MICROSTRUCTURES AND MECHANICAL PROPERTIES OF SPUN PIPE BLANKS OF RS AlFeX ALLOY①

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ABSTRACT Two pipe blanks of rapidly solidified AlFeVSi alloy were prepared respectively by two kinds of different processings of rapid solidification-cold isostatic compact-hot extrusion and spray deposition-hot extrusion, and their microstructures and properties before and after hot extrusion were investigated comparatively using optical microscope, SEM, TEM and tensile test. The results showed that the pipe blank prepared by the former processing has higher strength and lower plasticity, and exhibits more intensive anisotropy than that of the latter, the main factors affecting the dissimilarity are degree of deformation, thickness of powder surface oxide film and cooling rate of solidification.

Key words aluminum alloy extrusion rapid solidification spray deposition

1 INTRODUCTION

Among the new-type of high strength and high heat-resistant aluminum alloy, rapidly solidified (being abbreviated to RS in the following) AlFeVSi alloy is one of the important alloys possessing high room and elevated-temperature strength, good fatigue strength, moderate plasticity and excellent resistance to heat and corrosion[1, 2]. So far main problem with the development of this alloy is how to produce large-sized component and enlarge scope of its application[3, 4]. We have been trying to adopt shear spinning techniques to research and produce large-sized pipe of this aluminum alloy, however the domestic and foreign investigation on that aspect was seldom reported. Therefore the first key to the settlement of the above-mentioned main problem and the realization of our development purpose lies in how to prepare spun pipe blanks with good properties by using certain suitable manufacturing technique. In this paper, FVS0812(RSA-8.5Fe-1.3V-1.7Si) is chosen as the alloy studied, pipe blanks used in shear spinning test are prepared by means of hot-extrusion consolidated technique, and their microstructures and properties were comparatively investigated, main purpose is to seek for an effective and practical way to produce qualified spun pipe blanks.

2 EXPERIMENTAL METHOD

Spun pipe blanks were prepared by two kinds of different processing, some were done by extrusion from powder cold compact pipe blanks produced after atomization, cold isostatic compaction and vacuum degasification, and the others from deposited pipe blanks prepared by spray deposition. Extruded pipe blanks were about (d_{ext}275 mm-d_{int}150 mm) × 360 mm, the extrusion was carried out by 50 MN horizontal extruder, extrusion barrel internal diameter d_{int} = 280 mm, punching needle diameter d = 140 mm, extrusion temperature T = 470~520 ℃ and reduction rate λ = 6.3.

The samples were cut out from pipe blanks along longitudinal and traverse directions, their

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microstructures were characterized by using Neophot-2 optical microscope and the samples were etched in Keller's reagent, their mechanical properties were examined at nominal strain rate of approximately $5 \times 10^{-4} s^{-1}$, which were done by WD-10A universal testing machine at room-temperature and by Instron 8032 testing machine at high temperature (350 ℃) after heat preservation for 420 seconds, and tensile fracture surfaces were observed by using KYKY AMRAY 2000B scanning electron microscope. In order to be concise in the following, powder cold isostatic compacted pipe blank and deposited pipe blank will be called PG and DG for short respectively, and after extrusion their extrudates will be PEG and DEG correspondingly.

3 RESULTS

3.1 Microstructures and mechanical properties of pipe blanks before extrusion

Optical microstructures of PG and DG are shown in Fig. 1. PG is composed of near-spherical powders varied in size, there is a vast amount of small hole and primary powder boundary among the powders and thus binding among the powders is mainly mechanical adherence, fine powders come up to completely supersaturate and they exhibit featureless microstructure (*A* zone), but in the overwhelming majority of coarse powders fine second phase particles have precipitated (*B* zone), which is identical with the results in Ref. [1]. However, if the region formed after solidification of a melted drop is regarded as a powder, the powder particles of DG have irregular appearance, there is also small hole and primary powder interface but their quantities have obviously reduced and binding among the powders has mostly come up to metallurgical adherence, the microstructures of DG under optical microscope is similar to those of PG, but due to its lower cooling rate, the amount of *A* zone of DG is evidently decreased and that of *B* zone increased, even there exists the microstructure with coarse lumpish particles of second phase (*C* zone). Therefore, actual density of PG is about 2.41 g/cm^3 which is only 75% of theoretical density, its mechanical properties are nearly zero, but density of DG is about 2.84 g/cm^3 and its mechanical properties (σ_b, $\sigma_{0.2}$ and δ) are 171 MPa, 148 MPa and 3.2 % respectively.

Fig. 1 Microstructure of PG(a) and DG(b)

3.2 Extrusion breakthrough force and extrusion temperature

The extrusion breakthrough force (P) can be estimated theoretically by using the following formula[5]:

$$P = \frac{\pi}{4}(D_0^2 - d_0^2) C \ln \lambda (1 + f L_0 / D_0) Z \sigma_b \quad (1)$$

where D_0, d_0 and L_0 are extrusion barrel internal diameter, punching needle diameter and pipe blanks length after filling up; and f is friction coefficient, C is shape coefficient of the section, Z is cooling coefficient of the metal, σ_b is tensile strength of extruded material at extrusion temperature. Under this testing condition, the extrusion breakthrough force of FVS0812 at 520 ℃ should be about 17.8 MN theoretically, but, in fact, the force of PG is about 24.0 MN and that of DG is 13.0 MN. As comparing with each other, the force of PG is greatly higher than the

theoretically estimated force, the main reasons are that, ① larger force against deformation of fine powder itself is reqired, ② more powder surface oxide film need to be broken, ③ finer $Al_{12}(Fe, V)_3Si$ particles precipitated during hot-extrusion have excellent dispersion strengthening effect and hindrance effect from dynamically recrystallization softening of aluminum matrix, thus it is very easy for DG to be extruded out because the amount of its oxide film decreases and precipitation of coarse lumpy phase weakens dispersion strengthening effect. Due to the similar reason, DG can be extruded out smoothly at 470 ℃ but PG can not, Lowering extrusion temperature like that is of significance to produce rapidly solidified heat-resistant aluminum alloy[6].

3.3 Microstructures of pipe blank after extrusion

Under low-powered microscope, lots of long and thin black streamlines are distributed over both blanks (PEG and DEG) after extrusion along extrusion direction, seeing Fig. 2(a). Analysis under high-powered microscope shows that the streamlines are actually long narrow strips with coarse lumpish phases, seeing C' zone in Fig. 2(b). Carefully observed, the white-gray region between the streamlines is made up of strips (A' zone and B' zone) with fine particles differed in size, the select area diffraction shows second phases in the A', B', C' strips are still metastable $Al_{12}(Fe, V)_3Si$. Hence the A', B', C' zones are formed out of the A, B, C zone after stretching along primary deformation direction during extrusion, simultaneously fine $Al_{12}(Fe, V)_3Si$ phase precipitates from supersaturated solid solution and the existed silicide particles coarsen distinctively and even polygonizate under the circumstance of high temperature and stress[7]. The A' and B' contents of PEG are absolutely dominant and the C' content is very small, and the strips are thin and narrow, however the dominantive in the PEG is B' and C', and the strips are thick and wide, therefore not only microstructure inhomogeneity of DEG is evidently more serious than that of PEG but also its microstructures, especially second phase particles, are coarser.

3.4 Mechanical properties of pipe blanks after extrusion and their tensile fractograph

Table 1 shows along the longitudinal (extrusion) direction, PEG has higher room and elevated temperature strength than DEG, but plasticity of the former is lower, in comparison with longitudinal and transverse properties, both pipe blanks exhibit anisotropy but PEG does

Table 1 Tensile properties of PEG and DEG

Pipe blank	Sample direction	25 ℃ σ_b /MPa	25 ℃ $\sigma_{0.2}$ /MPa	25 ℃ δ /%	350 ℃ σ_b /Mpa	350 ℃ $\sigma_{0.2}$ /Mpa	350 ℃ δ /%
PEG	Longitudinal	421	374	5.6	174	160	3.8
	Transverse	375	343	2.3	/	/	/
DEG	Longitudinal	396	344	8.7	161	148	6.3
	Transverse	386	330	8.1	/	/	/

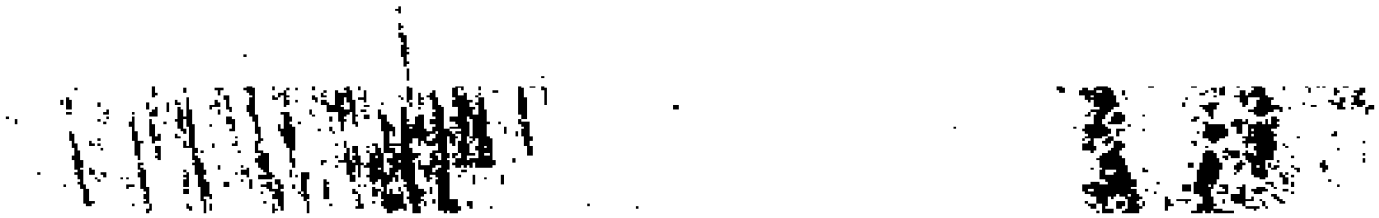

Fig. 2 Steamlines (a) and its microstructural characteristic (b) of as-extruded pipe blank

more intensively.

Room temperature tensile fractographes of pipe blanks are shown in Fig. 3, PEG has, in general, mixed fractograph of brittleness and toughness, the longitudinal tensile fractrograph exhibits more toughness on the fractograph than the transverse. Second crack can be apparently observed, which indicates the inter-powder binding is not perfect and there exists weak powder interface, therefore under the effect of tensile stress the crack initiates easily nearby the oxides which were broken incompletely at weakly bound primary powder boundary, and propagates rapidly along the weak-interface and gives rise to break. On the other hand, nearby zone of the tip of the main crack is under the state of three dimension direct tensile stress, so second crack will be produced along weak interface which is vertical to propagating plane of the main crack. Both tensile fractographes of DEG along longitudinal and transverse directions are toughness, which are composed of the dimples varied in size and depth, and the dimple groups formed by splitting open along the streamlines are still observed on the transverse tensile fractograph. The second cracks are not found evidently, it indicates bind of powders has been enough strong so that the crack is more easy to initiate nearby the coarse second phases in powder particles.

4 DISCUSSION

In general, the streamline microstructure can lead to anisotropy of the material and the coarse cube phase can lower its plasticity and strength , but seen from the data in the Table 1 and fractrographes of Fig. 3, PEG exhibits more intensive anisotropy and lower plasticity than PEG. Probing to the roots of it, deformation degree of the powder is smaller because of lower reduction rate of extrusion, and thus thicker powder surface oxide film is more difficult to be broken fully. In the course of the extrusion, shear stress make powder surface oxide film break into pieces and direct pressure stress result in metallurgical

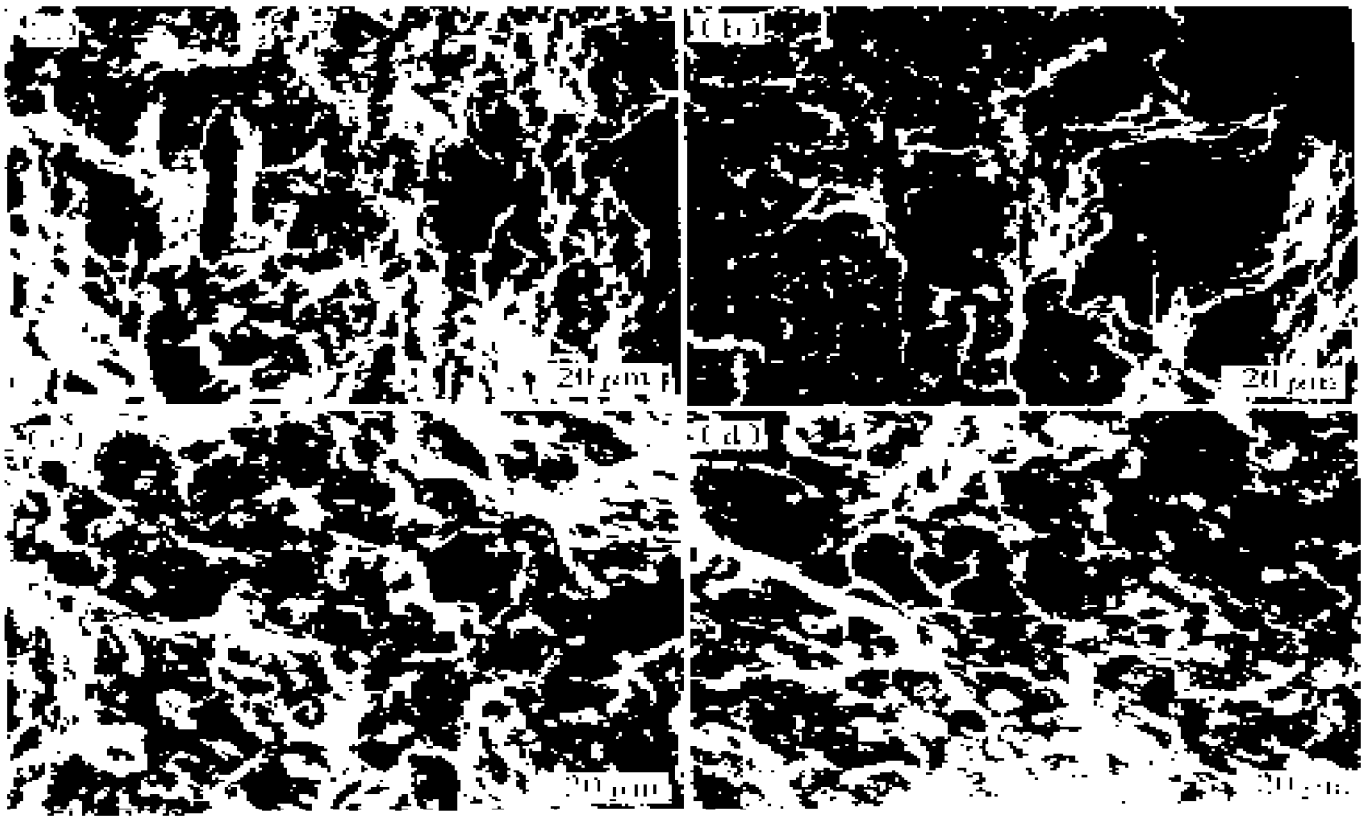

Fig. 3 Tensile fractographes of PEG and DEG at room temperature

(a) —PEG, longitudinal; (b) —PEG, transverse;
(c) —DEG, longitudinal; (d) —DEG, tra

adherence of powder particles. According to Ref. [8], the parameter R_s, which stands for area ratio of oxide film (or pieces) between after and before extrusion, can evaluate qualitatively fracture degree of the oxide and binding state of the powders.

$$R_s = 0.4(\sqrt{R_e \cdot R_a} + \sqrt{R_e/R_a + 1/R_e}) \quad (2)$$

where R_e is extrusion ratio and R_a is aspect ratio of cross section of extrusion produce. In the condition of this extrusion test, $R_e = 6.3$, $R_a = 5.2$, and thus $R_s = 2.76$. Ref. [8] pointed out that only when R_s is larger than its critical value ($R_{sc} = 4$) the corresponding extrusion process can eliminate primary powder boundary, and make the oxide film fracture fully and the oxide distributed uniformly, therefore, under the condition of this test, the oxide film of PEG is not fully broken into pieces and the oxide is not well-distributed, and thus it is certain to exist weakly bound primary powder boundary, especially along interfaces being parallel to main deformation direction, more primary powder boundary existed because more oxide distributed along the interfaces, as a results, PEG has lower plasticity and exhibits more intensive anisotropy.

DG itself is composed of little primary powder boundary and its oxygen content is lower which is 1~2 orders of magnitude smaller than that of PG, hence, under the same extrusion condition, DEG has much higher binding strength of the powders, therefore DEG is utterly distinct from PEG in fracture mechanism.

Although DEG also exhibits certain anisotropy because of streamlines, it is far behind that of PEG, therefore, PEG is easy to burst apart along longitudinal direction when being spun, however DEG has more excellent spinning formability but strength of its spun finished product is lower.

To sum up, the main effect factors that cause enormous microstructure and properties difference between PEG and DEG are degree of deformation, thickness of powder surface oxide film and cooling rate of solidification.

5 CONCLUSIONS

(1) Both rapidly solidified powder-cold isostatic compact pipe blank (PG) and spray deposition pipe blank (DG) are able to extrude into spun pipe blanks of FVS0812 aluminum alloy, but the former needs greater extrusion force and higher extrusion temperature than the latter.

(2) Extrusion pipe (PEG) of PG has higher room and elevated temperature strength, but its plasticity is lower, in contract, DEG of DG has better plasticity but lower strength. On the other hand, PEG exhibits more intensive anisotropy.

(3) Fracture of PEG is carried out by the crack initiating and propagating along primary powder boundaries, which belong to mixed fracture of brittleness and toughness, and fracture of DEG takes place according to following steps: the initiating of tiny pores in the coarse second phase, accumulating and growing up, which belongs to toughness fracture.

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