Investigation of Mechanical Properties & FEM Simulation of Cu-Sic Composites Fabricated by Stir Casting Technique

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Abstract— This paper presented on an experimental and finite element analysis (FEA) of the compression test of Cu-Sic composite. The influence of this test is to investigate the strength and reduction in length on the application of compressive load, of the cylindrical specimen. The composite material was prepared by Stir casting technique and specimen prepared by machining for the purpose of the experimental research. Compression testing was performed by UTM at fixed strain rate for every sample and hardness test was acquired by CETR-Nanoindentor. All data obtained from the instrumentation was taken and evaluated using a personal computer (PC). A finite element analysis (FEA) of the compression of sample was undertaken after the experimental programme. The FEA simulation was carried out using Hypermesh software. A 3D finite element model of the specimen was constructed for the analysis. Data obtained from the FE model included distributed load, effective stress and strain and material deformation rate. The correlation between the experimental, calculated and FEA data acquired in this research is presented and deliberated.

Key words: Mechanical Properties, Stir Casting Technique, FEM Simulation

I. INTRODUCTION

Pure Copper is used in many industries because of its good mechanical, thermal and electrical properties. It is mainly used in electrical applications due to its high thermal and electrical conductivity. Copper plays a big role in energy efficient and long lasting maintenance free structures that are visually good and fully recyclable. However its low hardness, high softness, and low wear resistance limits its uses in structural applications. It is better known that the silver has the highest electrical conductivity, but it has limited application due to its high cost. As major used materials are Copper and Aluminium, Copper is preferred first because of its higher conductivity as well as the high strength as compared to Aluminium [1, 2]. Now a day in the field of electronics industries there has been a huge demand of such materials which has high mechanical, thermal and electrical properties as well as high conductivity [3]. To fulfil this demand a new class of materials are introduced in terms of metal composites, which exhibits high mechanical properties and high wear resistance without compromising in thermal and electrical conductivity. The Cu-Sic composites are best suited in this place. Research on Cu-Sic composites have been widely done, for their excellent mechanical, electrical and thermal properties [4]. It has been also studied that the mechanical properties of Copper can be dramatically enhanced by age hardening or by adding dispersed particles such as ceramics in its composition. The age hardening of copper is less preferred because of its possibility to be low corrosion resistance at high temperature thereby reducing their strength drastically. The dispersion particles such as carbides, oxides, borides are insoluble in the Copper and thermally stable at high temperature [5].

The Cu-Sic composites shows high stiffness, superior room and elevated temperature strength, improved wear resistance and low coefficient of thermal expansion. Copper composite materials has capability of high electrical conductivity (above 80%) and high temperature workability (refer from International Annealed Copper Standard (IACS)) [5, 6]. Thus the research in fabricating Copper based composite is ongoing including Cu-Al_2O_3, Cu-Zr-Al_2O_3, Cu-Si_3N_4, and Cu-Sic [6-7]. Method of fabricating these composite materials includes casting, liquid and powder metallurgy [7]. The mechanical properties of ductile material can be obtained by tensile test. However when the plastic deformation is the aim of study there tensile test limits, in spite of that compression test is preferred. As it allows large deformations without the fracture of the specimen. For this test cylindrical specimen is mostly adopted. Many studies had done concerning the mechanical properties of metals and composite materials. Altan et.al, Studied the influence of flow stress and friction upon metal flow in upset forgings of rings and cylinder [8]. Hashmi analysed the compression of cylinders between flat platens with unequal frictional properties [9]. P.K. Rohtagi studied prediction of mechanical properties of bimodal nano-aluminium alloys investigating stress and strain [10].G. Celebi studied the effect of sic particle size on Cu-SiC composite [11]. A.S. Prosviryakov, G. Celebi, K. K. Gan et. al. studied the effect of the sic content on the properties of Cu-Sic composites [12, 13, and 14]. The present investigation aims to evaluate and predict the compressive strength of short cylinder specimen made of Cu-Sic (2 and 4 wt %). The industrial importance is attached to this material; hence an attempt has been made to investigate the influence of deformation behaviour of Cu-Sic composites at 8.6 g/cm^3 and 8.35 g/cm^3 density for 2 and 4 wt% respectively of composite. In addition, we have made attempt to define the stress-strain and deformation of specimen at different loads.

II. EXPERIMENTAL DETAILS

A. *Material Synthesise & Sample Preparation*

The Cu-Sic composites having 2 and 4 wt% of Sic, was prepared using Vibrating Stir Casting technique. The flow sheet of technique is shown in figure 1. The Cu was first melted at 1100^0C in an Electrical Resistance Furnace and then the melted metal was mixed with Sic (2 and 4 wt% separately) through the mechanical stirrer rotating at an angular velocity of 300 rpm. Cu-Sic melted mixture was poured in to the preheated cylindrical dies and stirring continuous till proper mixture of Cu-Sic. 5kg batch of Cu-Sic (2 and 4 wt %) was made through this technique. Fingers were casted in cylindrical cast iron die of 20mm diameter and 20mm height. Eight Samples of 10mm diameter and 10 mm height were prepared out of which four samples was of 2 wt% and remaining four samples was of 4 wt% Sic particles and then the compression test was done.

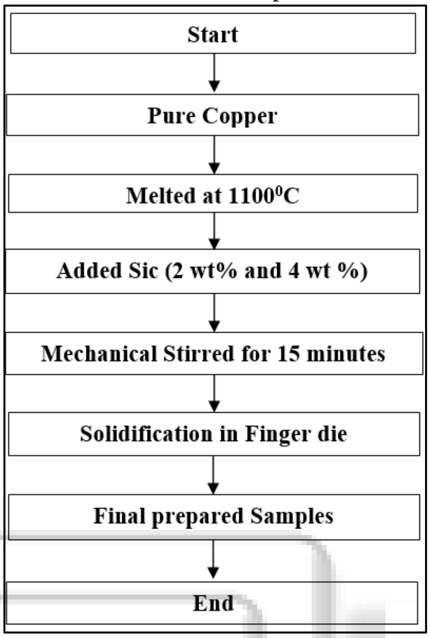


Fig. 1: Flow Sheet for Making Cu-SiC Composite

B. *Compression Test*

Eight cylindrical samples of 10mm diameter and 10mm height were examined for compression test at 0.01mm/s strain rate at room temperature (24^0C). The compression test was conducted using an Instron Universal Testing Machine (Model No. 8801). During the compression test sample were allowed to come at particular room temperature for 15 minute in order to ensure uniform temperature during deformation. In order to reduce the friction between sample surface and test platen, the specimen surface as well as the platen surface were coated with solid lubricant Mo_2S_2. The deformed sample were cut transversely, polished, etched and proposed for nano hardness measurement, using a load of 50mN in a CETR-Nanoindentor (Model: Nanosurf-Nanite B). The hardness was determined through nano hardness measurement. To explain the plastic deformation the experimental data obtained from compression test is described by the Holloman equation (see equation a), where σ_T is true stress, ϵ_T is true strain, K strength coefficient and n is strain hardening exponent.

$$\sigma_T = K \in_T{}^n \qquad (a)$$

The coefficient in equation (a) can be obtained by power law approximation of the experimental data obtained by compression test. With the corresponding forces and the displacement of plate, the strain can be calculated by;

$$\in = \frac{L - L_o}{L_o} \qquad (b)$$

Where L is deformed length and L_o is initial length. The area of contact of specimen with plate in contact is assumed to be remains constant the stimulating stress can be determined from the following relation;

$$\sigma = \frac{F}{A_o} \qquad (c)$$

Where F is maximum Load applied and A_o is area of cross section.

C. *Hardness*

Contour diagram as shown in fig.2 shows the measured hardness values for Cu and Cu–SiC composites versus SiC particle size and content[at present. To predict the hardness of Cu–SiC composite as an amount of added SiC ingredient a contour diagram was established. Actually, the hardness of copper improves significantly with the additions of SiC particles at the cost of its ductility [15] that can be attributed to higher hardness of SiC [16]. This result was consistent with another research [17]. It is thought that higher amount of ceramic particles in the composite would result in increment of hardness of the composite [18, 19]. The average hardness of Cu–SiC composite specimen with 2 and 4 wt% of SiC particles is 188 HV and 262 HV respectively higher than that of the Cu. This may be due to the inclusion of SiC in the composite.

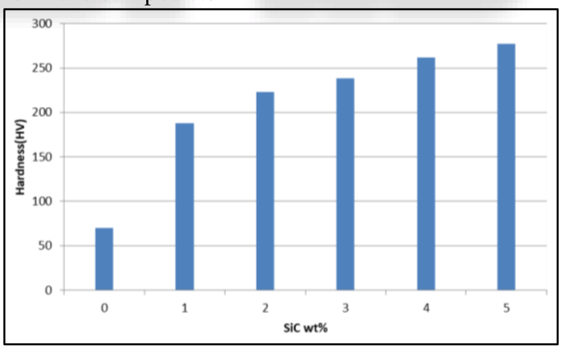


Fig. 2: Hardness Contour Diagram for Cu-SiC Composite

Specimen	Displacement Applied (mm)	Load (N)	Stress (MPa)	Strain (MPa)	Young's modulus E (MPa)	Yield Stress (MPa)	Ultimate Compressive Stress (MPa)
2a	6.651	89766	1143.000	0.3349	3411.94	205	370
2b	7.123	94997	1209.544	0.2876	4180.56	195	370
2c	6.775	94999	1209.566	0.3225	3750.33	220	370
2d	6.918	95010	1209.709	0.3090	3912.00	175	370
4a	7.233	94995	1206.599	0.277	4369.82	170	350
4b	7.202	94766	1206.599	0.798	4311.91	160	350
4c	7.036	95033	1209.998	0.296	4082.32	140	350
4d	7.298	94999	1209.563	0.270	4476.55	130	350

Table 1: Experimental Results

Specimen	Strength Coefficient K (MPa)	Strain Hardening exponent (n)
2a	370.704	0.172
2b	355.569	0.134
2c	362.941	0.189
2d	342.099	0.140
4a	348.487	0.198
4b	417.924	0.233
4c	352.165	0.142
4d	338.999	0.592

Table 2: Coefficients of Hollomon Equations

D. *Finite Element Analysis*

The finite element analysis consists of tetrahedral elements with 1.0mm length. The software adopted was Hypermesh (Pre-processor), Radioss (solver) & Hyperview (postprocessor). Here lower and upper faces present only axial displacement in the compression test. In FE model the lower face was fixed (restricted from all degrees of freedom) and a plate with contact elements was used to apply the compression forces in the upper face, its value is taken from reference table 1, respectively for every specimen. Poisson's ration taken is 0.33 for every specimen and the elastic modulus considered was the value determined from the experimental test. Figure 3 shows the analysed FE model.

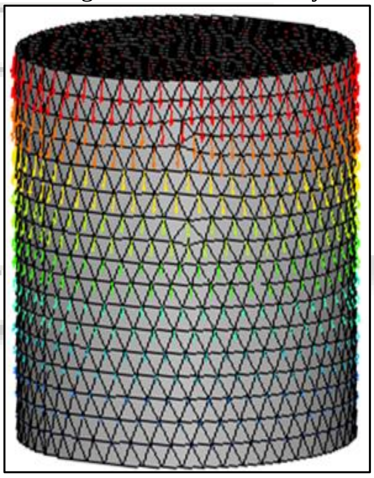


Fig. 3: Finite Element Model

III. RESULTS & DISCUSSION

A. *Compression Test*

The true stress- true strain curves of Cu-SiC with 2 wt% and 4wt% of SiC at room temperature, at a fixed strain rate (i.e. 0.01/s) is shown in fig. 4. It is obvious, that there is no discrete yield point on these curves. Rather, there exists a continuous transition from yield to plastic region as was observed in most of the cases in compression test of ductile materials. It is clearly noted from the fig. 4, that the flow stress of Cu-SiC composite increases with increase in load. It is also noted that the flow stress of Cu-SiC composites increases with increase in SiC content. It was further noted that from the specimens that in the true stress-true strain curve which was due to shearing of sample and generation of cracks in the shear plane during compression testing. After shearing, the sample again gets compacted and the stress increases. It is evident from this fig. 4 that the flow curves vary marginally with strain rates indicating that the deformation response was marginally influenced with the strain rate. There is a tendency of either softening or work hardening after yielding (i.e. in the plastic region). The yield stress (0.2%proof stress), maximum compressive stress and elongation are recorded from these stress- strain curves and reported in table 1. It is evident from this table that the yield stress and maximum compressive stress increase significantly with increase in SiC content. The magnitude of these parameters (yield stress and compressive stress) varies with increase in wt% of SiC content. The plastic strain increases with increase in wt% of SiC.

The summary of experimental test is shown in Table 1 for every specimen undergone through compression test and the calculated result (stress, strain and elastic modulus).

From table 2 and figure 4

1) All specimens entered in to the plastic region.
2) The average elastic modulus is 3813.675MPa which is lower than the real value of copper, this lower value was expected and is due to L_o/D=1 ratio, according to [13].
3) The yield stress varied from the 130MPa to 205MPa, theses value agrees with the result obtained Kuen-Ming Shu [7].
4) Strain calculated for every specimen, the specimen 4d results lower value.

As the true stress-strain curve presented in figure 2 and, the coefficient of Holloman's equation (a), were determined by the power law approximation method. The results are shown in table 3.

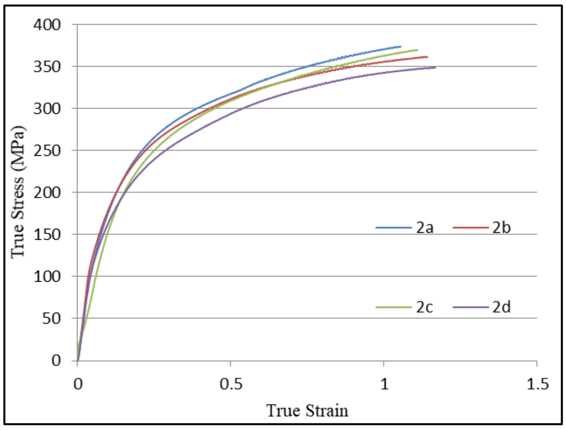
1) The strength coefficient (K) average value is 361.111MPa.
2) The strain hardening exponent (n) average value is 0.209, and specimen 4c leads to minimum value.

The value of strain hardening exponent for every tested specimen is found less than the strain hardening exponent (n) value of pure copper (0.44), which indicates the material to be plastic solid material. With the inclusion of Sic in copper it get strengthen and hardened [16].

B. *FEA Result*

The stress strain curve obtained from FEA simulation is shown in figure 5.

1) Minimum principle stress found in 2a specimen
2) The plastic strain obtained for specimen 4c is greater than calculated strain.



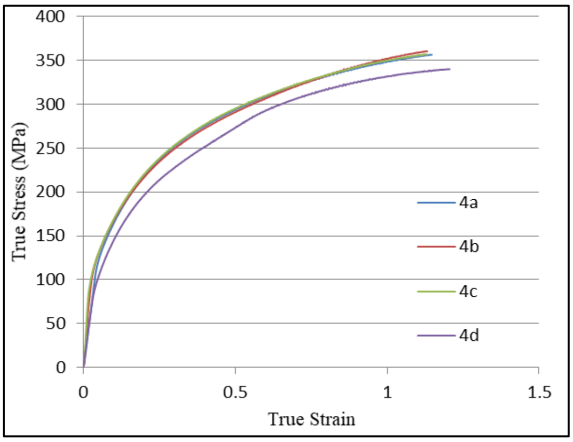
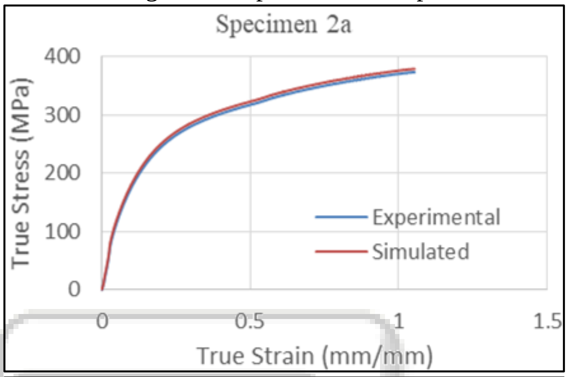
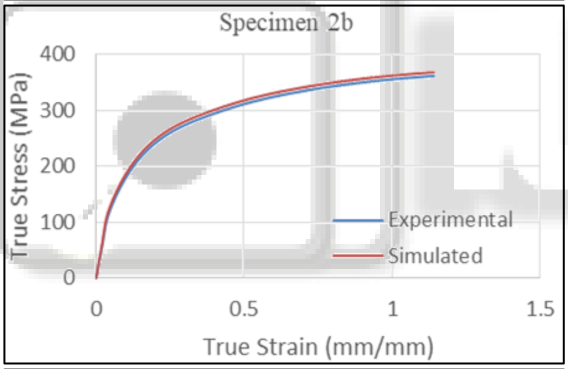
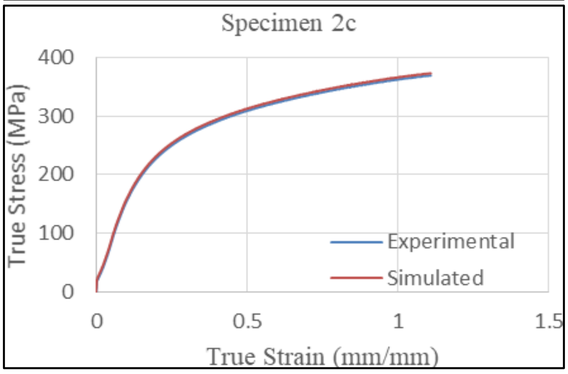
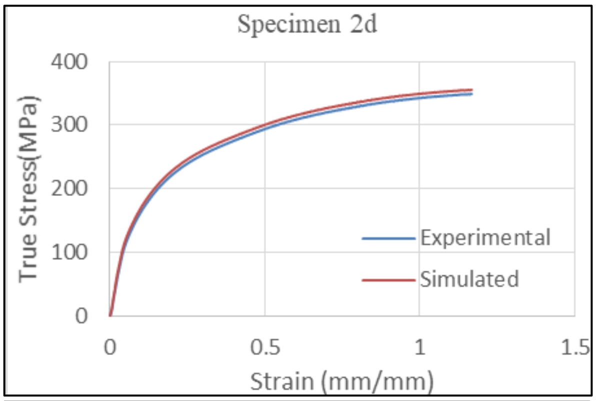


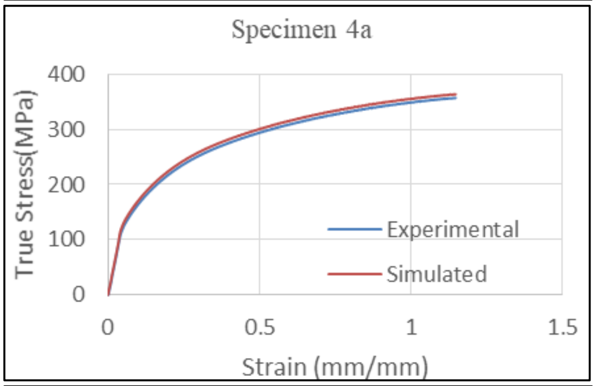
Figure 4: Experimental Graph

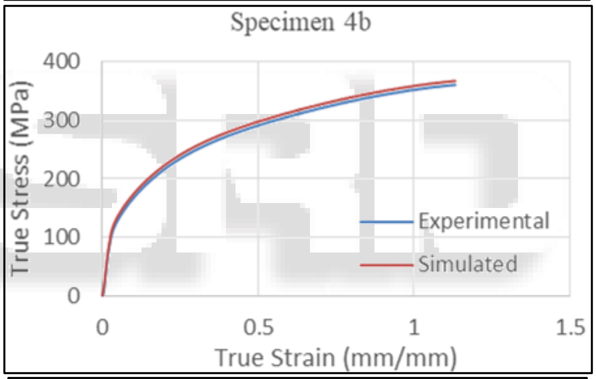


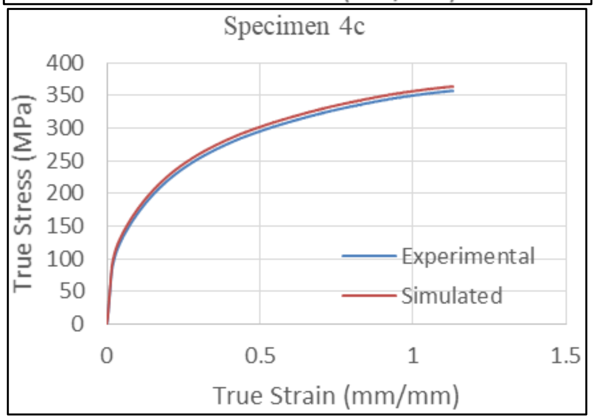












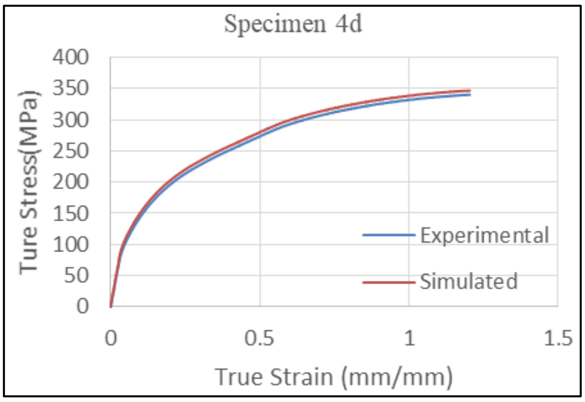
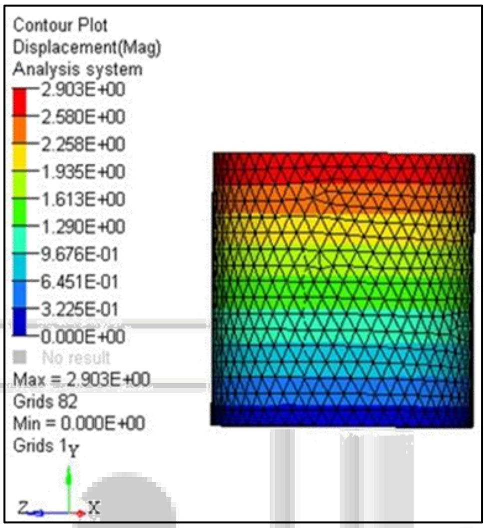
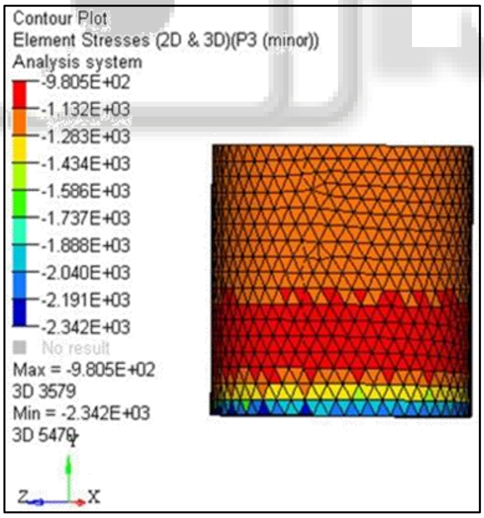
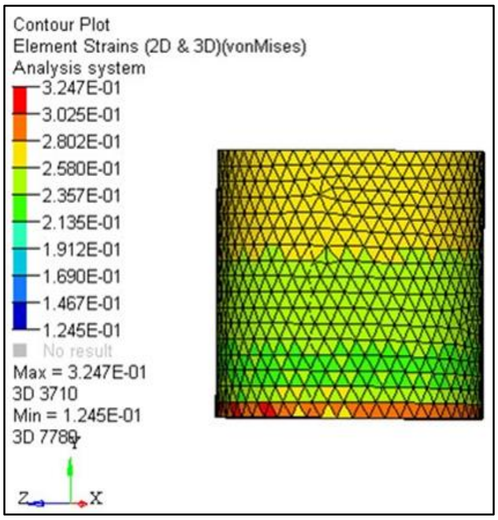


Fig. 5: Experimental & Simulated True Stress-True Strain Curve







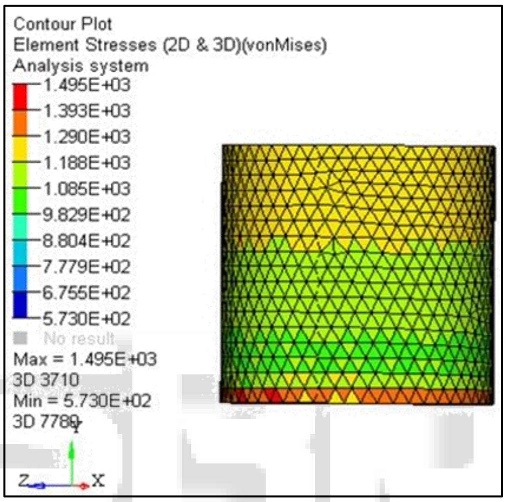


Fig. 6: FEA Results for 4c Specimen

IV. Conclusion

The average yield stress obtained from experiment (161.875MPa) is lower than the pure copper yields strength, which result that the Cu-Sic composites get harder as compared to pure copper. FEA results presented satisfactory correlation to the experimental test, the three dimensional FE simulations of compression tests have been examined to validate the defined model in transverse (Y) direction for all the specimens. From these tests, the true Stress–strain behavior (see fig 5) can be acquired, and these curves are considered to be a validation of hardening parameters and initial quality. The evaluation of the simulated stress–strain curves with the experimentally acquired stress–strain curves will disclose the validity of the material model. As it is clear from fig. 5, FE simulations are in good promise with the experimental values of the tired samples. However, there is a clear conformity at strains above of the drawn samples of 2d and 4a, as shown in fig. 5. This may be due to inclusion of SiC content in the copper. It is perceived that the hardness of sample 2d and 4a shows little less reduction in grain size, from the centre to the edge of the specimen, comparative to other samples, because the specimen is more compressed at the outer surface during the compression test. Here the difference, concerning specimen of 2 wt% of SiC has large deformation as compared to 4 wt% of SiC, it conclude that the properties of Cu-Sic composites such as hardness, density and strength has been improved with increasing the wt % of SiC. With the addition of SiC particulate, hardness of copper is effectively improved.

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