EFFECT OF CHILLS OF DIFFERENT MATERIALS ON MECHANICAL PROPERTIES OF Al11.9%Si ALUMINIUM ALLOY

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ABSTRACT

This research work investigated the effect of chills on mechanical properties of aluminium alloy. Green sand gating system was designed with incorporation of external chills. Brass, mild steel and cast iron were selected as chill materials for investigation. Plate castings of Al11.9%Si alloy were produced and cooled using the chills, each of which were made into nine (9) blocks of same shapes but varying thicknesses of 10mm, 15mm and 20mm. A control sample was cast without a chill for the purpose of making comparison. For every casting chilled with a chill material, test samples were taken at three regular distances from the point of contact between castings and chills to the free ends. The samples were tested for Ultimate Tensile Strength (UTS) and Brinell Hardness Number (BHN). The results revealed that UTS and BHN decreased with increase in distances from the edges of contact between the chills and castings and increased with increase in chills thicknesses. The highest volume (20mm thick) chills gave the maximum values (173MPa & 113BHN, 164MPa & 99BHN, and 158MPa & 83BHN for Brass, Cast iron and Mild steel respectively) across all chill materials used, both for tensile strength and hardness. Compared to the results of UTS and BHN obtain from unchilled casting, brass chill was the most effective, having increased the UTS and BHN by 15% and 34% respectively. Second to brass was cast iron which improved UTS by 10% and hardness by 28%. Mild steel was the least effective, having raised the properties by 7% for UTS and 13% for hardness.

Keywords: Al11.9%Si, unchilled, external chills, plate castings, control sample, ultimate, hardness.

1.0 INTRODUCTION

Generally speaking, the grain refinement of cast and wrought alloy is beneficial in improving room temperature mechanical properties such as strength, hardness, ductility and so on. The dendrite grain size often influenced by rate of solidification is an important determinant of mechanical properties of aluminium alloy casting [8]. Incorporation of metallic chills into a mould for faster heat extraction is one of several methods available.

[1] investigated the effect of chills and riser placement on mechanical properties of premium sand casting and found the relationship between soundness, solidification rate and fatigue properties in alloy A206. [6] worked on the hardness and micro structural characteristics of rapidly solidified Al-8-16%Si alloy. Rapid solidification by melt-spinning technique was used to examine the influence of the cooling rate/conditions on microstructure and mechanical properties. Evaluation of microstructure and micro hardness of chill cast Al-B4C composites was done by [5]. The chill material was observed to have a significant influence on the microstructure and hardness of the cast specimens. Finer structure and better hardness were observed with the specimens cast using copper chills, whereas, cast iron and stainless steel chills gave rise to coarse grain structure with reduced hardness.

Effect of chills on soundness of Al4.5%Cu alloy casting was conducted to study the influence of end chill of varying volumetric heat capacity (VHC) on bar type castings of the alloy by [7]. It was established that the rate of heat extraction of the chills depends on the VHC of the chill materials and their presence greatly improves the mechanical properties.

Meanwhile, using green sand casting technique, this research investigated three chill materials, namely: brass, cast iron and mild steel; each was machined into blocks of equal volume. Aluminium-Silicon alloy was chosen for this study. The alloy was cast into plate castings of equal dimensions. The mechanical properties investigated on the casting were ultimate tensile strength (UTS) and Brinell hardness.

2.0 Materials and Methods

The material used includes:

i. Aluminium scrap: Toyota car engines' pistons
ii. Chills: cast iron, mild steel, and brass:
iii. Sand Mould: silica sand, bentonite, and water
iv. Fluxes: aluminium fluoride, sodium chloride and potassium chloride

The equipment used were:

i. 20kg capacity coal fired lift-out crucible furnace
ii. Brinnel hardness testing machine: universal hardness tester, Location: Kaduna Polytechnic, Kaduna, Kaduna State.
iii. A tensile testing machine: Monsanto Tensometer type 'W', serial number 10975, UK., Capacity: 50KN, Location: Kaduna Polytechnic, Kaduna, Kaduna State.
iv. A metallurgical microscope: 40X-1000X, model: ME300TZ-2L, made in Germany. Location: Latex Labs, shop 4, Gidan Matasa, Bosso, Niger State.

2.1 Moulding Process

The 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 [4]. Typical sand mix composition for non-ferrous metals (Griffiths, 1999) was used: 90% silica sand, 6% bentonite and 4% water.

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vi. Steps 1 to 5 above was repeated for other eight (8) other castings and finally for unchilled casting. The chills were placed into the mould as shown in figure 2, having direct contact with the molten metal in order to enhance easy heat transfer from same to the chills.

The dimension of each of the chill of cast iron, steel and brass was 120mm x 20mm x (10mm, 15mm and 20mm), Figure 1. Figure 4 shows flow diagram of entire process.

Figure 1: Chills of Different Materials

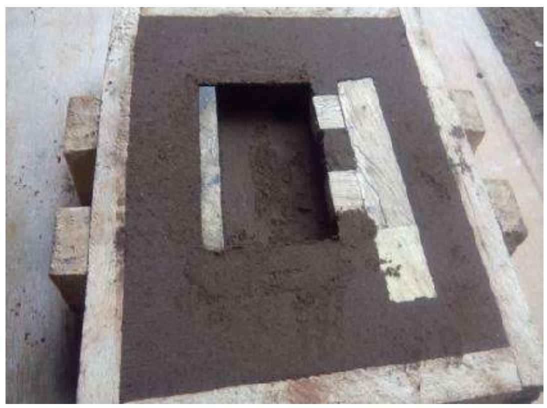

Figure 2: Brass Chill and Gating in position

Figure 3: Assembled Flasks

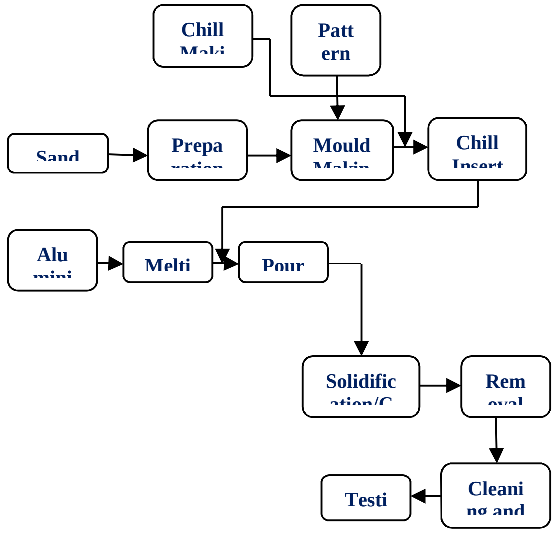

Figure 4: flow diagram of casting process.

3.0 Results and Discussion

3.1 Chemical Composition of Aluminium Alloy Used

The results of chemical composition analysis carried out on the scraps of Toyota car pistons melted confirmed that the alloy was Al.11.9%Si. Silicon was found to be 11.9%, an amount which is pretty close to eutectic point. Silicon if present in aluminium alloy up to 17% can increase strength drastically [3]. The alloy under investigation contained 0.10% copper. This amount improved the ultimate tensile strength (UTS) and hardness of the alloy to a little extent.

The maximum benefit in terms of copper composition is achieved at about 6.5%. Hence the not-so-high values of UTS and Brinell hardness obtained. Table 1 shows the chemical composition of the alloy.

3.2 Effect of the chills on Microstructure

In the microstructure shown by micrographs presented in Plate V, essentially two phases were observed. Firstly grey (white) spots representing ∝ phase of aluminium grain and dark spots are β phase of eutectic silicon grain. '(a)' is the structure obtained from the control sample. Through close observation, silicon grains appear larger when compared with other samples which of course were obtained from chilled castings of the various chill materials. '(b)' was a microstructure of sample cooled with cast iron chill. β Particles appear to have dissolved little as it looks finer than control sample structure. '(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)

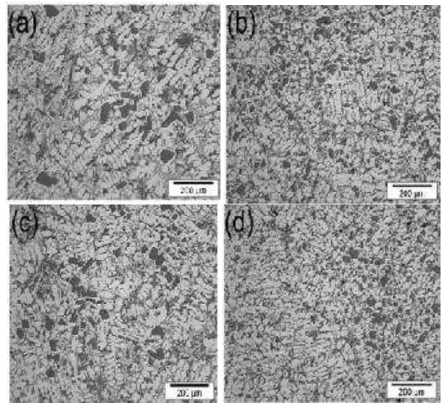

Plate V: (a) Micrograph of control sample (b) Micrograph of sample chilled with cast iron (c) Micrograph of sample chilled with mild steel (d) Microstructure of sample chilled with brass.

3.3 Effect of the chills on Ultimate Tensile Strength (UTS)

The charts shown below (Figures 5 a,b,c) give a clearer view of performance of each chill on UTS of the alloy (Al11.9%Si). Control sample has the lowest value of 151MPa. Starting with 10mm chill thickness, followed by 15mm and later 20mm, 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 [6]. Tables 2 and 3 present the results obtained from Ultimate Tensile Strength (UTS) and Brinell hardness tests respectively.

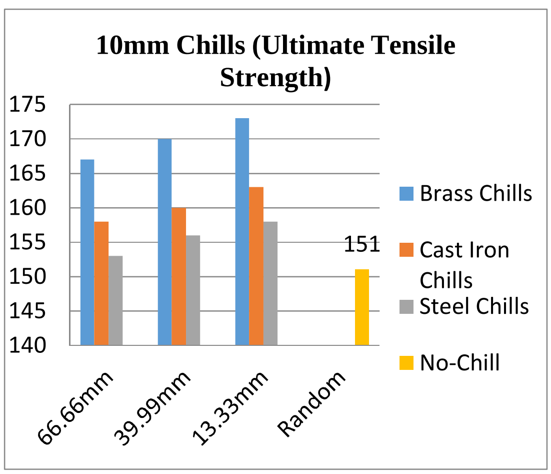

Figure 5 (a) UTS at various distances for 10mm chills

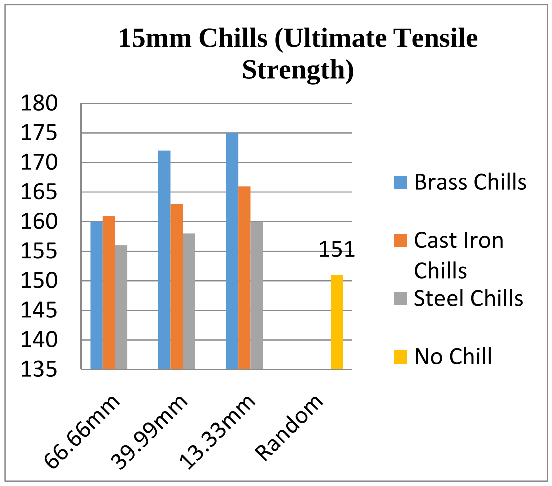

Figure 5 (b) UTS at various distances for 15mm chills.

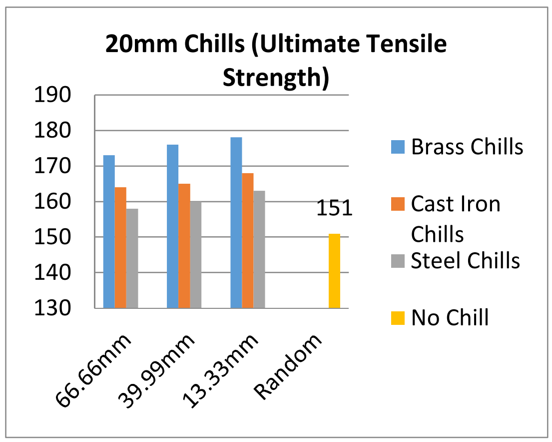

Figure 5 (c) UTS at various distances for 20mm chills

Table 1: Chemical Composition of the Aluminium Alloy.

Chemical Composition of alloy casting , wt.%									
Si	Cu	Mg	MN	Fe	Ti	Ni	Zn	Pb	Al
11.9	0.10	0.10	0.39	0.46	0.12	0.08	0.12	0.10	86.63

Table 2: UTS and Distance from Chill Edge

Distance From chill contact edge (mm)	ULTIMATE TENSILE STRENGHT OF SAMPLES (MPa)									
	Al	B_{10mm}	B_{15mm}	B_{20mm}	C_{10mm}	C_{15mm}	C_{20mm}	S_{10mm}	S_{15mm}	S_{20mm}
66.66	151	167	160	173	158	161	164	153	156	158
39.99	-	170	172	176	160	163	165	156	158	160
13.33	-	173	175	178	163	166	168	158	160	163

3.4 Effect of the chills on Brinell hardness

Similarly it was observed that results obtained from Brinell hardness lest followed the same pattern compared with UTS. Figures 6 (a), (b) and (c) represent Brinell hardness charts for chill thickness 10mm, 15mm, and 20mm respectively. Sample taken from unchilled casting was tested to have Brinell Hardness Number of 77 HB. Progressive introduction of different chill thicknesses of different material resulted in improved hardness, with the highest produced by samples chilled with brass, a similar result to that of [4] because higher thermal conductivity compare to other materials

According to the data contained in table 4, through observation, the following deduction can be made:

i. Chilling capacity of the tested metallic chills is independent of Volumetric Heat Capacity (VHC) from the results analysis so far, the order of decreasing positive effect on UTS and hardness is from brass to cast iron to steel. Data on Table 4 proofs the contrary. Cast iron has the highest chilling effect, followed by brass and lastly steel.

ii. Also from the same table, chilling capacity seems to increase with increase in thermal conductivity of chill material. Meaning that brass with thermal conductivity of 111W/m^{o}k is expected to extract heat from the solidifying metal faster than cast iron (68 W/m^{o}k) and cast iron than steel (36 W/m^{o}k), all at temperature of 20^{o}C. Suffice to say that chilling capacity is directly proportional to thermal conductivity of the chill material.

iii. Results showed that cast iron that is slightly less dense than mild steel was more effective. It can therefore be stated that chilling effect of a metallic material is independent of density.

Table 3: Brinell Hardness and Distance from Chill Edge

Distance From chill contact edge (mm)	BRINELL HARDNESS OF SAMPLES (BHN)									
	Al	B_{10mm}	B_{15mm}	B_{20mm}	C_{10mm}	C_{15mm}	C_{20mm}	S_{10mm}	S_{15mm}	S_{20mm}
66.66	77	103	107	113	90	93	99	80	81	83
39.99	-	108	109	114	93	97	104	84	83	85
13.33	-	111	113	118	98	103	108	84	86	89

Table 4: Thermo-physical properties of the chill materials

Material	Density (g/m^3)	Specific Heat (Jk/kg^oK)	Thermal Conductivity (W/m^oK)	Volumetric Heat Capacity (VHC) ($J/^OK$) for 120mm by 80mm by 10, 15,20mm respectively.		
				$96000mm^3$	$144000mm^3$	$192mm^3$
Brass	8.550	0.390	111	320	480	640
Cast Iron	7.300	0.460	68	322	484	645
Steel	7.850	0.421	36	317	476	635

The results obtained at the edge of contact (about 13.33mm) between the chills and castings were slightly higher and decreased slightly, moving further away from the edge (about 66.66mm). This is in line with a work done by [2]. That was the case for all chill materials and thicknesses (10mm, 15mm, and 20mm). Evident by pattern of charts displays in figure 5 (a), (b) and (c), brass chill produced castings with highest value of UTS, followed by cast iron; and steel chill with the lowest value.

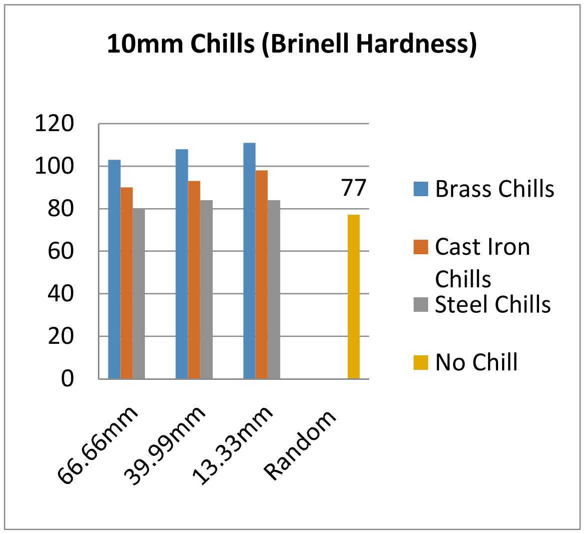

Figure 6 (a) Brinell hardness At Various Distances for 10mm Chills

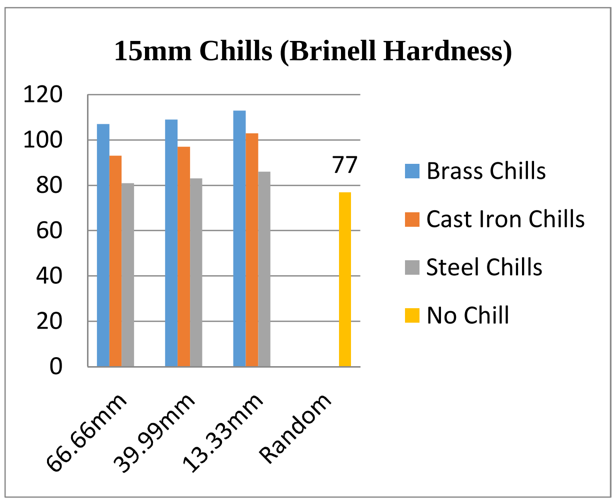

Figure 6 (b) Brinell Hardness At Various Distances For 15mm Chills

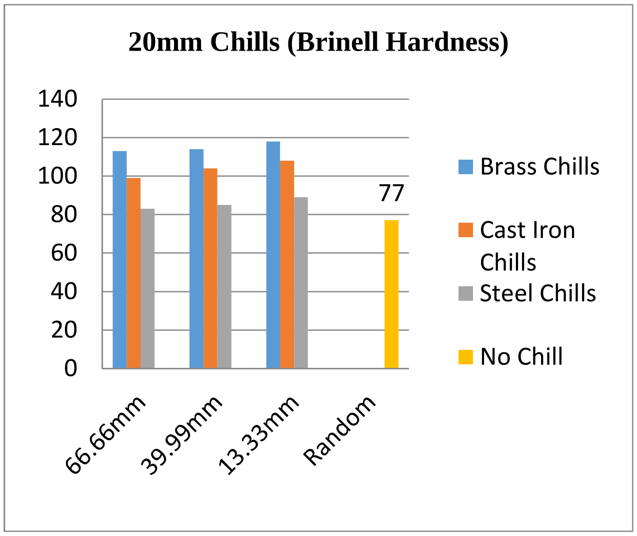

Figure 6 (c) Brinell Hardness At Various Distances For 20mm Chills.

4.0 CONCLUSIONS

The investigation carried out on the effect of chills of different materials on mechanical properties of Al11.9%Si alloy has established that the following:

I. The gating system was designed with external chills incorporated.
II. Castings of the aluminium alloy used were cast using brass, cast iron and mild steel as external chills.
III. The sample taken from the alloy casting produced without a chill was tested to have UTS of 151MPa and hardness of 77BHN. Base on the results of tested samples of chilled castings, the following conclusions can be made:

a) For all the chill materials, the mechanical properties under investigation increased with increase in chill thickness and decrease with increase in distance from the edge of contact between the chill and castings. That is to say that the UTS and Brinell hardness were maximum at 20mm chill thicknesses and 13.33mm distance.
b) Brass chill produced maximum values of UTS and hardness of 178MPa and 118BHN respectively. In other words brass chill improved UTS and hardness by 15% and hardness by 34% compared to the unchilled casting.
c) Cast iron chill produced second best results. It gave UTS OF 168MPa and hardness of 108BHN. Therefore, cast iron chill has been able to improve UTS and hardness by 10% and 28% respectively.
d) Mild steel chill was the least in terms of effect on the properties. It gave UTS of 163MPa and hardness of 89BHN, which implied that it has been able to raise the values of UTS by 7% and hardness by 13%.

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Figure 1: Chills of Different Materials

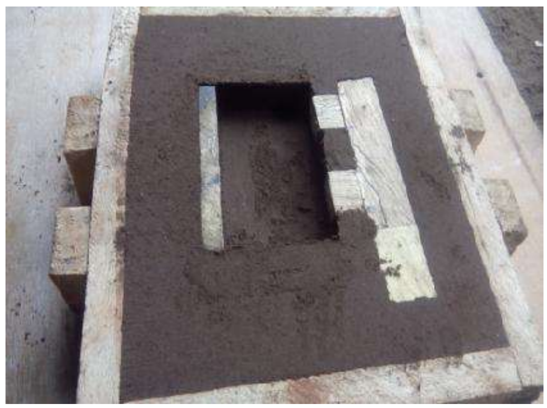
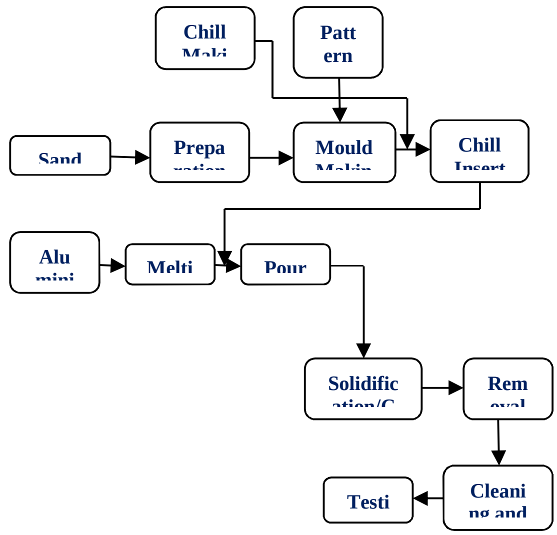


Figure 2: Brass Chill and Gating in position

Figure 3: Assembled Flasks



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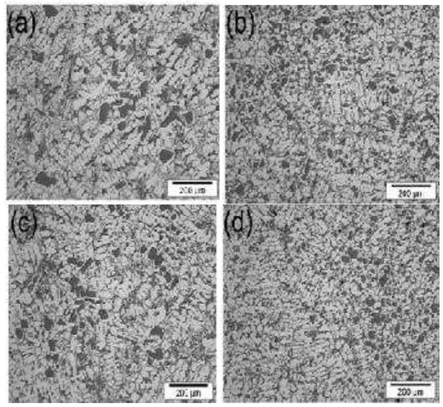

Plate V: (a) Micrograph of control sample (b) Micrograph of sample chilled with cast iron (c) Micrograph of sample chilled with mild steel (d) Microstructure of sample chilled with brass.

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The charts shown below (Figures 5 a,b,c) give a clearer view of performance of each chill on UTS of the alloy (Al11.9%Si). Control sample has the lowest value of 151MPa. Starting with 10mm chill thickness, followed by 15mm and later 20mm, 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 [6]. Tables 2 and 3 present the results obtained from Ultimate Tensile Strength (UTS) and Brinell hardness tests respectively.

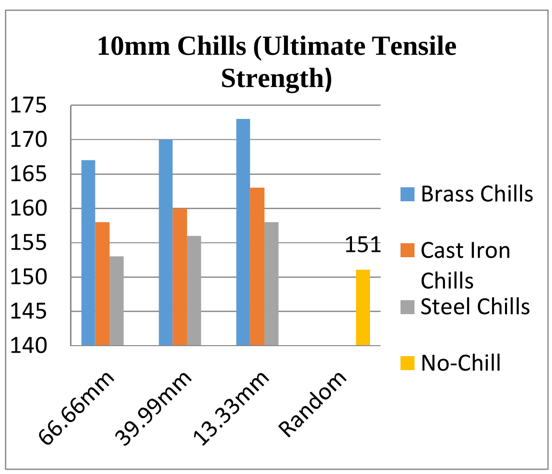

Figure 5 (a) UTS at various distances for 10mm chills

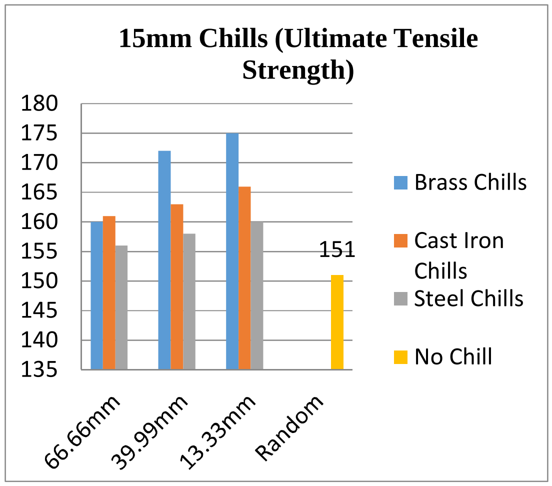

Figure 5 (b) UTS at various distances for 15mm chills.

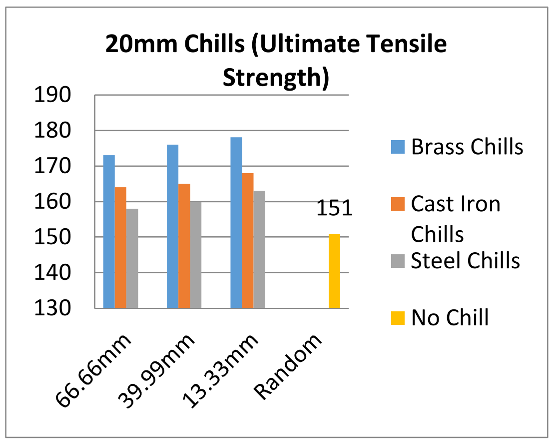

Figure 5 (c) UTS at various distances for 20mm chills

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Similarly it was observed that results obtained from Brinell hardness lest followed the same pattern compared with UTS. Figures 6 (a), (b) and (c) represent Brinell hardness charts for chill thickness 10mm, 15mm, and 20mm respectively. Sample taken from unchilled casting was tested to have Brinell Hardness Number of 77 HB. Progressive introduction of different chill thicknesses of different material resulted in improved hardness, with the highest produced by samples chilled with brass, a similar result to that of [4] because higher thermal conductivity compare to other materials

According to the data contained in table 4, through observation, the following deduction can be made:

i. Chilling capacity of the tested metallic chills is independent of Volumetric Heat Capacity (VHC) from the results analysis so far, the order of decreasing positive effect on UTS and hardness is from brass to cast iron to steel. Data on Table 4 proofs the contrary. Cast iron has the highest chilling effect, followed by brass and lastly steel.
ii. Also from the same table, chilling capacity seems to increase with increase in thermal conductivity of chill material. Meaning that brass with thermal conductivity of 111W/m^{o}k is expected to extract heat from the solidifying metal faster than cast iron (68 W/m^{o}k) and cast iron than steel (36 W/m^{o}k), all at temperature of 20^{o}C. Suffice to say that chilling capacity is directly proportional to thermal conductivity of the chill material.
iii. Results showed that cast iron that is slightly less dense than mild steel was more effective. It can therefore be stated that chilling effect of a metallic material is independent of density.

Table 3: Brinell Hardness and Distance from Chill Edge

Distance From chill contact edge (mm)	**BRINELL HARDNESS OF SAMPLES (BHN)**									
	Al	**B_{10mm}**	**B_{15mm}**	**B_{20mm}**	**C_{10mm}**	**C_{15mm}**	**C_{20mm}**	**S_{10mm}**	**S_{15mm}**	**S_{20mm}**
66.66	77	103	107	113	90	93	99	80	81	83
39.99	-	108	109	114	93	97	104	84	83	85
13.33	-	111	113	118	98	103	108	84	86	89

Table 4: Thermo-physical properties of the chill materials

Material	Density (g/m^3)	Specific Heat (Jk/kg^oK)	Thermal Conductivity (W/m^oK)	Volumetric Heat Capacity (VHC) ($J/^OK$) for 120mm by 80mm by 10, 15,20mm respectively.		
				$96000mm^3$	$144000mm^3$	$192mm^3$
Brass	8.550	0.390	111	320	480	640
Cast Iron	7.300	0.460	68	322	484	645
Steel	7.850	0.421	36	317	476	635

The results obtained at the edge of contact (about 13.33mm) between the chills and castings were slightly higher and decreased slightly, moving further away from the edge (about 66.66mm). This is in line with a work done by [2]. That was the case for all chill materials and thicknesses (10mm, 15mm, and 20mm). Evident by pattern of charts displays in figure 5 (a), (b) and (c), brass chill produced castings with highest value of UTS, followed by cast iron; and steel chill with the lowest value.

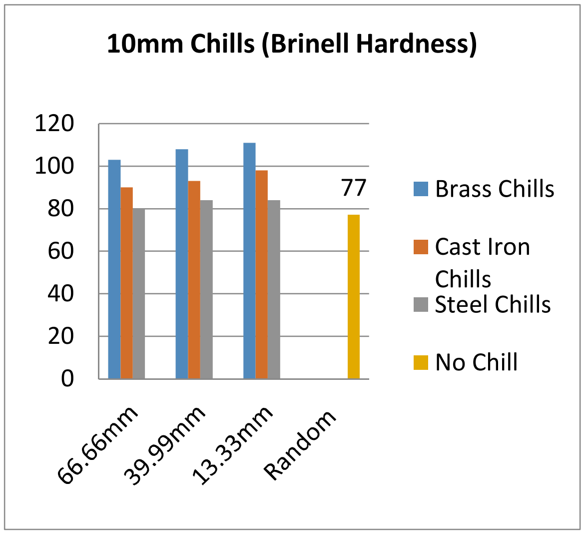

Figure 6 (a) Brinell hardness At Various Distances for 10mm Chills

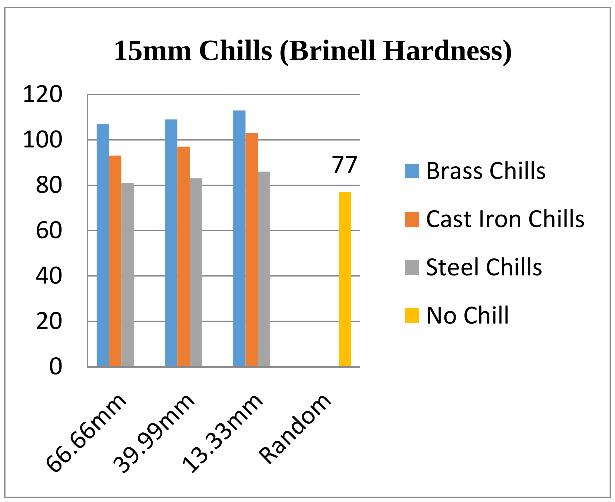

Figure 6 (b) Brinell Hardness At Various Distances For 15mm Chills

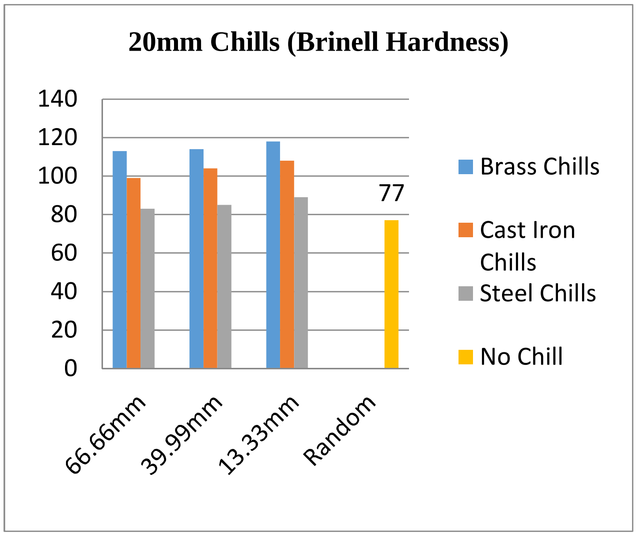

Figure 6 (c) Brinell Hardness At Various Distances For 20mm Chills.

4.0 CONCLUSIONS

The investigation carried out on the effect of chills of different materials on mechanical properties of Al11.9%Si alloy has established that the following:

I. The gating system was designed with external chills incorporated.
II. Castings of the aluminium alloy used were cast using brass, cast iron and mild steel as external chills.
III. The sample taken from the alloy casting produced without a chill was tested to have UTS of 151MPa and hardness of 77BHN. Base on the results of tested samples of chilled castings, the following conclusions can be made:
   a) For all the chill materials, the mechanical properties under investigation increased with increase in chill thickness and decrease with increase in distance from the edge of contact between the chill and castings. That is to say that the UTS and Brinell hardness were maximum at 20mm chill thicknesses and 13.33mm distance.
   b) Brass chill produced maximum values of UTS and hardness of 178MPa and 118BHN respectively. In other words brass chill improved UTS and hardness by 15% and hardness by 34% compared to the unchilled casting.
   c) Cast iron chill produced second best results. It gave UTS OF 168MPa and hardness of 108BHN. Therefore, cast iron chill has been able to improve UTS and hardness by 10% and 28% respectively.
   d) Mild steel chill was the least in terms of effect on the properties. It gave UTS of 163MPa and hardness of 89BHN, which implied that it has been able to raise the values of UTS by 7% and hardness by 13%.

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