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Mechanical Properties of Cast Aluminium Rods under Varied Oundry Sand Sizes and Mould Preheat Temperatures

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Abstract: The impacts of foundry sand sizes and mould preheat temperatures of range 30-200°C on the mechanical properties of cast aluminium rods were experimentally investigated and presented. At the same mould preheat temperature, cast specimens from fine sand mould exhibited highest tensile, impact and torsional properties with better hardness values. Also, preheating as-prepared fine sand mould to isothermal temperatures of 100 and 200°C for 1 h caused the percentage elongation of its cast specimen to increase from 9.8-11.8 and 13.5, respectively impact energy increased by 13.3 and 33.3%, respectively from initial value of 15 J, while its hardness, tensile strength and ultimate shear strength having respective initial values of 61.8 HRB, 144.6 MPa and 2.050 GPa correspondingly decreased by 11.5, 13.0 and 9.76% due to mould preheat to 200°C. Hence, for optimal mechanical properties, fine sand is found appropriate and preheating sand mould to about 200°C for some period in the furnace is considered adequate in effecting small changes in the mechanical properties of cast specimens, while avoiding crack formation in the sand mould due to excessive heat accumulation.

Key words: Mechanical properties, cast aluminium, sand sizes, mould preheat

INTRODUCTION

Casting has remarkable advantages in the production of parts with complex and irregular shapes, parts having internal cavities and parts made from metals that are difficult to machine. Because of these obvious advantages, casting is one of the most important manufacturing processes. The various processes differ primarily in the mould material and the pouring method. Sand casting is the most widely employed technique of all foundry methods; about 80% by volume of all cast products made annually had been attributed to the conventional sand casting technique (Benjamin *et al*., 1989).

The qualities and properties of cast products are greatly influenced by the different processing parameters involved in casting such as the gating system where sudden change in molten metal diversion causes mould erosion, turbulence and gas pick up. The mode of solidification also affects the properties of the casting, because a casting acquires a metallographic structure which is determined during solidification. Other parameters are the type of foundry sand, pouring temperature, mould preheat and shakeout times.

The findings of a research work (Oyetunji, 2002) showed that gray cast iron samples obtained from mould of fine sand size grade have improved strength, hardness and surface finish. However, other mechanical properties like torsional properties were not evaluated and the effects of other production parameters on the mechanical properties were not investigated. The rate at which castings are cooled depends on a number of factors that include foundry sand sizes, thickness of a casting, metal temperature at pouring and heat accumulation in the mould. The sand sizes and heat accumulation in the moulds are therefore considered in the present research by evaluating the mechanical properties of cast aluminium (a common non-ferrous alloy) under varied foundry sand sizes and mould preheat temperatures. This is with a view to controlling the mechanical properties of cast aluminium for optimal performance in practical applications.

MATERIALS AND METHODS

Materials and specimens' preparations: Properly dried and seasoned mahogany wood was machined on a wood lathe to obtain patterns for tensile, impact, hardness and torsion specimens. They were then surface-finished by sanding to erase tool marks and other irregularities. To fill up the pores and impart a smooth finish, two coats of shellac were applied on them. As-received sand was sun-dried and separated into fine, medium and coarse

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sand sizes using sieves having aperture diameters of 0.2, 0.6 and 2.0 mm, respectively. However, un-sieved as-received sand was also considered for casting. In accordance with Oyetunji (2002), 28.7 kg of the respective sand size grades were mixed with 1 kg of boiled starch, 1 L of water and 1.5 kg of bentonite powder. With the respective foundry sand size grades, the wooden patterns were used in obtaining the mould cavity inside a drag and cope assembly. A gating system of sprue and riser was incorporated to allow the flow of molten aluminium.

According to Khanna (1997), dry sand moulds are actually made with moulding sand in green condition and then the entire mould is dried in ovens (at temperature of 300-650°F i.e., 148-337°C) and allowed to cool before the molten metal is poured into it. However, Sharma (2005) explained that the prepared moulds in green condition with some additives are usually baked in an oven at 110-260°C for several hours to qualify as dry sand mould. Therefore, in this research, a green sand mould of the required sand sizes and additives was retained as as-prepared (i.e., at room temperature), while others were preheated to respective isothermal temperatures of 100 and 200°C for 1 h. However, to attain correct preheat temperatures, the moulds were preheated slightly above the respective temperatures, casting commenced as soon as the temperature dropped to the required level as monitored by an iron-constantan thermocouple placed just below the mould cavity.

The research material used in this investigation was aluminium alloy obtained from overhead electric cables and aluminium scraps. The wires and scraps were cut to smaller pieces and melted in an electric furnace and the required amount of the molten metal was poured at a constant temperature of about 750°C into the cavity of the respective as-prepared and preheated moulds of varied sand sizes. Immediately after filling the mould cavity with the molten aluminium, temperature curves showing the cooling rates of castings inside as-prepared and preheated moulds of different sand sizes were then obtained by recording the mould temperature (via the thermocouple inserted through the sand and slightly exposed to the bottom of the mould cavity) at 4 min intervals until the mould cools to room temperature, 30°C. The cast specimens were knocked out of the moulds after sufficient cooling to room temperature and then surface-finished. Figure 1 shows the schematic drawing of the sand casting.

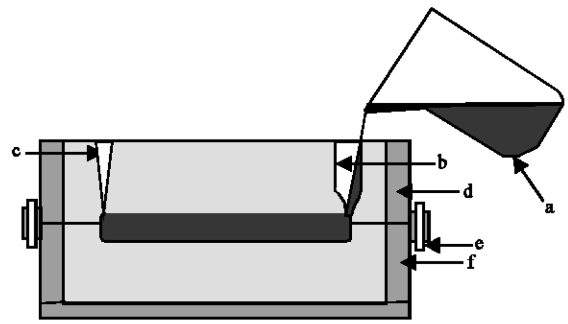

Fig. 1: Schematic drawing of the sand casting. a: molten aluminium, b: sprue, c: riser, d: cope, e: pin, f: drag

Experimental test procedures

Tensile test: Tensile tests were conducted on the specimens, having gauge section of 80 mm length and 6 mm diameter, with the aid of a Universal Testing Machine made by Avery Denison Ltd, England. The tensile properties of the specimens were recorded from the machine, while a Hounsfield Tensometer was used for a repeat test to confirm initial readings. Repeated tests showed good agreement within a measurement accuracy of ±3%.

Impact test: Impact specimens of 60 mm ×10 mm ×10 mm dimensions were notched at the middle to a depth of 3 mm to create an area of stress concentration for initiating fracture. The specimens were respectively fixed on a Charpy Impact Testing Machine to receive the fast moving hammer blow from a fixed height on the machine. The readings on a dial gauge on the machine showed the impact energy absorbed by the respective specimens. Repeated tests, carried out to confirm initial readings, indicated an accuracy of ±2% in the recorded impact energy values.

Hardness test: Measurements of hardness properties of the cast specimens of 60 mm ×10 mm ×10 mm dimensions were carried out with a Rockwell Hardness Machine using R_B scale. Measurements were taken in axial and transverse directions as shown in Fig. 2 and average values were evaluated. Accuracy within ±0.9 R_B scale was observed from the measurements repeated on similar specimens.

Torsion test: The test rig on a Tecquipment SM I MK II Torsion Testing Machine was leveled on a suitable bench by adjusting the two feet. Thereafter, torsion specimens were respectively mounted on the machine. A pair of 8 mm hexagonal drive sockets was fitted between the input and torque shafts in which the specimen was placed. The torque shaft was connected to an electrically powered E101 digital meter. The input hand wheel was rotated until one socket remained fixed, while the other moved freely. The scale and the digital meter set to zero reading by turning the cursor and knob, respectively.

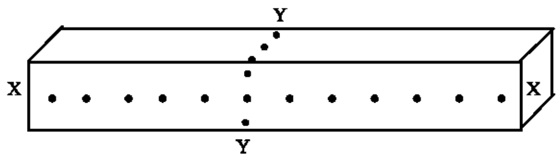

Fig. 2: Measurement of hardness properties of cast specimen. X-X: Axial measurement; Y-Y: Transverse measurement

An interval of 20 revolutions of the input hand wheel was chosen and the corresponding angles of twist from the protractor scale and the torque readings displayed on the digital torque meter were recorded. The procedure continued until the test specimen failed. Repeat tests were carried out on identical specimen to confirm initial readings. The values of torque recorded for similar specimens were within an accuracy of 2.5 Nm.

RESULTS AND DISCUSSION

Effects of sand sizes and mould preheat temperatures on mould cooling rates: Temperature curves indicating the rates of cooling of fine-sized sand, medium-sized sand, as-received sand and coarse-sized sand moulds of different mould preheat temperatures are shown in Fig. 3-6. For moulds of the same sand sizes, as-prepared sand mould was found to cool faster than the preheated moulds due to a relatively large thermal cooling gradient resulting from the absence of any previous heat accumulation before the pouring of the molten aluminium into the cavity. However, the relatively high preheat accumulation in the 200°C-preheated sand mould was responsible for its slowest cooling rate.

At the same preheat temperature, moulds made of coarse-size sand were found to exhibit fastest cooling rate, the quick heat dissipation could be attributed to the presence of void in the mould due to low level of sand compaction and cohesiveness. However, fine-size sand mould was observed to display slowest cooling rate due to the impedance to heat dissipation by the highly compacted and cohesive fine sand grades.

Effects of sand sizes and mould preheat temperatures on tensile properties: The variations of tensile properties of cast specimens from the as-prepared and preheated moulds of different sand sizes are shown in Table 1. However, Fig. 7 and 8 show respectively the plots of tensile strength and percentage elongation of the cast specimens with mould preheat temperatures. It was observed that, at the same mould preheat temperature, cast samples from fine sand mould exhibited highest tensile properties followed successively by those from medium, as-received and coarse sand moulds. The highest level of compactness and cohesiveness of the fine sand coupled with the relatively non-existence of voids, un-noticeable metal penetration in the mould and absence of sand inclusions in the casting attributed to the improved tensile properties displayed.

Increase in mould preheat temperature was found to reduce the values of tensile strength but increase the percentage elongation of castings made using different sand sizes, but at varying rate. Hence, maximum tensile strength and minimum percentage elongation were exhibited in cast specimens from as-prepared moulds i.e., non-preheated moulds (Fig. 7 and 8). However, the reduction in tensile strength and increase in percentage elongation due to mould preheat were found to be maximum in cast specimens made from fine sand mould but minimum in cast specimens made from coarse sand mould.

Preheating as prepared fine sand mould to respective temperatures of 100 and 200°C resulted in 5.4 and 13.0% reductions in 114.6 MPa tensile strength value of its casting, while percentage elongation correspondingly increased to 11.8 and 13.5 from initial value of 9.8. However, there were 1.6 and 5.3% reductions in 92.4 MPa tensile strength value of cast specimen made from coarse sand mould when preheated to the corresponding temperature ranges while percentage elongation increased to 8.3 and 8.9 from initial value of 8.1. These developments could be attributed to the varying degrees of mould preheat accumulation and cooling rate.

Effects of sand sizes and mould preheat temperatures on impact and hardness properties: Table 2 shows the variations of impact and hardness properties of cast specimens from the as-prepared and preheated moulds of different sand sizes. At the same mould preheat temperature, the impact energy of cast specimens from fine sand moulds were found to be the highest. However, because of the fastest cooling rate exhibited in coarse sand mould, its cast specimen has higher hardness value than the corresponding one from fine sand mould. Also, increase in mould preheat temperature was found to have increasing effects on the impact energy of cast aluminum specimens (as shown in Fig. 9). Preheating as-prepared fine sand mould to respective temperatures of 100 and 200°C resulted in 13.3 and 33.3% increases in impact energy of the cast specimen having an initial value of 15 J. This could be attributed to the fact that mould

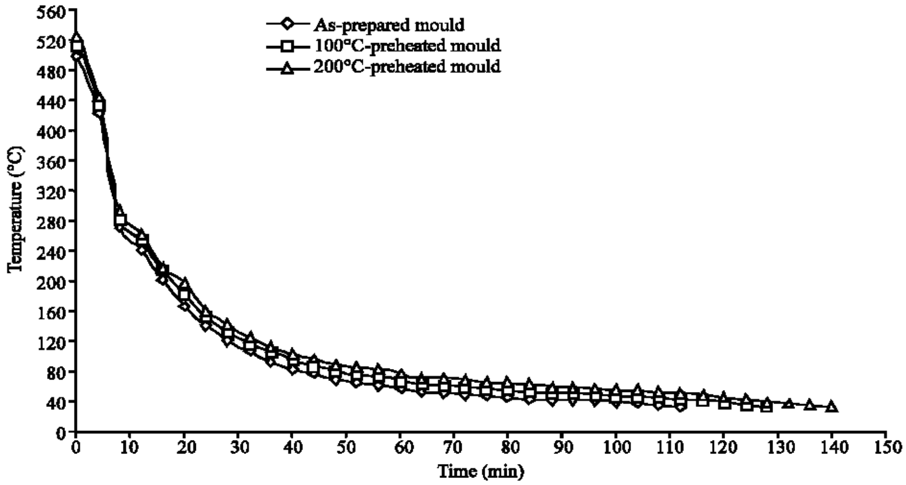

Fig. 3: Temperature curves showing the cooling rates of castings inside fine-sized sand mould

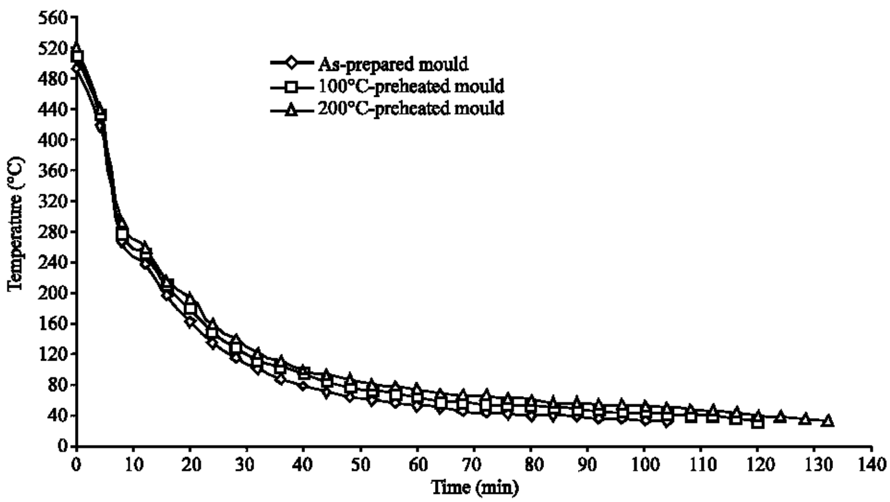

Fig. 4: Temperature curves showing the cooling rates of castings inside medium-sized sand mould

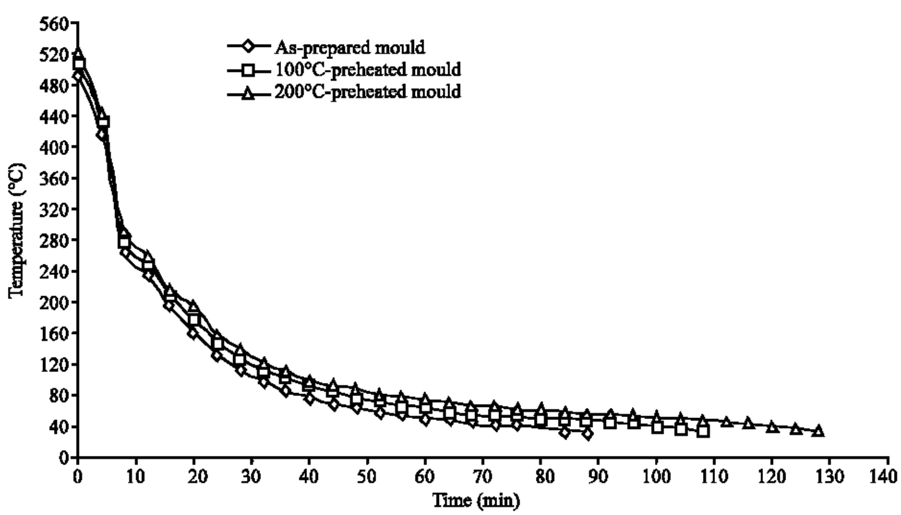

Fig. 5: Temperature curves showing the cooling rates of castings inside as-received sand mould

Table 1: Variations of tensile properties of cast specimens from moulds of different sand sizes with mould preheat temperatures

Sand mould preheat temp. (°C)	Fine-size sand		Medium-size sand		Coarse-size sand		As-received sand	
	Tensile strength (MPa)	Elongation (%)	Tensile strength (MPa)	Elongation (%)	Tensile strength (MPa)	Elongation (%)	Tensile strength (MPa)	Elongation (%)
As-prepared, 30	114.6	9.8	105.2	9.6	92.4	8.1	94.9	9.2
100	108.4	11.8	102.4	10.7	90.9	8.3	91.3	9.7
200	99.7	13.5	93.6	11.5	87.5	8.9	89.6	10.5

Table 2: Variations of impact and hardness properties of cast specimens from moulds of different sand sizes with mould preheat temperatures

Sand mould preheat temp. (°C)	Fine-size sand		Medium-size sand		Coarse-size sand		As-received sand	
	Impact Energy (J)	Hardness (R_B scale)	Impact Energy (J)	Hardness (R_B scale)	Impact Energy (J)	Hardness (R_B scale)	Impact Energy (J)	Hardness (R_B scale)
As-prepared, 30	15	61.8	14	58.5	10	63.0	12	60.0
100	17	60.2	17	55.4	11	60.5	14	57.6
200	20	54.7	19	50.8	14	55.2	17	51.3

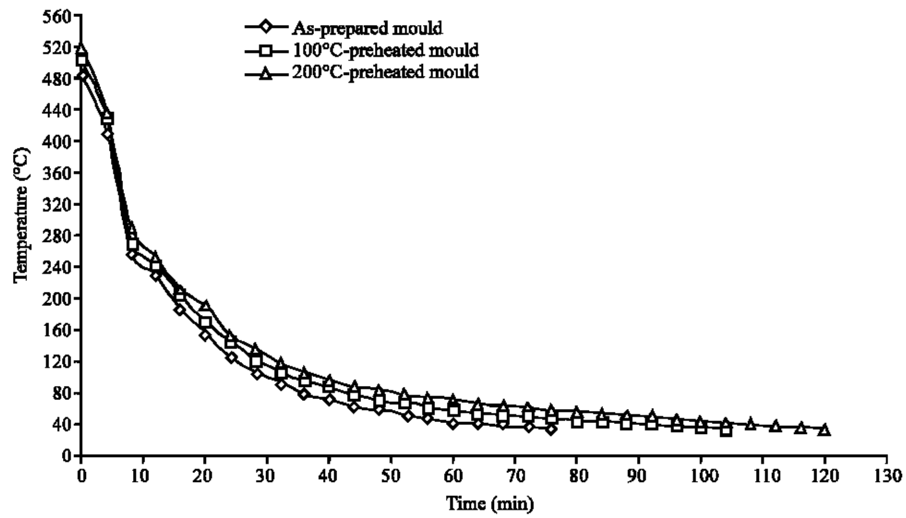

Fig. 6: Temperature curves showing the cooling rates of castings inside coarse-sized sand mould

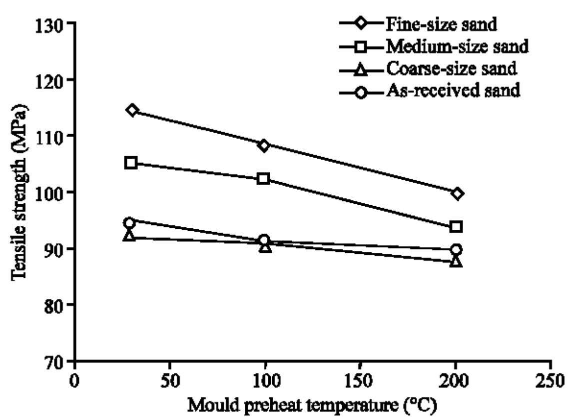

Fig. 7: Plot of tensile strength of cast specimens with mould preheat temperatures

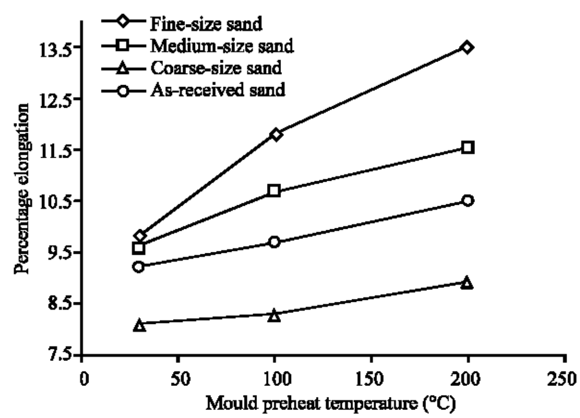

Fig. 8: Plot of percentage elongation of cast specimens with mould preheat temperatures

preheat prolongs the solidification and cooling of the molten aluminium. On the other hand, corresponding decreases by 2.59 and 11.5%, were respectively observed in the hardness value at the mould preheat temperature range (Fig. 10).

Table 3: Variations of torques of all cast specimen with angles of twist

		Torque, T (Nm)											
		Fine-size sand			Medium-size sand			Coarse-size sand			As-received sand		
	Angle of		Preheated			Preheated			Preheated			Preheated	
No of rev.	twist, θ (rad)	As-prepared	100°C	200°C	As-prepared	100°C	200°C	As-prepared	100°C	200°C	As-prepared	100°C	200°C
20	2.09	65.14	63.83	61.71	64.89	63.28	61.41	64.08	62.47	59.84	64.34	63.02	60.90
40	4.19	93.69	89.50	88.32	90.63	88.50	85.38	84.52	91.02	87.42	87.04	89.44	86.37
60	6.28	106.04	102.44	99.18	103.76	102.03	96.69	98.04	96.68	93.19	100.68	100.50	95.29
80	8.38	112.96	107.66	103.74	109.01	104.73	102.35	106.16	102.35	96.07	106.13	103.27	98.27
100	10.47	115.43	110.27	104.61	111.74	107.44	101.22	108.86	104.05	98.96	108.86	106.03	99.58
120	12.57	115.92	108.81	101.89	111.11	104.73	96.69	103.45	102.35	90.30	106.13	103.27	93.51
140	14.66	113.45	106.10	96.46	106.38	102.03	81.43	95.34	93.85	78.76	100.68	97.74	81.61
160	16.76	107.23	99.83	85.60	98.50	92.28	72.94	89.93	79.69	70.11	97.95	86.68	71.49
180	18.85	93.69	86.79	72.03	85.37	74.97	53.15	73.71	73.46	47.03	78.85	75.62	53.64
200	20.94	-	63.31	55.74	-	56.03	33.36	-	45.70	23.95	-	50.75	26.86
210	21.99	-	-	48.13	-	-	27.71	-	-	-	-	-	-

Table 4: Variations of torsion shear stresses of all cast specimen with shear strains

			Torsion shear stress, τ (GPa)											
			Fine-size sand			Medium-size sand			Coarse-size sand			As-received sand		
	Angle	Shear		Preheated			Preheated			Preheated			Preheated	
No of rev.	of twist, θ (rad)	strain γ = rθ/L	As-prepared	100°C	200°C	As-prepared	100°C	200°C	As-prepared	100°C	200°C	As-prepared	100°C	200°C
20	2.09	0.0628	1.536	1.505	1.455	1.530	1.492	1.448	1.511	1.473	1.411	1.517	1.486	1.436
40	4.19	0.1257	1.825	1.751	1.700	1.775	1.725	1.660	1.700	1.725	1.650	1.725	1.725	1.650
60	6.28	0.1884	1.950	1.875	1.800	1.900	1.850	1.760	1.825	1.775	1.700	1.850	1.825	1.725
80	8.38	0.2514	2.020	1.925	1.842	1.950	1.875	1.810	1.900	1.825	1.725	1.900	1.850	1.750
100	10.47	0.3141	2.045	1.950	1.850	1.976	1.900	1.800	1.925	1.840	1.750	1.925	1.875	1.761
120	12.57	0.3771	2.050	1.936	1.825	1.970	1.875	1.760	1.875	1.825	1.675	1.900	1.850	1.710
140	14.66	0.4398	2.025	1.910	1.775	1.925	1.850	1.625	1.800	1.750	1.575	1.850	1.800	1.610
160	16.76	0.5028	1.962	1.850	1.675	1.850	1.760	1.550	1.750	1.625	1.500	1.825	1.700	1.525
180	18.85	0.5655	1.825	1.725	1.550	1.725	1.600	1.375	1.600	1.570	1.300	1.650	1.600	1.375
200	20.94	0.6282	-	1.500	1.400	-	1.425	1.200	-	1.325	1.100	-	1.375	1.150
210	21.99	0.6597	-	-	1.330	-	-	1.150	-	-	-	-	-	-

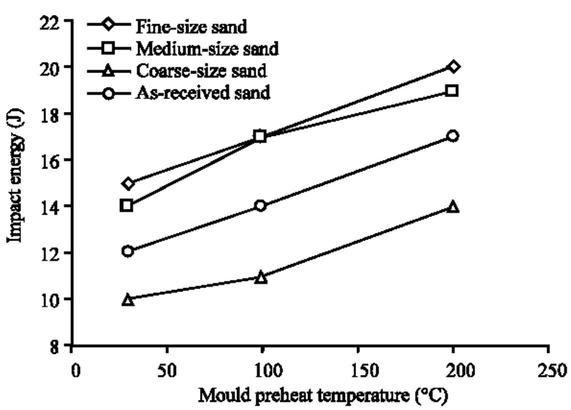

Fig. 9: Plot of impact energy of cast specimens with mould preheat temperatures

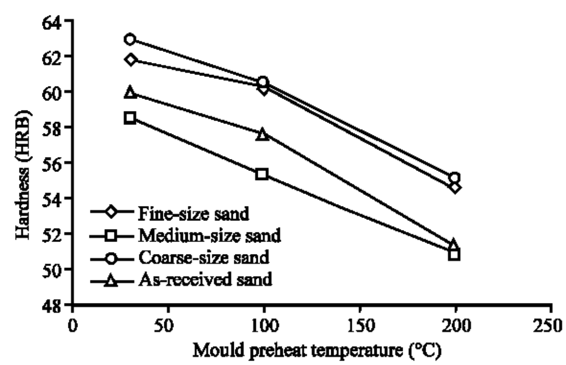

Fig. 10: Plot of hardness of cast specimens with mould preheat temperatures

Effects of sand sizes and mould preheat temperatures on torsional properties: The variations of torque of cast specimens from as-prepared and preheated moulds of different sand sizes with angle of twist are shown in Table 3. Beyond torsional yield strength τ_y, the shear stress over a cross section of a metallic rod is no longer a linear function of the distance from the axis and the equation:

$$\tau_r = 16\ T/\pi d^3$$

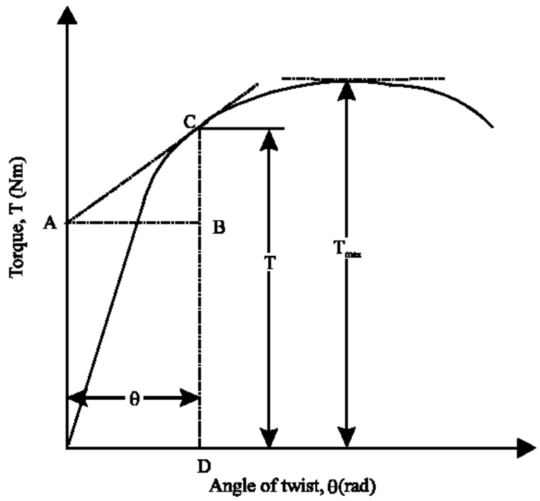

Fig. 11: Method of calculating shear stress from torque-twist diagram

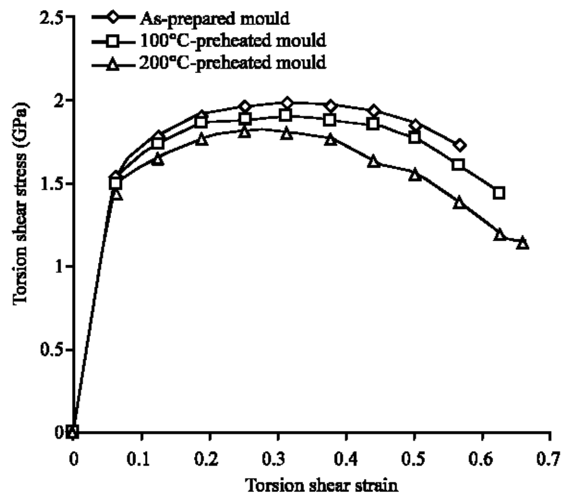

Fig. 13: Plot of torsion shear stresses of medium sand mould cast specimens with shear strains

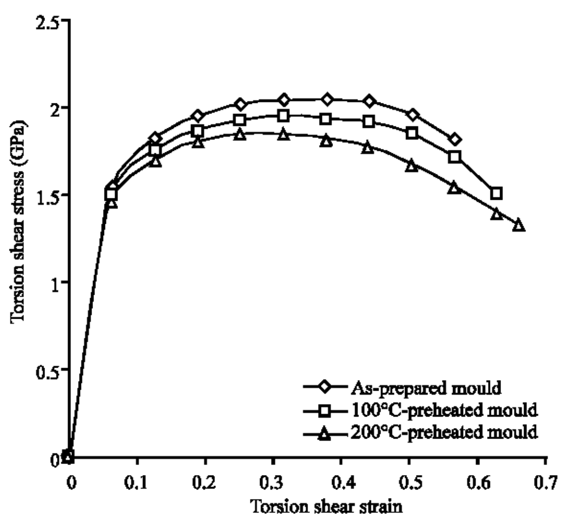

Fig. 12: Plot of torsion shear of fine sand mould cast specimens with shear strains

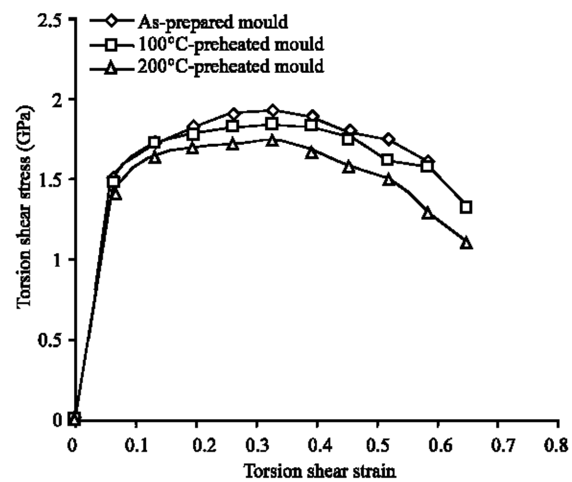

Fig. 14: Plot of torsion shear stresses of coarse sand mould cast specimens with shear strains

does not apply, hence a method for calculating the shear stress in the plastic range was presented (Nadai, 1950) if the torque versus angle of twist curve is known. The shear stress was derived as:

$$\tau_r = (\theta^{dT}/_{d\theta} + 3T)/2\pi r^3$$

Where:

r = Radius of the rod.

θ = Angle of twist (rad.).

T = Torque on the torque-twist curve.

However, the analysis was simplified (1981) and torsional shear stress was shown as:

$$\tau_r = (BC + 3CD)/2\pi r^3$$

with reference to the geometry of Fig. 11.

Table 4 shows the variations of torsional shear stress with shear strain as obtained from the analysis above, while the plots of torsional shear stress with shear strain for all specimens are shown in Fig. 12-15. At the same mould preheat temperature, cast specimens from fine sand mould were observed to exhibit highest values of ultimate shear strength while lowest values were displayed by those from coarse sand moulds. As shown in Fig. 16, increase in mould preheat has reduction effects on the ultimate shear strength of cast specimens.

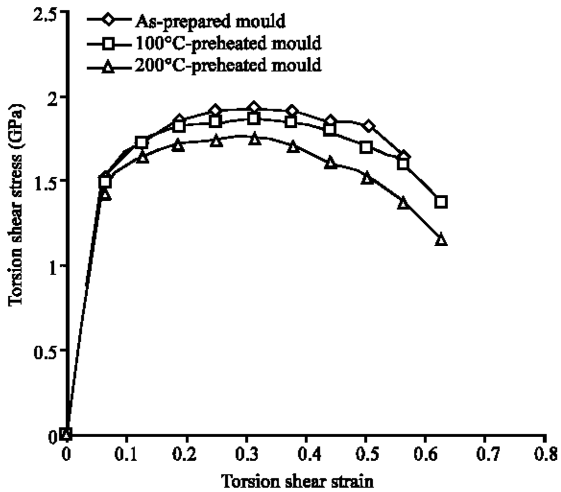

Fig. 15: Plot of torsion shear stresses of as-received sand mould cast specimens with shear strains

The ultimate shear strength of cast specimen from as-prepared fine sand mould was found to decrease by 4.88 and 9.76% from its initial value of 2.050 GPa due to mould preheating to 100 and 200°C, respectively. However, 4.41 and 9.09% reductions in ultimate shear strength from initial value of 1.925 GPa were observed in casting from as-prepared coarse sand mould when pre-heated within same temperature ranges.

CONCLUSION

In this investigation, the following conclusion can be made:

- At the same mould preheat temperature, cast samples from fine sand mould exhibited highest tensile, impact and torsional properties with better hardness values. The highest level of compactness and cohesiveness of the fine sand coupled with the relatively non-existence of voids, un-noticeable metal penetration in the mould and absence of sand inclusions in the casting attributed to the improved properties displayed.
- Increase in mould preheat temperature has reduction effects on the tensile strength, maximum torque and ultimate shear strength but increasing effects on ductility and impact energy.
- For optimal mechanical properties, fine sand is therefore found appropriate and preheating sand mould to about 200°C for some period in the furnace is considered adequate in effecting small changes in the mechanical properties of cast specimens while avoiding crack formation in the sand mould due to excessive heat accumulation.

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