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Effects of Hot Extrusion Parameters on Microstructure and Properties of RS P/M Al-7Fe-1.4Mo-1.4Si Alloy Based Composites

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Low density damping composites of compositions Al-7Fe-1.4Mo-1.4Si (FMS0714) /15Al and FMS0714/15(Zn-30Al) (wt.%) were prepared by the rapidly solidified powder metallurgy process. Effects of extrusion temperature and extrusion ratio on their microstructures, tensile properties and damping capacities were investigated. The results indicate that, at a constant extrusion ratio, for FMS0714/15Al, with increasing extrusion temperature from 380℃ to 520 ℃, elongation increases, but strengths decrease remarkably. Increase of extrusion temperature produces little effect on damping capacity and Young's modulus. For FMS0714/15(Zn-30Al), with increasing extrusion temperature from 410℃ to 445℃, strengths and Young's modulus change little, but elongation and damping capacity decrease remarkably. At a constant extrusion temperature, with increasing extrusion ratio from 6.3:1 to 17.4:1, for both composites, elongation is improved; while strengths, damping capacities and Young's modulus remain unchanged. By comparison, FMS0714/15(Zn-30Al) exhibits better damping capacity than FMS0714/15Al. The results are discussed according to their microstructures.

Introduction

Since 1980's, the ceramic and graphite (fiber, particle, or whisker) reinforced aluminum metal matrix composites with good damping capacity (usually greater than 6×10^{-3}), such as 6061Al/SiC, 6061Al/Gr, etc., have been received considerable attention [1]. However, their mechanical properties, especially ductility, can not compete with the conventional aluminum alloys. In the early 1990's, Beijing Institute Aeronautical Materials (BIAM) started to use the rapidly solidified powder metallurgy (RS P/M) process to develop some low density damping metal/metal composites with good mechanical properties. Among them, both Al-7Fe-1.4Mo-1.4Si (FMS0714)/15Al, and especially FMS0714/15(Zn-30Al) (wt.%) show good mechanical properties and high damping capacity [2,3]. This paper aims to investigate the effects of extrusion parameters including extrusion temperature and extrusion ratio on the microstructures, tensile properties and damping capacities of these composites.

Experimental Procedures

Powders smaller than 75μm of elevated temperature Al-7Fe-1.4Mo-1.4Si (FMS0714) (wt.%) alloy, commercial purity aluminum, and high damping Zn-30Al (wt.%) alloy were prepared by gas atomization process using nitrogen gas (N_2). Their composite powders of FMS0714/15Al and FMS0714/15(Zn-30Al) were first mixed and canned, then degassed, and finally extruded into 12 mm diameter bars under extrusion temperatures ranging from 380℃ to 520℃, and extrusion ratios ranging from 4:1 to 17.4:1.

The extruded bars were subjected to tensile test, damping measurement and microstructure examination. Tensile tests were performed on an Instron 1196 machine. Damping capacity and Young's modulus were measured using a specimen of size 48×8×1 mm^3 on a dynamic mechanical thermal analyzer (DMTA-IV) in three point bending mode at a constant amplitude of 4×10^{-5} and frequencies of 1 Hz and 28 Hz. X-ray diffraction (XRD) was performed on a D/MAX-RB diffractometer with Cu-K_α radiation and a scanning rate of 8 °/min. Transmission electron microscopy (TEM) was done on a JOEL electron microscope operated at 160 kV.

Results and discussion

XRD Identification

Both of the composites were based on the elevated temperature Al-7Fe-1.4Mo-1.4Si alloy. It has been reported that the Al-8Fe-2Mo-Si alloy is composed of $Al_{12}(Fe,Mo)_3Si$ dispersoids and Al matrix [4]. $Al_{12}(Fe,Mo)_3Si$ possesses the b.c.c. structure with lattice parameter of (1.263 ± 0.003) nm and space group Im3, showing thermal stability similar to the $Al_{12}(Fe,V)_3Si$ dispersoids in RS Al-Fe-V-Si alloys [4,5]. Fig. 1 shows XRD traces for both composites extruded with a constant extrusion ratio of 17.4:1 at different extrusion temperatures (ET). Apparently, either for FMS0714/15Al extruded at temperatures from 380 ℃ to 520℃, or for FMS0714/15(Zn-Al) extruded at temperatures from 410℃ to 445℃, only $Al_{12}(Fe,Mo)_3Si$ and Al are identified, indicating that no phase transformation occurs.

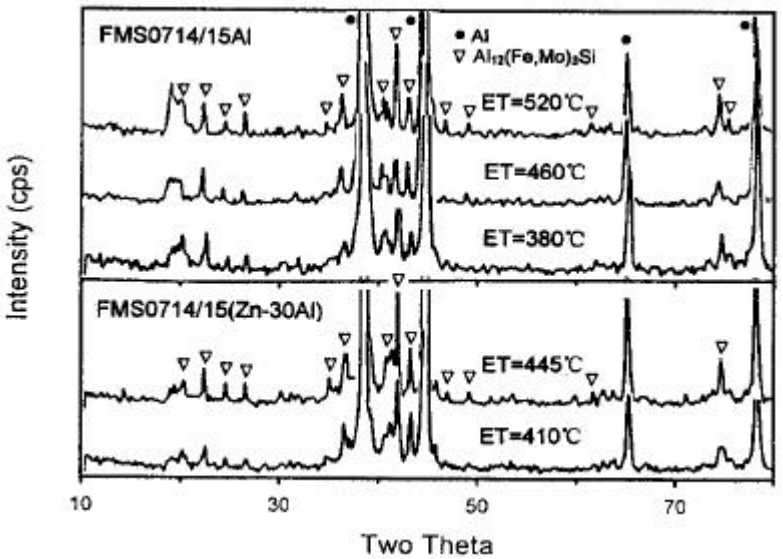

Fig.1 XRD traces for FMS0714/15Al and FMS0714/15(Zn-30Al) extruded at different temperatures.

TEM Observation

Fig. 2 shows the $Al_{12}(Fe,Mo)_3Si$ dispersoids in FMS0714 alloy (a, c, e) and pure Al (b, d, f) in FMS0714/15Al extruded with a constant extrusion ratio of 17.4:1 at 380℃, 460℃, and 520℃. With increasing extrusion temperature, $Al_{12}(Fe,Mo)_3Si$ dispersoids just coarsen (from ~100 to ~200 nm), in agreement with the former XRD result. When the composite is extruded at 380℃, the pure Al deforms little, and few dislocations can be found at grain boundaries. With increasing extrusion temperature to 460℃, the pure Al deforms seriously, showing elongated grains of size ~3 μm. In addition, the density of dislocations at grain boundaries is much higher than that in the grains. When increasing the extrusion temperature to 520℃, although grains shows little change, the density of dislocations is extremely low.

Fig. 3a and Fig. 3b show the microstructure of Zn-30Al in FMS0714/15(Zn-30Al) extruded with a constant extrusion ratio of 17.4:1 at 410℃ and 430℃, respectively. When extruded at 410℃, the Zn-30Al consists of former α (solution of Zn in Al) grains (20-50 nm)

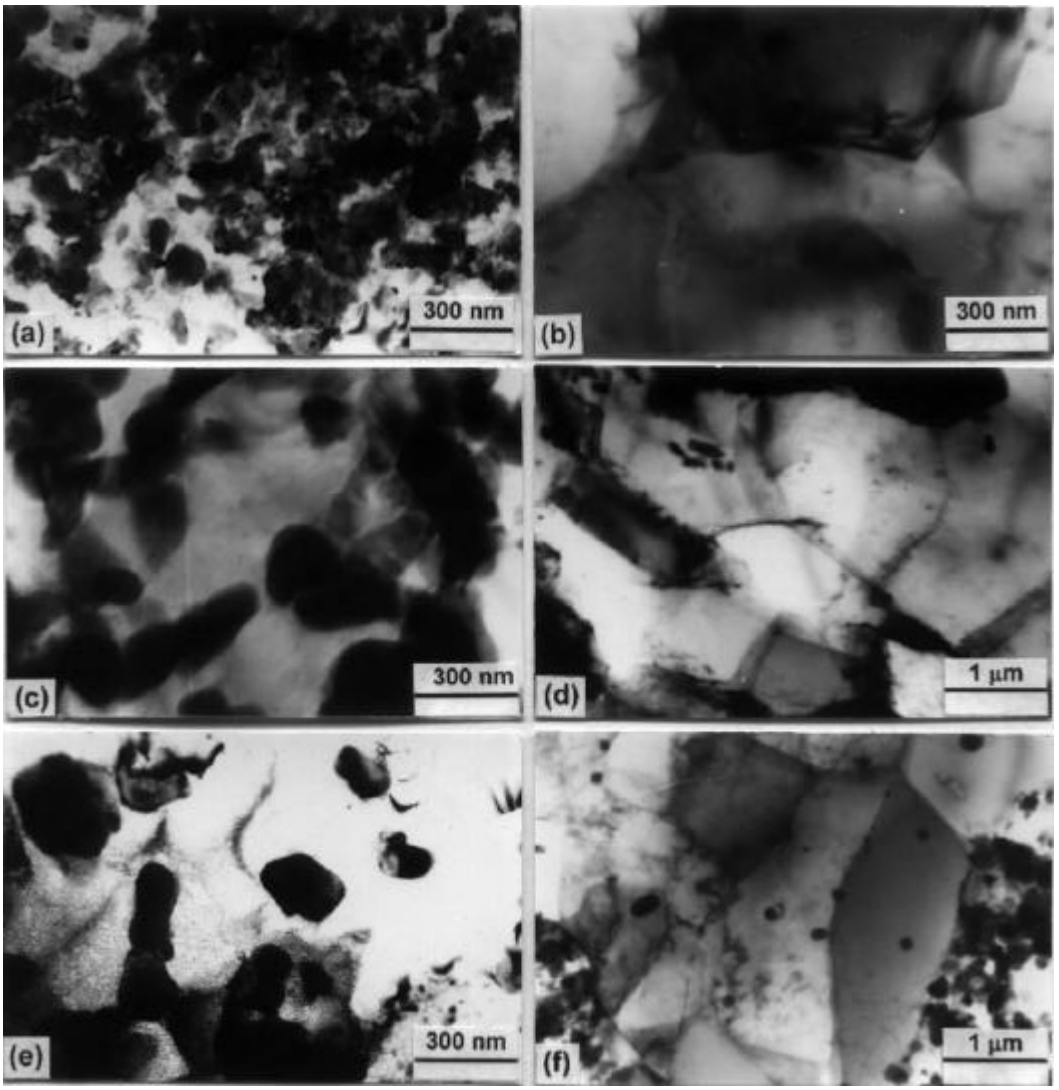

Fig. 2 TEM micrograhs showing the $Al_{12}(Fe,Mo)_3Si$ dispersoids (a, c, e) and pure Al (b, d, e) in FMS0714/15Al extruded with a constant extrusion ratio of 17.4:1 at 380℃ ((a), (b)), 460 ℃((c), (d)) and 520℃ ((e), (f)).

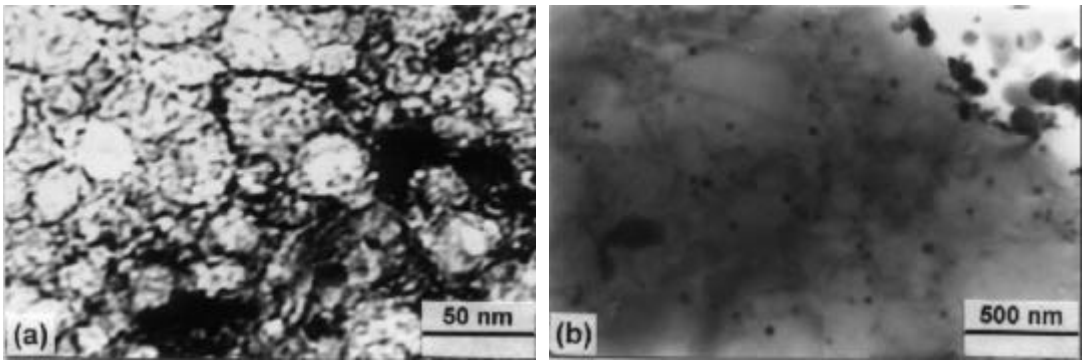

Fig. 3 TEM micrographs showing the Zn-30Al alloy in FMS0714/15(Zn-30Al) extruded with a constant extrusion ratio of 17.4:1 at 410℃ (a) and 430℃ (b).

and the eutectoid ($\alpha + \beta$) (β: solution of Al in Zn)) lamellar structures between the grains. The former α grains also encompass the ($\alpha + \beta$) lamellar structure. When the extrusion temperature is increased to 430℃, in stead of the aforementioned ($\alpha + \beta$) lamellar structure, some spherical β particles (~80 nm) precipitate, and large α grains (~500 nm) appear. This may be resulted from that the temperature increase of billet during extrusion exceeds to 445℃ (the melting point of Zn-30Al). However, these variations have not been identified by XRD, mainly because of the small amount of Zn-30Al powders (only ~9.9 vol.%) in the composite.

Tensile Properties

Fig. 4a and Fig. 4b show the tensile properties at room temperature of both composites as functions of extrusion temperature (ET) and extrusion ratio (ER), respectively. In Fig. 4a, the ER of both composites remained at 17.4:1. For FMS0714/15Al, with increasing the ET, the ultimate tensile strength (UTS) and yield strength (YS) decrease, accompanying the increase of elongation (El). This may be associated with the coarsening of the $Al_{12}(Fe,Mo)_3Si$ dispersoids. For FMS0714/15(Zn-30Al), the UTS and YS also decrease with increasing the ET, however, the El increases slightly first when ET is increased from 410℃ to 420℃, and then decreases to

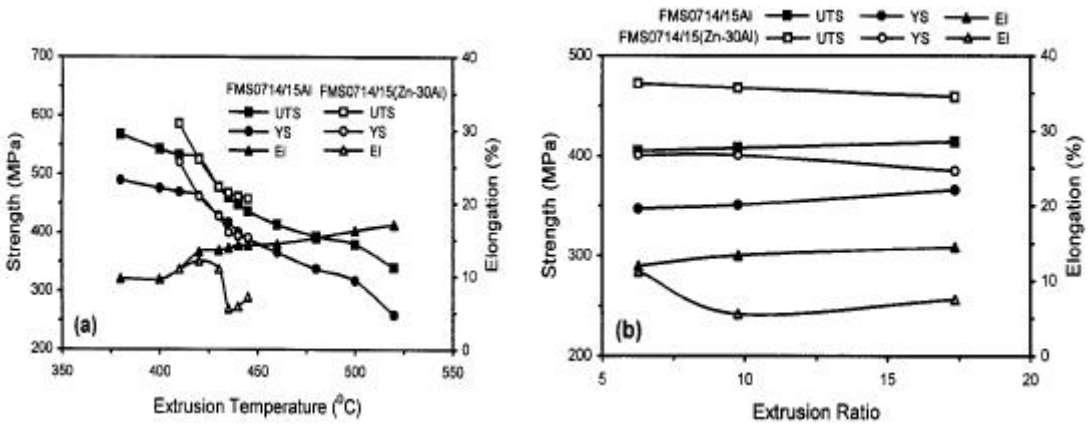

Fig. 4 Tensile properties at room temperature for FMS0714/15Al and FMS0714/15(Zn-30Al) as a function of extrusion temperature (ER=17.4:1) (a) and extrusion ratio (ET=460℃ for FMS0714/15Al and 445℃ for FMS0714/15(Zn-30Al)) (b).

the lowest at 435℃, with further increase of ET, El again increases. This phenomenon may be related to the aforementioned melting of Zn-30Al alloy. In Fig. 4b, the ETs for FMS0714/15Al, and FMS0714/15(Zn-30Al) remained at 460℃ and 445℃, respectively. For FMS0714/15Al, all the UTS, YS and El increase slightly with increasing the ER. For FMS0714/15(Zn-30Al), with increasing the ER, both the UTS and YS decrease slightly, while the El decreases first and attains to the lowest value at ER of 9.8:1, and again increases slightly with further increase of the ER. This is also related to the melting of Zn-30Al.

Damping capacity

The temperature dependence of damping capacity and Young's modulus of both composites extruded with a constant extrusion ratio of 17.4:1 at different temperatures are shown in Fig. 5. For FMS0714/15Al (Fig. 5a), with increasing the extrusion temperature, the Young's modulus decreases slightly. When extruded at 380℃, the composite shows the lowest damping capacity at low temperature range (3.8×10^{-3} to 4.9×10^{-3} from room temperature to 50 ℃). When extruded at 520℃, the composite shows the lowest damping capacity at high temperature range (5.9×10^{-3} to 1.6×10^{-2} from 100℃ to 250℃). When extruded at temperatures from 400℃ to 520℃, the damping capacity at room temperature varies from 6.1×10^{-3} to 8.3×10^{-3}, showing little change. For FMS0714/15(Zn-30Al) (Fig. 5b), when extruded at 410℃, the composite shows damping capacity at room temperature as high as 1.58×10^{-2}, attaining the level of conventional high damping alloys (10^{-2}) [6]. However, when extruded at 445℃, the damping capacity decreases remarkably. The Young's modulus shows no remarkable difference.

Fig. 6 shows the temperature dependence of damping capacity and Young's modulus of both composites extruded at different extrusion ratios (ER). FMS0714/15Al and FMS0714/15(Zn-30Al) were extruded at 460℃ and 445℃, respectively. With increasing the ER (from 4:1 to 17.4:1 for FMS0714/15Al, and from 6.3:1 to 9.8:1 for FMS0714/15(Zn-30Al)), the Young's modulus of both composites increases slightly. However, the damping capacity of FMS0714/15Al almost remains unchanged, while that of FMS0714/15(Zn-30Al)

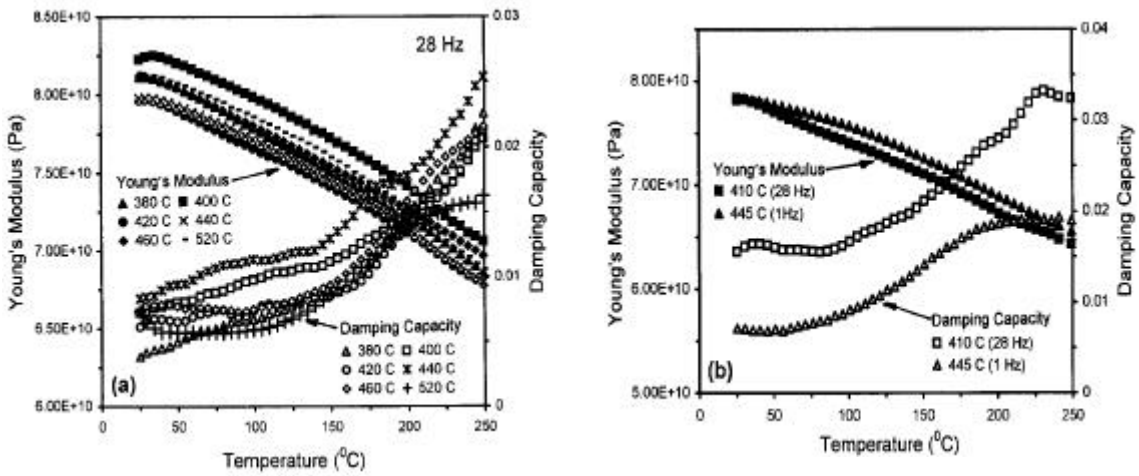

Fig. 5 Temperature dependence of damping capacity and Young's modulus of FMS0714/15Al (a) and FMS0714/15(Zn-30Al) (b) extruded at different temperatures

(ER=17.4:1).

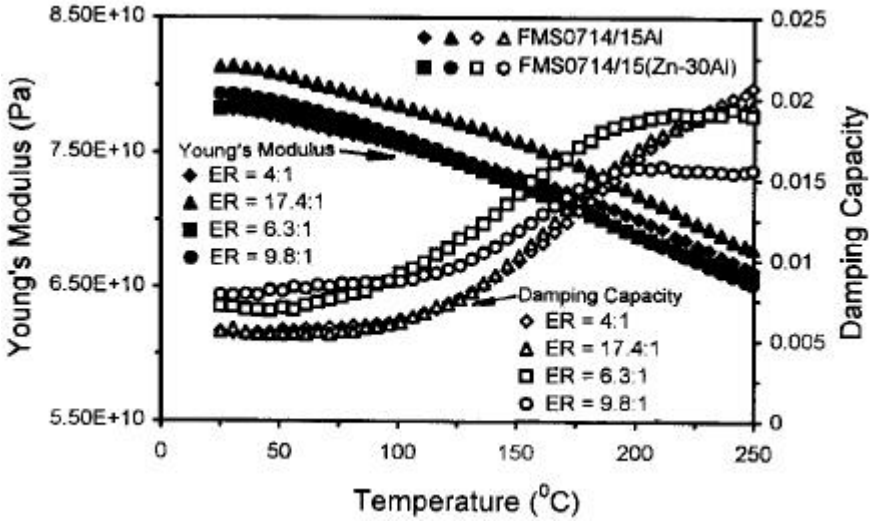

Fig. 6 Damping capacity and Young's modulus of FMS0714/15Al and FMS0714/15(Zn-30Al) composites extruded at different extrusion ratios (ET=460℃ for FMS0714/15Al and 445℃ for FMS0714/15(Zn-30Al), f=1Hz).

increases slightly at room temperature and decreases slightly at high temperature range (100-250℃). By comparison, FMS0714/15(Zn-30Al) still shows higher damping capacity than that of FMS0714/15Al.

For FMS0714/15Al, damping arises from the glidings of dislocations, Al/Al grain boundaries in pure Al powders, FMS0714/Al powder particle boundaries (PPBs), and $Al_{12}(Fe,Mo)_3Si$/Al interfaces in FMS0714 powders. Variations in extrusion temperature and ratio only lead to the coarsening of $Al_{12}(Fe,Mo)_3Si$ dispersoids, producing little effect on the aforementioned interfaces and boundaries. For FMS0714/15(Zn-30Al), damping comes from the glidings of dislocations, α/α, α/β, β/β interfaces in Zn-30Al powders, FMS0714/(Zn-30Al) powder particle boundaries (PPBs), and $Al_{12}(Fe,Mo)_3Si$/Al interfaces in FMS0714 powders. Since Zn-30Al belongs to a high damping alloy, in which α/β and β/β interfaces possess much higher mobility than α/α [7,8]. Therefore, $Al_{12}(Fe,Mo)_3Si$/(Zn-30Al) shows higher damping capacity than FMS0714/15Al. However, because of the low melting point (~445℃), with increasing the extrusion temperatures exceeding to 420℃, Zn-30Al may melt. In stead of the (α+β) lamellar structures, only some spherical β particles and large α grains exist. Thus, the amount and area of α/β and β/β interfaces decrease remarkably, and as a result, the damping capacity decreases.

Conclusions

1. For FMS0714/15Al, with increasing extrusion temperatures from 380℃ to 520℃, the $Al_{12}(Fe,Mo)_3Si$ dispersoids coarsen from ~100 to ~200 nm; while the pure Al deforms more seriously. The room temperature strengths decrease remarkably, while elongation is improved. The damping capacity at room temperature at 28Hz first increases from 3.8×10^{-3} to 8.3×10^{-3}, and then decreases to 7.3×10^{-3}. The Young's modulus decreases slightly. With increasing the extrusion ratio, the damping capacity, Young's modulus and strengths almost remain

unchanged, while elongation is improved somewhat.

2. For FMS0714/15(Zn-30Al), with increasing extrusion temperature from 410℃ to 445 ℃, besides the $Al_{12}(Fe,Mo)_3Si$ dispersoids coarsen, with the disappearence of the (α+β) lamellar structures, some spherical β particles and large α grains appear. The strength, elongation and damping capacity decrease remarkably. Increase of the extrusion ratio produces little effect.

3. When extruded at ~410℃, FMS0714/15(Zn-30Al) shows superior properties as compared to FMS0714/15Al. Especially, the room temperature damping capacity of the former is 1.58×10^{-3}, about two times that of the second.

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