Coarse and cheap may beat fine and expensive

One of the basic realities of powder metallurgy is that you pay more for finer powders than for coarser grades. Spanish researchers looking for ways to strike at the comparatively high cost of gas-atomised MIM powders experimented with mixtures of gas- and water-atomised bronze powders...

Metal injection moulding (MIM) is a process for manufacturing PM parts inspired by the polymer injection process that allows the fabrication of small, complex, near-net shaped components at an economic price. With increasing competition between MIM manufacturers, several pieces of work have been carried out recently aimed at diminishing the process cost for metals usually used in MIM, such as stainless steel or iron. However information on other MIM materials is sparse.

One factor that increases the MIM component price is the use of fine, spherical powder, characteristics which are known to be quality attributes expected from MIM powders [1]. Studies have shown that small size and spherical shape are not essential to attain good properties and the use of irregular powders, cheaper and therefore better in terms of process economics, can lead to components with density and mechanical properties as good as those of components fabricated with fine and spherical powders [2-3] or even wrought material [4]. In this case the irregularly shaped powder was one fifth of the price of the spherical gas-atomised powder, so the use of irregular or coarse powder can be a key factor in cutting costs.

In a project carried out by a research group at Universidad Carlos III in Madrid, bronze 90/10 parts were fabricated with the same binder by MIM using an irregular water atomised powder, a conventional gas atomised MIM powder and mixtures of both powders. The aim of the study was research and compared the processing and the properties of MIM compacts made from spherical and irregular powders to see how the powder shape/size affected each process step.

The particle characteristics and chemical composition of the gas- and water-atomised 90/10 bronze powders used (supplied by Osprey Metals Ltd and Pometon respectively) are given in Tables 1 and 2. The water-atomised powder particles were bigger and had a narrower size distribution than the gas atomised samples.

The shapes of the powders, observed using scanning electron microscopy (SEM), are shown in Figures 1 (a) and (b). The gas-atomised powders are spherical in comparison with water-atomised samples, which present a rounded and irregular morphology.

To study the influence of the irregular powder on processing four blends were prepared mixing different amounts of both powders as seen in Table 3. The different powder blends were mixed with a wax-polyethylene binder (50/50%vol.) in a 252P ThermoHAAKE internal mixer at 170ºC for 30 minutes. Torque measurements were very useful to determine the solid loading for the different blends which were estimated to be 68 per cent, 65 per cent, 63 per cent and 60 per cent by volume for blends A, B, C and D respectively. In these proportions, feedstocks A, B, C and D were fabricated in a ThermoHAAKE twin screw extruder at 170ºC and then injection moulded into a toroidal cavity to fabricate green parts. Thermal debinding was driven in a Nitrogen-5% Hydrogen atmosphere with different time/temperature cycles, since each feedstock needed a different heating rate to obtain brown parts without defects (the maximum temperature always was 450ºC but the total time changed from 307 minutes for feedstock A to 531 minutes for feedstocks C and D, depending on the heating rate used in each cycle). Residual carbon content from the debinding was analysed using a Leco CS-200 carbon analyser. Brown parts were sintered in a N_2-10%H_2-CH_4 atmosphere between 800-860ºC for 30 minutes at heating rate of 10ºC/min.

Dimensional change during the sintering cycle was measured to characterise sintered material. The densities were determined by the Archimedes water immersion method.

The Brinell hardness was also measured to see what the mechanical properties progression is when the powder shape and the sintered temperature change. Finished samples were polished and etched with a $FeCl_3$/HCl/ethanol solution at room temperature to expose the pores and internal microstructure

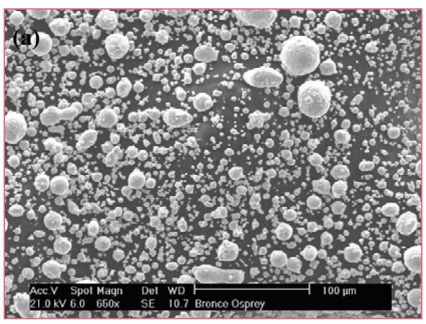

Figure 1a. Gas atomised bronze powder.

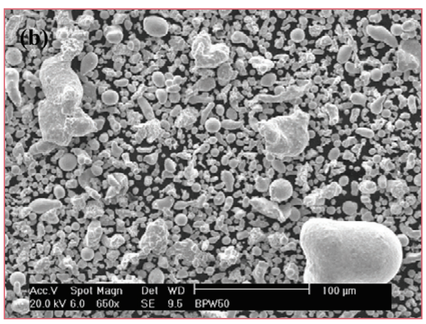

Figure 1b. Water-atomised bronze powder.

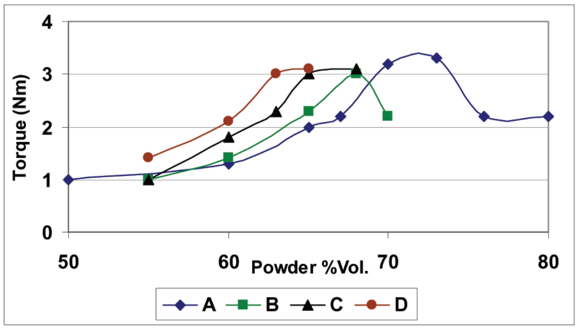

Figure 2. Final torque variation of the powders after mixing at 170°C.

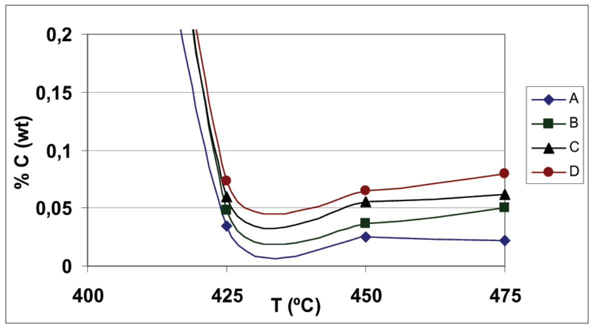

Figure 3. Carbon content variation after debinding.

Figure 2 shows the final torque after mixing different feedstocks at 170°C for 30 minutes. Feedstocks made with gas-atomised powder show lower viscosities than those fabricated with water-atomised powder. This means that higher solids loadings can be used. When the proportion of water-atomised powder is increased in the blend the viscosity also increases and the optimal solids loading decreases. All the curves present a maximum after which the viscosity starts to decrease due to the fact that the binder cannot coat all the powder and some powder is free.

Green parts were injection moulded from feedstocks A, B, C and D to perform a detailed study of the processing. The time and heating rates required to eliminate binder in green parts fabricated from gas and water atomised powder were different in such a way that binder elimination took longer in feedstocks with irregular powders, increasing the time and decreasing the heating rates with the irregular powder content to avoid defects on the parts surface. Figure 3 shows that residual carbon content decreased with the gas-atomised powder content as feedstocks A, B, C and D had 0.025 per cent, 0.036 per cent, 0.055 per cent and 0.065 per cent by weight respectively at 450°C.

After that, brown parts were sintered in a controlled atmosphere furnace to make final components. Figure 4 gives the shrinkage of the different materials.

Feedstock D presents the highest shrinkage for every temperature (achieving 36 per cent at 840°C), and feedstock A the lowest. This is due to the different solids loading of each feedstock and, therefore, to the higher green density of the gas-atomised injection moulded compacts.

Densification curves of the sintered parts can be seen in Figure 5. It was found to be 95 per cent in feedstocks A and B at 820°C and 840°C respectively. Somewhat lower densification was found in feedstocks C and D (94.5 per cent and 93.8 per centrespectively) at 840 °C. In general, the gas-atomised powder shows an earlier and higher densification than the water atomised version. Parts fabricated with only gas atomised powders have the highest hardness from 800°C to 840°C and this does not show much variation between those temperatures. This material achieved 80 HB at 820°C, but it quickly lost the mechanical properties and hardness at 860°C. Parts fabricated from feedstock C presented the worst mechanical properties in almost all the temperature range. However, B, C and D components have the same highest hardness (70 HB) at 840°C. Porosity follows the opposite trend to hardness. From 800-840°C parts made with only spherical powder show less porosity than the others. Above 840°C, parts fabricated with only irregular powder become less porous than the rest of the samples. Figure 6 shows the optical micrographs of the components obtained from feedstock A, B, C and D sintered at 800°C and 840°C before they were etched to expose their microstructures. All the samples show small and rounded porosity at 800°C and the pore size increases with temperature as can be seen in the micrographs. It was found that parts made only from

Table 1: Particle characteristic of bronze powders

G/A W/A		
Production method	Gas Atomised	Water Atomised
Shape	Spherical	Irregular
Particle size (µm)		
>22	19.9%	60%
>45	0.1%	20%
>63	0%	5%
Aparent density (gr/cm³)	4,25	3,2
Pycnometer density (g/cm³)	8,85	8,82

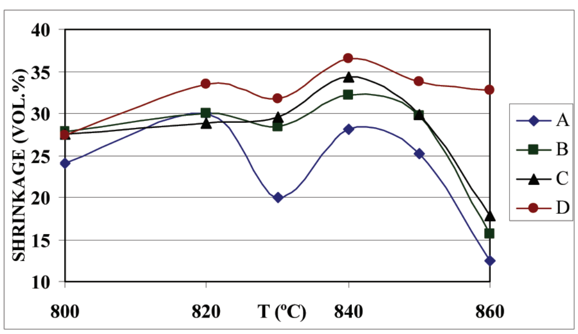

Figure 4. Volume change of the parts after sintering.

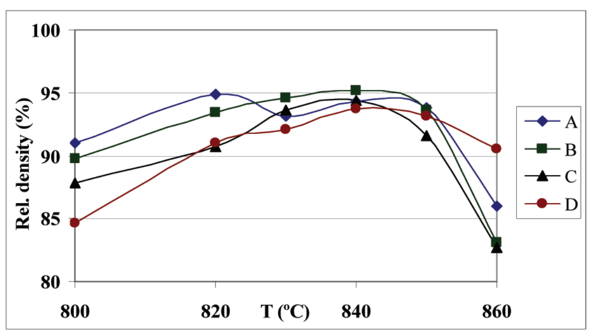

Figure 5. Relative density of the parts after sintering.