



Flow stress behavior and processing map of extruded 7075Al/SiC particle reinforced composite prepared by spray deposition during hot compression



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Abstract: Hot compression tests of the extruded 7075Al/15%SiC (volume fraction) particle reinforced composite prepared by spray deposition were performed on Gleeble–1500 system in the temperature range of 300–450 °C and strain rate range of 0.001–1 s^{−1}. The results indicate that the true stress–true strain curve almost exhibits rapid flow softening phenomenon without an obvious work hardening, and the stress decreases with increasing temperature and decreasing strain rate. Moreover, the stress levels are higher at temperature below 400 °C but lower at 450 °C compared with the spray deposited 7075Al alloy. Superplastic deformation characteristics are found at temperature of 450 °C and strain rate range of 0.001–0.1 s^{−1} with corresponding strain rate sensitivity of 0.72. The optimum parameters of hot working are determined to be temperature of 430–450 °C and strain rate of 0.001–0.05 s^{−1} based on processing map and optical microstructural observation.

Key words: 7075 Al; SiC; particle-reinforced composite; hot compression deformation; flow stress; processing map; superplastic deformation

1 Introduction

SiC particle reinforced aluminum matrix composites are widely used in structural applications, especially in the aerospace and automobile industries, due to their high specific stiffness and strength, high wear resistance, high dimensional stability, good erosion resistance and low thermal expansion coefficient [1–3]. Nowadays, many processes have been used to fabricate particle reinforced aluminum matrix composites [4], such as powder metallurgy [5], spray deposition [6], stir casting [7], rheo-casting technique [8]. Compared to the unreinforced matrix alloys, the composite materials are more sensitive to process variables, i.e., temperature, strain and strain rate, since the hard particles embedded in the soft matrix will lead to localized deformation [9]. Owing to the presence of hard ceramic reinforcements, these composites have worse hot workability than that of matrix alloy, hence it is of practical importance to explore hot deformation behavior of aluminum matrix composites.

The hot workability of SiC particle reinforced aluminum matrix composites has been extensively studied [10–14]. SU et al [10] compared the workability of spray-formed 7075/SiC_p aluminum matrix composites with conventional continuously-cast 7075Al alloy by employing the upset forming technique, and found that the yield strength of the spray-formed 7075/SiC_p aluminum matrix composites is larger than that of the continuously-cast 7075Al alloy for all initial strain rates. RAJAMUTHAMILSELVAN et al [11] studied the hot deformation behavior of 7075Al alloy reinforced by 10% of SiC particles fabricated by stir casting technique, and discovered that the flow stress is significantly low at lower strain rates whereas the work hardening rate is relatively high.

The processing maps, based on the dynamic materials model (DMM), considering the workpiece as a dissipator of the power supplied by a particular source, are frequently used to evaluate material workability as a function of process parameters such as temperature, strain rate, and strain [11–18]. ZHANG et al [12] obtained the optimum working regions of extruded

Al–1.1Mn–0.3Mg–0.25RE alloy using processing maps. The processing map of 35%SiC_p/2024 aluminum alloy composites was established to evaluate the efficiency of the forging process in the ranges of temperature and strain rate investigated and the optimal hot deformation conditions were obtained by HAO et al [13]. The domains of dynamic recrystallization and wedge cracking were observed in the processing maps of 6061 Al/SiC_p composites by GANESAN et al [14], and the optimum working regions were identified. These studies suggest that the use of processing maps is currently a promising method to predict the deformation mechanisms under different deformation conditions, and it has been used to analyse the response of several aluminum matrix composites. It is also possible to optimize deformation process parameters and obtain products with improved properties.

According to DMM, the total provided power dissipated P can be obtained by the following relationships [15,16]:

$$P = \sigma \dot{\epsilon} = G + J = \int_0^{\dot{\epsilon}} \sigma d\dot{\epsilon} + \int_0^{\sigma} \dot{\epsilon} d\sigma \quad (1)$$

where the first integral (G) represents the temperature rise during deformation and the second integral (J) represents the power dissipated through metallurgical transformations (recovery, recrystallization, phase transformation) and material damage (void and fractured particle).

$$\sigma = K \dot{\epsilon}^m \quad (2)$$

$$m = \frac{\partial(\lg \sigma)}{\partial(\lg \dot{\epsilon})} \quad (3)$$

where K is a constant and m is the strain rate sensitivity.

According to PRASAD et al [17], the power dissipation capacity of the material can be evaluated by the efficiency of power dissipation η which is defined as

$$\eta = \frac{2m}{m+1} \bigg|_{\epsilon, T} \quad (4)$$

The variation of η with deformation temperature and strain rate was used to construct power-dissipation maps which are viewed as an equivalent efficient contour map. The power-dissipation maps describe the internal microstructure deformation mechanism of the work piece in a given range of processing temperature and strain rate. And the best hot working region is defined as a region with high power dissipation. However, a series of damage mechanisms, such as void formation, wedge cracking, inter-crystalline cracking, and other types of cracking processes, could happen in high power dissipation regions [18]. Hence, the instability criterion formulated on this basis is developed on the basis of the extremum principles of irreversible thermodynamics applied for large plastic flow. The instability map is

developed on the basis of an instability criterion and given by the parameter ζ [13]:

$$\zeta(\dot{\epsilon}) = \frac{\partial \ln[m/(m+1)]}{\partial \ln \dot{\epsilon}} + m < 0 \quad (5)$$

In the present work, the hot compression tests of the extruded 7075Al/15%SiC particle reinforced composite prepared by spray deposition were performed on Gleeble–1500 system in the temperature range of 300–450 °C and strain rate range of 0.001–1 s^{−1}. The hot deformation mechanism and optimum processing parameters were investigated by processing maps and microstructural observations.

2 Experimental

The 7075Al/SiC_p alloy metal-matrix composites, nominally containing 15% SiC particles (volume fraction), were produced by spray deposition [6]. The chemical compositions of matrix 7075Al alloy were 5.5% Zn, 2.2% Mg, 1.7% Cu, 2.2% Cr, 0.1% Mn, 0.4% Fe, 0.3% Si and balanced Al (mass fraction, %). The average diameter of SiC particles is 15 μm. The spray deposition billets were preheated at temperature of 400 °C and extruded on 1250T extruding machine with extrusion ratio of 64. The cylindrical specimens for hot compression test with diameter of 10 mm and height of 15 mm were machined from the extruded rods in respect to the extrusion direction. Hot compression tests were carried out on Gleeble–1500 system in the temperature range of 300–450 °C and strain rate range of 0.001–1 s^{−1}. The specimens were resistance heated to deformation temperature at a heating rate of 5 °C/s and maintained at that temperature for 3 min before deformation. The graphite mixed with machine oil lubricant was used on the interface of specimens and crossheads to minimize friction effect. After being compressed to a total true strain of 0.5, the specimens were quenched with cold water immediately to preserve the deformed microstructure.

The compressed specimens were sectioned parallel to the compression axis along the direction of centerline and prepared by the conventional methods for the optical microstructural observations on MM-6 metallographic microscope (OM).

3 Results and discussion

3.1 Flow stress behavior

A series of typical true stress–true strain curves of spray-deposited 7075Al/15%SiC_p composites obtained during hot compression at strain rate of 0.001–1 s^{−1} and deformation temperature of 300–450 °C are shown in Fig. 1. It can be seen that the true stress–true strain

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