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Influence of Sand Mould Additives on Tensile Properties of Aluminium (6061) Alloy Cooled in Different Media

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Abstract: Aluminium is an important engineering material that is widely utilized due to its suitable mechanical properties in manufacturing industries. The effectiveness and efficiency of cast aluminium alloy depend greatly on various casting methods. The additives in the sand mould and quenching media contributed to perfect casting. Present study investigated the influence of various sand mould additives (Sawdust Ash, Groundnut Shell Ash, and Eggshell Ash) on the tensile properties of the cast Aluminium (6061) alloy cooled in different media (Water, Palm Oil, and Engine Oil). The additives were varied at 5%, 15%, 25% and 35%. After cooling, the samples were subjected to a tensile test and the result showed significant differences in the tensile strength properties of the cast samples. Ultimate tensile strength values increased as the percentage of additive in sand mould increased. However, for all the additives studied, water had the highest ultimate tensile strength values (107.52 MPa, 100.5 MPa and 94.55 MPa) followed by palm oil and engine oil at 25% but decrease at 35%. Percentage elongation values of the samples decreased with an increase in additives ratio up to 25% but had the highest values when quenched in engine oil. These observed behaviours are attributed rate of solidification the moulds and cooling rate behaviours of the media.

Keywords: Aluminium Alloy, Additives, Water, Palm Oil, Engine Oil, Tensile Strength

1. Introduction

One of the most widely utilized lightweight engineering materials is Aluminium, and the demand for aluminium and its alloys for critical industrial components like automobiles and aerospace is on the rise. It can also be used to make machine parts, home appliances, electrical equipment, and a variety of other things. Aluminium’s growing popularity can be due to its desirable mechanical, thermal, and electrical qualities, as well as its low density, ease of recycling, and ease of coating [1]. Two major types of aluminium alloys are wrought alloys and cast alloys. Aluminium casting alloys are particularly common among cast alloys because they offer the best castability ratings, higher fluidity, and relatively low melting points [2].

1.1. Additives

Sand casting is currently used to cast more than 70% of all alloy castings worldwide. Sand is used as the mould material in this procedure. Different process parameters, such as the percentage of clay and water used, additives, grain fineness, and the number of strokes used to produce a mould, influence its properties [3]. Among the various process variables that influence the qualities of the final casted product, the presence of additives in the sand has a considerable impact. Surface polish, dry strength, refractoriness, and cushioning qualities are all improved by adding additives to moulding components [4].

1.2. Quenching

The quench's goal is to create a supersaturated solution. To achieve this type of structure, the temperature must drop more or less quickly, depending on the initial temperature, chemical composition, and desired microstructure. The material is cooled more or less fast from the solution temperature to the final temperature. The cooling rate is determined by the final mechanical qualities required as well as the chemical composition. The major goal is to prevent the production of precipitates or second phases during the cooling process.

1.3. Some Selected Literature Review

To improve the cast product qualities, several researchers have suggested using agricultural waste or fly ash as additives in mould sand. However, most studies focused solely on the features of sand-based moulds and additives used in casting. Meanwhile, the effect of the sand mould additives mixture on casted aluminium, particularly heat-treated aluminium quenched in specific quenching media, has not been well explored. Some previous published research studies are;

Ikebudu *et al*. [5] investigated the effect of green sand mixture with dextrin additives on the mechanical properties of aluminium 6351. The results were improved to obtain optimum proportions of the mixtures to give effective results, and from the best possible validation values, 5 percent water content, 12 percent bentonite, and 8.85 percent dextrin organic additive was found to be the optimized solution that gave the most effective hardness at (40.4GSS and 112PN), while 3 percent water, 12 percent bentonite clay, and 9 percent dextrin organic additive displayed the most effective toughness at (30.4GSS and 112PN) (41.9GSS and 96.10PN).

Investigation was conducted by Kumar *et al*. [6] on the effect of additives on the mechanical properties during the casting of 6351 aluminium. These different additives (tamarind powder, starch powder, coal dust) were utilized in varying percentages. Starch power of 1% content in sand increases the compressive strength of mould which increases the tensile stress of all alloy when compared to tamarind powder and coal dust according to the test result.

Furthermore, Ayoola *et al*. [7] presented the effect of using the CO_2 process, metal mould, cement-bonded sand mould, and naturally-bonded sand mould on the hardness, tensile and impact strengths of as-cast 6063 Aluminium alloy. The results demonstrated that when a naturally-bonded sand mould is used to make the alloy, it has a significantly higher hardness (33.7 HB) than when metal, CO_2, or cement moulds are utilized. The stress-strain curves of the specimens also revealed that the naturally bonded sand sample has the best tensile strength and ductility. When a metal mould is used for sample preparation, the alloy has the maximum impact strength when compared to other moulds.

Dharshan *et al*. [8] studied the effect of variation in the percentage of additives on the quality of moulds and hence the properties of aluminium castings Three distinct additives, Fly-ash, Tamarind powder, and Coconut shell powder were utilized in varied ratios in this direction. In comparison to tamarind powder and coconut shell powder, castings made using Chromite sand, 1% fly ash, 7% water, and 8% bentonite had a better surface quality and hardness. When compared to the other two additives, chromite sand with 1% tamarind powder has a greater surface polish and hardness.

Also, Sivareddy [9] presents the statistical evaluation of selected properties of moulding sands chromite and zircon sands with the addition of various binders and various additives. The result with defined proportions of binding clay, bentonite, coal-dust, and iron-oxide additions, revealed the existence of peak values for the green compressive strength and water absorption of the untreated sand. Furthermore, the operating range for each type of property appeared to fluctuate depending on the amount of water in the sand. The findings proved that sand may be used to create sand casting moulds.

Studies were conducted by Seidu and Kutelu [10] on the effects of sawdust, coal dust, and iron filling additives at varied proportions on some selected properties of moulding sand. The samples with 25% sawdust had a maximum moisture content value of 39.2 percent, compared to specimens with 25% iron filler and charcoal, which had moisture content values of 33.7 percent and 32.5 percent, respectively. The specimen with 25% coal dust addition had the maximum permeability and porosity values of 6.53 105 cm/s and 45.8%, respectively, whereas the specimen with 25% sawdust had the least value of 5.06 105 cm permeability and 33.2 percent. Moulding sand specimens containing sawdust were found to have good compaction, with a maximum green compressive strength of 108.99 kPa, owing to the enhanced moisture absorption strength of sawdust. On the moulding sand, the synergistic impact of 25% sawdust, coal dust, and iron filling gave the optimum green shear strength value of 54.49 kPa. As a result, when green shear strength is most important, this combination should be chosen.

Moreover, Karim *et al*. [11] stabilized soft clay models with sawdust ash (SDA) additive using different percentages (0, 2, 4, 6, 8, and 10% by dry weight of soil). Due to the clay concentration, the additive harms the properties of soil indices, raising the liquid limit and plasticity index. With an increase in SDA content, the mixing of sawdust ashes with soft clay soils improves most other physical and mechanical qualities of the soil, as measured by a general decrease in specific gravity and maximum dry density (MDD), as well as a decrease in compression coefficients (Ccand Cr). With an increase in SDA content, the optimum moisture content (OMC) and undrained shear strength (cu) increase. Low CBR values (1.6-1.2 percent) were obtained from stabilized soils (with 4 and 10% ash content), which can be used as a sub-base.

Adebayo *et al*. [12] investigated the effects of local cooling media on the mechanical properties of heat-treated mild steel and found that quenching in a medium with a faster cooling rate reduces elongation. As a result, the water-cooled specimen with the fastest cooling rate had the least percentage elongation at the fracture compared to the other quenching media.

Ma *et al*. [13] studied the effects of the process parameters like polymer concentration and agitation) on the quenching behaviour of cast aluminium alloy A356 in the aqueous solution of Aqua-Quench 260 using the CHTE quenching-agitation system. It is found that the average cooling rate gradually decreases with the increase in polymer concentration. But agitation enhances only the average cooling rate at low and medium levels. ANOVA results showed that the process parameter that affects the average cooling rate most is the polymer concentration; its percentage of contribution is 97%. The effects from agitation and the interaction between polymer concentration and tank agitation are insignificant.

In addition, Offor *et al*. [14] into reported the effects of various quenching media (air, brine, and SAE 40 engine oil) on the mechanical properties of intercritically annealed hot-rolled 0.15wt%C - 0.43wt% Mn steel showed that quenching media and higher intercritical annealing temperature improves the strength and hardness properties but decrease the ductility and notch impact properties of the original steel.

Therefore, this present work aims at investigating the influence of various sand mould additives (sawdust ash, groundnut shell ash, and eggshell ash) on tensile properties of the aluminium (6061) alloy cooling in water, palm oil, and engine oil. The responses of mechanical properties of aluminium alloy to these local cooling media would be evaluated through a tensile test and hardness test result.

2. Material and Experimental Methodology

2.1. Materials

Natural sand employed in the preparation of the green sand mould were taken from the riverbank in the Asa/Ballah area of Ilorin, Nigeria. The sand sample used was sieved with a 75 µm sieve to separate the substance from deleterious substance. Aluminium alloy (Al6061) ingot was obtained at Nigerian Aluminium Extrusions Limited (NIGALEX), Lagos, Nigeria. The chemical composition of the aluminium alloy was obtained from the company and this reveals that the aluminium alloy have a high percentage of aluminium (89.7%) and trace components of the other elements.

The additives (Figure 1) added to the sand mould were egg shell ash (ESA), sawdust ash (SDA) and groundnut shell ash (GSA), and were sourced from Madi Poultry Farm, Geri Sawmill and Oja Gboro, respectively, in Ilorin, Nigeria. These are waste materials that can cause environmental pollution. The cooling media employed were water, palm oil and engine oil, and were obtained in Ilorin, Nigeria. These cooling media were used due to their varied viscosity and cooling rate attributes during quenching process.

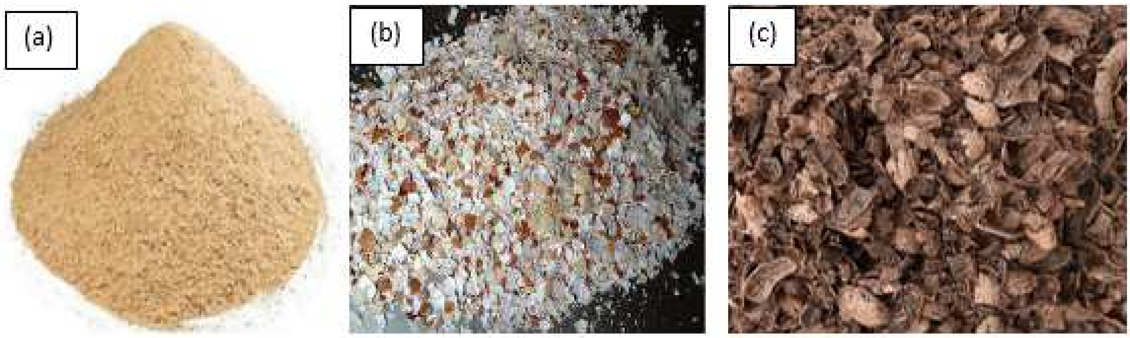

Figure 1. *Sand mould additives: (a) sawdust (b) egg shell and (c) groundnut shell.*

2.2. Material Preparation

20 kg of each of the additives (Figure 1) were sun-dried for 13 days and then, the eggshell and groundnut shell were grated into a particulate using the manual mortar method. The three materials were burned locally using a charcoal-burner by a method of dry frying. The burned ashes were then grounded to powdery form as shown in Figure 2 using grinding machine. The powders were subsequently sieved with a 75 µm sieve in accordance with BS 12 (1991), and the escaped materials were stored in the air-tight container for later use in the preparation of the sand moulds.

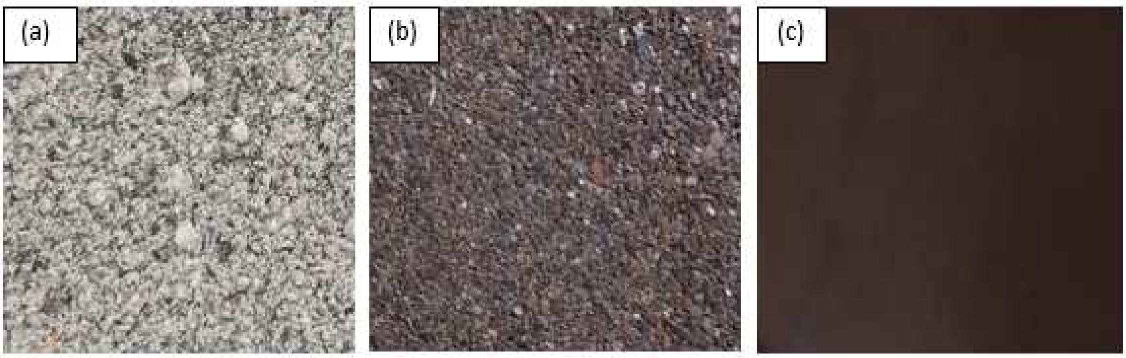

Figure 2. *Additive ashes (a) egg shell ash (b) sawdust ash and (c) groundnut shell ash.*

2.3. Preparation of Sand Mould

Mixing of sand and additives took place in muller mixer machine. The different percentage values of additives used in mould making process as shown in Table 1. Each prepared sand mould as a mass 30 kg with the addition of various weight percentages of additives. 13 moulds were prepared for this experiment; the first box consists of sand moulds without any additives while the other 12 moulds consist of sand moulds plus various percentages of additives (4 moulds for each additive). Since the pattern used for this experimentation is not a split pattern, 3 mould patterns were inserted vertically into each moulding box which implied that each mould would have three samples and the total number of 39 aluminium alloy samples would be produced. Subsequently, mould patterns were removed and the sand acquired its shape for the casting process.

Table 1. *Weight percentage of additives added to the sand mould.*

Additives	Additives (%)	Sand (%)	Total weight of sand mould (kg)
Control	0	100	30
GSA	5, 15, 25, 35	95, 85, 75, 65	30
SDA	5, 15, 25, 35	95, 85, 75, 65	30
ESA	5, 15, 25, 35	95, 85, 75, 65	30

2.4. Cast

The aluminium ingot (Al6061) was melted at a maximum temperature of 850°C in a crucible furnace. 20 kg of aluminium was melted and the molten metal was tapped from the furnace, then poured into the hollow cavities in each prepared mould. After 5 seconds of solidification, the cast alloy samples were shaken out (dismantled) of the mould and immediately quenched at a rapid rate in different cooling medium (Water, Engine Oil, and Palm Oil) such that the solute atoms do not have enough time to precipitate out of the solution. Samples of the quenched cast aluminium alloy are shown in Figure 3.

Figure 3. *Quenched samples in water, palm oil, and engine oil.*

2.5. Tensile Testing

Quenched samples of cast aluminium alloy from moulds with and without additives were cut into smaller rods and machined into standard specimens according to ASTM E8 specifications for tensile test (Figure 4). Thirty-nine specimens were produced (three specimens from each of the thirteen different moulds as shown in table 1) for the tensile test. The tensile test was carried out on Tensile Testing Machine (Model No: 500-101133) at the Material Science Department of Obafemi Awolowo University, Ile Ife, Nigeria. The values for ultimate tensile strength and percentage elongation for each of the tested specimen were recorded.

Figure 4. *Samples of (a) quenched aluminium alloy rods (b) cut aluminium alloy rods and (c) machined specimens.*

3. Result and Discussion

3.1. Analysis of Tensile Properties

The effects of various additives in the sand mould and different quenching media on the ultimate tensile strength of the cast aluminium alloy samples are depicted in results of the tensile test carried out on each sample as shown Table 2 and graphically illustrated in Figure 5.

The results of the tensile test showed that specimens chilled in water had the highest ultimate tensile strength and followed by specimens cooled palm oil and engine oil, respectively. This trend was observed for specimens from sand moulds with and without additives. Increment of 11.5 MPa and 6.35 MPa was recorded in strengths of specimens from mould without additives and cooled in water and palm oil respectively, over specimen cooled in engine oil. This could be attributed to the varying cooling rate of the specimens in the media which is most pronounced in water than the other. The higher the cooling rate, the faster is the rate of solidification and the finer the grain structure of the aluminium alloy. The fine eutectic phase (Mg_2Si) produced in the aluminium matrix have tendency of obstructing motion of dislocations which caused the observed increase in strength as the cooling rate increases [15].

Table 2. *Ultimate tensile strength values.*

Additives	Additives (%)	Quenching Water	Palm Oil	Engine Oil
	0	87.3	82.1	75.8
SDA				
	1.5	92.6	86.2	78.2
	4.5	96.1	88.1	81.2
	7.5	102.6	93.2	86.2
	10.5	101.1	89.5	84.5
GSA				
	1.5	95.1	89.4	83.2
	4.5	98.4	93.6	87.2
	7.5	105.8	96.1	91.2
	10.5	102.0	94.9	88.7
ESA				
	1.5	98.7	93.3	86.6
	4.5	102.4	97.4	90.3
	7.5	107.9	100.5	94.6
	10.5	105.2	98.2	94.1

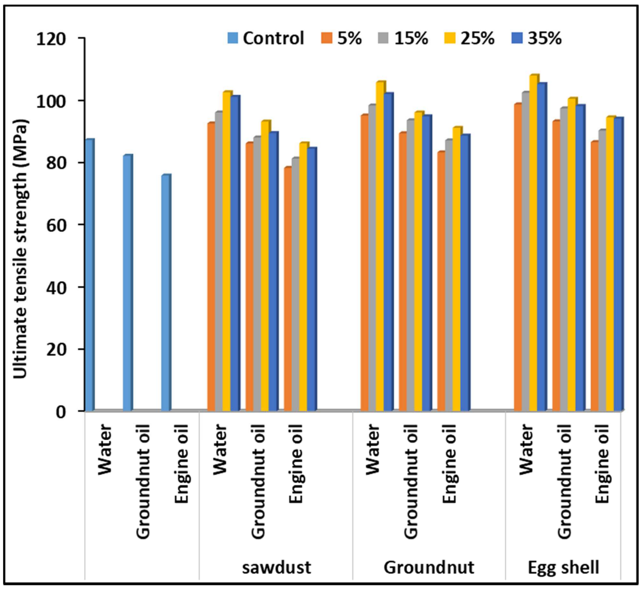

Figure 5. *Ultimate tensile strength of aluminium alloy casted in sand mould with varying additives and quenched in different media.*

The tensile test analysis, as depicted in Figure 6, showed that aluminium alloy specimens casted in sand mould with additives exhibited superior tensile strength when compared to sample without additive. For example, increase of 5.8%, 8.2% and 11% were recorded in the ultimate tensile strength for water quenched samples from sand moulds with addition of 5% sawdust ash, groundnut ash and egg shell ash, respectively. This may be attributed to the inability of the additives to retain heat, leading to a high solidification rate and improved tensile strength as previously explained and also in agreement with literature [6]. The tensile strength values of the samples were also observed to increase as the percentage of each additive in the sand mould increases up to 25%, but at higher percentage of sand additives above 25%, the UTS values tend to decline or have no significant improvement. This could be due to excess additives blocking the pores in the sand, and thereby retaining heat and hence slow down cooling rate.

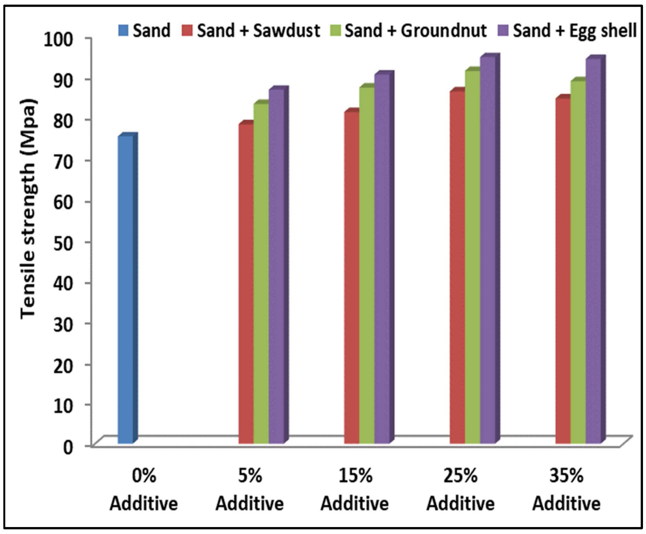

Figure 6. *Tensile strength of aluminium alloy quenched in engine oil for various percentage of additives.*

It can also be observed in Figure 6 that that the aluminium alloy samples casted in sand mould with egg shell as additive showed highest tensile strength for each percentage of added additive in the sand mould followed by groundnut shell ash additive and then sawdust ash additive. This could be attributed to the different in their bond between the sand particles and the additives. The finer the grains size of additive in a mould, the lesser the bond between its particles and sand particles and the poorer the ability of the mould to retain heat [6]. Egg shell having coarsest particle size compared to groundnut and sawdust ashes retained least heat and was responsible for the observed superior strength exhibited by the specimen from the mould with egg shell additive.

3.2. Percentage Elongation

Table 3 and Figure 7 showed the results of the percentage elongation. It could be observed from the results that specimens quenched in engine oil with least cooling rate have highest values of percentage elongation, whereas water-cooled samples that have the fastest cooling rate compared to the others have the least percentage elongation at fracture for all the specimen casted in moulds with and without additives. This is contrary to observation on tensile strength where the tensile strength value increases as cooling rate increases. Nevertheless, this is in line with the findings of Gündüz and Çapar [16] and Adebayo et al. [12] that quenching in a medium with a fast cooling rate tends to harm elongation of metal.

As shown in Figure 8, specimens casted in sand mould with studied additives showed lower ductility values when compared to specimen cast in sand mould without additive. The value of the ductility of specimens casted in sand mould with sawdust ash, groundnut shell ash and Egg Shell ash additives decreased by 23.6%, 12.7% and 3.6%, respectively, when compared to specimen cast in sand mould alone. This could also be ascribed to inability of the additives to retain heat, leading to varying rate of cooling and solidification of the specimens in the various moulds.

Table 3. *Percentage Elongation of specimens cast in sand moulds Values.*

Additives	Additives (%)	Quenching		
		Water	Palm Oil	Engine Oil
	0	87.3	82.1	75.8
SDA				
	1.5	92.6	86.2	78.2
	4.5	96.1	88.1	81.2
	7.5	102.6	93.2	86.2
	10.5	101.1	89.5	84.5
GSA				
	1.5	95.1	89.4	83.2
	4.5	98.4	93.6	87.2
	7.5	105.8	96.1	91.2
	10.5	102.0	94.9	88.7
ESA				
	1.5	98.7	93.3	86.6
	4.5	102.4	97.4	90.3
	7.5	107.9	100.5	94.6
	10.5	105.2	98.2	94.1

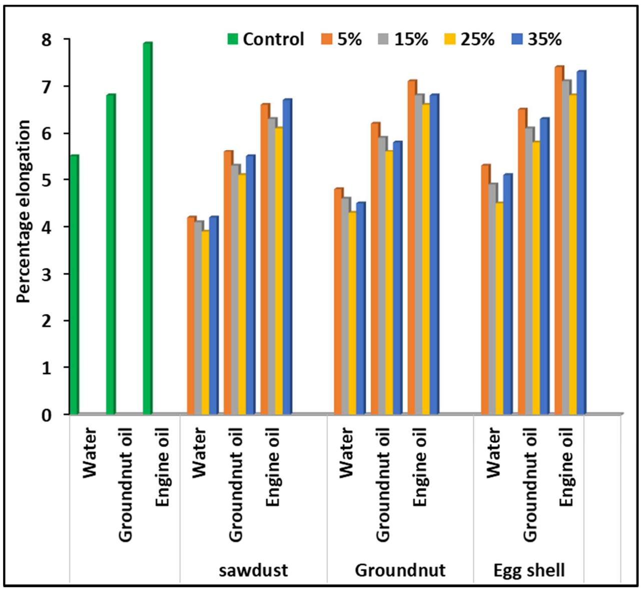

Figure 7. *Percentage elongation of aluminium alloy casted in sand mould with sawdust ash additive and quenched in different media.*

Furthermore, it could be noticed that for all the studied additives, the value percentage elongation decrease with an increase in mould additive percentage up to 25% added but increase again with a further increase in additive. This could also have been attributed to excess burnt grains in the surrounding cast specimen thereby improved the heat retention in the mould.

In general, the cooling rate of samples quenched in formulated quenchant oils influenced their tensile strength and percentage elongation, resulting in an overall decrease in percentage elongation, making the material less ductile than the as-cast material, as reported by Zaki [2], Kumar et al. [6], and Adebayo et al. [12]. However, it has been found that the quenching behaviour of all quenched samples is substantially impacted by the heat treatment quenching behaviour [17, 18].

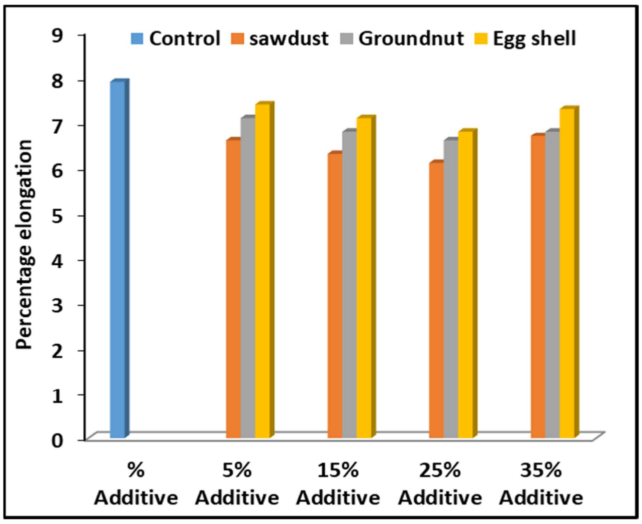

Figure 8. *Percentage elongation of casted aluminium alloy quenched in engine oil for various percentage of additives in the sand mould.*

4. Conclusion

The tensile strength properties of cast aluminium alloy produced through the addition of sawdust ash, groundnut shell ash, and eggshell ash to the sand mould and quenched in water, palm oil, and engine oil were investigated. The results showed that after quenching, all alloys show an increase in UTS and a decrease in percent elongation as the additive proportions increase. The quenched samples' characteristics (ultimate tensile strength and percent elongation) improved in the order of water > palm oil > engine oil, and engine oil, palm oil, and water, respectively. The results showed that the tensile strength and percentage elongation of cast aluminium alloy can be improved for different applications by varying the casting process through the use of agricultural waste products as additives in the sand mould to achieve good mechanical properties on cast aluminium alloy.

Further research work by the authors will be focus on the influence of other agriculture waste products as additives in green mould, and optimizations of the additives in the mould.

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