ISSN 2786-7447
EUROPEAN JOURNAL OF THEORETICAL AND APPLIED SCIENCES
OPEN ACCESS
PEER REVIEWED

# Effect of Moulding Temperature on Mechanical Properties of Pure Aluminum Sand Casting

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**Article Information**

**Suggested Citation:**
Al-Mashikhi, S.O., Raffi, N.F., Al-Maashani, R.M.M., Al-Zawamri, A.M.A., Al-Shanfari, A.M. & Al-Rawas, M. (2023). Effect of Moulding Temperature on Mechanical Properties of Pure Aluminum Sand Casting. *European Journal of Theoretical and Applied Sciences, 1*(3), 160-166.
DOI: 10.59324/ejtas.2023.1(3).17

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## Abstract:

In this study, mechanical properties (Tensile test, Brinell hardness and microstructure analysis) of pure aluminium after sand casting were investigated. Tensile test, Brinell hardness and microstructure analysis were performed using MAX text software, Universal Testing Machine and Escope with Clemax Imager, respectively. Sand cast aluminium was observed to have good tensile and hardness properties. From the observations, sand cast sample had uniform distribution of aluminium.

**Keywords:** *mould temperature; sand casting, pure aluminium, mechanical properties.*

## Introduction

The wide range of the application of aluminium alloys is obvious. The electrical, aviation, marine, aerospace, construction, and automotive industries, to name a few, benefit from their advantageous properties of light weight, great resistance to corrosion in the atmosphere and water, strength, and high thermal conductivity more than other metals (Allen, 1969; Rundman, 2005). Since they are used more frequently, it is necessary to comprehend their mechanical behavior and the effects of processing factors more thoroughly (Mrowka et al., 2007; Kauffman & Rooy, 2005). With this information, the designer may make sure that the casting will have the appropriate qualities for its intended application (Li et al., 2004; Shabestari & Moemeni, 2004).

There is no disputing the fact that casting as a process involves numerous variables, including, but not limited to, the melting temperature of the charge, the temperature of the mold, the pouring speed, the pouring temperature, the composition, the microstructure, the size of the casting, the size of the runner, the composition of the alloy, and the solidification time. Studies on the various effects of casting process factors on the mechanical properties of cast metals and their alloys have been effectively conducted, only to name a few (El-Aini et al., 2010; Timelli & Bonollo, 2010; Lee, 2007; Oji, 2011; Mohammad & Akpan, 2007; Boileau et al., 1997).

The non-uniform cooling of the molten metal in the mould is what causes the variation in the casting's structure. If this difference, which results in inadequate mechanical properties, is not controlled, it will impact how well the casting performs when it is being used (Novikov, 1998). Numerous processes have evolved as a result of this claim (Jatau & Datau, 2002). Investigating the varying effects of some of these parameters on the mechanical properties of related products is necessary due to the difference in structure of the casting that cannot be completely eliminated by many casting techniques and the inability to maintain the law of constant volume par second during the pouring stage. In this work, only two process parameters and one mechanical property are used. This study's purpose is to examine a sand casting part's mechanical characteristics and cast defects using X-ray and liquid penetrant techniques.

## Material Selection

### Preparation of Material and CNC Machining

High purity, dust- and contamination-free aluminum wires were charged in a graphite crucible and kept in an electric resistance furnace. When melting the metal, 0.01% (w/w) sodium chloride-potassium chloride (NaCl-KCl) powder was used as a cover. This reduced the amount of oxidation of aluminum by keeping oxygen out of the furnace and fostering a protective environment. When melting of pure aluminum began, the furnace temperature was increased to 750 °C and the melt was thoroughly stirred with progressive melting. The furnace temperature was then increased to 800 °C, and the melt was maintained at this temperature for ten minutes.

The pattern is made of acrylic plastic, and the process begins with rough cutting with a chop saw cutting machine with dimensions of 30 mm width, 250 mm length, and 20 mm thickness.

**Figure 1. Tensile Specimen Pattern (acrylic plastic)**

The sample will then be turned on a CNC milling machine and the machining operation will be performed to obtain the final shape. Center point marking is done on the strip before clamping it to the CNC milling machine table and following the milling machine operation procedure. CNC codes and programs are used to create the size and shape of the material sample, as well as the specific ASTM E8 testing specification.

### Preparation of Mould, Casting of Specimen and Methodology

In order to prepare foundry sand for molding, a specific amount of water was added. Mold boxes, also known as drag and cope boxes, were made of wood. A tensile pattern was then placed on a board that had one of the boxes on it. The tensile pattern has been used because the specimens that needed to be created have tensile shapes (Figure 1). The moulding sand was properly rammed into the pattern. After being properly rammed, the mould box containing the pattern was turned upside down, and parting sand was then applied before setting the other box. Following that, the moulding sand was added, but first, runner and riser pipes were installed to mark the locations of the gate and the riser is located at center of cavity. Then the sand was rammed. The cope was taken off after it had been properly rammed, and after that, the pattern was taken off. The pouring cup's cross-sectional area at the sprue and cavity were each 380mm$^2$ and 100mm$^2$, respectively. The assembled mold was then put in a furnace and heated to a holding temperature of 150°C to 200°C for 30 minutes. Then, each mold received another pour of the molten metal. The procedure was then repeated, this time with the molten metal being poured at temperatures of 750°C and 800°C for a holding period of 20 minutes.

(a) (b)

**Figure 2. Aluminum Cast Part (a)Before and (b) After Machining**

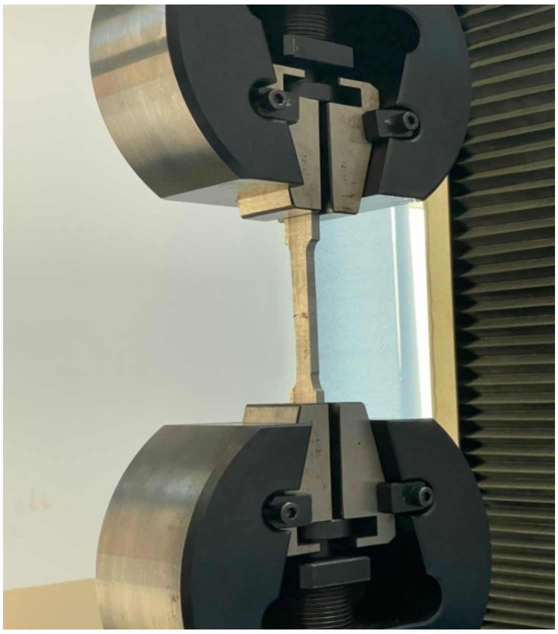


**Figure 3. Tensile Specimen Arrangement in Test Machine**

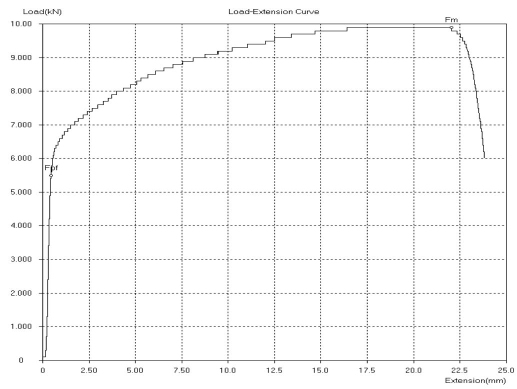
## Determination of Ultimate Tensile Test

Figures 2(a) & (b) shows aluminum cast part before and after machining in the CNC machine, respectively. The castings were shaped as per ASTM E8 specifications. A universal material testing machine, model EdLabquip GmbH (MT220i), digital indicating system, is the tool used for the ultimate tensile test (Figure 3). The device is hydraulically powered. The machined test specimen was then fed into a locking socket, which provided grip of the specimen at the base and at the top. The test piece was held at both ends while being made to be slightly tensioned, and the meter was set to zero with the pump handle in the down position and locked. The press was then loosened to release the extension to allow for easy monitoring on the tensile test piece alongside the socket in which it is fitted. To apply the load, the pump handle was raised and depressed. The extension was observed as the load was uniformly increased. Other specimens went through the same procedure again.

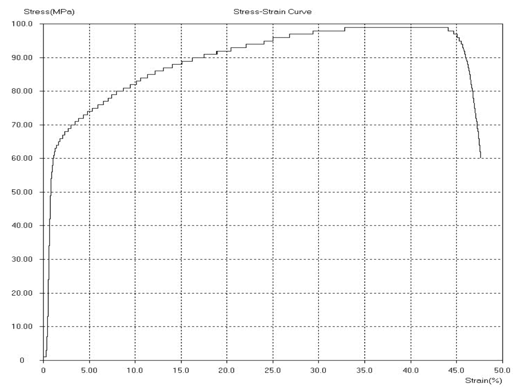
## Results And Discussion

### Tensile Test

Pure recycled aluminum scraps were melted, and then, poured into the cavity of the mold made of sand. The results of the effect of mould temperature on the mechanical properties of aluminium parts. Also, Figures 4(a) and (b) represent load and displacement and stress-strain curves of aluminium cast part. It was observed that an increase in load, elongation increases from yield point to ultimate tensile strength. After necking formation, load reduces to fracture point. The yield point, ultimate tensile strength and fracture point were determined to be 5.5, 9.8 and 6 kN, respectively. The decrease in the mechanical properties after necking point may be as result of non-uniform crystal structure formed because of the decrease in the load (Llewellyn, 1997). Since the velocity of molten metal going in the mould cavity is decreased, the filling of the mould cavity is delayed resulting to non-uniform solidification of the molten metal and this can results to non- uniform microstructure formation within the solidified casting (i.e. coarse and fine grain structure within the casting).




(a)




(b)

**Figure 4. (a) Load vs Displacement and (b) Stress Strain Curves for the Aluminum Cast Part**

Tensile testing is a destructive test process that provides information about the tensile strength, yield strength, and ductility of the metallic material. It measures the force required to break aluminium specimen and the extent to which the specimen stretches or elongates to that breaking point (Mohammad & Akpan, 2007). The basic idea of a tensile test is to place a sample of a material between two fixtures called grips which clamp the material.

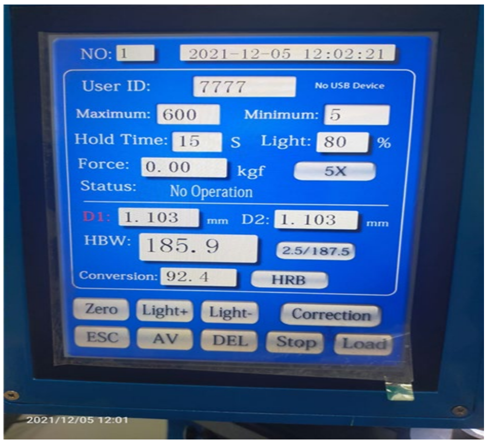
### Hardness Test

Hardness testing is a destructive test process, which is a measure of the resistance to localized deformation induced by either mechanical indentation or abrasion, resistance of a material to deformation, indentation, or penetration. The types of hardness test are Rockwell, Knoop, Vickers, and Brinell Hardness Test. Brinell Hardness Test is employed in this study. During Brinell hardness test, an accurately controlled force is maintained when an indenter, generally a carbide ball, is forced into the test model for a specific period of time. Upon removal, it leaves an encircling indentation, the measurement of which is taken to calculate material hardness as per the formula.

The larger the indent left in the surface of a workpiece (specimen) by the Brinell indenter with a defined ball diameter and a defined test force, the softer the tested material. In order to determine the Brinell hardness (BHN), the spherical, hard metal (tungsten carbide) indenter is pressed into a specimen (workpiece) with a defined test load (between 1 kgf and 3000 kgf). The BHN results from the quotient of the applied test force and the surface area of the residual indent on the specimen (the projection of the indent) after withdrawing the test force. To calculate the surface area of the residual spherical indentation, the arithmetic mean (d) of the two perpendicular diagonals (d1 and d2 in mm) is used, because the base area of Brinell indents is frequently not exactly round. The typical test uses a 10 mm diameter steel ball as an indenter with a 3,000 kgf force. For softer materials, a smaller force is used; for harder materials, a tungsten carbide ball is substituted for the steel ball. The indentation is measured and hardness calculated as given in Equation (1):

$$BHN = \frac{2P}{\pi D(D-\sqrt{D^2-d^2}} \qquad (1)$$

where, P is applied load, D is diameter of indenter and d is indentation.



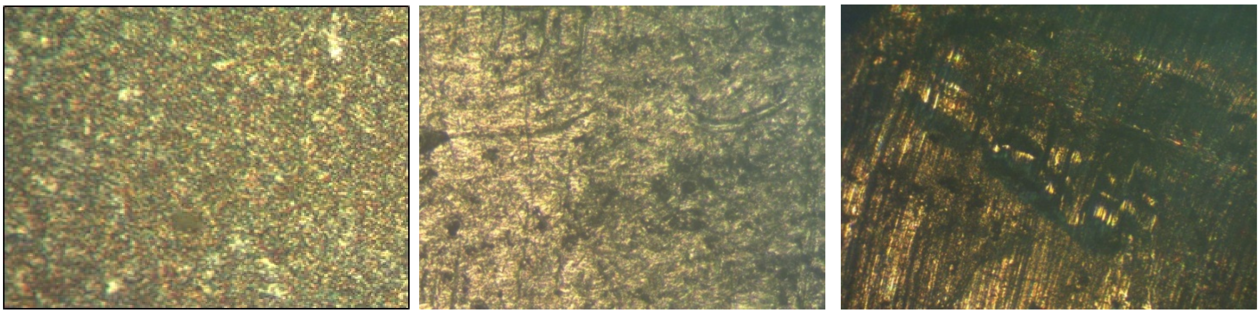

**(a)** **(b)**

**Figure 5. (a) Digital Hardener Tester and (b) Reading**

A digital Brinell hardness tester was used to measure the hardness for the various samples. Hardness values are useful tool in determining material properties. Brinell hardness testing was carried out on the sand cast samples. The BHN readings were taken using a digital Brinell hardness machine with an applied load of 56.5 kgf. A 2.5mm diameter ball indenter is used to find the hardness number. Indentations were taken from the digital screen and by viewing of the microscope at two position one is horizontal position ($d_1$) and anther from vertical position ($d_2$) on the indented diameter as shown in Figures 5(a) and (b). Hardness values are a useful tool in determining material properties. Brinell hardness testing was carried out on the welded materials and heat affected zone of welded joint samples. The Brinell hardness readings were taken using a Digital Brinell hardness Machine with an applied load of 15.625kgf. A 2.5mm diameter ball indenter is used to find the hardness number. Indentations were taken from the digital screen and by viewing of the microscope at two position one is horizontal position ($d_1$) and anther from vertical position ($d_2$) on the indented diameter. The BHN was found to be 10.6.

## Microstructure Analysis

Microstructural analysis is used extensively in failure investigations and supplements material performance tests such as environmental degradation studies and casting qualification testing (Jatau & Datau, 2002). Figure 6(a) shows the microstructure of aluminium casting the particles morphology is typical dendrites and length were studied. Figure 6(b) shows aluminum particles are uniform throughout the entire cast. The particles morphology is almost spherical and they are uniformly disturbed through the microstructure and the liquid aluminum solidity within a short time Figure 6(a) (Jatau & Datau, 2002). The micrograph clearly shows ductile structures of cast aluminum in Figure 6(b) and deformation that has produced coarse elongated grains which clearly show a ductile failure Figure 6(c).



(a) (b) (c)

**Figure 6. (a) Uniform Cast, (b) Ductile Structures and (c) Elongated Structure of Aluminum**

## Conclusion

In this study, the state of liquid metal influences the microstructure and mechanical properties are studied. Modern industries focused to produce the components with superior properties by utilizing the liquid metal in an effective way. Through the sand casting process, aluminum material is melted in a liquid form and poured into mould cavity. After solidified, machining process carried out and studied the quality of the casting by destructive and non-destructive methods. The sand casting is economical process when cost is considered. From the stress strain curve, the investigation carried out gave the yield point for sample 1 ($5.5N/mm^2$) and sample 2($5.8N/mm^2$), an ultimate tensile strength (UTS) result for sample 1 ($9.8N/mm^2$), and sample 2($9.5N/mm^2$) fractured for sample 1 ($6N/mm^2$), and sample 2($5.5N/mm^2$). The BHN value found from the Digital Hardness machine for the sample 1 (9.7 BHN) it is the lowest value and (11.3 BHN) it is the highest value. for the sample 2 (10.2 BHN) it is the lowest value and (13.1 BHN) it is the highest value. The micrograph clearly shows deformation that has produced coarse elongated grains, which clearly show a ductile failure. Through the non-destructive methods like X-ray and LPT, the quality of cast was revealed No defects found. This study will definitely be helpful in choosing the casting process based on the aforementioned criteria. Further studies may be required to consider suitability of different materials to each process.

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