

Looking for lean-alloy PM steels with performance and economy

Joe Capus, *MPR* contributing editor, continues his ongoing reporting of the technical papers presented at PowderMet 2013 in Chicago this past June. In this piece, he puts the focus on attributes of lean-alloy PM steels.

There were, as usual, a large number of separate ferrous PM topics presented during the recent PowderMet 2013 APMI/MPIF conference in Chicago (see *Metal Powder Report*, July/August 2013 edition). One of the more interesting sessions held on the first day dealt with developments in lean-alloy PM steel compositions.

As Ian Donaldson (GKN Sinter Metals) pointed out in a joint presentation with Bruce Lindsley (Hoeganaes Corp.), the continuing demands of the automotive manufacturers are [still] driving innovation in the PM industry. Furthermore, in recent years the need for higher strength components has been compounded by the extreme volatility in prices of the alloy elements that traditionally have been used to boost the strength of pressed and sintered parts. Result: the risk that PM will lose out on new engine and transmission developments, and consequently cede market share to manufacturers using less-costly, wrought-based materials.

Hence, there has been an ongoing battle to find leaner or alternative alloy compositions, as well as other means of reaching desired properties. A consequence of the many studies and developments that have been made on this

in the recent past is that there is now a multiplicity of options to explore.

In the work presented by Donaldson, this was illustrated by results from several related investigations giving sets of comparison test data. The first set of lab tests involved warm-die compaction of ferrous-based mixes to a green density of 7.1 g/cm³, followed by high-temperature sintering at 1250°C in a roller-hearth furnace using a lean 95/5 nitrogen/hydrogen atmosphere and then accelerated cooling to provide sinter-hardening — and, finally, tempering at 205°C for one hour. Six different lean alloy compositions with molybdenum contents ranging from 0.3% to 0.8% and various additional alloy combinations selected from chromium, manganese, silicon and nickel were compared with a “base-line” FD 0405 (4% Ni, 1.5% Cu) diffusion-alloyed PM steel that is successfully used in synchronizer hubs and other auto components. The lean-alloy compositions contained only 10-30% of the expensive alloying ingredients (Mo, Ni, and Cu) that are employed in the FD-0405 mix. With a constant combined carbon level of 0.5%, variations in properties resulted from changes in microstructure brought about by the different alloy contents. The lean alloys showed apparent

hardness and tensile strength values mostly surpassing that of the FD-0405 steel base-line. However, the nickel steel showed a higher elongation, at 2%. All of the sinter-hardened materials showed complex but fairly similar microstructures, with various combinations of tempered martensite, bainite, pearlite, and nickel-rich regions (where nickel was added to the mix). In other tests, the influence of atmosphere and sintering temperature were investigated. For the atmosphere study, sintering of lean-alloy (1.3% Mn, 0.5% Mo, 0.3% Si) mixes was made in a mesh-belt furnace at 1140°C for 20 minutes. Endothermic atmosphere diluted with nitrogen was used, to compare with sintering with a 90/10 N₂/H₂ atmosphere. Diluting the atmosphere to either 68% or 51vol.% Endo caused a significant rise in the sintered oxygen content (0.40/0.45% vs. 0.16%) and substantially lower strength and % elongation.

In further experiments with the same manganese and molybdenum-containing composition — as well as one with a higher molybdenum content (0.8%) and a chromium-containing mix (0.8% Mo, 1.0% Cr, 1.0% Ni and 0.6% Si) — the effect of sintering atmosphere was confirmed. In this investigation, using a roller-hearth furnace with

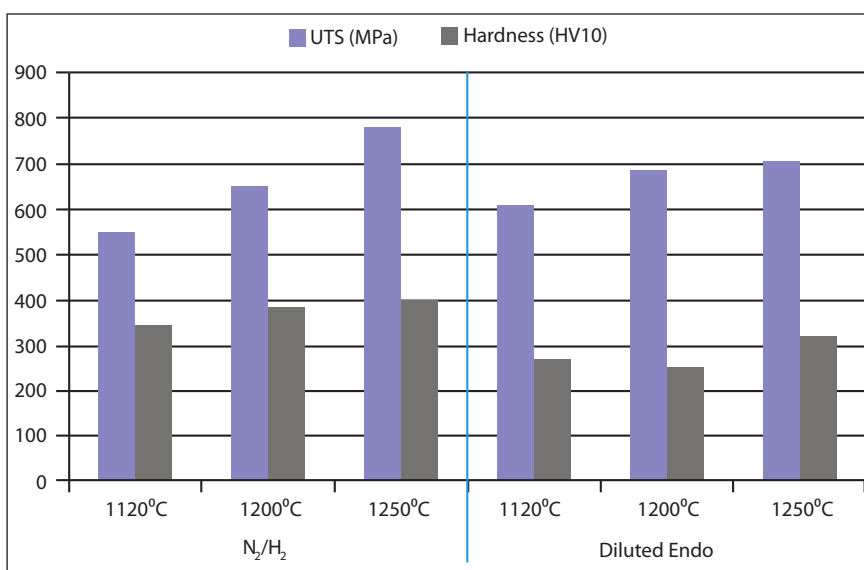
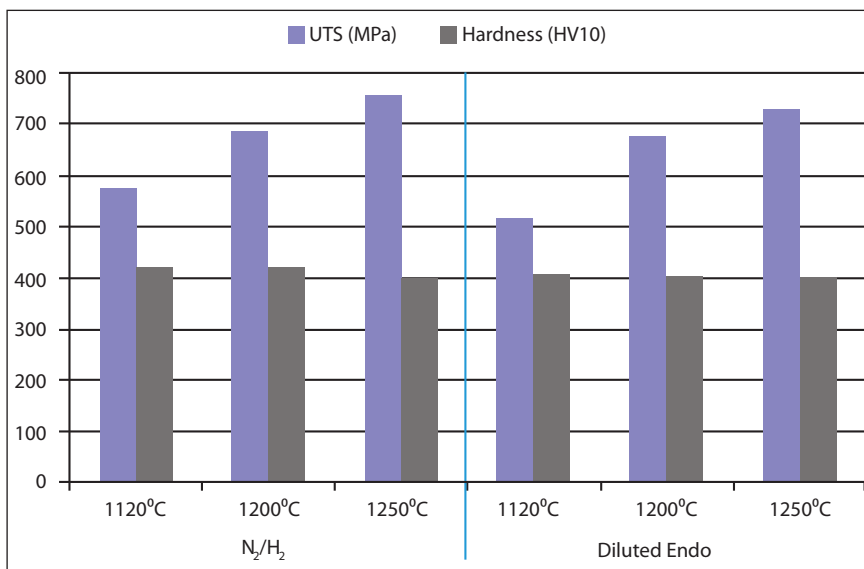
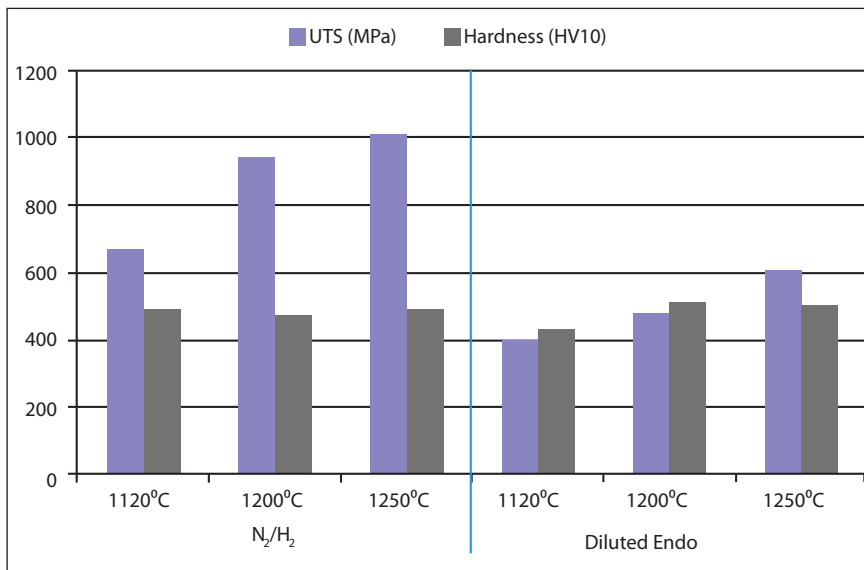


Figure 1. UTS and apparent hardness for different sintering temperatures and atmospheres (95/5 N₂/H₂ or 90/10 N₂/Endo) with accelerated cooling in a roller hearth furnace. (After Donaldson and Lindsley) (Mix 1: 0.8% Mo, 1.0% Cr, 0.6% Si, 1.0% Ni, Mix 4: 0.5% Mo, 1.3% Mn, 0.3% Si, Mix 8: 0.8% Mo, 1.3% Mn, 0.3% Si) (Ancorbond®FLM), (All mixes contained 0.65% graphite)

accelerated cooling, the atmosphere was either 95/5 N₂/H₂ or diluted Endo (90/10 N₂/Endo). The tests were run at three sintering temperatures: 1120°C, 1200°C, and 1250°C. The use of diluted Endo reduced the UTS more-or-less significantly, but the hardness was little affected for all three compositions (see Figure 1). The conclusion was that using Endo, even when diluted with nitrogen/hydrogen, was not a good idea.

Looking at specific application examples, such as an automotive gear currently using a 4% nickel material, the authors demonstrated how targeted properties like YS, UTS and impact energy could be met by the right selection of a lean alloy composition to replace the more expensive material. Compared were mechanical properties of the base-line FD-0405 (4% Ni) and the lean 1.0%Cr, 1.0%Ni, 0.6% Si, 0.3% Mo alloy steel, both sintered in a mesh-belt furnace at 1180°C with accelerated cooling.

The authors concluded by referring to successful applications for new lean Cr-Mo-Ni PM steels when suitable compaction and sintering conditions were employed. These included torque-vectoring systems for premium all-wheel-drive vehicles (see Figure 2) and synchronizer hubs for manual and double-clutch transmissions.

Nickel-free Lean Alloy PM Steels

A novel approach to nickel-free lean alloy PM steels was presented by François Chagnon in a paper co-authored by Lydia Aguirre, both with Rio Tinto Metal Powders. In this work, Mn-Cr-Mo steels were synthesized by mixing together pre-alloyed Mo-containing steel powder with ferro-alloys containing Mn or Cr, plus a new carbon master-alloy. The carbon master-alloy was designed to replace the conventional graphite admixture. The carbon master-alloy (M.A.1) was produced in house by atomising a 2% carbon, 1% silicon iron melt and subsequently malleablising the powder by heat treatment. (Details of this malleable powder product were given at last year's MPIF conference, PowderMet 2012, in



Figure 2. Pressure and activator plates made with lean Cr-Mo PM steels: high-temperature sintered in a roller hearth furnace and accelerated cooling. After Donaldson and Lindsley.

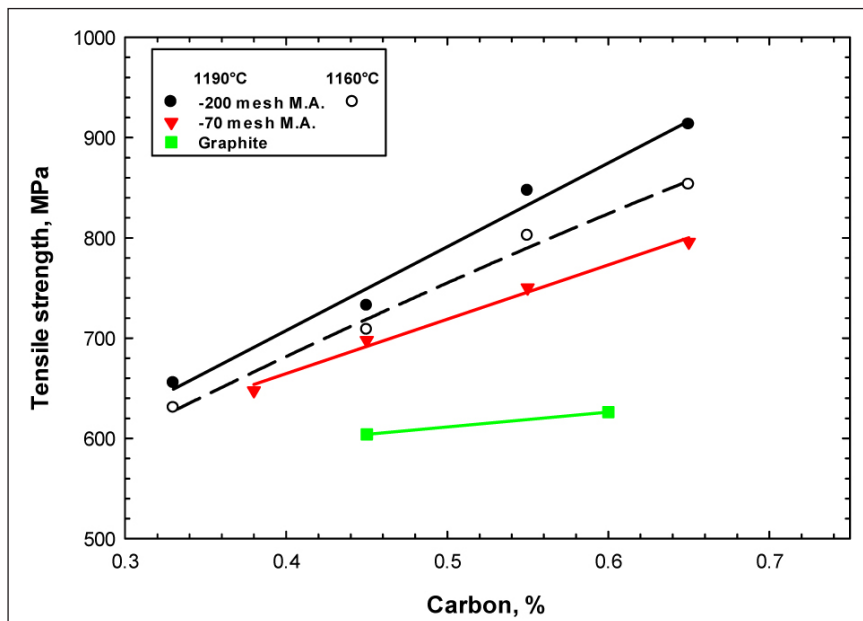


Figure 3. Effect of carbon content and sintering temperature on tensile strength of experimental lean alloy PM steels made with free graphite or carbon master alloy (-70 mesh and -200 mesh screen sizes). After Chagnon and Aguirre)

Nashville, TN. (*Metal Powder Report*, July/August 2012, (5), pp.30-32).

Tests were made on a lean alloy composition containing 0.9% Mn, 0.6% Cr, and 0.5% Mo with a range of carbon contents from 0.3% to 0.65%. The alloy contents were achieved by mixing together the appropriate amounts of the pre-alloyed Mo

powders, the two types of ferro-alloy and the calculated percentage of carbon master-alloy to produce the desired level of carbon. Two screen sizes of the carbon master-alloy were employed, a minus 70 mesh version and a minus 200 mesh screened fraction. For comparison with the more traditional mix compositions using graphite, two versions

with 0.40% and 0.57% graphite were included in the test programme. All mixes contained 0.75% wax lubricant.

To evaluate and compare the sintered properties of all these materials, standard test bars were compacted to a 6.9 g/cm³ green density and sintered at either 1160°C or 1190°C for 30 minutes in 90/10 N₂/H₂ atmosphere followed by cooling at about one degree/minute in the 650° - 315°C range and, finally, tempering for one hour at 200°C. Results showed that the replacement of graphite with the carbon master-alloy produced some confusing, although logical trends. While all of the mixes were compacted to 6.9 g/cm³ green density, because of the lower compressibility of the carbon master-alloy the mixes containing M.A.1 required significantly higher pressure to reach the target density, and this pressure increased with the carbon level in contrast to the mixes with graphite.

The next difference was in the dimensional change on sintering. The materials containing carbon master-alloy all shrank from die-size, while the graphite mixes were reported as showing the opposite trend. This difference slightly complicated the interpretation of the mechanical properties, since the M.A.1-containing materials had sintered densities of 6.88-6.89 versus 6.83 g/cm³ for the graphite mixes. However, such differences are too small to explain the significant increases in YS, UTS and TRS obtained when the carbon master-alloy is substituted for graphite (see Figure 3). The elongation, on the other hand, was only slightly affected. Similarly, the bending fatigue tests showed the minus 70 mesh materials with carbon master-alloy gave 25% higher fatigue strength than the graphite mixes at the same carbon level (0.57%). Metallographic examination (Figure 4) showed that these multi-component materials were quite heterogeneous after sintering at either temperature, with martensite, bainite and pearlitic constituents distributed roughly according to the alloy content of the original particles, due to incomplete diffusion. It was noted that diffusion had evidently progressed less in the graphite mix materials, producing more bainite and less martensite, hence less hardening. It was also pointed out that the presence of silicon from the

carbon master-alloy (at 0.1 to 0.4% according to the carbon level) could have contributed to the higher strength levels.

Role Silicon Plays

The role of silicon in low-alloy PM steels was the subject of the third presentation in this session. Christopher Schade and co-authors from Hoeganaes Corp. and Drexel University made a detailed study of the effect of increasing levels of silicon on the mechanical properties and hardenability of PM steels containing selected alloying elements. Silicon was found to have similar effects as in wrought high-strength steels: increasing strength of ferrite by solid-solution hardening, refining the structure of pearlite, and increasing hardenability; the latter synergistically with chromium and molybdenum. Silicon also suppressed the formation of carbide networks in higher carbon (>0.8%) compositions. A comparison of sinter-hardened properties of an experimental alloy containing 0.5% Mo and 0.75% Si with the properties of

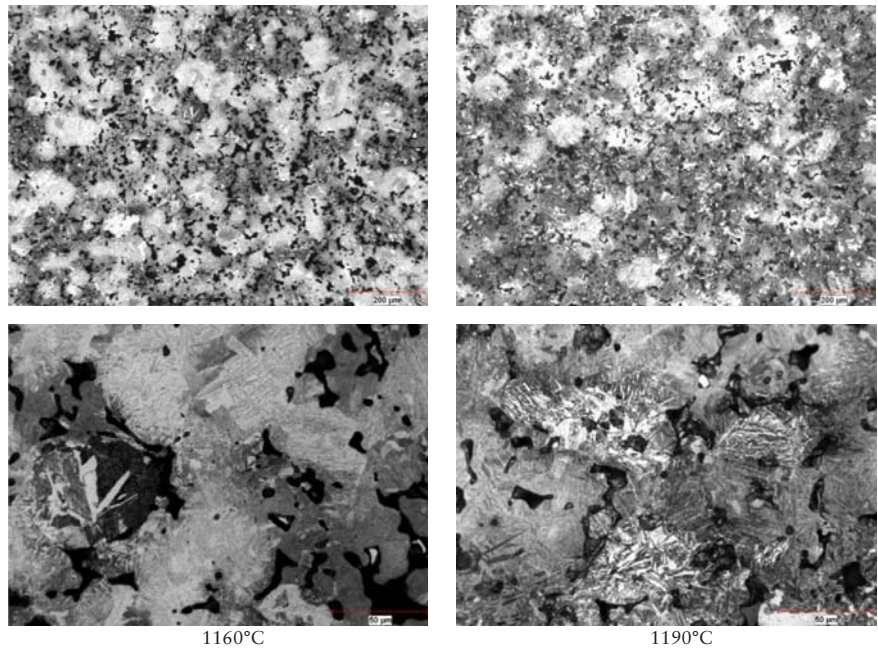


Figure 4. Microstructures of Fe-0.55C-0.9Mn-0.6Cr-0.5Mo materials containing -200 mesh carbon master alloy sintered at either 1160 (left hand photos) or 1190°C; (Nital etching; 100X and 500X) After Chagnon and Aguirre.

several MPIF standard compositions for sinter-hardening showed that strength levels could be matched in most of the sinter-hardening grades with improved

elongation. It was suggested that the use of silicon, in combination with high graphite levels, could result in considerable savings in alloy cost. ▀

Metal Powder Report Wants Your Technical Papers!

Among the topics/areas to be explored in 2013:

- Alloys
- Metal Injection Moulding
- Refractory/Hardmetals
- Ferrous & Non-Ferrous Powders
- Pressing
- Sintering
- End-User Case Studies

Please submit abstracts or deadline inquiries to Reginald Tucker, editor, at re.tucker@elsevier.com