Densification and Consolidation of Powders by Equal Channel Angular Pressing

Seung Chae Yoon¹,a, Sun Ig Hong¹,b, Soon Hyung Hong²,c and Hyoung Seop Kim¹,d,*

¹Department of Metallurgical Engineering, Chungnam National University, Daejeon, 305-764, Korea
²Korea Advanced Institute of Science and Technology, Yuseong, Daejeon, Korea

a scyoon@cnu.ac.kr, b sihong@cnu.ac.kr, c b sihong@cnu.ac.kr, d hskim@cnu.ac.kr,
*corresponding author

Keywords: equal channel angular pressing, metallic powders, densification, severe plastic deformation, shear deformation, hydrostatic stress

Abstract. In this study, bottom-up type powder processing and top-down type SPD (severe plastic deformation) approaches were combined in order to achieve both full density and grain refinement of metallic powders with least grain growth, which is considered as a bottle neck of the bottom-up method that uses the conventional powder metallurgy of compaction and sintering. ECAP (Equal channel angular pressing), one of the most promising method in SPD, was used for the powder consolidation. In the ECAP process of not only solid but also powder metals, it is important to get a good understanding of the density as well as internal stress, strain and strain rate distribution. We investigated the consolidation, plastic deformation and microstructure evolution behavior of the metallic powders during ECAP using an experimental method. It was found that high mechanical strength could be achieved effectively due to the well bonded powder contact surface during ECAP process of gas atomized Al-Si powders. The experimental results show that SPD processing of powders is a viable method to achieve both fully density and nanostructured materials.

Introduction

It is well known that heavy cold deformation, e.g. by cold rolling, extrusion, forging or drawing, can result in significant refinement of the microstructure of metals and alloys [1]. Using the idea of this grain refinement effect, recently, bulk nanostructured materials processed by several methods of severe plastic deformation (SPD), such as equal channel angular pressing (ECAP), high pressure torsion straining, accumulated roll bonding, equal channel angular rolling, groove rolling, equal channel multi-angular pressing etc., were developed [2-7]. The main advantage of SPD processed materials, compared to other nanostructured materials processed by gas condensation or ball milling with subsequent consolidation, is that it is possible to overcome a number of difficulties associated with residual defects and powder contaminations in the compacted samples. Among the various SPD processes, ECAP is a convenient procedure for obtaining ultrafine grained materials by extruding metallic materials through specially designed channel dies without a substantial change in geometries. A schematic of ECAP and a photograph of an ECAP die set are shown in Fig. 1. The properties of the materials processed by ECAP are strongly dependent on the plastic deformation behavior during pressing, which is governed mainly by die geometry (a channel angle Φ and a corner angle Ψ), material properties (strength and strain hardening behavior) and process variables (lubrication and deformation speed).
In a separate development, studies of rapidly solidified alloy powders have suggested the possibility of producing new alloys having metastable microstructures, e.g. amorphous and nanostructured phases, characterized by superior mechanical properties. Generally, it is necessary for powder consolidation to be performed by solid-phase diffusion at temperatures far below the melting points of the raw material powders, in order to ensure that the structural features obtained by rapid solidification are not lost. Indeed, grain growth, which was considered as a bottle neck of the bottom-up method that use the conventional powder metallurgy of compaction and sintering. In addition, the surfaces of metallic powders are usually covered by an oxide layer, which prevents powder bonding. Unless this oxide film is ruptured and the fresh powder particle surfaces are allowed to come into contact with each other, it is not possible to obtain good bonding by diffusion. Therefore, the powder particles must be bonded together by plastic deformation during powder compaction step as well as forging step, and so imposing shear stresses as well as hydrostatic pressures during powder compaction is very important to achieve good powder bonding. From this point of view, the ECAP process can be seen to be effective for the consolidation of gas atomized metallic powders at a relatively low temperature [8].

In this study, bottom-up type powder processing and top-down type SPD (severe plastic deformation) approaches were combined in order to achieve both full density and grain refinement of metallic powders with least grain growth. ECAP (Equal channel angular pressing), one of the most promising method in SPD, was used for the powder consolidation. In the ECAP process of not only solid but also powder metals, knowledge of the density as well as internal stress, strain and strain rate distribution is important for understanding the process. We investigated the consolidation, plastic deformation and microstructure evolution behavior of the metallic powders during ECAP through an experimental method.

Experimental Procedure
Al-Si alloy powders and pure metal (Cu) powders were studied. Al-20 wt% alloy powders were N$_2$ gas atomized. The gas atomized Al-Si powders with +25 μm in diameter and commercial copper powders were put into pure copper can and/or cold isostatically pressed to a sample size of 6 mm x 6 mm x 50 mm. In the ECAP process, samples were pressed through a die having two channels, equal in cross-sectional area, that intersect at a channel angle $\Phi$ of 90$^\circ$ and a corner angle $\Psi$ of 0° at room
temperature. The ECAP processing was conducted up to eight passes at 200 °C, following Route C, that is, rotating a workpiece by 180° around the longitudinal axis between the passes, respectively. The die parameter used, viz. the channel angle (Φ = 90°), the outer corner angle (Ψ_o=0°) and the inner corner angle (Ψ_i=0°) yielded a maximum effective strain of 1.155 for a single pass, which decreased with increasing strain hardening coefficient. The pressing speed was 1 mm/min, which is slow enough to keep the temperature rise during ECAP to less than several K. A mixture of MoS2 powder and commercial oil was used for lubrication between the can and the channel surfaces. The starting powders were characterized by scanning electron microscopy (SEM). The density of the compacts was measured by the Archimedes method.

Results and Discussion

Figure 3 shows a scanning electron micrograph of gas atomized Al-20Si powders sieved to 105~145 μm, showing mixtures of eutectic matrix and primary Si particles of 4~5 μm. The size of eutectic Si particles is less than 1 μm.

![Fig. 3 Scanning electron micrograph of gas atomized Al-20 wt% Si powders.](image)

Figure 4 shows low magnification scanning electron micrographs of longitudinal sections of 200 °C equal channel angular pressed Al-20 wt% Si bars after various number of route C passes. By examining the interfaces and mechanical properties, a good bonding between powders is found after 1 pass at 200 °C. This is not shown in this paper. The good bonding is attributable to the combined effect of hydrostatic pressure and shear stress. Relative densities of 96% and above 98% after 1 and 8 passes can be measured by image analysis, respectively. This high densification as well as good powder bonding represents the promising future of ECAP for powder processing.

The main deformation mode in ECAP of solid (non-porous) materials is simple shear [2] involving large plastic shear deformation in a very thin deforming layer of a workpiece moving through a die. However, the volume of porous workpiece can be changed according to the imposed hydrostatic stress, because the deformation mode in powder ECAP is not so simple as for non-porous materials. Finite element simulations for densification during ECAP based on the constitutive model of porous materials [9-12] are now underway.

Conclusions

The ECAP process was applied to metallic powders in order to achieve both powder consolidation and mechanical alloying. Various general phenomena, such as densification, plastic deformation and microstructure evolution behavior of the metallic powder compact were investigated. By using the
powder ECAP process with an appropriate sheath metal, an almost full densification could be achieved at room temperature.

Fig. 4 Low magnification scanning electron micrographs of longitudinal sections of 200 °C equal channel angular pressed Al-20 wt% Si bars; (a) 1 pass, (b) 2 passes, (c) 4 passes and (d) 8 passes of route C.

Acknowledgements

This work was supported by Korea Research Foundation Grant (KRF-2005-202-D00205).

References