Journal of Ceramic Processing Research. Vol. 7, No. 2, pp. 161~163 (2006)

J O U R N A L O F
Ceramic Processing Research

Effect of *In-situ* TiC particles on the microstructure and mechanical properties of Al8.5Fe1.4V1.7Si aluminum alloy

Baohong Zhu*, Yong'an Zhang, Baiqing Xiong, Hongwei Liu, Likai Shi, and Songxiao Hui
State Key Laboratory for Fabrication and Processing of Nonferrous Metals, General Research Institute for Non-ferrous Metals, Beijing, 100088, China

Heat-resistant Al-Fe-V-Si aluminum alloys enhanced by *in-situ* TiC particles have been prepared by spray forming process with suitable process parameters. Research results show that the microstructure of the as-deposited alloy is fine and homogeneous. *In-situ* TiC particles prevent the unstable phases from coming into being. On the other hand, the TiC particles increase the volume fraction of heat-resistant phases. So the mechanical properties of the reinforced alloy by *in-situ* TiC particles are better than that of Al-Fe-V-Si alloy without the TiC particles. The hot extrusion temperature is also an important parameter to be considered. It is proved better to extrude the alloy at lower temperature. The tensile strength of the alloy without TiC particles is about 435 MPa at room temperature and is about 204 MPa at 350°C. However, when the alloy is enhanced by in-situ TiC particles, the strength of alloy is about 482 MPa at room temperature and is about 224 MPa at 350°C.

Key words: spray forming, Al-Fe-V-Si alloy, heat-resistant aluminum alloy, *in-situ* TiC particle.

Introduction

Most of Al-Fe-V-Si series aluminum alloys that have been widely used in aerospace were prepared by traditional Rapid Solidification/Powder Metallurgy (RS/PM) process [1-7]. A single spherical second phase $Al_{12}(Fe,V)_3Si$ dispersing in the matrix is the main character of the microstructure of these alloys. The $Al_{12}(Fe,V)_3Si$ phase has good stability at elevated temperature, which is the main reason that the alloys remain good mechanical properties at high temperature as well as at room temperature. Generally, Al-Fe-V-Si series heat-resistant aluminum alloy have to be prepared by rapid solidification process because of the high content of Fe and Si elements. Some disadvantages of traditional rapid solidification process, however, are also obvious such as the process complexity, uncontrollable oxide content, and the difficulty to prepare the large parts. So spray forming process, a new kind of rapid solidification process, has been introduced into the preparation of this type of alloy in the 1990s [8, 9]. Unfortunately, because of the lower cooling and solidification rate of the spray forming process, some unexpected second coarse phases such as $Al_{13}Fe_4$, Al_8Fe_2Si etc., come into being in the alloy. And then the mechanical properties of the alloy will decline. In this paper, some TiC particles were added into the alloy by *in-situ* reaction, and the microstructure and properties of the alloy changed obviously.

*Corresponding author:
Tel : +86-10-82241161-208
Fax: +86-10-82240096
E-mail: sprayform@grinm.com

Experimental

The preparation experiments were carried out on the SF-200 spray forming equipment that was built in General Research Institute for Nonferrous Metals. Two types of Al-Fe-V-Si alloys have been prepared by spray forming process. One of the alloys is 8009 whose nominal composition is: Fe 8.5 wt%, V 1.4 wt%, Si 1.7 wt%, the balance is Al. The other alloy is 8009+3 wt%TiC.

The atomization gas was N_2. The other parameters for the process are described as blow: Atomization temperature was between 1000-1050°C; flight distance was about 400-500 mm, spray angle was about 20-30°; rotation rate of the substrate was about 30-60 rpm and its drop velocity was about 1-3 mm/s; atomization pressure was about 0.6-0.8 MPa and the flow ratio of atomization gas to melt (G/M) was 4. The microstructures of the preforms and extruded alloys have been studied with a NEOPHOT-2 optical microscope, a H-800 transmission electron microscope. The tensile tests were carried out on a MTS-810 tensile test machine.

Results and Discussions

Effect of in-situ TiC particle on the microstructure of 8009 alloy

Figure 1 shows the comparison of the microstructure of the as-cast and as-deposited Al-Fe-V-Si aluminum alloy. It can be seen that the coarse phases in the as-cast alloy were eliminated in the as-deposited alloy.

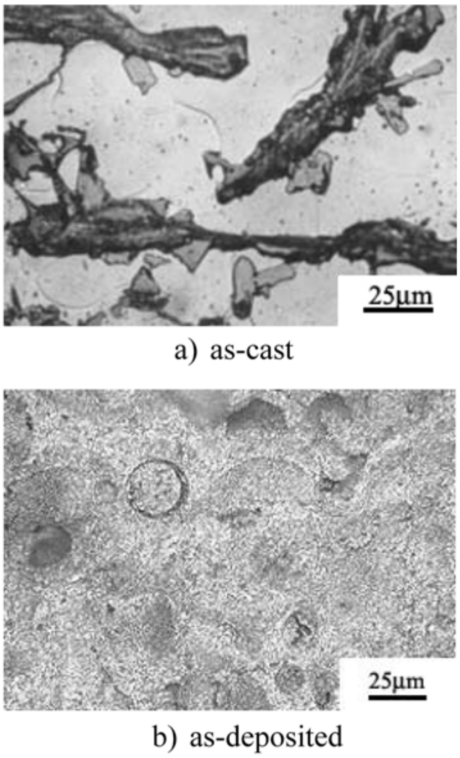

Fig. 1. Microstructure of Al-Fe-V-Si alloy of as-cast and as-deposited.

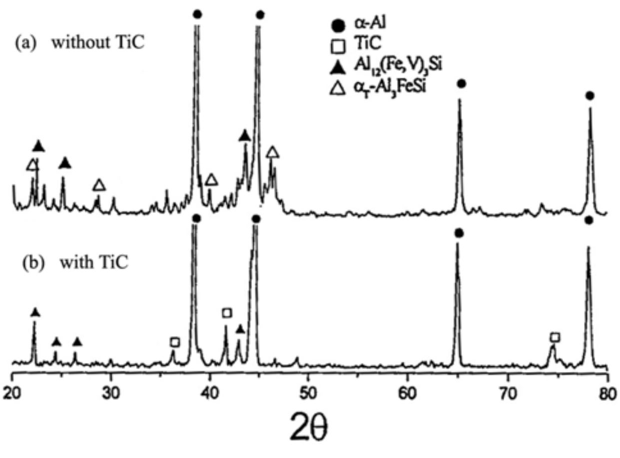

Fig. 2. XRD spectra of the as-deposited Al-Fe-V-Si alloy without and with TiC particles.

When the spray forming parameters were suitable, the microstructure of the as-deposited alloy was homogeneous, the grain size was very fine, and the density of the alloy was very good. Figure 2 shows the XRD spectra of the as-deposited Al-Fe-V-Si alloy without and with the TiC particles. It can be seen that the phases in the as-deposited 8009 alloy without TiC particles consist of α-Al, $Al_{12}(Fe,V)_3Si$ and a few α_T-Al_3FeSi. The phases in the as-deposited 8009 alloy with TiC particles consist of α-Al, $Al_{12}(Fe,V)_3Si$ and TiC. This result shows that the TiC particles can restrain the formation of some coarse phases that are harmful to the properties.

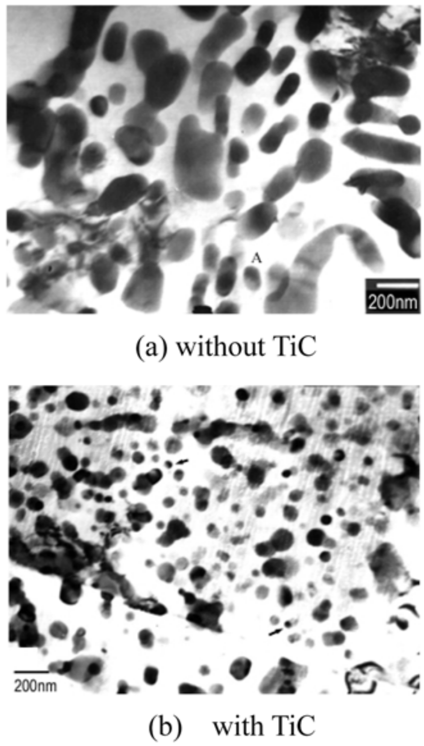

Fig. 3. TEM images of the as-deposited Al-8.5Fe-1.4V-1.7Si alloy without and with TiC particles.

Figure 3 gives the microstructure of the as-deposited 8009 alloy without and with TiC particles. Considering the results of EDS analysis, in the without-TiC alloy, the spherical phase whose size is about 100-300 nm is $Al_{12}(Fe,V)_3Si$. Particles of this phase are distributed in the grains homogeneously. Besides the $Al_{12}(Fe,V)_3Si$ phase, there are also some ribbonlike phases whose size is about 600 nm dispersed in the grain. The EDS analysis indicates these phases are α_T-Al_3SiFe. If *in-situ* TiC particles are added into the 8009 alloy, fine and spherical TiC phase particles dispersed in the matrix are seen as pointed to by the arrow in Figure 3(b). The size of the TiC phase is about 50 nm. The long ribbonlike phase in the without-TiC alloy disappears when the *in-situ* TiC particles are added into

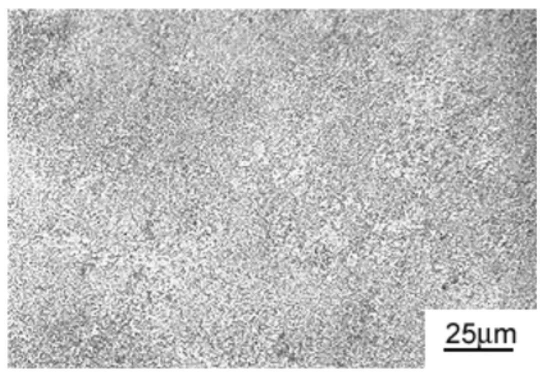

Fig. 4. Optical Microscope image of extruded Al-8.5Fe-1.4V-1.7Si/TiC alloy.

Table 1. Mechanical property of the extruded alloys

No.	Alloy composition	Extrusion temperature [°C]	Tensile Temperature [°C]	σ_b [MPa]	$\sigma_{0.2}$ [MPa]	δ_5 [%]
1	Al8.5Fe1.4V1.7Si	450	25	395.0	310.0	7.5
			350	195.0	171.0	12.0
2	Al8.5Fe1.4V1.7Si	350	25	435.0	330.0	7.0
			350	204.0	181.0	14.0
3	Al8.5Fe1.4V1.7Si+TiC	350	25	482.0	427.0	7.0
			350	224.0	191.0	15.0

the alloy. Also the size of the $Al_{12}(Fe,V)_3Si$ phase become smaller. The dispersed spherical phases are stable at high temperature and are beneficial to the mechanical properties not only at room temperature but also at elevated temperature. Using the Rietveld quantity analysis method, we calculate the volume fraction of the $Al_{12}(Fe,V)_3Si$ phase in the without-TiC 8009 alloy to be about 22.5%.

Effects of *in-situ* TiC particles on the mechanical properties

The preforms were extruded at different temperatures with a 14:1 extrusion ratio. Figure 4 is an optical microscope image of the extruded alloy. The grains are fine and some particles are fractured after hot extrusion. Hot extrusion encourages the densification of the alloys.

The cooling rate of the spray forming process is lower than that of RS/PM process. Then some unstable phases such as the ribbonlike phase mentioned above will come into being during the preparation of the alloy. These phases may be sensitive to temperature. So when the alloy is extruded at a rather high temperature (Table 1, No.1), these phases may coarsen to harm the mechanical properties. In contrast, when the alloy is extruded at a lower temperature (Table 1, No.2), the unstable phase will not grow and thus the tensile strength is higher than that of the former. When the *in-situ* TiC particles are added into the 8009 alloy, as shown in Figure 3(b), more fine and spherical phase dispersed in the matrix is observed. The effects of TiC phase in the 8009 may be described in two ways. One is that the TiC phase prevents some unstable phases, such as α_T-Al_3FeSi phase, from forming or growing. On the other hand, the TiC particles themselves are also heat-resistant phase and their existence will increase the volume fraction of heat-resistant phase in the alloy. The higher volume fraction of the heat-resistant strengthening phases gives more resistance to dislocation motion. So the tensile strength of Al-8.5Fe-1.4V-1.7Si+ TiC alloy is higher than that of 8009 alloy (Table 1, No.3).

Conclusions

(1) The microstructure of an Al-Fe-V-Si alloy prepared by spray forming process is fine and homogenous, but some temperature-sensitive phases such as α_T-Al_3FeSi phase may come into being due to the rather low cooling rate during the process.

(2) Temperature-sensitive phases may transform or grow to coarse phases that will worsen the properties of the alloy. So the alloy should be extruded at a lower temperature.

(3) TiC particles are added into the traditional Al8.5Fe1.4V1.7Si alloy by an *in-situ* method. The TiC particles prevent the unstable phases such as α_T-Al_3SiFe from growing. At the same time, the existence of TiC particles increases the volume fraction of heat-resistant phases in the alloy. So the properties of Al8.5Fe1.4V1.7Si+TiC alloy are improved obviously.

Acknowledgement

Financial support from the National “973” Program of China is gratefully acknowledged.

References

1. M.P. Thomas, I.G. Palmer, and C. Baber, Scripta Met. 12 (1992) 337-342.
2. N.J. Kim, Int. J. Rapid Solidification 6 (1991) 175-184.
3. L.M. Rylands, D.M.J. Wilkes, W.M. Rainforth, et al., J. Mater. Sci. 29[7] (1994) 1895-1900.
4. J.Q. Wang, M.K. Tseng, X.F. Chen, et al., Mater. Sci. Eng. A A179-A180 (1994) 412-415.
5. Xiong Baiqing, Chinese Journal of Rare Metals (Chinese) 23[6] (1999) 425-430.
6. D.J. Skinner, R.L. Bye, and D. Rayhould, Scripta. Metall. 20 (1986) 867-872.
7. S.K. Das, J. Powder Metallurgy 24[2] (1988)175-183.
8. M.F. Amateau, T.J. Eden, J.M. Galbraith, et al., the 3rd PRICM, Vol. II (1998) 1645-1650.
9. Jin Tou-nan, Y.D. Xiao, and W.X. Li, Trans. Nonferrous Met. Soc. China (Chinese) 11[2] (2000) 166-172.