

THE ROLE OF PROCESSING CONDITION ON MICROSTRUCTURE AND POROSITY BEHAVIOUR IN ALUMINIUM ALLOY

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Abstract

The present paper deals with the role of severe plastic deformation involved by ECAP in aluminium alloy. A commercial ready-to-press aluminium based powder (ECKA Alumix Al - 0.95 wt. % Mg - 0.49 wt. % Si - 0.21 wt. % Cu - 0.07 wt. % Fe - 1.5 wt. % lubricant) was used as material to be investigated. After applying different compacting pressures, specimens were debinded in a ventilated furnace (Nabertherm) at 400°C for 60 min. Sintering was carried out in a vacuum furnace at 610°C for 30 min. The specimens were ECAPed for 1 pass. The various densification stages with the porosity distribution, size and morphology during application of various processing conditions including pressing, debinding, sintering and ECAP were presented. Microstructures and porosity distribution observations were carried out using light and SE microscopy and TEM analysis. The main role in ECAP process is played by the involved severe shear deformation causing stress distribution in deformed specimens, transforming initially interconnected pores into small isolated nanopores.

Keywords: aluminium alloy, pressing, sintering, ECAP, SPD, porosity

INTRODUCTION

Aluminium alloys show excellent properties such as high thermal and electrical conductivity, corrosion resistance, workability and especially light weight [1-3]. These represent a good option for the powder metallurgy (PM) industry to produce new materials having unique capabilities, not currently available in any other powder metal parts.

The cheapest preparation way of PM aluminium alloys are conventional press-and-sintering methods. However, some difficulties may arise from the extremely stable oxide layer that cannot be broken or removed by heating due to its thermodynamic stability. One possible way to overcome this problem is by means of liquid-phase sintering (LPS). Several works analyze the use of sintering additives on enhancing aluminium sinterability [4-8]. Another chance for overcoming problems is represented by the use of a shear stress that is beneficial for mechanical disruption of surface oxide layers which provides better interparticle bonding. This stress is minimal in hot isostatic pressing (HIP) and increases gradually from quasi-isostatic pressing to uniaxial pressing in a die (hot pressing), to uniaxial pressing without a die (sinter-forging) and finally to extrusion [9]. It is important to

note that extrusion is the main route for consolidating Al base powders. In the present times, a new possibility way for preparation is severe plastic deformation (SPD) [10-14].

The main aim of the presented paper is to show the densification processes after different processing steps in order to quantify the porosity phenomena in studied PM aluminium alloy.

EXPERIMENTAL CONDITIONS

A commercial ready-to-press aluminium based powder (ECKA Alumix 321) has been used as material to be investigated (Al - 0.95 wt.% Mg - 0.49 wt.% Si - 0.21 wt.% Cu – 0.07 wt.% Fe – 1.5 wt.% lubricant). Specimens were obtained using a 2000 kN hydraulic press, applying different pressures. Unnotched impact energy specimens $55 \times 10 \times 10 \text{ mm}^3$ (ISO 5754) were prepared. The green compacts were weighed. The dimensions were measured with a micrometer calliper. Specimens were dewaxed in a ventilated furnace (Nabertherm) at 400°C for 60 min. Sintering was carried out in a vacuum furnace (TAV) at 610°C for 30 min, with an applied cooling rate of 6 K/s. The equal channel angular pressing (ECAP) was realized by hydraulic equipment at room temperature, which makes it possible to produce the maximum force of 1 MN. The die had a 90° angle with sharp corners and channels of diameter 10 mm in the cross section (the specimens were turned to this dimension). The specimens were ECAPed for 1 pass.

The samples for microstructure evaluation were taken from locations in the centre of specimen along the length. Optical characterization was carried out on the minimum of 10 different image fields. For the determination of porosity characteristics 100x magnification were used for specimens prepared by pressing and sintering and 500x for ECAPed specimens. Pores were recorded and processed by Leica Qwin image analysis system. D_{circle} , as the diameter of the equivalent circle, and the morphological characteristics f_{shape} and f_{circle} were measured for each pore individually in order to describe the dimensional and morphological characteristics. The calculations of both parameters are reported in [12, 15]. Density was measured using the Archimedes technique.

RESULTS AND DISCUSSION

The densification behaviour of aluminium alloy Al-Mg-Si-Cu-Fe during the processing conditions is presented in Fig.1 as well as morphological and dimensional characteristics of porosity, Table 1.

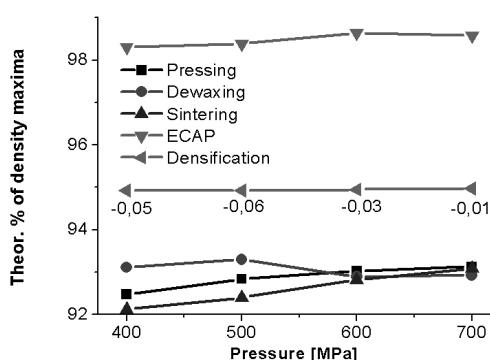


Fig.1. The densification behaviour of studied material.

Tab.1. The porosity behaviour of studied material.

p [MPa]	ECAP					
	before			after		
	D _{circle} [μm]	f _{shape} [-]	f _{circle} [-]	D _{circle} [μm]	f _{shape} [-]	f _{circle} [-]
a	30.64	0.70	0.92	0.97	0.67	0.91
b	30.20	0.72	0.93	0.90	0.65	0.91
c	23.64	0.69	0.92	0.85	0.67	0.91
d	21.27	0.64	0.89	0.79	0.64	0.90

It can be seen that with increasing pressing pressure the values of density increase. Fig.1 shows negative densification values (around -0.3 %). Sintering of aluminium often causes swelling, e.g. [5, 6]. A high heating rate in transient systems also promotes liquid formation because it limits the time available for dissolution of the additive in the base prior to melting. The sintering brings to the formation of secondary porosity during transient LPS as well as the swelling presented seems to be related to the amount of liquid generated, on the other hand, swelling caused by transient liquid phase is not necessarily linked to secondary pores remaining after sintering. LPS effects lead to the generation of secondary pores in approximate range from 21 to 31 μm, Table 1. The formation of secondary pores, according to [7, 8] is dependent to the previous formation of a liquid able to migrate away from the site of the prior alloying particles. The mix of primary, secondary and residual porosity reveals the mean values of pores size decreased with increasing pressing pressure, as well the coarse additive particle sizes leave large residual pores behind. Sintering under vacuum gave rise to the presence of higher pore content and excessive amounts of residual porosity at grain boundaries. ECAP process can be sufficient to achieve a good densification. Also, the presence of adsorbed and absorbed gases by the Al particles, as well as water vapour present during vacuum sintering would increase the size of the compacts and therefore reduce their sintered density due to volume expansion. FEM analyses of ECAP show that the porosity is located in particular in the bottom region of the workpiece close to the outer corner of the die [14, 16]. The interaction of severe shear and the surface oxides, which are not disrupted neither during deformation nor in the processing (pressing and sintering) is therefore present in the component. The SEM microstructure, Fig.2 (pores in black), and the TEM microstructure at the same area in higher and lower magnification are shown in Fig.3 (pores in white).

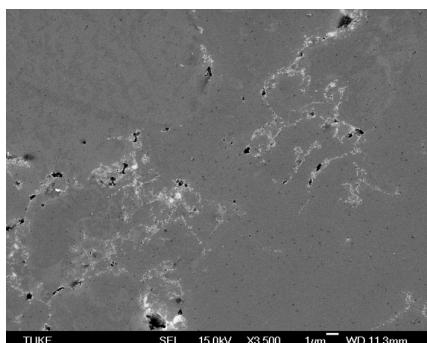


Fig.2. The microstructure of studied material after ECAP (SEM).

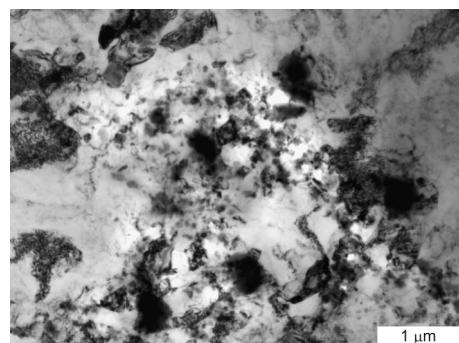


Fig.3. The microstructure of studied material after ECAP (TEM).

For the extremely large strains imposed by SPD processing, even more extensive nucleation of nanopores/voids is expected at grain boundaries or at particle-matrix interfaces [17]. Formation of ultrafine grains during SPD processing increases the total area of grain boundaries and, therefore, the availability of nanopores/voids nucleation sites. It means that nanopores/voids are detected not only in the PM produced materials (in PM materials residual porosity still remains, then we obtain near net form material), as confirmed by [10, 11]. The continual grain refinement is an increase in the density of triple junctions that can act as preferred sites for nanopores nucleation (strain-induced porosity).

It comes to this, that SPD has a structure characterized by some nanoporosity occurring in the areas of triple junctions. Such pores are different from those typical of PM materials (micropores), which are deriving from the compaction and/or sintering steps. In case of SPD process nanopores are formed during severe deformation.

CONCLUSION

The ECAP process causing stress distribution in deformed specimens, made the powder particles to squeeze together to such an extent that the initially interconnected pores transform to small isolated nanopores. Moreover, these newly generated nanopores during ECAP are different from those typical of PM materials (micropores).

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