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Wear properties of brass samples subjected to constrained groove pressing process

M. Ebrahimi [a,*], Sh. Attarilar [b], F. Djavanroodi [a,c], C. Gode [d], H.S. Kim [e]

[a] Department of Mechanical Engineering, Iran University of Science and Technology, Tehran, Iran
[b] Department of Materials Science and Engineering, Sahand University of Technology, Tabriz, Iran
[c] Department of Mechanical Engineering, Prince Mohammad Bin Fahd University, Al Khobar 31952, Saudi Arabia
[d] School of Denizli Vocational Technology, Program of Machine, Pamukkale University, Denizli, Turkey
[e] Department of Materials Science and Engineering, Pohang University of Science and Technology, Pohang, Republic of Korea

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ABSTRACT

Ultrafine grained materials have experienced a rapid development during the last two decades. Constrained groove pressing (CGP) process is one of the severe plastic deformation methods to fabricate ultrafine grain sheet materials. In this research, wear behavior of brass sheet subjected to CGP process was investigated. Generally it is shown that CGP process enhances the wear resistance of the material and this behavior is improved by increasing pass number. Also, the effect of initial pass and lower applied normal load on the wear resistance is more profound than subsequent passes and higher applied normal load, respectively. In addition, the influence of normal load is more profound than pass number at the increment of friction force. Although CGP process results in reduction at the specific wear rate, the influence of the first pass is much higher than the subsequent ones. Furthermore, lower specific wear rate is occurred at the higher applied normal load. The scanning electron microscopy analyses indicated that the wear mechanism is transferred from adhesion, delamination, abrasion and oxidation for the annealed condition to abrasion and adhesion for the third pass CGP sample. Also, it is found that there is a reverse relationship between specific wear rate and hardness.

1. Introduction

Various metals and alloys are desired to have enhanced physical, mechanical, superplasticity, wear, corrosion and fatigue properties for various applications [1–3]. Over the past twenty years, microstructural refinement by imposing ultra large plastic deformation for producing ultrafine grained (UFG) and nanostructured (NS) materials have gained researchers' attention [1,4,5]. Fig. 1 shows the terminology that corresponds different ranges of grain size for the material microstructure. Two examples about the application of these methods are aerospace and automobile industries in which the importance of light weight parts with high performance are obvious in order to reduce fuel consumption and environmental issues [6]. Recently, the application of the severe plastic deformation (SPD) materials in the biomedical implants and also, the biocompatibility property of such advanced materials have been investigated [3].

During the last two decades, several SPD methods have been proposed and developed such as equal channel angular pressing (ECAP) [7], high pressure torsion (HPT) [8], accumulative roll bonding (ARB) [9], repetitive corrugation and straightening (RCS) [10], tubular channel angular pressing (TCAP) [11], constrained groove pressing process (CGP) [12], surface mechanical attrition treatment (SMAT) and severe shot peening (SSP) [13,14]. Although ARB method has been designed and manufactured for the sheet metal samples similar to CGP one, its application has been limited because of bonding defects, edge cracking and less feasible problems leading to the material waste and mechanical properties diminution [9,12]. It can be said that the dominant rule of all SPD methods is the increment of the polycrystals' free energy and the generation of more defects and interfaces (grain boundaries) [13].

Depending on the limitation of a sheet sample elongation during the process, three types of GP process are defined as constrained GP (CGP), semi constrained GP (SCGP) and GP. In the CGP type, the sheet material is confined by a die set-up (container) in which the sheet is not free to extend during the process in any direction. In the SCGP, the sheet sample is constrained by a channel [15,16]. In the CGP process, a sheet material is repetitively

* Corresponding author. Tel.: +98 914 401 7268; fax: +98 421 2240862.
E-mail address: mebrahimi@iust.ac.ir (M. Ebrahimi).

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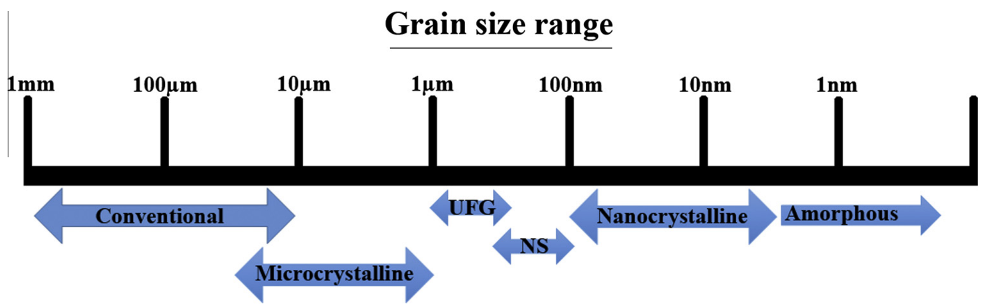

Fig. 1. The terminology and grain size ranges for describing materials microstructure.

subjected to shear plastic deformation by application of asymmetrically grooved and flat dies, respectively as can be seen in Fig. 2. In this method, the gap between the upper and lower dies is equivalent to the thickness of the sheet sample (Fig. 2b), hence the inclined regions of the sample are exposed to the pure shear deformation in the plain strain condition (Fig. 2c) [17]. Then during the second cycle, the grooved sample is straightened using the flat die; see Fig. 2d. During this process, a sheet material is placed in the dies and it cannot freely elongate in any directions, therefore this process can be repeated up to the desired strain magnitude and higher strength. The width (t) and depth (t) of corrugated die are equal hence, the inclined angle is 45°. The theoretical magnitudes of shear and effective strains (γ and ε) after one cycle CGP process has been represented in Eqs. (1) and (2) [10]:

$$\gamma = t/t = 1 \tag{1}$$

$$\varepsilon = \left(\frac{4}{3}(\gamma/2)^2\right)^{1/2} = 0.58 \tag{2}$$

Every pass of the CGP process has four cycles. As mentioned above; at first, the flat sheet sample is corrugated by the grooved die. By this way, inclined regions which are shown with the vertical lines are imparted to the effective plastic strain of 0.58 as can be seen in Fig. 2c. Subsequently, the grooved sample is straightened by the flat die where in previously pressed inclined regions are subjected to the plastic shear deformation in the reverse direction leading to a total effective strain of 1.16; see Fig. 2d. Then, the produced flat sample in the previous two cycles is rotated 180° around the axis perpendicular to the plane of the sheet (Fig. 2e). This rotation allows the undeformed regions to be deformed by further pressings due to the asymmetry characteristic of the grooved die and so, the grooving and softening stages are carried out again according to Fig. 2(f and g). Finally, material with the homogenous and uniform effective plastic strain of about 1.16 is successfully attained [12,16].

The CGP process was firstly invented by Shin et al. [18] for fabrication of UFG sheet metal. Lee and Park investigated the plastic deformation during the CG pressing and rolling in both numerically and experimentally methods [19]. They revealed that the deformed specimen is not uniform in the thickness direction and the magnitude of effective strain at the center of the specimen is greater than that at the surface. In the other study, Krishnaiah et al. studied the production of UFG aluminum sheet by application of CGP process at the ambient and cryogenic temperatures [20]. They showed that pressing of commercial pure (CP) Al in the

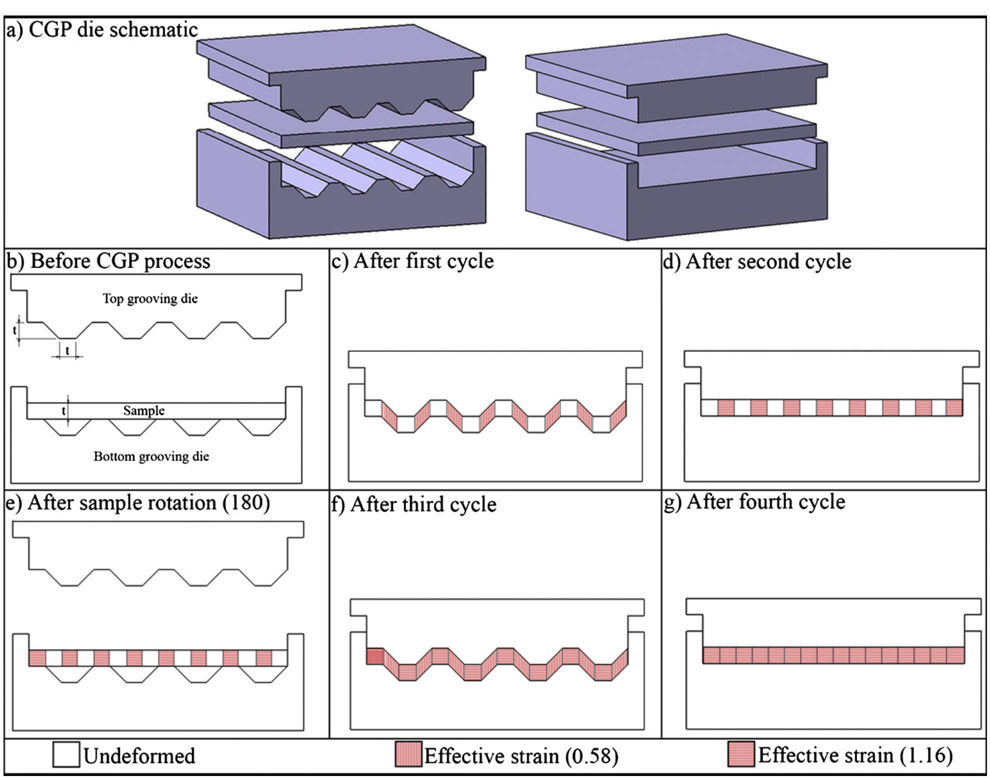

Fig. 2. The schematic representation of CGP process during one pass.