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Characterization of Tensile Properties in Thermal Modified Cu-Ni Content Al-Si Hypoeutectic Alloy under Different Strain Rates

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Abstract

This paper focuses on a typical Cu-Ni content Al-Si hypo-eutectic alloy to characterize its tensile properties and fractographic appearance at various strain rates after tensile rupture. Evaluation of tensile strength, yield strength and ductility at the three strain rates (0.0001, 0.001 and 0.01s^{-1}) showed that strain rates affect the above properties and fracture behavior significantly. The material strength obviously increases with the increase of the strain amplitude where ductility reduces. The tensile fracture surfaces mainly exhibit the dimples and shear type dimples pattern under the low strain rates. Ordinary trans-crystalline cleavage (facets, quasi-cleavage) and brittle fracture is observed under high strain rates.

Keywords: Tensile properties, strain rate, SEM.

1. Introduction

Good forge and machinability, corrosion resistance and high strength-to-weight ratio make heat treatable aluminium alloys suitable for various crucial applications in the automotive industry, such as engine blocks, pistons and cylinder heads. The mechanical properties of Al alloys containing Si, Cu, Mg has been found to depend on distribution and shape of the silicon particles. The strengthening of these alloys during age-hardening has been attributed to the precipitation of Mg and Cu-rich phases [1-3].
Addition of Cu to Al-Si alloys leads to the formation of Al_2Cu phases and other intermetallic compounds, which influences the strength and ductility [4]. In high copper content alloys, complete dissolution of the Al_2Cu phase is sluggish and a longer time must be chosen to allow maximum dissolution of this intermetallic phase. However, solution treating the alloy for a long time is expensive and may not be necessary to achieve the optimum strength. Moreover, prolonged annealing can lead to the formation of porosity and it has been shown that porosity deleteriously affect the mechanical properties [5]. For Al–Si–Mg alloys, the age hardening is caused by the precipitation of β'' and/or β' phases (precursor of Mg_2Si phases) [6-7]. For Al–Si– Mg–Cu alloys, the precipitation behaviors are rather complicated and several phases such as β (Mg_2Si), θ ($CuAl_2$), S ($CuMgAl_2$) or Q ($Cu_2Mg_8Si_6Al_5$) in metastable situations may exist [8-9].
A lot of works on the microstructure, heat treatment and mechanical behavior of Al-Si-Mg-Cu alloys have been done. The major advantages of Cu addition are increase in strength and hardness, both in the as-cast and in the heat-treated condition. Addition of Cu also affects corrosion resistance and ductility. Nickel is almost insoluble in aluminium (nickel solubility is about 0.05 weight % at 640ºC, and less than 0.005 weight % at 450ºC). The adding of nickel up to 2 weight % increases the strength of aluminium, but reduces its ductility [10]. Addition of Ni leads to the formation of Al_3Ni in the aluminum matrix through eutectic reaction during solidification. In previous works Ni was identified to significantly enhance the high-temperature performance of Al-Si foundry alloys, though just to a certain level, depending on the fraction of eutectic phase in the alloy. Ni stabilizes the continuity of the eutectic network by increasing the volume fraction of rigid phases (Si + Al_3Ni) in the eutectic [11-15]. The mechanical properties of Cu and Ni content Al-Si-Mg alloys showed their optimum properties at 200-225ºC for 1 hr ageing [16-17].
Results of tests on aluminium alloys at different strain-rate levels have been reported by a number of investigators. At room temperature, a very low, yet slightly positive, increase in flow stress with strain rate [18].

Similar observations regarding rate sensitivity of AA7003-T79 and AA7108-T6 alloys in tension have been reported [19]. Flow stress and fracture strain of AA6005-T6 alloys were shown to have rather strong positive strain-rate sensitivity [20].
The aim of this paper is to characterize the tensile properties in thermal modified Al-6Si-2Cu-2Ni alloy under different strain sates and establish data on the stress–strain behaviour of the alloy with automotive engineering applications.

2. Experimental procedure

The alloy (Al-6Si-2Cu-2Ni) was prepared by melting Al-7Si-0.3Mg (A356) alloy and adding Al, Cu and Ni into the melt.Table1 shows the chemical compositions of the casting. The cast sample was ground to remove the oxide layer from the surface and homogenised for 24 hours 500ºC. Samples for tension tests were prepared from the homogenised plates according to ASTM B-557M-06 standard (subsize, E8 M–04). The tension test samples were solution treated at 540ºC for 2 hrs and quenched in ice-salt-water solution. The samples were subjected for ageing at 225ºC for 1hr. Tensile testing was carried out in an Instron testing machine at three different cross-head speeds: 0.15, 1.5 and 15mm/minute which are equal to the nominal strain rates of 0.0001, 0.001 and 0.01s^{-1} respectively for the alloy. The averages of three consistent test results were accepted as the tensile value for the corresponding sample. Fractographic observations of the fractured surfaces of selected samples were carried out in a Scanning Electron Microscope. The overall experimental steps were shown in Fig.1.

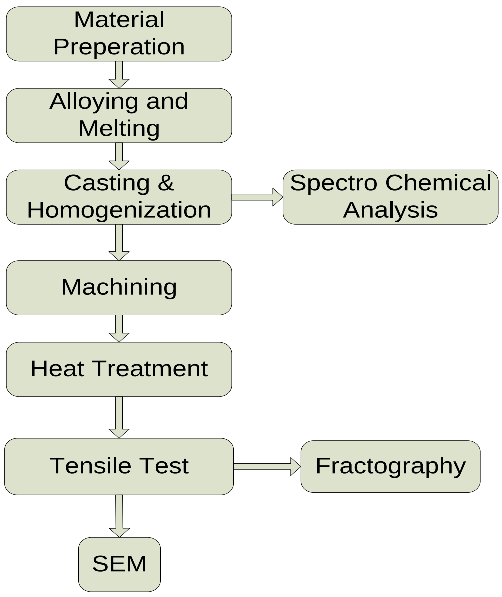

Fig.1. Alloy synthesis and production of samples for tensile studies

Table 1. The chemical compositions (wt %) of the alloy

Alloy	*Si*	*Mg*	*Cu*	*Ni*	*Fe*	*Zn*	*Mn*	*Ti*	*Sb*	*Al*
Al-6Si-2Cu-2Ni	**5.760**	0.501	**1.968**	**2.001**	0.265	0.001	0.004	0.081	0.005	Bal

3. Result and discussions

3.1 Tensile properties at various strain rates

Enhancing strain rates results in an obvious increase in tensile strength (Fig. 2). When the strain rates are below 0.001s^{-1}, work hardening decreases strongly. Work hardening decreases strongly during the plastic deformation of samples at 0.0001s^{-1}, and sometimes necking phenomenon is observed in this strain rate before fracture. The increasing in yield strength (proof strength) with strain rates of the alloy is very similar to the ultimate tensile strength (Fig.3). Fig.4. shows the variation of ductility (% elongation) of the alloy with strain rates. It is observed that at the strain rate for which strength is maximum ($0.01 s^{-1}$), the ductility value of the alloy pass through minima.

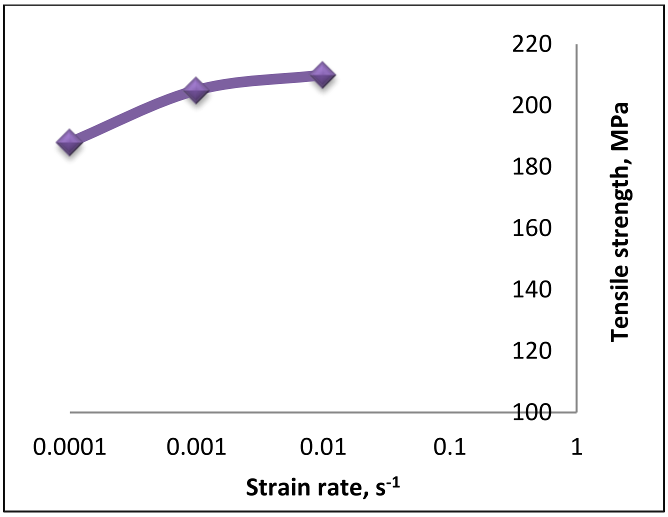

Fig.2. Typical tensile strength-strain curve of Al-6Si-2Cu-2Ni alloy

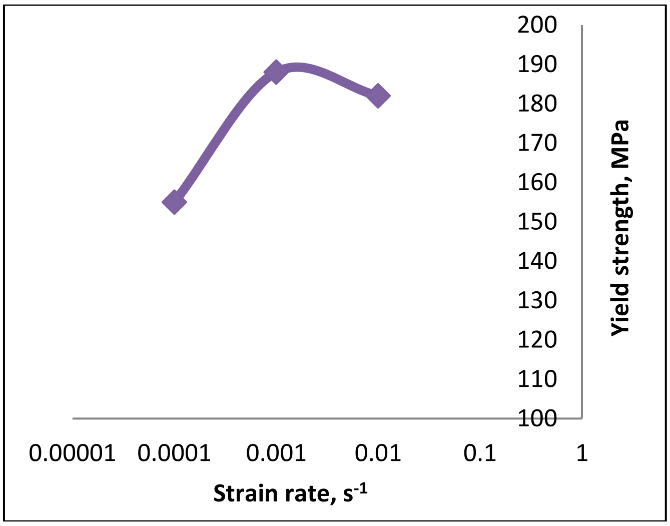

Fig.3. Typical yield strength-strain curve of Al-6Si-2Cu-2Ni alloy

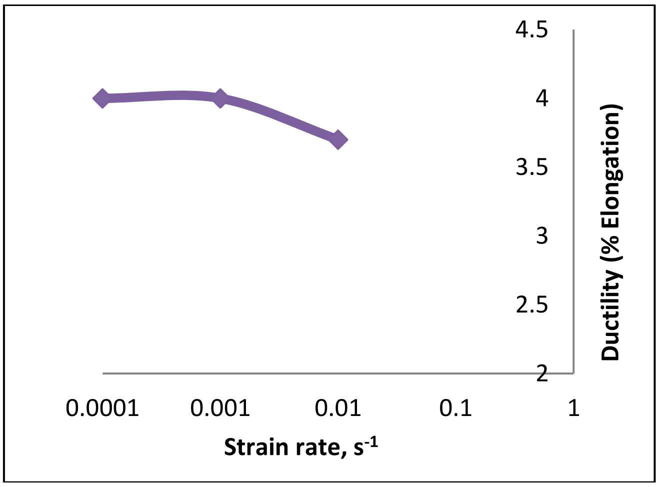

Fig.4. Typical yield strength-strain curve of Al-6Si-2Cu-2Ni alloy

3.2 Effect of the strain rate on fracture surface and structure

Fig. 5 shows the SEM micrographs of the fracture surfaces of the Al-6Si-2Cu-2Ni alloy at various strain rates. At lower strain rate ($0.0001s^{-1}$) the dimples are larger and deeper than the higher strain rates ($0.001s^{-1}$, $0.01s^{-1}$) tensile testing sample. Dimples in Fig. 5.a are higher and deeper than Fig. 5.b and Fig.5.c. At higher strain rates there is less change for coalescence and facet planes are generated (Fig.5.c). The cleavage facets are mainly created at high strain hardening tensile testing.

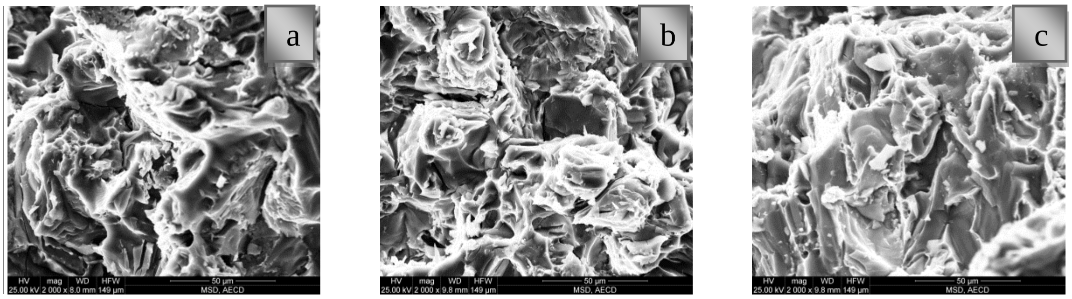

Fig.5. SEM micrographs of fracture surfaces at the strain rates (a) $0.0001s^{-1}$; (b) $0.001s^{-1}$; (c) $0.01s^{-1}$

4. Conclusions

Strain rate has found to affect the tensile strength, ductility and fracture behavior of the Al-6Si-2Cu-2Ni alloy. As the strain rate has increased, tensile strength has increased but ductility has decreased. The rupture surfaces have mainly exhibited the deeper and higher number dimples pattern under the low strain rates, ordinary dimple fracture surfaces have observed. The dimple size and depth have increased as the strain rate has decreased. The fracture surface has some transcrystalline cleavage planes and river patterns, there have also a few tearing ridges and dimples exist at the higher strain rate.

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