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EFFECTS OF HEAT TREATMENT ON THE STRENGTH AND HARDNESS OF HOT ROLLED 2SR, 3SR AND 8SR ALUMINIUM ALLOYS

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ABSTRACT: *This paper examines the effects of selected heat treatment processes on the strength and hardness of hot rolled aluminium alloys, namely 2SR, 3SR and 8SR. Three heat treatment processes – annealing, solid solution heat treatment and precipitation heat treatment, are carried out on the alloy samples and their effects on the samples are evaluated by subjecting the samples to tensile and hardness tests before and after heat treatment. The results indicate an increase in hardness with 2SR aluminium alloy after annealing and solution heat treatment processes, and a drop in this property upon subjecting the sample to precipitation annealing, implying that the 2SR aluminium alloy can be better hardened by both annealing and solution heat treatment processes. On the other hand, precipitation heat treatment softens the alloy. This trend is equally applicable to 8SR sample but with a total deviation from this trend with 3SR sample, in which hardness decreases with each heat treat process. The results also suggest aluminium alloys 2SR and 8SR can be better hardened by both annealing and solution heat treatment processes and softened by precipitation hardening. However, 3SR alloy cannot be hardened by any of the heat treatment processes.*

KEYWORDS: Heat Treatment, Aluminium Alloy, Strength, Hardness, Materials Properties

INTRODUCTION

Aluminium and its alloys have good electrical and thermal conductivities, low density, high ductility and good corrosion resistance. They are widely used in many industrial applications, especially for automobiles, aviation, household appliances, containers, electronic devices and food industry (Capauano and Davenport, 1971; Fellener et al, 1981; Yang, 1994). But like all pure metals, aluminium has low strength and cannot be readily used in applications where resistance to deformation and fracture is essential. Therefore, other elements are added to aluminium primarily to improve strength. The low density with high strength has made aluminium alloys attractive in applications where specific strength (strength-to-weight ratio) is a major design consideration (Segun, 2013).

However, the electrical, magnetic, structural, physical and mechanical properties of aluminium and its alloys can be changed through heat treatment. As the applications of metal are varied, different environments prioritize different qualities. For example, in engineering applications, toughness is desired; in electrical applications, low electrical resistivity is important. There are a number of ways of heat-treating metals which are commonly used to transform these properties. The temperature to which the metal is heated and the rate of cooling of the metal are carefully controlled to achieve the desired outcome (MS, 2015; Nwigbo, 2016). Heat treatment refers to an operation or a combination of operations, which involves heating a metal or alloy in its solid state at a prescribed rate to a predetermined temperature, followed by holding at this temperature long enough for structures to stabilize, followed by cooling at a prescribed rate with the object to obtain desired properties (Nwigbo, 2016).

Current investigations connected with the improvement of mechanical properties of aluminum alloys pertain mostly to the advancement in selection of alloy additions methods, using contemporary acquired knowledge of the synthesis of alloys, the improvement in selection of complex modifiers, the reduction of quantities of the hydrogen and gaseous porosity, the reduction of non-metallic impurities, the development and the implementation of modern heat treatment technology (Wang and Chang, 1996; Adler et al, 1986). For instance, addition of Mg in Al-Si-Cu alloys accelerates and intensifies hardening process of the alloy (Sanjay and Ajay, 2014). In view of this, many researchers (Sanjay and Ajay, 2014; Liu et al, 2003; Majidi et al, 2007) have developed aluminium alloy composites that would provide desirable mechanical and physical properties. Composite materials can be selected to give combination of properties such as stiffness, strength, high temperature performance, corrosion resistance, hardness, conductivity etc (Sanjay and Ajay, 2014)

Other researchers (Yang, 1994; Cavaliere et al, 2005; Sjölande and Seifeddine, 2010) concentrate on materials properties modification and improvement through series of heat treatment cycles. The modified or improved properties are then evaluated by mechanical and metallurgical methods and other viable methods depending upon the materials properties in focus. Numerous studies on heat treatment parameters were already performed for the Al-Si-Cu alloys, both with and without addition of Mg (Pezda, 2010a; Pezda, 2010b; Cavaliere, 2005).

At the moment, tests for mechanical properties are undertaken in accordance with standards and codes devised by different institutions such as the American Society for Testing and Materials (ASTM) and the British Standards Institution (BSI). To carry out these tests on non-uniform materials, various techniques and recommendations were suggested for preparing and evaluating the results (MT, 2015).

The aim of this study however, was to examine the influence of heat treatment on tensile strength and hardness of aluminium alloys. The mechanical properties at different heat treatment temperatures are compared with those evaluated with non-heat-treated specimens.

MATERIALS AND METHODS

Three different grades of hot rolled aluminium alloys (Composition given in Table 1), obtained from First Aluminium Nigeria Limited, Port Harcourt, were used to analyze the influence of heat treatment processes on the mechanical properties of the aluminium alloys. The materials and equipment used in the experimental phase include hack saw, venier calipers, lathe machine, muffle furnace, Rockwell hardness testing machine, extensometer, etc.

Table 1: Composition of Samples

Alloy	Cu [%]	Mg [%]	Si [%]	Fe [%]	Mn [%]	Zn [%]	Ti [%]	Al [%]
8SR	0.05	0.01	0.44	0.81	0.90	0.06	0.01	98.87
3SR	0.05	0.01	0.41	0.64	0.12	0.07	–	98.65
2SR	0.04	0.11	0.39	0.74	–	0.06	–	98.59

Mechanical Testing

The specimens in hot rolled and heat-treated condition were tested for tensile strength and hardness before and after heat treatment. The ultimate tensile strength (UTS) and yield strength (YS) were evaluated on computer-controlled extensometer (Electron Universal testing machine, Model: WDW - 05) at Metallurgical and Materials Engineering Laboratory, Federal University of Technology, Owerri, Nigeria. Hardness was evaluated on Rockwell hardness tester.

Hardness Test**:** The control and the heat-treated samples were subjected to hardness test using Rockwell hardness tester. To start the test, the indenter is "set" into the sample (polished and mounted on the machine using a dwell time of 15 seconds) at a prescribed minor load. A major load is then applied and held for a set time period. The force on the indenter is then decreased back to the minor load. The Rockwell hardness number is calculated from the depth of permanent deformation of the indenter into the sample, i.e. the difference in indenter position before and after application of the major load (ASTM, 2016).

Tensile Test**:** The test is made by gripping the ends of a suitably prepared standardised test piece (Figure 1) in a tensile test machine and then applying a continually increasing uni-axial load until such time as failure occurs (Pezda, 2014; ASTM, 2016). The *tensile strength*, also known as the *ultimate tensile strength*, is estimated by dividing the load at failure by the original cross-sectional area where the ultimate tensile strength (UTS) occurred as (Colley et al, 2011)

$$\boldsymbol{\sigma_{max} = p_{max} / A_o} \quad (1)$$

where P_{max} = maximum load (N) and, A_0 = original cross-sectional area (m^2).

The *yield stress* (YS), the stress at which deformation changes from elastic to plastic behavior, ie below the yield point unloading the specimen means that it returns to its original length, above the yield point permanent plastic deformation has occurred, is estimated using the relation (Wang et al, 2006),

$$\boldsymbol{\sigma_y = P_{yp} / A_o} \quad (2)$$

where P_{yp} = load at the yield point (N).

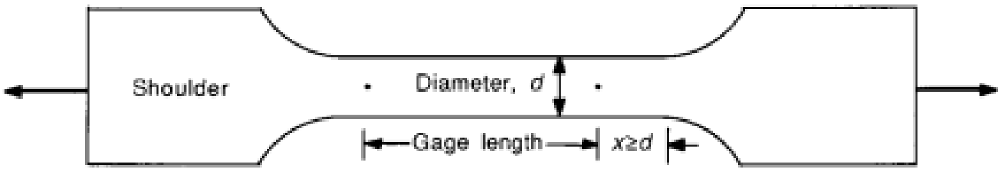

Figure 1: Tensile Test Specimen

Heat Treatment

All three grades of the samples (pretested for hardness and strength) were subjected to annealing, solid solution heat treatment and precipitation heat treatment. The heat treatment processes were carried out using Muffle furnace model MFL – 2000. For annealing, test samples of the three grades of alloys were heated to 360^0 C, followed by holding for 3 hours and then cooled in still air. For solid solution heat treatment, test samples of the three grades of alloys were heated to 540^0 C, followed by holding for 3 hours and then quenched in water. In precipitation heat treatment, three samples of each grade which have already undergone solid solution heat treatment were heated to 230^0 C and held for 5 hours, then cooled in still air.

RESULTS AND DISCUSSION

The results of the mechanical tests performed on the samples before and after heat treatment processes are given in Tables 2 & 3 and graphically represented with Figure 2.

Table 2 Rockwell Hardness Test Result

Alloy condition	**Hardness HR [kg/mm^2] for:**		
	2SR	**3SR**	**8SR**
Before heat treatment (Control)	63.0	70.0	62.0
After annealing	68.0	63.5	58.0
After solution heat treatment	68.0	62.5	64.5
After Precipitation heat treatment	57.0	61.0	57.0

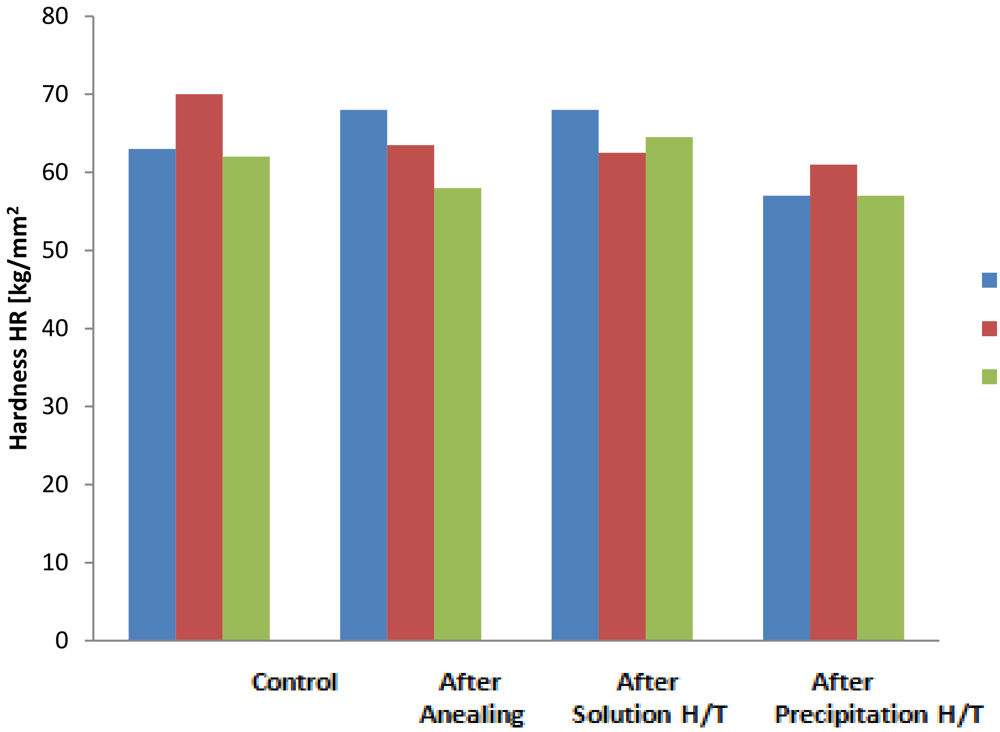

Figure 2: Variation of Hardness with Heat Treatment Process

Table 3 Tensile Test Result

Properties	**Before Heat Treatment (Control)**			**After Annealing**			**After Solution Heat Treatment**			**After Precipitation Heat Treatment**		
	2SR	**3SR**	**8SR**	**2SR**	**3SR**	**8SR**	**2SR**	**3SR**	**8SR**	**2SR**	**3SR**	**8SR**
YS [N/mm²]	101	106	86.60	91.70	106	96.79	66.23	50.94	66.22	66.22	71.32	56.03
UTS [N/mm²]	112.07	122.26	101.88	96.79	112.07	101.88	71.32	66.23	76.41	71.32	76.41	66.22

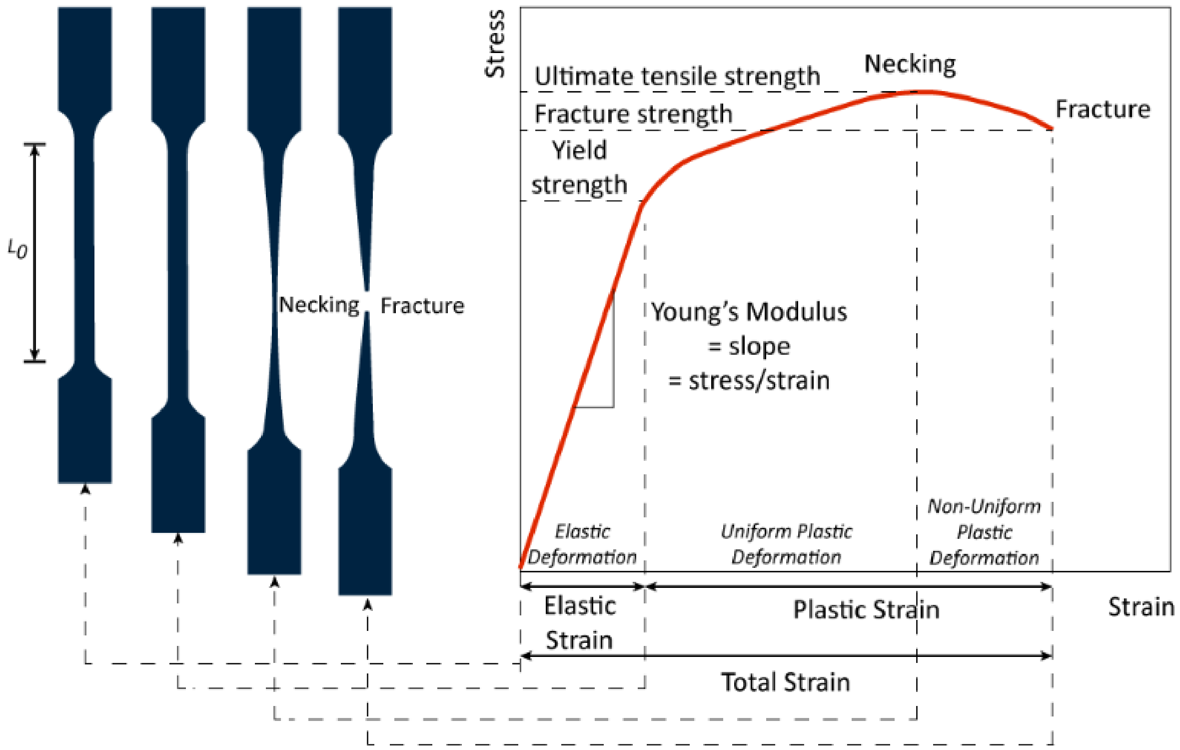

Figure 3: The Shape of a Specimen Changes During Tensile Testing

Table 2 and Figure 2 present the hardness values for the three alloy samples before and after heat treatment as determined on Rockwell hardness tester. The results indicate an increase in hardness with 2SR aluminium alloy after annealing and solution heat treatment processes, and a drop in this property upon subjecting the sample to precipitation annealing. This suggests that the 2SR aluminium alloy can be better hardened by both annealing and solution heat treatment processes. On the other hand, precipitation heat treatment softens the alloy. This trend is equally applicable to 8SR sample, but with a total deviation from this trend with 3SR sample, in which hardness decreases with each heat treat process. This might be caused as a result of the absence of tin in the alloy. The yield strength (YS) decreases significantly for all samples after each heat treatment cycle except for 3SR sample which remains unchanged after annealing (Table 3) which indicates that the alloy had approximately good thermal stability (Fallahi et al, 2013). The ultimate tensile strength (UTS) of the samples equally decreases significantly after each heat treatment cycle (Table 3). These results suggest that the strength and hardness properties of the aluminium samples are generally not improved by the various heat treatment processes employed.

CONCLUSION

The strength and hardness properties (mechanical properties) of 2SR, 3SR and 8SR aluminium alloys can be altered through various heat treatments processes. Aluminium alloys 2SR and 8SR can be better hardened by both annealing and solution heat treatment processes and softened by precipitation hardening. However, 3SR alloy cannot be hardened by any of the heat treatment processes. Heat treatment remains one of the methods employed for improving desirable properties of engineering materials.

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