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Bearing composites made from aluminium and aluminium bronze chips

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Abstract

The good bearing materials can be made from the compacted mixture of aluminium and aluminium bronze chips without participation of metallurgical processes. The parameters to obtain a good bonding of aluminium and CuAl8 aluminium bronze chips separated by a layer of oxide can be determined on the base of the new form of sintering criterion. Diffusion bonding process of aluminium and aluminium bronze chips leads to creation of the phases typical for Cu–Al equilibrium diagram. Because during the hot extrusion the diffusion bonding is very slow, after extrusion heat treatment must be applied.

Keywords: Chips; Aluminium; Aluminium bronze; Sintering criterion; Phases

1. Introduction

Recently, it has been shown that products with predetermined properties can be manufactured by recycling of different kinds of chips [1–4]. In the conventional, metallurgical recycling processes of the chips, a lot of the metal is lost by the oxidation. In such processes, the costs of labour and energy as well as the expenditures on environment protection raise the general cost of product manufacturing. Therefore, the direct conversion of metal chips recycling into compact products, where the melting process is eliminated, was elaborated. This kind of recycling can be applied to aluminium [1,2], copper, iron and even to cast iron [3,4].

In case of the aluminium and its alloy chips, no more than 54% of metals are recovered in the metallurgical recycling. In the case of the direct conversion of the same metals chips into compact metal ultimately 95% of the metal is recovered [5,6]. The benefits of the direct conversion of aluminium and its alloy chips into compact metal include also reduction of the funds spend on the labour, energy and environment protection as a result of the reduced consumption of ores and energy carriers, and smaller degradation of the natural environment.

The bonding of aluminium and its alloy chips is significantly affected by following factors: size of chips, pre-compaction parameters, stress and strain states in extrusion or forging processes, temperature, strain rate, lubricant and lubrication method. For good bonding of chips, the large plastic deformation is needed. Such deformation can be easily obtained in extrusion process. The good lubrication improves achievement of the large, uniform deformation, but it can hinder the bonding of the chips.

The recycling of chips by conventional method contains following operations: pre-compaction, melting, casting, cutting of ingot, hot extrusion and cutting to final size. The direct conversion of chips contains: comminution, cleaning, drying, pre-compaction, hot extrusion and cutting to final size.

The direct conversion of chips was applied not only to pure aluminium and its alloy chips [1] but also to these materials with additional reinforcing phases: tungsten, carbon, silicon carbide, ferro-chromium and aluminium oxide [2]. On the one hand, reinforced phases decrease free movement of the dislocations and increase the strength properties of composites, but on the other hand increase the porosity and reduce these properties as well. Therefore, the optimal content of reinforcing phase should be applied according to destination of composites.

Good friction properties are the main reason that the modern bearing composites based on aluminium powders with silicon, silicon–carbide, and graphite additions were elaborated as bearing materials [7,8].

An original concept of production such composites from the chips of aluminium and aluminium bronze chips through the mixing, cold pre-compaction, hot extrusion and heat treatment,

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has been developed [9]. As a result of the reciprocal diffusion of copper and aluminium during extrusion and heat treatment applied just after extrusion hard phases leading to an increase of wear resistance takes place. The mechanical properties of composites are correlated to phases created according to Al–Cu equilibrium diagram [10]. The kinetics of phenomena taking place during extrusion and heat treatment has the distinct effect on the sintering of the products [11]. The original sintering criterion [12,13] was elaborated using partly the deformation processing map [14,15].

The main aim of the paper is to apply the new sintering criterion to determinate the sintering conditions and to investigate the phases created during bonding and their effect on the composites properties.

2. Materials and processing

As the starting materials the granulated chips of aluminium of two fractions, i.e. below 2 mm and 2–4 mm were mixed with different amount of reinforcing phase: 15, 22, 30 and 45%. As the reinforcing phase, the aluminium bronze containing 8% of aluminium was chosen. High-power ball mill with a horizontal axis of rotation filled with 20 mm-diameter steel balls up to 45% of its volume was used for the mixing of granulated aluminium chips with particles of reinforcing phase. The mixtures were subjected to cold compacting, hot extrusion and heat treatment. The cold compacting was performed in a device with a floating die under the constant pressure of 400 MPa. The hot extrusion was applied to crushing the oxides layer and actuating diffusion processes under a high pressure and temperature. Hot extrusion was carried on in the temperature range of 500–525 °C. As lubricant mixture of zinc stearynian with graphite was used. The last operation was heat treatment at 545 °C and different time, changing in the range of 0.5–10 h. Using optical and scanning electron microscopes and image analysis system VISILOG-4 the structure was investigated.

3. Sintering criterion

The determination of the best conditions of chips recycling was based on new sintering criterion. In the early studies [12] the older sintering criterion was used, but in this paper the new one [13] was applied.

The sintering criterion is based on the assumptions that on the bonding of particles two factors have fundamental effect:

- The contribution of clear surface of particles, which are exposed during working processes as a result of the brittle surface layer fracture, to whole particle surface.
- The values of normal stresses acting on the clear surface of particles.

The fracture of oxide surface layer and atomic contact of clear surface take place in such area where the biggest tensile strain and perpendicular to it compression stress exist. Therefore, it can be stated that the adequate large tensile strain and normal stress are needed for good junction of particles. So the sintering criterion can be expressed by these factors in the following form:

$$\mathrm{d}W_\mathrm{s} = f(\sigma_n, \mathrm{d}\varepsilon_1) \tag{1}$$

where $\mathrm{d}W_\mathrm{s}$ is the sintering indicator characterising the local quality of particles junction, $\mathrm{d}\varepsilon_1$ the increment of the largest tensile strain and σ_n is the compression stress normal to the direction of the largest tensile strain.

For isotropic materials, there is consistence of the principal stress and strain directions and the normal compression stress σ_n is equal to the largest principal compression stress σ_3.

The indicator characterising the local quality of sintering of particles can be described by the product of both factors as follows

$$\mathrm{d}W_s = \sigma_3\,\mathrm{d}\varepsilon_1 \tag{2}$$

The good junction of the particles takes place when sintering indicator W_s obtain the critical value C_cr:

$$W_\mathrm{s} = \int_0^{\varepsilon_1} \sigma_3\,\mathrm{d}\varepsilon_1 = C_\mathrm{cr} \tag{3}$$

For axisymmetrical metal forming processes of incompressible materials component of principal strain ε_1 can be expresses by other component of principal strain ε_3

$$\mathrm{d}\varepsilon_1 = -2\,\mathrm{d}\varepsilon_2 = -2\,\mathrm{d}\varepsilon_3 \tag{4}$$

Taking into account that sintered materials especially during manufacturing do not keep incompressible, condition the compressible coefficient α must be introduced into relation:

$$\mathrm{d}\varepsilon_1 = -2\alpha\,\mathrm{d}\varepsilon_3 \tag{5}$$

Combining Eqs. (3) with (5) the following relation is obtained:

$$W_\mathrm{s} = \int_0^{\varepsilon_3} 2\alpha\sigma_3\,\mathrm{d}\varepsilon_3 = C_\mathrm{cr} \tag{6}$$

That means that for sintering of particles the defined unit work of the largest principal compression stress on the largest suitable displacement is needed. For an application of such a criterion the critical value of C_cr, which secures good junction of particles, has to be known.

The parameter C_cr can be determined experimentally or analytically. Experimental determination of the parameter can be obtained by measuring the forces of particles compacting in some process as a function of deformation degree at chosen temperatures and strain rates. Then by using finite element method, the components of strain state ε_{ij} and stress state σ_{ij} can be determined and plastic work of largest compression stress on the proper displacement, according to relation (6), would be calculated. The critical value of plastic work C_cr for good bonding, at above chosen conditions, is the value on the σ_3 true stress, corresponding to the point of outset of plateau (Fig. 1). The experimental method is very labour-consuming. Much easier is to analyse the sintering processes using the theoretically calculated values of C_cr parameter.

The theoretical calculation of the C_cr parameter is based on the assumption that an n-fold increase of the particle surface area is enough to fracture the brittle surface layer and to exposure the native structure for joining of particles. As a measure of the deformation degree of the particle, the change of its surface area is taken. Assuming the cylindrical shape of the individual