THE PROCESSING AND CHARACTERISTICS OF TRI-MODAL ALUMINUM METAL-MATRIX-COMPOSITES

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Introduction

Tri-modal Aluminum (Al) is a “multi-scale” Metal-Matrix-Composite (MMC) combining nano-grain aluminum (NG-Al), micron-scale Boron Carbide (B_4C) particles, and coarse-grain aluminum (CG-Al). AA5083 powder, with B_4C particles, is cryogenically milled in an attritor using liquid nitrogen (LN_2), yielding nano-grain aluminum agglomerates containing a uniform dispersion of B_4C particles. The nano-grain agglomerates are blended with coarse-grain AA5083 aluminum powder, vacuum degassed at an elevated temperature, and consolidated into billet.

Laboratory-scale fabrication of Tri-modal Al MMCs has demonstrated a material with compressive yield strength of >1,000 MPa, a more than 3X increase compared to commercially available monolithic AA5083 [1]. This elevated strength value is attributed to (1) grain size strengthening from the NG-Al; (2) particulate strengthening from the B_4C particles; (3) Orowan strengthening from dispersoids formed during the cryomilling process; and (4) baseline strength from the CG-Al [1].

The scale-up of Tri-modal Al MMC manufacturing presents many challenges. It is not certain the unique properties obtained at the laboratory-scale will be achieved using the production-scale processing necessary to yield large-scale billet and secondary product forms. To answer the question of properties vs. scale, work is currently underway to establish the feasibility of large-scale Tri-modal Al MMC manufacturing.

All process elements of Tri-modal Al MMC manufacturing are being investigated to ensure translation of mechanical properties for large-scale product forms. This paper will describe the engineering process development for (1) cryomilling of powders, (2) innovative vacuum degassing, and (3) consolidation of degassed powders into the bulk form. Additionally, the paper will describe the influence of various processing conditions on the microstructural features and mechanical properties of Tri-modal Al billet and secondary product forms.

Experimental

Inert-gas atomized AA5083 powder was cryomilled in LN_2 with 14.3 wt% B_4C particles for times ranging from 8 to 24 hours, using 6.3 mm and 4.8 mm stainless-steel ball bearing milling media. Batch weight for the combined raw materials was 20-kgs. Agglomerate formation during cryomilling was controlled by the addition of 0.2 wt% stearic acid [2]. Cryomilled powders were blended with 30 to 50 wt% coarse-grain (-325 mesh) AA5083 powder. Vacuum degassing of powders was accomplished over the temperature range of 176-454°C by two methods: (1) traditional “static” degassing inside an aluminum can and (2) a combination of “dynamic” degassing, in which the powder is tumbled in a rotating, axi-symetric vacuum chamber, followed by a short-term static degas cycle inside an aluminum can. Consolidation of powders was carried out by vacuum-hot-press (VHP) and cold-isostatic-press (CIP). Secondary processing of billet included low-strain rate (LSR) and high-strain rate (HSR) extrusion as well as forging and rolling.

The evaluation of manufacturing processing variables included: (1) particle size distribution for multiple cryomill batches, (2) uniformity of B_4C dispersion in cryomilled agglomerates, (3) vacuum degassing signatures for static and dynamically degassed powders, (4) nano-crystalline aluminum grain-size before and after vacuum degassing as well as post-consolidation and secondary processing, and (5) mechanical properties obtained over the range of primary and secondary processes employed.

Results and Discussion

Particle size distributions by laser diffraction were generated for eight (8) consecutive, 20-kg batch cryomill runs, using 4.8 mm diameter stainless steel milling media, to determine process repeatability. The results are shown in Figure 1. A 3-sigma analysis of this data demonstrates a controlled process with a projected -325 mesh (<44 μm) yield of 75% to 86% of the total population. Inert size classification (-325 mesh) of these lots resulted in an average yield of 84.6%.

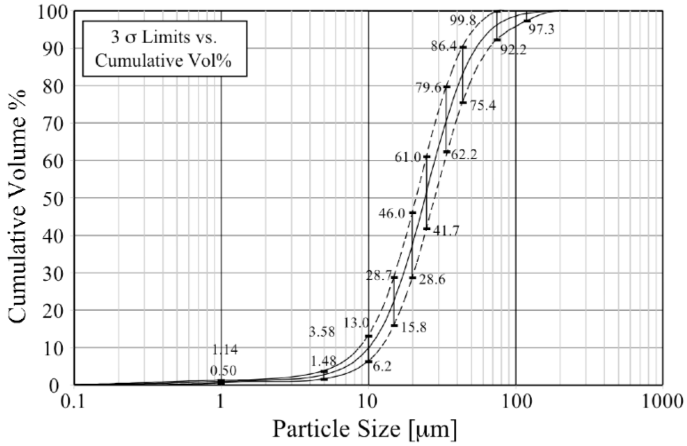

Fig. 1 Particle size distribution for cryomill runs 27 through 34 showing 3-sigma cumulative vol%

Dynamic degassing of powders to remove stearic acid and interstitial gases was developed to reduce time at temperature and minimize coarsening of the NG-Al by: (1) providing a reduced line-of-sight degassing path due to a pseudo-fluidized powder bed, (2) eliminating the volumetric and geometric degassing limitations of a static powder column, and (3) more rapid removal of degassable species. The effectiveness of the dynamic degas process is shown in Figure 2. A 13.6-kg powder charge was dynamically degassed to a lower vacuum pressure than a 1.1-kg statically degassed powder charge inside a can for the same elapsed time.

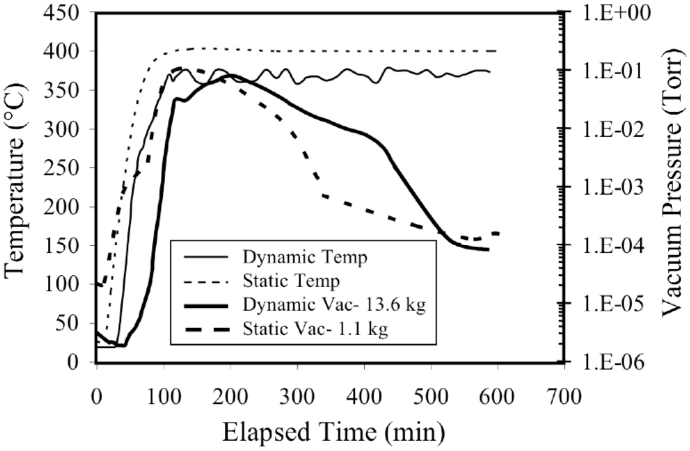

Fig. 2 Vacuum pressure-temperature plots for static and dynamic degassing methods

The compressive strength of 76 mm diameter, 1.1-kg Tri-modal aluminum MMC billets consolidated by VHP and CIP was measured in the extrusion direction after HSR extrusion. All billets posssessed a uniform composition of 14wt% B_4C/30wt% CG-Al/56 wt% NG-Al, using NG-Al created during a 24-hour cryomilling cycle. The results are shown in Table 1. The average compressive strength obtained for VHP billet was 923 MPa. The average for CIP billet was 871 MPa. Compressive yield strength was further analyzed to assess the influence of the vacuum degas times and temperatures used in the fabrication of these billets. The results of this analysis, shown in Figure 3, suggest that degassing temperature and the VHP consolidation method had the greatest influence on resultant strength.

Serial Number	Composition			Cryomill Cycle	Consolidation Method	Extrusion Method	Compressive Strength		Yield Strength	
	B4C	CGAl	NGAl				[MPa]	[ksi]	[MPa]	[ksi]
XC1369	14	30	56	24h	VHP	HSR	944	137	883	128
XC1370	14	30	56	24h	VHP	HSR	928	135	909	132
XC1472	14	30	56	24h	VHP	HSR	942	137	915	133
XC1473	14	30	56	24h	VHP	HSR	886	129	862	125
XC1474	14	30	56	24h	VHP	HSR	919	133	867	125
XC1475	14	30	56	24h	VHP	HSR	921	134	859	125
DWA21-1	14	30	56	24h	CIP	HSR	878	127	831	121
DWA21-2	14	30	56	24h	CIP	HSR	908	132	836	121
DWA21-3	14	30	56	24h	CIP	HSR	845	123	817	118
DWA21-4	14	30	56	24h	CIP	HSR	866	126	837	121
DWA21-5	14	30	56	24h	CIP	HSR	869	126	825	120
DWA21-6	14	30	56	24h	CIP	HSR	860	125	822	119

Table 1 Compressive strength for VHP and CIP Tri-modal Aluminum MMC statically degassed billet after high-strain-rate (HSR) extrusion

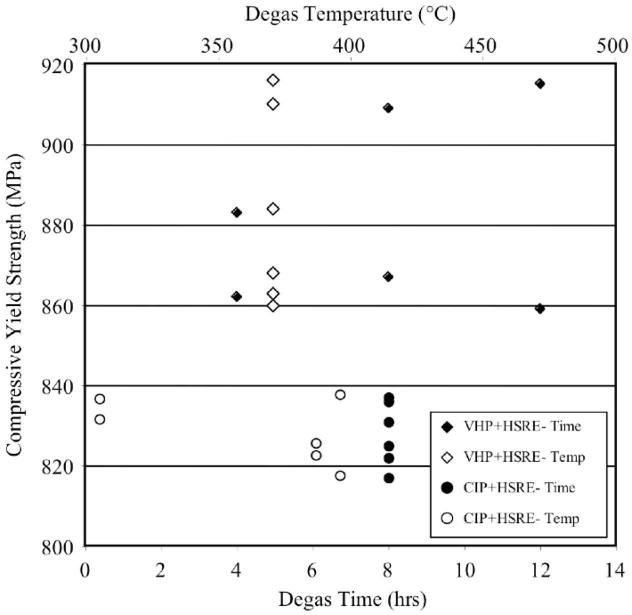

Fig. 3 Compressive yield strength expressed as a function of vacuum degas time and temperature

Conclusions

The engineering process development for Tri-modal Al MMCs is establishing baseline, commercial-scale manufacturing practices. Cryomilling of powders is a stable, repeatable process with high yields after -325 mesh size classification. Dynamic degassing of powders is an effective processing route that shortens cycle-time for large-scale powder batches. The compressive strength of experimental extrusion is exceeding minimum desired property levels.

References

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2. J. Ye, B.Q. Han, J.M. Schoenung, Mechanical behavior of an Al–matrix composite reinforced with nanocrystalline Al-coated B4C particulates, *Philosophical Magazine Letters*, Vol. 86, No. 11, November 2006, 721–732