SINTER HARDENING RESPONSE OF CHROMIUM PM STEELS

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ABSTRACT

The sinter hardening response of PM steels is affected by alloying system, cooling rate, density and mass of the component. In this paper the sinter hardening response of two chromium alloyed PM steels has been investigated when the mass and density are varied. Components of different size and green densities have been sinter hardened under production conditions for comparison. Macro hardness and micro structural transformations for each of the parts were evaluated to characterize the response. The objective of this work is to provide an aid for selecting correct sinter hardening material and processing conditions for a given application.

INTRODUCTION

High performance applications require material systems that exhibit high strength. Historically, nickel and molybdenum containing systems have often been used to meet these requirements. As the price of nickel passes $40,000 USD/ton[1] and molybdenum passes $50,000 USD/ton[1] new material systems are being explored. Chromium base steels are being evaluated to replace many of these nickel containing systems due to the low cost of chromium ($1500 USD/ton)[1].

In nickel containing systems, heat treatment of admixed nickel materials or sinterhardening of diffusion bonded or pre-alloyed materials are often used to maximize the performance of the material system. Sinterhardening is defined as materials with sufficient hardenability to enable hardening during the cooling cycle after sintering[2].

Chromium base materials have also shown good sinterhardening characteristics[3]. Many factors influence a material system's sinterhardening response. Alloying elements, surface area, cooling rate, density and component mass are just a few of the factors that can influence the achievable final properties[4]. Due to the wide variation in component mass and density in the PM industry, it is important to know the effect these variable have on the sinterhardening response of chromium steels. This paper intends to provide a guide for selecting the proper material system and processing conditions to achieve the desired final properties for an application.

EXPERIMENTAL PROCEDURE

The purpose of this study was to evaluate the effect of component mass and density on the sinterhardening response. For this study, a mix composition based on Astaloy CrL™ was manufactured. The chemical composition of the base iron used can be found in Table 1. The mix composition can be found in Table 2.

Table 1. Chemical Composition of Base Iron

Base Iron	Cr (%)	Mo (%)
Astaloy CrL™	1.5[1]	0.2[1]

1. Pre-alloyed

Table 2. Mix Composition

Mix	Base Iron (Balance)	Copper[1] (%)	Graphite[2] (%)	Lubricant[3] (%)
FLC-5208	Astaloy CrL™	2.0	0.75	0.60

1. ACuPowder 165
2. Asbury 1651
3. Kenolube™

Slugs of three sizes and two green densities were compacted from the mix outlined in Table 2 to simulate the different sizes of components manufactured in the PM industry. The slugs were compacted by PowderTech. To achieve slugs with a green density of 7.20 g/cm^3, press – delube – repress was used. Table 3 outlines the sizes of different slugs manufactured for this study.

Table 3. Slug Size and DensitySlug Diameter (mm)	Slug Height (mm)	6.80 g/cm^3 Green Density	7.20 g/cm^3 Green Density
25	25	X	X
50	50	X	X
75	50	X	X

To evaluate the mechanical properties of the mixes at different cooling rates, tensile specimens (MPIF Std. 10) and impact energy specimens (MPIF Std 40) were compacted to densities of 6.80 g/cm^3, 7.00 g/cm^3 and 7.20 g/cm^3. Sintering was conducted in an Abbott 6" belt furnace equipped with a Varicool Rapid Cooling Unit. All sintering was performed for 30 minutes at 1120°C (2050°F) in a 90$_{v/o}$ N_2 / 10$_{v/o}$ H_2 atmosphere. Varicool settings of 0, 15, and 30 Hz were used. The slugs that were sintered using accelerated cooling were tempered at 200°C (400°F) for 1 hour in air. Sintered slugs from each size and density were evaluated for apparent hardness and microstructure of the slug interior. The tensile specimens were evaluated for ultimate tensile strength, yield strength and elongation. The impact energy bars were evaluated for impact energy and apparent hardness. The microstructure of the test specimens was also evaluated to determine the cooling rate.

Results FLC-5208

Tables 4 and 5 compare the difference in mass and mass to surface area ratio of the slugs for each density.

Table 4. FLC-5208 Slug Mass and Surface Area to Mass Ratio

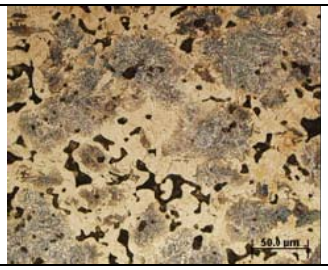
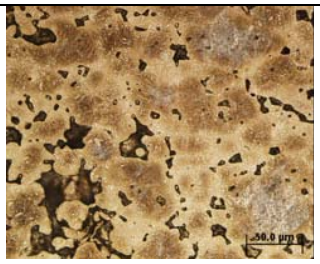
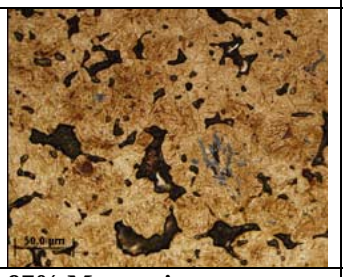
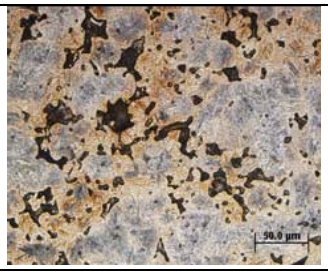
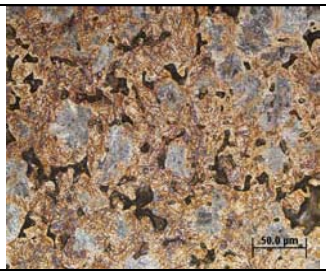
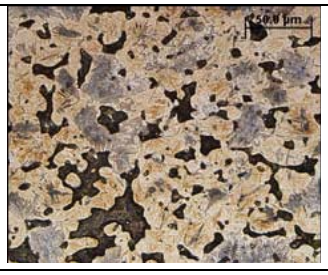
Slug Size (o.d. x height)	Slug Mass @ 6.80 g/cm^3 (g)	Surface Area to Mass @ 6.80 g/cm^3 (cm^2/g)
25 mm x 25 mm	84	0.35
50 mm x 50 mm	654	0.18
75 mm x 50 mm	1471	0.14

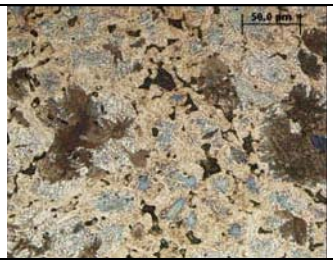
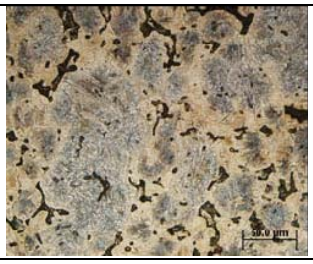
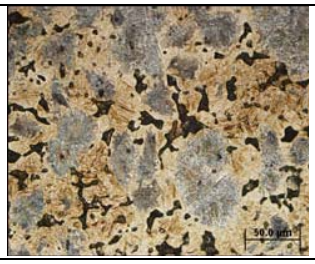
Table 5. FLC-5208 Slug Mass and Surface Area to Mass Ratio

Slug Size (O.D. x Height)	Slug Mass @ 7.20 g/cm^3 (g)	Surface Area to Mass @ 7.20 g/cm^3 (cm^2/g)
25 mm x 25 mm	89	0.33
50 mm x 50 mm	693	0.17
75 mm x 50 mm	1585	0.13

The 75mm x 50 mm slug is 17 times the mass of the smallest slug and 2.5 times the mass of the 50 mm x 50 mm slug. The largest slug has a surface to mass ratio that is 2.5x smaller than the 25 mm x 25 mm slug. It can be theorized that at the same Varicool setting, different cooling rates will be observed due to the difference in mass and surface to mass ratio between the slugs. Table 6 shows the microstructures and effective cooling rates of the FLC-5208 slugs at a density of 6.80 g/cm^3. The 25 mm x 25 mm slug at 0Hz exhibits a 60% martensitic / 40% bainitic microstructure. As the slug size increases, the amount of martensite decreases. At the largest slug, 40% martensite, 35% bainite and 25% fine pearlite are observed at 0Hz. As the Varicool speed is increased to 30 Hz, the amount of martensite found increased. The 75 mm x 50 mm slug showed approximately 60% martensite at 30Hz .

Table 6. Microstructure and Cooling Rate for FLC5208 @ 6.80 g/cm^3

Slug Size (O.D x Height)	Varicool = 0 Hz	Varicool = 15 Hz	Varicool = 30 Hz
25 mm x 25 mm			
	60% Martensite 40% Bainite Effective Cooling Rate 0.6°C/s	**80% Martensite 20%Bainite Effective Cooling Rate 0.8°C/s**	**97% Martensite 3% Bainite Effective Cooling Rate 1.0°C/s**
50 mm x 50 mm			
	50% Bainite 50% Martensite Effective Cooling Rate 0.5°C/s	**65% Martensite 35% Bainite Effective Cooling Rate 0.65°C/s**	**75% Martensite 25% Bainite Effective Cooling Rate 0.7°C/s**

75 mm x 50 mm			
	40% Martensite **35% Bainite / 25% Pearlite** **Effective Cooling Rate** **0.4°C/s**	**50% Martensite** **50% Bainite** **Effective Cooling Rate** **0.5°C/s**	**60% Martensite** **40% Bainite** **Effective Cooling Rate** **0.6°C/s**

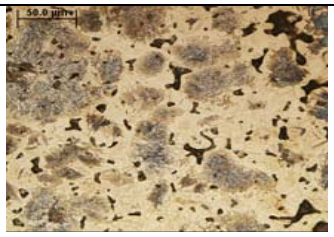
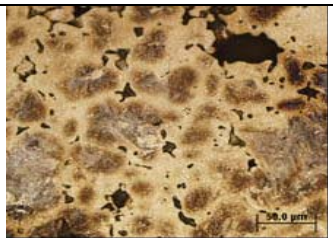
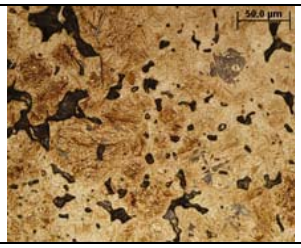
Apparent hardness results at 6.80 g/cm^3 for each of the slug sizes and Varicool setting are displayed in Table 7. The apparent hardness readings correspond to the microstructure of each slug.

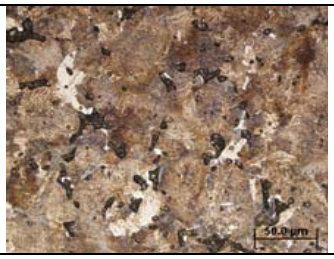
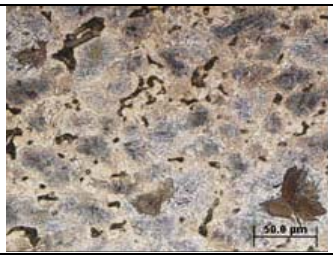
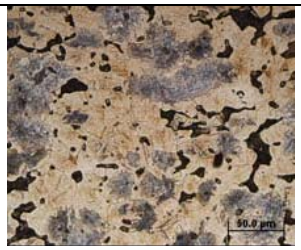
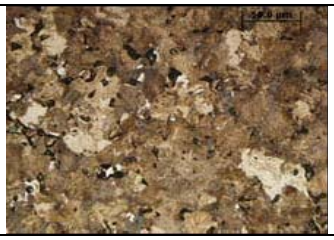
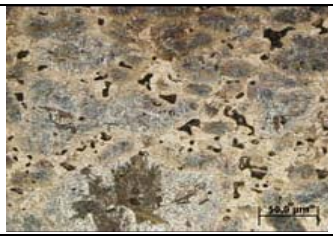
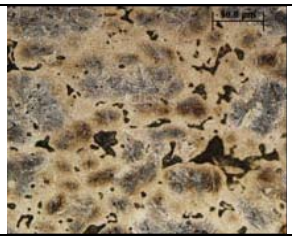
Table 7. FLC-5208 Apparent Hardness Results @ 6.80 g/cm^3

Slug Size (O.D. x Height)	**Varicool = 0Hz**	**Varicool = 15Hz**	**Varicool = 30Hz**
25 mm x 25 mm	96 HRB	31 HRC	33 HRC
50 mm x 50 mm	92 HRB	97 HRB	27 HRC
75 mm x 50 mm	85 HRB	95 HRB	24 HRC

Table 8 shows the microstructures and effective cooling rates of the FLC-5208 slugs at a density of 7.20 g/cm^3. The 25 mm x 25 mm slug at 0Hz exhibits a 60% martensitic / 40% bainitic microstructure. As the slug size increases, the amount of martensite decreases. At the largest slug size, 85% pearlite and 15% bainite is observed at 0Hz. As the Varicool speed is increased to 30 Hz, the amount of martensite found increased. The 75 mm x 50 mm slug showed about 65% martensite and 35% bainite at 30 Hz.

Table 8. Microstructure and Cooling Rate for FLC-5208 @ 7.20 g/cm^3

Slug Size (O.D x Height)	**Varicool = 0 Hz**	**Varicool = 15 Hz**	**Varicool = 30 Hz**
25 mm x 25 mm			
	60% Martensite **40% Bainite** **Effective Cooling Rate** **0.6°C/s**	**75% Martensite** **25% Bainite** **Effective Cooling Rate** **0.7°C/s**	**96% Martensite** **4% Bainite** **Effective Cooling Rate** **1.0°C/s**

50 mm x 50 mm			
	70% Pearlite **30% Bainite** **Effective Cooling Rate** **0.2°C/s**	**70% Bainite** **25% Martensite** **5% Pearlite** **Effective Cooling Rate** **0.3°C/s**	**70% Martensite** **30% Bainite** **Effective Cooling Rate** **0.7°C/s**
75 mm x 50 mm			
	85% Pearlite **15% Bainite** **Effective Cooling Rate** **0.15°C/s**	**75% Bainite** **15% Martensite** **10% Pearlite** **Effective Cooling Rate** **0.25°C/s**	**65% Martensite** **35% Bainite** **Effective Cooling Rate** **0.65°C/s**

Apparent hardness results at 7.20 g/cm^3 for each of the slug sizes and cooling rates are displayed in Table 9. The apparent hardness readings correspond to the microstructure of each slug.

Table 9. FLC-5208 Apparent Hardness Results @ 7.20 g/cm^3

Slug Size (O.D. x Height)	Varicool = 0Hz	Varicool = 15Hz	Varicool = 30Hz
25 mm x 25 mm	26 HRC	38 HRC	42 HRC
50 mm x 50 mm	96 HRB	33 HRC	35 HRC
75 mm x 50 mm	26 HRC	30 HRC	36 HRC

The results of the mechanical testing are shown in Figures 1 through 3. The cooling rates of the test specimens were determined to be 1.0°C/s and 2.5°C/s Microstructures of the test specimens at each cooling rate are shown on each of the graphs. At 2.5°C/s at 7.20 g/cm^3 at tensile strength over 1050MPa and an apparent hardness of 39 HRC were achieved.

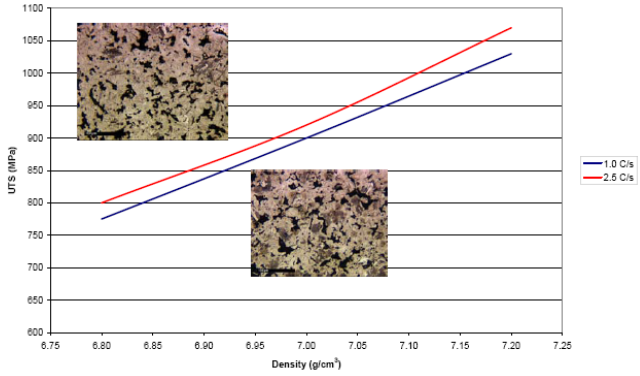


Figure 1. FLC-5208 Mechanical Property Results, UTS

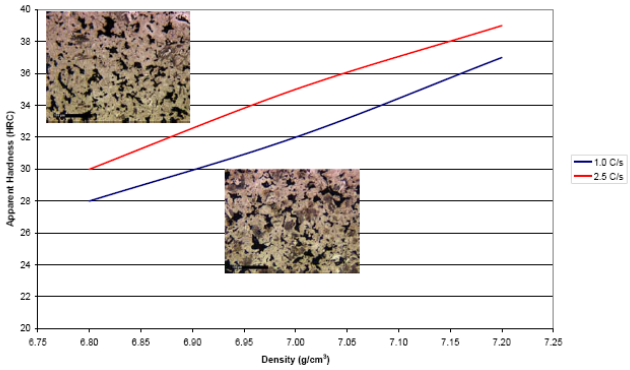


Figure 2. FLC-5208 Mechanical Property Results, Apparent Hardness

Conclusions

The size and surface area available strongly affect the cooling rate achieved during sinter hardening. Components with a large mass and small surface area to mass ratio did not achieved the same cooling rate as components with small mass and large surface area to mass ratio.

Density did not strongly affect the cooling rate. A cooling rate of 1.0°C/s was achieved at a Varicool setting of 30 Hz at 6.80 g/cm^3 and 7.20 g/cm^3.

The hardenability of FLC-5208 was in line with the Jominy hardness data found in MPIF Standard 35.

At a cooling rate of 2.5°C/s and a density of 7.20 g/cm^3, a UTS of 1070 MPa and an apparent hardness of 39 HRC were achieved.

References

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