MICROSTRUCTURE AND MECHANICAL PROPERTIES OF A EXTRUDED RAPIDLY SOLIDIFIED AlFeVSi ALLOY①

Zeng, Yuxiao Li, Songrui Li, Wenxian Wang, Richu Hu, Miao
Department of Materials Science and Engineering,
Central South University of Technology, Changsha 410083

ABSTRACT The microstructure and mechanical properties of a rapidly solidified AlFeVSi alloy after hot extrusion were studied by means of optical metallography, X-ray diffraction and transmission electron microscopy. Both hot extrusion and preheating prior to extruding bring about the change of the powder microstructure. During extrusion the precipitation and growth of $Al_{12}(Fe, V)_3Si$ dispersoids are accelerated and the inhomogeneity of the microstructure and properties exists distinctly along the extrusion direction. Extrusion stress might be responsible for it in addition to the temperature rise resulting from the deformation and friction heat.

Key words: Rapidly solidified alloy AlFeVSi alloy Extrusion

1 INTRODUCTION

AlFeVSi alloys produced by rapid solidification techniques are promising alloy systems for elevated-temperature applications due to their attractive combination of ductility, room-and elevated-temperature strengths and fracture toughness ascribed to uniformly distributed, fine $Al_{12}(Fe, V)_3Si$ dispersoids, which are resistant to coarsening[1]. These alloys are currently processed by planar flow casting into ribbons which are then comminuted into particles or gas atomizing into powder particles, and consolidation of particles by extrusion, forging and rolling. As a conventional method of powder consolidation, extrusion fabrication plays a critical role on the microstructure and properties of the alloys, into which few detailed investigations have been reported, especially in the case of bulk material with large dimensions. As such, this study was undertaken to explore the effect of extrusion on the microstructure and mechanical properties of a bulk rapidly solidified AlFeVSi alloy in order to be beneficial to its theoretical research and engineering application.

2 EXPERIMENTAL

Cast ingots of nominal composition Al-8.5% Fe-1.5% V-1.7% Si were obtained by induction melting pure elements and midalloys in a graphite crucible. The alloy powders were produced by multi-stage atomization rapid solidification powder-making device[2], followed by screened, canned, vaccum-degassed, cold-pressed into a cylindric billet 300 mm long and 80 mm in diameter and hot-extruded at 470 ℃ (preheat time 2 h) with a 16∶1 reduction ratio. Three samples prepared from the 3-metre-length extruded sheet which were at distance 0.3 m, 1.2 m, 2.5 m respectively (marked sample 1#, 2#, 3#) from the head of the sheet were used to examine the change of the microstructure and properties along the extrusion direction. Furthermore, in order to determine the influence of preheating, powder particles were heated to 470 ℃, annealed for 2

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h, and the phase change was determined using X-ray technique.

Tensile testing was carried out using an Instron machine. Hardness was measured by a microhardness meter using a 5 kg load with a 20 s dwell time. X-ray diffraction analysis was performed in a SIMENS-D500 X-ray diffractiometer employing CuK_α radiation. High-angle diffraction peaks (422) and (420) were applied to calculate the lattice parameter of α-Al matrix. Samples examined by optical microscopy were etched with keller's reagent and specimens for the TEM were electropolished in a twin jet polishing apparatus at 20 V using an electrolyte of nitric acid: methanol = 1:3.

3 RESULTS

3.1 *Mechanical Properties*

The property variation of the sheet along the extrusion direction is shown in Fig. 1, 2. The ultimate strength, elongation and hardness decrease gradually from head to end. The hardness value of sample $3^{\#}$ is lower by 17% than that of sample $1^{\#}$, just comparable to the reported result[1] that the hardness value of the AlFeVSi alloy with the same composition as the present study decreased by 18% after annealed at 600 ℃ for 10 h. It is suggested that the property inhomogeneity in the sheet is pronounced, which is adverse to its application.

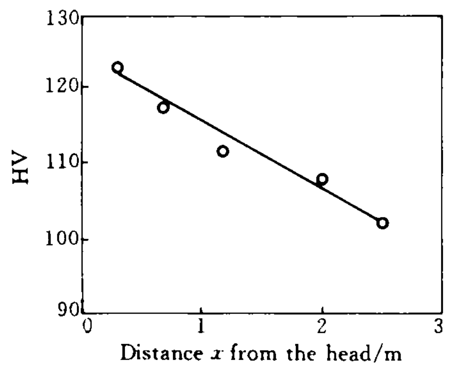

Fig. 1 Property variation along the extrusion direction

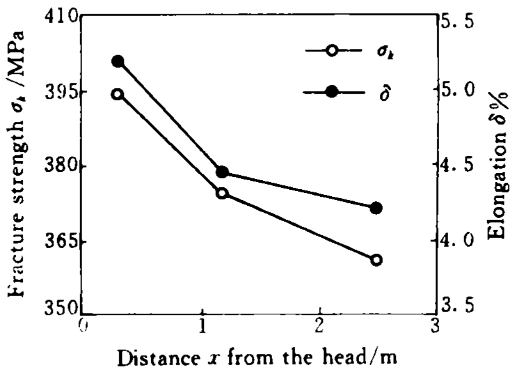

Fig. 2 Hardness change along the extrusion direction

3.2 *X-ray Analysis*

Fig. 3 indicates the X-ray analysis results for the as-received powders, annealed powers, sample $1^{\#}$, $2^{\#}$ and $3^{\#}$. Table 1 contains their measured lattice parameters of Al matrix. All diffraction patterns were identified, showing that there are no other phases than supersaturated solid solution and $Al_{12}(Fe, V)_3Si$ phase. According to the change of the diffraction peak intensities of $Al_{12}(Fe, V)_3Si$ dispersoids in different samples, it is found that, after annealed at 470 ℃ for 2 h, the quantity of dispersoids increased remarkedly compared to the atomized powders originally with little evidence of the dispersoids, and this tendency is more evident in the extruded samples along the extrusion direction, which is corresponding with the variation of lattice parameters presented in Table 1. The results implicate that both preheating at high temperature for a long period of time and hot extrusion influenced the microstructure strongly.

Table 1 Lattice parameters of α-Al matrix in various conditions (corresponding with Fig. 3)

Condition	(a)	(b)	(c)	(d)	(e)
Lattice parameter /Å	4.0486	4.0493	4.0512	4.0519	4.0525

3.3 *Microstructure*

A comparison of the typical microstruc -

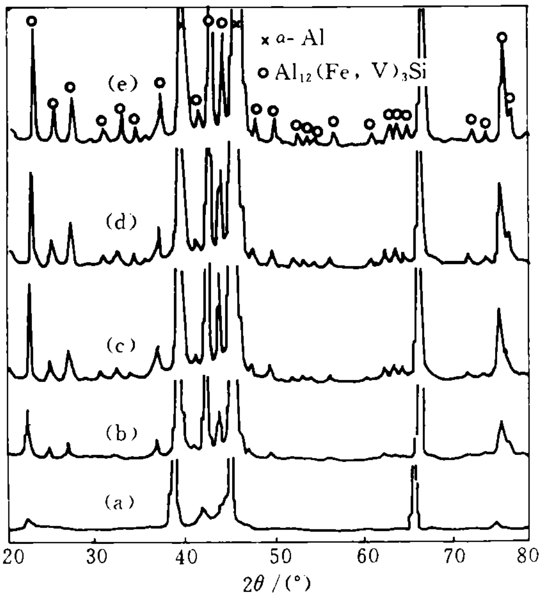

Fig. 3 A comparison of X-ray diffraction patterns

(a)—as-received powders;
(b)—annealed powders (470 ℃, 2 h);
(c)—1#; (d)—2#; (e)—3#

ture for various samples is revealed in Fig. 4. Featureless A-zone microstructure exhibited in as-received powders almost completely transformed into B-zone due to the decomposition of the supersaturated matrix. Compared with sample 1#, 3# seems to display more dispersoids and more homogeneous distribution of dispersoids.

4 DISCUSSION

4.1 *Effect of Microstructure on the Mechanical Properties*

The principal contributions to the low-temperature strength of the particle-hardened material have been thought to include Orowan bowing strengthening, solid-solution strengthening and grain-size strengthening, among which the last one was calculated to be less dominated[3,4]. The Orowan strengthening mechanism can be described as[5]:

$$\sigma = \alpha G \boldsymbol{b} f_v^{\frac{1}{3}} / d_p \quad (1)$$

where α is a coeficient close to unity; G is the shear modulus of the matrix; $\boldsymbol{b}$ is the Burgers vector of the dislocation, d_p is the mean size and f_v is the volume fraction of the precipitaties.

As shown previously in Fig. 3, the quantity or volume fraction of the precipitates and the lattice parameter of Al matrix increased from head to end in the extruded sheet. Increase of the lattice parameter suggests loss of Fe, V and Si from the solid solution, indicating more dispersoids precipitatied from the matrix, which is one reason for the increasing quantity of dispersoids. In addition, from the TEM pictures in Fig. 5, in comparision with 1#, some dispersoids in sample 3# show signs of coarsening and some even coalesce into clusters which has also been reported by ref [1]. This might be another reason for the increasing quantity of dispersoids.

Accoridng to equation (1), the increasing f_v improves σ value, while the increasing d_p reduces σ value. Nevertheless, since σ is proportional to the cube root of f_v and inversely proportional to d_p, it is reasonable to think that σ value is still reduced after the improved σ value caused by increasing f_v is offset by the decreased σ value due to increasing d_p when the variations of f_v and d_p are in proper order of magnitude.

On the other hand, the solid-solution strengthening effect decreaces contributed to the reduced supersaturated solid solubility, although quantitative relation is difficult to set up. There is no evidence of the coarsening of the grains, implicating that the role of grain-size strengthening can be ruled out.

The decrease in elongation can be traced to the increasing volume fraction of the precipitates[6] and the coarsening and clustering of the precipitates[1].

4.2 *Reasons for the Variation of Microstructure*

In general, the variation of the microstructure for the rapidly solidified powder alloy during extrusion can be interpretted by the rise of the temperature resulting from the deformation heat and friction heat, which is more evident in the large - size bulk material

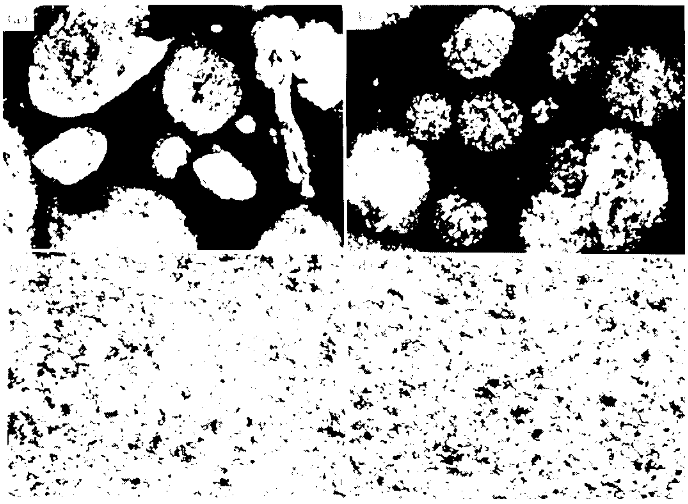

Fig. 4 Microstructure in different conditions (×1500)
(a)—as-received powders (b)—annealed powders (470 ℃, 2h)
(c)—1#; (d)—3#

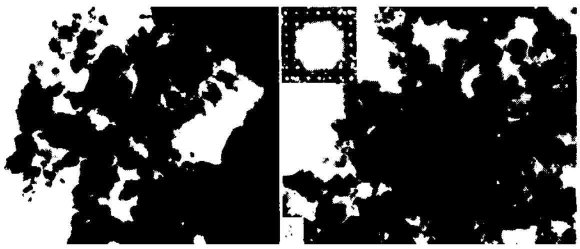

Fig. 5 Microstructure of sample 1# **and** 3# **(TEM)** (×40 000)

just as the present case. In present study, the extruded sheet is long enough, so the temperature rise in different extrusion stages is sure to be different. During the initial stage, little deformation and friction heat, thus small temperature rise, along with short heated time of the extruded section, lead to little difference

(*To page 146*)

5 CONCLUSION

(1) The derivations of the formulae for energy losses and analysis of relationship among β, P_{in} and total efficiency are of practical value in optimizing hydraulic impact mechanisms.

(2) On analyzing the two feature values of accumulators the motion laws of the mechanism are revealed thoroughly.

(3) The computing procedures introduced in the paragraph above is of convenience in determining the parameters of the mechanism precisely.

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(*From page 127*) compared to the preheated powders. With the progressing of the extrusion, temperature rise is more considerable and the powders in the extrusion container are heated for more time, so more dispersoids precipitate.

However, considering the fact that the coarsening rate of $Al_{12}(Fe, V)_3Si$ dispersoids is very small and the the duration of the extrusion processing is also relatively short, it is not enough to explain the clear coarsening of the dispersoids only by the temperature rise. The precipitate coarsening rate is given by[7]:

$$dr/dt = Dc\sigma r^{-2} \quad (2)$$

where r is the precipitate size; D is the solid diffusion coefficient; c is the equillibrium solubility; σ is the interfacial energy between the matrix and the precipitate.

The measurement of the coarsening rate as described is usually carried out in the case without applied stress on the precipitates. It is apparent, however, that very high extrusion force exists during extrusion, which is necessarily considered in the calculation of the coarsening rate. The coarsening rate is directly proportional to the solid diffusion coefficient D. It is well accepted that atoms can diffuse by transgressing the potential barrier with the help of heat activation if there exists chemical potential gradient of the solute constituent in the solid solution. However, diffusion can also occur if stress exists, even if the solute atoms are uniformly distributed. The increment of the solute flux because of the applied stress can be thought to correspond with the improvement of diffusion coefficient D in equation (1), leading to faster coarsening rate compared to that without stress. Therefore, the clear coarsening of the precipitates in the late stage of extrusion is possible on account of the effect of temperature rise and high stress regardless of the low initial coarsening rate.

5 CONCLUSION

(1) The inhomogeneity of the microstructure and properties exists evidently in the extruded, rapidly solidified AlFeVSi material with decreaing mechanical properties, improved size and quantity of the precipitates along the extrusion directon.

(2) The variation of the microstructure might result from the extrusion force in addition to the temperature rise during extrusion.

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