

**NEW HIGH PERFORMANCE P/M ALLOY SUBSTITUTES  
for  
MALLEABLE and DUCTILE CAST IRONS**

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**Abstract**

To advance applications of powder metallurgy (P/M) into areas where current products do not have the desired performance characteristics, a series of new alloys has been developed. These new materials exhibit mechanical properties comparable to those of malleable and ductile cast irons. Some possible applications include ring gears, pinion gears, and carriers.

The tensile and impact properties of the new materials are presented for compaction pressures of 415, 550, and 690 MPa and comparisons are made with current high performance P/M materials as well as with various cast irons.

**Introduction**

The mechanical properties of ferrous P/M materials are directly related to their density and microstructure. In the as-sintered condition, most admixed ferrous P/M materials have a microstructure that consists of ferrite and pearlite. Diffusion-alloyed materials exhibit a more complex microstructure with martensite, bainite, nickel rich ferrite, and nickel rich regions in addition to ferrite and pearlite. The relative proportion of martensite and bainite depends on the extent of diffusion processes during sintering and the rate of cooling following sintering. The complex microstructure of the as-sintered diffusion-alloyed materials results in a special combination of tensile strength, ductility, and impact energy ; better strength and ductility coupled with higher impact energy than admixed and prealloyed ferrous P/M materials. Some hybrid ferrous P/M materials may exhibit higher yield strengths but generally fail to match the combination of strength, ductility, and impact energy of the diffusion-alloyed products. Recently, engineered binder-treated hybrid alloys have been developed that equal, and in some instances exceed, the performance characteristics of the diffusion-alloyed materials (1,2). While high performance diffusion-alloyed powders have been developed to increase the range of mechanical properties, they too have been matched in performance by engineered binder-treated hybrid alloys (3).

Gray, malleable, and ductile cast irons are used widely in automotive applications. Gray irons have moderate strength and ductility and P/M copper steels have comparable properties. However, malleable and ductile cast irons have significantly higher mechanical properties compared with gray cast iron their strength/ductility values depending on whether the cast irons are in the ferritic, pearlitic, or martensitic condition ; ultimate tensile strengths range from 650 to 1000 MPa, yield strengths from 500 to 700 MPa, and elongation values from 2 to 4%.

Ferrous P/M materials, generally, are unable to match the combination of strength and ductility of these higher performance cast irons. Hanejko has shown that a warm compacted FLN4-4405 material sintered at 1260 °C meets the ultimate strength of a heat treated malleable cast iron (900 MPa), and almost meets the yield strength (690 MPa) but falls short of the 4% elongation of the cast iron (4,5). When sintered at 1120 °C, the FLN4-4405 material exceeds the strength of the pearlitic malleable iron but has much less ductility (2.5% compared with 8%).

The material development program reviewed in the present paper was aimed at meeting the performance characteristics of malleable and ductile irons without the need for warm compaction. Warm compaction processing of the materials covered in the present paper will result in higher densities and hence increased mechanical properties compared with those reported here.

### Experimental Procedure

Press-ready, binder-treated premixes were made with 0.75 w/o (weight percent) additions of an ethylenebis-stearamide wax (Acrawax C). The as-sintered materials had the nominal compositions listed in Table 1.

**Table 1: Nominal Compositions of the Sintered Materials (w/o)**

Material	Fe	Si	Cr	Mn	Ni	Mo	C
MDB	Balance	0.7	0.03	0.13	2.0	0.85	0.6
MDC	Balance	0.7	0.03	0.13	4.0	0.85	0.6

Tensile and room temperature unnotched Charpy impact properties of the materials were evaluated for samples compacted at 415, 550, and 690 MPa. Material MDB was tested in the as-sintered condition whereas material MDC was tested after tempering at 190 °C for one hour. Sintering was carried out at 1260 °C in a laboratory Hayes pusher furnace for 30 minutes at temperature in a 75 v/o hydrogen : 25 v/o nitrogen atmosphere.

The as-sintered, and sintered and tempered tensile properties were based on flat, unmachined (dog-bone) specimens conforming to ASTM E 8 (MPIF Std. 10). Tensile testing was performed on a Tinius Olsen machine at a crosshead speed of 0.6 mm/min. Data from an extensometer attached to the specimens permitted automated readouts of the 0.2% offset yield strength, ultimate tensile strength, and percentage elongation values.

Impact testing was performed at ambient temperature (approximately 20 °C) using standard unnotched Charpy specimens in accordance with ASTM E 23 (MPIF Std. 40).

Density checks of the specimens were conducted in accordance with the immersion method described in ASTM B 328 (MPIF Std. 42) and, typically, were limited to two specimens per condition.

The reported values for tensile and impact properties were, in all cases, based on a minimum of three measurements and, in most cases, five measurements per condition.

Apparent hardness values were measured on the grip end-faces of the tensile specimens prior to testing. Measurements were made using the Rockwell “A” scale (diamond indenter and 60 kgf load). The “A” scale has the convenience of covering the whole of the “C” scale and most of the Rockwell “B” scale.

Dimensional change measurements were made on transverse rupture bars (TRS bars) in accordance with ASTM B 610 (MPIF Std. 44).

## Results

The green and as-sintered densities of the materials are illustrated in Figure 1. While both materials have similar green densities, the MDC material shrinks more during sintering and reaches higher sintered densities than the MDB material. The dimensional change of the materials, relative to die size, for the range of compaction pressures evaluated is shown in Figure 2.

The tensile strength of the materials versus compaction pressure is summarized graphically in Figure 3. The yield strength of the MDC material exceeds the ultimate tensile strength of the MDB material at each applied compaction pressure. The tensile elongation results are shown in Figure 4 with both materials exceeding 2% elongation for compaction pressures of 550 MPa and higher.

The apparent hardness of the materials is shown with respect to compaction pressure in Figure 5. Note that the values for material MDB are for the as-sintered condition while those for material MDC are after tempering at 190 °C.

Room temperature, unnotched Charpy impact energy data for the materials are summarized in Figure 6. Once again, please note that the values for material MDB are for the as-sintered condition while those for material MDC are after tempering at 190 °C.

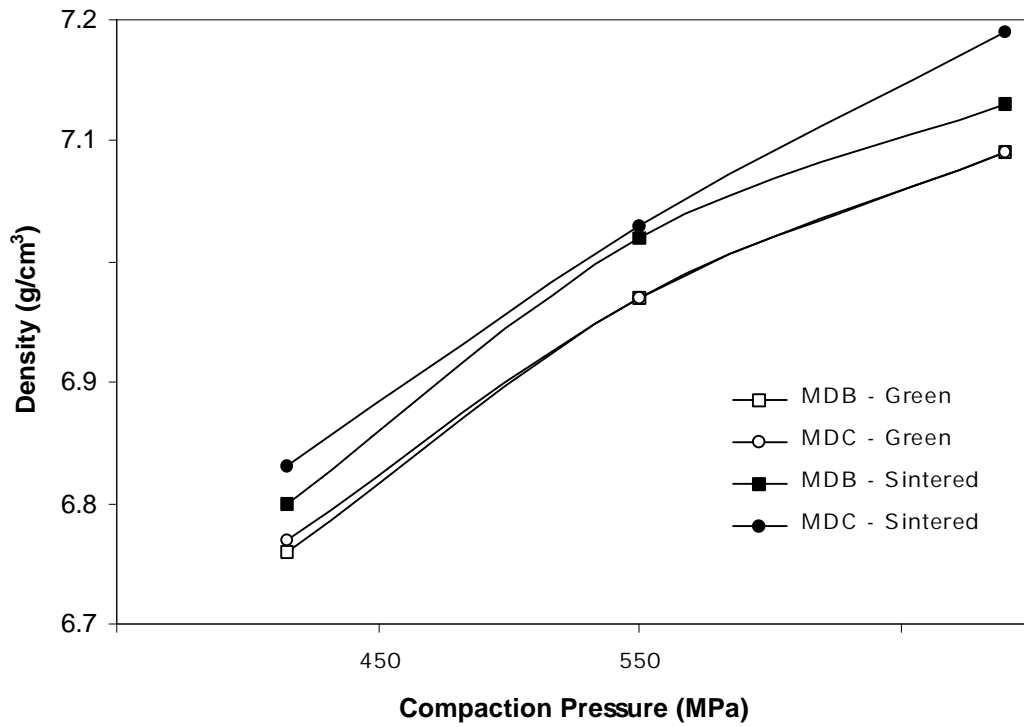
Photomicrographs illustrating the microstructure of each of the materials are presented in Figures 7 and 8. The microstructure of material MDB consists of martensite, some bainite, and divorced pearlite with some areas of very fine unresolved pearlite. Material MDC has a predominantly martensitic microstructure with some bainitic areas.

## Discussion

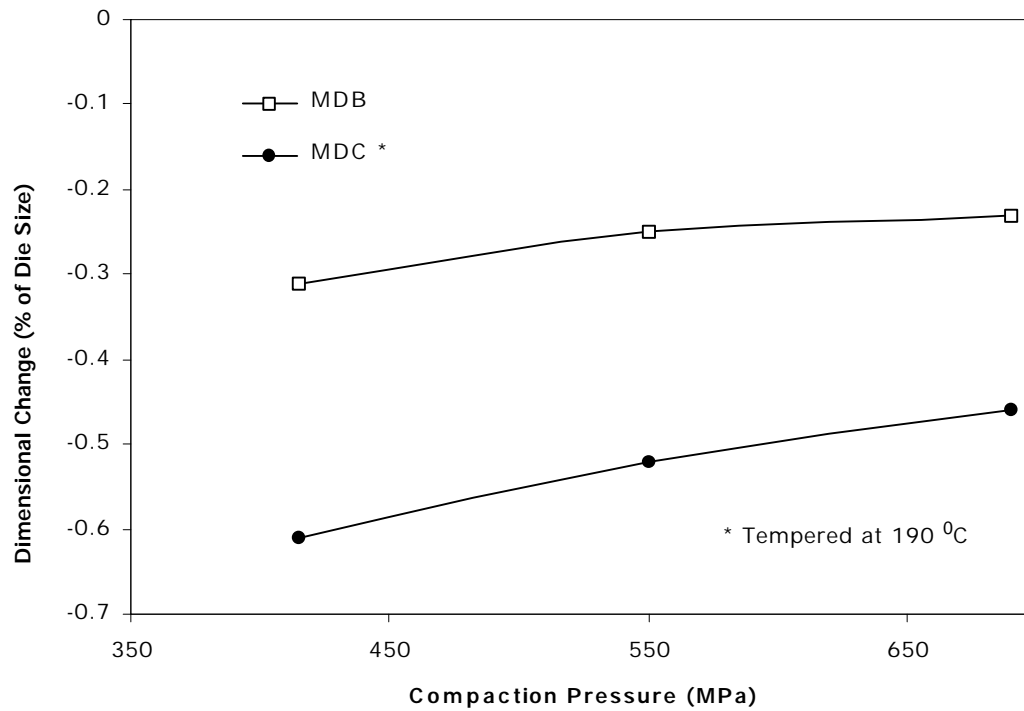
The yield strength of material MDC exceeded the ultimate tensile strength of material MDB at all the compaction pressures that were evaluated. For an applied compaction pressure of 550 MPa, material MDB had an ultimate tensile strength of 760 MPa and a yield strength of 510 MPa. For the same compaction pressure, material MDC had an ultimate tensile strength of 1160 MPa and a yield strength of 840 MPa. The tensile elongation of both materials was 2%. The materials therefore compare favorably with malleable and ductile irons used for pinions, ring gears, and carriers (e.g. ASTM A 220 grades 80002 and 90001 ; and ASTM A 536 grades 100-70-03 and 120-90-02).

In order to establish a frame of reference for the new alloys, their tensile and impact properties were compared with those of selected high performance ferrous P/M alloys (2,3,6,7). The materials selected for comparison with materials MDB and MDC were:

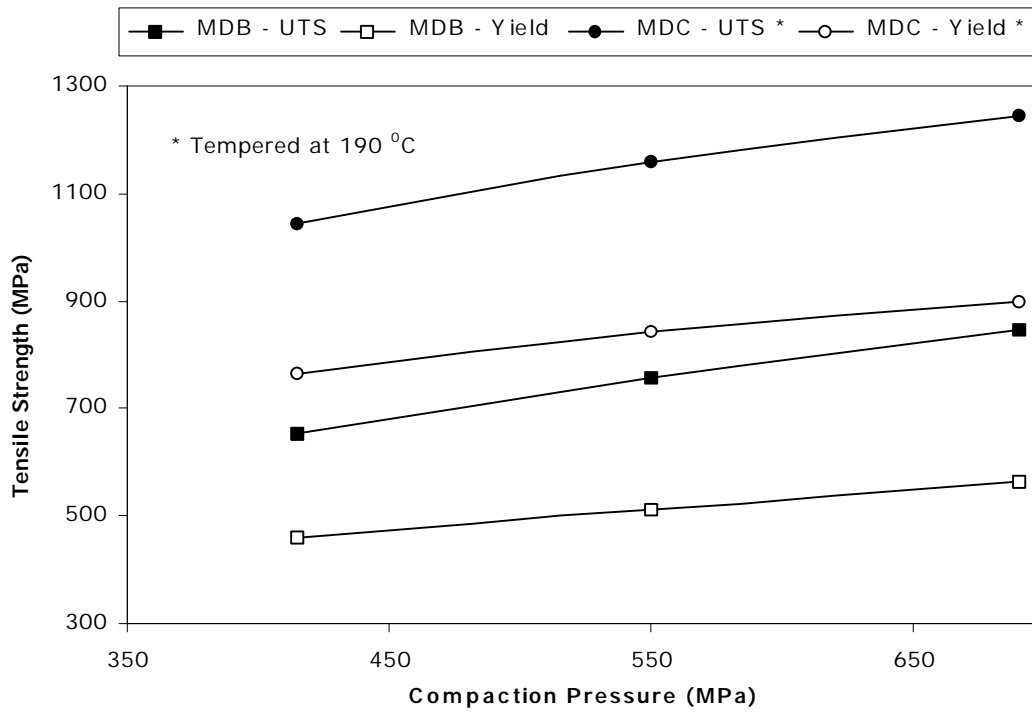
1. Ancorloy 4 + 0.6 w/o graphite – sintered at 1120 °C (ref. 2),
2. Ancorloy HP-1 + 0.6 w/o graphite – sintered at 1120 °C (ref. 3),
3. Distaloy HP-1 with 0.5 w/o combined carbon – sintered at 1250 °C (ref. 6), and
4. FLN4-4405 and FLN6-4405 – sintered at 1315 °C (ref. 7).



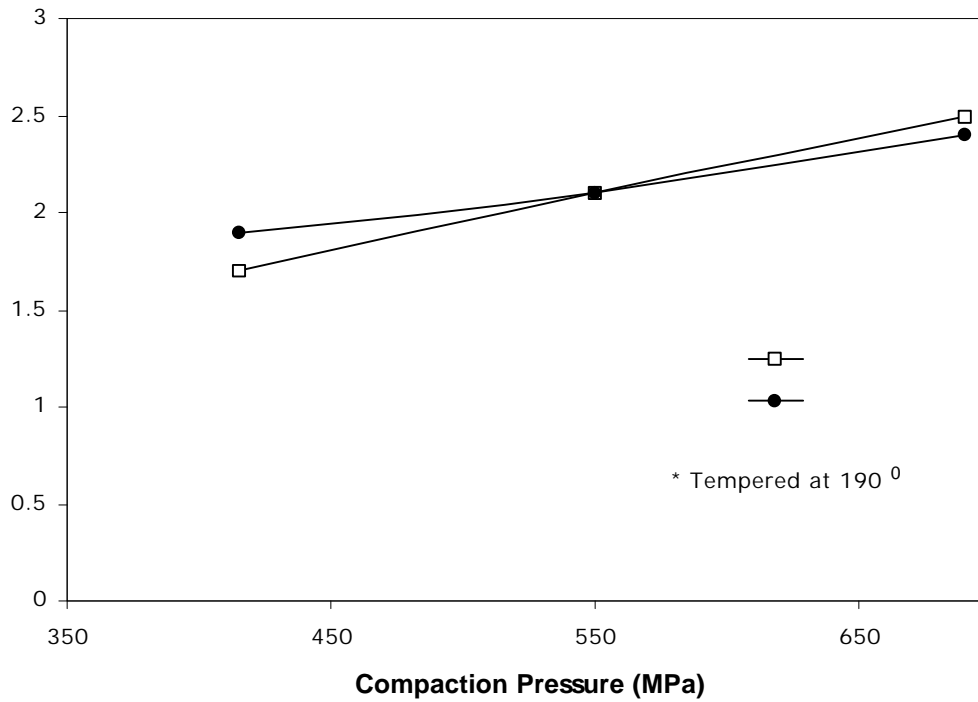
**Figure 1: Green and Sintered Densities of the Materials versus Compaction Pressure**



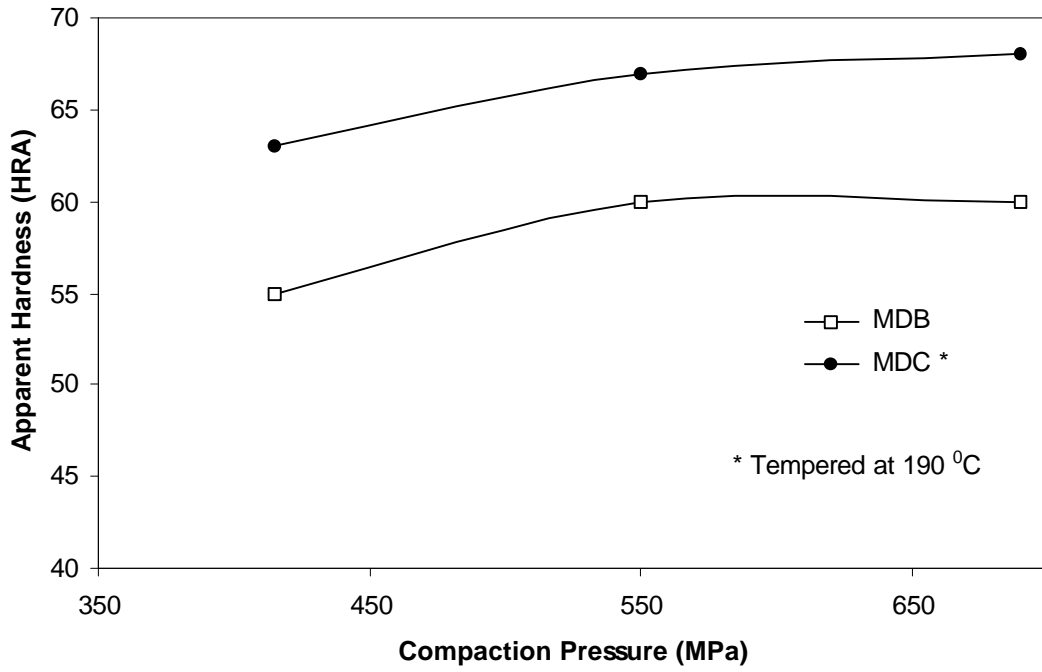
**Figure 2: Dimensional Change versus Compaction Pressure**



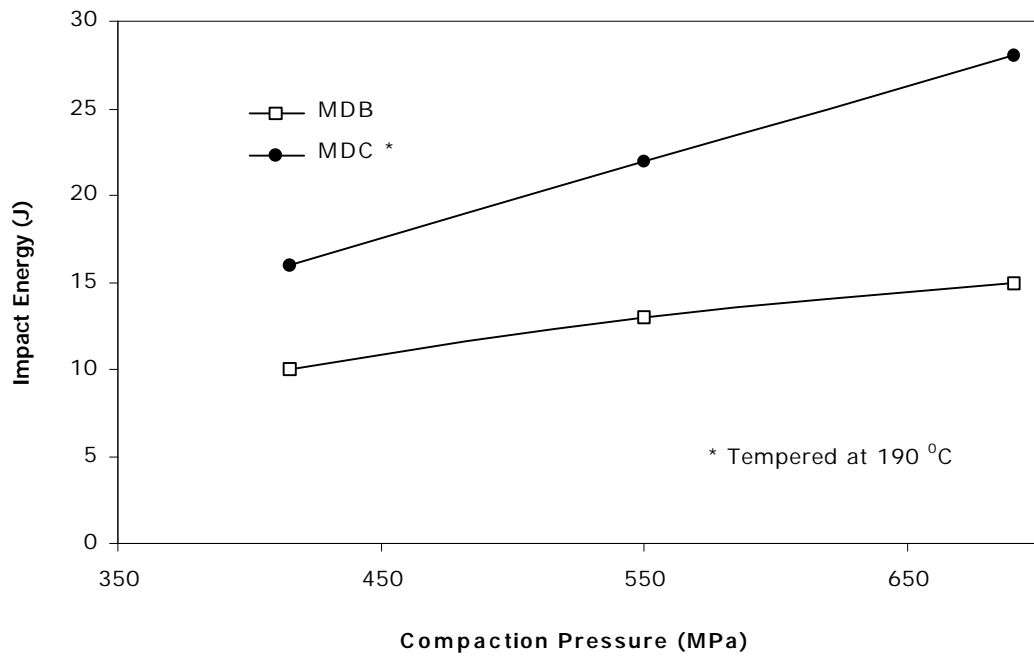
**Figure 3: Tensile Strength versus Compaction Pressure**



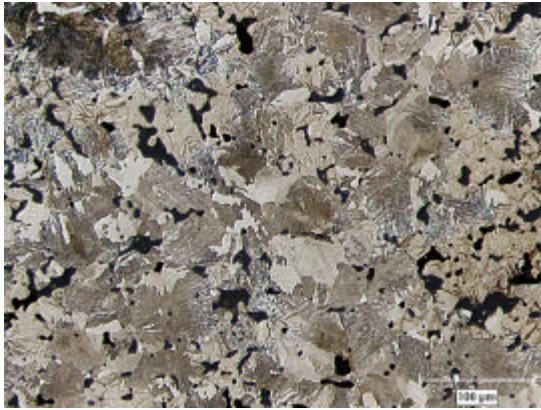
**Figure 4: Tensile Elongation versus Compaction Pressure**



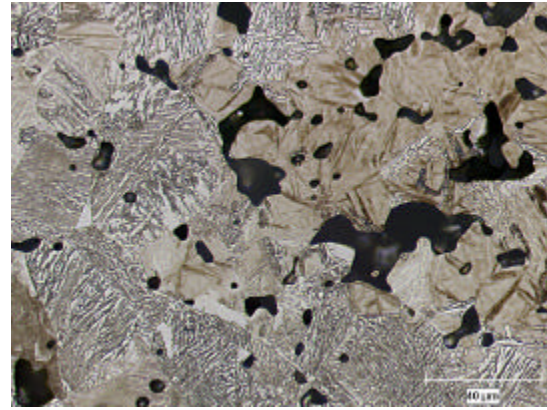
**Figure 5: Apparent Hardness versus Compaction Pressure**



**Figure 6: Room Temperature Unnotched Charpy Impact Energy**

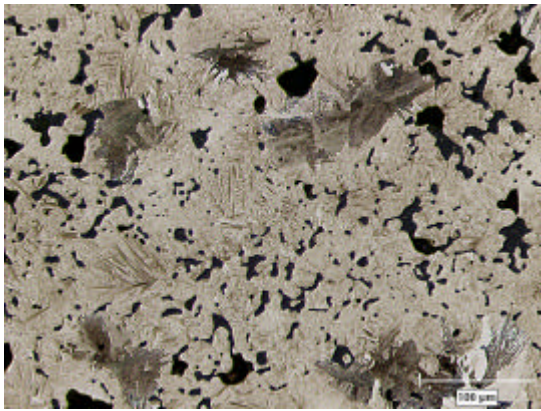


a

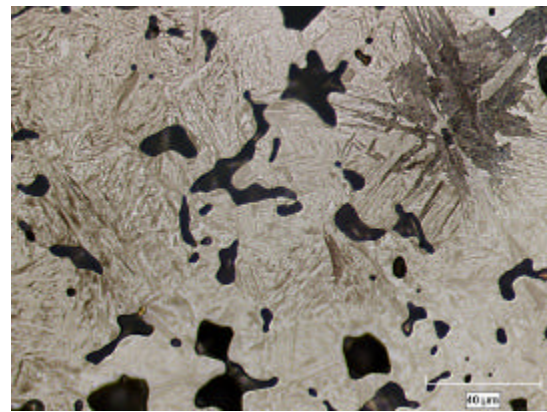


b

Figure 7: Microstructure of Material MDB. Etched with 2% nital / 4% picral. Original Magnification: a = 200X ; b = 500X



a



b

Figure 8: Microstructure of Material MDC. Etched with 2% nital / 4% picral. Original Magnification: a = 200X ; b = 500X

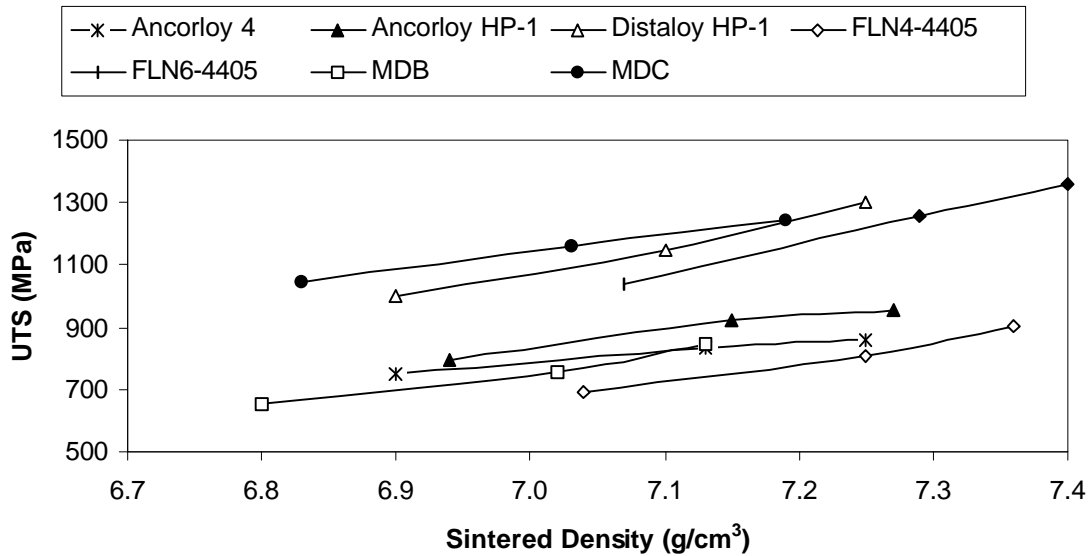
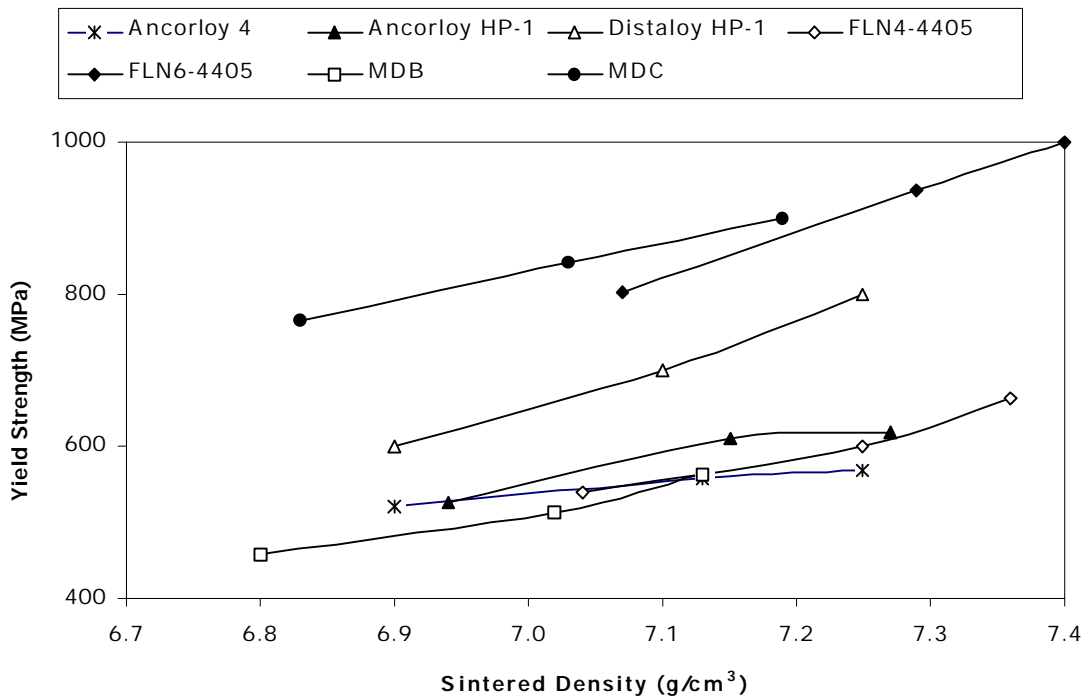
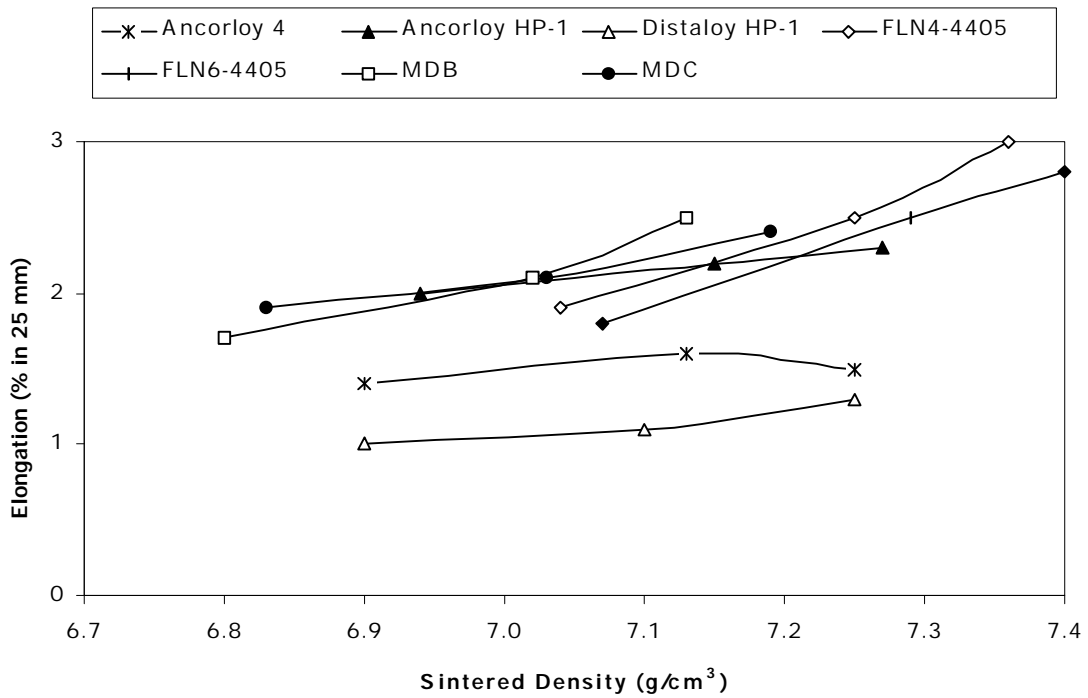


Figure 9: Effect of Sintered Density on the Ultimate Tensile Strength of Selected High Performance Ferrous P/M Materials

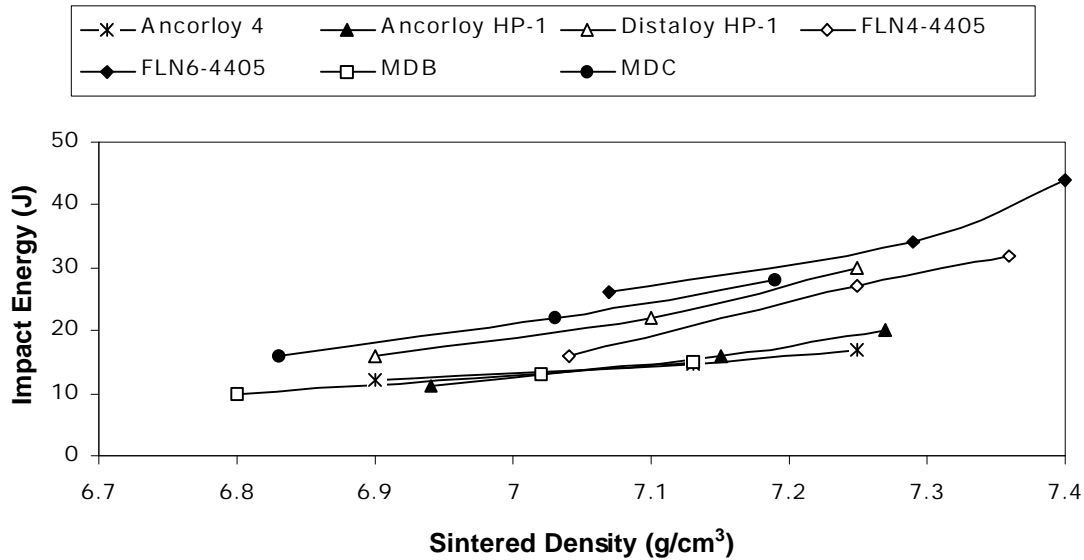


**Figure 10: Effect of Sintered Density on the 0.2% Offset Yield Strength of Selected High Performance Ferrous P/M Materials**



**Figure 11: Effect of Sintered Density on the Tensile Elongation of Selected High Performance Ferrous P/M Materials**





**Figure 12: Effect of Sintered Density on the Room Temperature Unnotched Charpy Impact Energy of Selected High Performance Ferrous P/M Materials**

The ultimate tensile strengths of the various materials are compared in Figure 9. Material MDC matched the tensile strength of Distaloy HP-1 and FLN6-4405. The diffusion-alloyed material is a hybrid alloy based on a 1.5 w/o prealloyed steel to which 4 w/o nickel and 2 w/o copper have been partially alloyed. The FLN6-4405 material is a hybrid alloy based on a 0.85 w/o molybdenum prealloyed steel to which 6 w/o nickel has been admixed. Material MDC is less highly alloyed than these two materials that exhibited comparable strength.

Material MDB matched the tensile strength of Ancorloy 4, FLN4-4405, and fell just short of matching the strength of Ancorloy HP-1. Each of these materials is more highly alloyed than material MDB.

The only material that reached the yield strength achieved by material MDC was the hybrid alloy FLN6-4405 as illustrated in Figure 10. The high temperature sintered, high performance diffusion-alloyed material, Distaloy HP-1 fell considerably short of matching the yield strength of the top two materials. The yield strength of material MDB matched that of Ancorloy 4, Ancorloy HP-1, and the hybrid alloy FLN4-4405, all of which are more highly alloyed.

Materials MDB and MDC had tensile elongation values comparable to those for Ancorloy HP-1, FLN4-4405, and FLN6-4405 as shown in Figure 11. The tensile ductilities of the Ancorloy 4 and the high temperature sintered Distaloy HP-1 were somewhat lower than for the other materials.

The hybrid alloy FLN6-4405 had the best impact properties. However, as may be seen in Figure 12, material MDC matched the performance of Distaloy HP-1 and FLN4-4405. Material MDB had comparable impact properties to those of Ancorloy 4.

Future work will evaluate the fatigue performance of the new materials and production trials will be conducted on potential part applications.

## Conclusions

The new materials MDB and MDC exhibited an extremely good combination of tensile strength, tensile ductility, and impact energy. The elevated sintering temperature needed for the

materials results in microstructures that contain significant amounts of martensite and the materials are effectively sinter hardened. Higher ductility might be obtained at the expense of tensile strength, by tempering the MDC material at a higher temperature. The effect of tempering the MDB material needs to be evaluated as the microstructure of this material contained a significant proportion of martensite.

The new materials, MDB and MDC, match many of the characteristics of a number of malleable and ductile cast irons and should be evaluated in potential applications such as ring gears, pinion gears, and carriers.

## References

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