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DEVELOPMENT OF PREALLOYED ALUMINUM POWDERS FOR HIGH PERFORMANCES IN AUTOMOTIVE APPLICATIONS

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Abstract

The paper presents some special prealloyed aluminum powders for use in transport applications. Gas atomized and granular products are at various stages of development and commercialization. Case studies are presented to illustrate the diverse possibilities for auto parts designers to exploit the unique properties of rapidly solidified powders. In addition to discrete parts, prealloyed powders can have a significant role to play in facilitating joining of aluminum structures. Performance of the finished fabrications is described in relation to initial powder properties and subsequent processing methods.

1. Introduction

The majority of atomized aluminum powders are used in non-structural applications such as paints and pigments, metallurgical additives/reductants, chemicals and propulsion. Interest in aluminum powders for structural applications has grown significantly over the past 10 years, driven particularly by the desire for light weighting of vehicles. North American consumption of aluminum in PM was reported as 1200 t in 1998, 1353 t in 1999 and is projected to grow at between (15 – 20) percent in the next 10 years [1].

The big three US Auto producers lead the world in the use of PM parts and in aluminum in particular. Lall [2] reports that to date >27 M camshaft bearing caps have been produced without a single service failure. It is possible that all cam bearing end caps will be made in PM - Al by 2003. Other components under investigation include pump generators, gerotors, con-rods etc.

A market size of 25,000 t parts is envisaged ultimately by some observers. The majority of aluminum powders used in PM are blends of aluminum with minor constituents added elementally or as master alloys. While this has advantages in terms of compaction behavior, there are some potential downsides in flow and segregation difficulties that may lead to non-optimum consistency and mechanical properties [3, 4].

Prealloyed powders are generally less compactable than blends, but can offer distinct advantages in terms of consistency and absolute properties. The rapid solidification inherent in the atomizing process leads to refined microstructures and opportunities for extended solid solubility versus conventional ingot metallurgy and PM blends. To date this route has been less well developed, primarily on cost grounds. There are, nevertheless, some examples of successful applications of prealloyed aluminum powders and the following will give a flavor of some current activities.

2. Powder Production Routes

Commercial production of aluminum powders is dominated by Gas Atomization (GA) and smaller quantities are prepared by centrifugal spinning. The latter produces a relatively coarse product: depending on the rotation rate of the spinner, this can be <1mm. (Fig 1).

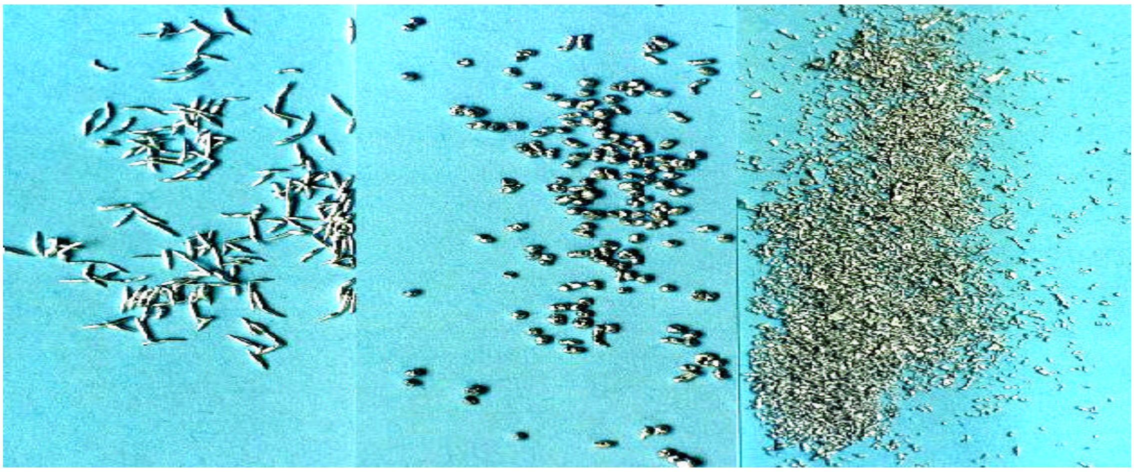

Fig.1 Morphologies of different powdered aluminum products: needles, granules, powder.

GA may be further sub-divided into air and inert gas atomizing. The former predominates, accounting for ~90% of powder production which goes into conventional aluminum powder markets (paints and pigments, metallurgical additives/reductants, chemicals). Special spherical powders for propulsion and superfine powders are produced by the more expensive inert gas atomizing. The particle size distribution can be controlled by adjusting the gas-to-metal feed ratio during the atomizing process (Fig.2).

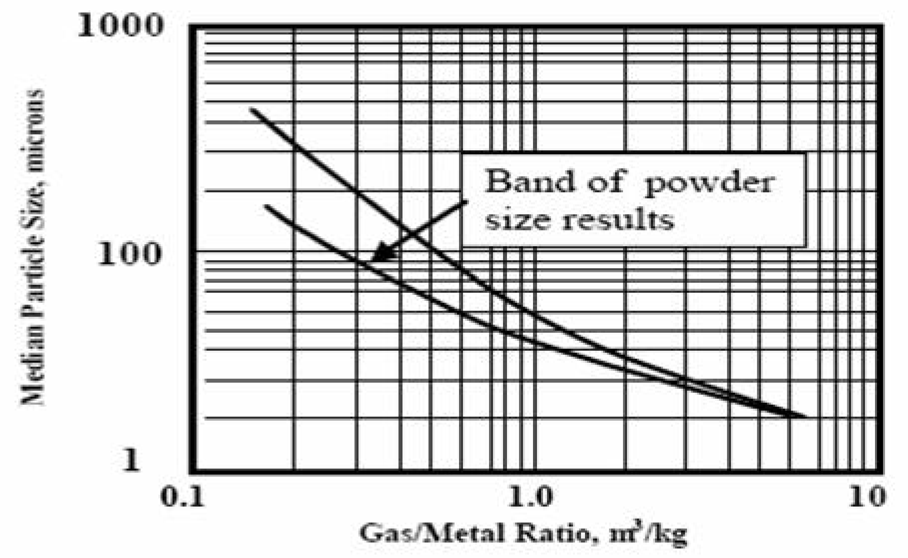

Fig.2 Gas/Metal Ratio vs. Median Al Particle Size for close-coupled atomization processes.

At larger gas flow rates, finer powders can be obtained. The powder size distribution can be varied by selection of atomizing gas (He provides greatest rates of heat transfer), nozzle and manifold design and gas temperature. The different particle sizes result in different cooling rates and hence different levels of micro structural refinement (Fig. 3).

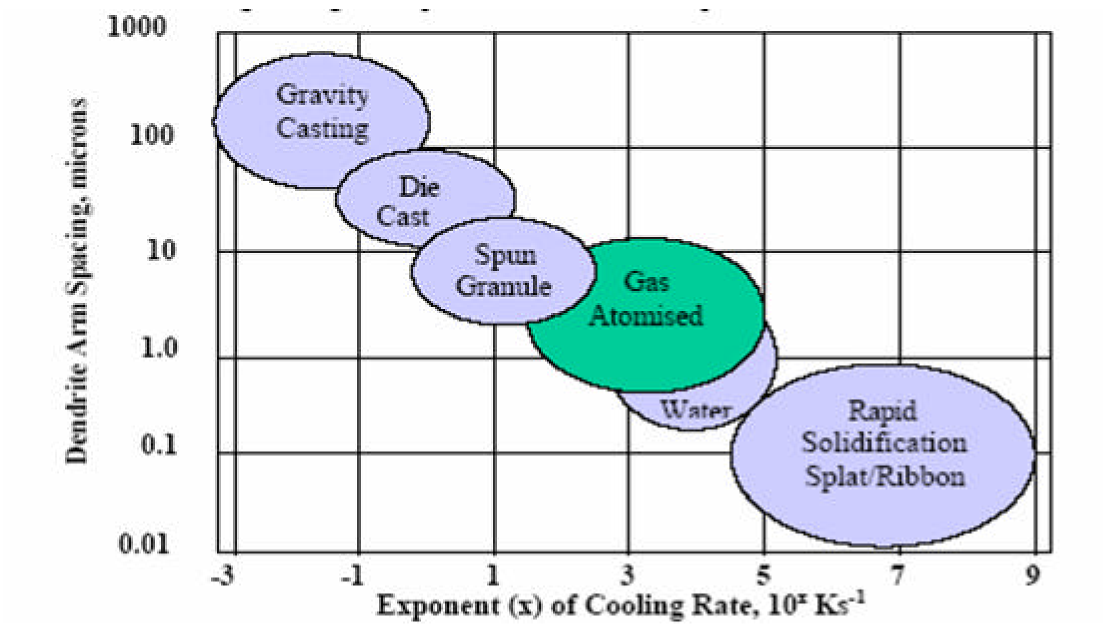

Fig.3 Micro structural refinement vs. Cooling Rate (different Solidification Processes) (13)

The atomizing environment also dictates the surface characteristics of the powder and indirectly, the morphology of the powder particles. Air atomized powders tend to have thicker oxide layers and greater quantities of adsorbed moisture than inert gas atomized powders. For coarser particles, which take longer to solidify, differential contraction of the metal core and oxide coating results in a more irregular surface. This has consequences for compatibility, green strength and degassing characteristics, which are important with respect to consolidated properties. It is possible to influence particle shape in inert gas by control of moisture in the gas.

The alloy composition and purity also influence these properties: the presence of alkali metals in particular can lead to defective oxides (e.g. Al-Li, Al-Mg) which result in thicker films. It is interesting to note that air blown granules can have lower oxygen levels than air atomized powders.

3. Metal Matrix Composites (MMCs)

Aluminum-based MMCs are carving out in the transport sector where they can offer cost-effective increases in vehicle performance through increased strength, stiffness, fatigue, wear or thermal resistance. The largest single consumer of prealloyed Al powders in the UK is AMC who have gradually grown their market base for application of MMCs. The largest market is in performance vehicles for Formula 1 and Indy car racing. The majority of AMC's products are based on inert gas atomized. The initial approach was to atomize alloys and to produce base alloys which complement the reinforcement to give the best combination of stiffness, strength and fatigue. The Al powders are produced deliberately to a fine size range (-75nm) to improve mixing with the fine SiC particulate that confers improved stiffness, wear etc. The manufacturing process involves mechanical alloying of the powders to crush oxide films and ensure homogenization of the mix. This is followed by encapsulation, degassing and hot isostatic processing (HIPing). The HIP'ed billet, after decanting may be extruded, forged, rolled, machined and heat- treated as appropriate to arrive at the finished component.

The components shown in Fig 4 demand high specific stiffness and fatigue resistance approx. double that of the unreinforced alloy.

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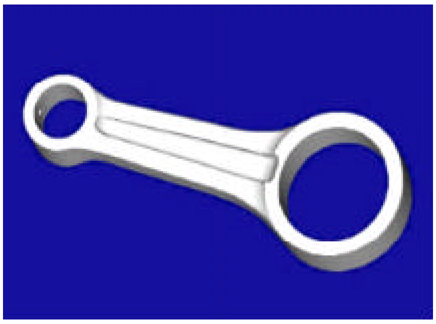

Fig. 4 Examples of current production: Brake caliper and Con rod.

4. Superplastic Forming (SPF)

The centrifugal spinning process is being developed for the preparation of precursor powders for superplastic alloy production. The SPF technique is relatively expensive (high material manufacturing costs combined with low forming rates) but is economically viable for complex components required in modest numbers. Conventionally cast and rolled SPF aluminum is well established for the manufacture of body panels for special vehicles.

The extrusion was cross-rolled warm to 1.5 mm thickness prior to SPF. The sheet showed approx. 350% elongation at strain rates of 1-10 s^{-1} with a relatively low flow stress of 10 MPa. Increasing %Zr in the range (0.5 - 1.0) % leads to increased SP Formability. The latest material exhibited tensile ductility of 460% (flow stress 20 MPa) at 10^{-1} s^{-1} and 650% (10 MPa) at 10^{-2} s^{-1} strain rate.

5. Foams

Aluminum foams are a class of materials with considerable interest in the transport sector for use in energy-absorption applications. There are two main processing routes under commercial development:

a - Cast foams from gas injection into a melt;

b - PM, using a gasifying additive, typically TiH_2.

Consolidation is by either Cold Isostatic Pressing/Extrusion or Conforming followed by controlled thermal treatment in a closed mould to achieve the foamed structure.

Advantages of the PM route include shape versatility, control of density, closed pore structure and the ability to produce sandwich structures. The process is however more expensive than the cast route and it is difficult to control pore size. A key feature of the foam is the consistency and isotropy of properties and a major challenge is to define and maintain cost effective processing windows to make consistent parts. The aluminum powder producer has a vital role to play in this regard. Many of the criteria that apply to best practice in conventional PM to get uniform density/shrinkage are equally valid in production of foams. The benefits in the long term are to improve lightweighting and crashworthiness of vehicles.

6. Al-Si for Plasma Welding

Joining of wrought aluminum components is important in relation to the use of aluminum in tubular frameworks e.g. for bicycles, aerospace control rods etc. The tenacious oxide film that forms immediately when fresh aluminum surfaces are exposed to air, make this a difficult operation. Industrially, Gas Tungsten Arc (GTAW) and Gas Metal Arc (GMAW) processes are used and laser welding is also increasing in popularity. GTAW gives high quality, but is not easily automated.

Powder Plasma Arc Welding (PPAW) is a relatively new process (Developed by Plasma Modules OY, Finland) that is being investigated with the potential for automating a.c. welding of tubular sections (10). Research in collaboration with European partners is seeking to establish the potential for a.c. plasma welding with the aid of inert gas atomized Al-Si powders as a filler material.

Key aspects of the powder are the flow characteristics for feeding into the plasma gun and the level of oxygen contamination on the surface of the powder. It has been established that the use of +125, -212 micron powder will give adequate flow characteristics to the plasma gun and that high weld integrity is achieved. The technique is being developed for bicycle and auto use and should be another advance towards the increasing use of Al in auto applications

7. Conclusions

1. A variety of aluminum atomizing processes has been applied to the production of precursor powders for prospective automotive end-users. Prime examples have been drawn from high performance composites, pressed and sintered wear parts and SPF sheet. The majority of aluminum powders used in PM are blends; prealloyed powders have established specific niches for high performance applications.

2. The powder producer can exercise good control over the atomizing process to achieve the desired powder characteristics. Micro structural refinement conferred by rapid solidification can be beneficial, but to achieve best wear resistance and compressibility for PM, then the degree of refinement needs to be tempered. Very clean powders can be required for applications such as welding consumables and metal matrix composites

3. Key to the economics and ultimately the likely exploitation of these powders are achieving maximum yield of the desired fraction and cost effective consolidation routes.

References

[1]. A. Wrigley, American Metal Market, July 28, 2000; Advanced Materials & Processes, July 2000 “Automotive Materials”.
[2]. C. Lall, Proc. Conf. “SAE 2000 World Congress”, Detroit, MI 6-9 March 2000.
[3]. W.H.Hunt, “New Automotive Directions for Al-based PM”, Metal Powder Report, May 2000, 28.
[4]. D.P.Bishop, B. Hoffmann & KR.Couchman, Proc. Conf. PM2TEC, New York, USA, June 1-3, 2000.
[5]. Z. Ishijima et al.,J. Japan Soc. of Powder & Powder Metall., 42 (1995), 1114.
[6]. C.G.Purnell & P.S.Smith, Proc. Conf. Powder Metallurgy 1994, Tribology & Materials p645.
[7]. C. Degnan & J.V.Wood, Proc. PM ’98: World Congress on Powder Metallurgy, Granada, Spain, Oct. 1998, publ. EPMA.