Capability of "Tube Channel Pressing" as a novel Severe Plastic Deformation process

Mohammad Hassan Farshidi[1*], Mohsen Kazeminezhad[1], Hiroyuki Miyamoto[2], Amir Ali Zangiabadi[1]
[*]Corresponding author; E-Mail: farshidi@mehr.sharif.ir

[1]Department of Materials Science and Engineering, Sharif University of Technology, Azadi Avenue, Tehran, Iran
[2]Department of Mechanical Engineering, Doshisha University, Kyotanabe city, Kyoto, Japan

Abstract:
Severe Plastic Deformation (SPD) Processes are a usual method for improving mechanical properties and synthesis of Ultra Fine Grained (UFG) and Nano Crystalline (NC) materials. Although many SPD processes have been introduced for different shapes of material during last decades, SPD of tubes has remained less considered. A novel SPD process for tube named "Tube Channel Pressing" (TCP) has been developed for SPD of tubes recently. Studies on characteristics of TCPed materials show that TCP has comparable capabilities in improving mechanical properties and grain refinement comparing to conventional SPD processes. For example, crystallite size of solid solution treated aluminum alloy after impression to equivalent strain of 3.09 through TCP was measured 52 nm which is comparable with amount of 57.5 nm measured for this material subjected to equivalent strain of 3.46 through "Accumulative Roll Bonding"(ARB) and 42 nm for equivalent strain of 2.4 through "Dissimilar Channel Angular Pressing" (DCAP).

1. Introduction
SPD processes are widely used to improve mechanical properties of materials and to produce UFG and NC materials. The main advantage of SPD processes is to produce bulk NC materials with lower costs and higher quality comparing to other methods [1-2]. Multiple SPD processes have been introduced during last decades including Equal Channel Angular Pressing (ECAP) [3-6], ARB [7-8], High Pressure Torsion (HPT) [9], Multi Axial Forging (MAF) [7], Constraint Groove Pressing (CGP) [10] and Cyclic Extrusion and Compression (CEC) [11]. However, little works have been focused on SPD of tubular materials. Recently, a new process has developed for SPD of tubes named TCP [12-14]. This paper is aimed to compare capability of this new process with conventional SPD processes.

2. Principles of TCP
Fig.1 shows principle of TCP. As can be seen, tube is passed through a bottleneck region between die and mandrel which causes consecutive decrease and increase in both inner and outer diameter of tube. The mandrel cave consists of three equal diameter tangent circles as shown in Fig.1 (d). Mandrel design parameters are dependent to die design parameters as shown before [12]. The die convex consists of three tangent circles similarly. Die convex height and diameter of tangent circles are two main parameters controlling the deformation behavior during TCP. In this work, a die with convex height of 1.5 mm and curvature diameter of 7.5 mm was used which results to average plastic strain of 1.03 per each pass. The inner and outer diameter of tube was 19 and 26 mm, respectively.

3. Materials and Experiments
In order to study effect of TCP as a new SPD process, tubes of two different types of aluminum alloy were subjected to TCP in room temperature. The first alloy was commercial pure aluminum known as AA-1100 and second one was AA-6061 which contains 1wt% of Mg, 0.486 wt% of Si and 0.312 wt% of Cu as main alloying elements.

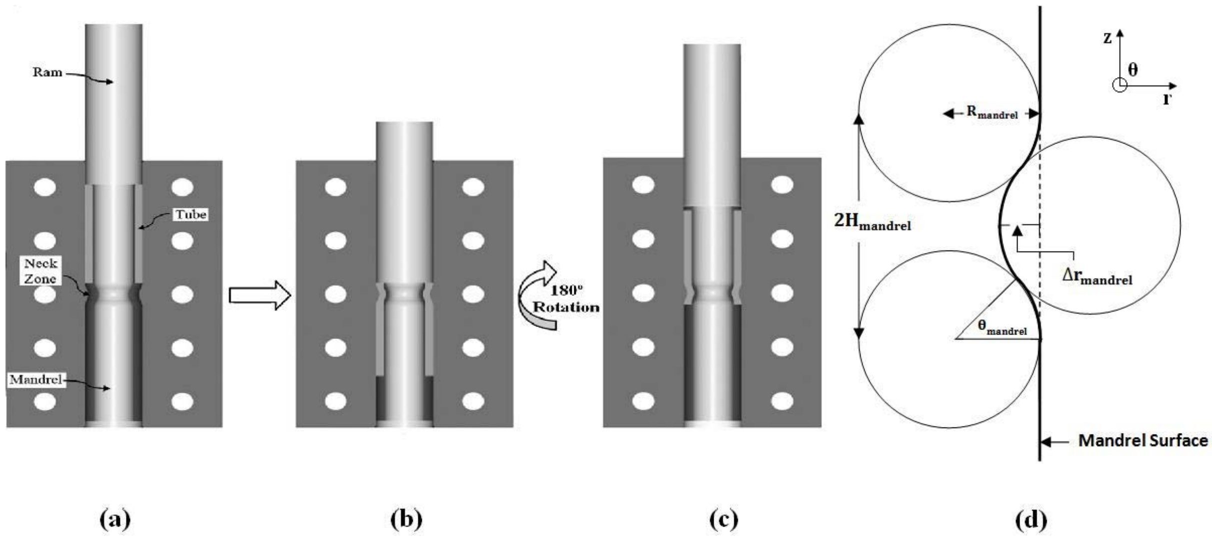

Fig. 1. Principles of TCP: (a) start of first pass, (b) end of first pass, (c) start of second pass and (d) mandrel cave morphology

Tubes were received in wrought form and were subjected to annealing prior to TCP process. After annealing, specimens were subjected to TCP which comprise up to six pass for AA-1100 alloy and up to three pass for AA-6061 alloy. After TCP, specimens were subjected to mechanical properties measurement containing Vickers microhardness test and tensile test. Vickers microhardness test was achieved on R-θ plane (see Fig.1) while tensile samples are machined parallel to Z-direction in accordance with ASTM E32.

X-ray diffraction examinations were carried out on specimens by $Cu - K_{\alpha}$ X-ray which has wave length of 1.54 Å. Williamson-Hall method was applied to measure crystallite size of specimens subjected to multiple passes of TCP. Finally, TEM was applied to study microstructure evolution for Al-6061 specimen subjected to two pass of TCP.

3. Results and Discussion

Fig.2 (a) compares Vickers microhardness of AA-1100 alloy after subjecting to equivalent plastic strain of up to six through different SPD processes including TCP. Fig.2 (b) compares changes of Vickers microhardness of AA-6061 alloy after subjecting to plastic strain of up to three through TCP and other SPD processes.

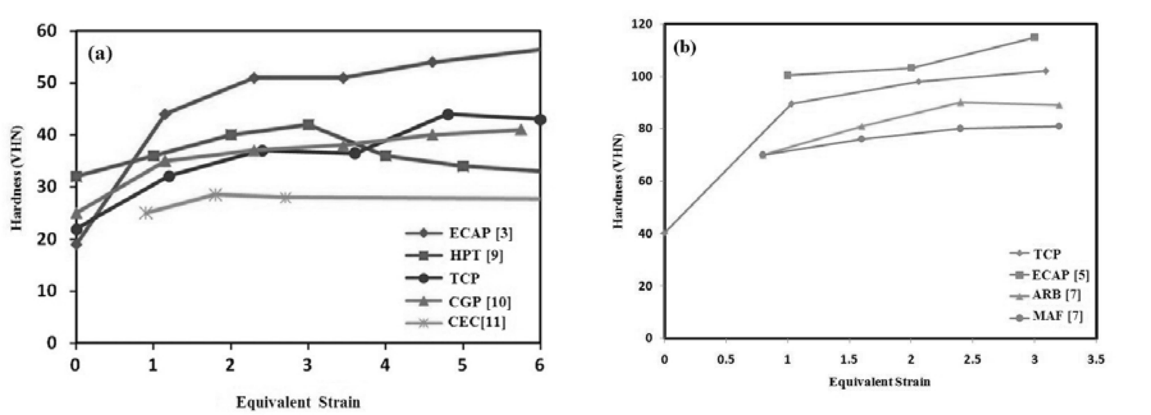

Fig.2. Vickers microhardness increase in (a) AA-1100 and (b) AA-6061 alloy subjected to different SPD processes

Fig.3 (a) compares Yield Stress (YS) and Ultimate Tensile Stress of AA-1100 alloy after impressing to plastic strain of up to six through multiple SPD processes including TCP. Increase of

YS and UTS of AA-6061 alloy after subjecting to plastic strain of three through TCP and other SPD processes are compared in Fig. 3(b).

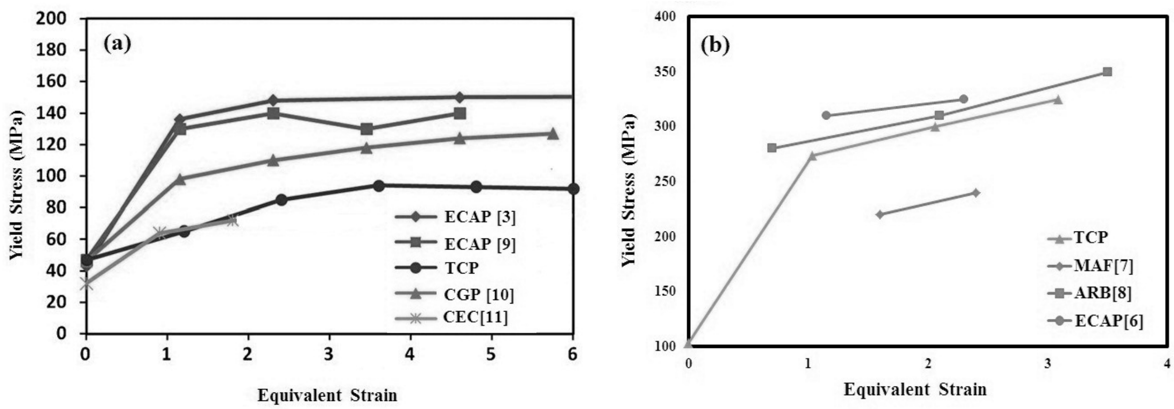

Fig.3.Yield strength increase in (a) AA-1100 and (b) AA-6061 alloy subjected to different SPD processes

Considering Fig.2 and Fig.3, It can be inferred that TCP has moderate capability in improving mechanical properties of materials. TCP efficiency in improving mechanical properties is more than MAF and CEC, comparable to HPT and ARB and a little less than ECAP.

Fig.4 (a) shows XRD measured crystallite size of aluminum AA-6061 after subjecting to strain of up to 3.5 through different SPD processes. As can be seen, TCP capability in grain refinement is comparable to other SPD processes. For example, crystallite size of 6061 aluminum alloy after impression to equivalent strain of 3.09 through TCP was measured 52 nm which is comparable with 57.5 nm for equivalent strain of 3.46 through ARB and 42 nm for equivalent strain of 2.4 through DCAP. This amount is also comparable with 80 nm measured by TEM for specimen subjected to equivalent strain of 3 through “large strain machining” [17].

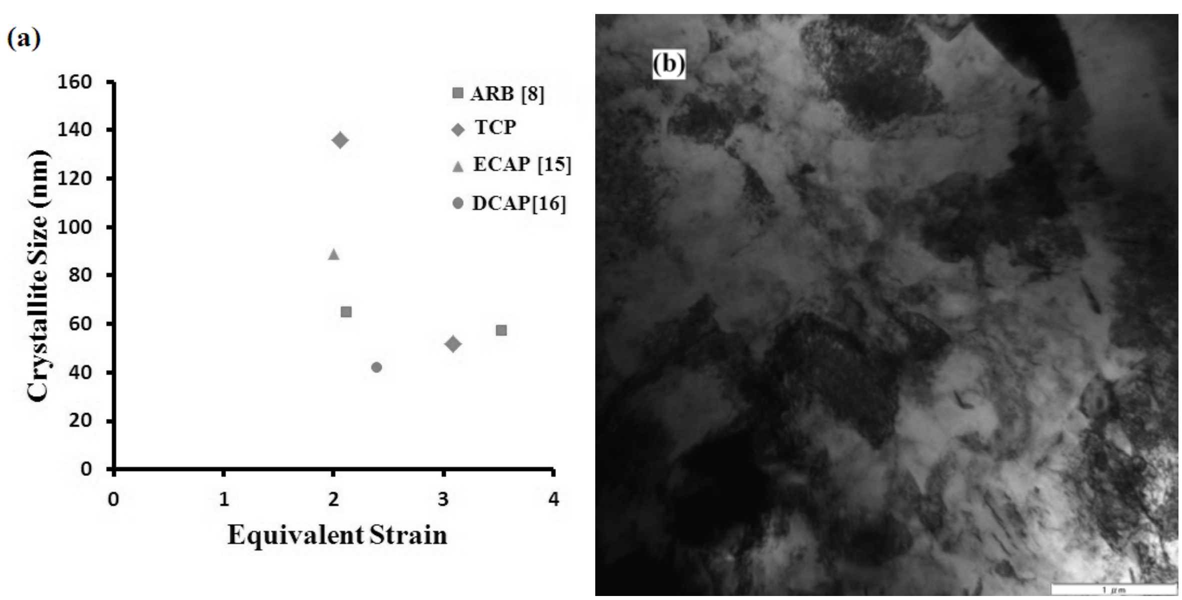

Fig.4.(a) XRD measured crystallite size of AA-6061 alloy subjected to different SPD processes; (b) TEM microstructure of AA-6061 alloy subjected to two pass of TCP

Fig.4 (b) shows microstructure of AA-6061 alloy after two pass of TCP. As can be seen here, the size of grains appears after TCP is mostly about one micrometer. This result is similar to findings for other SPD processes such as ECAP, MAF and HPT [7, 15-16, 18].

4. Conclusion

Concerning what mentioned above, it can be concluded that:

1- TCP is a capable process in both grain refinement and mechanical properties improvement.
2- TCP has a moderate efficiency in improving mechanical properties comparing to other SPD processes. Its efficiency is more than MAF and CEC, comparable to HPT and ARB and a little less than ECAP.
3- Very fine grained Al-6061 alloy can be obtained by subjecting to two pass of TCP which implies that TCP has analogous capability in grain refinement comparing to other SPD processes.

References:

[1] R. Srinivasan, P.K. Chaudhury, B. Cherukuri, Q. Han, D. Swenson, final technical report of an industrial project in Wright State University, June 2006.
[2] L. Olejnik, A. Rosochowski, Bullet. Polish Academy of Sci., Tech. Sci. 53 (2005) 413-423.
[3] E.A. El-danaf, M.S. Soliman, A.A. Almajid, M.M. El-rayes, Mater. Sci. Eng. A 458 (2007) 226–234.
[4] G.J. Raab, R.Z. Valiev, T.C. Lowe, Y.T. Zhu, Mater. Sci. Eng. A 382 (2004) 30–34.
[5] W.J. Kim, H.K. Kim, U.S. Yoon, Mater. Sci. Eng. A 487 (2008) 360–368.
[6] M. Prell, C. Xu, T. G. Langdon, Mater. Sci. Engineering A 480 (2008) 449–455.
[7] B. Cherukuri, T. S. Nedkova, R. Srinivasan, Mater. Sci. Eng. A 410–411 (2005) 394–397.
[8] M. R. Rezaei, M. R. Toroghinejad, F. Ashrafizadeh, Mat. Sci. Eng. A 529 (2011) 442– 446.
[9] Y. Ito, Z. Horita, Mater. Sci.Eng. A 503 (2009) 32–36.
[10] E. Hosseini, M. Kazeminezhad, Mater. Sci. Eng. A 526 (2009) 219–224.
[11] M. Richert, Q. Liu, N. Hansen, Mater. Sci. Eng. A 260 (1999) 275–283.
[12] M.H. Farshidi ,M. Kazeminezhad, J. Mater. Eng. Perf., Available Online 7 Feb. 2012.
[13]A. Zangiabadi, M. Kazeminezhad, Mater. Sci. Eng.A 528 (2011) 5066–5072
[14]A. Zangiabadi, M. Kazeminezhad, Comp. Mater. Sci. 59 (2012) 174–181
[15] M. Yu. Murashkin, E. V. Bobruk, A. R. Kil'mametov, R. Z. Valiev, The Phys. of Met. Metallog.108 (2009) 415–423
[16] E. Tan, A. A. Kibar, C. H. Gür, Mater. Charact. 6 2 (2011) 391 – 397
[17] M. Ravi Shankar, S. Chandrasekar, A. H. King, W. D. Compton, Acta Materialia 53 (2005) 4781–4793
[18] C. Xu, Z.Horita, T.G. Langdon, Acta Materialia56 (2008) 5168–5176