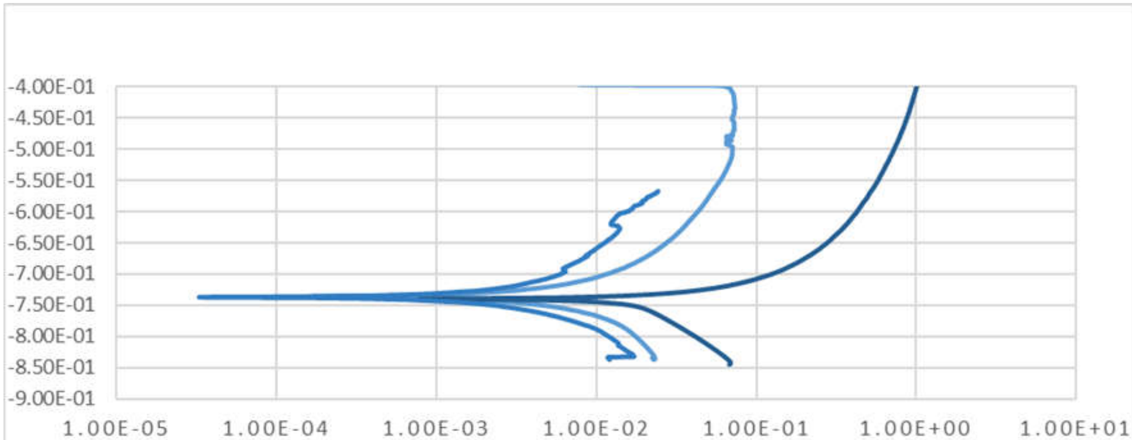

Figure 4c: Polarization curves from electrochemical tests of 6xxx aluminum alloy cooled in mould cooled at 140 °C.

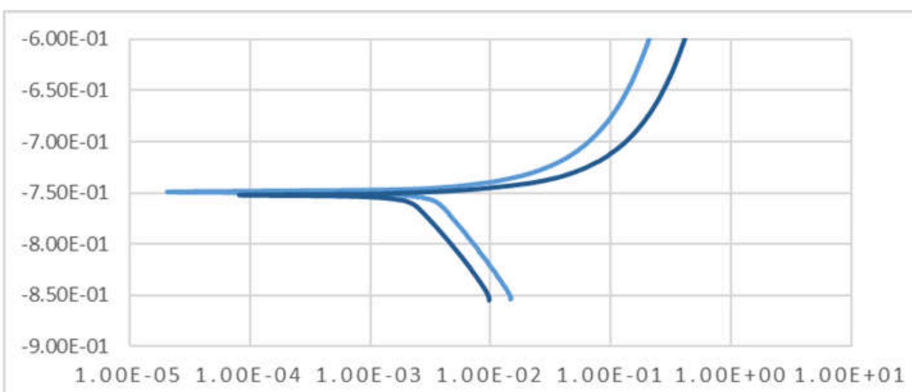

Figure 4d: Polarization curves from electrochemical tests of 6xxx aluminum alloy cooled in mould at 230°C.

From figures 4 a-d, a general feature of the potential current density for all studied conditions is the absence of passive region after active dissolution range. Another important observation is the shift in corrosion potential. The corrosion potential increased as the cooling rate increased.

Table 3 shows a summary of corrosion potential (E_{corr}) and the corrosion current density (I_{corr}) of 6xxx aluminum alloy under different cooling conditions during casting.

Table 3: Corrosion behaviour of 6xxx aluminum alloy under different cooling conditions.

Specimen	Cooling conditions	Cooling rate (°C/min)	I (corr) µA/cm²	E (corr) mV
A	Mould maintained at room temperature	8.2	1960	750
B	mould immersed in Ice-block	19.1	1370	761
C	Mould at 140 °C	3.82	3070	741
D	Mould at 230 °C	2.76	3110	750

From Table 3, it can be seen that the alloy exhibited higher corrosion potential as the cooling rate increased. Corrosion potential is the result of the electrochemical reaction at the interface between sample and the SBF solution. This suggests that the increase in cooling rate decreases susceptibility to electrochemical reaction. Rapid cooling brings about an increase in the solid solubility of some impurity element forming nucleating sites which decreases susceptibility to corrosion.

5. Conclusions

Different cooling rates during casting were investigated in order to clarify the effect of cooling rate on the microstructure, mechanical properties and corrosion behaviour of 6xxx aluminium alloy. On the basis of the results of the investigation, the following conclusions are drawn:

1. Increasing cooling rate resulted in a decrease in the grain size
2. Rapidly solidified cast has very good strength which is basically due to finer grains and homogenous microstructures.
3. The corrosion resistance and mechanical properties improved with the increasing cooling rate
4. The improvement in the corrosion resistance is attributed to the microstructural refinement and chemical homogeneity.

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