Commercial Processing of Aluminum Matrix Nano Alumina Composites

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Abstract

Use of a proprietary process, patent applied for, enables us to implant individual alumina nanospheres into aluminum alloy matrices via conventional powder metallurgy processing. No ball milling or other attrition process is required to implant these nanoparticles. Implantation occurs at room temperature. This allows for easy and inexpensive scale-up of composite fabrication. To date, we have produced 200 lb. lots of such materials. Once produced in amounts over 1,000,000 lb., the price per pound is projected to be \$10/lb. to \$ 20lb. in conventional bar, sheet, and plate form. In this presentation, we report on the tensile mechanical behavior of two Al alloy matrices containing as much as 10 volume percent 50 nm and 100 nm alumina spheres produced via our proprietary process. The alloy matrices chosen were 6063 Al and 1100 Al. In all cases, the composites were annealed at 500 degrees C for 1 hour and furnace cooled before testing. The purpose of the pre-test anneal was to remove all vestiges of cold work so that we could simply determine the effects of the nanoparticles.

Keywords: aluminum matrix composites, nano size particles, strength, modulus, low cost

Introduction

Aluminum alloys mechanical properties are normally enhanced over the values they exhibit in their annealed states by either precipitation or work hardening. These techniques work very well to strengthen conventional aluminum alloys up to 300˚C. Both rely on creating nano size regions which are strong enough to hinder easy dislocation flow. In order to use aluminum alloys at temperatures above 300˚C, ceramic particles with in the same nano size dimensions can be blended into aluminum alloys to replace the hardening precipitates and/ or cold work structure that is unstable above 300˚C. Typical ceramic particle chemistries include SiC, B_4C, Al_2O_3 and AlN for example. Typically, the ceramic particles are incorporated in the matrix aluminum alloy as a melt addition (Ref 1) or powder metallurgy (Ref 1). In the case of powder metallurgy with small particles, the ceramic particles can be added by ball milling the matrix alloy powder and the ceramic nanoparticles together for a long period of time. The current work demonstrates that it is possible to blend alumina nanospheres, 100 nm > particle diameter > 50 nm at room temperature without the use of ball milling and achieve a uniform dispersion of the reinforcing alumina nanoparticles. We employed tensile test data at room and elevated temperature to show the strength enhancements we can achieve as we increase the volumetric density of alumina nanoparticles from 0 to 10% without ~~a~~ major loss in ductility.

Experimental Procedure

Composite Compositions Tested

1100 Al; median particle size 3μm
Al_2O_3; median particle size 50nm.

6063 Al; median particle size 10μm
Al_2O_3; median particle size 100nm

Using a proprietary method to prevent the alumina nanoparticles from flocculating, we blended the Al alloy particles with the alumina nanoparticles in isopropanol at room temperature. This process decorates the aluminum particles with the nanoparticles. In order to judge that our blended powders did not exhibit extensive regions of alumina segregation, we pressed and sintered a small sample of each blend for examination. Density of the sintered compacts are approximately 75%. Using the EDS associated with our SEM, we looked for alumina agglomerations, see Figure 1. The decoration of the aluminum particles with the nano alumina are clearly visible in this figure. The extrusion of the billet made from this blended powder will cause the nanoparticles to be incorporated within the aluminum grains, thus creating the nano reinforced aluminum composite.

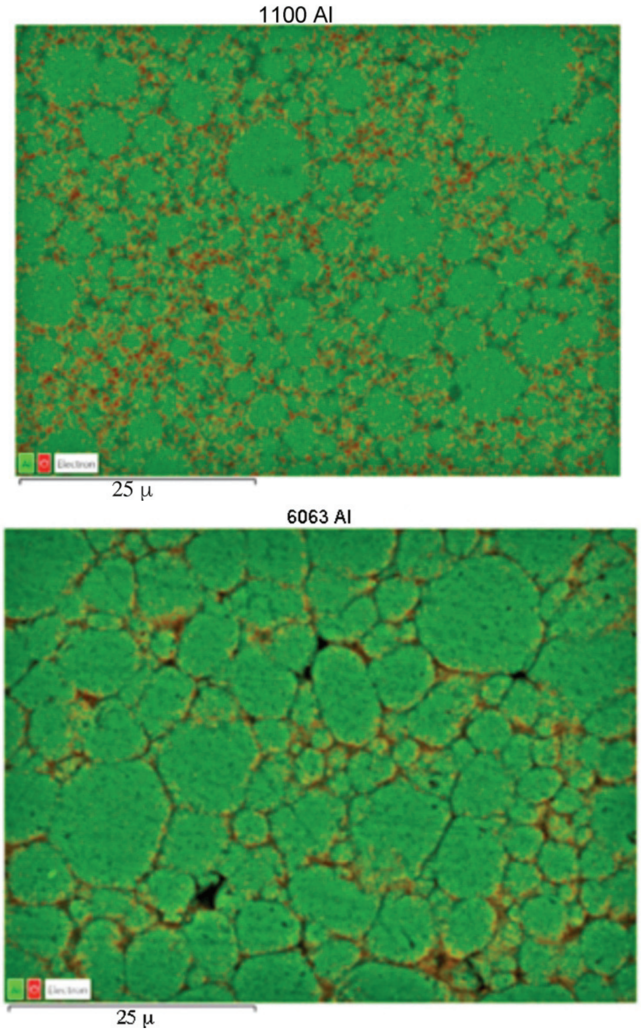

Figure 1 Alloy Maps for both composite chemistries at 2,000X. Legend: Green=Aluminum, Red=Oxide, Yellow or Orange= blended aluminum plus oxide.

As one can note from the above photos, there are no large agglomerates of alumina nanoparticles to be seen. After blending, the powder blends are cold isostatic pressed (CIP) and sintered at the appropriate temperature for each matrix composition. The billets were then hot extruded 49:1 in terms of reduction in area. The resulting bars were then held at 500˚C for ½ hour and furnace cooled. The purpose of the anneal was to remove all vestiges of the work put in during extrusion.

Tensile tests were conducted at room temperature and 375˚C. The elastic modulus of each composition at room temperature was measured using an ultrasonic technique, ASTM E-494.

Results and Discussion

The strength data as a function of deliberately added alumina nanoparticles is shown in Figure 2 and 3. One can also note that in the case of the 6063: 10% composite, the yield strength of this material is greater than that of 6063 –T6 produced by the cast and wrought process. This suggests that one day one may be able to eliminate the need for heat treating Al alloys. The measured elastic modulus as a function of the alumina content is contained in Figure 4

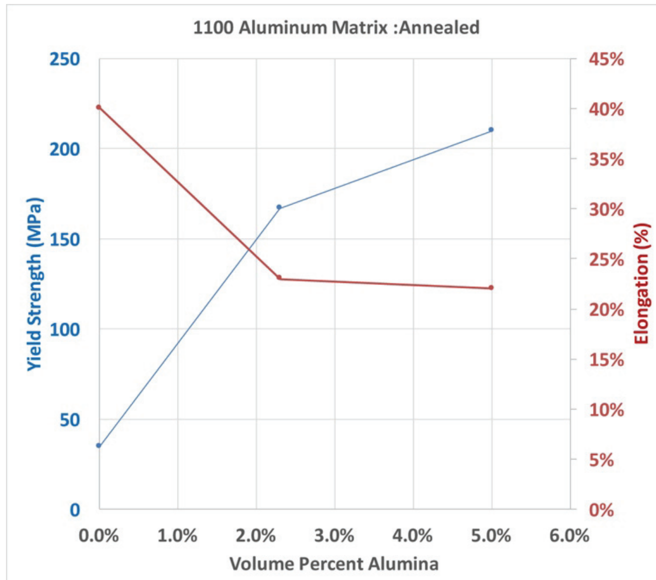

Figure 2 Plot of yield strength as a function of alumina content for 1100 matrix

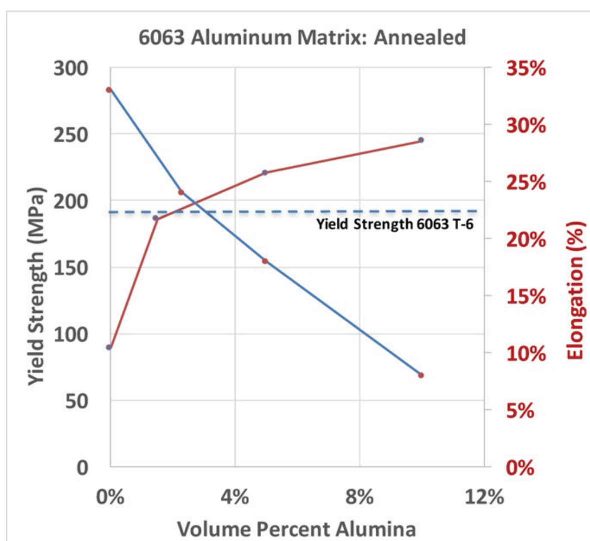

Figure 3 Plot of yield strength as a function of alumina content for 6063 matrix.

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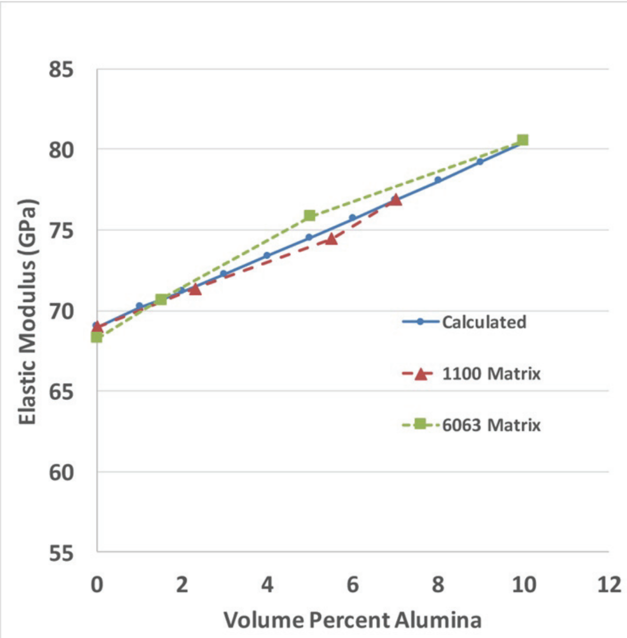

Figure 4 The measured, this study, and calculated (Ref. 2) dependence of the composite's Young's modulus on alumina content.

The data for elevated temperature tensile tests are shown in Figure 5 for the 1100 matrix composites. These data demonstrate that the presence of alumina nanoparticles in an Al 1100 matrix also enhances the strength of the matrix at 375˚C.

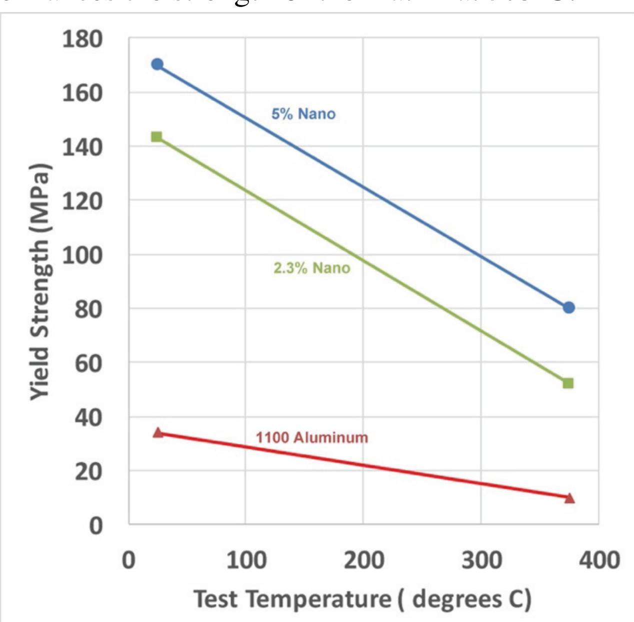

Figure 5 The effect of test temperature on the yield strength of Al 1100 matrix as a function of nano oxide content.

Conclusions

The alumina nanoparticles we added to the matrix of our composites improved strength similarly to the nano precipitates produced by heat treatment. The advantage of our method is that nanoparticles do not go back into solution at high temperature, thus broadening the useful temperature range for conventional Al alloys.

The nanoparticles also increase the elastic modulus of the composite in a manner similar to that of micron size particles.

The composites were produced with techniques that allow for processing of large quantities of the composite at low cost.

References

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