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The Effects of Copper Addition on the compression 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 effect 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 ; Strain Rate Sensitivity ; Strain Hardening exponent ; Strength Coefficient ;Copper Contents.*

I. 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 (200^0C) because of its low recrystallization temperature.[9] A recent study has shown that ultrahigh-strength and high-conductivity copper can be produced by introducing a high density of nanoscale twin boundaries.[10] Copper and its alloy possess high strength and high conductivity in the prime-aged condition, and good fracture toughness and fatigue properties in both nonirradiated and irradiated conditions.[11] Plastic strengthening coefficient and strain-hardening exponent of the Ca added alloy varies with strain rate.[12] These values for this alloy are considerably higher than for 7178 alloy without Ca addition [12]. The compressive deformation behavior of Ca added 7178 alloy as a whole varies marginally with strain rate. The strain rate sensitivity of the alloy at ambient temperature is noted to be very low.[12]The strain hardening exponent of Al-Ca alloy is rated to be the maximum for 2wt% Ca. whereas 2wt% Ca, the plastic strengthening coefficient is noted to be the minimum.[13] No attempts have been made and reported on the Effect of Cooper Addition on the deformation behavior of Al-Ca-Cu Alloy using stir casting method . In this present paper attempt is made and characterize in the terms of compressive deformation behavior at varying strain rates at room temperature.

II. Experimental Procedure:

2.1 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 700°C to 800°C, a vortex was created within the melt using a mechanical stirrer. When temperature reaches to 800°C the Ca granules (2wt %) were also added to melt, at same time mechanical string was also in process. Mechanical string provides better distribution in alloy. The melt temperature was maintained at 800 °C for 30 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

2.2 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.

III. Results:

3.1 Compressive deformation:

The true stress-strain curves of the investigated material when tested at different are shown in the fig.1 fig.2 and fig.3. From these true stress-true strain plots, the yield stress and flow stress at different strain are determined using a standard methodology. It may be noted that the curves do not show any sharp yield point. The Composition of Al-Ca-Cu at 0.5 % Cu having elastic limit in between 52.71 MPa to 64.61 MPa. See fig.1 The Composition of Al-Ca-Cu at 1 % Cu having elastic limit in between 34.58 MPa to 52.94 MPa fig. 2 The Composition of Al-Ca-Cu at 1.5 % Cu having elastic limit in between 34.72 MPa to 62.95 MPa see Fig. 3

In general, it is noted that there is no sharp yield point .There is gradual change from yielding to plastic region. In the plastic region stress increases gradually with strain indicating strain hardening . As there is no sharp yield point, so the 0.2% proof stress criteria is used to calculate yield stress (σ_y) . For better evaluation of yield stress, elastic limit stress (σ_e) was determined [14]. The Strain rate sensitivity is calculated as per standard method [15]

$$\sigma_f = K\varepsilon^m \quad \ldots\ldots (1)$$

Where

K = Plastic Strength Coefficient

m = Strain Rate Sensitivity

σ_f = Flow Stress (MPa)

ε = Strain Rate

In the elastic region $\sigma = E\varepsilon$, where E is the elastic modulus and ϵ^- is the strain; the above equation can be written as follows

$$\ln(\sigma) = \ln(K) + n\ln(\varepsilon) \quad \ldots\ldots (2)$$

The ln(σ) Vs 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: [15]

$$y = a_1 x + b_1$$
$$y = a_2 x + b_2$$

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

$$y = \{(a_1 b_2 - a_2 b_1)/(a_1 - a_2)\} \ldots\ldots (2) \qquad [15]$$

Table.1 Elastic limit, plastic strength coefficient, proof stress and strain hardening exponent.

Cu Contents	St.Rate	Strain hardening exponent ($n=a_1$)	Elastic limit ($\sigma_e=e^y$) MPa	Plastic Strength coefficient ($k=e^{b1}$)MPa	Proof Stress (σ_y) MPa
0.50%	0.001/s	0.426	52.71469215	254.7544143	55.843
	0.01/s	0.42	55.92122676	242.0200896	56
	0.1/s	0.435	52.79785623	227.0113463	59
	1/s	0.472	64.61101064	207.6803253	63.127
1.00%	0.001/s	0.42	34.58407938	235.3326394	36.768
	0.01/s	0.447	38.12674576	231.8662197	38.56
	0.1/s	0.421	52.94855891	225.4278157	56.37
	1/s	0.468	48.08777164	224.0792984	46.428
1.50%	0.001/s	0.456	62.95762802	232.5255241	62.15
	0.01/s	0.492	44.15031227	240.5673279	47.546
	0.1/s	0.49	34.72404171	216.1559202	37.214
	1/s	0.455	44.34293286	195.5859647	43.37

Table .2 Variation of Strain Rate sensitivity (m) and Strength Coefficient (K_s) with Strain of Compression test result.

Cu-Content	Strain	Strain rate sensitivity (m)	Strength coefficient (K_s)
0.5%	0.05	-0.07	50.40044478
	0.1	-0.035	80.47929932
	0.15	-0.036	91.56050403
	0.2	-0.031	103.855447
	0.25	-0.026	115.2380513
1%	0.05	0.056	64.650769
	0.1	0.04	86.05615085
	0.15	0.028	101.1900063
	0.2	0.025	116.1636532
	0.25	0.015	123.2235272
1.5%	0.05	-0.161	27.743
	0.1	-0.109	48.91088652
	0.15	-0.09	63.49746603
	0.2	-0.088	72.24044001
	0.25	-0.074	84.69020911

3.2 Effect of Cu Addition on the Al-Ca-Cu Alloy:

The Al-Ca-Cu alloy is giving maximum value of elasticity in 0.5% Cu at 1/s and minimum in 1% Cu at 0.001/s .And analyzing at all strain rate in all composition it is found that the value of elasticity varies with variation in Cu contents and strain rates . The value of plastic strength coefficient is found least in 1.5% Cu at 1/s and maximum in 0.5 % Cu at 0.001/s thus it is found that plasticity also varies with the variation in Cu contents and strain rates. The yield stress of the Al-Ca-Cu alloy also varying with deferent Cu contents and strain rates. It has the maximum value in 0.5% Cu at 1/s and least in 1% Cu at 0.001/s.

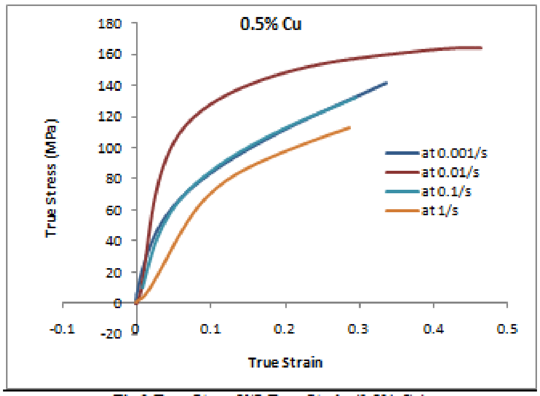

Fig 1 True Stress V/S True Strain (0.5% Cu)

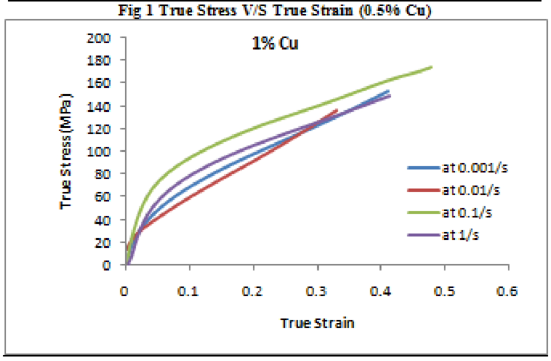

Fig 2 True Stress V/s True Strain (1% Cu)

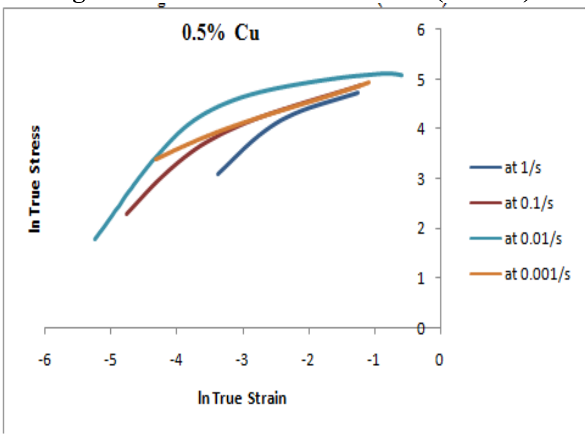

Fig.4 ln True Stress v/s ln True Strain

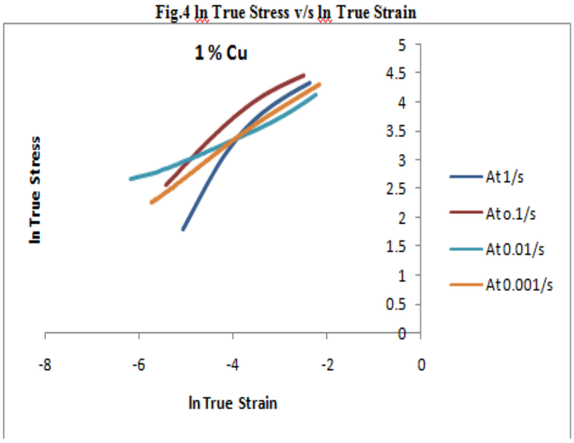

Fig.4 ln True Stress v/s ln True Strain

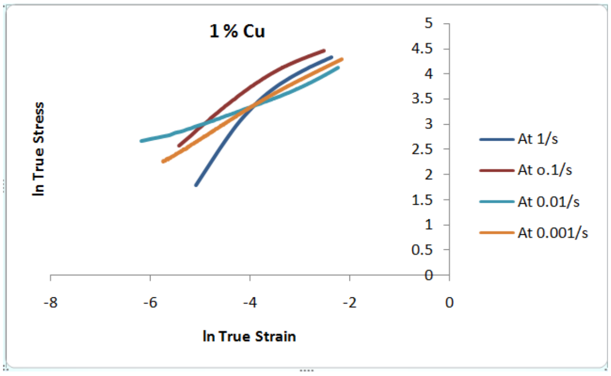

Fig 5 ln True Stress v/s ln True Strain

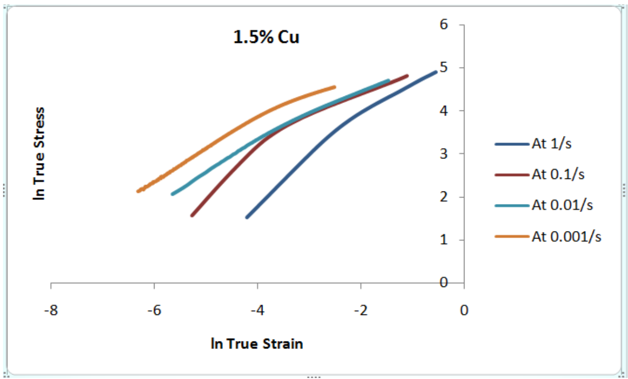

Fig.6 ln True Stress v/s ln True Strain

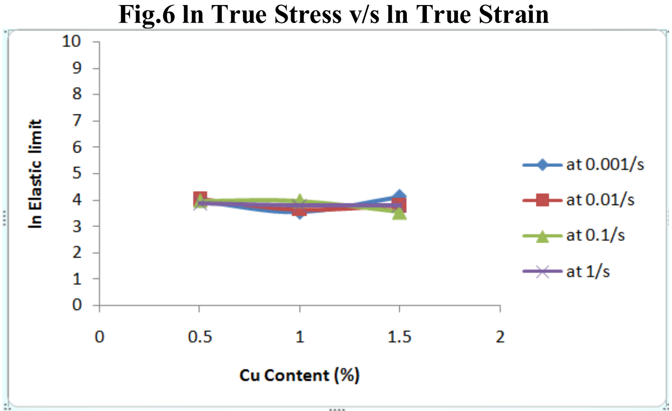

Fig 7 ln Elastic limit v/s Cu Contents

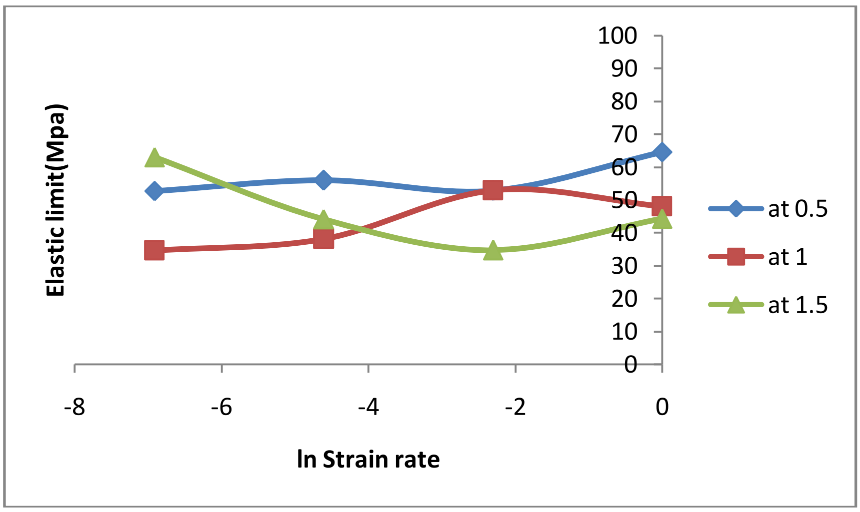

Fig. 8 Elastic limit stress v/s ln Strain rate

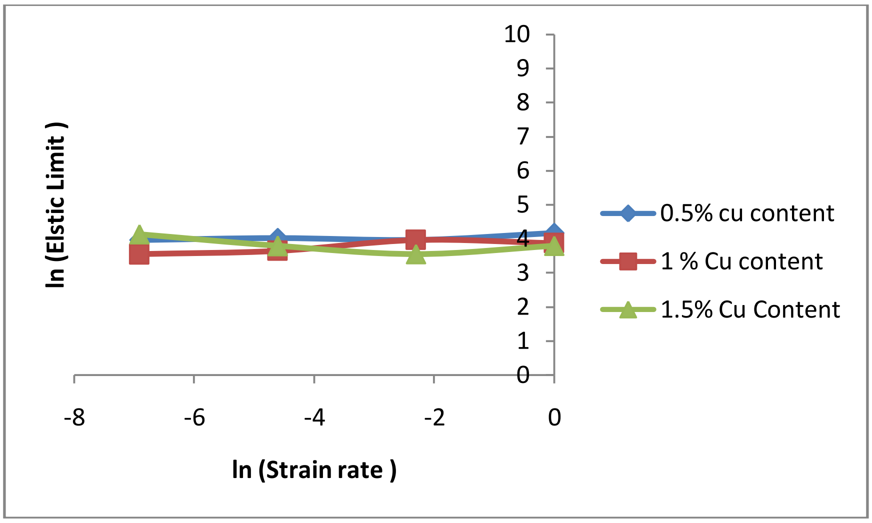

Fig 9 ln Elastic limit v/s ln Strain rate

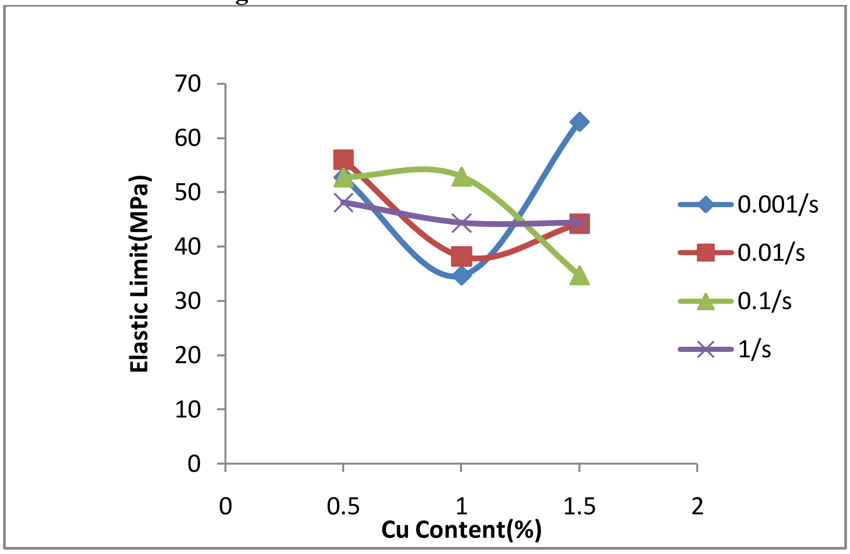

Fig.10 Elastic limit v/s Cu contents

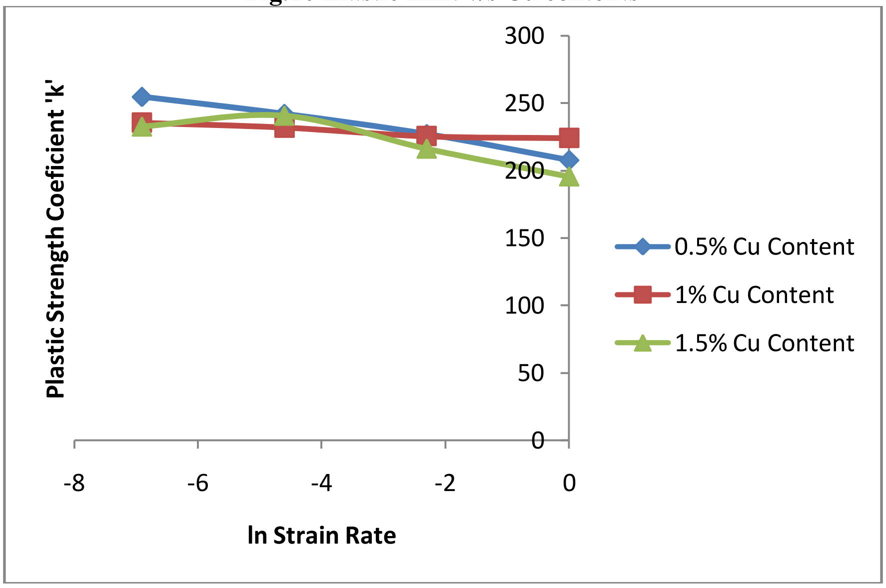

Fig.11 Plastic strength coefficient 'k' v/s ln Strain rate

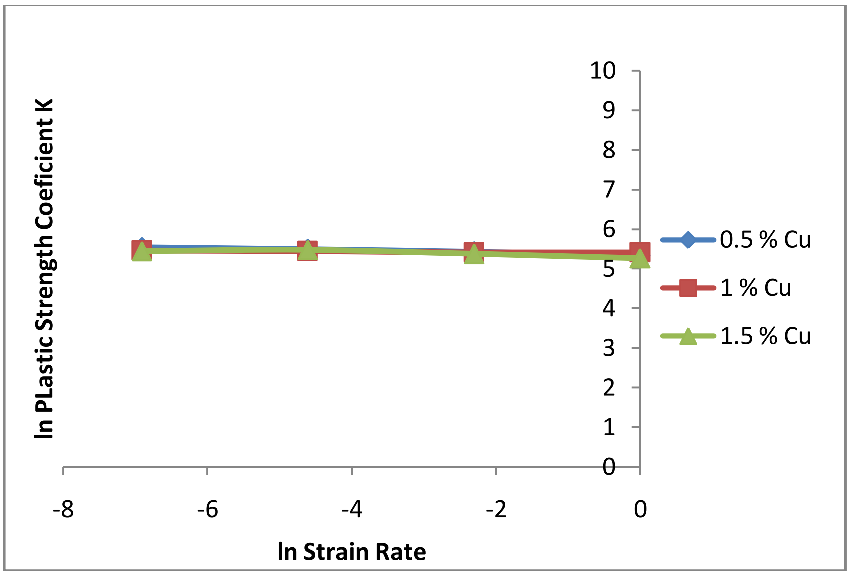

Fig 12 ln Plastic Strength coefficient 'k' v/s ln Strain rate

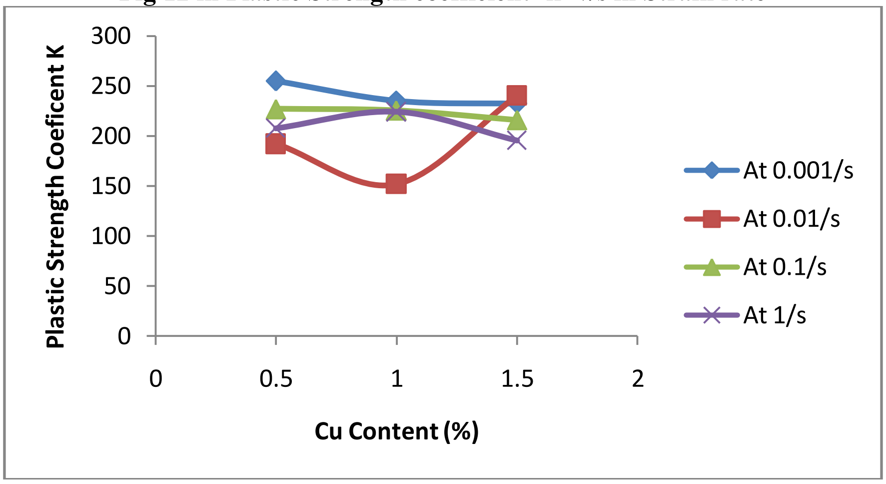

Fig.13 Plastic Strength coefficient 'k' v/s Cu Content

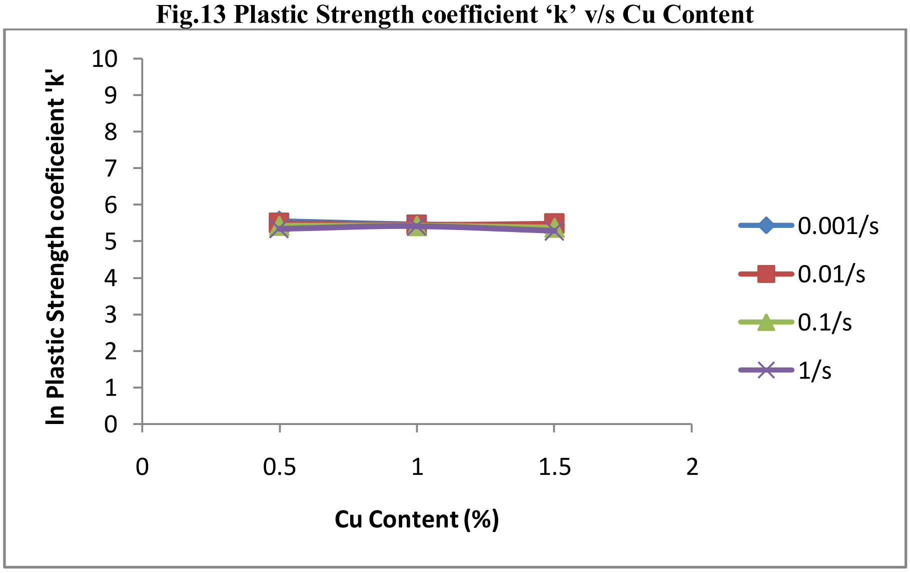

Fig. 14 ln Plastic Strength Coefficient 'k' v/s Cu Content

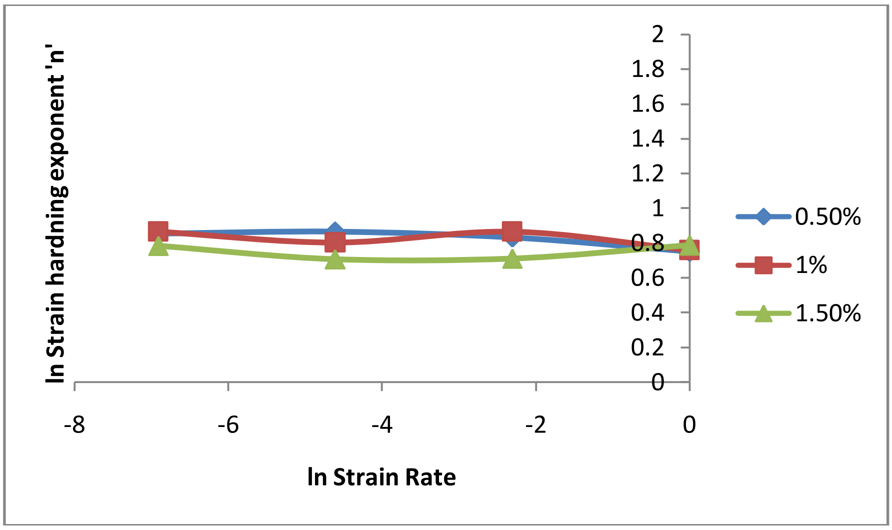

Fig.15 ln Strain hardening exponent 'n' v/s ln Strain rate

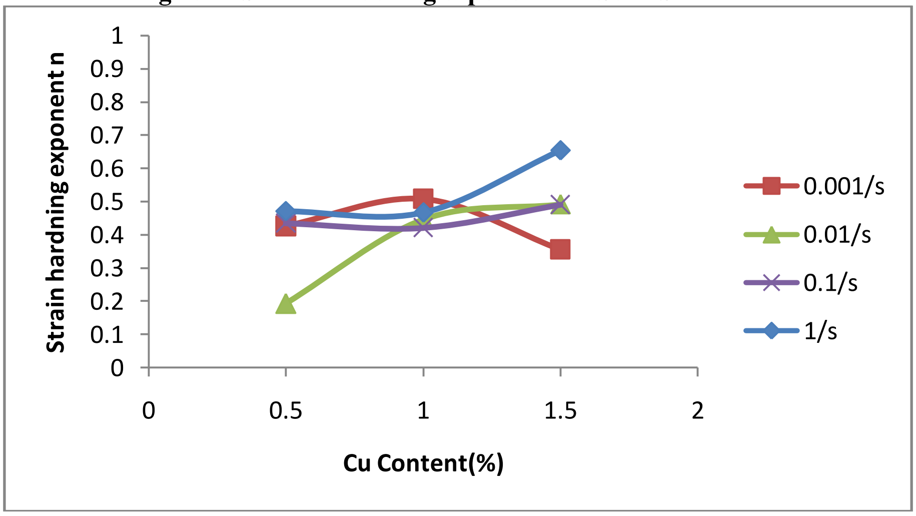

Fig.16 Strain hardening exponent 'n' v/s Cu content

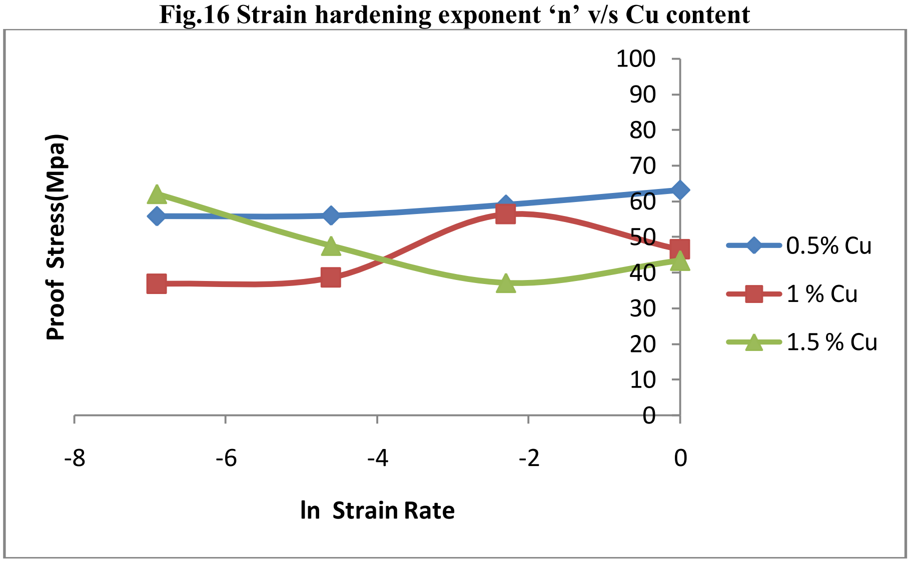

Fig.17 Proof Stress v/s ln Strain rate

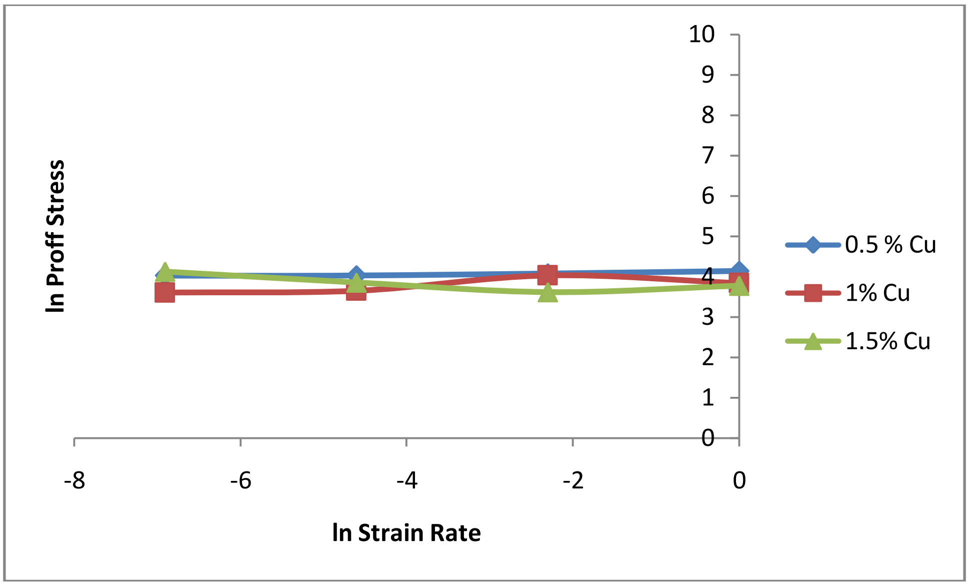

Fig.18 ln Proof Stress v/s ln Strain arte

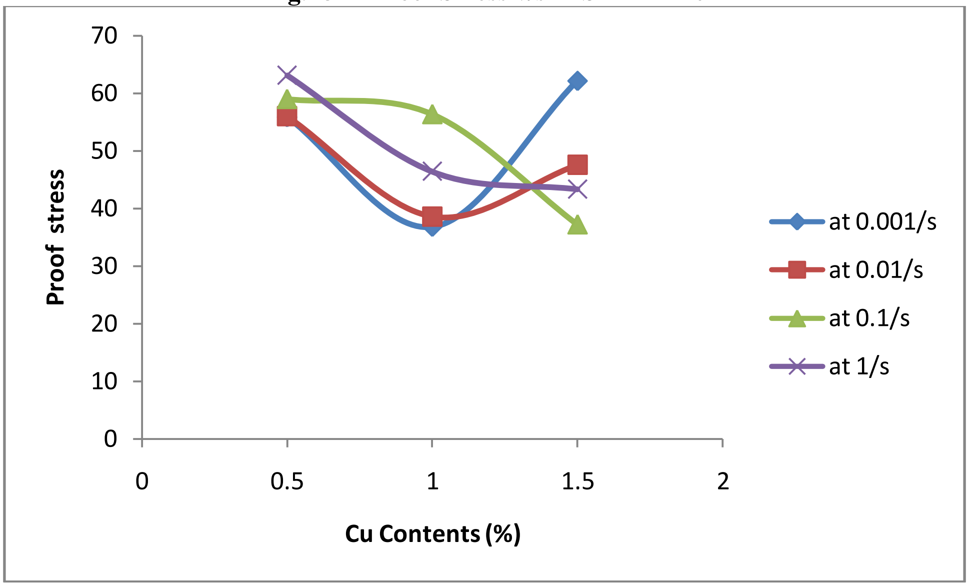

Fig.19 Proof Stress v/s Cu Contents

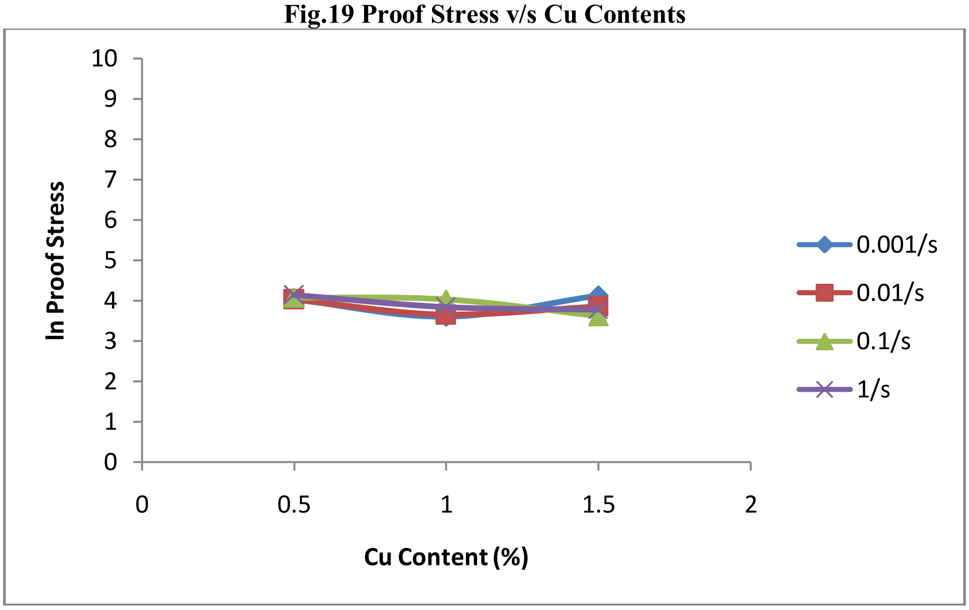

Fig. 20 ln Proof Stress v/s Cu Content

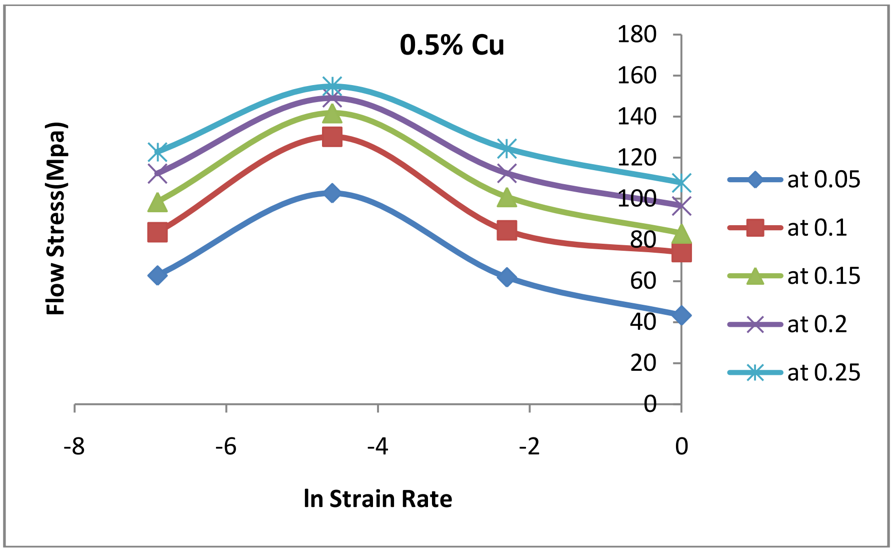

Fig 21 Flow Stress v/s ln Strain Rate

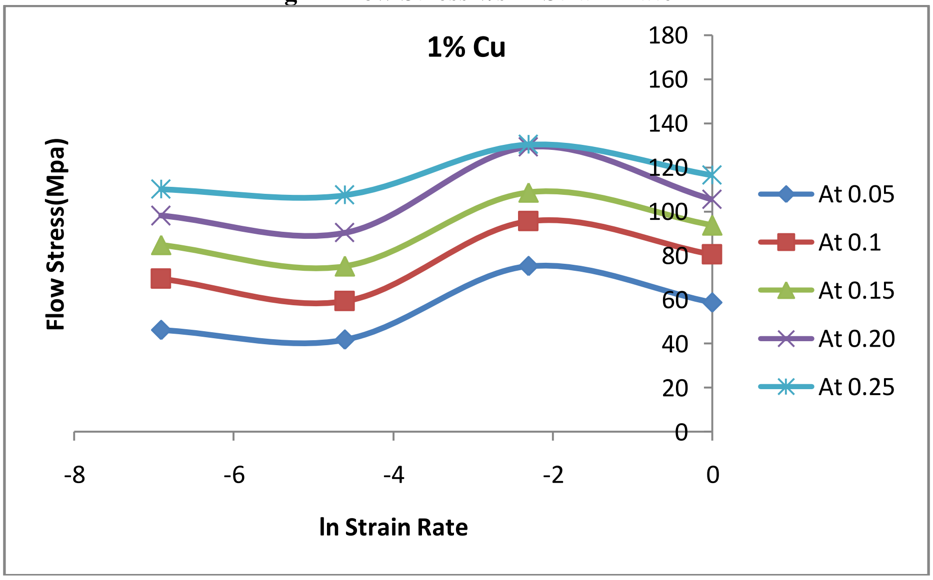

Fig. 22 Flow Stress v/s ln Strain Rate

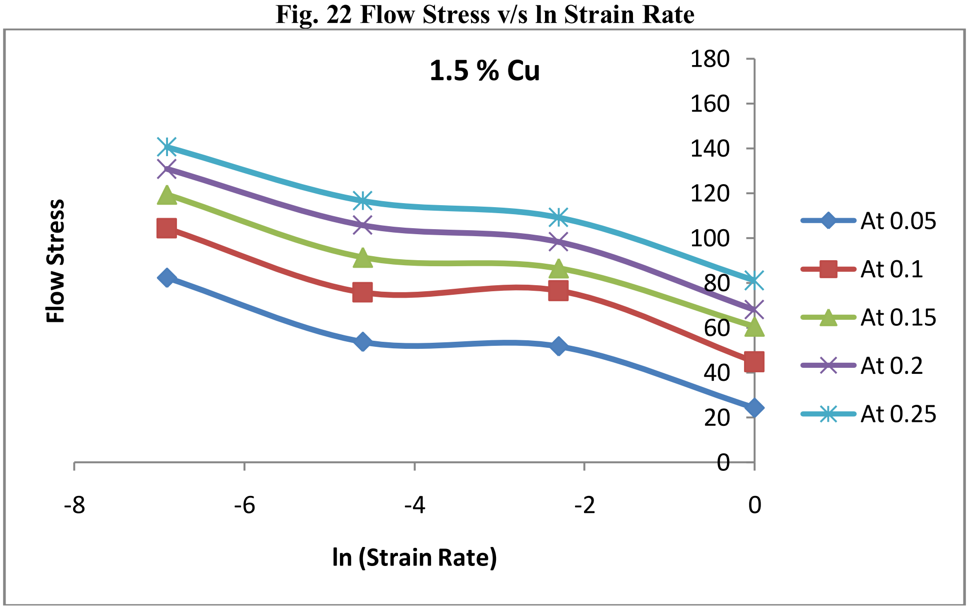

Fig 23 Flow Stress v/s ln (Strain Rate)

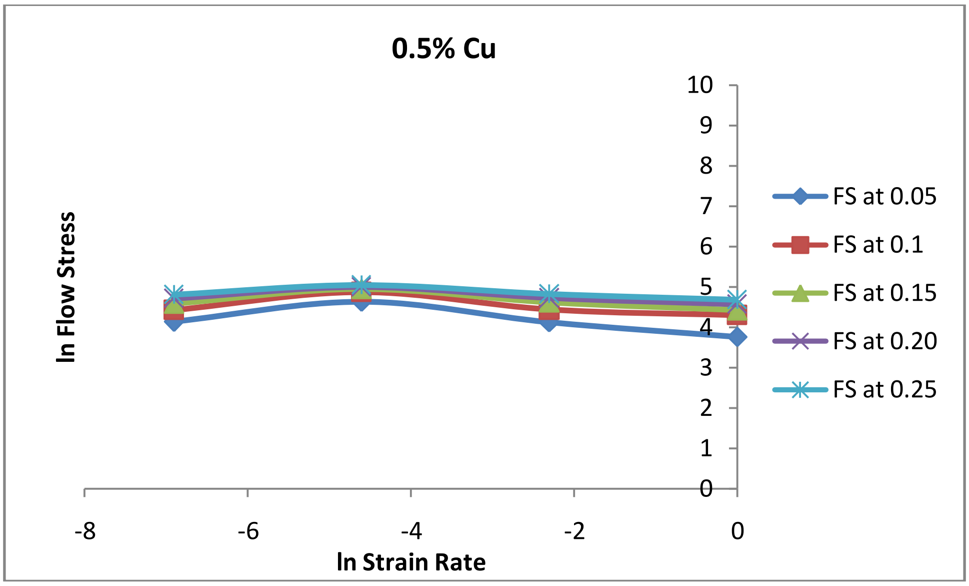

Fig. 24 ln Flow Stress v/s ln Strain Rate

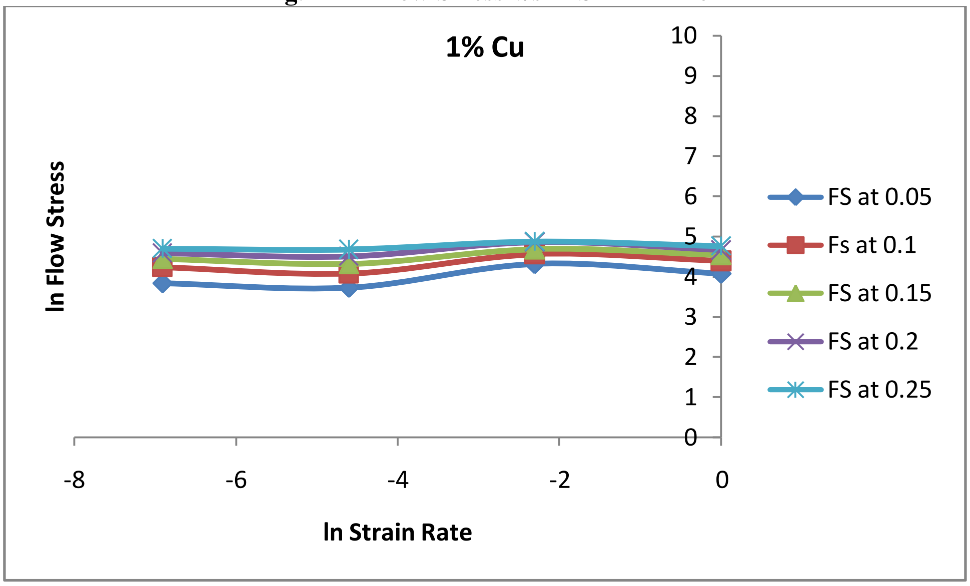

Fig 25 ln Flow Stress v/s ln Strain Rate

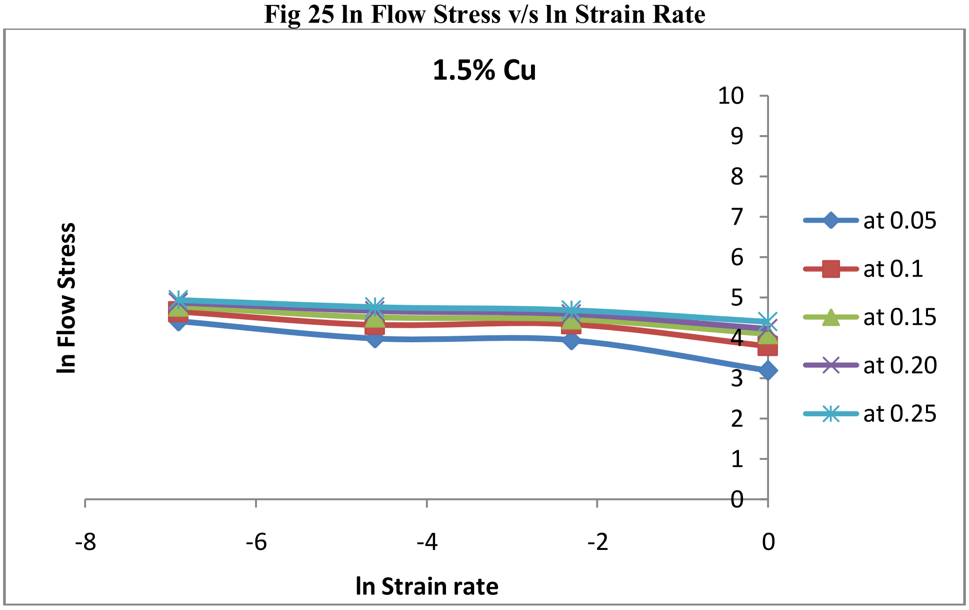

Fig. 26 ln Flow Stress v/s ln Starin Rate

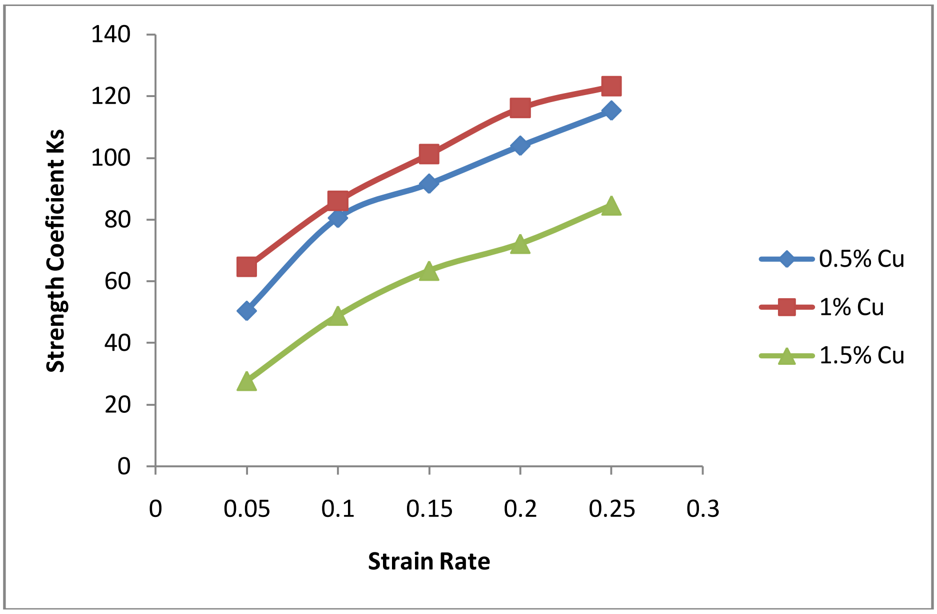

Fig. 27 Strength Coefficient 'Ks' v/s Strain Rate

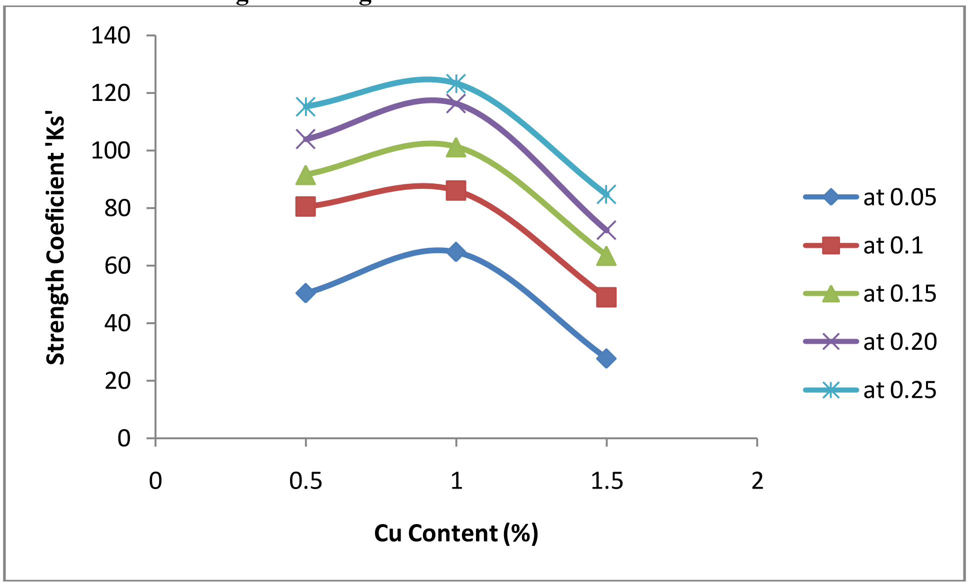

Fig. 28 Strength Coefficient 'Ks' v/s Cu Content

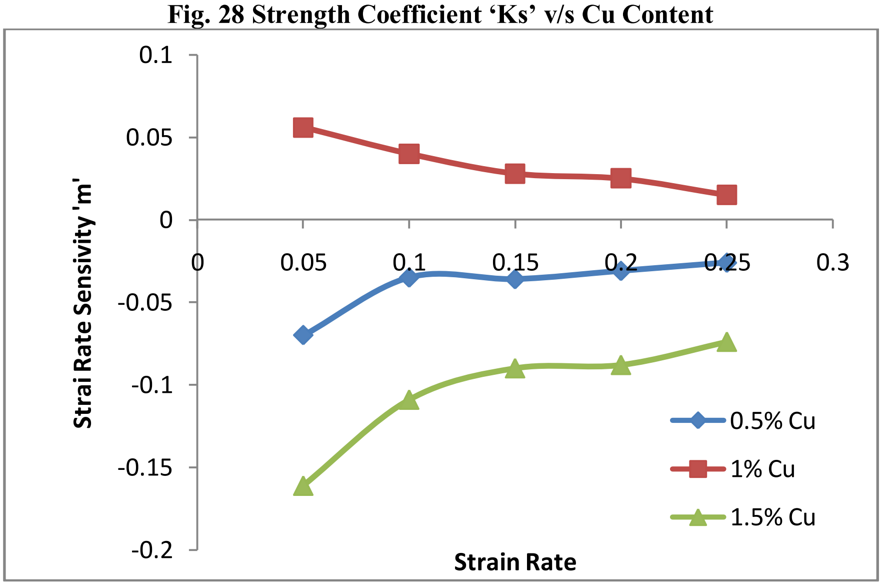

Fig.29 Strain Rate sensitivity 'm' v/s Strain Rate

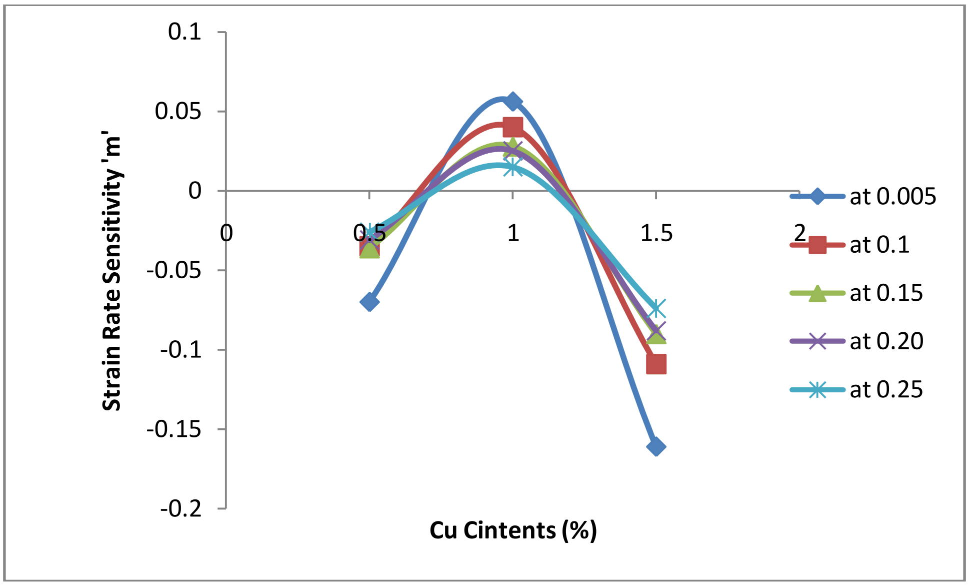

Fig. 30 Strain Rate Sensitivity 'm' v/s Cu Contents

IV. Conclusion:

The following are the 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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