

Influence of Cu on Tensile Properties of Thermal Treated Al-6Si-0.5Mg Cast Alloys at Various Strain Rates

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Abstract: Effects of Cu additions on tensile properties of Al-6Si-0.5Mg cast alloy at different strain rates were studied. The solution treated Cu containing alloys (0.5 – 4 wt %) were aged isochronally for 1 hour at temperatures up to 300°C. The uniaxial tension test was carried out in a standard tensile test machine at strain rate ranging from 10^{-4} to 10^{-2} s^{-1} in order to investigate the effects of Cu on tensile properties at these strain rates. Tensile strength was found to increase with ageing temperature and the maximum being attained at peak aged condition (1 hr at 225°C). The additions of Cu resulted in an increase in tensile strength and 2 wt% Cu addition showed maximum strength all over the experimental strain rates and ageing temperatures. Evaluations of tensile properties at the three different strain rates (10^{-4} , 10^{-3} & 10^{-2} s^{-1}) showed that they affected the tensile properties significantly. The strength was better at higher strain rate but ductility was poor. The fracture surfaces of the broken specimens showed that both ductile and ductile-brittle mixed fracture depending on strain rates and allowable Cu concentrations

Keyword: Al-6Si-0.5Mg alloy, T6 heat treatment, tensile properties, strain rate

I. INTRODUCTION

Excellent aptitude to casting and forging processes, machinability, corrosion resistance and high strength-to-weight ratio, which increases performance and fuels economy, make heat treatable aluminium alloys suitable materials for various crucial applications in the automotive industry, such as engine blocks, pistons and cylinder heads [1], [2].

The high strength levels are achieved by the T6 heat treatment that provides strengthening through the precipitation hardening mechanism [3]. T6 heat treatment consists in three fundamental steps: solution, quench and artificial aging (carried out in furnace). In the solution treatment the high temperatures promote the homogeneous diffusion of the hardening elements in the matrix. Through the water quench and subsequent artificial aging, a supersaturated matrix and a precipitation of hardening phases are respectively obtained. After the quench in fact, the supersaturated matrix, force the constitutional elements to form coherent precipitates reducing the total free energy of the system. These precipitates hind the dislocation motion resulting in increased yield strength and hardness. However, the final hardness of the alloy results from the heat treatment parameters, such as time and temperature of the solution treatment, the quenching conditions and the artificial aging procedure. In the case of Al-Si-Mg casting alloys, also the short storage at room temperature between quenching and aging phases, due to the industrial handling of the components, is one of the crucial parameters affecting the tensile properties of the material [4].

This time, known as “preaging”, affects the precipitation sequence of metastable phases that occurs during the artificial aging. This sequence, for Al-Si-Mg alloys, can be summarised as follows: $\alpha(\text{sss}) \rightarrow \text{zone_GP} \rightarrow \beta'' \rightarrow \beta' \rightarrow \beta$ (Mg_2Si) [5]. In it, α (sss) is the supersaturated solid solution, GP zones are coherent Guiner-Preston zones, β'' are needle shaped precipitates associated with the peakaged condition, β' rod shaped precipitates form after β'' precipitates in the aging sequence and β is the equilibrium phase [3], [6]. For Al-Si-Mg-Cu alloys, the precipitation behaviors are rather complicated and several phases such as $\beta(\text{Mg}_2\text{Si})$, $\theta(\text{CuAl}_2)$, $S(\text{CuMgAl}_2)$ or $Q(\text{Cu}_2\text{Mg}_8\text{Si}_6\text{Al}_5)$ in metastable situations may exist [7], [8], [9].

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 was reported by [10]. Similar observations regarding rate sensitivity of aluminium alloys, now in tension, were reported by investigating the alloys AA7003-T79 and AA7108-T6 [11]. On the other hand, the flow stress and fracture strain of AA6005-T6 were shown to have rather strong positive strain-rate sensitivity [12].

The objective of this research work is to study the effects of various Cu additions to Al-6Si-0.5Mg cast alloys and different strain rates on the tensile properties in engineering applications.

II. EXPERIMENTAL PROCEDURE

Al and Al-Si binary alloy, contained in a clay-graphite crucible, was melted in a gas-fired pot furnace. Copper, in the form of sheet (99.98% purity), was then added by plunging. Magnesium (99.7% purity) in the form of ribbon and packed in an Al-foil was added to the melt. The final temperature of the melt was maintained at $900 \pm 15^\circ\text{C}$. Before casting, the melt was degassed with solid hexachloroethane (C_2H_6) and homogenized by stirring at 700°C . Casting was done in a metal mould measuring 15mm x 150mm x 300mm and preheated to 200°C . All the alloys were analysed by wet chemical and spectrochemical methods simultaneously (TABLE I).

The cast samples were ground to remove the oxide layer from the surface and were homogenised for 24 hours 500°C . Samples for tension tests were prepared from the homogenised plates according to ASTM standard (Sub-size standard ASTM E8 M-04). The tension test samples were solution treated at 540°C for 120 minutes and quenched in ice-salt-water solution. Isochronal ageing was carried out at temperature up to 300°C for determining the peak strength.

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 10^{-4} , 10^{-3} and 10^{-2} s^{-1} respectively for each 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.

TABLE I: THE CHEMICAL COMPOSITIONS OF THE ALLOYS (WT %)

Alloy	Si	Mg	Cu	Ni	Fe	Mn	Ti	Al
Al-6Si -0.5Mg	5.902	0.461	0.007	0.005	0.146	0.002	0.099	Bal
Al-6Si -0.5Mg-0.5- Cu	6.033	0.517	0.558	0.006	0.129	0.003	0.094	Bal
Al-6Si -0.5Mg-Cu	6.105	0.555	1.185	0.029	0.334	0.005	0.088	Bal
Al-6Si -0.5Mg-2Cu	5.801	0.497	1.980	0.003	0.300	0.004	0.094	Bal
Al-6Si -0.5Mg-4Cu	5.884	0.532	3.800	0.014	0.181	0.003	0.086	Bal

III. RESULTS AND DISCUSSION

The tensile strengths of different Cu containing investigated alloys under various aging conditions are shown in Fig.1 at a strain rate of 10^{-3} s^{-1} . The maximum tensile strength of 249MPa was found for 2 wt% Cu addition to Al-6Si-0.5Mg cast alloy after ageing for 1 hour at 225°C . 4 wt% Cu containing alloy shows the lowest tensile strength all over the ageing conditions. The maximum tensile strength achieved at $\sim 225^\circ\text{C}$ and the tensile strength decreases gradually beyond the ageing temperature of 225°C .

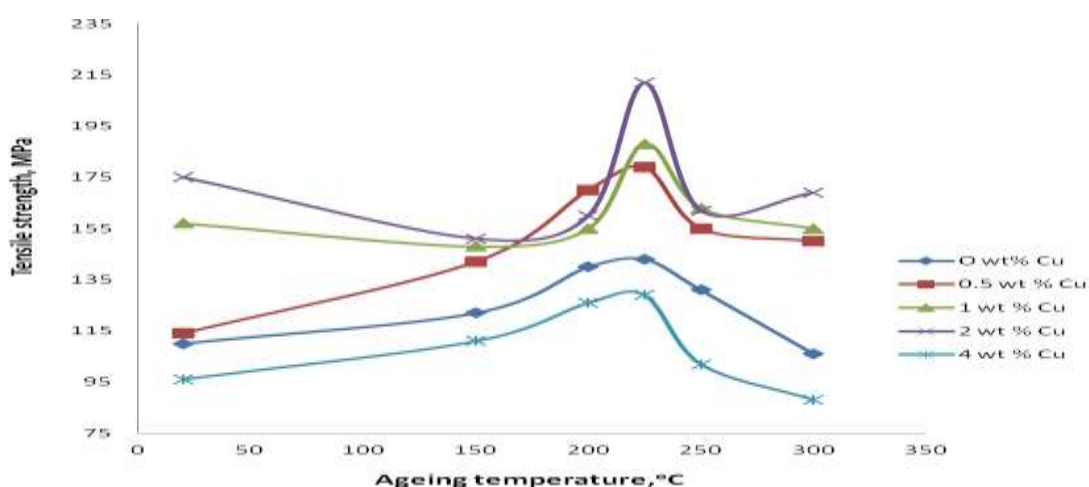


Fig.1 Tensile strength of various Cu containing Al-6Si-0.5Mg cast alloys at various ageing temperatures

Fig.2 shows the typical ultimate tensile strength —various wt% of Cu additions to Al-6Si-0.5Mg cast alloy at different strain rates at peakaged condition. For comparing the Cu additions with the tensile behaviors of the alloys, tensile test experiments are conducted at three different strain rates (10^{-4} , 10^{-3} & 10^{-2} s^{-1}). Strong work hardening happens during the tensile testing. Enhancing strain rates results in an obvious increase in ultimate tensile strength all over the Cu

additions and the maximum tensile strength being attained at a strain rate of 10^{-2} s^{-1} . When the strain rates decrease, work hardening decrease and work hardening decrease maximum at a strain rate of 10^{-4} s^{-1} all over the Cu additions. The tensile strength increases more pronounced with the increase of strain rates and Cu additions and 2 wt% Cu additions to Al-6Si-0.5Mg cast alloy shows the highest ultimate tensile strength all over the strain rates.

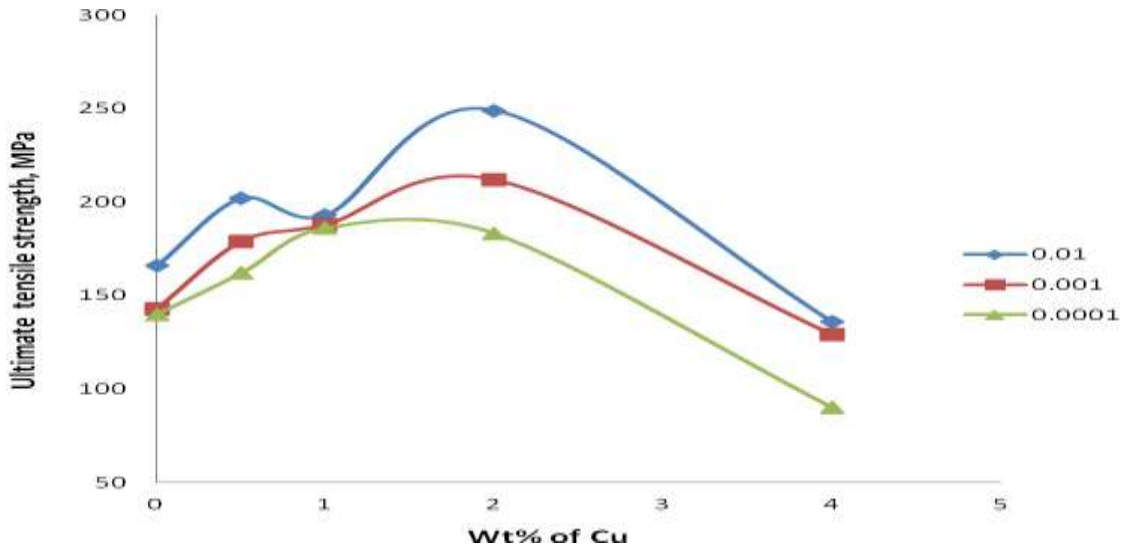


Fig.2 Ultimate tensile strength – wt. % of Cu additions to Al-6Si-0.5Mg cast alloy at different strain rates

Fig.3 indicates that the yield strength (0.2% proof strength) vs. wt% of Cu contents at various strain rates. The increasing in proof strengths with Cu additions to Al-6Si-0.5Mg cast alloys at different strain rates is very similar to the Ultimate tensile strength. Cu addition increases the yield strength with strain rates and the 2wt% Cu addition, was found to highest yield strength among the Cu additions investigated alloys. Yield strength increases with increase of strain rate and the maximum yield strength being attained at a strain rate of 10^{-2} s^{-1} .

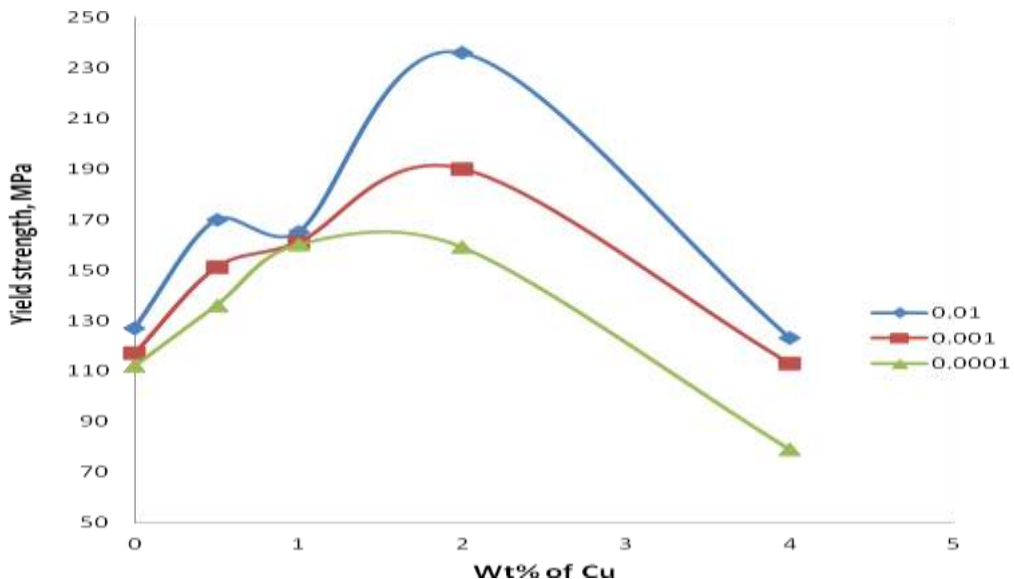


Fig.3 Yield strength – wt. % of Cu additions to Al-6Si-0.5Mg cast alloy at different strain rates

Fig.4 demonstrates the variation of % elongation with Cu additions at various strain rates. It is observed that at the strain rate for which the strength is maximum (10^{-2} s^{-1}), the ductility values of the Cu containing alloys pass through minima. The ductility increases with increase of Cu contents and maximum being attained at a strain rate of 10^{-4} s^{-1} for 2wt% Cu addition. Cu addition beyond this level decreases the ductility all over the strain rates.

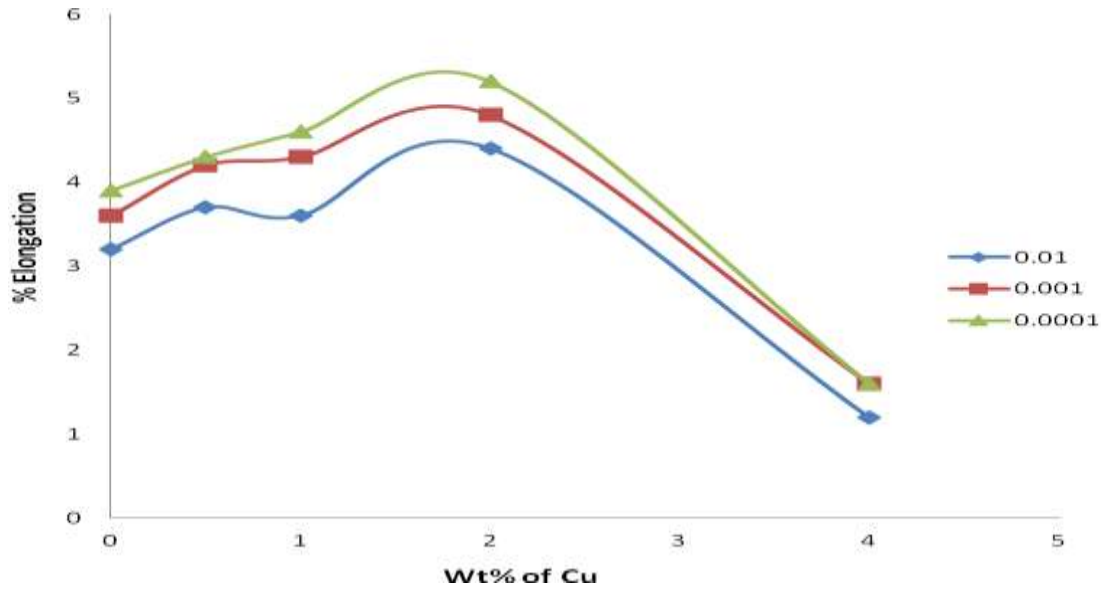


Fig.4 Ductility – wt. % of Cu additions to Al-6Si-0.5Mg cast alloy at different strain rates

The fracture surfaces of various Cu containing alloys at peakaged conditioned, that failed during tensile tests were investigated for identifying the micro mechanisms of failure. Samples after tensile testing were cut to the specified dimensions and then ultrasonically cleaned in acetone and examined the fractured surfaces in a SEM. At low strain rate ($10^{-2} s^{-1}$), the total numbers of dimples are increasing and the dimples are deeper (Fig.5). With the decrease in strain rates the less number and shallow dimples are observed in the fracture surfaces (Fig.6 and Fig.7) i.e. the ductility decreases with increase in strain rates.

2 wt% Cu containing Al-6Si-0.5Mg-2Cu alloy shows a mixed mode type of tensile fracture. The large-deep dimples and lots of cracks are present (Fig.8) at a strain rate of $10^{-4} s^{-1}$. At higher strain rate ($10^{-2} s^{-1}$) a very few dimples are present and the fracture mode is overall brittle fracture (Fig.9)

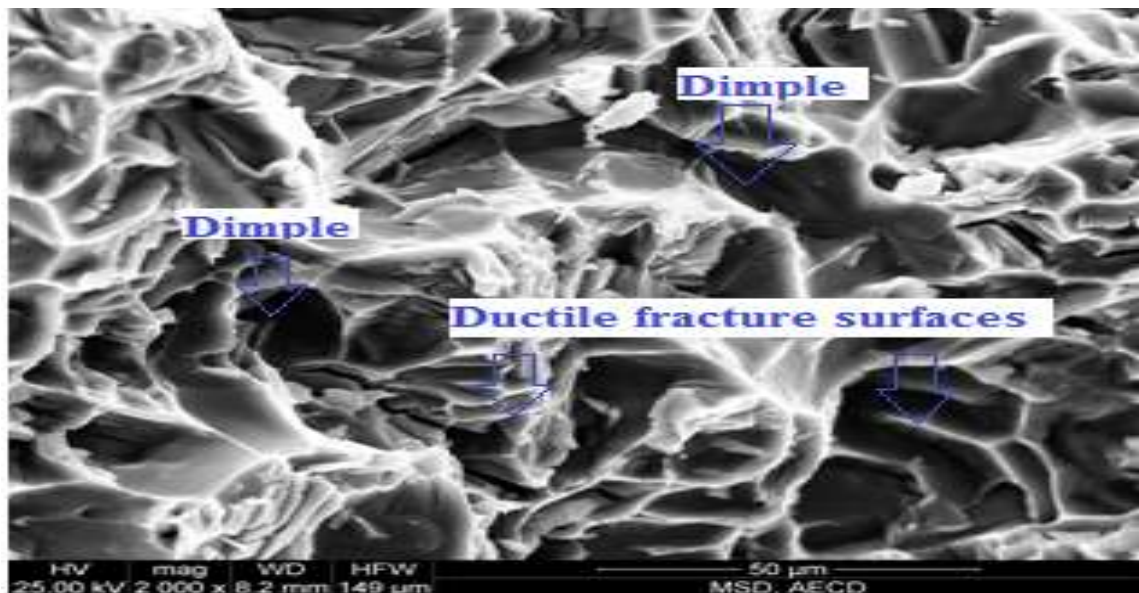


Fig.5 Tensile Fractographs for 0.5 wt% Cu containing alloy at three strain rates of $10^{-4} s^{-1}$

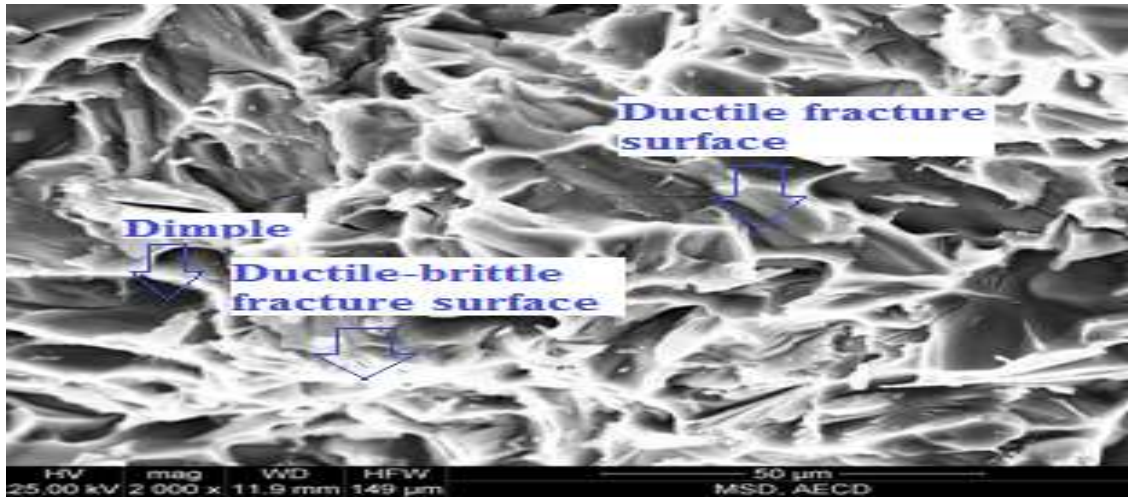


Fig.6 Tensile Fractographs for 0.5 wt% Cu containing alloy at three strain rates of 10^{-3} s^{-1}

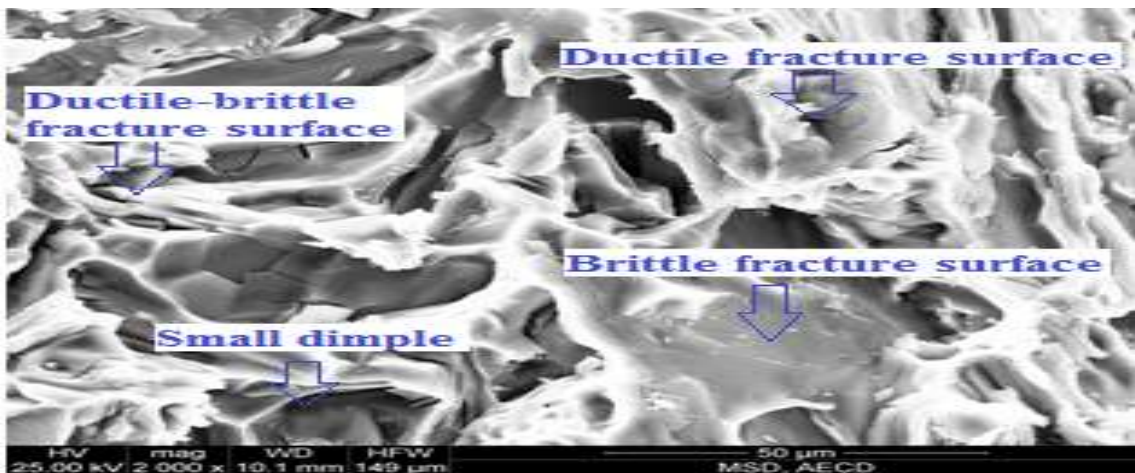


Fig.7 Tensile Fractographs for 0.5 wt% Cu containing alloy at three strain rates of 10^{-2} s^{-1}

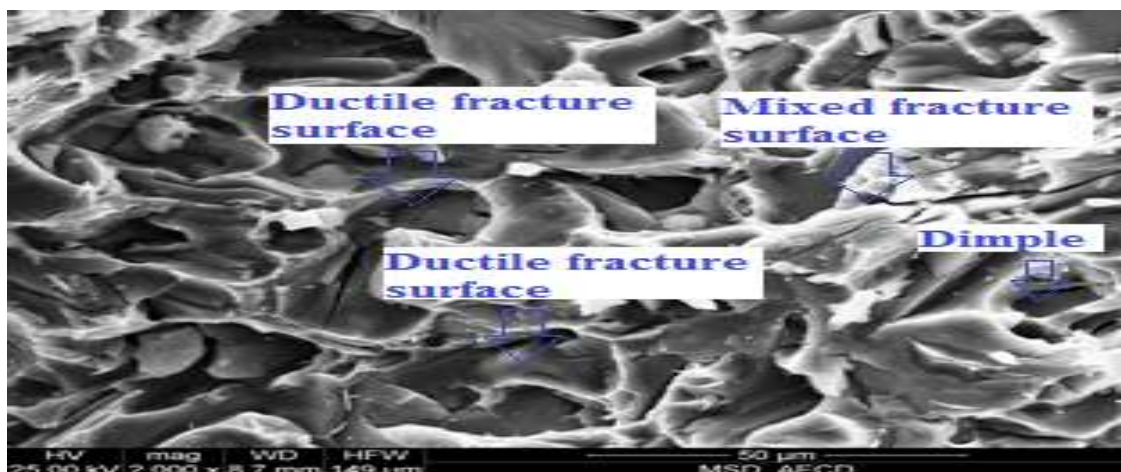


Fig. 8 Tensile Fractographs for 2 wt% Cu containing alloy at two strain rates of 10^{-4} s^{-1}

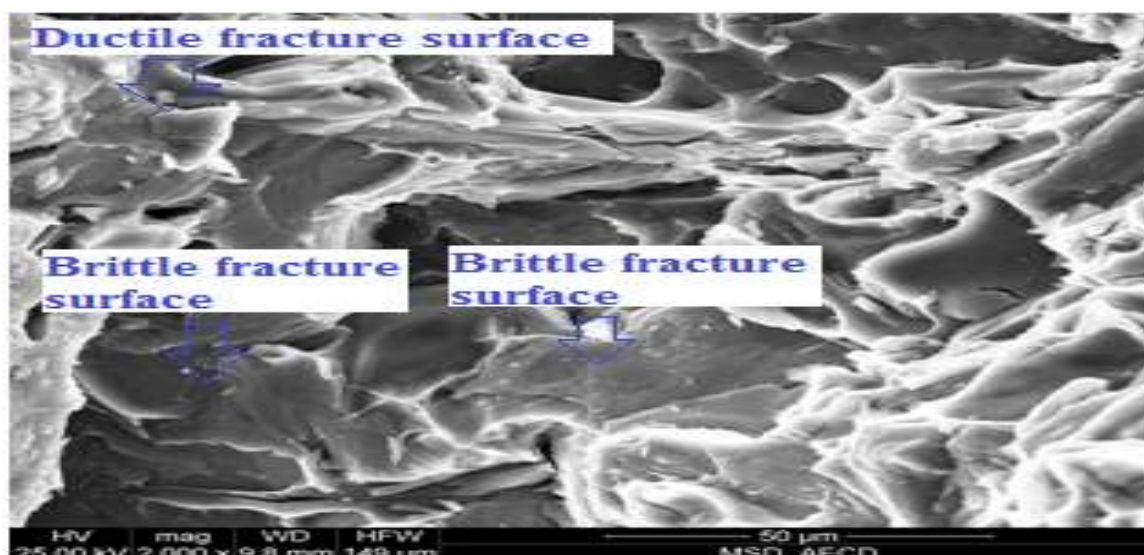


Fig. 9 Tensile Fractographs for 2 wt% Cu containing alloy at two strain rates of 10^{-2} s^{-1}

IV. CONCLUSIONS

The tensile properties of various Cu containing Al-6Si-0.5Mg cast alloys as a function of strain rates for a particular ageing temperature. At higher strain rates, the tensile strength is found to maximum but ductility reduces. 2 wt % Cu additions to Al-6Si-0.5Mg cast alloy shows the excellent tensile properties. At lower strain rate the fracture behavior is ductile and at higher strain rate the fracture behavior is brittle or ductile-brittle mixed fracture among the investigated Cu containing alloys.

REFERENCES

- [1] J. G. Kaufman and E. L. Rooy, "Aluminium alloy castings, Properties, Processes and applications", ASM International, 2004.
- [2] L. Ceschini, Al. Morri, An. Morri and G. Pivetti, "Predictive equations of the tensile properties based on alloy hardness and microstructure for an A356 gravity die cast cylinder head", Materials and design, vol.32, pp.1367–1375, 2011.
- [3] M. H. Jacobs, "Precipitation Hardening", TALAT Lecture 1204, European Aluminium Association, 1999.
- [4] S. Shivkumar, C. Keller and D. Apelian, "Aging Behavior in Cast Al-Si- Mg Alloys", AFS Transactions, vol.98, pp.905-911, 1990.
- [5] J. Lendvai, T. Ungár and I. Kovács, "The Effect of the Temperature of Solution Treatment and Quenching on the Zone Formation Process in Al-Mg-Si Alloys", Materials Science and Engineering, vol.16, pp.85-89, 1974.
- [6] I. Dutta, and S. M. Allen, "A calorimetric study of precipitation in commercial aluminium alloy 606", Journal of Materials Science Letters, vol.10, pp.323-326, 1991.
- [7] I. C. Barlow, W.M. Rainforth and H. Jones, "The role of silicon in the formation of the (Al₅Cu₆Mg₂) τ phase in Al-Cu-Mg alloys", J Mater Sci., vol.35, pp.1413–1418, 2000.
- [8] W. Reif, S. Yu, J. Dutkiewicz, R. Ciach and J. Kro'1, "Pre-ageing of AlSiCuMg alloys in relation to structure and mechanical properties", Mater Des, vol.18, pp.253–256, 1997.
- [9] R. K. Mishra, G. W. Smith, W. J. Baxter, A.K. Sachdev and V. Franetovic, "The sequence of precipitation in 339 aluminum castings", J Mater Sci., vol.36, pp.461–468, 2001.
- [10] L.D. Oosterkamp, A. Ivankovic and G. Venizelos, "High strain rate properties of selected aluminium alloys" Mechanical Science and Engineering A, vol.278, pp.225–235, 1999.
- [11] Aa. Reyes, O. S. Hopperstad, O. G. Lademo and M. Langseth, "Modeling of textured aluminum alloys used in a bumper system: material tests and characterization", Computational Materials Science, vol.37, pp.246–268, 2006.
- [12] T. Børvik, A. H. Clausen, M. Eriksson, T. Berstad, O. S. Hopperstad and M. Langseth, "Experimental and numerical study on the perforation of AA6005-T6 panels" International Journal of Impact Engineering, vol.32, pp. 35–64, 2005.