

Higher Density and Higher Performance by Single Pressing and Sintering

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ABSTRACT

Further improvements were made in binder and lubricant technology that makes it possible to reach green densities approaching 7.4 g/cm³ in some applications, without the need to heat the iron powder or to double press and double sinter. The effect of die temperature and part length on ejection behavior and final properties will be studied. In addition, optimal processing parameters as well as mechanical data will be presented.

INTRODUCTION

The powder metal industry has experienced an average growth rate approaching 10% per year for the last decade¹. To maintain this growth in the PM industry requires the continuous development of new products, processes and technologies. One such development in compaction technology, that was introduced several years ago, involves the warm compaction of the iron powder to achieve higher densities. The ANCORDENSE* process, combined with highly compressible powders, provides the means to reach green densities in the range of 7.3 to 7.4 g/cm³. However this technology requires the heating of both the iron powder and the die to a temperature in the 270 to 290°F (132°C to 143°C) range. To eliminate the need to heat the iron powder but still reach a green density similar to ANCORDENSE, a new proprietary binder/lubricant system, AncorMax D was introduced, that yielded higher densities at die temperatures of 140°F to 160°F (60°C to 71°C)^{2,3}. This technology does not require the preheating of the iron powder. One major limitation to this system is a restriction of the overall length of the parts that can be processed. In general, the AncorMax D system is limited to parts with overall lengths less than or equal to 0.75 in (19 mm). To overcome this limitation a more refined lubricant system has been developed to improve the length capability of this high density system. This paper discusses the physical and mechanical properties of the refined system, that makes it possible to reach larger part lengths. This new AncorMaxD Mod system will be discussed in comparison to the standard AncorMax D.

* ANCORDENSE, AncorMax D, and Ancorsteel are registered trademarks of Hoeganaes Corporation.

EXPERIMENTAL PROCEDURES

Materials

The testing was carried out on FLN2-4405 premixes made with Ancorsteel 85HP, a base iron prealloyed with 0.85 w/o Mo, 0.6 w/o graphite (Asbury 3203) and 2.0 w/o nickel (INCO 123). Two versions were prepared using both proprietary AncorMaxD and AncorMaxD Mod binder/lubricant systems. The mixes were made as 500 lbs (227 kg) mixes with compositions listed in Table I.

TABLE I: Compositions of the Powders Evaluated

Designation	Base Material (w/o)		Elemental Additions (w/o)		
	Fe	Mo	Ni	Graphite	Lube & Binder
AncorMaxD	Balance	0.85	2.00	0.60	0.55
AncorMaxD Mod	Balance	0.85	2.00	0.60	0.55

Processing

A Tinius-Olsen hydraulic press was used for pressing the TRS bars and the tensile bars with a heated die that maintained temperature at $\pm 5^{\circ}\text{F}$ ($\pm 2.8^{\circ}\text{C}$). Compaction of test samples was performed between 40 tsi and 60 tsi (550 MPa and 830 MPa). After compaction the test specimens were sintered in a belt furnace at 2050°F (1120°C) for 30 minutes in an atmosphere of 90 v/o N_2 – 10 v/o H_2 . The parts were subsequently tempered at 400°F (204°C) for 1 hour in 100 v/o N_2 . A ToniTechnik hydraulic press was used to press cylinders with a diameter of 0.563 in (14.3 mm) at various lengths to compare the ejection properties of the two mixes. The die was preheated to 145°F (63°C) and the cylinders were compacted to 60 tsi (830 MPa). The ejection force was collected as a function of time with an ejection rate of 0.04 in/s (1.0 mm/s). The resulting force data was then normalized by dividing it by the surface area of the cylinder wall adjacent to the die surface (different for each part length). This results in pressure data that is largely dependent on the performance of the lubricant.

Testing

Green properties and static and dynamic ejection pressures were determined on test bars measuring 1.25 in (32 mm) x 0.5 in (13 mm) x 0.5 in (13 mm). Sintered properties were determined on TRS bars measuring 1.25 in (32 mm) x 0.5 in (13 mm) x 0.25 in (6 mm). Tensile properties were determined from flat, unmachined “dogbone” tensile bars according to ASTM E8 and MPIF Standard 10. Ejection pressure, measured continuously as a function of time, was determined on test cylinders 0.563 in (14.3 mm) in diameter, with heights of 0.3 in (8 mm), 0.5 in (13 mm), 0.8 in (20 mm) and 1.1 in (28 mm), respectively. As the height changes, the surface area of the part/die interface increases. This increases the ratio of the interface area to punch area. As this number goes up the demand on the lubricant increases.

RESULTS AND DISCUSSION

Ejection Measurements

The ejection testing was done at several part heights to examine the lubricant system's ability to maintain high density in taller parts while maintaining a good surface finish. Samples were pressed at a high compaction tonnage [60 tsi (830 MPa)] to gauge the ejection characteristics under an extreme condition. Figure 1 shows a comparison between the two binder/lubricant systems of how density changes with part length and the absolute density difference between each material. The Mod version achieves a slightly lower density than the standard, however, the drop off in density for both materials is 0.01-0.02 g/cm³. This is a very tight range considering the large change in fill length within the die from 0.3-1.1 in (8-28 mm).

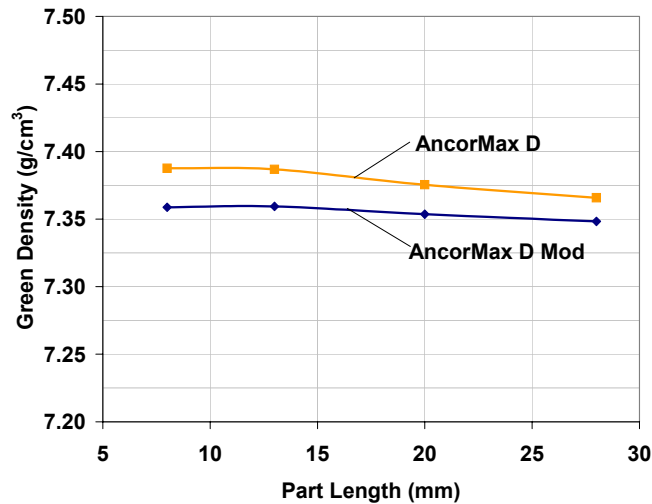
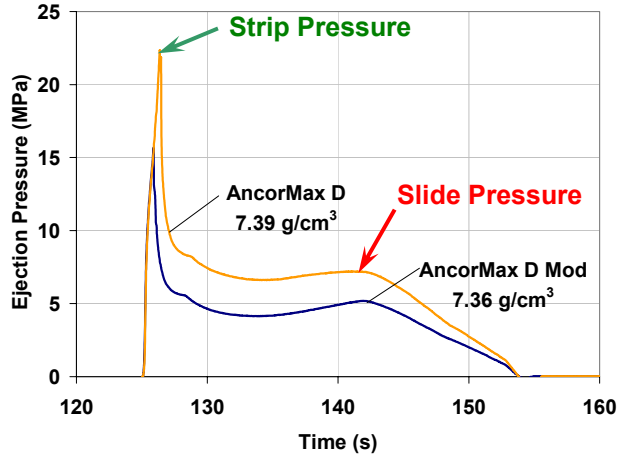


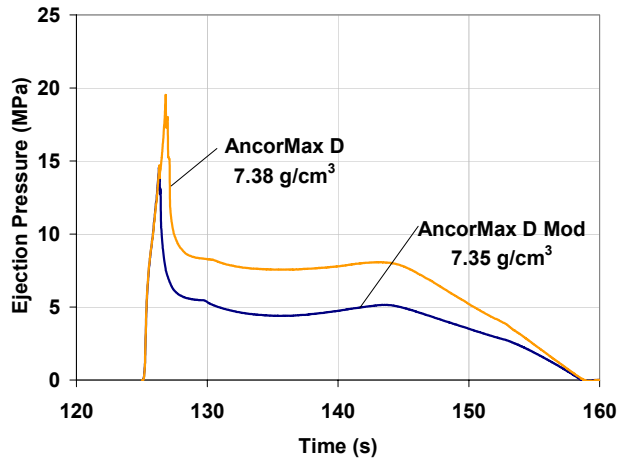
Figure 1: Effect of part length on the green density. Cylinders compacted to 60 tsi (830 MPa), die preheated to 145°F (63°C).

Figure 2 shows the ejection curves for slugs pressed to 60 tsi (830 MPa). Note that as the part length increases the ejection forces increase. However, the AncorMax D Mod exhibits a large improvement in ejection pressure over the standard version. This lowers the strip (break free pressure, see arrow in Figure 2a) and the sliding pressure (pressure as the part exits the die, see arrow in Figure 2b) by 30-40 %. Also noteworthy is the shape of the ejection curves, as this indicates how the lubricant is behaving. For instance, the lubricant is breaking down if the ejection pressure sharply rises as the sliding pressure is approached. A flat or decreasing curve is preferred, indicating good lubrication. A part free of scoring and laminations will have a flat ejection curve. Examining the curve shapes in Figure 2 shows that the ejection curves are fairly flat with only a slight rise as the sliding pressure is approached. This shape is consistent for both versions of the binder/lubricant system. The only indication that the lubricant is beginning to be strained is that the overall pressures rise as the part length increases (see Figure 2c).

a.) Part Length: 0.5 in (13 mm)



b.) Part Length: 0.8 in (20 mm)



c.) Part Length: 1.1 in (28 mm)

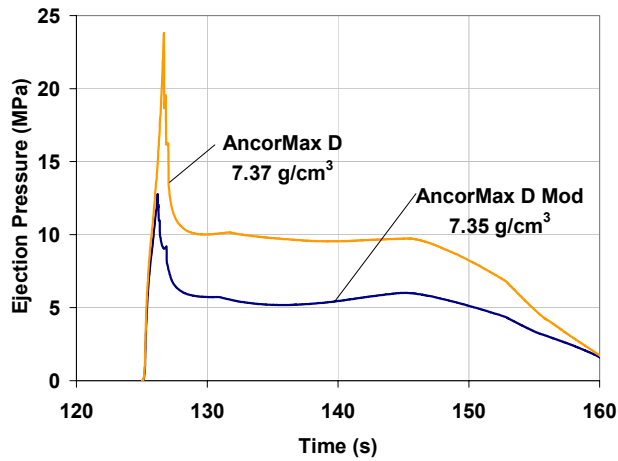


Figure 2: Ejection curves for slugs pressed to 60 tsi (830 M-a) at 145°F (63°C), a.) 0.5 in. (13 mm) long, 0.8 in (20 mm) long, and 1.1 in (28 mm) long.

Figure 3 shows a photograph of the green slugs. The AncorMax D Mod slugs are slightly more reflective than the standard material. This indicates that the level of fine score marks is lower due to the improved lubricity. This improved surface finish is beneficial and can be translated into taller part lengths with high densities.



Figure 3: Photograph of FLN2-4405 green slugs.

Compact Properties

Figure 4a shows a compressibility curve for FLN2-4405 pressed at 145°F (63°C). At the higher compaction pressures the Mod version results in a slightly lower green density. This indicates that some high density performance is sacrificed for taller components and the binder/lubricant system should be chosen for the particular application. The impact of compaction temperature on the density is shown in Figure 4b. This shows that the die temperature must be held in a tight range to ensure the maximum density benefit. Also note the density decreases as the range is exceeded. The shaded area is the recommended temperature range for both versions of this binder/lubricant system.

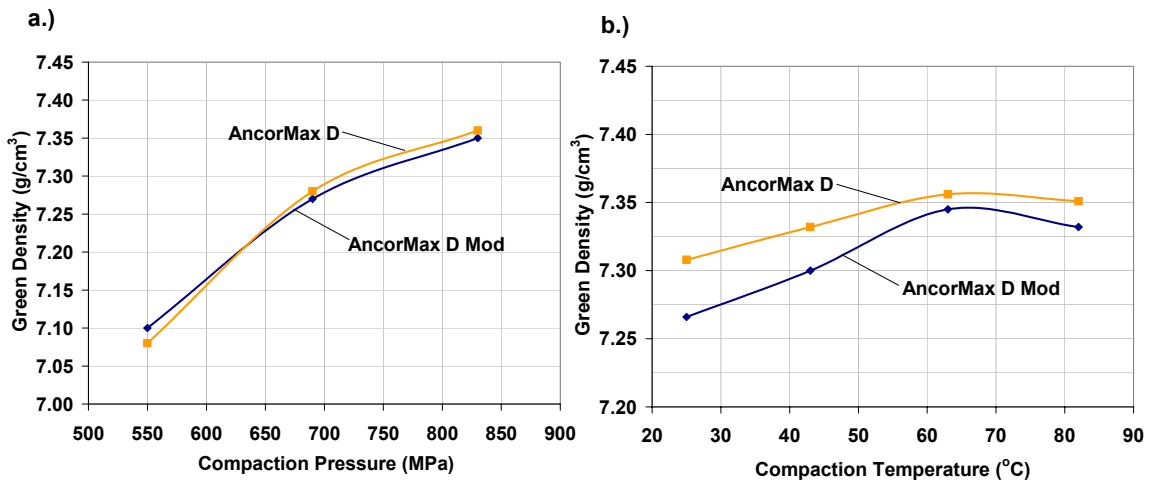


Figure 4: a.) Compressibility of FLN2-4405 pressed at 145°F (63°C) and b.) effect of die temperature on the density of FLN2-4405 pressed at 60 tsi (830 MPa).

Another important aspect to consider when adjusting the lubricant system is the part performance. It is important to ensure that the high density lubricant does not degrade the properties. Table II and Table III summarize the green and sintered properties for both systems. Aside from the differences in ejection pressures discussed above the only other notable difference is the reduction of green strength for the Mod version. All other parameters including TRS and hardness are consistent with the standard version. The dimensional change is also consistent for both systems.

Over the range of densities tested, the Mod version exhibits strip and sliding pressures that are consistent as compaction pressure increases. This is beneficial for producing higher density parts without breaking down the lubricant.

TABLE II: Green Properties of the Powders Evaluated

Pressure		Green Density (g/cm ³)	Green Strength		Green Expansion (%)	Strip		Slide	
(tsi)	(MPa)		(psi)	(MPa)		(psi)	(MPa)	(psi)	(MPa)
AncorMax D Mod Room Temperature									
40	550	7.02	1106	7.6	0.19	3125	21.6	1617	11.2
50	690	7.18	1318	9.1	0.21	3376	23.3	1609	11.1
60	830	7.27	1482	10.2	0.24	3428	23.6	1542	10.6
AncorMax D Room Temperature									
40	550	7.04	1087	7.5	0.16	3355	23.1	1993	13.7
50	690	7.21	1348	9.3	0.18	3632	25.0	2262	15.6
60	830	7.31	1528	10.5	0.22	3938	27.2	2594	17.9
AncorMax D Mod 145°F (63°C)									
40	550	7.10	1558	10.7	0.15	3255	22.4	1565	10.8
50	690	7.27	1872	12.9	0.17	3325	22.9	1372	9.5
60	830	7.35	1869	12.9	0.21	3345	23.1	1210	8.3
AncorMax D 145°F (63°C)									
40	550	7.08	1757	12.1	0.15	3908	27.0	2112	14.6
50	690	7.27	2294	15.8	0.19	4463	30.8	2520	17.4
60	830	7.36	2270	15.7	0.28	4274	29.5	2473	17.1

TABLE III: Sintered Properties of the Powders Evaluated
(Sintered at 2050°F (1120°C) in 90 v/o N₂ – 10 v/o H₂)

Pressure		Sintered Density (g/cm ³)	D.C. (%)	TRS		Hardness (HRA)	UTS		0.20% Yield Strength		Elongation (%)
(tsi)	(MPa)			(ksi)	(MPa)		(ksi)	(MPa)	(ksi)	(MPa)	
AncorMax D Mod Room Temperature											
40	550	7.06	-0.03	180	1244	53	Not Evaluated				
50	690	7.22	0.01	204	1405	55					
60	830	7.31	0.03	221	1525	56					
AncorMax D Room Temperature											
40	550	7.06	-0.04	185	1278	53	Not Evaluated				
50	690	7.25	0.00	208	1432	56					
60	830	7.34	0.03	226	1562	57					
AncorMax D Mod 145°F (63°C)											
40	550	7.14	-0.05	196	1349	53	97	666	69	476	2.24
50	690	7.29	-0.02	216	1491	56	104	717	73	503	2.72
60	830	7.37	0.02	229	1577	57	106	731	75	517	2.36
AncorMax D 145°F (63°C)											
40	550	7.14	-0.06	189	1305	53	96	662	69	476	2.32
50	690	7.31	-0.01	223	1539	56	106	731	73	503	3.14
60	830	7.4	0.02	239	1646	57	109	752	75	517	3.08

CONCLUSIONS

1. The improved binder/lubricant system provides 30-50% lower ejection pressure than the standard AncorMax D, thus making it possible to press taller parts to high density in a single press and single sinter process.
2. The ejection pressures were constant as compaction pressure increased when the Mod version was used, especially near the recommended processing temperature of 145°F (63°C).
3. Increasing the die temperature from room temperature to 145°F (63°C) at the same compaction pressure resulted in an increase in green density, however there was no further increase in density when the die temperature was raised to 180°F (82°C).
4. The as-sintered mechanical properties were consistent for both systems.

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