[Influence of Chill Materials on Microstructure and Mechanical Properties of Aluminium-Silicon Alloy Casting]

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ABSTRACT: Microstructure and mechanical properties of aluminium alloy casting is influenced by the rates of solidification and cooling. Solidification of molten metal in casting is improved by the use of chill materials. Therefore, this study investigates the influence of chill materials on microstructure and mechanical properties of aluminium-silicon alloy using green sand casting technique. Green sand moulds were designed with incorporation of external chills. Brass, Mild Steel and Cast Iron were selected as chill materials for investigation. Plate of aluminium-silicon alloy castings were produced and cooled using chills, each of which were made into nine (9) blocks of same shapes but varying thicknesses of 10 mm, 15 mm and 20 mm. For every chilled casting, test samples were taken at three distances from the point of contact between castings and chills to the free ends. Evaluation of the microstructure and mechanical properties of the samples were carried out. The results revealed that Ultimate Tensile Strength (UTS) and Brinell Hardness Number (BHN) decreased with increase in distances from the edges of contact between the chills and castings as well as increased with increase in chills thicknesses. The results show that Brass chill was the most effective, having increased the UTS (18%) and BHN (53%). Second to Brass was Cast Iron chills with an improved UTS (11%) and BHN (40%). Mild Steel chill was the least effective, having raised the UTS (8%) and BHN (16%). Therefore, the use of Brass chill material is most suitable for green sand casting of Aluminium-silicon alloy; in contrast to other chill materials investigated.

Keyword; Aluminium-Silicon, Casting, Chill, Green Sand, Mechanical Properties

1. INTRODUCTION

Chills are metallic inserts incorporated into the mould to promote directional solidification of the casting. Normally molten metal in the mould cools at a rate relative to thickness of the casting. Though, complexity in geometry of the mould cavity may prevents directional solidification from occurring naturally; then the use of chill become necessary in order to improve microstructure and mechanical properties of the casting.

Selection and choice of chill material is guided by specific heat and thermal conductibility of the material, which must be higher than that of the casting. Some materials investigated include Cast-Iron, Brass, Aluminium or Copper and others material are graphite as well as special sand. These special sand include chromite sand and zircon sand. There are two commonest types of chill namely internal and external chills. The type of chill used depends on ease of manufacture and location in the mould relative to the casting. Therefore, this study investigates the effect of external chill material on microstructure and mechanical properties of aluminium alloy casting. The distance between the chill material and casting interface is an important factor that may influence microstructure and mechanical properties of the casting.

Biswast *et al*., [1] investigated the influence of internal chills on properties and microstructure of aluminium alloy castings using cylindrical form of the chill of the same material; evaluating effects of temperature gradient, placement of chills on solidification time as well as grain size of the casting. It was discovered that the solidification time of the casting samples decreases linearly with an increasing volume fraction of chills. In addition, the use of internal chills enhanced mechanical properties of the aluminium alloy casting. Joel [2] investigated the effect of chilling on quality of the aluminium composite, the quality of the composite developed is highly dependent on the chilling rate and its dispersoid.

Rapid solidification via melt-spinning technique was studied by Ozun *et al*., [3] and the influence of the cooling rate and its conditions on microstructure and mechanical properties of the aluminium alloy casting. The effect of cooling rate on microstructure and mechanical properties of aluminium alloy Dobrzanski *et al*., [4], and aluminium composites Ahamed *et al*.,[5] were investigated; the investigation revealed that increasing cooling rate refines the grain size and improved mechanical properties of the casting. Likewise, Zhang *et al*., [6] studied the effect of cooling rate on microstructure and mechanical properties of aluminium alloy. It was established that an increase in cooling rate leads to a decrease in the dendrite arm spacing, and an increase in both the strength and hardness.

A comparative investigation was carried out by Raji [7] to evaluate the grain size and mechanical properties of Al-Si alloy. Boutorabi and Zandira [8] studied the effect of fins and moisture content on local solidification time of aluminium alloys casting as well as on cooling rate of the mould. Microstructure and hardness of cast chilled aluminium composites using copper, cast iron and stainless steel chill materials were investigated by Leela and Sreenivas [9]. The results of the investigation showed that copper chilled aluminium composites produced better hardness and fine grain microstructure were observed. Vijayan and Prabhu [10] assessed the effects of melt treatment and chilling on cooling curve parameters and microstructure of aluminium-silicon alloy. It was reported that formation of the intermetallic compound decreased with increase in cooling rate and modification of the eutectic silicon. Though, an increase in the degree of modification was associated with decrease in the volume fraction of the intermetallic compound formed.

Current research into the use of chill casting technique have being extended to the investigation of surface modification. For instance, Natalino *et al*., [11] investigated the effect of preheating temperature on chill plate to determine hardness, surface layer thickness, and element contained on cast surface. Three preheating temperatures (500, 700 and 900 ^{o}C) were investigated. It was discovered that as the preheating temperature increases, an increase in the thickness of the hardened layer on the ductile iron surface which leads to a raise in hardness value of the surface.

2. MATERIAL AND METHODS

2.1 Materials and equipment

Aluminium scrap from Toyota car engine pistons and chill materials of Cast Iron, Mild Steel and Brass. In addition, sand and its constituents as well as fluxes were used. While, equipment used include a 20 kg capacity coal fired lift-out crucible furnace. Tensile testing machine: Monsanto Tensometer, type 'W', 3 serial number 10975, UK, capacity: 50 KN; Brinell Hardness testing machine: Universal hardness tester and Metallographic analysis using Microscope: 40X-1000X, model: ME300TZ-2L, made in Germany. Other tools used include: Rammer, Trowel, Strike-off bar, Flasks, Clamps and Riddle.

2.2 Methods

The methodology adopted for the green sand casting and evaluation of the casting are reported as follows.

2.2.1 Mould preparation

Moulding sand was prepared with compositions as per American Foundry Society's Grain Finess Number (AFS-GFN) of 80, which is generally considered normal for aluminium alloy casting [12]. Furthermore, the constituents of the green sand mould were prepared in accordance to formulation by Griffiths, [13] with proportions of: Silica sand (90 wt.%), Bentonite (6 wt.%) and Moisture (4 wt.%). A prepared sample mould showing mould cavity and position of the chill material is shown in Figure 1.

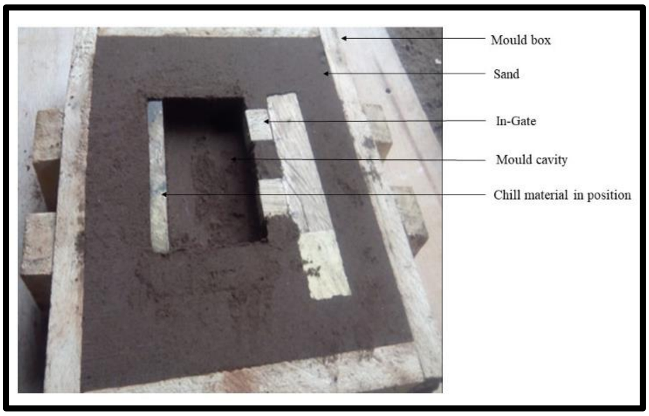


Figure 1: Mould cavity and Brass chill in position

2.2.2 Evaluation of elemental compositions

The surfaces of the materials to be analysed were polished with emery paper. This was necessary to remove surface contaminants. For the analysis, an Energy Dispersive X-ray Fluorescence (EDXRF) Spectrometer of model "Minipal 4" (DY 1055) was used.

The prepared samples were placed in the measuring positions on a sample changer of the elemental composition analyser. The condition set are as follows: elemental composition determination, nature of the samples, and 14 kv for major oxides, 20 kv for the trace elements /rare earth metals, and kapton for major oxides. The time for each of the sample was 100 seconds and air medium was used throughout the test. The chemical compositions of the chill materials and aluminium scrap were carried out, these are shown in Tables 1 and 2.

Table 1: Composition of the chill materials

Chill Materials	Percentage Compositions (%)							
	Cu	Zn	C	Si	Mn	P	S	Fe
Brass (Apha-Beta)	61.00	39.00	-	-	-	-	-	-
Cast Iron	-	-	3.40	1.80	0.50	-	-	94.30
Mild Steel (ASTM A36)	0.20	-	0.25	0.28	1.03	0.04	0.05	98.15

Table 2: Composition of the aluminium alloy

Si	Cu	Mg	Mn	Fe	Ti	Ni	Zn	Pb	Al
11.90	0.10	0.10	0.39	0.46	0.12	0.08	0.12	0.10	86.63

The elemental composition analysis of the aluminium scraps from Toyota car pistons shows that it is an alloy of Al11.9%Si.

2.2.3 Melting, Casting and experimental design

The Al11.9%Si sourced was placed inside the lift-out crucible and heated to 660^{o}C. Then, followed by fluxing; 5 g each of sodium chloride (NaCl) and potassium chloride (KCl) tablets were added to 3.04 kg of aluminium alloy melts. Heating continued to 770^{o}C, at this temperature the melt was then ready to be pour into the mould cavity.

Pouring of the melt into mould cavity was carried out. Inspection of the castings were physically carried out for likely defects. All the castings produced were free of any defects whatsoever, as can be seen in Figure 2.

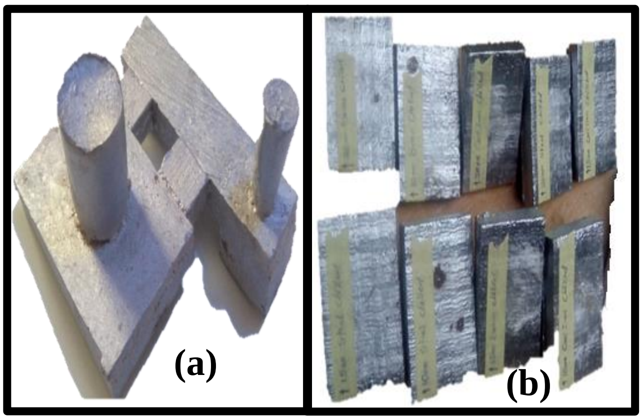


Figure 2: Aluminium alloy casting (a) Samples after fettling (b) Raw cast plate with gate and riser features

Figure 2 illustrates aluminium alloy castings showing samples that have undergoes fettling, labelled for easy identification for further tests covering microstructure and mechanical properties.

A total of ten experiments were performed. Nine of the experiments were performed using chill materials in different proportion as shown in Table 3 and one control, without using any chill material.

Table 3: Experimental design of casting with chill materials

Chill materials	Various thickness of the chill materials [mm]		
	10	15	20
Brass (B)	B_{10}	B_{15}	B_{20}
Cast Iron (C)	C_{10}	C_{15}	C_{20}
Mild Steel (M)	M_{10}	M_{15}	M_{20}

Nine samples of the chill material were machined into dimensions as shown in Figure 3, considering three Varieties of thickness (t) ranging from 10, 15 and 20 mm for each chill material investigated. Samples of the machined chill materials ready for use are shown in Figure 4.

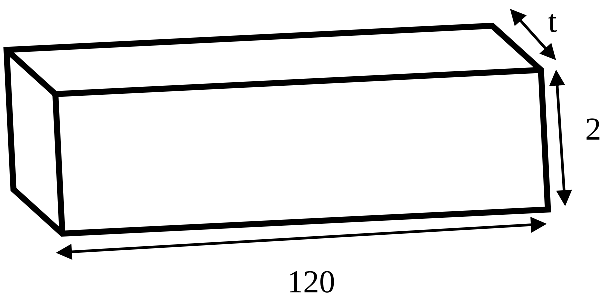
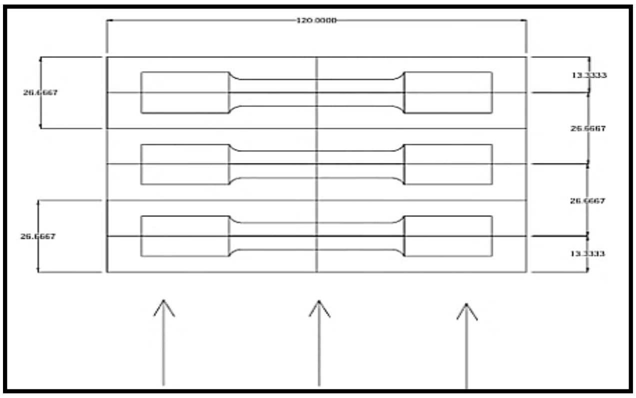


Figure 3: Sketch of the chill material, all dimensions are mm

Figure 4: Chill materials investigated

2.2.4 Evaluation of microstructure of the aluminium-silicon casting



Metallographic analysis of samples were conducted using optical microscope, 40X-1000X, model: ME300TZ-2. Grinding of the sample was carried out using emery papers progressively to obtain finer grade required. Grind samples were polish to produce mirror like and ridges free surface. Then, samples were etched with 2% nital solution and then dried. Thereafter, the microstructure of the prepared samples were taken under microscope.

2.2.5 Determination of mechanical properties of the aluminium-silicon casting

Tensile strength test was carried out using universal tensile testing machine. Three specimens were machine out from each of the casting according to the dimension shown in Figure 5.

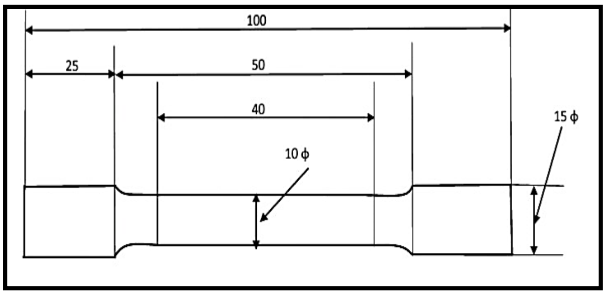


Figure 5: Standard Test Specimen for Tensile Test, all dimensions are in mm

Brinell hardness test were carried out on each specimen after which they were machined to tensile test specimen dimension. The arrows indicate the point of contact between the casting and the chill material as shown in Figure 6.

Figure 6: An illustration of the casting, chill material and casting interface and specimen marking

The applied load used was 40 kgf and a dwell time of about 15 s. To obtain Brinell Hardness Number (BHN), a steel ball of diameter 2 mm was used as an indenter. It was obtained according to the Equation (1):

$$\mathrm{BHN} = \frac{2\mathrm{P}}{\mathrm{D}[\mathrm{D}^2 - \mathrm{d}^2\ ]} \qquad (1)$$

where *P* is the applied force [N], *D* is diameter of indenter [mm] and *d* is diameter of indentation [mm].

Percentage improvement of the chilled over unchilled casting are determined by Equation (2):

$$Percentage\ Improvement = \frac{(Change\ in\ Value\ of\ the\ Property\ Measured)}{(Actual\ Value\ of\ the\ Property\ Measured)}\ x\ 100 \qquad (2)$$

3. RESULTS AND DISCUSSION

3.1 Influence of chill materials on microstructure

The microstructure of the chilled and unchilled casting are shown in Figure 7.

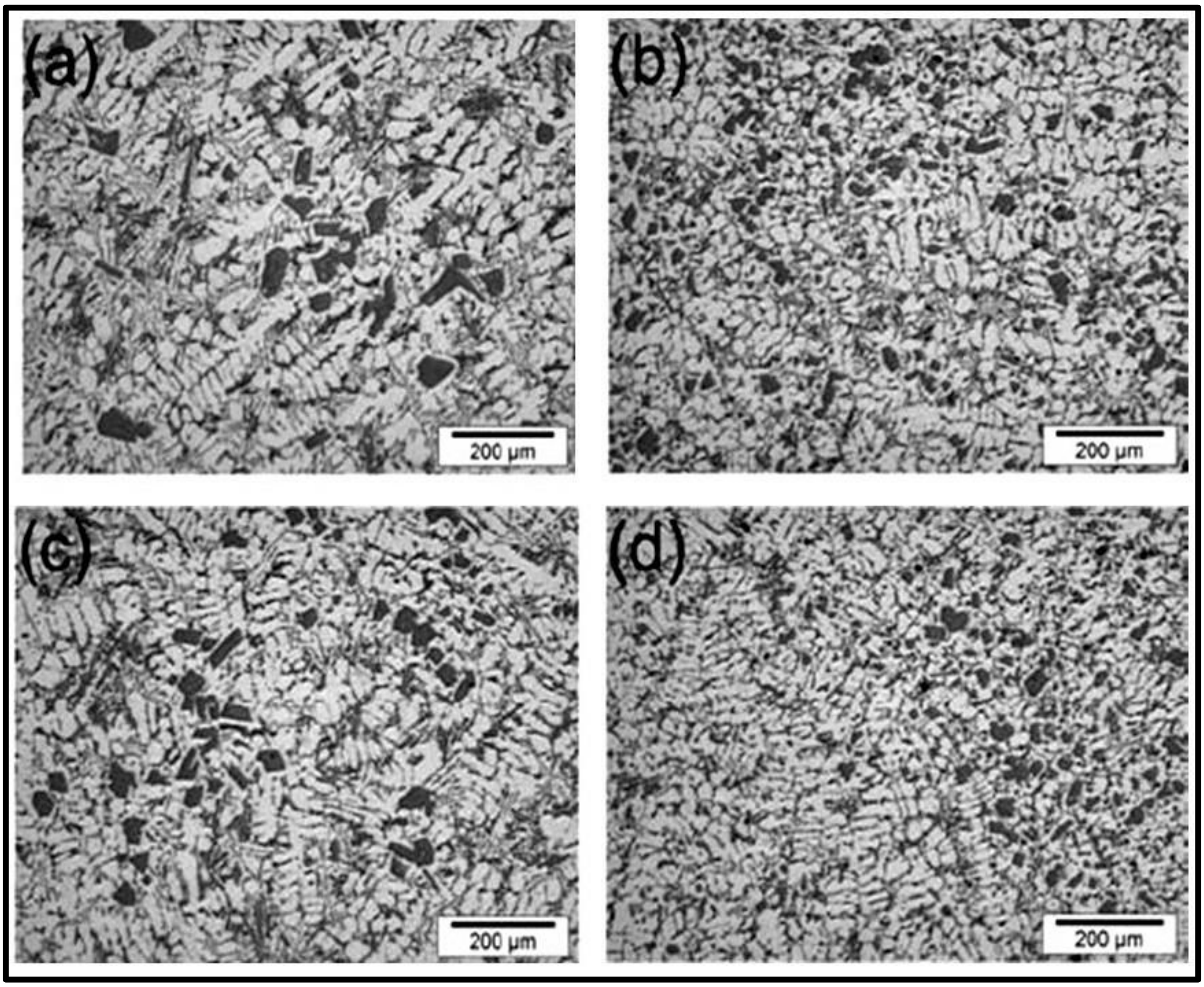


Figure 7: Micrograph of samples (a) unchilled casting (b) cast iron chilled casting (c) mild steel chilled casting (d) brass chilled casting

In the microstructure shown in Figure 7, essentially two phases were observed. Firstly grey (white) spots representing $\propto$-phase of aluminium grain and dark spots are β-phase of eutectic silicon grain. A close observation of the Figure 7(a), shows silicon grains appear larger when compared with other samples which of course were obtained from chilled castings of the various chill materials. Figure7(b) was a microstructure of sample cooled with cast iron chill. β Particles appear to have dissolved little as it looks finer than that of the unchilled sample. Figures 7(c) and (d) were result obtained from samples chilled with mild steel and brass, respectively. Brass chill turned out to have produced sample with the finest grain structure. That of mild steel is only slightly different from control sample (unchilled casting).

3.2 Effect of chill materials on mechanical properties

Results of the UTS of the cast product are shown in Figures 8-10.

The Figures 8 to 10 give clear view of performance of each chill on UTS of the Aluminium-silicon alloy. Starting with 10 mm chill thickness, followed by 15 mm and later 20 mm, the value of UTS increased proportionately with increase in chill thickness. That means that the higher the mass of chill, the higher the cooling effects on the casting provided the mass of casting remains constant. In other words, the higher the rate of heat transfer, which in turn results in higher solidification rate of the casting; these disagree with Prakash & Rajesh, [14].

The results obtained at the edge of contact (about 13.33 mm) between the chills and castings were slightly higher and decreased slightly, moving further away from the edge (about 66.66 mm). This is in line with a work done by Griffiths [13]. This scenario applied to all chill materials at various thickness. Similarly, the results of the Brinell hardness test are shown in Figures 11-13.

Progressive introduction of various thicknesses of chill materials resulted in improved hardness, with the highest produced by samples of brass chilled casting, a similar trend was obtained by Leela and Sreenivas [9].

The Mechanical properties of unchilled casting is investigated. The UTS of the unchilled casting was determined to be 151 MPa and hardness to be 77 BHN. Table 4 show percentage improvement of the chilled over unchilled casting.

Table 4: Improvement of the mechanical properties for chilled and unchilled castings

Chill Materials	UTS		Hardness	
	UTS[MPa]	Percen-tage [%]	UTS[MPa]	Percen-tage [%]
Brass (B)	178	18	118	53
Cast Iron (C)	168	11	108	40
Mild Steel (M)	163	8	89	16

Analysis of the results shows that the mechanical properties of the aluminium alloy improved as the distance between the chill interface and casting decreases.

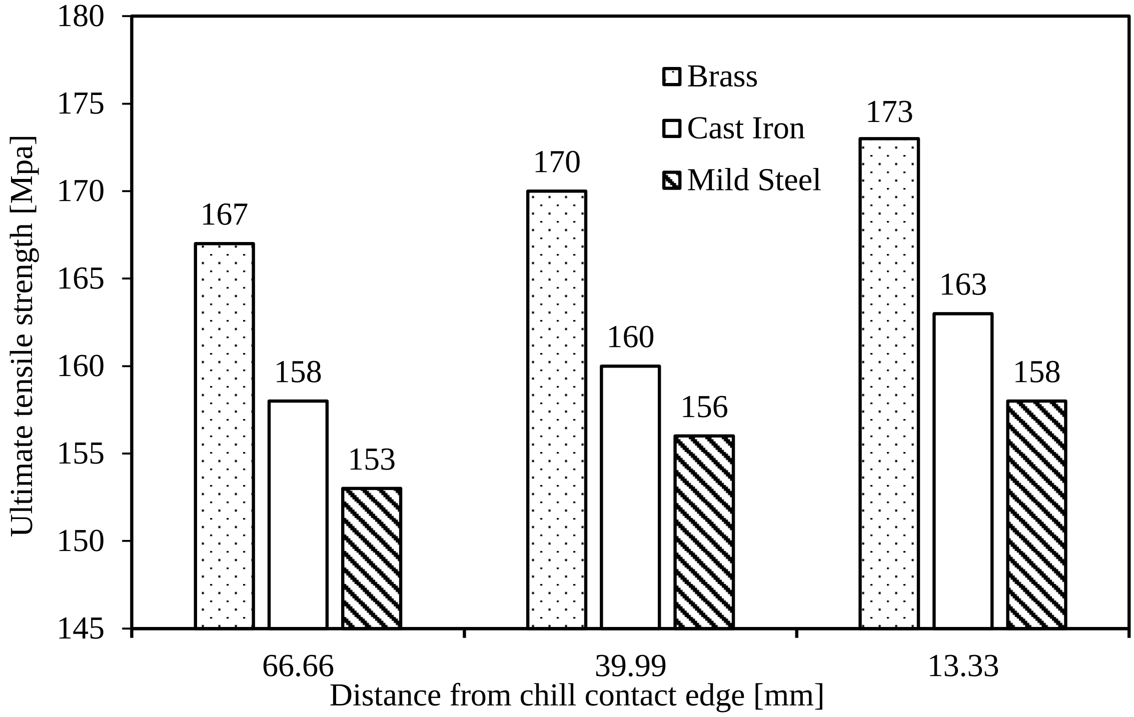


Figure 8: UTS at various distances away from chill materials of 10 mm thickness

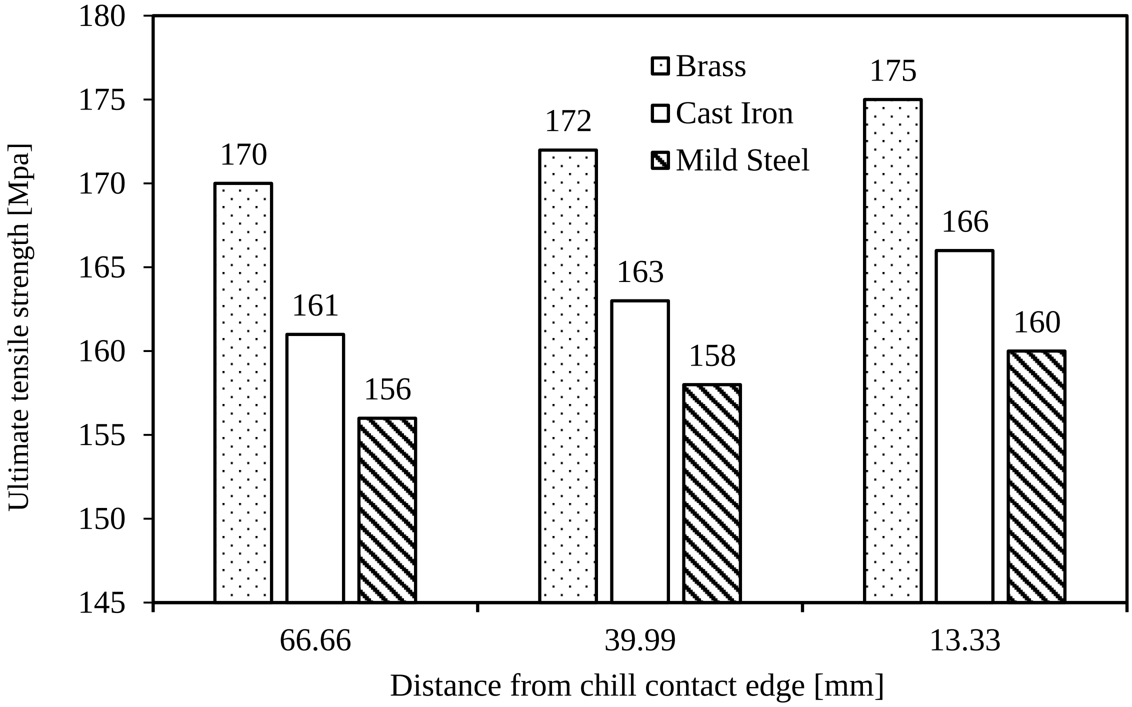


Figure 9: UTS at various distances away from chill materials of 15 mm thickness

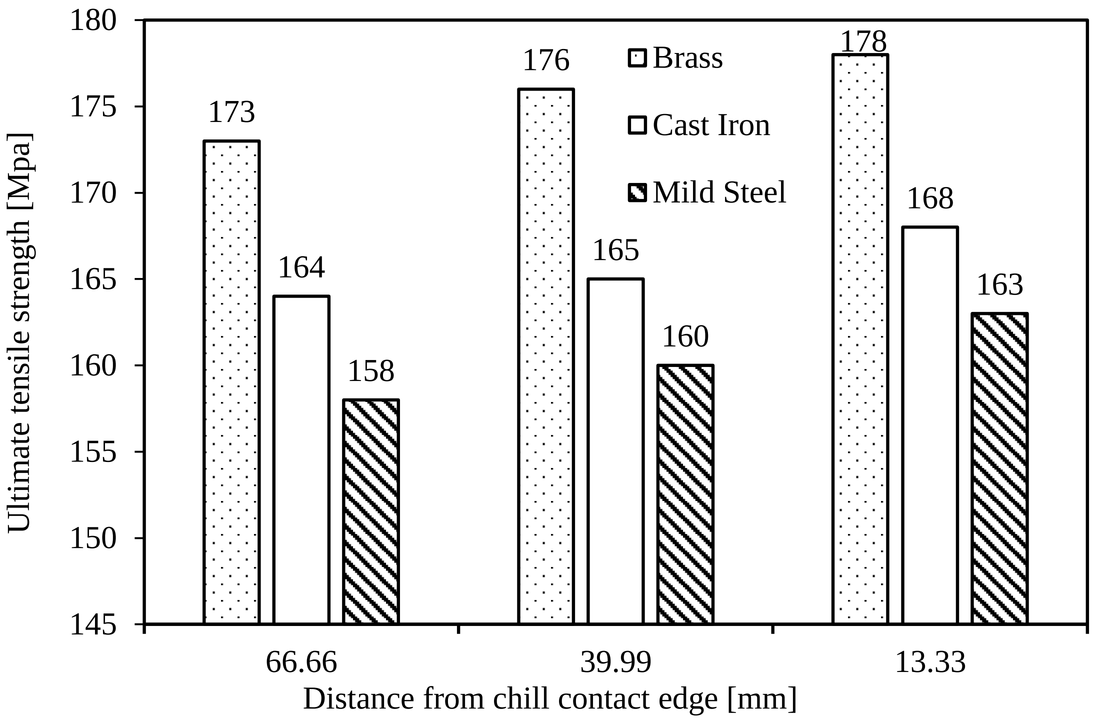


Figure 10: UTS at various distances away from chill materials of 20 mm thickness

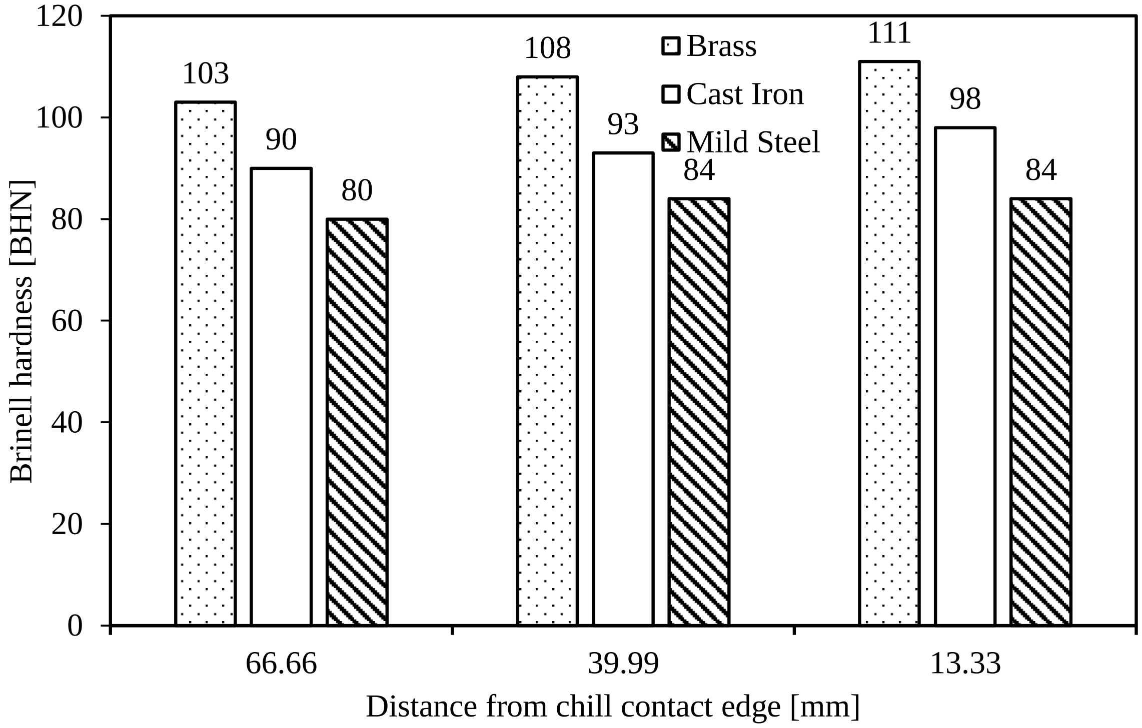


Figure 11: Brinell hardness at various distances away from chill materials of 10 mm thickness

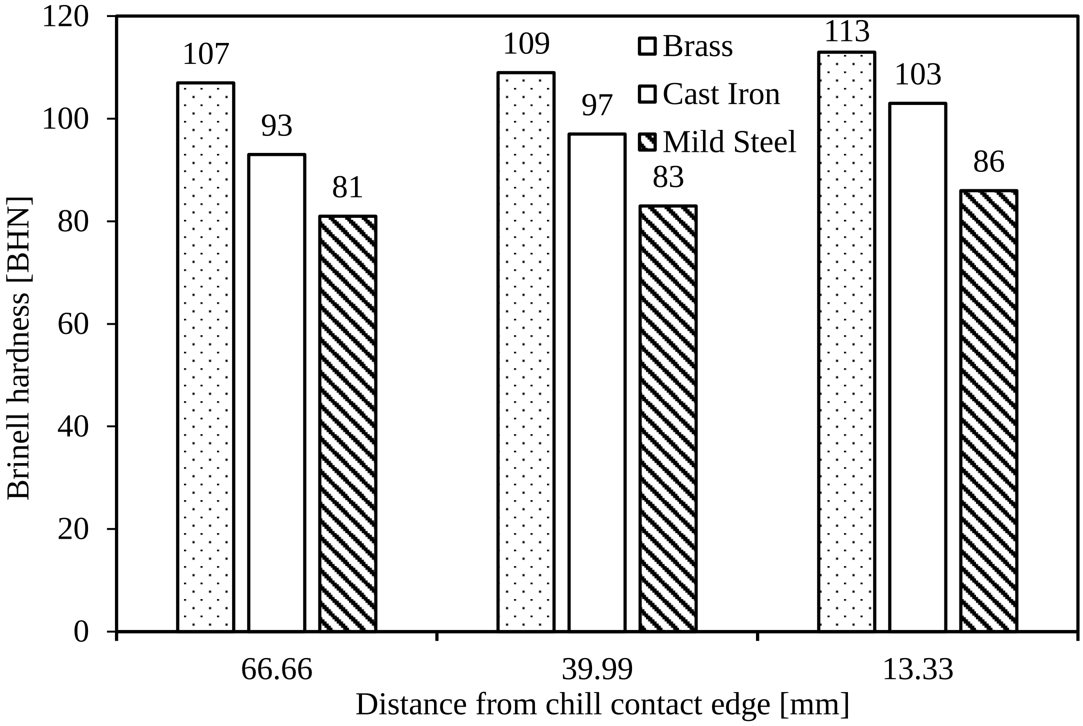


Figure 12: Brinell hardness at various distances away from chill materials of 15 mm thickness

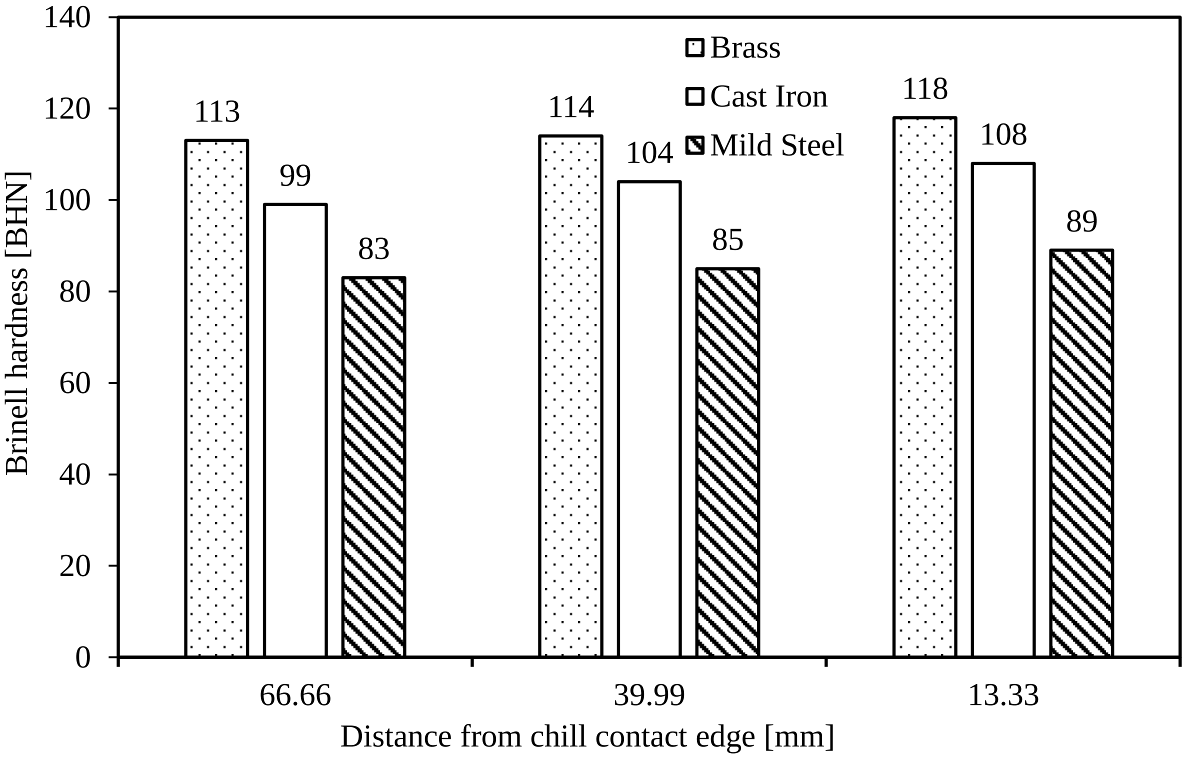


Figure 13: Brinell hardness at various distances away from chill materials of 20 mm thickness

4. CONCLUSION

The following conclusions were drawn:

(i) the use of chill materials influences the microstructure of the aluminium alloy casting.

(ii) ultimate tensile strength of the aluminium alloy casting is improved by the use of chill material. The percentage improvements were determined for Brass chill (18%), Cast Iron chill (11%) and Mild Steel chill (8%).

(iii) hardness of the aluminium alloy casting is improved by the use of chill material. The percentage improvements were determined for Brass chill (53%), Cast Iron chill (40%) and Mild Steel chill (16%).

(iv) both hardness and UTS of the Al11.9%Si alloy is improved as the distance between the chill interface and casting decreases.

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