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Effect of Heat Treatment Process Parameters on Tensile Strength Properties and Hardness of the Recycled Aluminium Alloy

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ABSTRACT
The increase in the use of Aluminium (Al) components in different industries such as Automobile, Aerospace, building, electronics, cooking utensils, marine, beverages, construction, etc, has accounted for the high volume of Al scraps that littered the environment thereby causing seriou ecological problem in most developing countries like Nigeria. In this study, Al alloy produced from Al scraps through sand casting were heat treated to improve tensile strength and hardness characteristics. The Scraps were sourced from scraps market in Bauchi and casted into simple cylindrical shapes at the foundry workshop in Federal Polytechnic, Bauchi. Samples for chemical composition analysis, hardness and tensile strength tests were prepared according to the standard specification. The samples were heat treated at temperature range from room temperature to 500^{0}C; and holding time range from 2hours to 6hours. The result of the chemical analysis confirmed the recycled scrap as Aluminum alloy with high concentration alloying elements such as Silicon (Si), Copper (Cu) and Iron (Fe). The tensile strength and hardness of the recycled Al alloy at room temperature were determined as 232 MPa and 89 HRB respectively. Results showed decrease in tensile strength and hardness with increase in holding time and temperature. However, increased in percentage elongation and reduction in area was observed for the same temperatures and holding times. The recycled Al alloy can be used as a structural material for application that does not involve high temperature application.
***Key words**: Auminium alloy, temperature, holding time, tensile strength and hardness*

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I. Introduction

Secondary Al alloys are alloys that are produced by recycling Al scraps. Commercial Al alloys in use for structural applications in most developing countries like Nigeria are mostly imported (Datau et al, 2020). Due to the high cost of primary Al alloys, commercial Al alloys in use are secondary Al alloys. Many developed nations have been involved in the recycling of Al scraps for the purpose of packaging beverage such as sodas, energy drinks, sparkling waters, craft brew beers, etc. In 2016, Al industry reported a 73% in recycled Al compare to other recycled materials such as plastics and glass (Shakila, 2013; Jokhio *et al*, 2017). It is observed that Al scraps recycling in cans maintained a steady increased in countries like Brazil, Japan, Argentina, European and EUA as shown in figure 1 below (El-Zomor and Hany, 2013; Shakila, 2013).

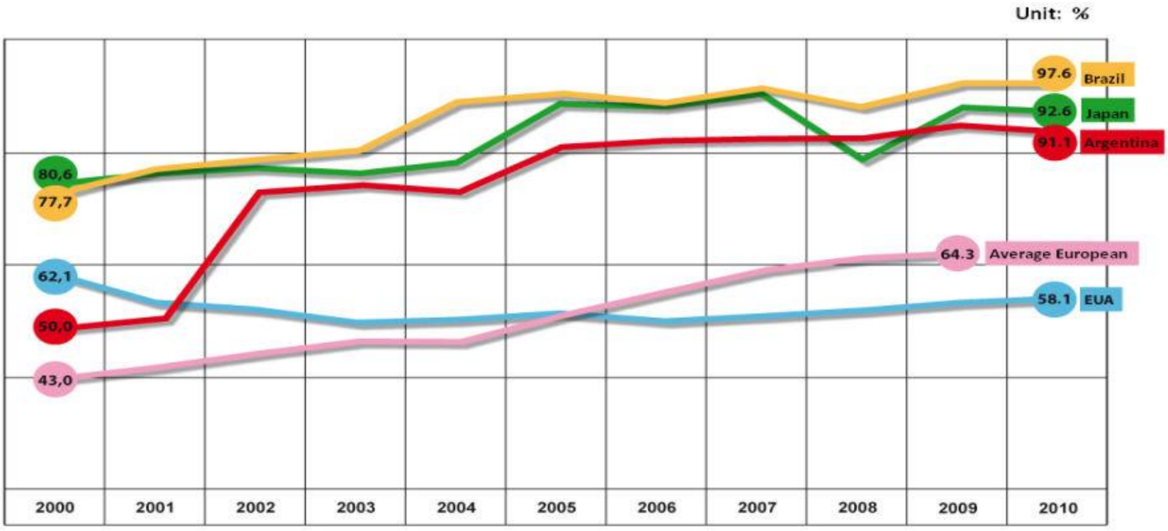

Figure 1: *Al recycling rate for for some countries between 2000 and 2010*

Source: (El-Zomor and Hany, 2013))

Recycling Al scraps is beneficial because it is cheap and has less environmental impact. Less energy is consumed and green house gas is emitted during recycling compare to producing the alloys from the raw materials (Datau et al, 2020; Shakila, 2013).

In Nigeria, one of the most valuable wastes in most waste bins are Al scraps such as beverage can scraps (Akindayo, 2019; Obi**,** 2016). Although, Al scraps exist in large quantity, the challenge remains recycling and treating the alloys to meet service requirements as structural materials.

Heat treatment is one of the important thermal treatments that is usually use as a finishing treatment during the fabrication of metal based materials (James, 1985). When properly designed and implemented, heat treatment can lead to substantial increase in mechanical properties due to changes in the distribution of phases in the microstructures of the metal alloys (Rajan et al, 1983; Novikov, 1978). Chemingui et al (2009) investigated the effect of heat treatment on the plastic properties and microstructure of Al-Zn-Mg Al alloy. Ageing of the Al-Zn-Mg alloy showed significant changes in the microstructure and mechanical properties. Ageing at 135°C, gave maximum value of hardness. Also, ageing at two stages (at 70°C plus at 135°C) led to increase in the yield strength and maintaining the ductility due to the high volume fraction of this precipitates.

Heat treatment is temperature-time dependent, so appropriate selection of heating and cooling rate is important in heat treatment (Khurmi, 1987). Different heat treatment types exist -annealing, normalizing, quenching, solid solution, carbonizing, nitriding, thermo-mechanical treatment, etc.

Annealing is type of heat treatment that is usually carried out to relieve build-in internal stresses and refine of grain size in produced metal alloys (James,1985; Higgin, 1974). Palkar et al (2017) investigated the effect annealing on the hardness, microstructure and corrosion behavior of a commercial 7075-T6 Al alloy rolled plate in the T6 temper with a thickness of 6mm and width 20mm at temperatures of 400^{o}C for 4, 8 and 12 hours The annealed samples (4, 8, & 12 hours) have a corrosion rate greater than the base metal and rate decreased monotonically with increase in time duration due to the possible passivation of the Al alloy. The micrographs of SEM revealed severe intergranular attack on the surfaces of the Al alloy specimens at high annealing time.

In this study, the effects of temperature and holding time on the tensile strength and hardness properties of the Al alloy recycled from Al scraps were investigated.

II. Material and Methods

2.1 Material/equipments

The materials and equipments used for this study include aluminium scraps, moulding sand, thermocouple, crucible furnace, heat treatment furnace, universal tensile tester, hardness tester

2.2 Experimental methodology

2.2.1 Preparation and heat treatment of specimens

The aluminium scraps were sourced from the scrap market in Bauchi metropolis in Bauchi L.G.A. The scraps were cleaned and melted in a gas - fired crucible furnace. A thermocouple was used to check the temperature of the melt in the furnace and at 750^{o}C, the melt was then poured into sand moulds to produce Al alloy castings cylindrical shapes. The casting was done in the Foundry workshop at the National Metallurgical Development Centre in Jos.

Using standard specifications, three (3) specimens each for the chemical composition analysis, tensile strength and hardness property tests were produced using a Lathe at the machine workshop of Abubakar Tafawa Balewa University, Bauchi. A total of thirty six (36) specimens were produced for the analysis and tests.
The machined specimens for tensile strength and hardness were heat treated in a furnance of capacity of 1400^{o}C. A set of specimens for tensile strength and hardness test was placed in the furnance and the furnace was set to a temperature of 200^{O}c at a heating rate of 200^{o}C per hour. The specimens in the furnace were held for 2 hours, 4 hours and 6 hours respectively. The specimens were allowed to cool in the furnance at a cooling rate 20^{O}C per hour. This procedure was repeated for temperatures of 300^{O}C, 400^{O}C and 500^{o}C.

2.2.2 Chemical Composition Analysis and Property Test
The equipments and the methods of carrying out the composition analysis and determining tensile strength properties and hardness of the recycled are discussed as follows:
i. Chemical composition analysis
The chemical composition of the recycled Al scraps was analyzed using optical emission spectrometry (OES). The chemical composition of the scraps is as presented in table 1.
ii. Tensile strength test.
A Universal testing machine (OLSEN TINUS, model 290 of capacity 300KN with a digital indicating system) was used for the tensile tests. Each specimen is mounted in the upper and lower grip of the machine and the load was then applied until the specimen fractured. The maximum extension and the ultimate tensile load were recorded. This was repeated for all the specimens produced at 200^{O}C, 300^{O}C, 400^{O}C, 500^{O}C and holding times of 2hours, 4hours, 6hours. Also, the final length and diameter of the specimen after fractured neck were measured using a vernier caliper. The ultimate tensile strength, percent elongation and percent reduction in area were determined using equations 1, 2 and 3 for each specimen. The results are as presented in tables 2, 3 and 4 respectively. Again, the tensile strength properties and hardness of the as-cast specimens were determined and are as presented in table 5.

iii. Hardness test
The equipment that was used for the hardness test was Frank hardness tester, model Wellest 38506. The Rockwell hardness test method was used. The specimen of disc shape was placed flat base and the load applied at 3 different positions on the specimen. The 3 values of the hardness were recorded and their average value determined as presented in table 5.

III. Results and Discussion

3.1 Results
The chemical analysis, tensile strength properties and hardness of the heat treated of recycled Al alloy are presented in tables 1, 2, 3, 4 and 5 below.

Table 1 Chemical composition of recycled Al scraps (%)

Al	Si	Cu	Fe	Mg	Mn	Zn	Ti	Ni	Pb
Balance	4.93	0.86	0.56	0.62	0.13	0.07	0.024	0.006	0.008

Table 2 Tensile and hardness characteristics at room temperature

Tensile Strength (N/mm^2)	Hardness (HRB)	Elongation (%)	Reduction in area (%)
232.36	89.00	2.60	1.17

Table 3 Tensile and hardness characteristics at holding time of 2 hours

Temperature (^{O}C)	Tensile strength (N/mm^2)	Hardness (HRB)	Elongation (%)	Reduction in area (%)
200	212.36	21.20	4.60	3.17
300	180.21	17.90	1.76	9.34
400	147.56	14.00	2.56	11.00
500	108.24	10.02	3.20	10.41

Table 4 Tensile and hardness characteristics at holding time of 4 hours

Temperature	Tensile strength	Hardness	Elongation	Reduction

(^{O}C)	(N/mm^2)	(HRB)	(%)	in area (%)
200	114.08	15.02	1.92	1.59
300	97.78	9.60	2.44	3.17
400	65.19	5.80	7.56	4.75
500	40.08	1.80	8.16	5.83

Table 5 Tensile and hardness characteristics at holding time of 6 hours

Temperature (^{O}C)	Tensile strength (N/mm^2)	Hardness (HRB)	Elongation (%)	Reduction in area (%)
200	99.22	10.21	2.20	5.90
300	70.25	6.32	3.25	10.83
400	40.02	3.84	4.56	14.81
500	19.81	2.01	5.14	17.93

3.2 Discussion of results

3.2.1 Chemical compositions of the recycled Al scrap.

The chemical composition of the recycled Al scraps is as presented in table 1. The composition shows that it is a Al-Si-Cu Al due to the high concentrations of Silicon (Si) and Copper (Cu) when compared to other alloying elements. The high concentration of Al further confirmed the recycled scrap to be an alloy of aluminium. This shows that the recycled scraps can be used as a structural material in applications requiring high thermal conductivity and corrosion resistance, and light weight.

3.2.2 Effect of temperature on tensile strength properties and hardness

From the results shown in tables 1, 2, and 3 and figures 1, 2, 3 and 4; it is observed that increase in temperature brings about decrease in tensile strength and hardness but increase in percentage elongation and reduction in area. For example an increase temperature from 200^{O}C to 300^{O}C and 400^{O}C, and at the holding time of 2hours, the tensile strength decreases from 212.36N/mm^2 to 180.21N/mm^2 to 147.56N/mm^2 respectively as shown in figure 1. The hardness on the other hand decreases from 21.20HRB to 17.90HRB and 14.00HRB as indicated in figure 2.

Also, the uniform percentage elongation for example increases from 1.92% to 2.44% and 7.56% at temperatures of 200^{O}C, 300^{O}C and 400^{O}C respectively as shown in table 2 and figure 3. The percentage reduction in area also increases from 1.59% to 3.17% to 4.75% at temperatures 200^{O}C, 300^{O}C, and 400^{O}C respectively at holding time of 4hours as shown in table 2 and figure 4. This could be as a result of the increase in ductility due to the refinement of the crystals (Das et al, 2006, Khurmi et al, 1987.)

Effect of holding time on tensile strength properties and hardness

From tables 1, 2, and 3, an increase in a holding time from 2hours to 4hours to 6hours at temperature 300^{O}C for example, the tensile strength decreases from 180.21N/mm^2 to 97.78N/mm^2 to 70.25N/mm^2. The hardness also decreases from 17.90HRB to 9.60HRB and 6.32HRB respectively. This could be as a result of the reduction in the density of dislocation, and elimination of the effect of strain-hardening (Khurmi et al, 1987).

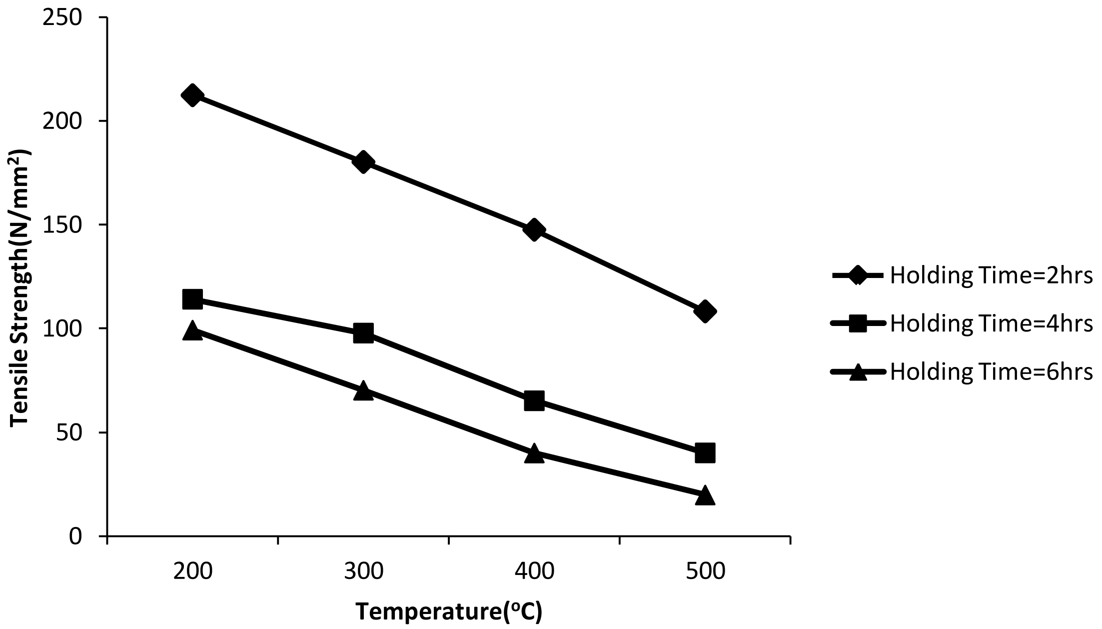

Fig.1: Tensile strength versus temperature for different holding time

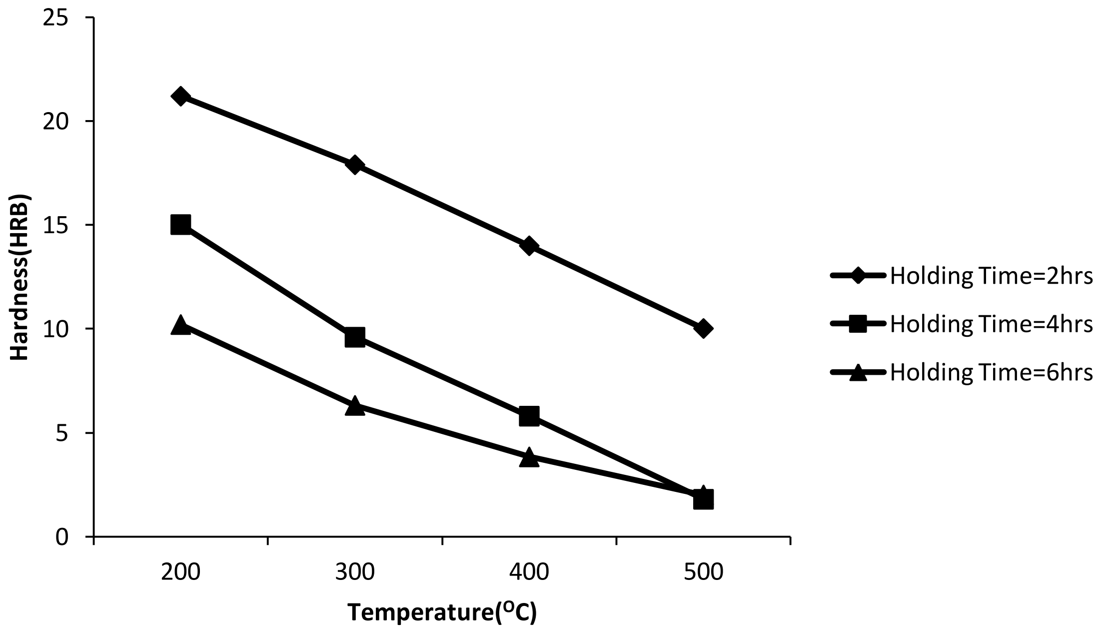

Fig. 2: Hardness versus temperature for different holding time

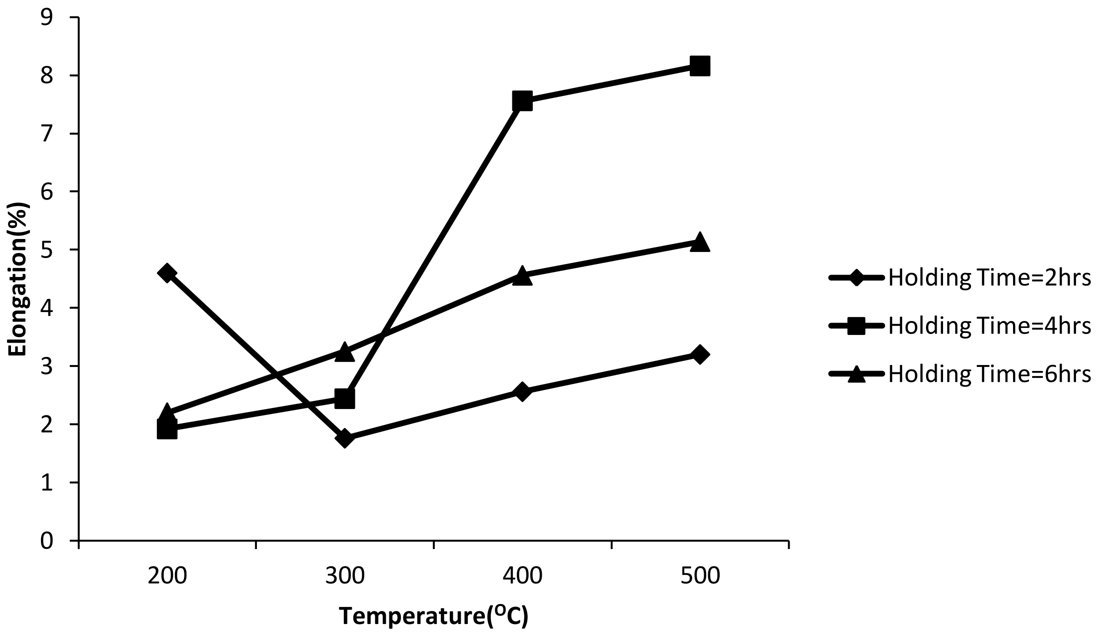

Fig.3: Elongation versus temperature for different holding time

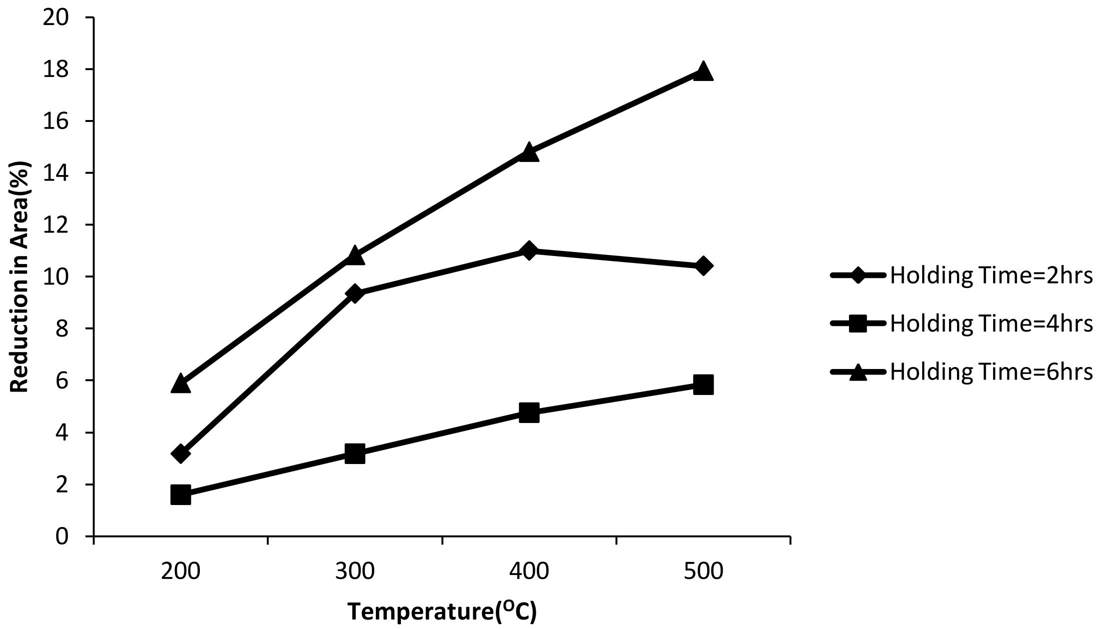

Fig. 4: Reduction in Area versus temperature for different holding time

IV. Conclusion

The following conclusions were made from this study:

i. The ultimate tensile strength, percent elongation, percent reduction in area and hardness of the as-cast recycled Al scraps were obtained as 232.36 MPa, 2.6%, 1.17% and 89 HRB

ii. The chemical composition showed that the recycled scraps is Al-Si-Cu Al alloy because of the high concentrations of Si and Cu compared to other elements in the alloy

iii. It is observed that increase in annealing temperature and holding time has led to decrease in the ultimate tensile strength and hardness while percentage elongation and reduction in area increased. The maximum percentage elongation of 8.6% occurred at 470^{O}C while its minimum value of 1.7% occurred at 330^{O}C at holding time of 4hours

iv. The recycled Al alloy can be used in applications where high temperature is not a measure requirement.

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