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A REVIEW ON SPD PROCESSES TO PRODUCE ULTRAFINE-GRAINED AND MULTILAYER NANOSTRUCTURED TUBES

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Abstract: During the many years, severe plastic deformation study carried out based on processes suitable for sheet and solid materials. But the review to study the SPD methods suitable for nanostructure tube yet not done. So efforts have been put to review and develop effective SPD processes suitable for producing cylindrical tubes. Severe plastic deformation is recognized to be the paramount method for manufacturing bulk ultrafine-grained and nanostructured materials with high strength and hardness. The present study is about the stat-of-the-art review on different SPD methods suitable to produce ultrafine-grained and multilayer nanostructured tubes. This study also reveals the impact of various tube SPD methods on the material properties of the tube. The comparison between them based on the advantages and disadvantages of SPD techniques are done based on the viewpoints of processing and properties. Also, find out the literature review gap for a more detail study on a multilayer nanostructured tube.

Keywords- **Severe plastic deformation process, Ultrafine-grained tube, Multilayer, Nanostructure, Microstructure, Mechanical properties.**

I. INTRODUCTION

The hall-Petch equations [2] state that when grain size decreases, It will increase the strength of the material very high at normal room temperature. A structural Mechanical characteristic of the material depends on microstructural properties and temperature at room temperature. This is a well-known fact. A polycrystalline material can be made infinitely strong by reducing its grain size. Also, the superplastic forming capability improves based on different hotness. One of the majority characteristics of the polycrystalline metal microstructure is grain size [1] dimensions. The advanced metal forming processes affect the high level of hydrostatic stress are known as severe plastic deformation method (SPD). These methods produce ultrafine-grained material that is with high angle grain boundaries exclusive of changing the material cross-section. Bridgman et al. [7, 8] offered a new method of severe plastic deformation in which both high hydrostatic pressure and shear deformation is considered for metal processing. This is the core of SPD methods today.The grain size is nomenclature based on different sizes. If the grain size of the metal in the industry is >10 µm, it is called coarse-grained material. If the grain size of the metal is 1-10 µm, Then the material is called fine-grained metal which is processed in the industry using thermo mechanical process.[3] If the size of the metal is less than 1 µm, it is called ultrafine grained material. And material having size of less than 100 nm is called nanograined. These material uses conventional thermomechanical and conventional metal forming processes. [1, 2, 4]

The main reason may be the limited amount of plastic strain that results from limitations in the cross-section. [5, 6] Conventional metal forming processes have limited values of hydrostatic compressive stress and very small grain boundaries angle [5, 6]. During the last twenty years, many severe plastic deformation methods have been planned. These methods are proposed to produce ultrafine-grained and nonmaterial's. The SPD methods are differentiated mainly based on deformation behavior, Different geometry of the workpiece.

SPD technique can be classified based on strain imposed in one pass and load required for the same pass. Complex shapes are difficult to process with SPD. Sheet and tubular components are processed using SPD methods [9] Equal channel angular pressing (ECAP), [2,10] cyclic extrusion-compression [11] and high-pressure torsion [12] are the oldest and main SPD processes suitable for bulk metals.

Other SPD techniques are bulk materials twist extrusion,[13,14]torsional-ECAP,[15] multiaxial forging,[16] cyclic expansion-extrusion,[17] cyclic close-die forging,[18] repetitive forging using inclined punch,[19] constrained groove pressing,[26] equal-channel forward extrusion,[27] parallel-ECAP,[28] pure shear extrusion,[29] vortex extrusion,[30] friction stir processing, [31,32] accumulative press bonding[37]. Ultrafine-grained and nanogrined metals are processed using the above severe plastic deformation method at laboratory scale. Scaling up SPD methods for industrial application is a real challenge for scientific community.

II. Illustration of Different Severe Plastic Deformation Processes :

Equal Channel Angular Pressing (ECAP)

Equal channel angular extrusion (ECAE, sometimes called Equal channel angular pressing, ECAP) was developed in the 1970s. In this process, a metal billet is pressed through an angled (typically 90 degrees) channel. A metal billet is pressed at an angle of 90^0 through the die channel. This process is repeated many times to get the good results of SPD technique. In each pass, billet orientation is changed. Due to this repetition uniform shear is produced throughout the bulk material. [4]. Nagasekhar et al worked on Ti grade 1 material. He used die angles of 150° and 30° for the experiment. He considered sand as a flexible mandrel for ECAP die. Nagasekhar sir concluded that mechanical properties were unchanged. Strength also remains unchanged and ductility was decreased. Valders et. al., worked on different commercial pure aluminum (Al) with different equal channel angular pressing routes. A plastic strain of 0.9 was observed in aluminum. As the hydrostatic stress was not sufficient, so maximum strain could not be observed in Al tube. Also, the high angle grain boundaries were not found. Djavanroodi et al. worked on commercial Pure copper material to produce ultrafine-grained tubes. He used mandrel made up of polyurethane rubber. He mostly studies on effects of route 90^0 in the tube ECAP method.

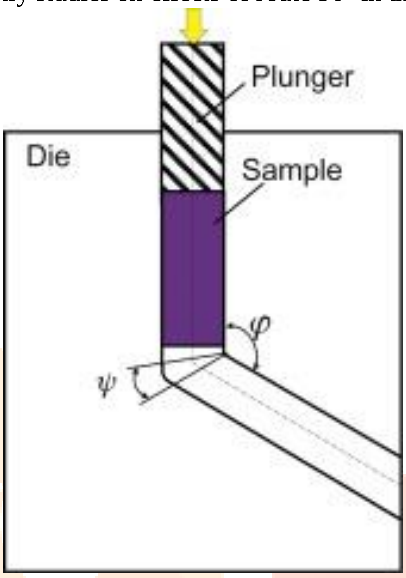


Fig.1.Equal Channel Angular Pressing (ECAP) [1]

Tube channel angular pressing (TCAP)

In Tube channel angular pressing (TCAP), the tube constrained by the inner and outer dies, is pressed by a hollow cylindrical punch into a tubular angular channel. The tube material is pressed into the tubular angular channel, where three shear events take place during one processing path.

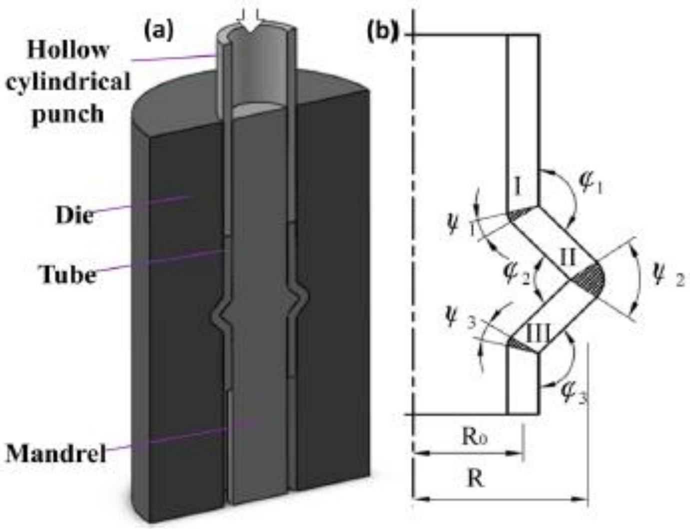


Fig.2. (a) TCAPand (b) Processing parameters [6,7,10]

Parallel Tubular Channel Angular Pressing (PTCAP)

PTCAP is suitable for deforming cylindrical tubes to extremely large strains. The tube constrained between mandrel and die is pressed by a first punch into a tubular angular channel with two shear zones and the diameter of the tube is increased and then pressed back to the initial dimension by the second punch. This process was applied to a commercially pure copper and a significant grain refinement resulted to a mean grain size of 150–300 nm was achieved even after a single pass PTCAP.

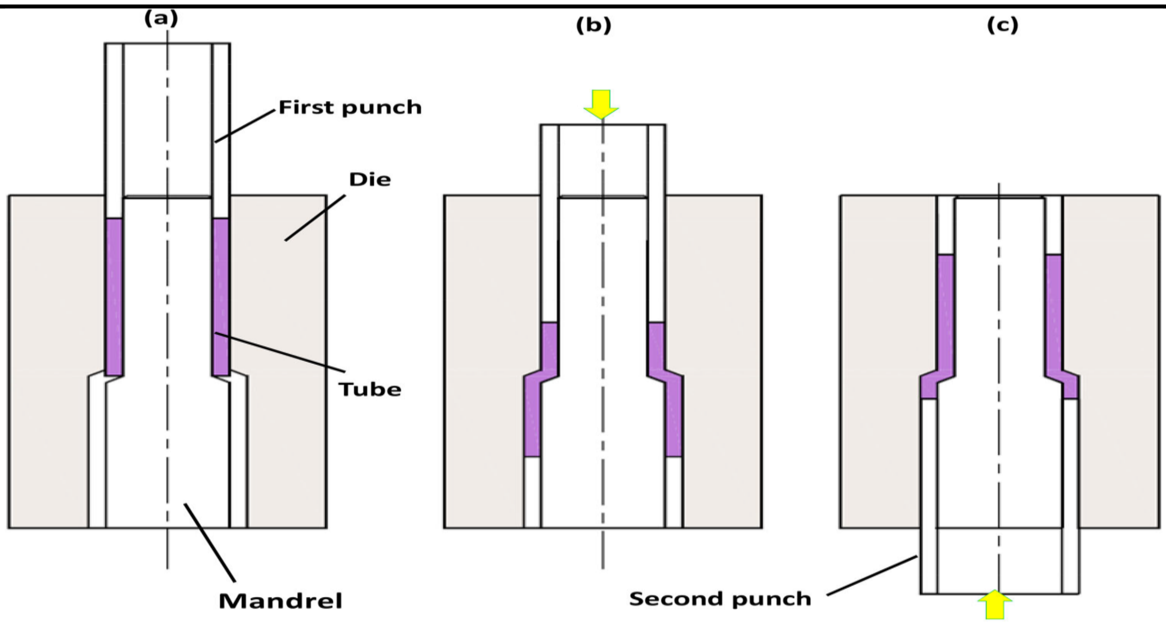
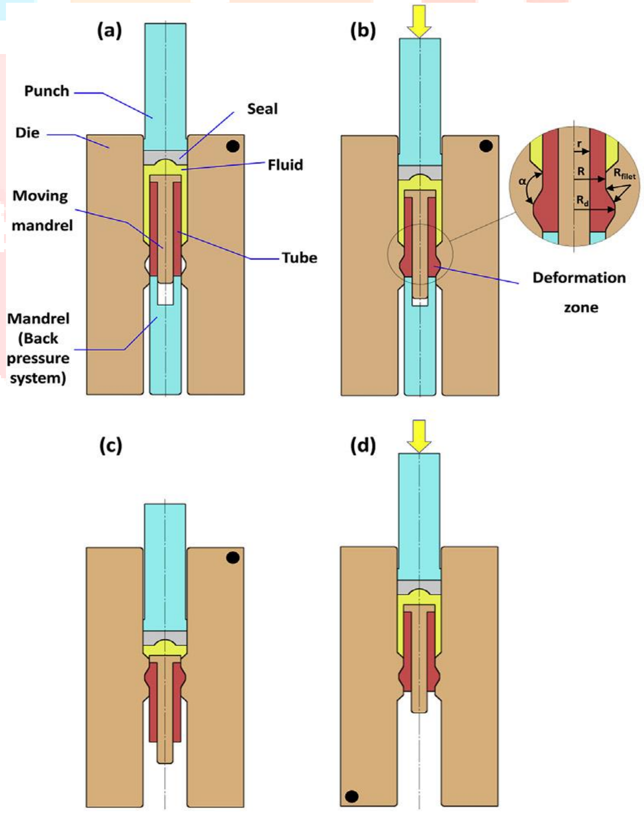


Fig 3. a PTCAP process an initial state, b PTCAP the first half-cycle, c The second half-cycle [11,26,27]

Hydrostatic tube cyclic expansion extrusion (HTCEE)

Hydrostatic tube cyclic expansion extrusion is a severe plastic deformation (SPD) process. In this process, a moving mandrel is placed inside the hollow tube sample and high fluid pressure technology. This process consists of die, punch, moving mandrel, mandrel, and seal. Before the process starts, the cylindrical tube with moving mandrel inside it is kept in the die as shown. Then fluid fills the gap between the tube and die so that there is no metal to metal contact. Then pressure is applied on the seal to press the tube and mandrel. The undeformed tube is pressed into the deformation cavity. When the material is expanded the mandrel is removed and process is repeated to get the initial size tube.[47]
Compared to other SPD processes, HTCEE has the benefit that in this technique, the processing load is independent of tube length. M.Motallebi et al., worked on this method. He found that grain size of material is reduced to below 150nm from the initial size of 65 µm.



Fig, 4. Hydrostatic tube cyclic expansion extrusion (HTCEE) [47]

Tube cyclic flaring and sinking (TCF)

Tube cyclic flaring and sinking (CFS) is used for producing ultrafine-grained thin cylindrical tubes. CFS process consists of flaring punch and sinking die. First of all flaring punch with two step region is pushed in to the tube. The tube diameter gradually increases as shear and normal tensile strains are formed as a result of shear zone. This increases tube diameter. In the second stage tube is pressed into the sinking die. While pressing tube is compressed due to compressive strain and shear strain. The tube again regain to its original size. In this technique yield strength and ultimate strength of the Al tube after CFS significantly increases to higher value as compare to earlier value. Yield strength increases by 50% and ultimate strength almost gets double. [14]

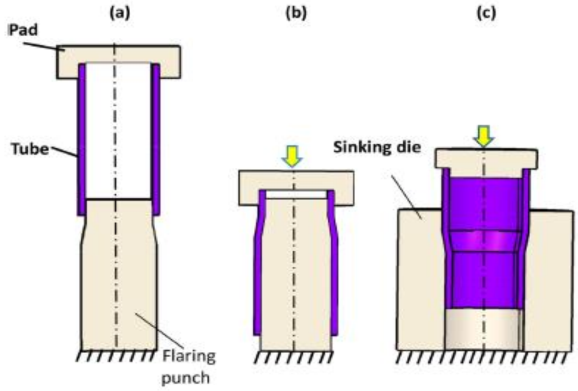
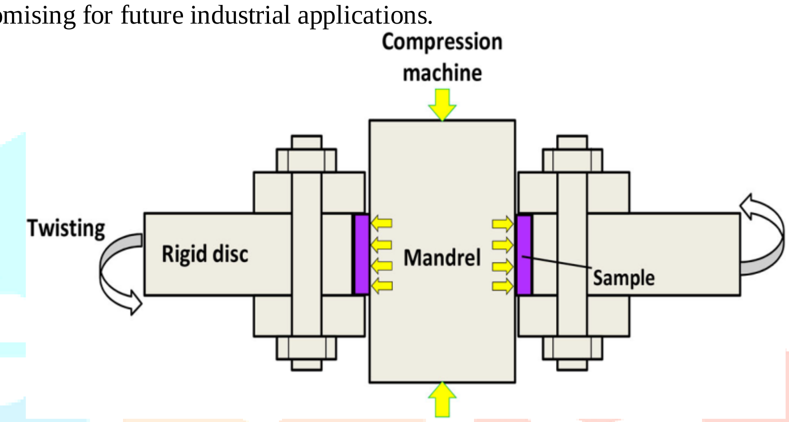


Fig 5. Tube cyclic flaring and sinking (TCF) [14]

High-pressure tube twisting (HPTT)

High-pressure tube twisting (HPTT) process is proposed that is suitable for deforming cylindrical tubes to extremely large strains without changing their dimensions. High hydrostatic pressure is achieved by axial compression of a cylindrical mandrel placed into the tube. The tube is twisted by an external torque with the help of the friction force generated by the hydrostatic pressure. This new SPD technique seems to be very promising for future industrial applications.



Fig,6. High-pressure tube twisting [15, 16, and 10]

III. THE ADVANTAGES AND DISADVANTAGES OF SPD

Ultrafine grained material developed by SPD processes has high market demand as it enhances these properties: Higher strength, Super plastic properties, Super plastic properties, High fatigue strength, Corrosion resistance, light weight, improves thermal conductivity, improves electrical conductivity, and improves bursting pressure capacity,

Material processed by SPD has huge application in automobile and aerospace industry. Some of the components are highlighted as below.

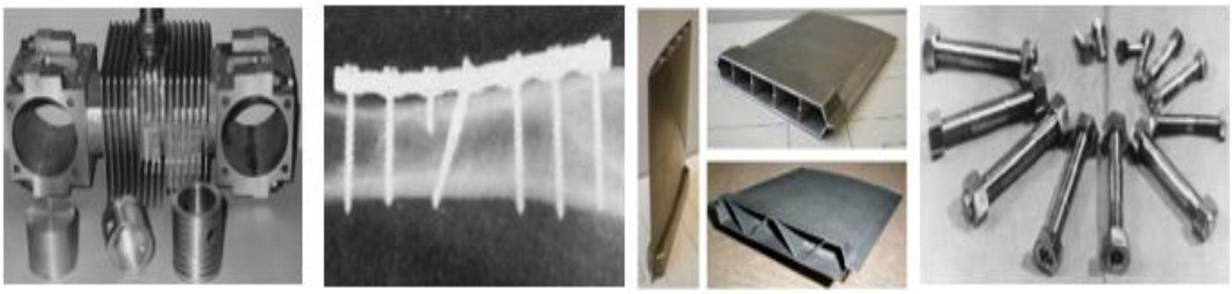


Fig.7. Significant grain refinement was achieved after single pass PTCAP. Lower loads are needed compared to TCAP. Excellent strain homogeneity was achieved.

IV. MECHANICAL PROPERTIES OF SPD PROCESSED TUBE

Faraji et al. worked on a novel method called tubular channel angular pressing (TCAP). It applied to the tubes component. Faraji did the experimental work. From the result, he got higher strain inside the tube. In this technique, material is subjected to deform by pressing through three shear zones. The first shear zone is above the center of the tube. The second zone is in the middle of the tube. And the third zone is below the centre of the tube. The stress-strain graph is different as compare to the convensional ECAP process. In TCAP process stain parameters are the same as other method except the radial tensile and compressive stresses are additional as the tube diameter changes during the process and then reverts to initial diameter at the end of the process.
A formula was proposed by Faraji to calculate the plastic strain. The plastic strain is diretly proportional to R/R0 ratio. Hence as the R/R0 ratio increases, the plastic strain also increases.

The hardness also increased in TCAP method. Only the difference is hardness homogeneity along the thickness is less than hardness homogeneity along the length of the tube. AZ91 material after TCAP process produces microstructure to ~1.5 μm after 1 pass from an initial grain size of ~150 μm. The microhardness increased to about 78 Hv from an initial value of 51 Hv.

TABLE 1: Summary SPD methods and mechanical properties of different cylindrical tube.

No.	Author	year	Base Material	SPD Method	Effe. strain	Yield Strength (N/mm^2)	UTS (N/mm^2)	El(%)	HV
1	G. J. Raab et al, 2004	2004	Commercially Pure Al	ECAP	~3	130	160	-	-
2	A. Zangiabadi et al, 2011	2011	Commercially Pure Al	TCAP	~2.5	85	160	6	42
3	G.Faraji et al.,2016	2016	Commercially Pure Al	CFS	~2.25	135	144	5	38
4	M. S. Mohebbi et al,2010	2010	Commercially Pure Al	ASB	~2	190	~230	8	~50
5	M. Arzaghi, J. Fundenberger, L. Toth,2012	2012	Commercially Pure Al	HPTT	~5	290	~340	5	--
6	M. Mesbah, G. Faraji and A. Bushroa,2014	2014	Commercially Pure Al	TCAP	~6	135	~200	-	~48
7	G.Faraji et al,2015	2015	Al 6061	PTCAP	~6	-	~180	17	~64
8	G. Faraji,	2013	Commercially Pure Cu	PTCAP	12	-	-	-	~140
9	M. Mashhadi,	2013	Commercially Pure Cu	PTCAP	12	-	-	-	~140
10	A. Bushroa and A. Babaei, 2013	2013	Commercially Pure Cu	PTCAP	12	-	-	-	~140
11	F. Djavanroodi et al, 2014	2014	Copper	Tube ECAP	~3	-	-	-	~130
12	G. Faraji, P. Yavari et al,2014	2014	AZ91,Mg	TCAP	6.6	250	375	~5	~98
13	H. Abdolvand et al,2015	2015		PTCAP+TBE	2.8	~210	~330	13	~75
14	M.A.Soufi,2015	2015	Magnesium alloy	TCAP	6.6	~160	~210	5	~60
15	A. V. Nagasekhar et al.,2006	2006	Titanium(Ti)	Tube ECAP	~0.9	~550	~580	~15	~200
16	G.Faraji et al,2014,2015	2015	Brass (70Cu-30Zn)	PTCAP	~5	~500	~600	~7	~205
17	F.Djavanroodi et al	2013	Al	ECAP	~3	130	160	-	-
18	J Valder, M. Rijesh et al	2012	Aluminium	ECAP	0.9	-	-	-	-
19	B.S.JaiBin et al.,2017	2017	Magnesium alloy	SPD	-	-	-	-	-
20	Bagherpour E. et al,2017	2017	Copper	SSE	Grain growth is 5% more after 12 passes as compare to 8 passes				

V. CONCLUSIONS

A literature review was done for different SPD processes. For over more than twenty years research work has been carried out on materials subjected to SPD. The results of the investigations reveal that there exists a change in material properties with structural changes. Also the knowledge of governing phenomena behind SPD has enhanced in last ten years. Yet, there exists a feeling that much work needs to be carried out on SPD and its effect. Literature review suggests

That there are a variety of SPD techniques available today. The problem associated with some of the SPD technique is that process has high frictional forces and high forming load. As per literature review, the tube channel angular pressing (TCAP) and parallel tube channel angular pressing (PTCAP) has low tube surface quality and tube diameter processed is less than 12 mm diameter. So processing SPD process for tube diameter greater than 12mm diameter is future scope of work.

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