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THE EFFECT OF THERMOMECHANICAL AGEING OF ALUMINIUM–COPPER ALLOY (MATLAB APPROACH)

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Abstract

The influence of thermomechanical ageing on the mechanical properties of Al-Cu alloy has been investigated. The alloy contains 4.23% of Cu, and was produced by casting process. The casting was warm worked between 0.3Tm-0.5Tm at various temperatures ranging from 300-560^{O}C at 5%, 10%, 15%, and 20% deformation respectively. The results showed that the mechanical properties in terms of hardness, tensile and toughness were improved with increasing percentage at a higher temperature. This was due to the progressive close-up of the voids emanating from casting sample by increasing deformation which is evident from the micrographs. It was concluded that thermo mechanical ageing is beneficial to the mechanical properties of Al-Cu alloy.

Introduction

The problem of safe vehicle design with maximum impact energy absorption is a significant subject in structural crash worthiness design [1]. All engineering designs are expected to ensure the safety of users' life. This informed several studies meant to probe the causes of component failures in equipment, vehicles, and aerospace design and decide on appropriate solutions through materials selection techniques. A common example is in the design of crankcases and heads, piston, and cylinder blocks. As with engine blocks, cylinder heads can be made of Cast Iron or Aluminium Alloy. A head made of Aluminium alloy is lighter in weight than if it were made of Cast iron [2].

In this work, the quest is to study the influence of thermo mechanical ageing on Aluminium alloy in which Aluminium is the principal element (parent metal) with traces of other elements such as Copper, Magnesium, Iron, and Zinc . Aluminum is subject to internal stresses and strains when it is overheated; the tendency of the metal to creep under these stresses tends to result in delayed distortions. The warping or cracking of overheated Aluminium automobile cylinder heads is commonly observed [3]. Thus, the aerospace industry avoids heat altogether by joining parts with adhesives or mechanical fasteners. The efficacy of Aluminum-Copper alloys lies in the inclusion of Copper in a range of 4-5% concentration. This formation of intermetallic phases together with the temperature-dependency of copper's solubility is the reason for Al-Cu being heat treatable.

The general requirement for precipitation strengthening of supersaturated solid solutions involves the formation of finely dispersed precipitates during aging heat treatment (which may include either natural aging or artificial aging [4]. The aging must be accomplished not only below the equilibrium solvus temperature, but below a meta-stable miscibility gap called the Guinier-Preston (GP) zone solvus line [5].

Aim and Objectives

The aim of the research is to develop a non-ferrous Aluminium alloy material locally, hat is a capable of competing with ferrous materials in service. This could be achieved by:

(i) Employing a suitable precipitation strengthening and age-hardening heat treatment process with specified parameters (time, temperature and furnace atmosphere).
(ii) Studying the effect of overheating on solution-treated and quenched alloy on its microstructure and hardness.

(iv) Examining the microstructures with relevance to, impact strength, tensile and yield strength.

Contribution to Knowledge

The work had helped to discover Aluminum –Copper alloy as an alternative material where strength-weight ratio and corrosion resistance are the required properties. The introduction of a mathematical model- $f(x) = P_1X^2+P_2X +P_3$ in form of MATLAB

[6] threw light into the extent of percentage deformation in variation to temperature limit. It is expected that it will bring about a new approach capable of determining the plastic deformation range in variation with working temperature.

Materials and Methodology

This work was conducted with the following four-principal approaches:

(a) Production of Al-Cu Alloy sample locally sourced from Al scrap, and Copper scraps with Aluminum alloy scraps in a Crucible furnace using Aluminium billet 9kg (base element) and 3.5%(≈.3326kg) wt Copper coils through Sand Casting.
(b) Obtain the alloy in an ingot–rod form
(c) Warm worked at 300-400^{O}C
(d) Solution treatment and aging with the following steps **:**

(i) the $CuAl_2$ phase is dissolved in the matrix, at 550°C
(ii) The alloy was quenched to room temperature to retain the solid solution formed at high temperature and soaked at150°C for 24 hours
(iii) following the quench, the alloy was aged naturally (i.e., held at room temperature) or aged artificially by heating at a relatively low temperature (93°C-204°C),but 165°C was employed in this work.
(e) Cut two samples each for tensile ,impact specimen samples
(f) Carry out the metallographic tests , by picking 2 tested samples each
(g) Performance evaluation


Plate 1

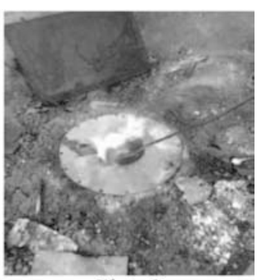
Plate 2

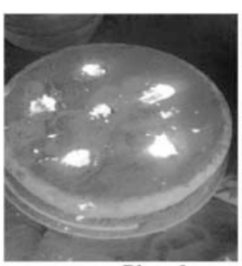
Plate 3


Plate 4

Plate 1: Al scrap, copper and Al billet

Plate2: Scrap mixture under heating in an Earth furnace

Plate 3: Cavities made ready for melt pouring

Plate 4: Solidified AlCu rods

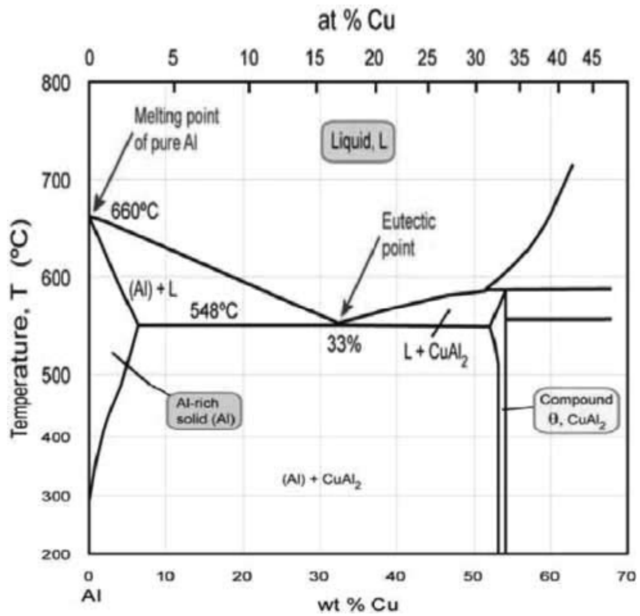

Fig.1: Phase diagram for part of the(Al-4.23Cu) Alloy system [7]

Results

Table I: Spectrochemical Analysis for Al-4.23Cu alloy at Aluminium Rolling Mill ,Otta, Nigeria

Run	Mg	Si	Mn	Cu	Zn	Ti	Fe	Na	B	Sn	Pb	Al%
1	0.9601	0.45592	0.67306	4.00972	0.80938	0.14931	0.741426	0.00093	0.00055	0.03342	0.10042	92.07
2	0.79060	0.47548	0.74361	4.06559	0.87384	0.1160	0.78992	0.00044	0.00053	0.03356	0.12608	91.98
3	0.77462	0.54733	0.65580	4.63990	0.91591	0.12608	0.77580	0.00333	0.00063	0.04245	0.12152	91.39
Av	0.84177	<0.4929	0.6908	4.2384	0.8663	0.3073	0.7690	0.00156	0.00057	0.03649	0.11605	91.63

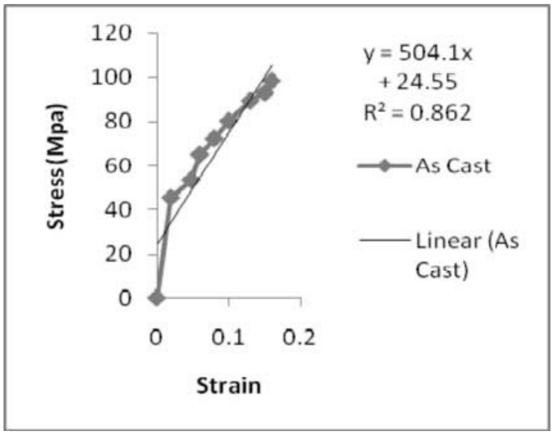

Fig.2:Stress (MPa)-Strain variation of as-cast

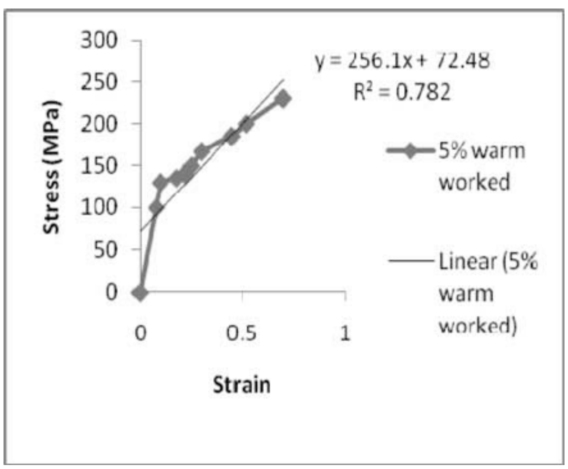

Fig.3:Stress (MPa) -Strain variation of 5% deformed AlCu

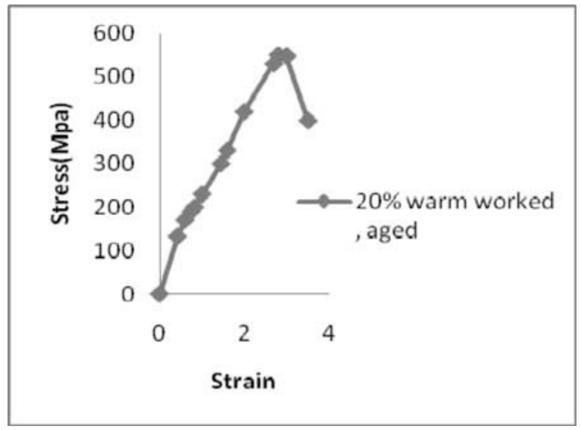

Fig. 4:Stress(MPa)-Strain Variation at 20%warm-worked, aged

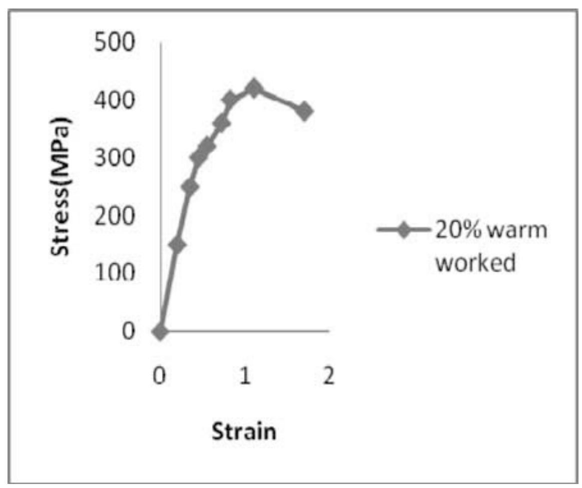

Fig. 5:Stress(MPa)-Strain variation at 20% warm-worked –worked

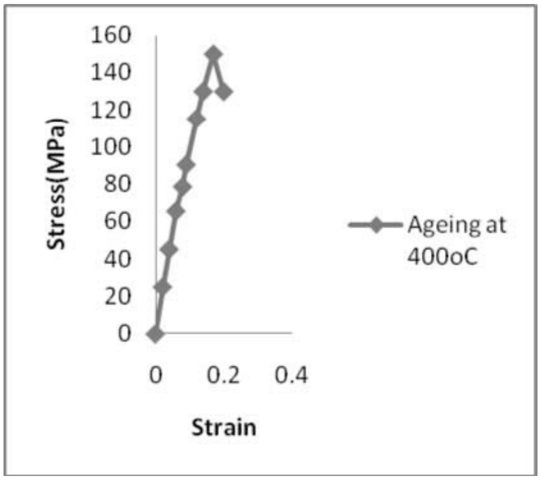

Fig.6: Stress(MPa) - Strain Variation at 20% *warm-Worked ana over heated*

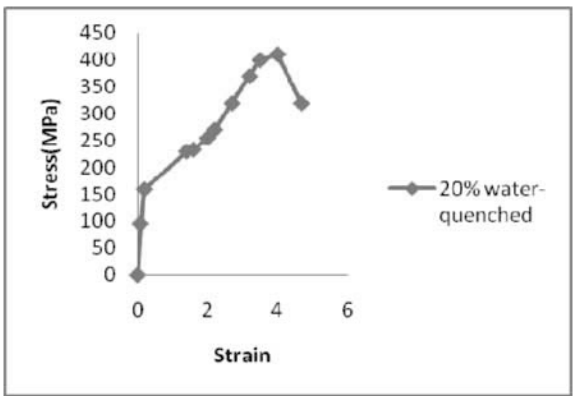

Fig 7: Stress(MPa) – Strain Variation at 20% deformed and *water- quenched*

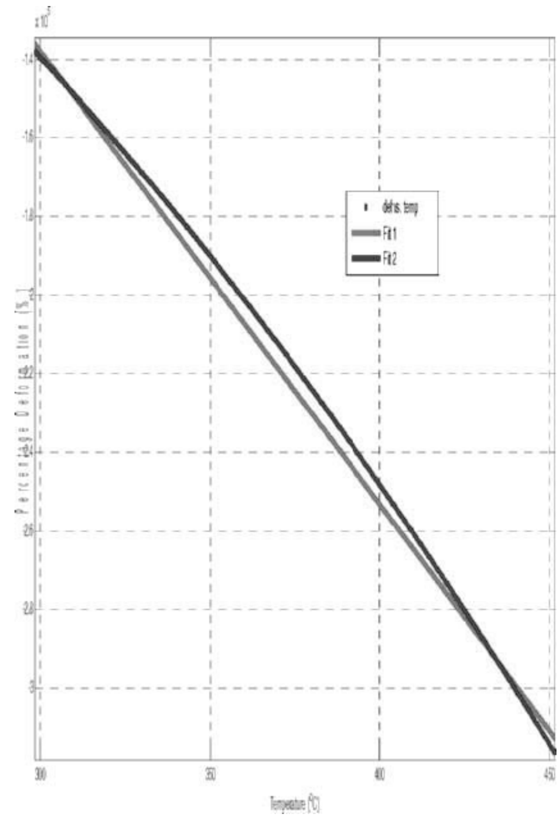

Fig. 8: Variation of Percentage Deformation (%) with Temperature (^oC)

Linear model Poly2: f(x) = p1*x^2 + p2*x + p3

Coefficients (with 95% confidence bounds):

p1 = -1.555 (-1.555, -1.555)

p2 = 1.433 (1.433, 1.433)

p3 = 90 (90, 90)

Goodness of fit:

SSE: 8.979e-020; R-square: 1; Adjusted R-square: 1 ; RMSE: 1.73e-010

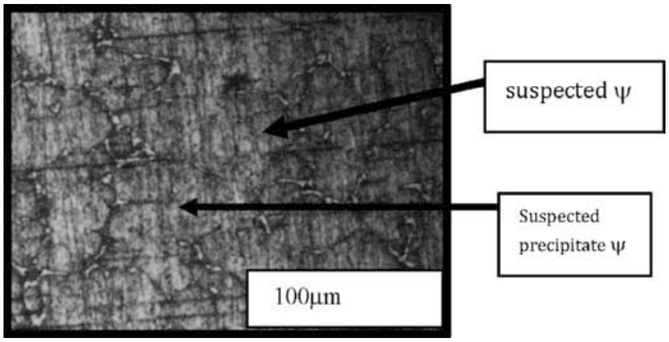

Plate 5: As cast (Al Cu) x 100 mag.

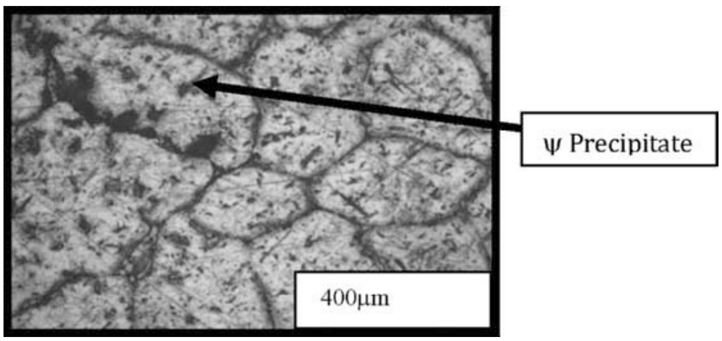

Plate 6: 20% deformation Al-Cu x 100 mag.

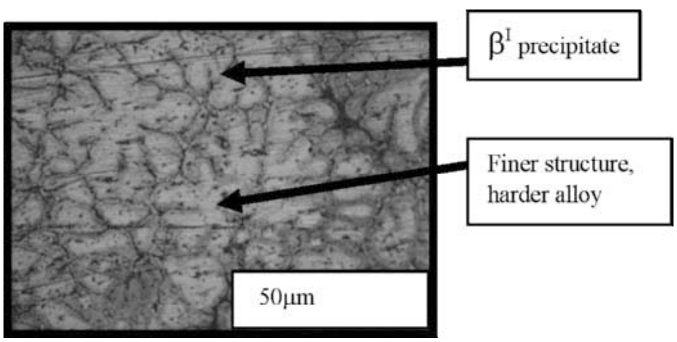

Plate 7.: 15% deformation (AlCu) water –quenched a t 320°C (x 100 mag)

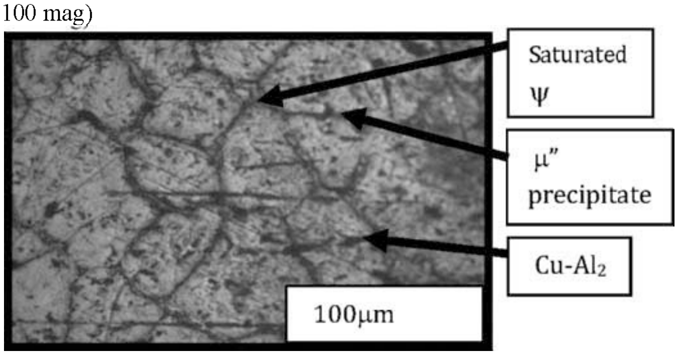

Plate 8.: 15% deformation(AlCu) Aged at 165°C for 6 hours x 100mag

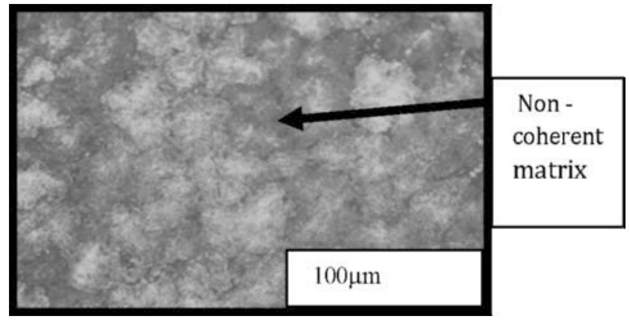

Plate 9: Overheated sample non- coherent matrix.

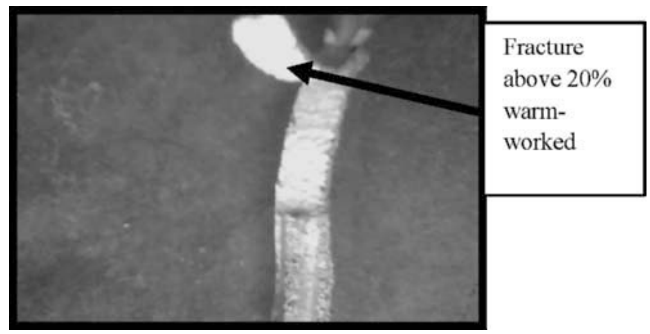

Plate 10: Fractured sample above 20% deformation

Discussion

From Fig.1 the Strength of As-Cast recorded 98.5 MPa but with low ductility of 10% and percent Area Reduction of 15.98%. This was enhanced to 550 MPa when aged and warm worked. This could be as a result of sparse distribution of suspected precipitates of ψ [8]. This is evident from the microstructure (Plate 8,Fig.4). It is however, important to mention that , the application is only limited to where loads of 1/3 of its Ultimate Strength can only be useful. There is a wide gap in the mechanical properties when the alloy was cooled rapidly rather than at ambient condition. During rapid cooling the alloy was water-quenched to allow the formation of a θ precipitates with a coherent lattice structure. The unbroken continuity led to coherency (Plate 7, Fig.7). Since, the rate of diffusion is slow, a separate β structure could not form rather, an intermediate β^I and α matrix led to a distortion in the □ -lattice in the neighbourhood of these nuclei. This distortion hindered the movement of dislocations and so the strength and hardness increased. This accounted for the UTS of 420.7MPa compared to as-cast sample which recorded half to one-third of the strength.

However, at ageing condition, Cu atoms segregate by diffusion to form Copper rich zones called Guinner –Preston (GP Zone 1). This increased with further growth at 165°C to produce a GP zone 2 where a μ" precipitate phase was formed. This produced a stronger effect as the precipitates generate stresses that helped in preventing dislocation movement.
This accounted for the variation between the Al-4.23 Cu (as-cast) when tested on the UTM and when heated to 165°C as a result of rapid diffusion at a higher temperature. As cast recorded 98.5 MPa with no precipitate formation, while at 165°C in 6 hours ageing the Alloy recorded 550MPa at 20 percent deformation(Plate8,Fig.4). This inferred that ageing and percent

deformation (mechanical) have the tendency of increasing the strength of Al-4.23Cu alloy.

Conclusion and Recommendation

A combination of load (mechanical) and heat treatment introduce a tremendous improvement to the strength of Al-4.23 Cu alloy required for piston in automobile. This was a result of finer precipitates of $CuAl_2$ and ψ obtained. It could be discovered that the properties required for a high performance Al-4.23 Cu could only be determined by the treatments at higher temperature, deformation , and time. The varying percentage of deformation at varying temperature conditions as 300^{O}C to 400^{o}C also played a major role in ascertaining the extent to which the material can be loaded with increasing temperatures. This was further substantiated by the MATLAB technique.

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