POST-DEFORMATION TENSILE PROPERTIES IN A RAPIDLY SOLIDIFIED POWDER METALLURGY MR64 ALLOY①

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ABSTRACT

A superplastic elongation of 260% of rapidly solidified powder metallurgy (PM) MR64 alloy can be obtained at the strain rate of $8.33\times10^{-3}\,s^{-1}$ and the temperature of 490 ℃. The relationship between mechanical properties and cavities' behavior has been demonstrated, and it was found that the strength and the ductility of the alloy decrease with increasing cavity amount.

Key words: MR64 alloy rapid solidification powder metallurgy superplasticity mechanical properties cavity

1 INTRODUCTION

Rapidly solidified PM alloys have superior combination of mechanical properties, not only exhibiting considerably increased strength and ductility as well as corrosion resistance and fatigue strength, but also exhibiting superplasticity under certain conditions.

In recent years, the interest in superplasticity of PM alloy has been increasing rapidly, and the focus has been on cavity change and grain growth behavior.

At present, there are a number of studies on the superplastic deformation mechanism and structure change, but those on post-deformed material properties at room temperature are absent. In this paper, rapidly solidified PM MR64 alloy is selected as the experimental material to investigate the room temperature tensile properties of this alloy superplastically deformed to some degree, and further improve mechanical properties of this material. The study is centered on the effect of cavities on the tensile properties, and adopting high temperature annealing to reduce cavities in superplastically deformed material.

2 EXPERIMENTAL

Rapidly solidified powder of PM64 alloy with average size of 50 μm was supplied by Institute of Aeronautical Material. Fig. 1 showes the shape and size of MR64 powder. The procedure used to prepare the MR64 alloy was a powder metallurgy method. Powders were pressed in vacuum and then compressed billets were extruded to 10 mm in diameter with an extrusion ratio of 25∶1. Tensile specimens, 5 mm in diametar with a 10

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mm gauge length, were machined from the extruded bar. These alloy were solution treated at 480 ℃ followed by aging for 10 h. The chemical composition of MR64 alloy shown in Table 1.

Table 1 Chemical composition

Element	Zn	Mg	Cu	Cr	Zr	Co	Al
/wt.-%	7.0	2.1	2.2	0.2	0.2	0.3	Bal

Superplastic tests were carried out on a Shimadzu testing machine. The samples deformed to some degree were quenched rapidly in water. In order to investigate the effect of superplastic deformation on cavity and mechanical properties, which with the reference samples with same sizes and gauge lengthes as those that were superplastically deformed to same degree were machined, and these reference samples were held sometime at superplastic deformation temperature. The microstructure of the samples were examined by a s-570 scanning electronic microscope.

3 RESULTS

Followed by solution heat treatment and age treatment, the superstrength MR64 alloy can reach 590 MPa in tensile strength and 9.5% in elongation. Three different kinds of strain rates were chosen to take superplastic testing, and the elongations as a function of temperature were shown in Fig. 2. It can be seen that, when the strain rate was up to $8.33\times10^{-3}\,s^{-1}$, the superplastic peak occurs at 480 ℃ and with maximum elongation 260%. With increasing strain rate, the superplastic peak value decreases slightly, and when the strain rate is $4.17\times10^{-2}\,s^{-1}$, the elongation can yet reach 230%. This means that this alloy has likely high strain rate superplastic behavior.

Testing results of room temperature mechanical properties from samples quenched after superplastically deformed to some degree is shown in Fig. 3, in which the strength line shows the properties of the reference samples. It indicates that the room temperature mechanical properties improve with increasing superplastic elongation, and when the strain reaches 0.4, the mechanical properties have the maximum values. The samples deformed to some degree were annealed for 15h and 22h at 450 ℃ respectively, their mechanical testing results are listed in Table 2.

Table 2 shows that the tensile strength of MR64 alloy is 590MPa after solution and

Fig. 1 Shape and size of MR64 powder

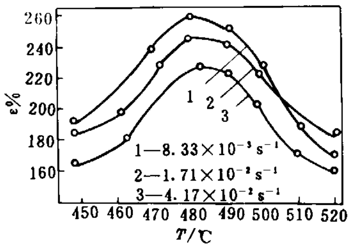

Fig. 2 Effect of strain rate on superplastiity in MR64 alloy

Table 2 Effect of annealing at 450 ℃ on room temperature tensile properties

Superplastic tensile strain	Superplastically deformed		Annealed for 15 h		Annealed for 22 h	
	UTS MPa	Elongation /%	UTS /MPa	Elongation /%	UTS /MPa	Elongation /%
0.095	600	9	600	9.5	590	10
0.180	618	11	620	11	615	13
0.300	655	12	665	14	650	13
0.405	665	14.5	675	15	665	16
0.531	645	13	640	14	630	15
0.668	620	12.5	620	13	615	14
0.788	560	10	555	13	540	13
1.047	500	7	500	8.5	495	9.5

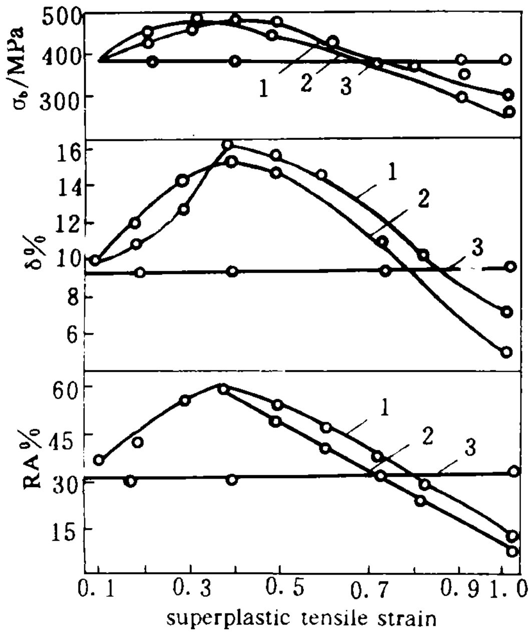

Fig. 3 Room temperature tensile properties as a function of superplastic tensile strain

its elongtion is 8.5%. Certain degree superplastic deformation can improve mechanical properties remarkably. For example, when the strain is 0.405, the tensile strength reaches 665 MPa and the elongation is 14.5%. After annealed at 450 C for 15h, the strength can reach 675 MPa and the elongation is 15%. When the anneal time increases to 22 h, the strength decreases slightly and the elongation increases to 16%. When the strain excedes 0.668, the mechanical properties begin to drop.

Annealing can decrease the amounts and change the shape of the cavities. The amount' decreasing of cavities can raise the tensile strength, and the cavity's globularising can reduce stress concentration, and help to improve the ductibilty. Microstructure analyses were made for all samples, and the results reflecting effects of superplastic strain on cavity amounts are shown in Fig. 4. Fig. 5 shows the reflecting effect of annealing temperature and time on cavity amounts. Fig. 6 is the microstructure

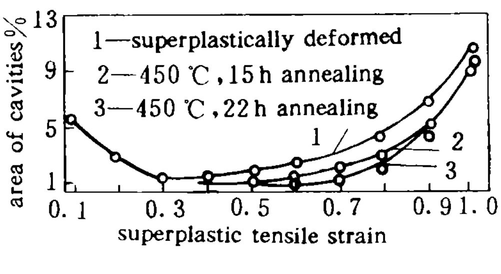

Fig. 4 Volume percent of cavities as a function of true superplastic strain at 480 ℃

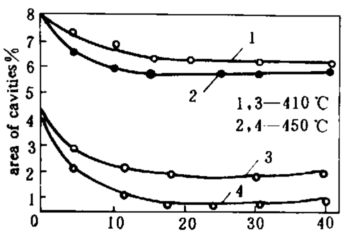

Fig. 5 Effect of annealing time on level of cavitation

photographies of cavities.

Fig. 4 indicates that there is a relationship between the cavity's volume fraction and the superplastic deformation strain, with increasing strain. The cavity amount decreases when the strain is 0.4. The values of cavity reach minimum. And when the strain excedes 0.4, the volume fraction of cavity increases with increasing strain. Fig. 4 also shows that under the condition of annealing at 450 ℃ for 15h or 22h, the reduction of cavity amount can be enhanced.

Fig. 5 shows that the volume fraction of cavity decreases with increasing annealing time, and after certain time the cavity amounts reach stablity. With annealing temperature rising from 410 ℃ to 450 ℃, the reduction of cavity amounts can be enhanced.

Fig. 6 shows that after annealing, the cavity amounts decreased, cavity sizes reduced, and small cavities enclosed.

4 DISCUSSION

The results from samples superplastically deformed at three various strain rates indicate that superplasticity of MR64 alloy is slightly insensitive to the strain rate. For example, the elongation can reach 260% at the strain rate of $8.33\times10^{-3}s^{-1}$. However as the strain rate is a 5-fold increasing ($4.17\times10^{-2}s^{-1}$), the high elongation 230% can be obtained, corresponding to the superplastic strain rate between $10^{-3}s^{-1}\sim10^{-2}s^{-1}$ of PM Al-Li alloy indicated in paper[1]. Compared with optimum strain rate between $10^{-5}s^{-1}\sim10^{-4}s^{-1}$ of general superplastic alloy, high strain rate is one of

Fig. 6 Microstructure of MR64 before and after annealed

(a)—Deformed at 480 ℃ and strain rate of $8.33\times10^{-3}s^{-1}$, with an elongation of 150%;
(b) After 450 ℃ annealing for 15h; (c) After 450 ℃ annealing for 22h

the characteristics of PM alloys.

4.1 *Effect of Cavity on Room Temperature Properties*

After solution and age heat treatment, the structure of MR64 is more stable during deformation and the tendency of growth is relatively weak. Because of rupture effect of cavity on the material structure to reduce effective bearing area of samples, the material strength decreases correspondingly. Rapidly solidified MR64 alloy powder compactness can merely reach 98% of theoretical density. After vacuum cutgasing and isotatic compacting, and even though undergoing the roll, there are still cavities in the material, resulting in the disadvantageous influence on properties of material.

From the investigation on cavities during superplastic deformation, it is found that catives of original material begin specifically disappearing during deformation. When the strain is below 0.4, cavity amount decreases with increasing strain degree, leading to that the strength can reach maximum one (665 MPa), as the strain is 0.4, in correspondence with the best ductility (14.5%), and when the strain exceed 0.4, cavity amounts increase with strain while the strength and the ductility begin decreasing. Hence, it is necessary for the micromechanism of cavity disappearance to be studied further.

The strain rate during deformatoin has much or less effects on room temperature properties. When at higher strain rate (4.17×10^{-2} s^{-1}) and when the strain is 0.34, the maximum values of the strength and the ductility can be obtained; while at the lower strain rate ($8.33 \times 10^{-3} s^{-1}$), the strain with 0.4 decreases somewhat in correspondence with those maximum ones. This is due to the disappearance rate of original cavities is higher at high strain rate.

4.2 *Effect of Annealing on Cavities*

The annealing time in the wake of superplastic deformation is proved to have considerable effect on properties of MR64 alloy. For instance, as the sample is annealed for 15 h at 450 ℃, the strength shares increase with the ductibility; expounding annealing time further; the strength inclines somewhat while the ductility rises further. These changes of room temperature properties are concerned with material structure, because following annealing for 15h, cavity amounts decrease as shown in Fig. 4. Meanwhile the cavities tend to close as shown in Fig. 6.

It is decided that the post-deformation strength depends on several factors such as cavity amounts, grain size and precipitate reinforcing phase amount. The strength increases as the reduction of cavity amounts prevails; whereas the strength decrease as increasing of grain size and precipitation reinforcing phase amounts gains as an advantage. As a result, the choice for annealing temperature should be considered from the three above factors. If annealing temperature is too high, correspondingly, grain growth sets on with ease; if too low, the reduction of cavity amounts is not enough. Hence, as for MR64 alloy, to decide optimum temperature of 410 ~ 450 ℃ is suitable; annealing not only reduce cavity amounts, but avoid abnormal grain growth.

As shown in Fig. 5, the reduction rate of cavity gradually decreases with expounding time; when up to a certain time, cavity amounts tend to be stable, and quickly lift temperature upward can reduce cavity

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sistance to necking of specimens. Concurrently, current pulses also promote dynamic recrystallization in the deformation. All these factors cause the favorable effects on superplastic deformation. Such a phenomenon that current pulses enhance superplastic properties is called electrosuperplasticity, which is in no doubt valuable to the superplastic forming of commercial alloys.

5 CONCLUSIONS

From the results, analyses and discussion above, it can be seen that current pulses promote atomic diffusions, dislocation slip, and increase the m value in superplastic deformation, and concurrently accelerate dynamic recrystallization in the deformation, which accordingly increases superplastic properties of 2091 Al-Li alloy.

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amounts. Too long holding time not only reduces cavity amounts effectually, but result in grain growth and strength decreas on the other hand. It can globularise cavity, and further improve material ductility.

5 CONCLUSION

(1) The original cavity in PM alloy begins disappearing when the alloy is superplastically deformed at the strain 0.3～0.4. In the case, the strength and the ductility at room temperature can reach the highest.

(2) The annealing for 15 h at 450 C after superplastic deformed can globlarise large size cavities, make fine cavities close, and result in the improvement of room temperature strength and ductility.

(3) The high strain rate is the specific characteristic of PM alloy, and when the strain rate reaches $8.33\times10^{-3}\,s^{-1}\sim4.17\times10^{-2}\,s^{-1}$, the elongation above 230% can be obtained.

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