PM light alloys gaining applications in automotive sector

Numerous papers presented at PowderMet 2013 reflected the innovative use of light alloys in automotive applications. Joe Capus, *MPR* consulting editor, discusses the trends.

In recent years the importance of reducing fuel consumption in vehicles has focused attention on the employment of the light metals such as aluminium, magnesium and titanium. Numerous developments have been pursued, including PM applications. PM applications of light alloys have been moving along thanks to collaboration between powder producers, parts manufacturers and end users, helped by R & D funding assistance from government sources. These activities have featured increasingly in the programmes of international PM conferences. One such application that has stood the test of time in the automotive sector was the subject of a presentation at the MPIF's PowderMet2013 conference in Chicago [1]. The outstandingly successful PM aluminium camshaft bearing cap application was launched by Metal Powder Products Company in 1991. These 'cam cap' components have been successful in a variety of automotive engine models and the part pictured in Figure 1 won a Grand Prize in the MPIF's 2006 PM Design Excellence Competition [2]. Authors Chaman Lall and Paul Williamson (MPP Co.) pointed out how extraordinary it was that "a relatively low hardness PM aluminium material [was] interfacing against a hard[er] wrought steel camshaft rotating at high speeds, while supporting significant side loads". Thus they introduced an account of wear studies on a selection of PM alloys, including the Al-4% copper composition, a popular choice for the manufacture of PM cam caps. Wear testing was done by simulation using sintered discs of the various alloys. Tests conducted at Penn State University were made according to an ASTM standard test (ASTM G65) in which samples were pressed against a rotating rubber wheel while dry sand was fed into the interface. Wear was assessed in terms of

Figure 1: PM aluminium camshaft bearing cap - 2006 Grand Prize Award Winner in the Automotive Category, After Lall and Williamson (courtesy: Metal Powder Products, GM, and MPIF).

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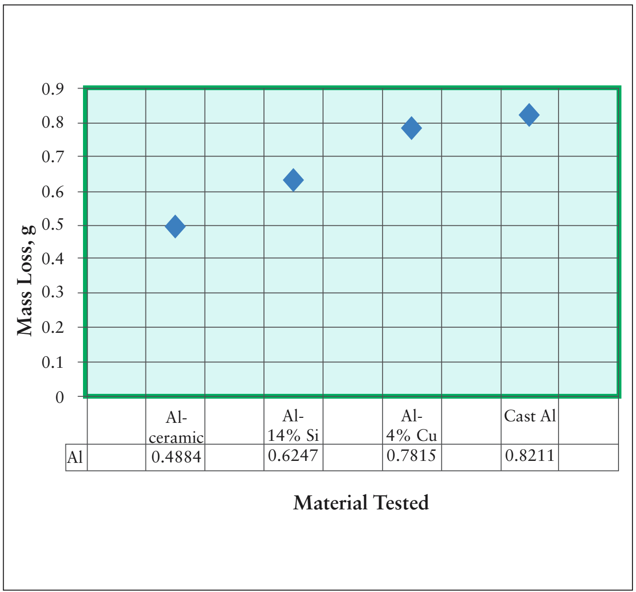

Figure 2: Mass loss observed for selected PM Al alloys subjected to test method ASTM G-65. Each test sample subjected to 1,000 wheel revolutions. (After Lall and Williamson)

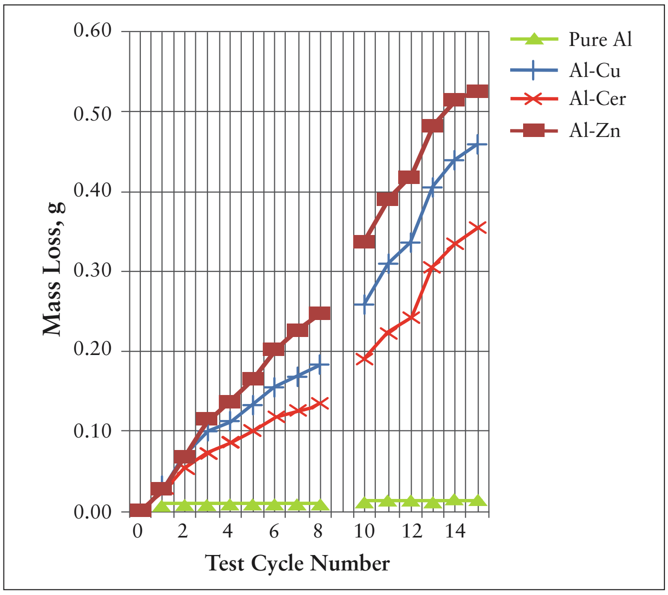

Figure 3: Mass loss exhibited by selected PM materials subjected to wear by a wheel bonded with 600 grit (nominally, 15 micron) SiC particles. (After Lall and Williamson)

the loss in mass after a fixed number of revolutions. Initial testing of the various PM samples showed the intriguing result that the softer alloys had better wear resistance than the harder alloys. A second series of tests with the number of revolutions increased from 100 to 1000 confirmed this finding. In Figure 2 results for PM Al-ceramic, Al-14% Si and Al-4% Cu are compared with a commonly-used cast aluminium alloy, A-380. The PM Al-4% Cu alloy showed slightly better wear resistance than the cast alloy.

Another set of wear tests on the same PM alloys was made at the MPP Technology Centre. In these the samples were held against a wheel bonded with fine 600-mesh SiC grit (nominal 15 micron dia.) while water flowed on to the wheel. Sintered pure aluminium was included with the other PM alloys. These tests gave even more striking differences between the materials. In particular, the pure aluminium sample showed a negligible amount of wear (<0.02 g) compared with the three alloys (0.3 – 0.5 g), even after a couple of hours of running time (Figure 3). The explanation of this surprising result was found in a microscopic examination of the pure aluminium sample. After the test, the sample surface was found to be covered in embedded SiC particles, transferred from the abrasive wheel surface. This led the authors to a new theory for the improved wear resistance of the Al-ceramic and Al-14%Si PM alloy samples as well as the pure aluminium. "It appear[ed] that the embedded SiC particles [had] created a new interface with 'islands' of hard particles in a 'sea' of soft aluminium". In other words the soft matrix had initially worn down to create pockets to hold the lubricating liquid (water), while the hard particles became the load-bearing phase. This theory was supported by profilometer traces on the surfaces of the pure aluminium, Al-4% copper and Al-ceramic materials after wear testing. Thus the superior wear performance of actual PM cam caps could be explained by the presence of lubricating engine oil in the interface with the (polished) steel camshaft surface, in an analogous fashion to the behaviour of PM bronze self-lubricating bearings where the lubricating oil is retained in the pores of the PM component.

In another study related to automotive applications, Randy Cooke and co-authors at Dalhousie University, Nova Scotia, Canada, and GKN Sinter Metals, USA, [3] did some lab-scale tests to determine the mechanical properties of hot-forged PM 2618 aluminium alloy and its response to elevated temperature exposure. Samples were prepared with blended alloy components and pressed at 200 MPa, followed by sintering in pure nitrogen at 610°C for 20 minutes. Small cylindrical sintered test-pieces were forged at 480°C in a rotary forge followed by heat treatment (530°C/120 minutes and water-quenched, then aged at 200°C/1200 minutes). A density of 2.74 g/cm³ (99.1% of theoretical) was obtained after sintering and a density equal to the wrought alloy after forging. However, the hardness, yield strength and UTS of the PM alloy fell short of those for the wrought alloy, while elongation and Young's modulus were superior, see Table 1. Since many automotive applications involve exposure to elevated temperatures, tests were made to compare the hot-forged PM alloy with its wrought counterpart. The effects of thermal exposure at 280°C for up to 1000 hours were recorded for mechanical properties. As shown in Figure 4, the yield strength of the PM and wrought alloys deteriorated at about the same rate, although the differential declined with time. UTS and Young's modulus also decreased, while the elongation improved.

Table 1: Density, hardness and mechanical properties of PM and wrought 2618 alloy (*After Cooke et al.*)

Alloy	Density (g/cc)	Hardness (HRB)	Tensile Properties			
			Yield (MPa)	UTS (MPa)	Elongation (%)	E (GPa)
PM2618-T6	2.77 ±0.0	73 ±1.0	335 ±5.0	426 ±14.4	9.9 ±1.3	77 ±6.3
IM2618-T6	2.77 ±0.0	75 ±0.7	400 ±3.2	456 ±2.9	9.1 ±0.4	72 ±2.8

Because of small differences in chemical composition of the two materials, some additional tests were made to study the influence of tin, copper and silicon. These were done by suitable adjustments to the blended mixes that were compacted. The resulting materials were given the same compacting, sintering, and hot-forging treatment as the original 2618 alloy in the study. The authors concluded that "tin was a necessary component of the alloy whereas increased copper content had minimal impact over the range of compositions assessed, [while] additions of silicon had a positive impact on yield strength and UTS, such that the final values for these attributes were very similar to [wrought] 2618-T6".

The next item in this report involves an entirely different application for aluminium powders, but still of serious interest in the automotive sector. In a Special Interest Programme devoted to technologies for future growth, Eric Wolfsgruber and Peter Stadlberger of MEPURA Metallpulvergesellschaft m.b.H., Austria, gave an update on the commercial production of aluminium foam products [4]. While the attractive properties of aluminium foam products have been known for a number of years, commercialisation has been slow to take off. The authors pointed to problems with costs and reproducibility of manufacturing. More recently, MEPURA has moved this technology forward by adopting the Conform™ powder extrusion process to produce a formable pre-cursor material. This has enabled the company to develop an automated manufacturing route and to produce cost-effective foam products. The pre-cursor material is made from a blend of atomised aluminium powder and titanium hydride (TiH_2) as the foaming agent. Both aluminium casting alloys (such as AlSi10) and wrought alloys (e.g. AlMg1Si0.6) are employed, depending on the desired properties of the completed foam product. Casting alloys tend to have lower melting points, giving a practical advantage in foaming, but the foamed product tends to have a lower ductility than those made from wrought alloy powders. Alulight® foamed products manufactured by MEPURA have found application with the automotive sector in 'crash elements' –components with large energy absorption capacity, employed in safety devices designed to prevent passenger injury in crash situations. MEPURA has set up an automated production line that includes loading of the pre-cursor material, all the way to finishing the foamed product. The complete process route is depicted in Figure 5. In addition to crash elements, the company manufactures Alulight® foamed products in the form of 'Stiffeners' that are inserted into hollow welded components for vehicles.

Another use for aluminium foams is in light-weight load-bearing panels, e.g. as dividers in equipment, containers, furniture, and transportation, as well as for various interior and exterior cover panels. Sensitivity to tensile stress can be overcome by incorporating diffusion-bonded cover sheets or reinforcing meshes on the tensile-loaded surface. MEPURA is looking at new applications in architecture and ship-building. In addition to the low density and high mechanical properties and fire-resistance, the foamed panels present sound-absorbing properties as well as decorative aspects.

Titanium and its alloys have very attractive properties in terms of strength-to-weight values as well as outstanding corrosion resistance. The high cost of titanium metal extraction and processing has been a major restraint in potential applications especially in the cost-sensitive automotive industry. As noted in a presentation by Xiaoyan Xu and co-authors from Illinois institute of Technology, Cristal Metal Inc. and Webster-Hoff Corporation [5], PM press-and-sinter is a cost effective manufacturing method and is especially appropriate in the case of titanium and its alloys for reducing machining costs and improving material yields. Following earlier work on the pressing and sintering of prealloyed and blended Ti6Al4V powders, the IIT researchers made further testing to optimise the process parameters for single pressing

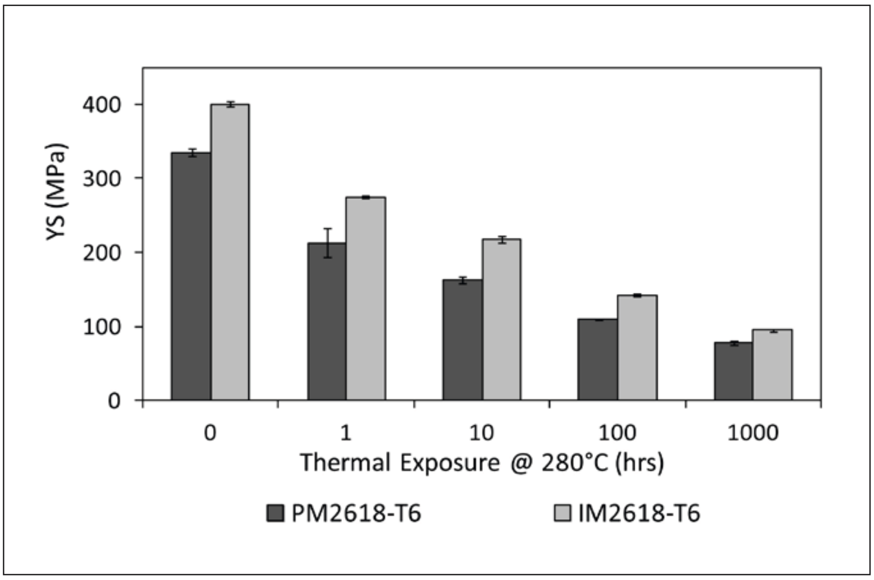

Figure 4: Effects of thermal exposure at 280°C on the yield strength of PM2618-T6 and (wrought) IM2618-T6. (After Cooke et al.)

Table 2: Tensile properties of sintered HDH blended Ti6Al4V compacts (*After Xu et al.*)				
Specimen	**Yield Strength, MPa**	**UTS, MPa**	**Elongation, %**	**Modulus, GPa**
1250°C/60 min.	699±31	725±40	1.1±0.3	97±2
1250°C/90 min.	665±20	783±30	5.8±1.4	97±3
1371°C/60 min.	705±15	815±12	8.4±2.6	98±4
1371°C/90 min.	722±10	854±35	6.9±3.1	101±5
Wrought Ti6Al4V	880	950	14	114

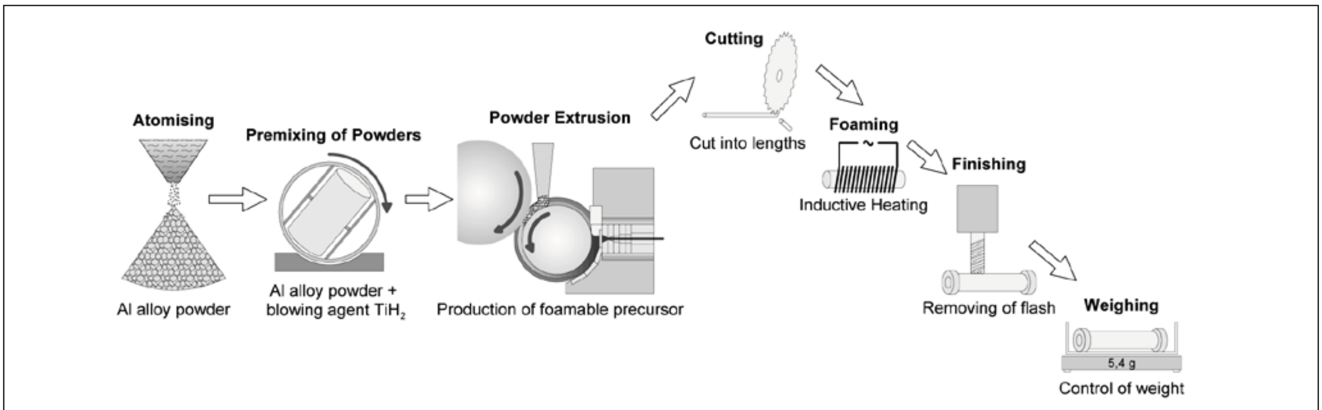

Figure 5: Schematic process flow diagram for Al-foam crash element. (After Wolfsgruber and Stadlberger).

and sintering to get the best combination of properties. With the cooperation of Webster-Hoff Corp., a parts manufacturer, and Oshkosh Corp. (formerly Oshkosh Truck) a heavy truck manufacturer, they used the information gained in the research to make and test a prototype truck part. The materials used in the present investigation were Armstrong prealloyed Ti6Al4V powder and a blend of HDH (hydride-dehydride) CP Ti powder with a 60/40 aluminium/vanadium master alloy powder. Particle sizes of these materials were between 150 and 45 microns. The powders were compacted at 690 MPa (50 tsi) using a combination of die-wall lubrication (zinc stearate) and an organic blended internal lubricant. Two processes were investigated for de-lubrication: (a) Nitrogen 'burnout' by heating the compacts in a muffle furnace at 400°C in a stream of pure nitrogen for a minimum of one hour; (b) Partial vacuum 'burnout' – heating in a muffle furnace at 400°C in a partial vacuum and a flow of argon for one hour. This second process (partial vacuum) worked best but was not too successful with the Armstrong powder, presumably on account of the sponge-like structure of the powder particles. The authors did not find an effective de-lubrication process for internal lubricant contents above 0.5%.

Test pieces were then sintered in a vacuum furnace at a pressure of 10^{-6} Torr and at temperatures of either 1250°C or 1370°C for 30 to 90 minutes. Both the Armstrong prealloyed and the HDH blended Ti6Al4V materials densified significantly during sintering (to 95-99% of theoretical), but the compacts also picked up oxygen, which affected the mechanical properties. The highest UTS for the HDH blended alloy samples (854 MPa) was obtained after 90 minutes at 1370°C, while the highest elongation was found after 60 minutes sintering (Table 2).

To evaluate the application of single-press-and-sintered Ti6Al4V alloy in an automotive part, PM component processing was provided by Webster-Hoff Corp., who designed a prototype two-piece pillow-block component for a truck application. The two parts were 2 inches and 1.38 inches tall, respectively, and for compaction, 1% internal lubricant was used in addition to die-wall lubrication to facilitate ejection. The higher lubricant level entailed a second de-lube treatment in a partial vacuum to ensure complete removal. The same commercial vacuum furnace was used for the sintering step. Finally the sintered parts were sent to Oshkosh Corp. for testing in a simulation device. The Ti alloy PM parts passed the load test without failure.

References

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