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Comparative Analysis of Mechanical Properties of plates cast through Investment Casting and Green Sand Casting Techniques.

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Abstract: Plates of Aluminium Silicon Magnesium alloy (A356) with thicknesses of 8 mm, 10 mm and 12 mm were cast using the green sand casting and investment casting methods at pouring temperatures of 665^{o}C, 690^{o}C and 715^{o}C. The castings were subjected to tensile strength test, impact test and hardness test and the results obtained were analysed using Minitab 17 software. From the results and comparative analysis, it was observed that the tensile strength was between 0.43 % and 1.1 %, the impact strength was between 1.90 % and 9.29 %, and the hardness was between 0.04 % and 0.30 %. The percentage differences in the mechanical properties of the green sand cast plates and the investment cast plates were minimal, hence the work concludes that investment castings or components can also conveniently serve under the same service condition with sand casting components without failure, and investment castings is a preferred choice when requirements like; casting of complex and intricate components, obtaining accurate dimensions and fine finishing are needed.

Keywords: Investment casting, Pattern, Plaster of Paris slurry, Sand casting, Silica sand.

I. Introduction

Metal casting is the manufacturing process in which metals are melted and in their molten state are poured into a mould which has a cavity of a desired shape, and as solidification takes place, the metal takes the shape of the internal geometry of the mould, to form a product called cast. The metal and the mould are thencooled, and the casting is extracted. Casting is most often used for making complex shapes that would be difficult or uneconomical to make by other methods.[1] There are different kinds of metal casting processes such as sand casting, investment casting, die casting, evaporating pattern casting, plaster mould casting, centrifugal casting and so on. This work however focuses on sand and investment castings. Green sand casting may be defined as a plastic mixture of sand grains, clay (as a binder), water (as activator) and other materials (as additive) which can be used for moulding and casting purposes[1]. The sand is called ‘green’ because of the moisture present and to distinguish it from dry sand[1] The sand casting utilizes a mould made of compressed or compacted moist sand packed around a wood or metal pattern.[2]Investment casting is a manufacturing process in which a wax or polystyrene pattern is coated with a refractory ceramic material, in which once the ceramic material is hardened its internal geometry takes the shape of the casting, the wax or polystyrene is then melted or burned out, leaving a cavity in the mould or shell which is an exact replica of the melted out or burnt off pattern. Molten metal is then poured into the cavity and as it solidifies, it takes the shape of the pattern that was originally in the cavity. The shell is then broken and the cast product is removed.[3] Sand casting has short lead time and is ideal for short production runs, low cost of tooling, wider choice of material since virtually all types of alloys can be cast. It gives room for design flexibility since there is no limit on size, shape or weight of part.However, it lacks dimensional accuracy, poor surface finish and presence of some defects such as porosity, shrinkage and secondary machining may be needed if tighter tolerance are required.[4] Investment casting on its own part can be used to produce intricate and complex shapes, better surface finish and dimensional accurate components can be obtained. [5]Nikhil and Karunakar[6] in their research work on the effect of process parameters on mechanical properties of investment castings showed that high mould firing temperature, higher pouring temperature, maximum firing time and high grain fineness number significantly reduced the mechanical properties of A713 alloy castings produced by the investment castings. Shrikant*etal*[7] carried out a study on the effect of section thickness on micro-structure of grey cast iron, where stepped bars of varying thicknesses of 3,6,10 and 16 mm were used. Through their work, it was observed that microstructures of thinner sections are fine compared to thicker sections because of the difference in their cooling rate. Their findings concluded that hardness was higher in thin sections than in thicker sections. The research gap this work seeks to fill is the comparison between the mechanical properties like tensile strength, impact strength and hardness of plates cast through investment casting and that cast through sand casting. The results obtained from the various test were analyzed using Minitab 17 software using the design of experiments (D.O.E) via Taguchi's L_9 orthogonal array method.

II. Materials and Methods

2.1 Materials

The following materials were used for the investment casting: Polystyrene pattern material which has a density value of 2g/cm^3, top gum glue for bonding the pattern materials at the joints of the sprue, sprue base well, runner, ingate, riser, investment slurry material of plaster of Paris powder which has a fineness number of -100 µm with silica sand of -75 µm, while the following materials were used for the sand casting: wooden plate pattern of 8 mm,10 mm and 12 mm thicknesses, wooden boxes (cope and drag), silica sand of – 75 microns and a metal ram. The casting material used is Aluminium Silicon Magnesium (A356) alloy with the elemental composition shown in Table 1.

Table 1: Elemental composition of the Al -alloy

Element	Al	Si	Mg	Cu	Fe	Ti	Mn	Zn
%	91.38	7.5	0.39	0.20	0.20	0.13	0.10	0.10

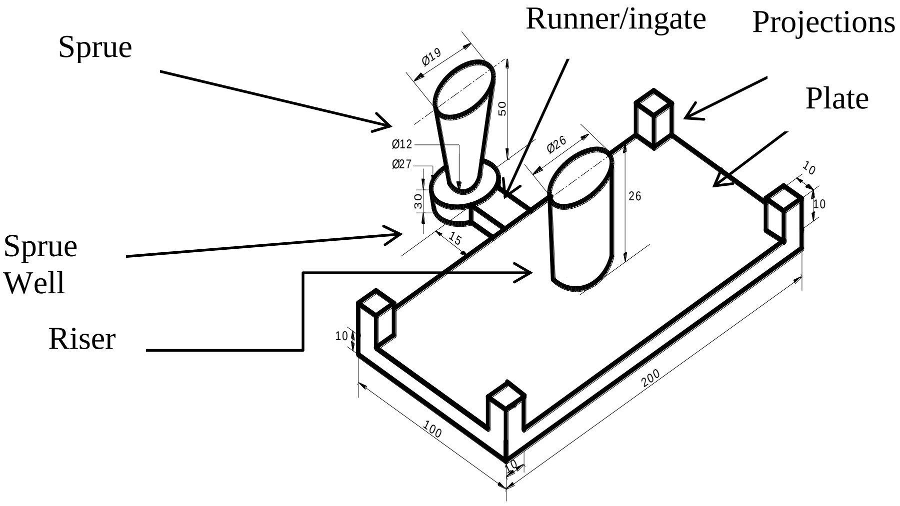
2.2 Methods

2.2.1 Sand casting

Wooden patterns of plates of thicknesses 8 mm, 10 mm and 12 mm were made with the gating element which comprise of the sprue, the sprue base, the ingate, the riser and projections as shown in Fig.1. The dimensions of the gating elements are as shown in Table 2

Table 2: The dimensions of the gating elements

Part	Thickness/ height (mm)	Length (mm)	Width (mm)
		Entry	Exit
Sprue	5	19.14	12.23
Sprue well	30.66		
Runner		15.33	15.33
Ingates	8	15.33	15.33
	10	15.33	15.33
	12	15.33	15.33



All dimensions are in mm
Fig. 1: Assembly of pattern with the gating system for 10 mm plate thickness

One of the wooden boxes (Drag) was first filled with the moist silica sand and then rammed, the second box (Cope) was placed on the first box and then firmly secured by the sides with clips. The wooden plate pattern was then placed carefully on the rammed sand and bentonite powder was sprinkled all around it. The reason for sprinkling bentonite powder was to enhance easy removal of the pattern from the boxes when the ramming operation was over. More silica sand was then used to fill the cope and the sand was properly rammed. This ramming caused the pattern to make an impression in the moist silica sand. The clips were then removed and the cope was carefully removed, after which the wooden pattern was also carefully removed. The impression of the wooden plate pattern was made on both the silica sand in the drag and the cope. The cope was then carefully replaced back on the drag and the clips were used to resecure the cope and drag together, after this, molten aluminium A356 was then poured at various pouring temperatures of 665 ^{o}c, 690 ^{o}c and 715^{o}c into the different moulds or cavities formed in the silica sand in different boxes. Solidification and cooling occurred in the sand mould, after which the sand mould was destroyed and the plate castings were removed. The riser, the projections, and runner were cut off during fettling, after which samples of the castings were cut out and prepared for tensile strength test, impact strength test and hardness test.

2.2.2 Investment casting

2.2.2.1 Polystyrene pattern and investment slurry preparation

This process involves cutting the polystyrene to plate’s shapes of 8, 10 and 12 (mm) thicknesses, filing it to the required size then polishing it with emery paper of grit size P220 to obtain a smooth surface. The prepared sprue, sprue well, runner/ ingate are then glued together and joined to the polystyrene plates with a top bond glue to form a pattern assembly as previously shown in Fig. 1.

The slurry of plaster of Paris (P.o.P) with silica sand was prepared by mixing 30% P.o.P and 20% silica sand in 50% water. Strawboard was then cut and shaped in a box like form to house the pattern assembly and the pattern was set in the strawboard box with a space allowance of 5 mm in between the pattern and the box and pins were used to suspend the pattern at various points in the box.

This slurry was then poured into the strawboard box housing the pattern assembly. It was poured up to the marked level on the strawboard indicating the required thickness. The slurry was then allowed to set for between 4 to 5 minutes. After setting, the strawboard was removed and the shell formed was allowed to dry for 5 days at room temperature of between 20^{o}C to 25^{o}C. Fig.2 shows the strawboard box temporarily housing the assembled pattern and the poured slurry and Fig.3 show the plate shell that was formed, when the shell had set and was left for drying.

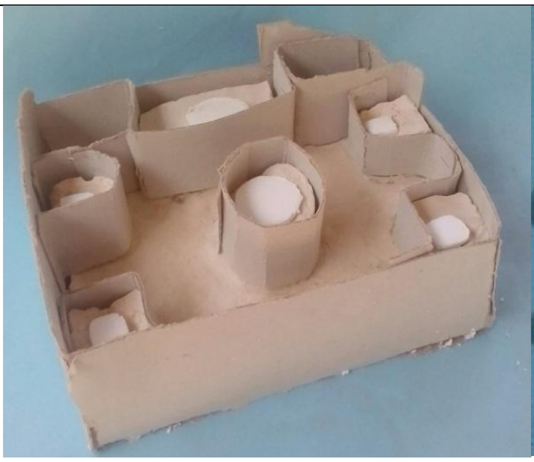


Fig 2: Strawboard box temporarily housing the pattern and the poured slurry

Fig 3: Plate shell formed and left for drying

2.2.2.2 Burning of polystyrene pattern and firing of shells

After pouring the slurry over the pattern, the dried shell was heated in an oven for a period of 4 hours at an average oven temperature of 250^{o}C. Longer time was spent in attaining the desired burning of the polystyrene because of the capacity of the oven that was available. The maximum temperature that was obtainable by the oven was 250^{o}C. The importance of the burning and firing of the shell is to ensure that all the polystyrene used for making the pattern and the gating system are completely vaporized and to strengthen the shells in preparation for receiving the aluminium melt. Fig.4 shows the shell produced after the burning of the polystyrene and firing of the shells for the plate.

Fig 4: Shell produced after burning of polystyrene and firing

2.2.2.3 Melting and Pouring of molten aluminium alloy

Aluminium alloy A356 used was melted in a gas fired crucible furnace shown in Fig.5. The furnace has a capacity of melting up to 50 kg of aluminium. The alloy used for casting each set of plate had a weight of 7.2 kg. The liquidus temperature of the alloy usedis 615^{o}C from literature[8][9]. The pouring temperature used for the castings from the process parameters are 665^{o}C, 690^{o}C and 715^{o}C for each run of the experiment using 665^{o}C as the lower limit and 715^{o}C as the upper limit of pouring. A clean and preheated plunging tool was used to slowly plunge 100g of Degasser 185 (Chlorine) tablet to the bottom of the melt when the temperature was approaching 650^{o}C. This degassing was done to eliminate the hydrogen gas in the melt and to improve its castability. The flux used was produced by mixing of 40% of potassium chloride with 60% of sodium chloride (KCl and NaCl). One percent of this flux mixture (150g) was used on a 15kg weight of melt. The dross obtained was carefully removed, and a clean melt was poured into the prepared shells.

The temperatures were measured using digital Fluke mini K thermocouple immersion pyrometer made from (Chromel-Alumel), which is used for general purpose and can measure temperatures within the range of 0^{o}C and 1100^{o}C. The Fig. 6 shows the pyrometer that was used.

Fig. 5: Gas fired crucible furnace

Fig 6: Digital immersion pyrometer

2.2.2.4 Knockout and Cleaning

After the solidification of the test castings in the investment shells, the shells were broken with a wooden mallet to remove the casting. Fig. 7 shows plate casting after the knockout operation of a 12 mm thickness plate produced in a 5 mm thickness shell at a pouring temperature of 665°C.

Fig. 7: Plate obtained after knockout operation

The riser, the projections, and runner were cut off during fettling, after which samples of the castings were cut out and prepared for tensile strength test, impact strength test and hardness test.

2.2.2.5 Testing of cast samples

After the sand and investment castings were concluded, the cast produced were subjected to tensile test using a Monsanto tensometer (ASTM E8/E 8M -08 standard), Impact test was conducted using impact testing machine (ASTE E23-07 standard), and hardness test was also carried out using Brinell hardness testing machine (ASTM E10-18 standard).

III. Results and Discussion

3.1 Experimental results

Table 3: Process parameters and their responses for sand casting (Plate)

Run	Pouring Temperature B (°C)	Plate thickness C (mm)	Tensile Strength (N/mm^2)	Impact Strength (Joules)	Hardness (BHN)
1	665	8	246.22	2.046	74.67
2	690	10	234.10	1.632	74.50
3	715	12	206.15	1.386	74.46
4	665	10	228.20	1.752	74.62
5	690	12	226.12	1.374	74.20
6	715	8	227.08	1.242	74.42

7	665	12	220.06	1.038	74.30
8	690	8	218.25	1.356	74.60
9	715	10	214.20	0.915	74.35

Table 4: Process parameters and their responses for investment casting (plate)

Run	Shell Thickness A (mm)	Pouring Temperature B (°C)	Plate thickness C (mm)	Tensile Strength (N/mm^2)	Impact Strength (joules)	Hardness (BHN)
1	5	665	8	240.15	2.054	74.40
2	5	690	10	230.10	1.156	74.34
3	5	715	12	208.05	1.025	74.29
4	5	665	10	229.25	1.426	74.35
5	5	690	12	215.00	1.612	74.27
6	5	715	8	220.18	1.042	74.30
7	5	665	12	222.08	1.088	74.31
8	5	690	8	227.20	1.442	74.32
9	5	715	10	212.14	1.420	74.28

Comparison of the tensile strength of castings

Fig.8 shows the comparison between the tensile strength of investment casting and that of sand casting at different temperatures, while Fig. 9 shows the comparison between the tensile strength of investment and that of sand castings at different plate thicknesses.

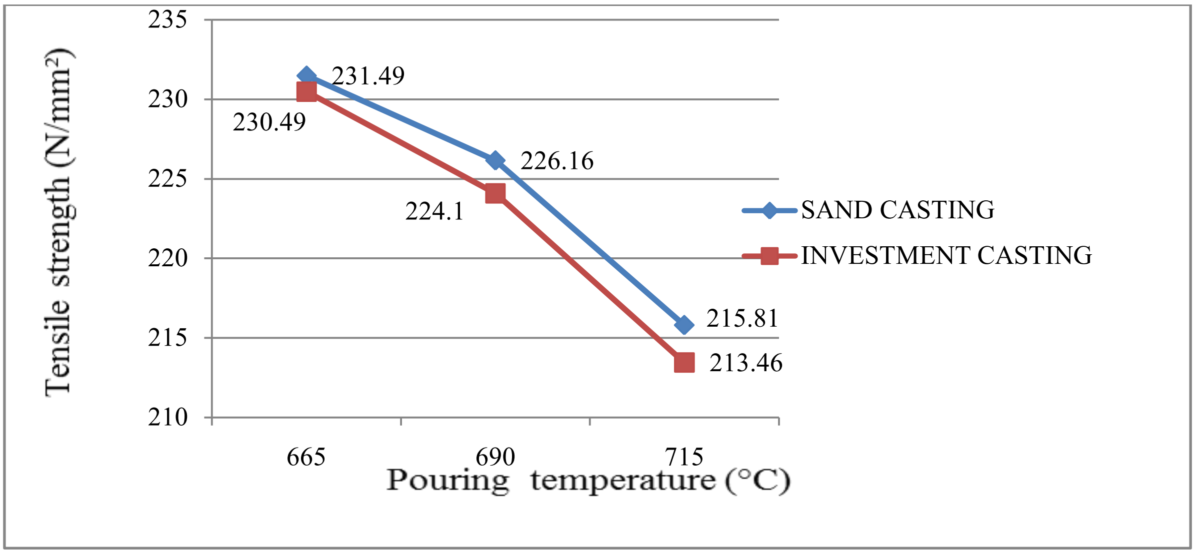


Fig. 8:Tensile strength vs pouring temperatures

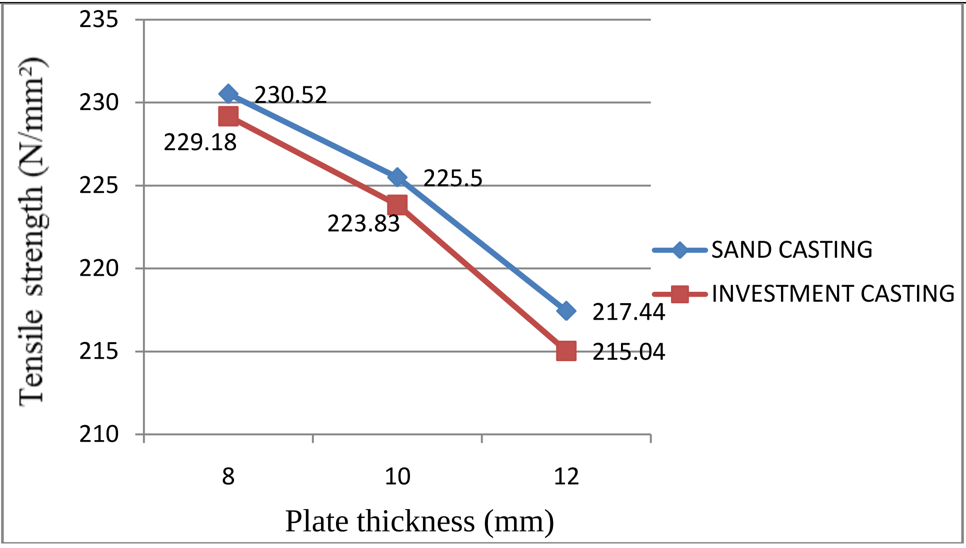


Fig. 9:Tensile strength vs plate thicknesses

Comparison of the impact strength of castings

Fig. 10 shows the comparison between the impact strength of investment casting and that of sand casting at different pouring temperatures, while Fig. 11 shows the comparison between the impact strength of investment and sand castings at various plate thicknesses.

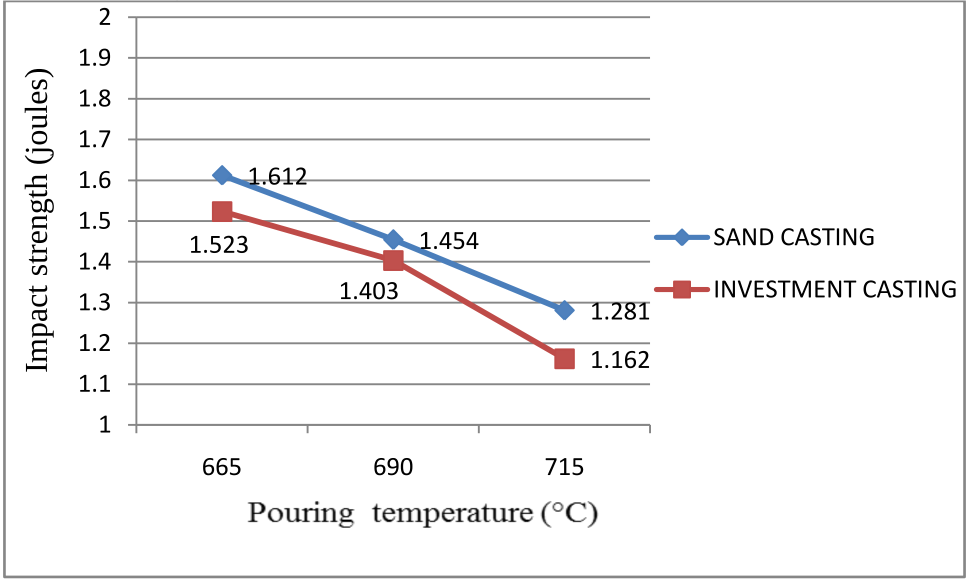


Fig. 10**:** Impact strength vs pouring temperatures

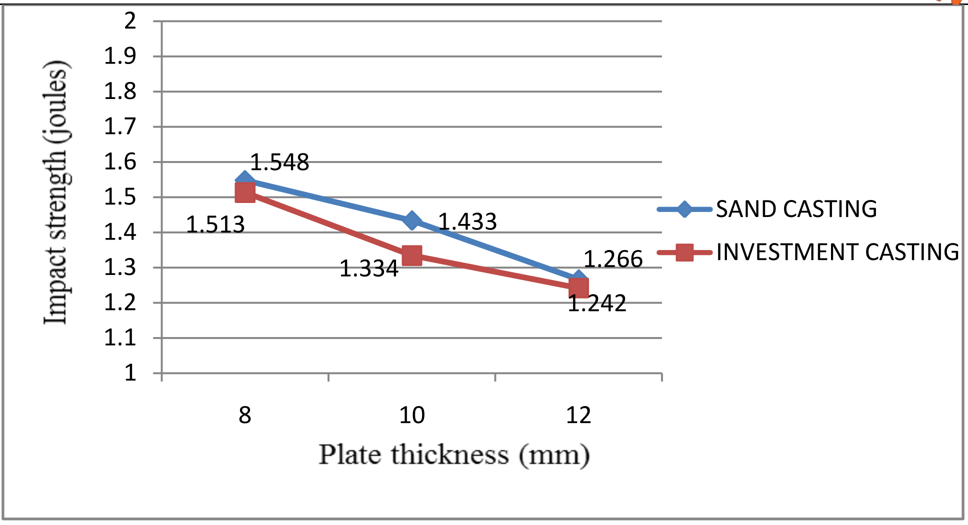


Fig. 11**:**Impact strength vs plate thicknesses

Comparison of the hardness of castings

Fig. 12 shows the comparison between the mean hardness of investment and that of sand castings poured at different temperatures, while Fig. 13 shows the comparison between the mean hardness of investment and that of sand castings of different plate thicknesses.

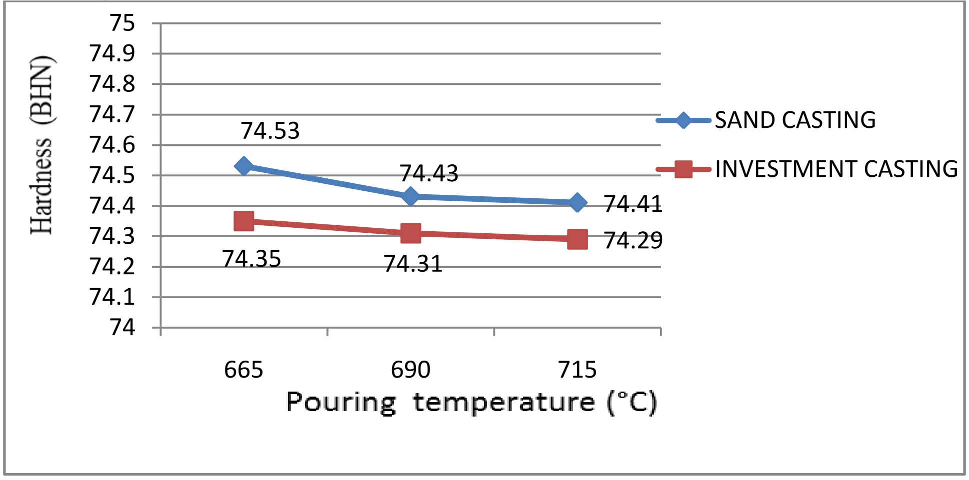


Fig. 12:Hardnessvs pouring temperatures

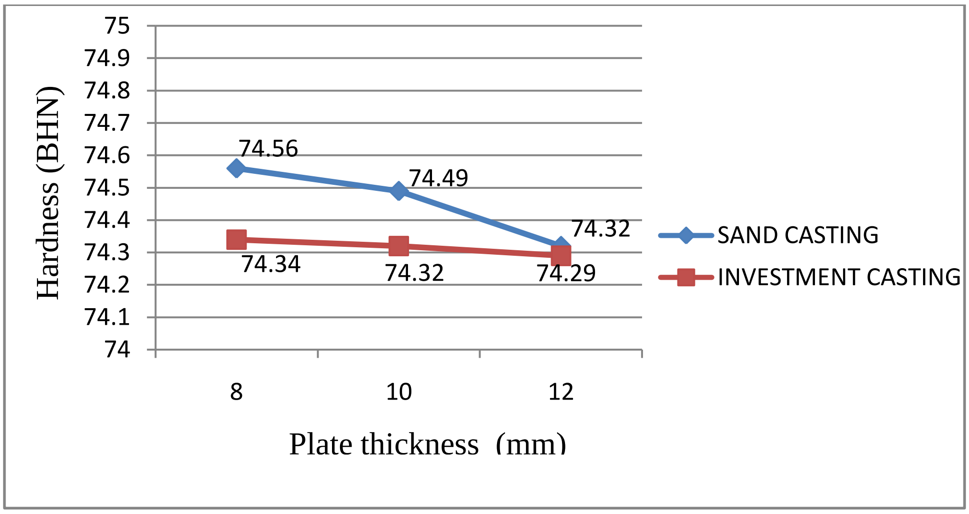


Fig. 13: Hardness vs plate thicknesses

Table 5: Comparing the difference in percentage in the mechanical properties

		Tensile strength (N/mm^2)				Impact strength (joules)				Hardness (BHN)			
Parameter	Parameter value	Sand casting	Investment casting	Difference	Difference in %	Sand Casting	Investment Casting	Difference	Difference in %	Sand Casting	Investment Casting	Difference	Difference in %
Pouring Temp	665	231.49	230.49	1.00	0.43	1.612	1.523	0.089	5.52	74.53	74.35	0.18	0.24
	690	226.16	224.10	2.06	0.91	1.454	1.403	0.051	3.51	74.43	74.31	0.12	0.16
	715	215.81	213.46	2.35	1.09	1.281	1-162	0.119	9.29	74.41	74.29	0.12	0.16
Plate Thickness	8	230.52	229.18	1.34	0.58	1.548	1.513	0.035	2.26	74.56	74.34	0.22	0.30
	10	225.50	223.83	1.67	0.74	1.433	1.334	0.099	6.91	74.49	74.32	0.17	0.29
	12	217.44	215.04	2.40	1.10	1.266	1.242	0.024	1.90	74.32	74.29	0.03	0.04

3.2 Discussion on the comparison between Investment casting and Sand casting

From Figures 8, 10 and 12, it was inferred that as pouring temperature was increasing between 665^{o}C and 715^{o}C, the tensile, impact and hardness were decreasing in both sand and investment castings. This decreasing trend was observed in all the plate castings. The reason for this decreasing trend is as a result of high thermal gradient that is generated as the temperature is increasing, the increasing thermal gradient, increases the time required for solidification to take place. This increased heat gradient causes an increase in the grain sizes and also results in coarse and dislocated grain structure which is responsible for the decreasing mechanical properties observed in both the sand and investment castings. This confirms the results of the investigation carried out by Nikhil and Karunakar.[6]

It was also inferred in Figures 9, 11 and 13 that as the section thickness increases in the sand and investment castings, the mechanical properties were reducing, this is as a result of increase in the required quantity of molten metal and subsequent increase in the amount of heat to be removed and hence lower cooling rate, but when the section thickness was less, solidification was faster, hence the reason why the mechanical properties were optimum when the plate thickness was at 5 mm. At this smaller section thickness solidification is faster than in the thicker sections, hence the grain structure in the thinner sections are fine and uniformly distributed which also confirms the work done byShrikant*et al*.[7]

It was observed in Figures 8 to 13 that the sand castings had higher mechanical properties than the investment castings; this is because solidification is faster in sand casting than investment casting. Solidification is faster in sand casting because of higher thermal conductivity of silica sand compared to that of PoP contained in the slurry; hence there is faster heat loss to the environment through radiation and conduction. The faster the thermal (heat) loss, the faster the solidification rate which results in finer grain structure with better mechanical properties.

From Table 5, the difference in percentage in tensile strength is between 0.43 and 1.1, the difference in percentage in impact strength is between 1.90 and 9.29, while the difference in percentage in hardness is between 0.04 and 0.30. It should be noted that the percentage difference in mechanical properties between the sand casting and investment casting is minimal, hence the investment castings or components can conveniently serve under the same service condition with sand casting components without failure, and investment castings also have numerous advantages over sand casting. Some of these advantages are; it can be used to produce very complex and intricate components or parts that cannot be produced by other methods, dimensionally accurate parts or components can be produced and very thin section components that cannot be produced by other methods can also be produced and finally parts produced through investment casting have fine surface finish that may not require further finishing.

IV. Conclusion

From the comparative analysis carried out, this work concludes that the percentage differences between the mechanical properties of plates cast by sand casting and investment casting are minimal, hence investment cast components can conveniently serve under the same service condition with sand cast components and investment casting is a preferred choice where other properties like fine finishing, precise and accurate dimensions, casting of complex and intricate parts are a requirement.

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References

[1]. Khan R.H., (2005). Metal Casting Technology in Nigeria- Present Status and Future Prospects. F.U.T. Minna Inaugural Lecture series 8.,Minna, Kings Plaza.

[2]. Rao, T.V., (2003). Metal Casting: Principle and Practice. London, New Age International Press. ISBN 978-81-224-0843-0.

[3]. Library of Manufacturing (2015) The Process of Investment Casting. Retrieved from http://www.thelibraryofmanufacturing.com/investment_casting.html.

[4]. Senthil J. Prakash (2017). Pros and Cons of sand casting. Retrieved from http://www.engineeringproductdesign.com

[5]. Prasad, R.,(2012), Progress in Investment Castings. *Science and Technology of Casting Processes,* 25-47,Retrieved from: http://www.academia.edu/10488981/progress_in_investment_castings

[6]. Nikhil,Y., and Karunakar, D.B. (2011). Effect of process parameters on mechanical properties of investment casting.*International journal of Advances in Engineering and Technology.* 1(3),128-137

[7]. Shrikant, S., Bhat, M.N., Kumar, A., Pratik, A., Amitesh, K. (2014). Effect of section thickness on the microstructure and hardness of gray cast iron (a simulation study).*International Journalof Engineering Research and Technology.*3(7). Retrieved from http://www.ijert.org

[8]. Wu, S., Xie, L., Zhao, J. Nakae, H. (2008). Formation of non-dendritic microstructure of semi-solid aluminium alloy under vibration.*ScriptaMaterialia* 58(7), 556-559, doi:10.1016/j.scriptamat.2007.11.010

[9]. 9. Legoretta, E.C., Atkinson, H.V.,and Jones, H. (2008). Cooling slope casting to obtain thixotropic feedstock II: observations with A356 alloy. *Journal of Material Science* 43:5456. Retrieved from https://link.springer.com