Influence of Copper addition on Mechanical Behavior of Al-Ca Alloy

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ABSTRACT

The Al-Ca-Cu alloys containing varying amount of Cu are used to study the influence of Cu addition on their deformation behavior at varying strain rate (0.001/s, 0.01/s, 0.1/s, 1/s).The material is prepared using stir casting technique The yield stress, flow stress and elastic limit are measured from the true stress-strain graph .The Strain Rate sensitivity and strain hardening exponent are also determined for each material at different strain rate. The Strain Rate Sensitivity of this alloy is very low. These values strongly demonstrate that compressive deformation of Al-Ca-Cu alloys almost independent to the strain rate at room temperature deformation.

Keywords: *Compressive deformation, Strain Rate, Strength Coefficient, Copper Contents*

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1. INTRODUCTION

The demands of rapidly evolving technology call for continuous research and development efforts aimed at invention of novel casting aluminum alloys. It often happens that the standard casting alloys, including high-quality materials, do not satisfy the rigorous requirements for applications in different areas of technology. Alloys containing small amounts of eutectic (e.g., on the basis of the Al–Cu, Al–Mg, and Al–Zn–Mg systems) have significant advantages – better mechanical properties [1]. Aluminum and its alloys have potential applications in aerospace and automotive industry because of its higher specific strength and stiffness [2–4].In general it is well known that the pure Aluminum is comparatively softer than other. For applications requiring greater mechanical strength, it is generally alloyed with other elements such as copper, magnesium, manganese, iron, silicon and zinc. The details of the effect of different alloying elements on the microstructure and mechanical behavior of aluminum and its alloys are reviewed by stake [5].

The Addition of Mg, Na and Sr in small quantities influenced the eutectic transformation of Al–Si cast alloys and modified silicon morphologies to a great extent and thus improve its strength and toughness [6]. It is further reported by Dash and Makhlouf [7] that the castability of Al–Si alloys improved, hydrogen absorption decreased and microstructure got refined and modified due to addition of Mg, Mn, Cu, Sr and Ti. All these factors lead to higher strength and ductility.

Alloying in copper can significantly improve mechanical strengths and raise the softening temperatures. However, additions of alloying elements also reduce electrical and thermal conductivity. Among the three alloying strengthening mechanisms, namely, solid solution hardening, precipitation hardening, and dispersion strengthening, solid solution hardening has the most detrimental effects on the conductivity [8] and is the least favored mechanism to obtain high conductivity, high-strength copper alloys. Cold work can significantly increase the strength of pure copper and has a relatively moderate effect on conductivity [8]. However, cold worked copper can be softened at relatively low temperatures (200ºC) because of its low recrystallization temperature [9].

2. LITERATURE REVIEW

Zhang et al. [1] studied the aluminum alloy conductors influenced by alloying elements and thermomechanical treatments. The new all-aluminum alloy conductors gradually replace the steel core conductors and develop rapidly and are widely used around the world in aerospace, construction, automobile, and civil industries. Some traditional processing methods and novel materials forming technologies are necessary processes for aluminum alloy conductors to improve their mechanical properties and conductivity, such as alloying elements additions, severe deformation, heat treatments, selective laser melting, and Al-based composites.

Zhu-Jin Li et al. [2] investigated the effect of Ce addition on hot deformation behavior and microstructure evolution of AZ80 magnesium alloy. The rare earth phase formed with added Ce hindered movement of the dislocations and grain boundaries, causing higher peak stress of AZ80-Ce alloy than that of AZ80 alloy. After hot compression, AZ80 alloy showed a fiber texture with the c-axis parallel to the compression direction, and addition of Ce caused texture-weakening. The constitutive equations and processing maps of AZ80 and AZ80-Ce alloys were constructed and analyzed. Adding Ce reduced deformation activation energy and Zener-Hollomon parameter, and enlarged non-instability zone in processing maps of AZ80 alloy.

Shiyu Zhong et al. [3] investigated the effect of Cu addition on the microstructure, mechanical properties and degradation rate of Mg-2Gd alloy. The demand for magnesium (Mg) alloy with high elongation, certain strength and good degradation rate used in oil and gas exploitation filed is increasing. Based on Mg-2Gd alloy, effect of copper (Cu) addition (0.25, 0.5 and 0.75 wt.%) on microstructure, mechanical properties and degradation rate were investigated. Nevertheless, the elongation was still up to at least 20%. Overall, the comprehensive mechanical properties and degradation rate of Mg-2Gd alloy can be effectively coordinated by Cu addition.

Jiangfeng Song et al. [4] studied the advances on magnesium and magnesium alloys worldwide. Significant progresses have been achieved in high-performance cast and wrought magnesium and magnesium alloys, magnesium-based composites, advanced cast technologies, advanced processing technologies, and functional magnesium materials, such as Mg ion batteries, hydrogen storage Mg materials, bio-magnesium alloys, etc. Based on the issues and challenges identified here, some future research directions are suggested, including further development of high-performance magnesium alloys having high strength and superior plasticity together with high corrosion resistance and low cost, and fundamental research on the phase diagram, diffusion, precipitation, etc., as well as the development of advanced welding and joining technology.

Jinbei Lyu et al. [5] investigated the effect of substitution of Zn with Ni on microstructure evolution and mechanical properties of LPSO dominant Mg–Y–Zn alloys. After homogenization at 500 °C for 12 h, the fraction of the LPSO phase increase and compounds decrease, moreover, the morphologies of the LPSO phase remain unchanged. Tensile tests indicate that the yield strengths of the extruded MYZ, MYZN, and MYN alloys are 325, 340, and 385 MPa, respectively; the increase can be explained by the higher fraction of the LPSO phase and different stress-withstanding capacity of the LPSO phase with different morphologies. In addition, the enhancement of strength is accompanied by slight drop in ductility.

3. EXPERIMENTAL SET-UP

3.1 Material Synthesis

Al-Ca-Cu alloy is prepared by stir casting technique. This technique involved melting of Al- Ca-Cu alloy in the electric resistance furnace .Pure commercial aluminum ingot was firstly cleaned and melt. Laboratory grad Ca granules were then added into the melt through mechanical string. Firstly preheated Al and Cu pieces were put in the Crucible and start the melting. After maintaining the temperature of melt between C, a vortex was created within the melt using a mechanical stirrer. When temperature reaches to 700°C to 800°C the Ca granules (2wt %) were also added to melt, at same time mechanical string was also in process. The melt temperature was maintained at 800 minutes, so that Ca and Cu got dissolve into the melt uniformly. Castings were prepared by pouring the melt into preheated cast iron mould of cylindrical shapes. For compressive behavior observations, Al-Ca-Cu alloy sample were cut, in cylindrical shape. The polished sample ware etched with Keller‟s reagent.

3.2 Compressive Deformation:

Compression test were performed on Universal Testing Machine at varying strain rates (0.001/s, 0.01/s, 0.1/s, 1/s) in room temperature condition. The dimension of the samples is 10 mm in diameter and 15 mm in length were prepared from the castings. The face were policed and lubricated with Teflon to reduce the friction between the specimen surface and the anvil or the punch. The engineering stress and engineering strain data were recorded from the digital display and these data were used for getting true stress –true strain curves. These data were further analyzed for determination of the strain hardening exponent, the plastic strength coefficient and the strain rate sensitivity.

4. RESULTS AND DISCUSSION

4.1 Strain Hardening Exponent Al-Ca-Cu alloys

The strain hardening exponent is calculated using the following type of empirical relation between flow stress and the strain in the plastic region:

$$\sigma = K\varepsilon^{n} \quad .... (4.1)$$

Where,

K = Plastic strength coefficient,

n = Strain hardening exponent

σ = Flow stress

ε = Plastic strain [9]

The ln(σ) v/s ln(ε) plots are drawn from the recorded true stress and true strain data. Each of the plots led to two lines having different shapes (for plastic and elastic region), which appear to be intersecting at a point. The equation of the lower (elastic region) and the upper line (plastic region) could be assumed as follows [9].

$$y = a_1 x + b_1$$

$$y = a_2 x + b_2$$

Where, $y = \ln(\sigma)$, $x = \ln(\varepsilon)$

a_1 & a_2 = Intercept of upper line and lower line respectively b_1 & b_2 = Slope of upper line and lower line respectively Thus a1 is equal to the strain hardening exponent and b1 is the ln(K). If it is assumed that at the point of elastic limit, the two lines will intercept, then by equating the above two equations, one can get the value of y in terms of a_1, b_1, a_2, b_2

$$y = \{(a_1 b_2 - a_2 b_1)/(a_1 - a_2)\}$$

Thus, the elastic limit stress (σ_e) can be expressed as:

$$\sigma_e = e^{y},\ k = e^{b1},\ n = a_1 \ [9]$$

4.2 Compressive Deformation Behavior of Al-Ca-Cu alloy with fixed Composition of Cu at different strain rates

4.2.1 Compressive deformation of Al-Ca-Cu alloy with 0.5% Cu at different strain rates

The Composition of Al-Ca-Cu at 0.5 % Cu having elastic limit in between 52.71 MPa to 64.61 MPa. Fig 4.1.

4.2.2 Compressive deformation of Al-Ca-Cu alloy with 1% Cu at different strain rates

The Composition of Al-Ca-Cu at 1 % Cu having elastic limit in between 34.58 MPa to 52.94 MPa Fig. 4.2

4.2.3 Compressive deformation of Al-Ca-Cu alloy with 1.5 % Ca at different strain rates

The Composition of Al-Ca-Cu at 1.5 % Cu having elastic limit in between 34.72 MPa to 62.95 MPa Fig 4.3.

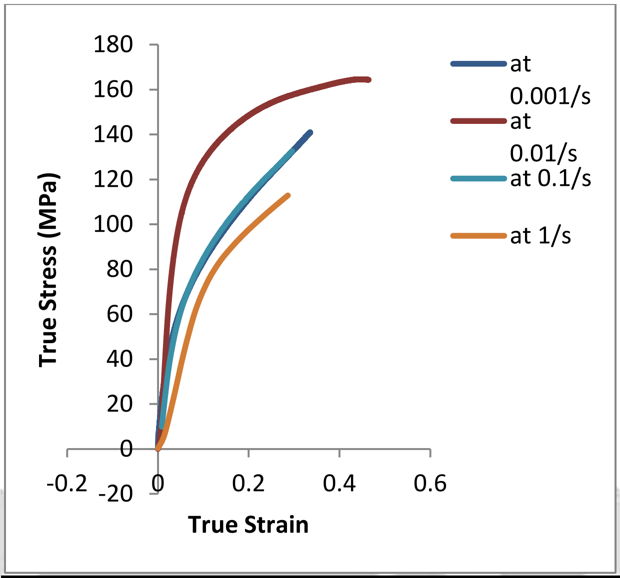

Fig. 4.1 True Stress V/S True Strain (0.5% Cu)

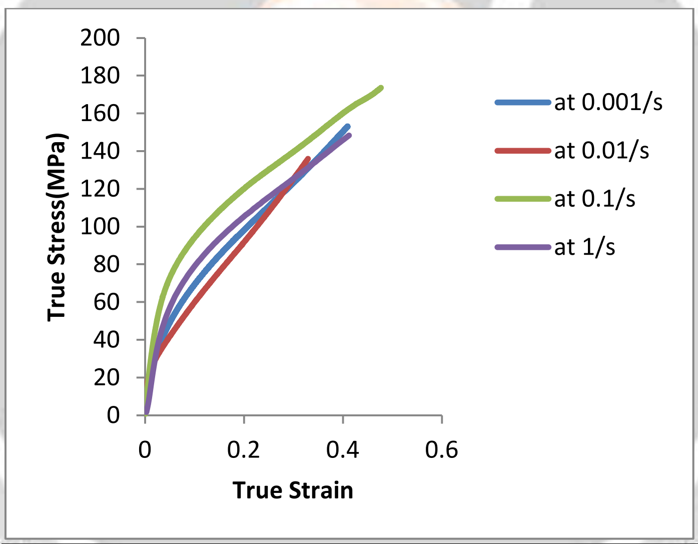

Fig. 4.2 True Stress V/s True Strain (1% Cu)

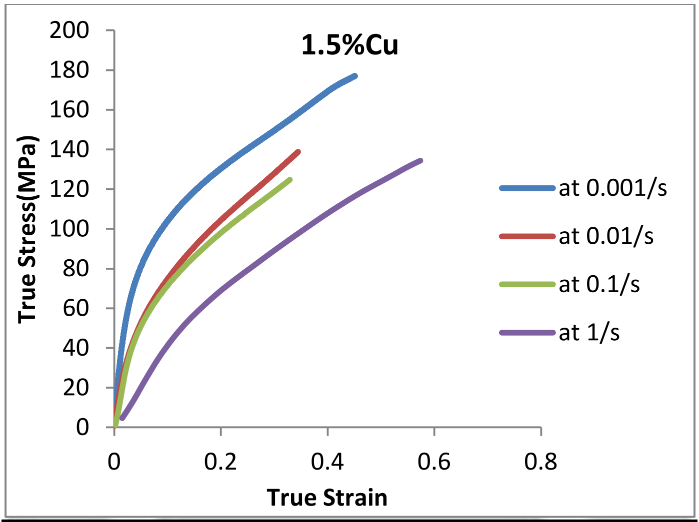

Fig. 4.3 True Stress V/s True Strain (1.5% Cu)

4.2.4 ln True Stress v/s ln True Strain of 0.5% Cu Composition

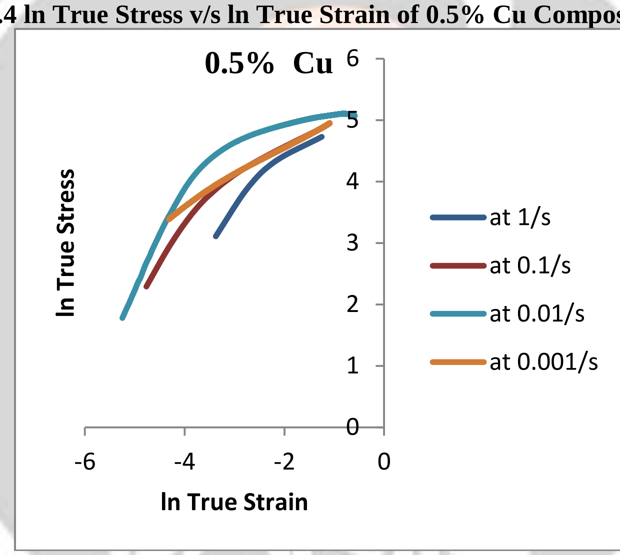

Fig. 4.4 ln True Stress v/s ln True Strain

4.2.5. ln True Stress v/s ln True Strain of 1% Cu Composition

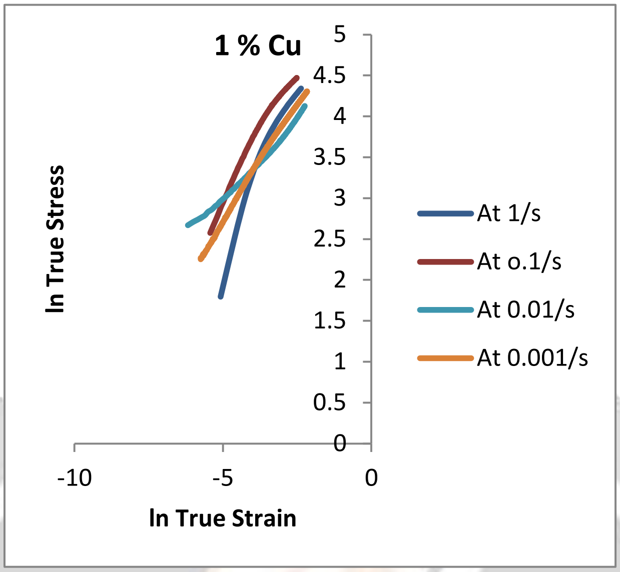

Fig. 4.5 ln True Stress v/s ln True Strain

4.2.6 ln True Stress v/s ln True Strain of 1.5% Cu Composition

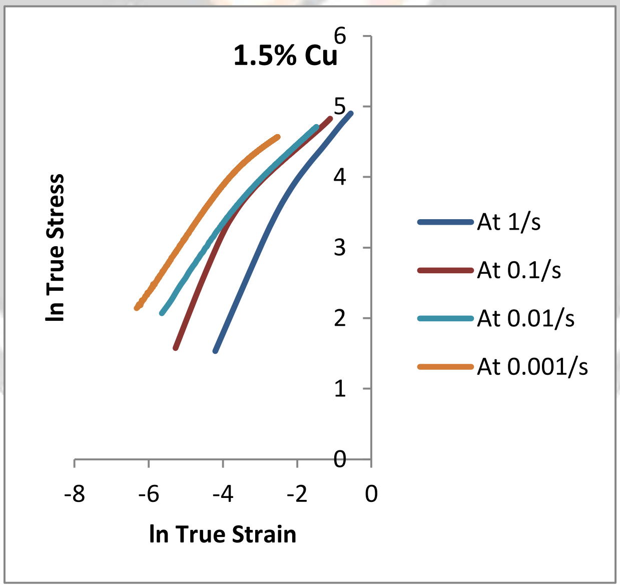

Fig. 4.6 ln True Stress v/s ln True Strain

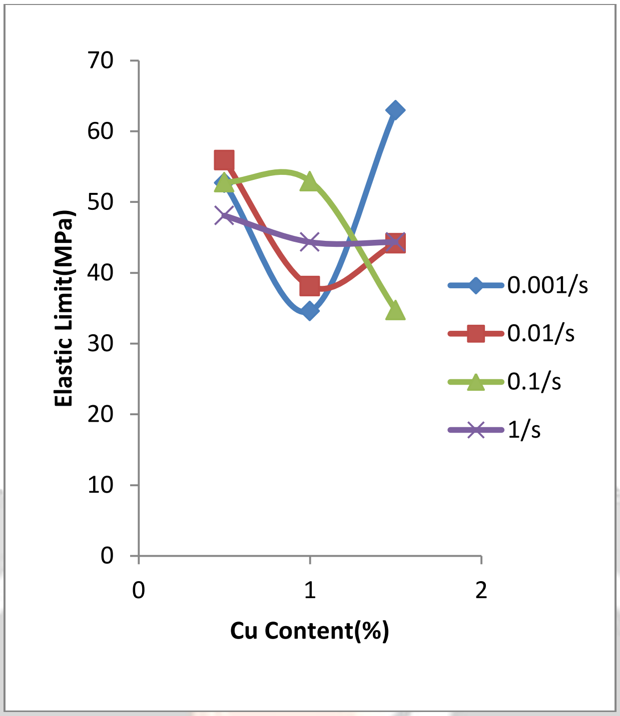

Fig. 4.7 Elastic limit v/s Cu contents

From the Fig 4.7 , it shows that elasticity decreases at increase of Cu content at 0.1/s and having varying value at change in Cu % at 0.001/s , 0.01/s and at 1/s. The elasticity is that property of a material by which the materials regain their actual size after removal of the forces.

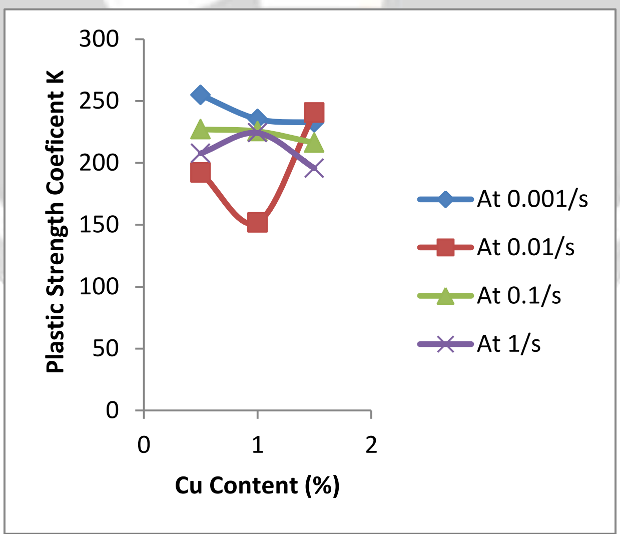

Fig. 4.8 Plastic Strength coefficient 'k' v/s Cu Content

Plastic strength coefficient is decreases with increase in Cu % excepting at 0.01/s. The values of Plastic strength coefficient are varies at different Cu component and strain rate. Higher value of plastic strength coefficient is shows the higher plasticity vice versa.

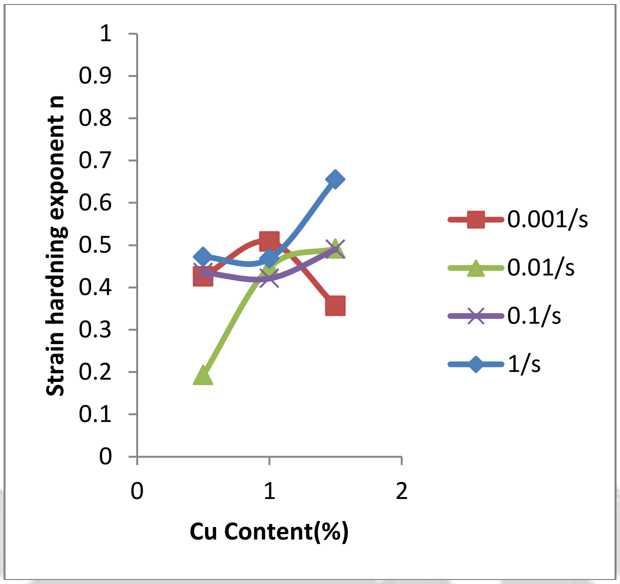

Fig. 4.9 Strain hardening exponent 'n' v/s Cu content

From Fig 4.9 Strain hardening exponent 'n' increases with increase in Cu % and maximum at 1/s and minimum at 0.001/s. The 'n' is presents that the material is plastic or elastic if it's value is 1 that means it is purely elastic whereas if it's value is 0 then it have excellent elasticity.

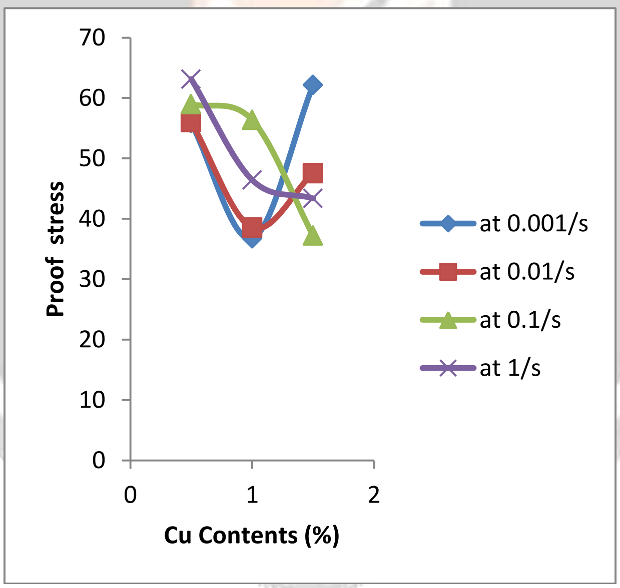

Fig. 4.10 Proof Stress v/s Cu Contents

From Fig 4.10 it observed that Proof Stress increases with Cu % at 0.001/s and at 0.01/s. And Proof Stress decreases with increase Cu % at 0.1/s and 1/s. Since the sharp yield point is not shown by the true stress-true strain curve, we need to find the proof stress and it provides the value of yield stress.

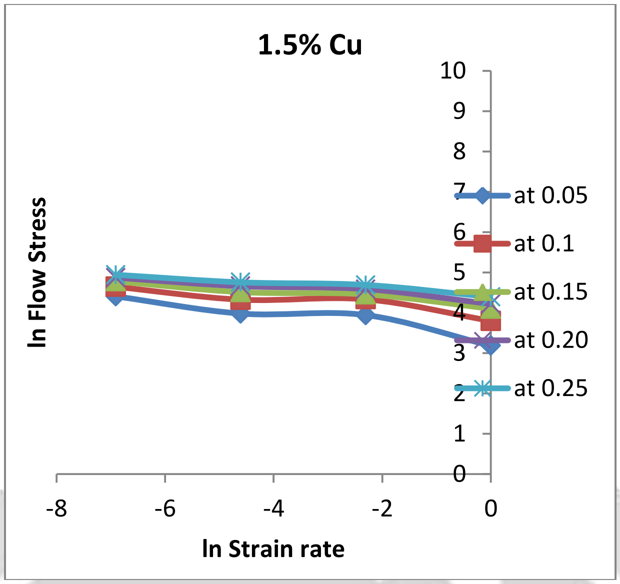

Fig. 4.11 ln Flow Stress v/s ln Starin Rate

From the above Fig 4.11, the values of Strain rate sensitivity ‘m’ and Strength Coefficient ‘K_s’ are found by lining trend line on these graph and then the table is plotted as below.

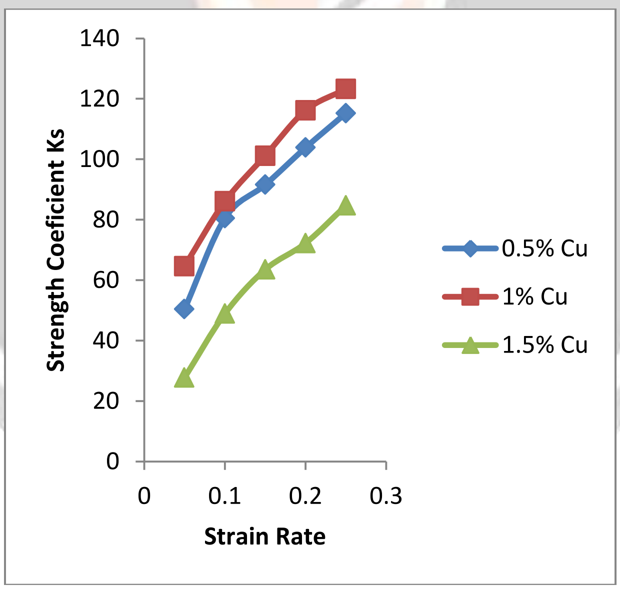

Fig. 4.12 Strength Coefficient ‘K_s’ v/s Strain Rate

From Fig 4.27 it shows the maximum value of Strength Coefficient ‘K_s’ at 1% Cu and least at 1.5% Cu. It is the correlation between two variables is the degree to which there is a 'linear relationship' between them. Strength coefficient which measures the strength of that linear relationship between the variables

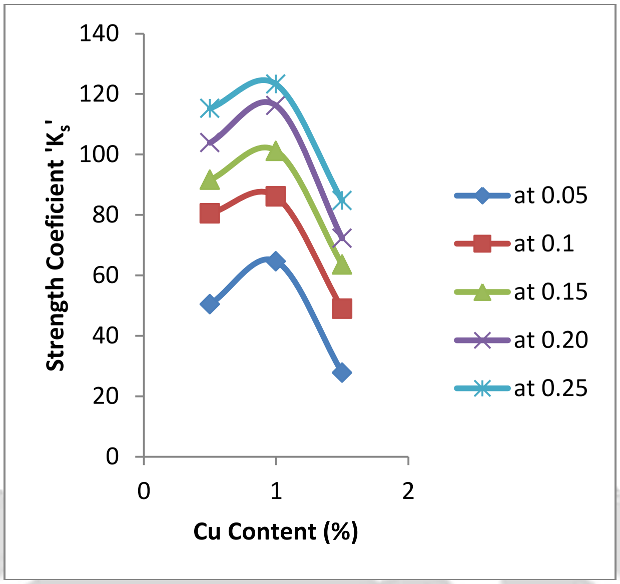

Fig. 4.13 Strength Coefficient ‘Ks’ v/s Cu Content

From the Fig 4.13 it showing the maximum value of Strength Coefficient ‘Ks’ at 1% Cu and least at 1.5% Cu

4.3 Tensile Deformation Behavior of Al-Ca-Cu alloy with fixed Composition of Cu at different strain rates

4.3.1 Tensile deformation of Al-Ca-Cu alloy with 0.5% Cu at different strain rates

The Composition of Al-Ca-Cu at 0.5 % Cu having elastic limit in between 49.17 MPa to 53.01 MPa See Fig. 4.14

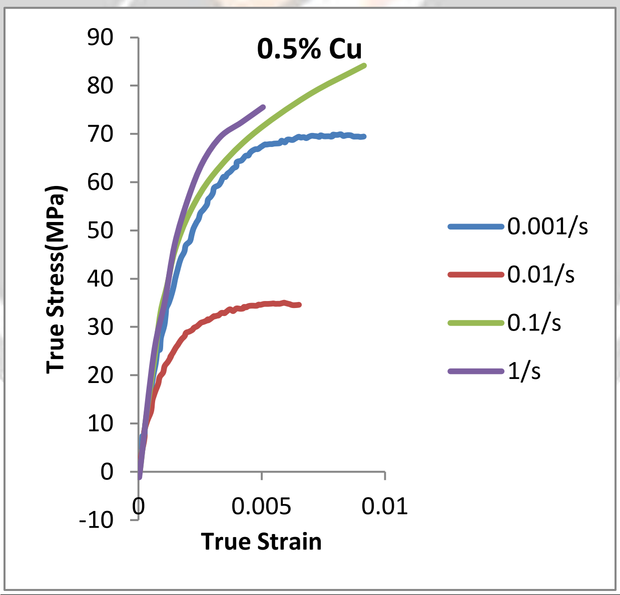

Fig. 4.14 True Stress v/s True Strain

4.3.2 Tensile deformation of Al-Ca-Cu alloy with 1% Cu at different strain rates

The Composition of Al-Ca-Cu at 1 % Cu having elastic limit in between 50.31 MPa to 56.73 MPa See Fig. 4.15

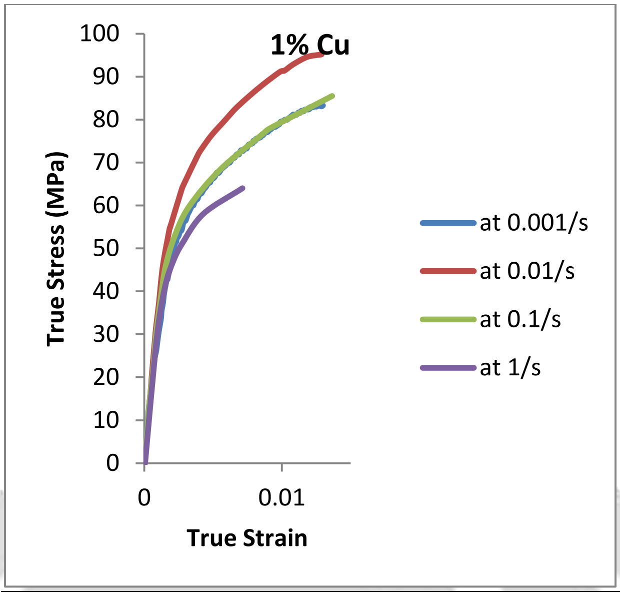

Fig. 4.15 True Stress v/s True Strain

4.3.3 Tensile deformation of Al-Ca-Cu alloy with 1.5 % Ca at different strain rates

The Composition of Al-Ca-Cu at 1.5 % Cu having elastic limit 49.52 MPa to 57.61 MPa Fig 4.16

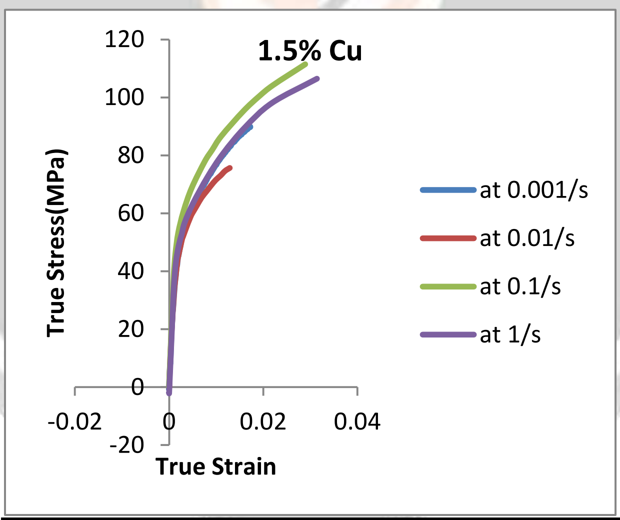

Fig. 4.16 True Stress v/s True Strain

4.3.4 ln True Stress v/s ln True Strain at 1 % Cu

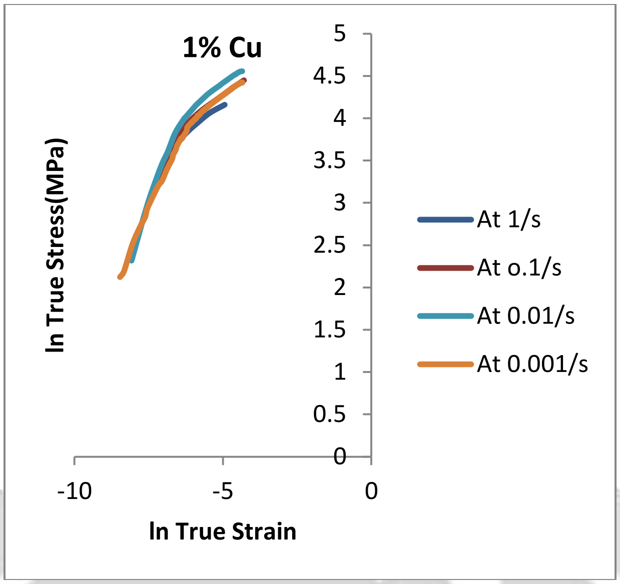

Fig. 4.17 ln True Stress v/s ln True Strain

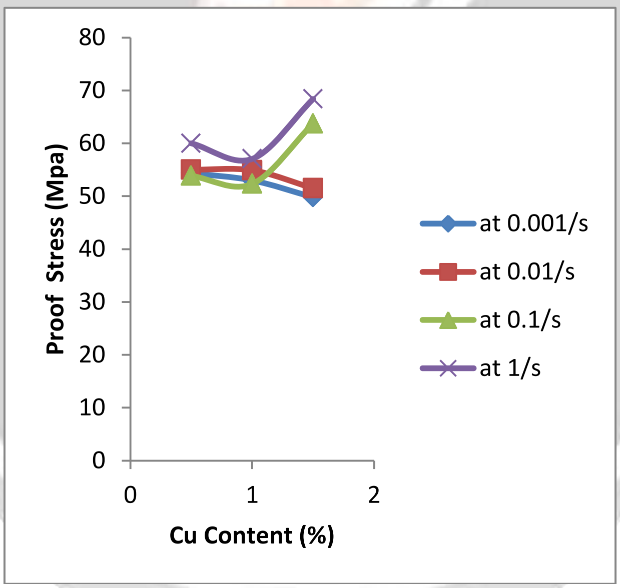

Fig. 4.18 Proof Stress v/s Cu Content (%)

It is also notice that from Fig 4.18 proof stress is increasing with increase in Cu % and maximum at 1/s (68 MPa). Since the sharp yield point is not shown by the true stress-true strain curve, we need to find the proof stress and it provides the value of yield stress.

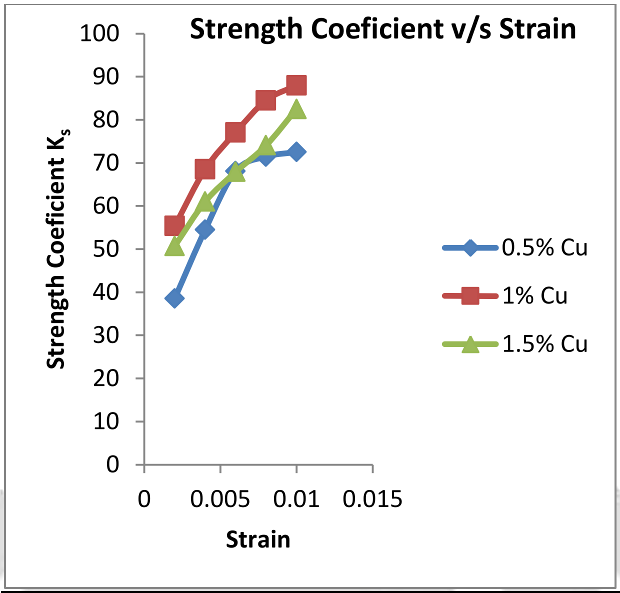

Fig. 4.19 Strength coefficient 'K_s' v/s Strain

From Fig. 4.19, it shows that the 1% Cu is showing highest value of 'K_s'. The value of 'K_s' in descending order is 1% Cu > 1.5% Cu > 0.5% Cu.

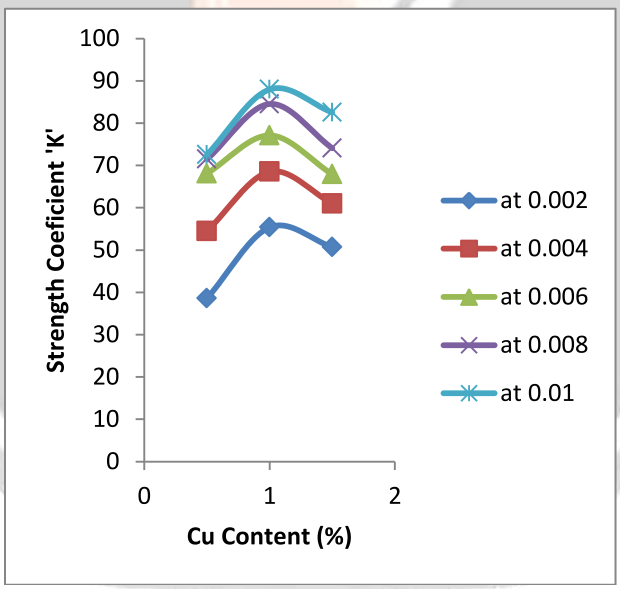

Fig. 4.20 Strength Coefficient 'K_s' v/s Cu Content

From the Fig. 4.20, it shows that Strength Coefficient 'K_s' increase at increase addition of Cu from 0.5% to 1% and then slightly decrease with further increase in Cu % from 1% to 1.5 %.It is the correlation between two variables is the degree to which there is a 'linear relationship' between them. Strength coefficient which measures the strength of that linear relationship between the variables

5. CONCLUSION

1. The flow curves of Al-Ca-Cu having 0.5%, 1%, and 1.5%, of Cu exhibits different trend with respective of strain rate. The yielding of 0.5%, 1% and 1.5% of Cu alloy at different strain rates starts at 63 MPa, 56 MPa and 62 MPa respectively.
2. The alloy containing 0.5% Cu having highest ductility as well as it has also highest strength.

3. The yield stress and the elastic limit stress are calculated from the stress-strain curves are has the different values with respect to different strain rate of different composition.
4. The Al-Ca-Cu alloy having 0.5% Cu has maximum value elastic emit and least of plastic strength coefficient.
5. The Strain hardening exponent having maximum value at 0.5% Cu Content Al-Ca-Cu alloy.
6. The Strain Rate Sensitivity of this alloy is very low. The maximum value of strain rate sensitivity (0.015) is achieved in 1% Cu. These values strongly demonstrate that compressive deformation of Al-Ca-Cu alloys almost independent to the strain rate at room temperature deformation.
7. Strength coefficient has the maximum value in 1% Cu of Al-Ca-Cu alloy.

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