

# Hardenability Response of Fe-Mo-Ni-C Powder Metallurgy Alloys

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## Abstract

Increases in the cost of the alloying elements used in ferrous powder metallurgy have led to the introduction of “lean” alloys. One of the recently introduced materials is a diffusion-alloyed powder that is based on an iron powder and has 0.5% Ni and 0.5% Mo diffusion alloyed to this iron powder base. The material has been developed for applications in which the PM parts are heat treated. While this material appears to offer a cost effective solution for PM parts makers, alternatives exist that are even more cost effective and are better from a metallurgical perspective. This paper will review the heat treatment response of three Fe-Ni-Mo-C materials that are similar in chemical composition. The benefit to hardenability of some, or all of the alloy additions being prealloyed will be highlighted.

## Introduction

In the development of leaner ferrous powder metallurgy (PM) alloys we need to use the additions more effectively. An alloying element that is prealloyed has a greater effect on hardenability than the same amount of that element that is diffusion alloyed or admixed. In the case of the prealloyed material, a full contribution to hardenability is obtained for the element that is prealloyed. When the alloy addition is diffusion alloyed or simply admixed it is only the portion of that element that has gone into solution in the steel after sintering that contributes to the hardenability of the material.

While beneficial to hardenability, prealloying sometimes has a negative impact on the compressibility of the material. It has been found, however, that when molybdenum is used as the principal alloy addition, up to 0.85% may be added without there being a loss of compressibility [1,2]. Hybrid alloys based on a molybdenum prealloyed powder are the fastest growing segment of the ferrous PM market.

One of the recently introduced lean ferrous PM materials is a diffusion-alloyed powder with 0.5% Ni and 0.5% Mo [3]. The nickel and molybdenum are diffusion alloyed to an iron powder base. While this maintains good compressibility, it significantly reduces the hardenability of the material and this is an important consideration as the material is targeted for PM parts that require heat treatment.

This paper will review the heat treatment response of three Fe-Ni-Mo-C materials. One is prealloyed, one diffusion alloyed, while the third is a hybrid alloy that is based on a prealloyed powder with 0.5% molybdenum.

## Experimental Procedure and Results

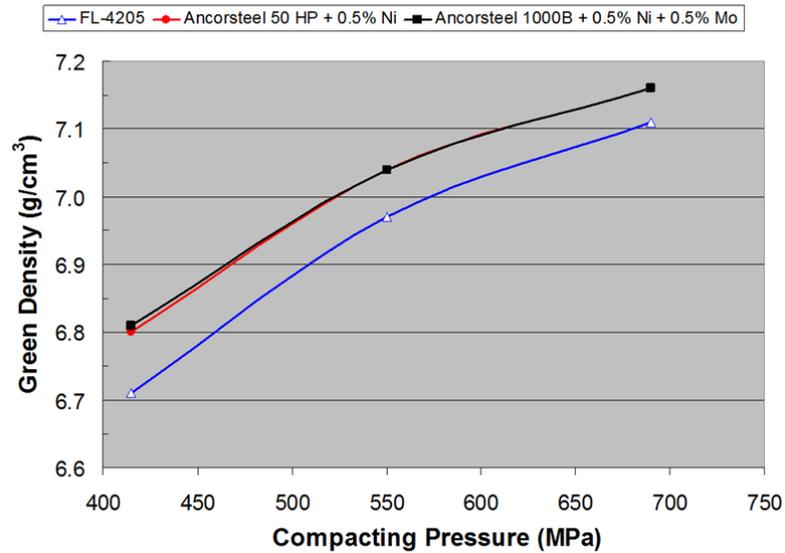
The chemical compositions of the three materials studied are summarized in Table 1. The prealloyed powder for the FL-4205 material was Ancorsteel 2000, a water atomized, nickel-molybdenum prealloyed powder. The hybrid alloy was the water atomized prealloyed powder Ancorsteel 50 HP to which 0.5% nickel was admixed. The diffusion-alloyed material was based on the water atomized iron powder, Ancorsteel 1000B. Additions of 0.5% Ni and 0.5% Mo were made to this iron powder and the mixture was subjected to a diffusion-annealing process. Each of the three materials had an addition of 0.6% Asbury 3203H natural flake graphite powder along with 0.75% Acrawax C lubricant.

Material	Ni	Mo
FL-4205	0.5*	0.6*
Ancorsteel 50 HP + 0.5% Ni	0.5	0.5*
FD-0105 (Ancorsteel 1000B + 0.5% Ni + 0.5% Mo)	0.5**	0.5**

\*prealloyed                      \*\*diffusion alloyed

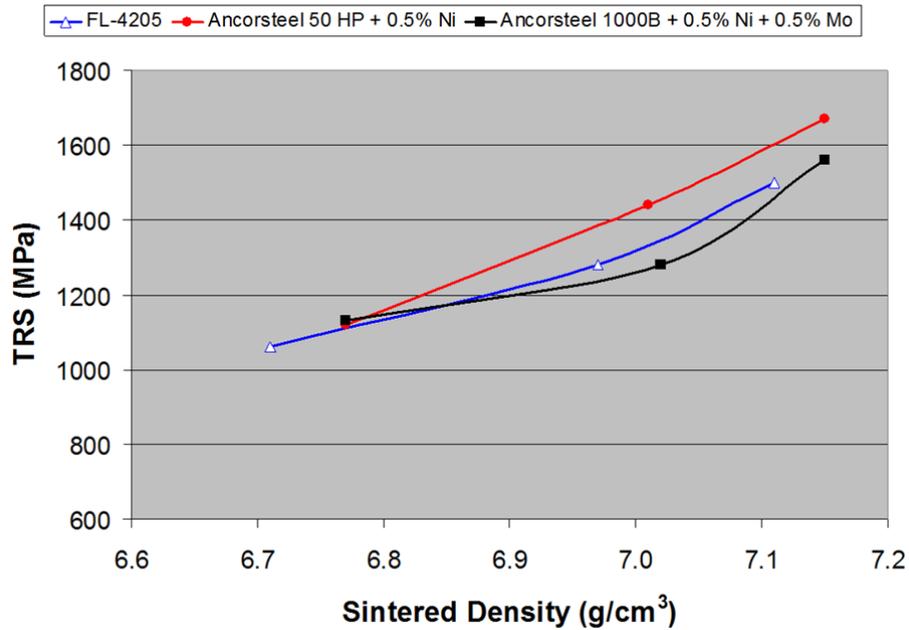
**TABLE 1: Chemical composition of the materials (mass %).**

Transverse rupture strength (TRS) bars and cylindrical compacts were pressed to a density of  $7.0 \text{ g/cm}^3$  then sintered at  $1120 \text{ }^\circ\text{C}$  for 15 minutes at temperature in a mixed gas atmosphere (90%:10% - nitrogen: hydrogen). The compressibility of the materials was tested in accordance with MPIF Standard 45 [4] and is illustrated in Figure 1.



**Fig 1: Compressibility curves for the three materials.**

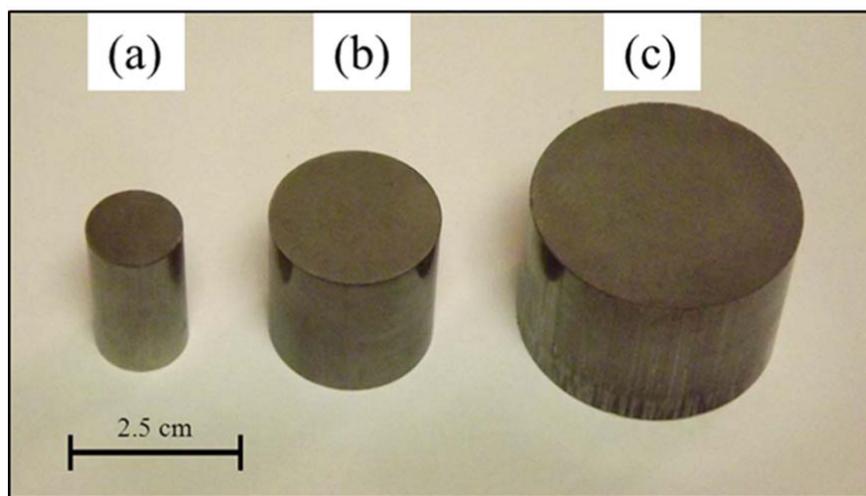
The transverse rupture strength of the three heat-treated materials was tested in accordance with MPIF Standard 41 [4] and the results are summarized in Figure 2.



**Fig 2: Transverse rupture strength of the heat-treated materials.**

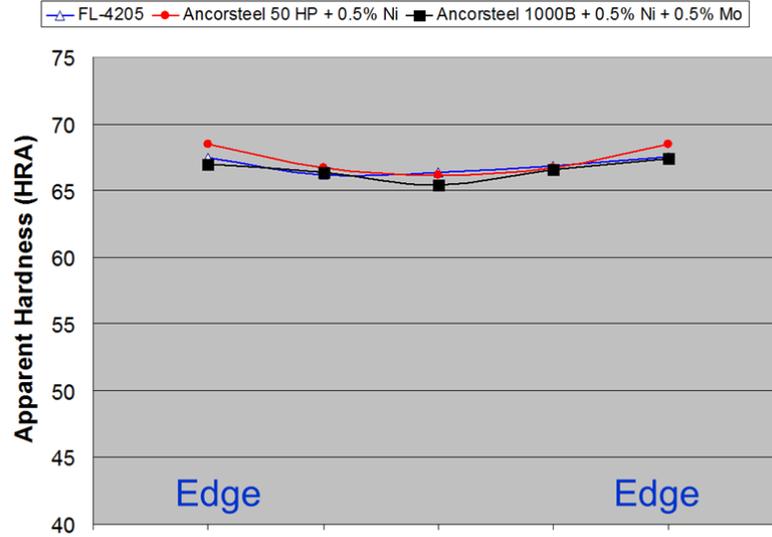
The cylindrical compacts were all 25 mm high and had three different diameters – 13 mm, 25 mm, and 38 mm – Figure 3. The mass of the cylindrical compacts was 25 g, 90 g, and 220 g respectively.

The sintered compacts were austenitized at 900 °C for 45 minutes in a synthetic dissociated ammonia atmosphere (75% hydrogen:25% nitrogen), quenched in circulating oil at 65 °C and tempered at 200 °C for 1 hour.

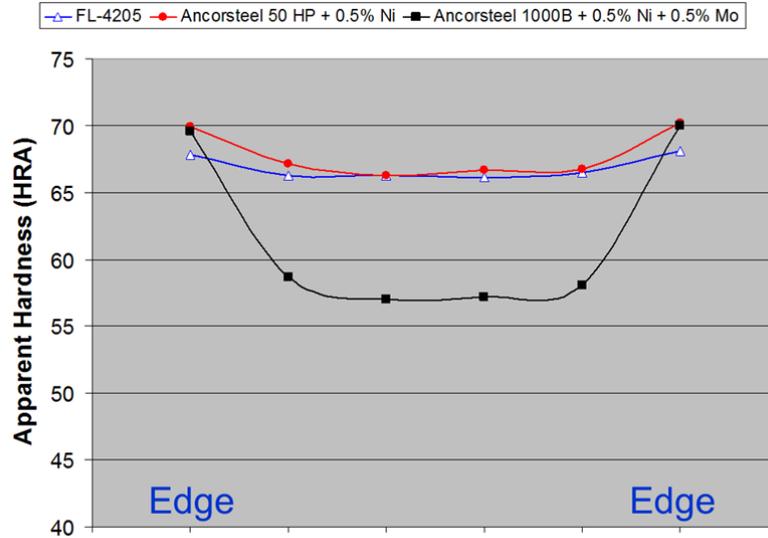


**Fig 3: Cylindrical compacts. Each is 25 mm high.**  
**(a) 13 mm diameter; (b) 25 mm diameter; (c) 38 mm diameter**

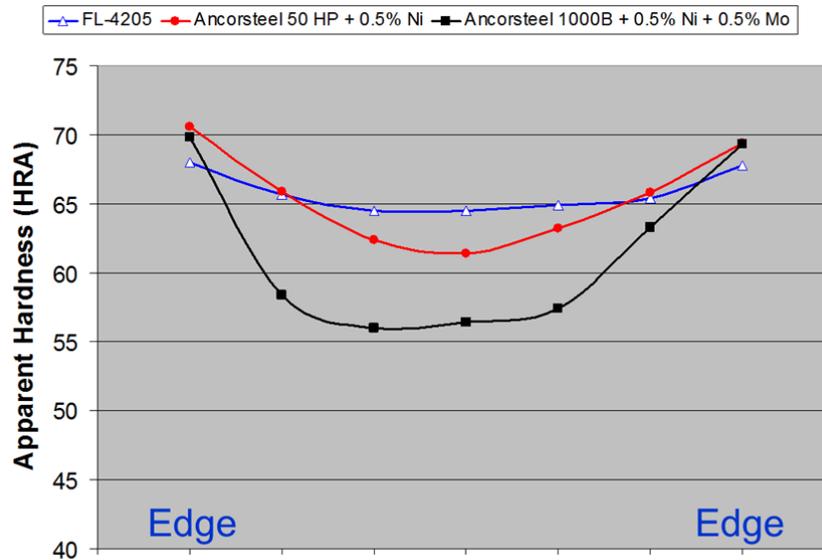
The heat-treated cylindrical compacts were cut in half in a longitudinal direction. Apparent hardness measurements were made from one edge of the compact to the other in a position near to the mid-height of the compact. The measurements were made in accordance with MPIF Standard 43 [4]. The hardness measurements were repeated three times and averaged. The results are summarized in Figures 4-6.



**Fig 4: Apparent hardness values for the 13 mm diameter cylindrical compacts.**



**Fig 5: Apparent hardness values for the 25 mm diameter cylindrical compacts.**



**Fig 6: Apparent hardness values for the 38 mm diameter cylindrical compacts.**

## Discussion

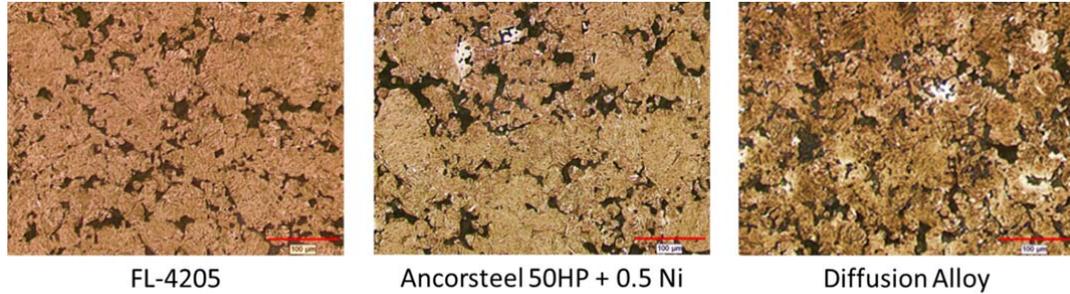
The compressibility of the prealloyed material (FL-4205) is slightly lower than that of the other two materials. This is the result of the solid solution hardening of the nickel and molybdenum in this alloy. The hybrid alloy with the prealloyed molybdenum (0.5% Mo) base and the diffusion-alloyed material (FD-0105) based on an iron powder have similar compressibility.

Although the three materials appear to have similar heat-treated transverse rupture strength, it is important to remember that the cross-section of these test bars (6 mm x 12 mm) may not be representative of many PM parts. Parts with larger cross-sections may not have the tempered martensitic microstructures of the TRS bars – they may contain higher amounts of bainite.

This is highlighted by the response of the cylindrical compacts to heat treatment. The apparent hardness values for the 13 mm diameter cylindrical compact are very similar. This indicates that the compacts have through hardened and that their microstructures are similar throughout the compacts. The microstructure at the core of the 13 mm diameter compact for each of the three materials is presented in Figure 7. The FL-4205 material has a tempered martensitic microstructure. The hybrid alloy also has a tempered martensitic microstructure along with nickel-rich regions. The diffusion-alloyed material (FD-0105) has a tempered martensitic microstructure with some nickel-rich regions and some bainitic areas.

When the diameter of the cylindrical compact is increased to 25 mm, while the microstructure of the FL-4205 material remains the same, there is some bainite present in the hybrid alloy as may be seen in Figure 8. The apparent hardness of these materials is similar to what it was for the 13 mm diameter compacts. While the apparent hardness of the 25 mm cylindrical compact made from the diffusion-alloyed material (FD-0105) remains the same at the edges of the cross-section (the

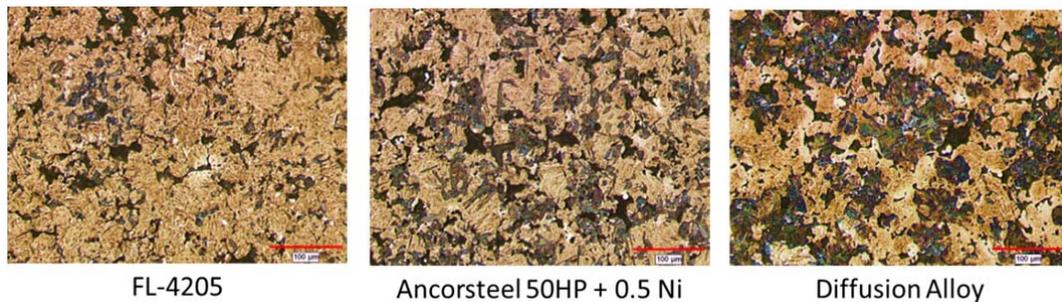
surface of the compact), it decreases significantly a short distance into the compact. This loss in apparent hardness is due to the presence of a significant amount of bainite rather than martensite in the microstructure – Figure 8.



**Fig 7: Etched microstructure for the core region of the heat treated 13 mm diameter cylindrical compacts. (etchant – 2 v/o nital: 4 w/o picral)**



**Fig 8: Etched microstructure for the core region of the heat treated 25 mm diameter cylindrical compacts. (etchant – 2 v/o nital: 4 w/o picral)**



**Fig 9: Etched microstructure for the core region of the heat treated 38 mm diameter cylindrical compacts. (etchant – 2 v/o nital: 4 w/o picral)**

When the diameter of the cylindrical compact is increased to 38 mm, even the FL-4205 material has a small amount of bainite in its microstructure – Figure 9. It still through hardens, however, and its apparent hardness remains similar to what it was in the smaller compacts – Figure 5. The apparent hardness of the hybrid alloy compact dips slightly nearer its core and this is the result of

the presence of some more bainite – Figure 9. The diffusion-alloyed material (FD-0105) has a microstructure similar to what it was for the 25 mm diameter compact of this material, and this is matched by the significant loss of apparent hardness a short distance from the edge of the cross-section of the compact – Figure 6.

## **Conclusions**

For the same chemical composition, elements that are prealloyed provide greater hardenability than those that are diffusion alloyed.

Although materials may appear to have similar heat-treated transverse rupture strength, it is important to remember that the cross-section of these test bars (6 mm x 12 mm) may not be representative of many PM parts. Parts with larger cross-sections may not have the tempered martensitic microstructures of the TRS bars – they may contain higher amounts of bainite.

Care needs to be taken when “lean” materials are used to make PM parts that are to be heat treated. If the lean material is based on an iron powder it may not have sufficient hardenability to develop the desired microstructure during heat treatment – depending on the size of the PM part.

Hybrid alloys based on prealloyed powders that have molybdenum as their principal alloy addition provide the desired hardenability and flexibility in material design.

## **Acknowledgements**

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## **References**

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