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Effects of Sand Mould Preheat Temperatures and Shake-Out Times on the Tensile, Impact and Hardness Properties of Cast Aluminium Alloy

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Abstract: The effects of sand mould preheat temperature of range 30-200°C and shakeout times of range 5-25 min on the tensile, impact and hardness properties of cast aluminium alloy were experimentally investigated and presented. Increase in mould preheat temperature and shakeout time were found to increase the impact energy and percentage elongation at fracture but decrease the hardness and ultimate tensile strength of the specimens. Preheating as-prepared mould of 5 min shakeout time to 200°C caused the impact energy and percentage elongation at fracture of the specimen to increase from 40.23 Nm and 0.48% to 43.55 Nm and 0.81%, respectively; while hardness and ultimate tensile strength decreased from 64.60 HB and 140.02 MP to 52.80 HB and 96.74 MPa, respectively. However, increasing the shake-out times of as-prepared mould from 5-25 min caused the impact energy and percentage elongation at fracture to increase from 39.23 Nm and 0.48% to 44.65 HB and 1.29%, respectively; while hardness and ultimate tensile strength decreased from 64.6 HB and 140.02 MN m^{-2} to 50.8 HB and 78.92 MN m^{-2}. These variations show that the mechanical properties of cast aluminium alloy can be controlled to suit particular application by varying the sand mould preheat temperature and shakeout time.

Key words: Mould preheat, shakeout time, hardness, aluminium alloy, tensile stress, compressive stress

INTRODUCTION

The basic simplicity of casting process had proved to be a boom for the growth of foundry industry and today a wide variety of products or components ranging from domestic to space vehicles are produced through foundry technique (George, 1961). Also, casting remains the traditional process of producing heavy machine frames and components of complicated shapes. These advantages of casting had made it to be one of the most significant manufacturing processes. The most widely used foundry method is sand casting because approximately 80% of annual turnout/production of cast products are made by sand casting (Benjamin *et al*., 1989). By varying the processing parameters involved in casting, qualities and mechanical properties of cast products can be controlled. Examples of processing parameters involved in sand casting are sand sizes, temperature of molten metal, mould temperature and shakeout time.

In the research (Oyetunji, 2002), effects of foundry sand size distribution on the mechanical and structural properties of spray cast iron were studied. It was found that the finer the grain size, the more improved the strength hardness and surface finish. Sand mould pre-heating in the process of increasing the ambient temperature of the mould to a given temperature in order to influence the properties of the mechanical cast in it (Ofoegbu, 2004).

Hence, in this research, the sand mould would be preheated to within a range having peak temperature of 200°C and the shakeout time will also be varied. This is with a view to knowing how these variations would affect tensile, impart and hardness properties. Here, aluminium alloy is considered as the workpiece because it is a common non-ferrous metal.

MATERIALS AND METHODS

Mould preparation and preheat: The "green" sand mould was prepared with silica sand, coal-dust, clay and starch (organic builder) that were mixed with right proportion of water. The moulds were enclosed in metal frames called flasks. Smooth mild steel rods of length 150 mm and diameter 15 mm were used as patterns.

The bottom flask called drag was filled with the moulding sand that was compacted with the aid of a rammer. The pattern was placed in the drag to create the mould cavity needed for the casting. The drag was then turned up and the top flask (The cope) was put on the top

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and prepared as the bottom flask. Wooden spacer are placed in the cope to form the sprue and riser channels, the in-gate was made with the aid of the hand trowel, which are the pathway for the molten metal to flow into the already made mould cavity.

The prepared moulds are left for about 3 days on the foundry floor to allow the water content of the mixed sand to reduce to a minimum level. Dry sand moulds are actually made with moulding sand in green condition and then the entire mould is dried in the ovens (at temperature 100-200°C) before the molten metal is poured into mould cavity (Khanna,1996).

Casting and shake-out: Melting of aluminium alloy scraps was done in a 10 kg capacity crucible placed inside the furnace. Flux was added at about 650°C by covering the surface of the already molten alloy with about 2% by weight of charge covering flux. Five dry sand moulds left as prepared cavity were fed with the molten metal until the spruce was filled up. The drag and cope housing of the dry sand mould were shaken-out at respective times of 5, 10, 15, 20 and 25 min after pouring the molten metal into the cavity.

Another 5 sets of the prepared drag and cope moulds were pre-heated to 100°C before pouring molten aluminium alloy in them and shakeout-times were taken as 5, 10, 15, 20 and 25 min, respectively.

Lastly, the remaining five sets of mould were preheated to 200°C, before casting and shaken out at the usual 5, 10, 15, 20 and 25 min and temperatures of the specimens were taken.

Specimen's preparation: The cast aluminium rods from as-received, 100°C preheated and 200°C preheated moulds were machined to obtain tensile, hardness and compressive specimens.

The tensile specimens were made out of the 15 mm diameters and 150 mm length of aluminium alloy rods of the conditions mentioned above by machining a guage of length 60 mm and diameters of 5 mm, respectively on the lathe machine with slow speed. Figure 1 shows the schematics of tensile specimen machined to specified standard for testing on Tensometer tensile testing machine.

The hardness specimen was also machined to the lengths of 20 mm and of diameter of 5 mm as shown in Fig. 2.

Impact test specimens were machined into the specification with the V-notch at the centre of the specimen as shown in the Fig. 3.

Experimental tensile test: Tensile properties of the machined specimens were determined on a Tensometer machine shown in Fig. 4.

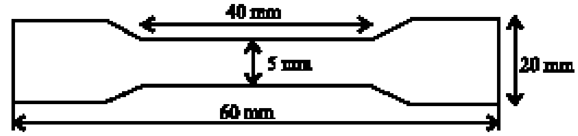

Fig. 1: Tensile test specimen

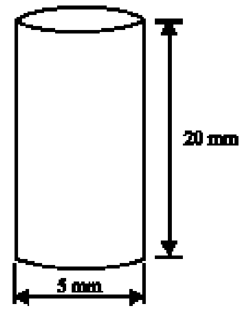

Fig. 2: Hardness test specimen

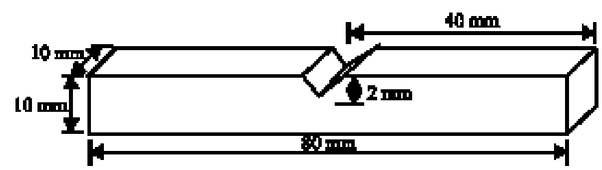

Fig. 3: Impact test specimen

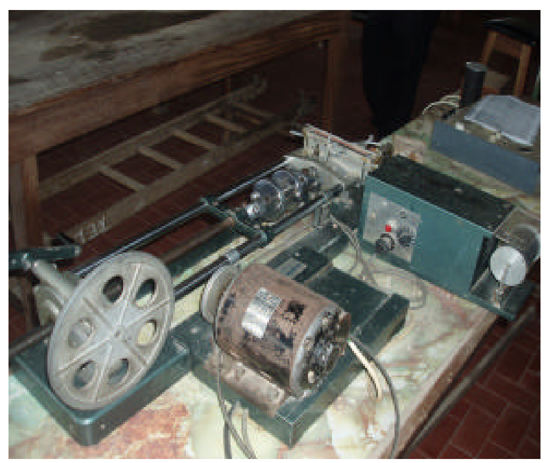

Fig. 4 : Tensometer tensile testing machine

The test began by first measuring the sample gauge length with vernier calliper and measuring the diameter of the gauge section with micrometer screw guage. The samples were then loaded tightly in the grips of the upper and lower crossbeams of the testing machine. The same tensile load was applied to the specimens until it fractures. The same procedure was repeated for the remaining specimens. After fracture, then two pieces of the broken

Fig. 5: Izod impact machine

specimen were placed together in close contact and the distance of final length between the 2 original gauges were measured.

Experimental impact test: The impact test was carried out according to the recommended standard for Izod V-notched method. The pendulum was released to zero scale. Cylindrical test bar was then gripped by the other hand of the pendulum as shown in Fig. 5.

The clamp of both pendulums was released and the blow applied by freely swinging the pendulum of the machine through an angle. The value of the angle corresponding to, with the value of the energy absorbed in breaking the sample were read on the machine and the process was repeated for the remaining specimens casted from as-prepared, 100°C preheated and 200°C preheated mould with different shakeout times and the respective impact strength values were recorded.

Experimental brinell hardness test: Hardness properties measurement on each specimen was carried out with the aid of hardness indentor dies attached to a Tensometer Testing machine. The specimen was clamped with the anvil of the machine and was loaded with the mass and the hand wheel was rotated till the specimen along with the anvil moved up and had contact with the (ball) indenter and it pressed until the no movement of the reading scale was experienced. At this stage, the hardness value of the test piece material was read directly from the dial scale. The process was repeated for the remaining specimens and readings were taken.

RESULTS AND DISCUSSION

Effects of mould pre-heat and shakeout times on tensile properties: The lengths of tensile specimens from different moulds of varied preheat and shakeout times are shown in the Table 1. The length of the specimens after tensile test is denoted as L_f The initial length of the specimen was carefully machined to 62.0 mm.

Table 1: Length of tensile specimens from different moulds of varied preheat and shakeout time

	Length L_f (mm)		
Shakeout time t (min)	As-prepared mould	100°C pre-heated mould	200°C pre-heated mould
5	62.3	62.4	62.5
10	62.4	62.5	62.8
15	62.5	62.5	62.8
20	62.5	62.7	62.9
25	62.8	62.9	63.4

Table 2: Variations of elongation at fracture of specimens from different moulds of varied preheat temperature and with shakeout-time

	Elongation at fracture (d_l)mm		
Shakeout time t (min)	As-prepared mould	100°C pre-heated mould	200°C pre-heated mould
5	0.3	0.4	0.5
10	0.4	0.5	0.8
15	0.5	0.6	0.8
20	0.6	0.7	0.9
25	0.8	0.9	1.4

Note: Original length of specimen = 62.0 mm

Table 3: Variations of percentage elongation at fracture from different moulds with shakeout time

	Percentage elongation at fracture, ε_f= dl/lo X 100		
Shakeout time t (min)	As-prepared mould (26°C)	100°C pre-heated mould	200°C pre-heated mould
5	0.48	0.65	0.81
10	0.65	0.81	1.29
15	0.81	0.97	1.29
20	0.97	1.13	1.45
25	1.29	1.45	2.26

The value of the elongation at fracture of the specimens from moulds of different preheat temperatures and shakeout times were compared to the original length of the specimen (i.e. at the onset of tensile test) to determine or evaluate the percentage elongation at fracture (Table 2). The percentage elongation at fracture is a measure of the ductility of the specimens. The variations of percentages elongation at fracture of the specimens are shown in Table 3.

The percentage elongation of the cast specimens was observed to increase with increase in mould preheats temperature. The percentage elongation of an as-prepared mould of 5 min shakeout time increases from an initial value of 0.48-0.65 and 0.81% due to mould preheat to 100 and 200°C, respectively. Also, there was an increase of percentage elongation from 0.81-0.97 and 1.29 when as-prepared mould of 15 min shakeout time was preheated to 100-200°C, respectively. Likewise, the percentage elongation of cast specimen from as-prepared mould increases from 1.29-1.45 and 2.26 when as-prepared mould of 25 min shakeout time was preheated to 100 and 200°C, respectively.

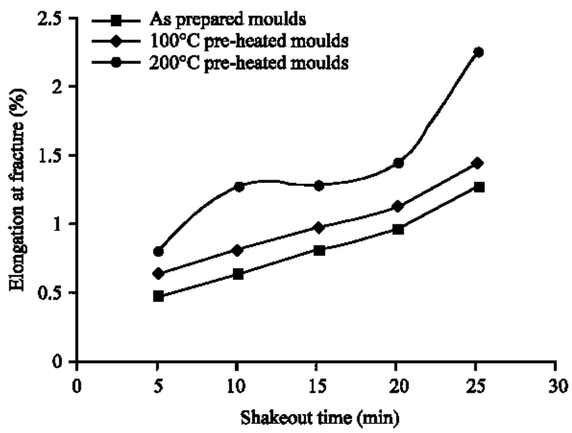

Fig. 6: The graph of percentage elongation at fracture against shakeout time (min)

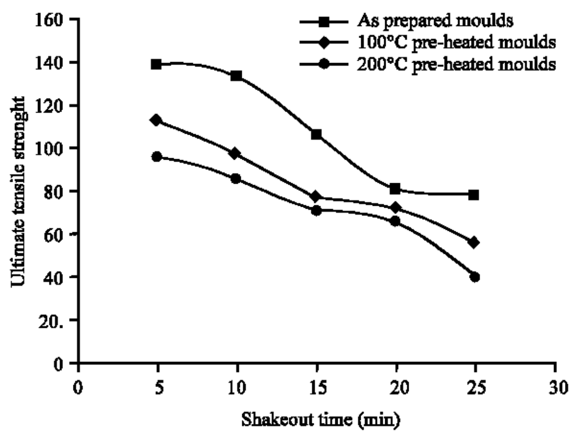

Fig. 7: The graph of ultimate tensile strenght against shakeout time (min)

The increase in percentage elongation with increase in preheat temperature denotes that ductility of cast specimens increases with increase in mould preheat temperature. Increase in ductility with increase in preheat temperature could be attributed to the fact that preheating as-prepared mould increases the heat accumulation in the mould before casting, thereby reducing the thermal gradient in the mould and lowering the cooling rates of both the preheated mould and the casting inside it. It is evident that the slower the cooling rate, the more ductile the specimen and also the faster the cooling rate, the less ductile the specimen. This explains why the specimen from 200°C preheated mould exhibited higher ductility than that from 100°C preheated mould which in turn displayed higher ductility than that from as-prepared mould, as shown in Fig. 6.

It would also be deduced from the graph that preheating the mould before casting and increasing the shakeout time have increasing effect on the percentage elongation of the cast specimens. Hence, for an application where reduction in ductility is needed, decreasing the mould preheat temperature and shakeout time would be appropriate.

Table 4: Variations of ultimate tensile load of specimens obtained from different mould with shakeout time

	Ultimate tensile load F_N (N) mould temperature °C		
Shakeout time t (min)	As-prepared mould (26°C)	100°C pre-heated mould	200°C pre-heated mould
5	2750	2200	1900
10	2700	1900	1700
15	2100	1500	1400
20	1600	1400	1300
25	1550	900	800

Table 5: Variations of ultimate tensile strength of specimen from different mould of varied preheat and shakeout time.

	Ultimate tensile stress, $\sigma_u = F_u/A_o$ (MN m^{-2}) Mould temperature 'T' (°C)		
Shakeout time t (min)	As-prepared mould (26°C)	100°C pre-heated mould	200°C pre-heated mould
5	140.02	112.02	96.74
10	134.47	96.74	86.56
15	106.92	76.37	71.28
20	81.47	71.28	66.19
25	78.92	54.82	40.73

Note: Original diameter of specimen A = 5.00 mm, hence original Area $A_o = 19.64\times10^{-6}m^2$

Table 4 shows the variations of ultimate load of specimens obtained from different mould of varied preheat temperature and shakeout times.

The table indicates that increasing the preheat temperature of the mould caused reduction in the ultimate tensile load of the specimens. Also, increase in shakeout time has reduction effect on the ultimate tensile load. Dividing the ultimate tensile load exhibited by the specimens by their original cross-sectioned area results in the ultimate tensile strength of the cast specimens. The variations of ultimate tensile strength of specimens from moulds of varied preheat temperature and shakeout times are shown in Table 5 while the graphical presentation is shown in Fig. 7.

The trend of variations of ultimate tensile strength is identical to the variations of ultimate tensile load. Ultimate tensile strength was found to decrease with increase in mould preheat temperature. The ultimate tensile strength of cast specimen obtained from as-prepared sand mould of 5 min shakeout time was observed to be the highest, i.e., 140.02 MN m^{-2} when compared to those of other specimens. Preheating, as-prepared mould to 100 and 200°C before casting and shaking out the sand mould at 5 min duration after completing the pouring in of molten aluminium causes the ultimate tensile strength of the specimen to decrease

Table 6: Variations of impact energy of specimens from different moulds with shakeout time

	Impact energy (Nm)		
Shakeout time t (min)	As-prepared mould (26°C)	100°C pre-heated mould	200°C pre-heated mould
5	39.23	40.37	43.55
10	41.47	41.75	43.82
15	42.13	43.86	45.48
20	43.55	44.10	45.76
25	44.65	44.85	46.18

Table 7: Variation of hardness valve (HB) of specimens from different moulds with shakeout time

Shakeout time t (min)	As-prepared mould HB (26°C)	100°C pre- heated mould (HB)	200°C pre-heated mould (HB)
5	64.6	59.9	52.8
10	59.8	59.0	52.0
15	55.0	53.4	42.0
20	53.4	48.6	40.2
25	50.8	46.4	38.1

from 140.02-112.02 and 96.74 MN m^{-2}, respectively. Also, the ultimate tensile strength of specimen from as-prepared mould of 15 min shakeout time decreased from an initial value of 106.92-76.37 and 71.28 MN m^{-2} due to an increase in preheat temperature from ambient temperature to 100 and 200°C, respectively. The observed decrease in ultimate tensile strength with increase in mould preheat temperature could be attributed to the increase in heat accumulation in the sand mould prior to casting which resulted in a reduction in thermal gradient in the mould after casting. The reduction in thermal gradient consequently resulted in a slower cooling rate which improves the softness/ductility of the cast specimen at the expense of its ultimate tensile strength. Hence, in a practical application where the ultimate tensile strength of cast specimen should be lower than that of a specimen obtained from as-prepared mould, preheating the sand mould is recommended.

Also, it was observed that increase in shakeout time causes a reduction in the ultimate tensile strength specimen. The ultimate tensile strength of cast specimen obtained from as-prepared mould of 5 min shakeout time decreases from 140.02-106.92 and 78.92 MN m^{-2} due to an increase in the shakeout time to 15 and 25 min, respectively. Likewise, increasing the shakeout time of a 100°C-preheated sand mould from 5-15 and 25 min causes the ultimate tensile strength of it cast specimen to decrease from 112.02-76.37 and 54.82 MN m^{-2}, respectively. This observation is also applicable to 200°C preheated mould of 5, 10 and 15 min shakeout times. The reduction in ultimate tensile strength of the specimens with increase in shakeout time could be attributed to the fact that specimen retains more heat in the mould when the shakeout time is elongated. The more the heat retained, the higher the ductility of the specimen and the lower the ultimate tensile strength of the specimen.

Effects of mould preheat and shakeout times on impact energy: The variations of impact energy of cast specimens with mould preheat and shakeout time are shown in Table 6.

From the Table 6, it is observed that the higher the mould preheats the higher the impact energy exhibited by the cast specimens. Likewise increase in shakeout time has increasing effect on the impact energy of the specimens. For a particular mould, cast specimen obtained after 5 min shakeout time displayed the least impact energy, while highest impact energy was exhibited by cast specimens obtained from 25 min shakeout time. Also, for a specific mould shakeout time, cast specimens from as-prepared mould displayed the least impact energy while highest impact energy was manifested in cast specimens from 200°C preheated mould.

For as prepared mould shake out at 15 min, increasing mould preheat temperature from ambient temperature to 100-200°C causes the impact energy of its cast specimen to increase from 42.13-42.86 and 45.48 Nm, respectively. Also, increasing the shakeout time of as prepared mould from 15-20 and 25 min causes an increase in the impact energy of its cast specimen from 42.13-43.55 and 44.65 Nm, respectively.

The graphical representation of the variations of impact energy of cast specimens with mould preheat and shakeout time is shown in Fig. 8.

The increase in impact energy with increase in mould preheat could be attributed to increase heat accumulation in the mould which improves the ductility of the cast specimen and enhance its ability to withstand sudden applied load from the striking pendulum of the impact testing machine. Also, the increasing effect on impact energy due to increased shakeout time could be attributed to the longer duration of heat accumulation by the cast specimen in the sand mould before shaking out. Hence, mould preheat and increased shakeout time are recommended for an improved impact energy (or impact strength) of cast specimens.

Effects of mould pre-heat and shakeout times on hardness properties: The variations of hardness value of specimens from different mould of varied preheat and shakeout times are shown in the Table 7. From the table, as-prepared mould was found to produce cast specimens having highest values of hardness property for the respective shakeout times. This could be attributed to the fact that the relatively highest thermal gradient experienced in the as-prepared mould necessitated fastest cooling rate which enhance the hardness of the specimens at the expense of ductility. The hardness value of cast specimen from as-prepared mould of 5 min shakeout time dropped from 64.6-59.9 and 52.8 HB when

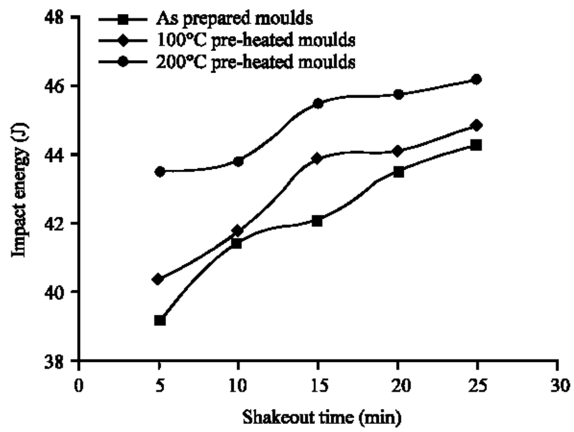

Fig. 8: The graph of impact energy, (J) against shakeout time, (min)

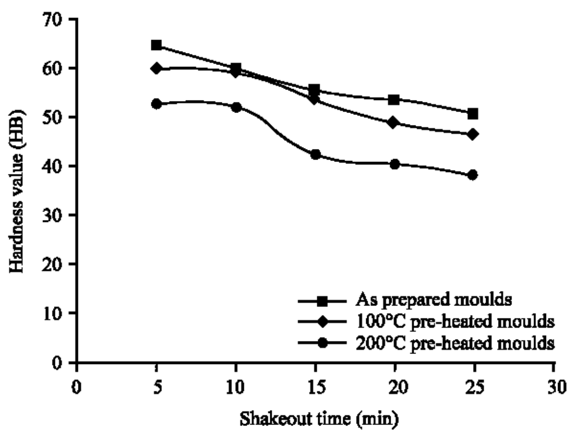

Fig. 9: The graph of hardness value (HB) against shakeout time (min)

the mould was preheated to 100 and 200°C, respectively. The hardness value of specimen from 100°C preheated mould was higher than that of the specimen from 200°C preheated mould of the same shakeout time because of the lower heat accumulation and faster cooling rate experienced in 100°C preheated mould when compared to 200°C preheated mould.

The graphical displays of the variations of hardness value of specimens from moulds of varied preheat and shakeout time is shown in Fig. 9. Increasing the shakeout time of as-prepared mould from 5-15 and 25 min caused the hardness value of the cast specimen to decrease from 64.6-55.0 and 50.8 HB, respectively. Also, when the shakeout time of 100°C preheated mould was increased from 10-20 and 25 min, the hardness value of the cast specimen decreased from 59.0-48.6 and 46.4 HB, respectively. The decrease in hardness value with increase in shakeout time could be attributed to the fact that cast specimen absorb more heat in the sand mould as the shakeout time is delayed. The higher the heat absorbed by the cast specimen in the mould before shakeout, the higher the ductility hence the lower the hardness value.

CONCLUSION

In this experimental research work, sand mould preheats temperature and shakeout times were varied with a view to controlling the mechanical properties of cast specimens. Increases in mould preheat temperature and shakeout times were found to increase the impact energy and percentage elongation at fracture (a measure of ductility). However, ultimate tensile strength and hardness of the specimen were found to decrease with increase in mould preheat temperature and shakeout time.

This could be attributed to the fact that increase in mould preheat temperature indicates an increase heat accumulation in the mould prior to casting and this results in a reduction in thermal gradient during casting and solidification and consequently results in a slower cooling rate which improve the softness/ ductility at the expenses of strength and hardness. Also, an increase in shakeout time indicates more heat retention in the mould before shaking out the mould, the more the heat retained in the mould before shaking out the mould, the higher the softness/ductility at the expense of strength and hardness.

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