

INFLUENCE OF ECAP ON DENSIFICATION BEHAVIOUR IN THE PM ALUMINIUM Al–Mg–Si–Cu–Fe ALLOY

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The main aim of this paper is to show how ECAP influences the densification behaviour of PM aluminium alloys. An aluminium based powder (Al–Mg–Si–Cu–Fe) was used as material to be investigated. After applying different compacting pressures, specimens were dewaxed in a ventilated furnace 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. Optical characterization was carried out on the minimum of 10 different image fields. The results were measured for each pore individually in order to describe the dimensional and morphological porosity characteristics. ECAP influences the porosity distribution in terms of the severe shear deformation involved.

Key words: Aluminium alloy, compressibility, vacuum sintering, ECAP, densification behaviour, porosity

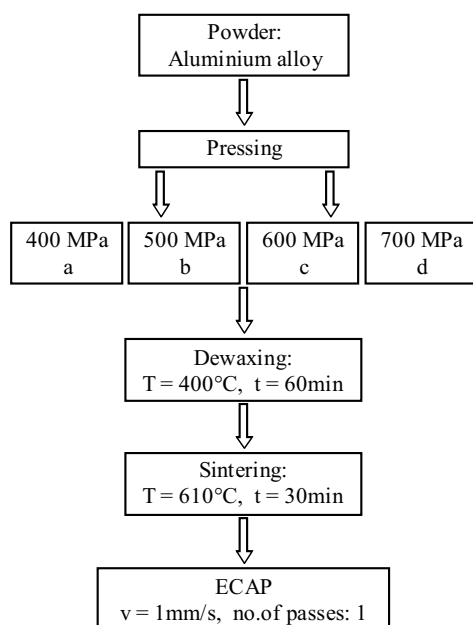


Fig. 1. Processing conditions

1 INTRODUCTION

Light weight aluminium alloys coupled to excellent workability, high thermal and electrical conductivity represent a good choice for the powder metallurgy (PM) industry to produce new materials having unique capabilities not available in present powder metal parts. Also the requirement on mechanical properties of high tensile strength with adequate plasticity should assure an

increasing role for aluminium alloys in the expanding PM market [1].

It is well known [2, 3] that conventional forming methods and heat treatment can determine a limit in the level of strength-plastic characteristics adequate to structural properties. One possible way for achieving higher mechanical properties is represented by severe plastic deformation (SPD), such as Equal Channel Angular Pressing (ECAP) [4–7]. In the PM area, is a relatively new technological solution for achieving high strength [8, 9].

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2 EXPERIMENTAL CONDITIONS

A commercial ready-to-press aluminium based powder (Al - 0.95 Mg - 0.49 Si - 0.21 Cu - 0.07 Fe - 1.6 lubricant) was used as material to be investigated.

Particles size distribution was carried out by sieve analyzer according to ISO 4497. After applying different compacting pressures (400, 500, 600 and 700 MPa), specimens were dewaxed before sintering in a ventilated furnace type (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 °Cs⁻¹. The ECAP was realized by hydraulic equipment at room temperature, which makes it possible to produce the maximum force of 1 MN. The specimens were ECAPed for 1 pass. Processing conditions are shown in Fig. 1.

Optical characterization was carried out on the minimum of 10 different image fields. For the determination of

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Table 1. Densification behaviour of investigated material as values of theoretical density %, except Ψ

| No. | Pressing | Dewaxing | Sintering | Ψ | ECAP |
|-----|----------|----------|-----------|--------|-------|
| a | 92.48 | 93.11 | 92.12 | -0.05 | 98.31 |
| b | 92.84 | 93.30 | 92.40 | -0.06 | 98.39 |
| c | 93.03 | 92.89 | 92.82 | -0.03 | 98.64 |
| d | 93.19 | 92.93 | 93.09 | -0.01 | 98.58 |

Table 2. Porosity distribution of studied material before ECAP

| No | D_{circle} | f_{shape} | f_{circle} |
|----|---------------------|--------------------|---------------------|
| a | 30.64 | 0.70 | 0.92 |
| b | 30.20 | 0.72 | 0.93 |
| c | 23.64 | 0.69 | 0.92 |
| d | 21.27 | 0.64 | 0.89 |

Table 3. Porosity distribution of studied material after ECAP

| No | D_{circle} | f_{shape} | f_{circle} |
|----|---------------------|--------------------|---------------------|
| a | 0.97 | 0.67 | 0.91 |
| b | 0.90 | 0.65 | 0.91 |
| c | 0.85 | 0.67 | 0.91 |
| d | 0.79 | 0.64 | 0.90 |

porosity characteristics 100 \times magnification were used for specimens prepared by pressing and sintering and 500 \times 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 as follows

$$f_{\text{shape}} = \frac{D_{\text{min}}}{D_{\text{max}}} = \frac{a}{b}, \quad (1)$$

where D_{min} μm is the parameter representing minimum of Feret diameter; D_{max} μm is the parameter representing maximum of Feret diameter, and

$$f_{\text{circle}} = \frac{4\pi A}{P^2}, \quad (2)$$

where A μm^2 is the area of the metallographic cross-section of the pore; P μm is the perimeter of the metallographic cross-section of the pore. The calculations of both parameters A and P are reported as follows

$$A = \pi ab, \quad (3)$$

$$P = \pi[1.5(ab) - \sqrt{ab}]. \quad (4)$$

Densification Ψ was calculated to determine the amount of shrinkage or swelling during sintering:

$$\Psi = \frac{\rho_s - \rho_g}{\rho_t - \rho_g}, \quad (5)$$

where ρ_s (g cm^{-3}) is the sintered density, ρ_g is the green density (g cm^{-3}) and ρ_t is theoretical density (g cm^{-3}).

3 RESULTS AND DISCUSSION

3.1 Powder Characterization and Densification Behaviour

Particle size distribution of the powder is in the range of 63–100 μm (48.8 % fraction) and in the range 100–160 μm (28.7 % fraction). It can be seen that dominate particle size is ~ 100 μm . Squared specimens of size $55 \times 10 \times 10$ mm^3 were pressed at pressures in the range of 400–700 MPa to study the compaction characteristics. The results presented in Tab. 1.

The maximum green density of $\sim 2.53 \text{ g} \cdot \text{cm}^{-3}$ of compacts is obtained at 700 MPa with a level of 93 % of theoretical density.

It can be seen that with increasing pressing pressure, in the values of theoretical density increase. It is well-known that aluminium powder would not require much sintering because its relative softness allows very high green densities to be obtained by compaction alone, as well green densities in excess of 90 % are typical. Indeed, sintering of aluminium often causes swelling and results in negative densification values [10–13]. 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. 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 [14] would increase the size of the compacts and therefore reducing their sintered density due to volume expansion.

3.2 Porosity Distribution

Table 2 shows the values of porosity characteristics for the investigated material processed before ECAP.

As expected, the sintering tends 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. The formation of secondary pores, according to [11–13] is dependent on the previous formation of a liquid able to migrate away from the site of the prior alloying particles. The mix of primary (which still present in studied materials), secondary and residual porosity reveals the mean values of D_{circle} decreased with increasing pressing pressure. As expected, 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.

Application of ECAP supported next decreasing of pore size, represented by the value of D_{circle} , Tab. 3.

It can be noted that most of the pores diameter values are less than $1\text{ }\mu\text{m}$. It could be expected that this large amount of small pores-nanoporosities, strongly influences both f_{shape} and f_{circle} considering that small pores evolve easily to a circular form despite of well-known ability of ECAP to alignment of particles and porosity [8, 15].

4 CONCLUSION

Coupling the experimental results obtained and the literature analysis it is possible to the achieved following conclusions:

1. ECAP influences the porosity distribution in terms of the severe shear deformation involved.
2. The application of SPD induced the stress distribution in deformed specimens causes the powder particles to squeeze together to such an extent that the initially interconnected pores transform to small isolated pores, determining a given value of the parameter D_{circle} and therefore influences the pore morphology which is represented by both f_{shape} and f_{circle} .

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