The search for full density in PM processing to replace machined wrought steel has engaged R & D group efforts in metal powder companies for a number of years. In most instances, the achievement of higher density has involved more complex and/or multiple-step processing, resulting in increased cost while the maximum sintered density is currently about 7.45 g/cm³. At the same time, there is a considerable market, developed over many years, for which moderate strength, fully dense parts can be produced by malleable iron/ductile iron castings. This is a market sector where PM has found it hard to compete because of cost – until now.

Enter Rio Tinto Metal Powders (QMP), which has developed a new ferrous powder that is able to compete with malleable iron, ductile iron, and compacted-graphite iron castings. François Chagnon and colleagues presented two papers at PowderMet 2012 in Nashville, Tennessee, USA, giving details of the new malleable iron powder grade (MIP)™. The basis for this development is the use of super-solidus liquid-phase sintering as applied to the iron-graphite-silicon alloy system. The author noted: “Super-solidus liquid-phase sintering is another way to achieve high density. The process requires pre-alloyed powders that – when heated to a temperature intermediate between the solidus and liquidus – nucleate a liquid within each particle. The amount of liquid produced is a function of the alloy content and the sintering temperature. The individual particles partially melt and promote densification by capillary-induced re-arrangement.”

Previous researchers have shown the feasibility of densification of ferrous PM materials by liquid-phase sintering, usually by sintering at higher temperatures than conventional sintering. RTMP researchers have shown the feasibility of reaching full density through super-solidus liquid-phase sintering at conventional sintering temperatures by using a new water-atomised Fe-2%C-1%Si alloy powder. After a malleablis- ing treatment, the annealed powder particles are completely ferritic with embedded graphite nodules, so that there is no need for added graphite. Carbon segregation is eliminated (see Figures 1 and 2). Hence compressibility and sinterability are each optimised.

The new powder requires careful control of the sintering temperature as well as the heating and cooling rates. Liquid-phase sintering occurs between
1156°C and 1165°C, in which range the alloy shrinks by about 2.5%, to give a relative density of 99.0–99.7%. Resulting microstructure is affected by the sintering temperature and cooling rate from 1166°C–1140°C. Sintering at 1162°C resulted in a fine pearlitic structure with nodular graphite particles showing some ferrite at the periphery (Figure 3). Tensile properties were found to be surprisingly insensitive to the sintering temperature between 1152°C and 1166°C (Figure 4). Thus, tensile strength averaged 776 ±11 MPa, yield strength was 523 ±20 MPa, with elongation averaging 2.2 ±0.4%. These values were said to be comparable with pearlitic malleable cast iron class 800 02 and ductile iron grade 100-70-03. Tensile strength, yield strength, and elongation were found to be “very sensitive to both the [part] density and the shape of the graphite particles.”

Previous researchers have shown the feasibility of densification of ferrous PM materials by liquid-phase sintering. The performance of the new MIP powder could be significantly improved by admixing a small fractional amount of ferro-phosphorus. In a second paper, presented by Maryam Moravej, mechanical properties and machinability results were reported for a comparison of MIP pressed and sintered with and without 0.2%P (samples MIP-A and MIP-B, respectively). The addition of ferro-phosphorus reduces the temperature range for sintering, with accompanying benefits from the resulting structure. Sintering of these materials each produced nearly fully dense structures when sintered in
the respective sintering windows of 1158°C–1166°C (for plain MIP) and 1118°C–1124°C (MIP + 0.2% P). The sintered densities of 7.53 and 7.52 g/cm³ represent 99.0 and 99.4% of full density because of the low density of the graphite content. The addition of phosphorus to the mix not only lowered the sintering temperature but also increased the number of graphite particles formed on cooling by a factor of almost three. Thus it significantly increased the proportion of spherical or nodular graphite and reduced the number of large graphite flakes.

As summarized in Table 1, tensile, yield strength and elongation were all higher for the MPI + 0.2% phosphorus composition, while hardness remained the same. Axial fatigue strength was improved by around 20% with phosphorus. On the other hand, impact energy was reduced from 33J to 22J.

The machinability of sintered MIP materials was compared with that of ductile iron grade DI 80-55-06 as well as powder-forged FC-0205PF + 0.3% manganese sulphide. Face-turning tests were made on ring-shaped samples measuring 50.8 mm OD, 25.4 mm ID, and 22.86 mm thick. Two types of cutting operations were performed: a semi-roughing operation at two cutting speeds (183 and 274 m/min) with feed rate of 0.254 mm/rev and 1.52 mm depth of cut; the second test was a finishing operation using a cutting speed of 137 m/min, feed rate of 0.102 mm/rev and depth of cut of 1.02 mm cutting-tool lead angles of +15° and -5° were employed. Two cutting forces were measured during the tests: feed force and tangential forces. Results obtained for the four materials are shown in Figures 6 and 7. With the same roughing operation, both feed force and tangential force values for MIP with phosphorus (MIP-B) were lower than for MIP alone (MIP-A) and were comparable with the ductile iron and powder-forged steel containing MnS. The same was more or less found for the finishing cuts. The lower machinability of MIP without phosphorus was attributed to its lower content of graphite clusters.

According to Rio Tinto Metal Powders, the MIP powder is now in production and expected to find applications in the replacement of castings. It will be interesting to see what the industry makes of this intriguing development.