

EFFECTS OF APPLIED PRESSURE AND DIE TEMPERATURE ON THE ELECTRICAL CONDUCTIVITY OF SQUEEZE CAST ALUMINIUM RODS

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ABSTRACT

The effects of applied pressure and die pre-heat temperature on the electrical conductivity of squeeze cast aluminium rods were experimentally investigated and presented. The results show that applied pressure and die temperature have significant and positive effects on the electrical properties of squeeze cast aluminium rods up to certain levels. With increase in applied pressure, there is a steady increase in the electrical conductivity up to a pressure level of 105 MPa, which gives a maximum value of electrical conductivity. Increasing the values of the applied pressure further leads to a decrease in the electrical conductivity up to a pressure of 150 MPa. Beyond this pressure, increase in applied pressure has no significant effect on the values of electrical conductivities. With die pre-heating, electrical conductivity increases with increase in die temperature, reaching a maximum value at die temperature of 150 °C. Further increase in the die temperature beyond 150 °C leads to a fall in the electrical conductivity.

Keywords: Electrical Conductivity, Electrical Resistivity, Applied Pressure, Die Temperature, Squeeze Casting.

1.0 INTRODUCTION

Aluminium has very wide and varied fields of applications (space, aircraft, vehicle, electricity, building, packaging, electronic, kitchen utensils etc) due mainly to its light weight, corrosion resistance, and good mechanical and electrical properties. Aluminium is a light metal and can be given great strength by alloying, mechanical and heat treatment thereby improving the mechanical properties [1, 2]. Aluminium metal resists corrosion, conducts heat and electricity and reflects light and radiant energy.

Alloying and metal working processes such as squeeze casting of aluminium metal improve the mechanical strength [1, 2, 3]. Until recently, copper was the dominant conductor material for electric power

transmission and distribution because of its good electrical properties. Today aluminium is now taking the place of copper because of its lightweight and relatively low cost [4]. The density of aluminium is about 30% that of copper [3, 4, 5].

In overhead line construction, the lighter weight of aluminium makes it more acceptable for use than copper, because heavy conductors lead to heavy and expensive pole structures [5, 6]. In handling and transportation, aluminium conductors are much easier compared to heavy copper conductors and cables. The electrical conductivity of aluminium is 2.12 times that of an equal mass of copper [4, 5, 6]. Due to its diversities of applications, this research work addresses the effects of casting parameters of aluminium on its electrical

properties. In this work, the effects of squeeze cast parameters such as applied pressure and die temperature on the electrical properties of solidifying aluminium metal were investigated.

2.0 EXPERIMENTAL METHODS

2.1 Squeeze casting rig

The rig used for the production of squeeze cast aluminium rods for electrical conductivity determination was a split-type steel mould rig. It has an external diameter of 85mm, internal diameter of 20mm and 140mm in height. It consisted of a movable punch, a split cylindrical steel mould and a lower support die (see Figure 1). The punch was used to apply predetermined loads on the solidifying molten aluminium metal in the steel mould. In the cylindrical steel mould were drilled three 12mm diameters holes to accommodate three heater rods (220V-100W) to heat the steel container/die. A bimetallic thermostat was used for the control mould.

2.2 Preparation of aluminium cast specimens

Aluminium electric overhead cables of percentage composition of 99.5% of aluminium and traces of other elements were cut into smaller sizes and melted in an electric heating furnace of maximum operating temperature of 1100°C, set at temperature of 750°C. The molten aluminium metal was soaked in the furnace for between 15 to 20 minutes at 750°C to allow the melt to achieve uniform temperature of 750°C. The melt average temperature of 720°C as indicated by the Chromel-Alumel thermocouple inserted in the aluminium melt, was used throughout the experiment as the pouring temperature. The inner surface of the die/container

core was lubricated initially with used engine oil before melt pouring to allow for easy removal of the cast specimen after solidification. A metered quantity of molten aluminium metal was poured carefully within 3-5 seconds so as to avoid turbulence into the steel mould cavity at a temperature of about 720°C to attain a height of about 90±5mm. The punch was released to close the mould cavity without applying any load on the aluminium melt and the mould at room temperature. The punch position was maintained without pressure application, until total solidification was achieved.

Cast specimens were produced with the punch used to apply varying pressures on the molten metal by a Vega Compression Machine, model UTM 3C, serial No 1061 with a capacity of 89,000 N. The compression loads were applied on the solidifying molten aluminium metal at a delay time of about 5 seconds, after pouring molten aluminium metal and retained on the solidifying molten metal for a retention period of about 60 seconds.

Aluminium cast specimens were produced with mould pre-heating temperatures of 50, 80, 150, 250 and 310°C without pressure application on the solidifying aluminium metal. The die heating process was carried out through three electric heater rods of 100Watts each, that were connected to a.c supply and the set temperatures for tool heating were maintained uniform by using bimetallic thermostat.

2.3 Electrical conductivity determination

The specimens produced were 100mm long and 20mm in diameter. The specimens obtained were machined on the lathe to give them good surface finish both at their ends and cylindrical

surfaces for proper contact during electrical testing. The cylindrical surfaces of the specimens after turning on the lathe machine were reduced to diameters of between 18.75 ± 0.25 mm and 90 ± 5 mm long.

The electrical circuit diagram shown in Figure 2, was used for the measurement of voltage across the specimens [7, 8, 9]. The circuit consisted mainly of a variable resistor, ammeter, voltmeter and energy source supply from the mains. The step-down transformer steps down the high alternating voltage from 240V to 12 volts, which was used as energy source for the circuit. The rheostat regulated the resistance across the circuit and was used to vary the current passing through the circuit of between 0.2 to 0.8A. The two flat copper metals (one at each ends of the specimen) acted as conductors [8, 9] and were used because copper possesses higher conductivity than that of aluminium metal and will allow minimal voltage loss across the entire circuit. The cast specimen was placed in between the two flat copper metals to maintain a good contact at both ends.

The rectifier was used to regulate and stabilise the circuit resonance. The regulator controlled the current across the circuit and maintained it at a constant value throughout the period of measurement. The ammeter read the current in the circuit in ampere (A) and the voltmeter reading was taken across the specimen to calculate the electrical conductivities and resistivities of the cast aluminium metal rods.

Each specimen was placed in between the two flat copper metals and potential difference (voltage) across it was read in millivolt by the digital voltmeter and the corresponding reading of the current was taken. Repeated

readings were taken for each selected current and average values of voltage and current were used for the determination of electrical conductivity and resistivity, using equations (1) and (2) respectively.

$$C = \frac{IL}{VA} \quad (1)$$

$$\rho = \frac{VA}{IL} \quad (2)$$

$$\rho = R \frac{A}{L} \quad (3)$$

where,

$$R = \frac{V}{I} \quad (4)$$

where, A -cross-sectional area of the specimen

C -electrical conductivity,

ρ -electrical resistivity,

V -voltage,

I -current,

L -length of specimen,

R -resistance of specimen.

The resistance of the cast specimens was also taken directly, using a high sensitive digital ohmmeter used to measure resistance in ohms. The electrical resistivities of the cast specimens were calculated using equation 3.

3.0 RESULTS AND DISCUSSIONS

Figure 3 shows the variation of electrical conductivity and resistivity of aluminium rod with applied squeeze casting pressure. As the values of applied pressure increases, there is an increase in the electrical conductivity of aluminium up to an applied pressure level of 105MPa with a corresponding electrical conductivity of $6.77 \times 10^{-7} (\Omega m)^{-1}$. Above this pressure, the electrical conductivity decreases and become relatively constant with increase in applied pressure. The decrease in electrical conductivity above applied

pressure of 120 MPa is due to greater obstacles required to overcome the more closely packed grains resulting from greater, non-uniform deformation occurring with increase in applied pressure. Also shown in Figure 3 is the variation of electrical resistivity with applied pressure, which is the reciprocal of electrical conductivity.

Figure 4 is the graph showing the effects of electrical conductivity on the die pre-heat temperature. There is also close agreement in the values as obtained from the two methods. The values of electrical conductivity increases fairly slowly at die temperatures maintained between room temperature and temperature of 80°C. Above this temperature, electrical conductivity rises with tool heating temperature to a peak value of $2.884 \times 10^{-8} (\Omega m)^{-1}$ at die temperature of 150 °C and dropping from this value to a lower value of $0.832 \times 10^{-8} (\Omega m)^{-1}$ at maximum tool temperature of 310°C.

The reduction in electrical conductivity at elevated pre-heat temperature is possibly due to high thermal conditions [1], which reduce die chilling effect on the molten aluminium metal that leads to lower thermal gradient during the process of metal solidification. This indicates that pre-heat temperature for good electrical conductivity should not exceed 150°C as die pre-heat temperature above this value reduces the electrical conductivity of aluminium metal. Figure 5 shows the effects of electrical resistivity on the die pre-heat temperature as determined by voltmeter/ammeter and ohmmeter methods, which is the reciprocal of the electrical conductivity given in Figure 4.

4.0 CONCLUSION

In the present work, applied pressures and die temperatures are found

to have significant effects on the electrical properties of squeeze cast aluminium rods. Electrical conductivity increases with increase in applied pressure up to an applied pressure level of 105MPa. Above this pressure, the electrical conductivity decreases. With die temperature, electrical conductivity reaches a maximum value of $3.204 \times 10^{-8} (\Omega m)^{-1}$ at die temperature of 150°C and falls again when die temperature exceeds 150 °C. Optimum value of electrical conductivity occurs at an applied pressure of 105 MPa and die temperature of 150 °C and therefore this pressure and temperature values are recommended for squeeze casting of aluminium rods for optimum electrical performance.

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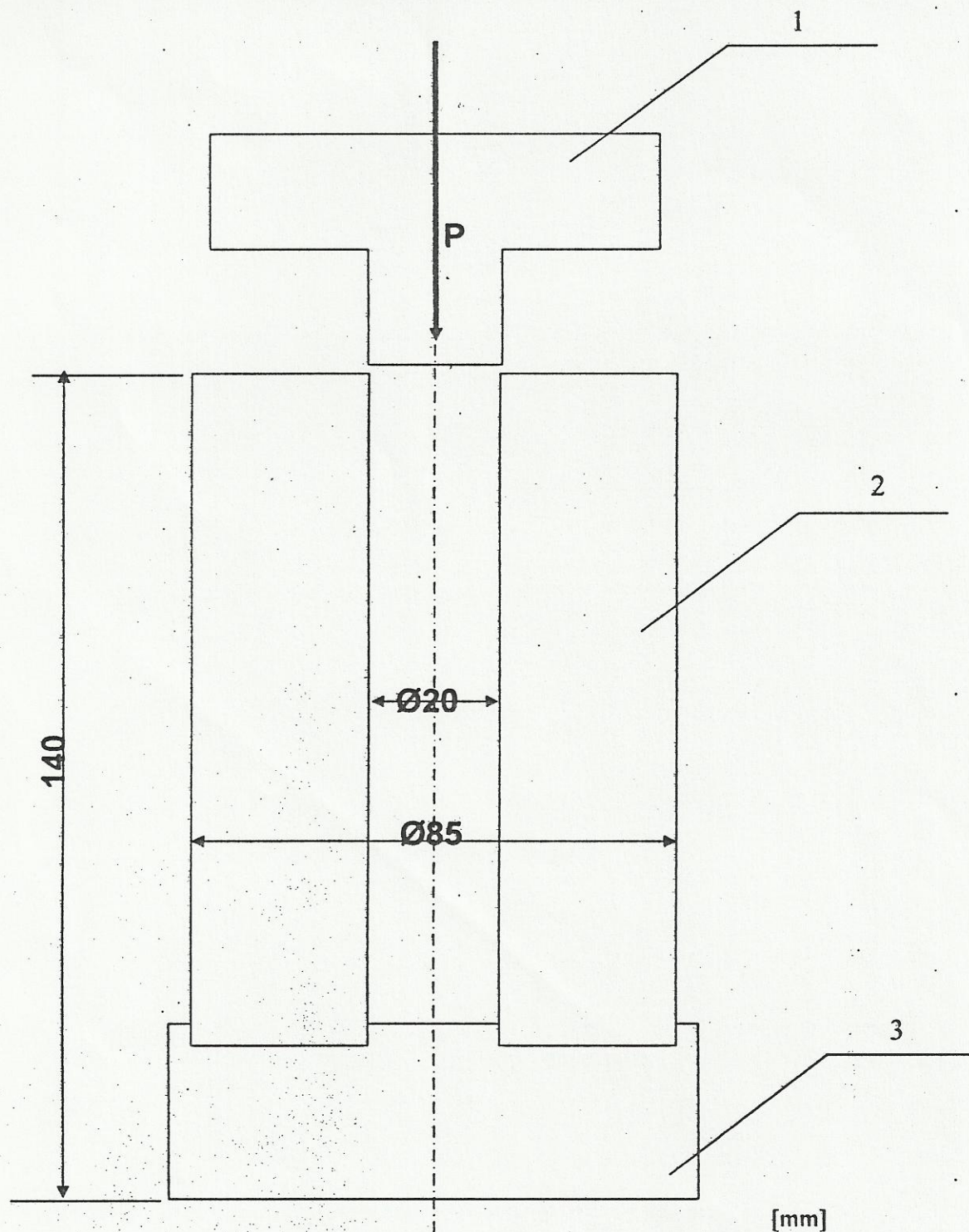


Fig. 1. Schematic diagram of the rig.
1-punch, 2-cylindrical split steel mould, 3-die support

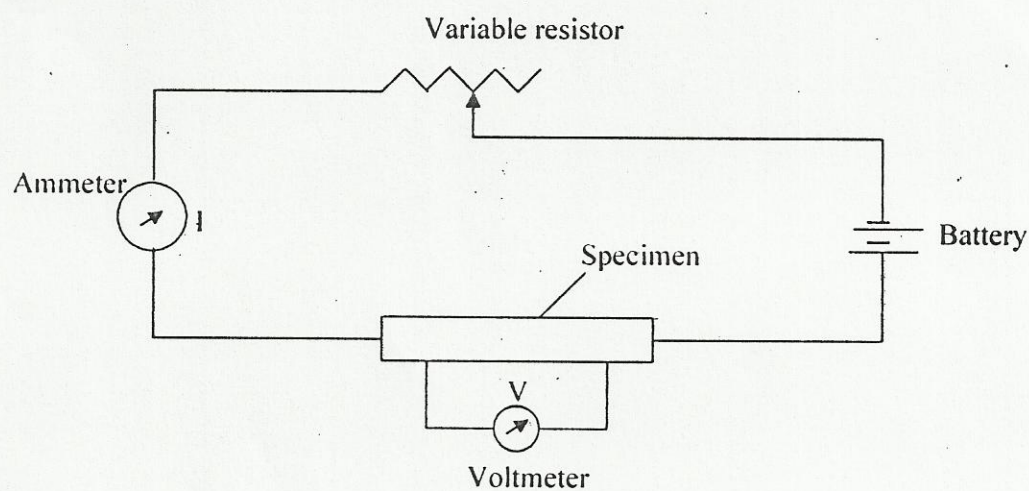


Fig. 2 Electric circuit used to measure voltage and current across the specimen

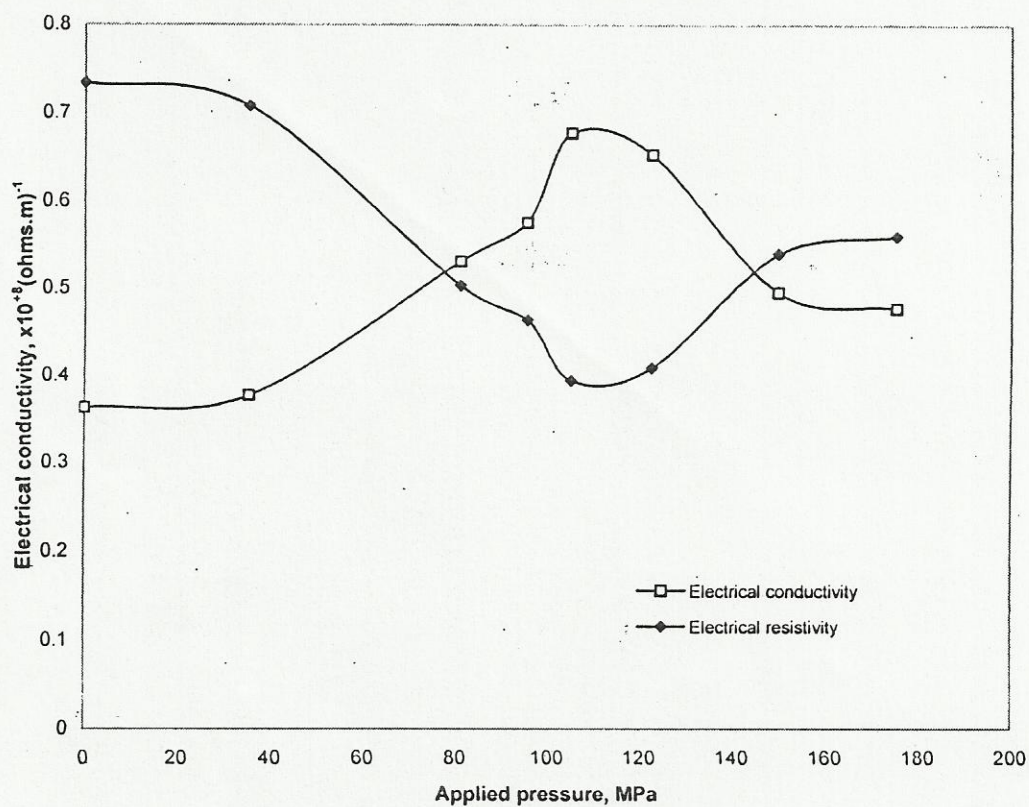


Fig. 3 Effect of applied pressure on the the electrical resistivity and conductivity of aluminium metal

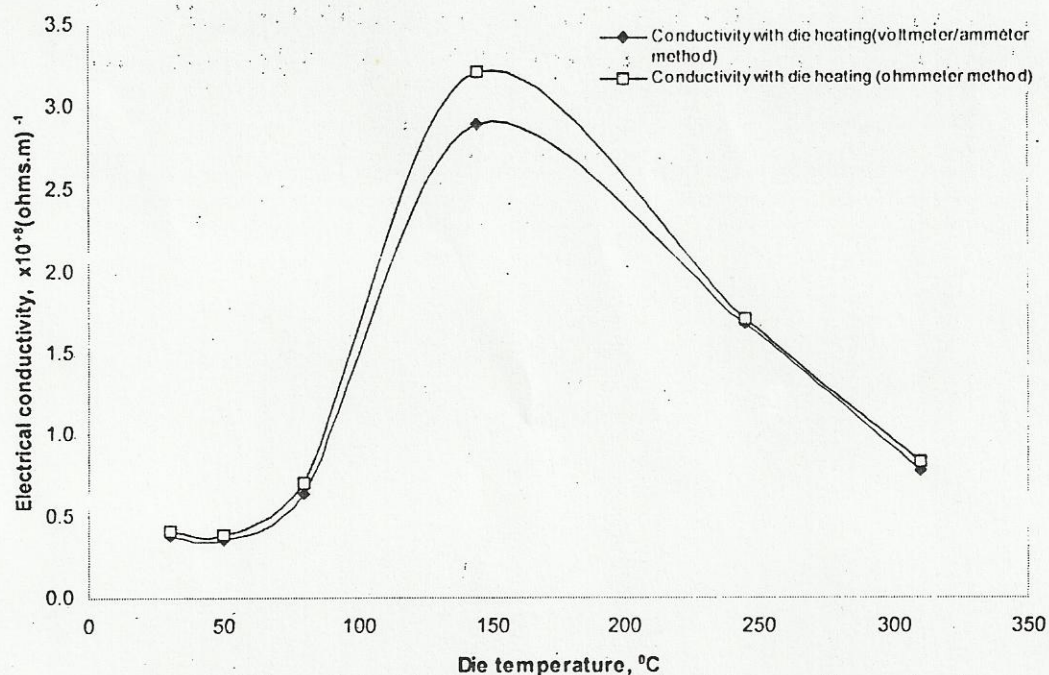


Fig. 4: Effect of electrical conductivity of aluminium on die pre-heat temperature by voltmeter/ammeter and ohmmeter methods (P=95.49MPa)

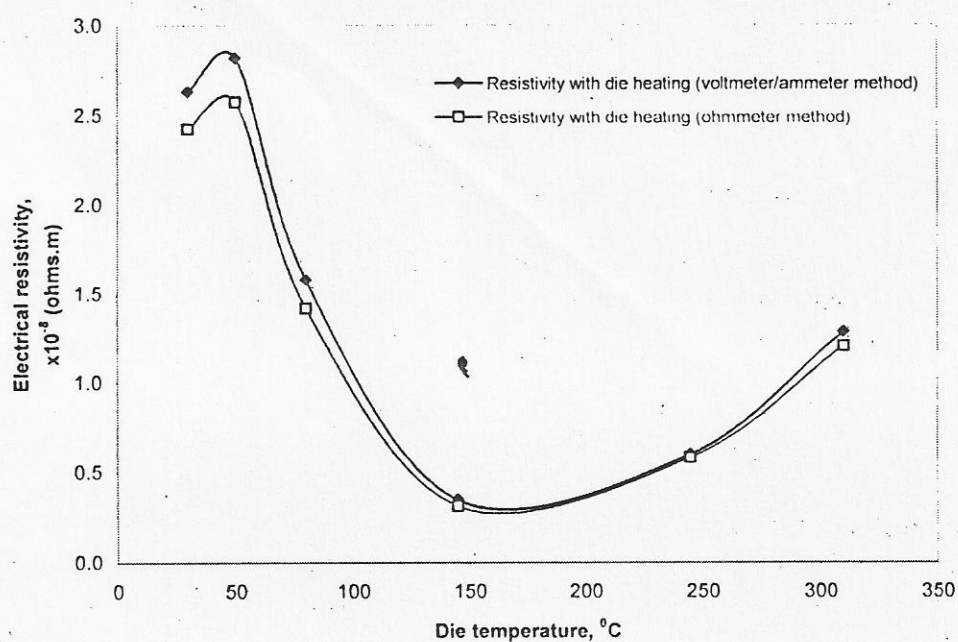


Fig. 5: Effect of electrical resistivity of aluminium on die pre-heat temperature by voltmeter/ammeter and ohmmeter methods (P=95.49MPa)