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Original Article

A Novel SPD Method and its Effect on Microstructure and Mechanical Properties of Cu Tube

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Abstract *- This article introduces tube channel tensile pulling, a groundbreaking method for the severe plastic deformation (spd) procedure for tubes. By performing many runs of the Tube Channel Tensile Pulling (TCTP) process, grain refinement as well as mechanical characteristics were investigated experimentally and numerically. The original tube size sample had a 1-inch diameter and a thickness of 0.3 cm. The TCTP procedure involved four passes of the tube through the die. After the third pass, the strength gradually increased significantly. Additionally, the grain size was around 200 nm, which was confirmed by EBSD (Electron Beam Electron Backscatter Diffraction). Mechanical properties such as Ductility, Ultimate Tensile Strength, and Hardness were also studied. The microhardness value of the tube increased after the third pass of the SPD process. Samples for Scanning Electron Microscopy (SEM) were polished using a polishing machine.*

Keywords *- Tube sample, Grain refinement, SEM, Microhardness, Tensile stress.*

1. Introduction

The Hall-Petch equations [1], [2] state that the strength of a material dramatically increases at standard ambient temperature as the grain size decreases. Microstructural characteristics and temperature at room temperature affect a material's structural and mechanical characteristics. In order to treat metal, Torkestani et al.'s [3] innovative technology of SPD severe plastic deformation takes into account both high hydrostatic pressure and shear deformation.

Today's SPD techniques are built on this. Bell et al. focused their [4] research on the numerical simulation of cold-drawn steel tubes with straight internal rifling. He examined different roll diameters pulling forces in KN. Limited hydrostatic compressive stress levels and negligible grain boundary angles can be found in unoriginal metal forming techniques [5], [6]. There have been several SPD approaches planned during the past 20 years.

These techniques are suggested for the production of nano- and ultrafine-grained materials. The cold working technique is utilised in the majority of sectors to produce a variety of components. Below the recrystallisation temperature for metals and alloys, a cold drawing is used. The die angle impacts the surface finish of the tube; a mild angle produces an excellent surface finish, while a steep angle produces a harsh surface finish. Using Equal Channel Angular Pressing (ECAP), H.S. Kim et al. [7], [8] worked on the finite element analysis of steel tubes. The most typical spd procedure for producing UFG metal, equal channel angular pressing, was the subject of his research. G. Faraji et al. [9, 10] looked into Tube Channel Angular Pressing (TCAP) and Parallel Tube Channel Angular Pressing (PTCAP) and found that the comparable plastic strain contour is denser in PTCAP than in TCAP.

He worked on finite element analysis of two routes; route A and route C ECAP process, and discovered that the grain size is lesser in route C as compared to route A. On AA 6061, Jafarlou D. M. et al. [11], [12] used Tube Channel Angular Pressing (TCAP). He discovered that the most efficient method for applying significant Equivalent Plastic Strain (EPS) via the sample tube is Tube Channel Angular Pressing.

Using the fem approach, he illustrates the distribution of eps within the sample. Due to the corner angle, he discovered that the Equivalent Plastic Strain (EPS) was 0.7 at the top surface of the tube.The observed EPS value for the bottom area was 0.57. He measured the tube homogeneity in the middle of the tube route and discovered that p2 had a lower level of Equivalent Plastic Strain Value (EPS), whereas p3 and p4 had large levels [13], [14].

Fig. 1 Experimental set-up showing copper tube and cylindrical channel

Fig. 2 Original copper tube and TCTP processed samples

2. Experimental Setup

This investigation utilised copper tubes with a minimum commercial purity of 99.90%. Their outside diameter was 1 inch, length was 200 mm, and thickness was 3 mm. After two hours of annealing at 600 °C, the tubes' structure was thoroughly recrystallised and uniform before the TCTP procedure was employed. Up to three iterations of the TCTP protocol were performed at room temperature with a 5 mm/min punch speed. Prior to treatment with TCTP, die components were hardened to 55 HRC.

3. Sample Preparation

The die configuration consists of a punch, a fixed mandrel, a seal, and a die. As depicted in Figure 1, the procedure commences with the insertion of a mandrel-equipped cylindrical tube into the die. The mandrel will be removed, and the previous procedures will be repeated. Metal is expanded via extrusion to generate the requisite backpressure for the operation. The identical process is depicted in Figure 19(d). This method is repeated for First pass, Second pass, and Third pass.

4. Results and Discussion

The uniaxial testing machine at the advanced mechanical testing facility at IIT Bombay is shown in the Figure. The tensile test specimens were prepared as per the following dimensions.

Fig. 3 Polishing machine sample preparation for microhardness testing

Fig. 4 (a) Uniaxial tensile test machine and (b) copper tube sample cutting

4.1. Mechanical Properties (UTS & YS)

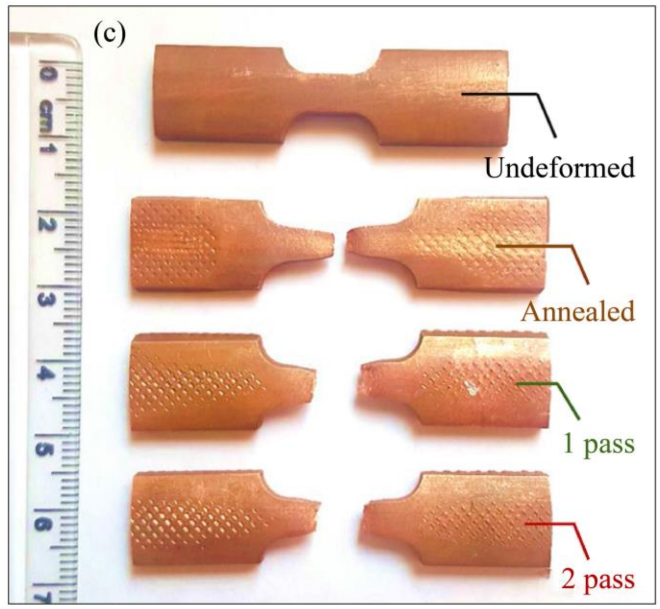
The microstructural and mechanical properties change as the metal is deformed and strain is induced in them. In the orthodox metal-making process, materials might be strong, but they might not essentially be ductile, and the reverse is also true. The stress-strain curves after three passes of the Severe Plastic Deformation (SPD) process for different copper tube samples are shown in Figure 4(a). After the Tube Channel Angular Pulling (TCAP) process, the identified mechanical properties of a tube, such as Ductility, Ultimate Strength (UTS), and Yield Strength (YS), significantly change. For different materials, strength as well as ductility are imperative mechanical properties.

The engineering stress vs strain curves of the original tube and processed tube are shown here. The Ductility Value, Ultimate Strength (UTS), and Yield Strength (YS) for the initial sample of the copper tube are low as shown. After the second and third pass of the TCAP process, the Ultimate Strength (UTS) Yield Strength (YS) goes on increasing. A material must absorb force and deform plastically without fracturing in order to be durable. The mechanical properties of TCTP processed tubes were studied over a uniaxial tensile test machine and microhardness tester. The testing samples required for uniaxial testing were prepared as per ASTM E8/E8M-9 standards It is carried out parallel to the axis of the tube. The deformed region was marked for or gauge zone, which is located in the middle of the tube and is more deformed. The length of the gauge region was 18mm. The width of the gauge region was 6mm. The depth of the gauge region was 3.5 mm. Generally, the tensile test goes at room temperature. The uniaxial tensile tests have to be executed at the strain rate of 1*10-4 s-1.

The Engineering stress vs strain curves were plotted for initial sheets and processed copper tubes in dissimilar passes of the TCAP process. It is witnessed that the tensile strength of processed tubes is higher than in initial tubes. Based on the uniaxial tensile test, the stress-strain diagram was plotted; ultimate tensile strain and elongation were calculated, as shown in the Figure 5(a)(b)(c).

4.2. Microhardness

The Vickers hardness test machine, as shown in Figure 5, is used to check the microhardness of the sample. For 20 seconds, a 50-gram load was applied to get VHN at the Vickers Hardness Test Machine. Six randomly chosen cross-sections perpendicular to the drawing directions were used to conduct a microhardness test on all three tube samples. Then, for all three copper tube samples Microhardness value was recorded.



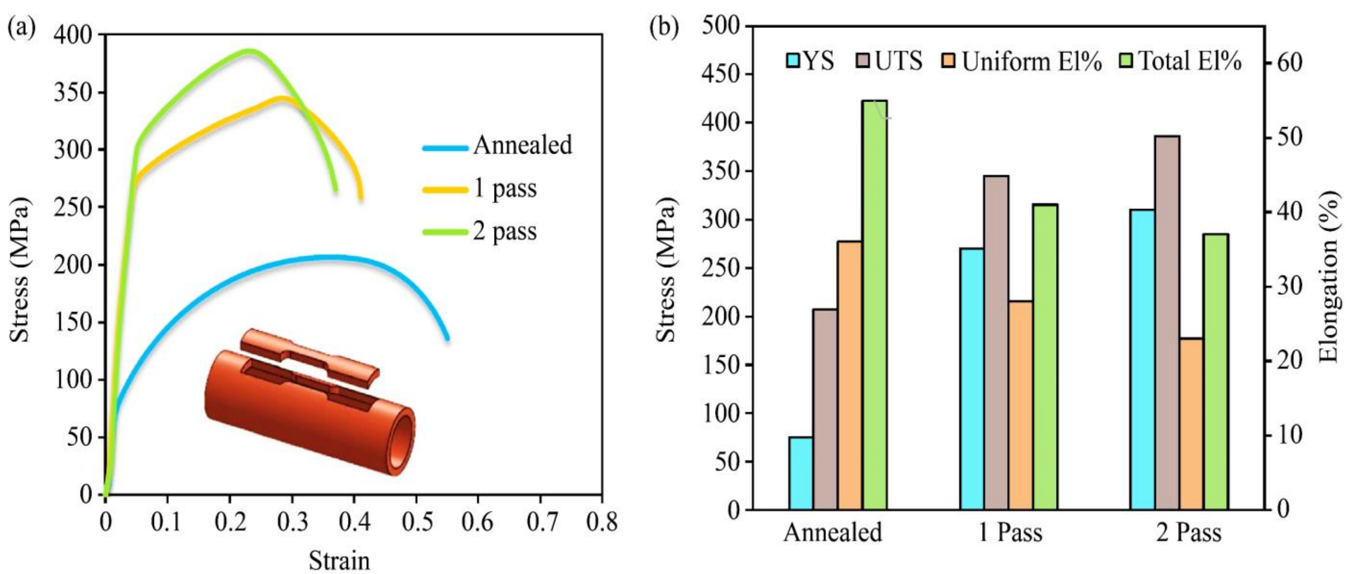


Fig. 5 (a) TCTP processed tube for stress-strain diagram, (b) Stress vs elongation for graph, (c) Tensile test samples

Fig. 6 TRB-250DM Microhardness testing machine

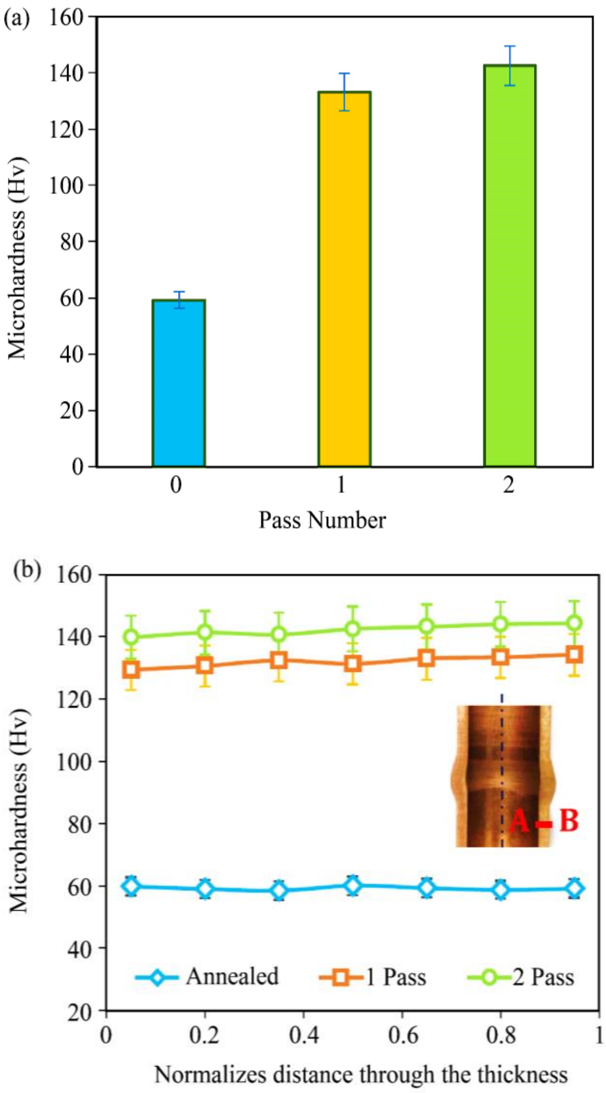


Fig.7 Effect of TCTP on Microhardness Vs Pass number

Table 1. Micro hardness values (Hv) and pass number

Microhardness Values (Hv)			
Annealed Tube	**Pass1**	**Pass2**	**Pass3**
60	84.3	83.8	85.8
75.1	79.2	85.4	92.1
76	84.5	81.4	94.5
75.4	79.9	86.9	94.9
74	79.5	84.6	94.2

In a TRB-250 DM micro hardness-testing instrument, the tubes' hardness was determined using a Vickers indenter with a force of 100 g and a stop time of 15 s. The indenter was inserted perpendicular to the tube's axis into a cross-section. The microhardness of five locations within the thickness of the tube was evaluated.

Table 1-Micro Hardness values (Hv) of tube samples after the TCAP process. From the table, we can observe that the microhardness value goes on increasing from pass 1 to pass 3.

4.3. Surface Morphology

Figure 8 shows SEM (scanning electron microscopy) images for the respective passes of the tube sample. Zeiss did the experiments at IIT Bombay. Surface roughness parameters Ra and Rq were derived to quantify the roughening defect evolution.

The next paper will detail the correlation between these two microstructural metrics, particle size and surface roughness. Surface roughness parameters are visualised as they change with particle size. As the grain size increases, the surface roughness value (Rq and Ra) also increases.

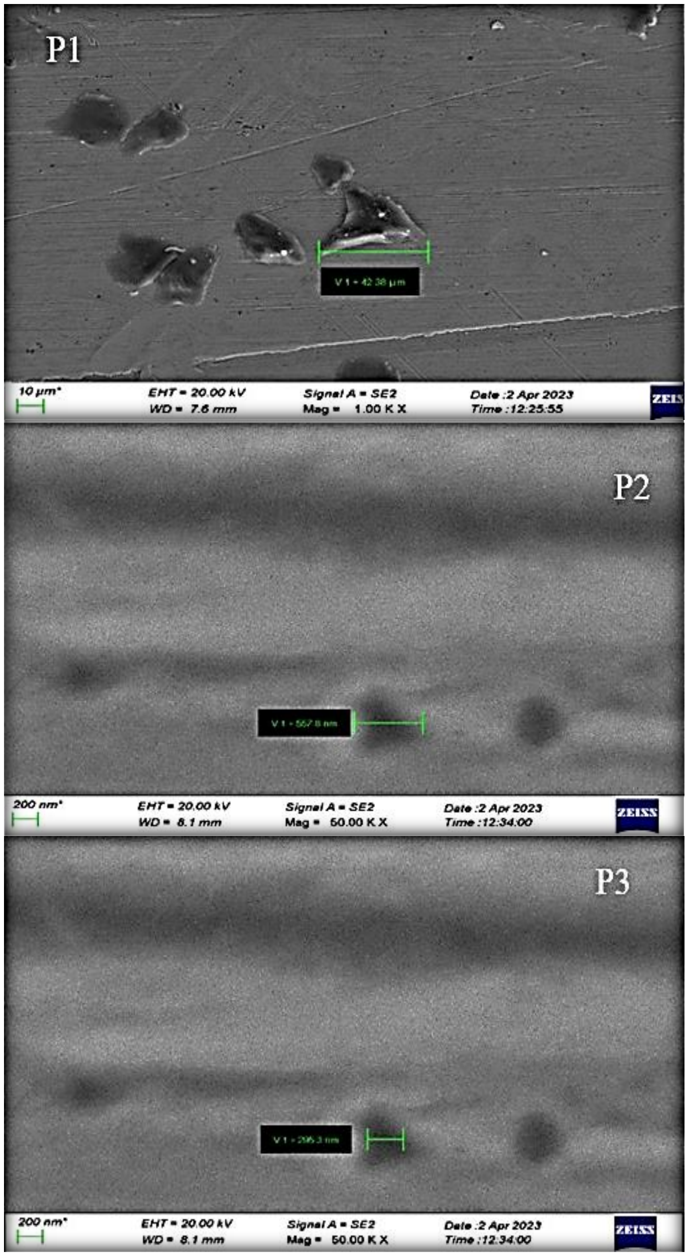
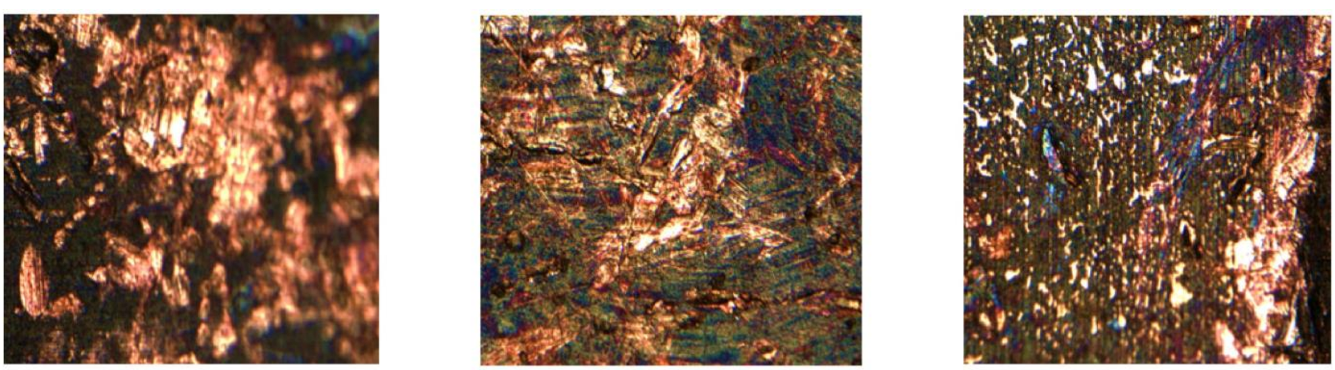


Fig. 8 Scanning electron microscopy images taken on tube surface view



Pass 1 Pass 2 Pass 3

Fig. 9 Optical microscope images for pass 1, pass 2 and pass 3

4.4. Analysis of Variance (ANOVA)

ANOVA is a statistical method used to compare the means of three or more groups to determine if there are statistically significant differences among them. There are several types of ANOVA, including one-way ANOVA, which compares the means of one factor across multiple groups, and two-way ANOVA, which considers the effects of two factors simultaneously.

The null hypothesis in ANOVA states that there are no significant differences among the group means. In contrast, the alternative hypothesis suggests that at least one group's mean is different from the others. ANOVA is designed to check differences among means from populations subject to different treatments. Here we have used ANOVA for statistical analysis of mechanical values such as ultimate tensile strength, strain variation and microhardness.

Ultimate tensile strength values in axial and peripheral directions are shown in Table 2. These values are analysed statistically by ANOVA test. We found that the P-value was not significant for ultimate tensile stress, as the P-value should be less than 0.05. This was due to a test carried out on one sample only. Similarly Strain variation values in axial and peripheral direction were studied statistically by ANOVA test. P-value of 0.43 was not significant. The P-value should be less than 0.05. Microhardness Values (Hv) in axial and peripheral directions were studied statistically by ANOVA test. P-value was significant which is less than 0.05. The P-value should be less than 0.05 to be significant.

Table 2. ANOVA for ultimate tensile stress in axial and peripheral direction

	Ultimate Tensile Strength (Axial Direction)	**Ultimate Tensile Strength (Peripheral Direction)**	**t-value**	**p-value**
Annealed sample	343	354	**0.37**	**0.73** Not Significant
One pass	374	389		
Two passes	411	429		
Three passes	443	442.5		
Mean	**393**	**404**		
SD	**43.6**	**40.1**		

Table 3. ANOVA for strain variation in axial and peripheral direction

	Strain Variation (Axial Direction)	**Strain Variation (Peripheral Direction)**	**t-value**	**p-value**
Annealed sample	12.5	15	**0.19**	**0.43** Not significant
One pass	6.42	7		
Two passes	5.4	4.5		
Three passes	5.5	5.6		
Mean	**7.46**	**8.03**		
SD	**3.39**	**4.76**		

Table 4. ANOVA for microhardness values for pass 1, pass2, pass3

	Microhardness values (Hv)				**F-value**	**p-value**
Sample 1	**Annealed Tube**	**Pass1**	**Pass2**	**Pass3**		
location 1	60	84.3	83.8	85.8	**21.07**	**0.00** Significant
location 2	75.1	79.2	85.4	92.1		
location 3	76	84.5	81.4	94.5		
location 4	75.4	79.9	86.9	94.9		
location 5	74	79.5	84.6	94.2		
Mean	**72.1**	**81.48**	**84.42**	**92.3**		
SD	**6.80**	**2.68**	**2.04**	**3.79**		

5. Conclusion

This work was carried out at Amity University in the mechanics of solid laboratory. In this work Tube Channel Angular Pushing Process (TCAP) is announced as the new method of the SPD deformation process. In this method, a pure copper pipe is passed through the die for several passes. Grain size after the three passes of TCTP is extremely small, as per EBSD analysis. The material's microhardness, ductility, and Ultimate Tensile Strength (UTS) were also measured.

The Yield strength and ultimate tensile strength of the material increased significantly. The TCAP procedure increased the tensile strength to 270 MPa and the Ultimate Strength (UTS) to 345 MPa from their respective original values of 75 MPa and 207 MPa, respectively. In addition, total and uniform elongation decreased from 55% to 36% and 41% to 28%, respectively, after just one cycle of TCTP. The loss of ductility was considerably less than with other SPD techniques.

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