

# SINGLE COMPACTION TO ACHIEVE HIGH DENSITY IN FERROUS P/M MATERIALS IN AUTOMOTIVE APPLICATIONS

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## ABSTRACT

The continued growth of ferrous powder metallurgy in automotive applications is dependent on the development of higher density and improved dynamic properties. New powder metallurgy applications also must be cost effective through the continued use of the process's, net shape forming capabilities and a reduced number of manufacturing steps. The processes utilized to manufacture some of these new parts also must provide the ability to produce thin walled parts with complex geometries.

The use of the warm compaction process (ANCORDENSE™) will be shown to develop high density levels with a single compaction process. The process also provides increased green strength and reduced ejection forces. The dependence of mechanical properties on density will be demonstrated.

An example of a potential application of the warm compaction technology is an output shaft. The capability of manufacturing this part with the warm compaction process is outlined and compared with the same part made by the double press/double sinter (DPDS) process. Part density and performance from both processes are compared.

## INTRODUCTION

The North American ferrous powder metallurgy industry has shown steady growth in the past several decades. Continued growth is partly dependent on the ability to provide both higher performing and cost competitive parts. Recent developments in both materials and processes provides the powder metallurgy process additional flexibility to meet these challenges.

The manufacture of parts with higher density levels is an established method for improving the performance of ferrous powder metallurgy parts. The use of the double press and double sintering process (DPDS) is an accepted method for providing higher density parts. In this process, a low temperature pre-sinter and a re-press step are performed between the first compaction and final sintering steps. The pre-sintering step, if performed correctly, allows the internal lubricant to be removed prior to putting the graphite into solution. Thus, the pre-sinter creates more porosity that can be eliminated during the second compaction step. Beyond the fact that DPDS adds two

extra steps to the part manufacturing process, complex part shapes, such as helical gears and complicated multilevel parts, present difficulty in the secondary compaction step.

The ANCORDENSE system, providing both a material and compaction process, allows the production of high density ferrous powder metallurgy parts via a single compaction process. The system utilizes heated tooling and powder during the compaction step. The powder and tools typically are heated between 130° and 150°C (260° and 300°F). In order for the premix to perform at these elevated temperatures, a highly engineered lubricant system has been developed that provides lower ejection forces than conventional lubricants. This new system also incorporates a binder system to limit segregation and provide the enhanced flow characteristics of the press-ready premix. By utilizing the ANCORDENSE system, the green density of the part can be increased from 0.10 to 0.25 g/cm<sup>3</sup> over traditionally processed materials. The green strength of the part typically is increased between 50 to 100 percent. This increase in green strength provides advantages such as the obvious reduction in green chipping and cracking due to handling prior to sintering and may make possible the crack-free compaction of complex multilevel parts. Additionally, the higher green strength may provide the opportunity to machine the P/M part in the green state. This capability may prove critical in the use of high performance alloy systems that achieve high hardness in the as-sintered state.

The following study was performed in two sections. The first section will evaluate the effect of density on as-sintered and heat treated properties of an FN-0205 premix processed by warm compaction. A direct comparison of ANCORDENSE and DPDS will then be undertaken utilizing an output shaft hub for the evaluation.

#### THE EFFECT OF DENSITY ON MECHANICAL PROPERTIES

An evaluation of an FN-0205 premix was performed. A binder-treated premix with the composition listed in Table I was prepared utilizing the ANCORDENSE lubricant system. It should be noted that the efficiency of the lubricant allows the addition level to be held at 0.60 w/o for most part applications. This lowering of the lubricant from traditional levels (0.75 w/o) allows for even further green density improvement with the warm compaction technology.

Table I: Premix Chemistry Utilized in Testing

Base Material	Ni w/o	Graphite w/o	Lubricant-ANCORDENSE w/o
Ancorsteel 1000B	2.0	0.60	0.60

The premix was tested for apparent density and flow properties. Since the premix is designed to operate at elevated temperatures, the powder properties were evaluated using a heated Hall flowmeter and cup. Both the powder and the testing apparatus were heated to 145°C (290°F) prior to testing. The apparent density of the premix was 2.93 g/cm<sup>3</sup> and the flow was determined to be 29 s/5Og. These results indicate the

ability of the binder system to provide excellent flow properties even at the elevated temperatures.

The premix was then compacted into test specimens at various pressures at a temperature of 145°C (290° F). The green and sintered densities were determined utilizing a 31.75mm x 12.7mm (1.25 inch x 0.5 inch) bar compacted to 12.7mm (0.5 inch) high for the green density and 6.35mm (0.25 inch) high for the sintered bars. The sintered density values were determined following sintering at 1120°C (2050°F) and 1260°C (2300°F) for 30 minutes at temperature in a 75 v/o H<sub>2</sub>5 v/o N<sub>2</sub> atmosphere. Figure 1 indicates the density results:

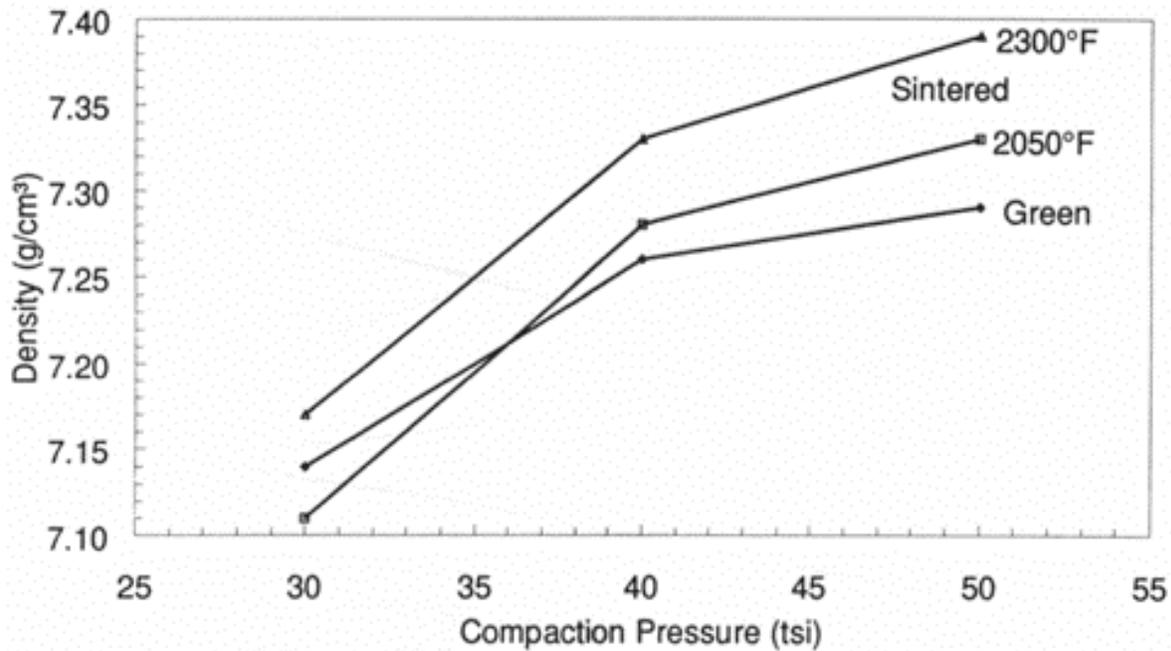


Figure 1: Green and Sintered Density of the FN-0205 Premix Compacted at 145°C (290°F)

Green and sintered properties were developed for the materials including green strength, transverse rupture strength and apparent hardness. The results are shown in Table II.

Table II: Green and As-Sintered Properties

Compaction Pressure (Mpa/tsi)	Green Density (g/cm <sup>3</sup> )	Sintered 1120°C (2050°F)			Sintered 1260°C (2300°F)		
		Sintered Density (g/cm <sup>3</sup> )	TRS (Mpa/10 <sup>3</sup> psi)	HRB	Sintered Density (g/cm <sup>3</sup> )	TRS (Mpa/10 <sup>3</sup> psi)	HRB
415/30	7.14	7.11	867/124	71	7.17	883/128	69
550/40	7.26	7.28	1020/148	75	7.33	1016/148	73

690/50	7.29	7.33	1093/159	77	7.39	1076/156	76
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Un-notched Charpy impact specimens and large blanks, 88.9mm x 11.43mm x 11.43mm (3.5" x 0.45" x 0.45"), were warm compacted at several pressures. The samples were divided into two groups with one group sintered at 1120°C (2050°F) and the second group at 1260°C (2300°F) in a 75 v/o H<sub>2</sub>5 v/o N<sub>2</sub> atmosphere for thirty minutes at temperature. The blanks were machined into threaded tensile specimens and all of the test specimens were heat treated. Heat treatment was performed as follows:

Austenitize: 870°C/1600°F in Endothermic Atmosphere for 30 Minutes

Oil Quench: 75°C/165°F Oil

Temper: 175°C/350°F in Air for Two Hours

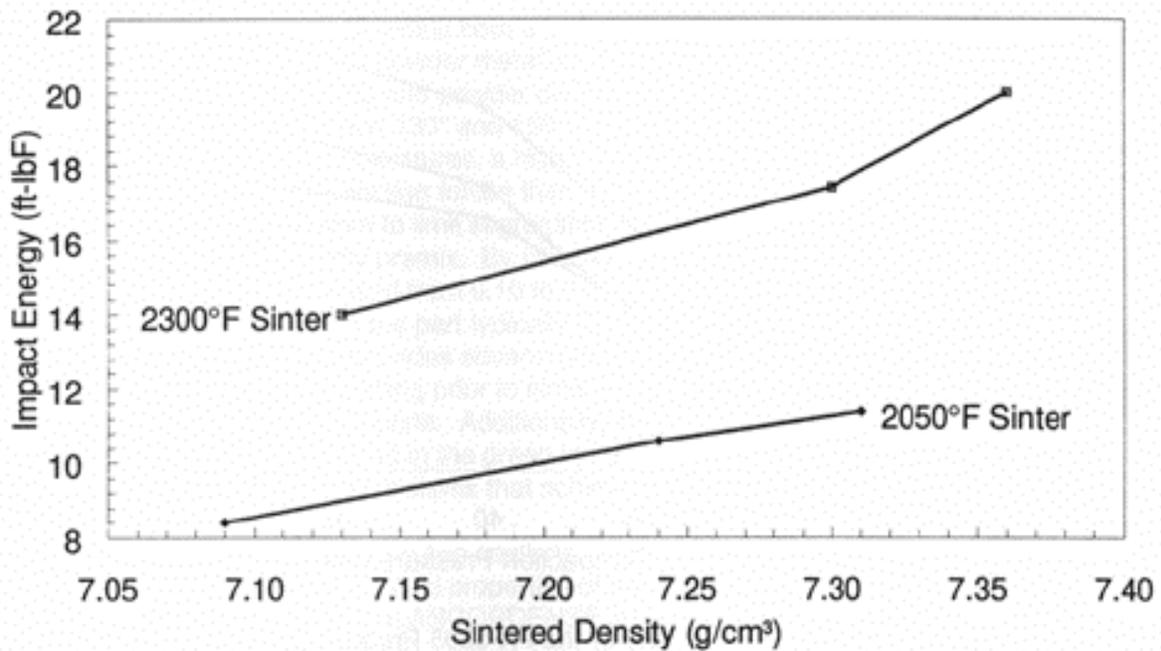


Figure 2: The Effect of Density on the Impact Properties of Warm Compacted FN-0205

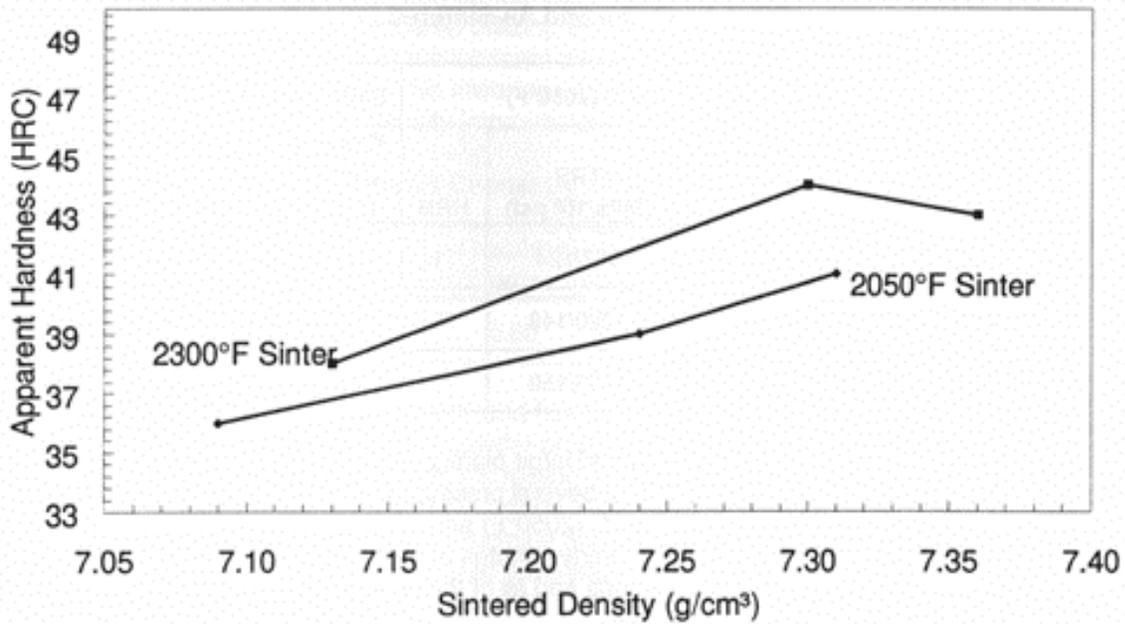


Figure 3: The effect of Density on Heat Treated Apparent Hardness of Warm Compacted FN-0205

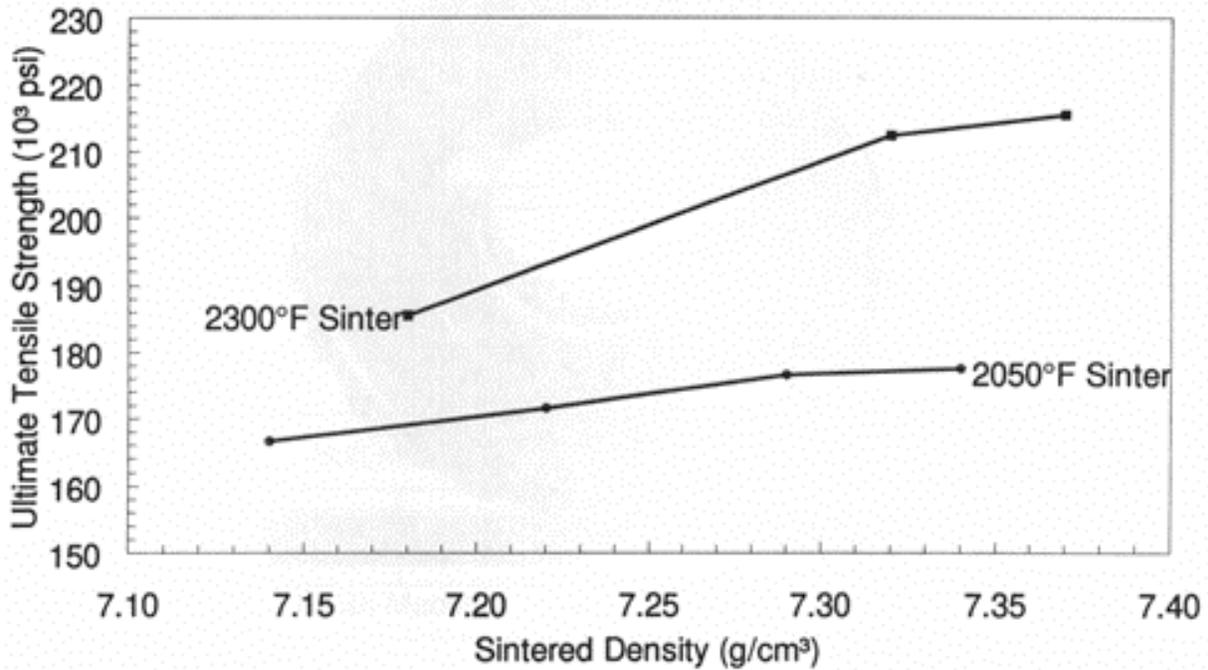


Figure 4: The Effect of Density on Heat Treated Ultimate Tensile Strength of Warm Compacted FN-0205

The results indicate that all three properties are increased significantly with the higher

density resulting from the combination of warm compaction and increasing compaction pressure. At the lower sintering temperature, the increase in density of about  $0.2 \text{ g/cm}^3$  results in an improvement of 6.5% in ultimate tensile strength while also increasing impact resistance over 35%. At the higher sintering temperature, a similar increase in density results in an improvement in ultimate tensile strength of over 15% while the impact properties are increased by over 40%. The data indicates also that the elevated temperature sintering resulted in a significant increase in performance for this composition. The improvement in strength with sintering temperature is most likely the result of a more complete diffusion of nickel into the iron matrix. The increase in impact properties is influenced also by pore refinement as a result of the elevated sintering temperature.

## PART TRIALS

A trial was performed to evaluate whether an ANCORDENSE-processed part could be substituted for the same part manufactured by a DPDS route. The part selected for this evaluation was an output shaft hub (Figure 5) that is currently in production utilizing the DPDS process. This part is utilized in transmissions for full size rear-wheel drive vehicles where it transfers power directly to the output drive shaft. A radial crush load of 18.4 kN (4150 lbf) and an axial crush load of 43.1 kN (9700 lbf) are specified to ensure structural integrity. The composition of the premix utilized in the manufacture of this part is listed in Table III.

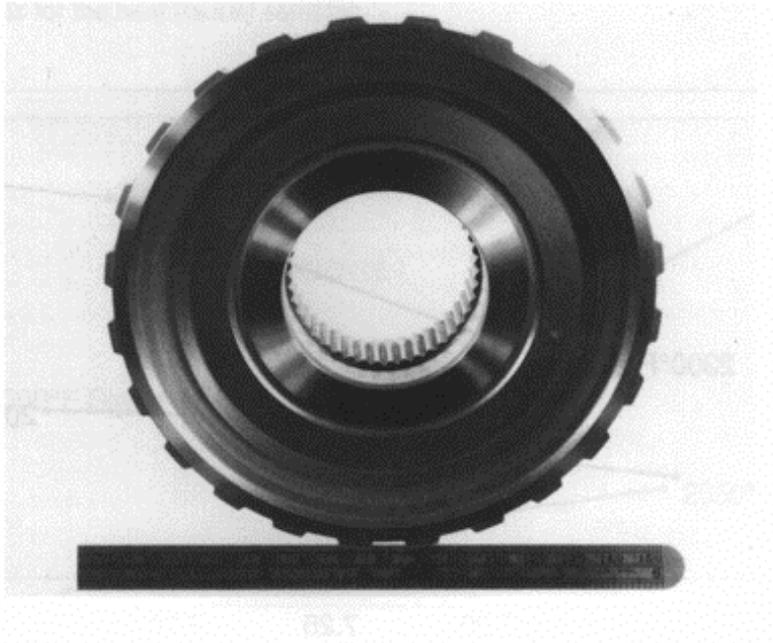


Figure 5: The Transmission Output Shaft Hub

Table III: The Premix Composition Utilized in the Manufacture of the Output Shaft Hub

Base Material	Ni w/o	Graphite w/o	Lubricant-ANCORDENSE w/o	Lubricant-DPDS w/o
Fe	2.5	0.60	0.55	0.75

A comparison between the processing steps of the ANCORDENSE and DPDS processes is given below (Figure 6). The samples produced via the ANCORDENSE process were compared with randomly selected DPDS-processed parts currently in production in terms of density, strength and microstructure. Wherever possible, post-compaction processing of both sets of parts were performed using essentially the same process. Both groups of parts were sintered at a temperature of 1120°C (2050°F) with the parts at temperature for approximately 12 minutes. The parts processed by each method were, however, sintered on different sintering furnaces. As the ANCORDENSE processing represented an initial trial, the experience with dimensional control was limited and therefore some dimensions were slightly out of tolerance prior to the sizing operation. These different dimensions required some modifications to the sizing operation to obtain acceptable finished dimensions. Despite these problems, the ANCORDENSE parts still were manufactured within size specification. Beyond these two differences, the ANCORDENSE sample parts were processed along with normal DPDS production parts. The mass of the component was 775 grams and the ANCORDENSE processed parts indicated a six sigma mass variation of 1.2 % ( $\pm 0.6$  %). This result compares well with the historic results for the DPDS process.

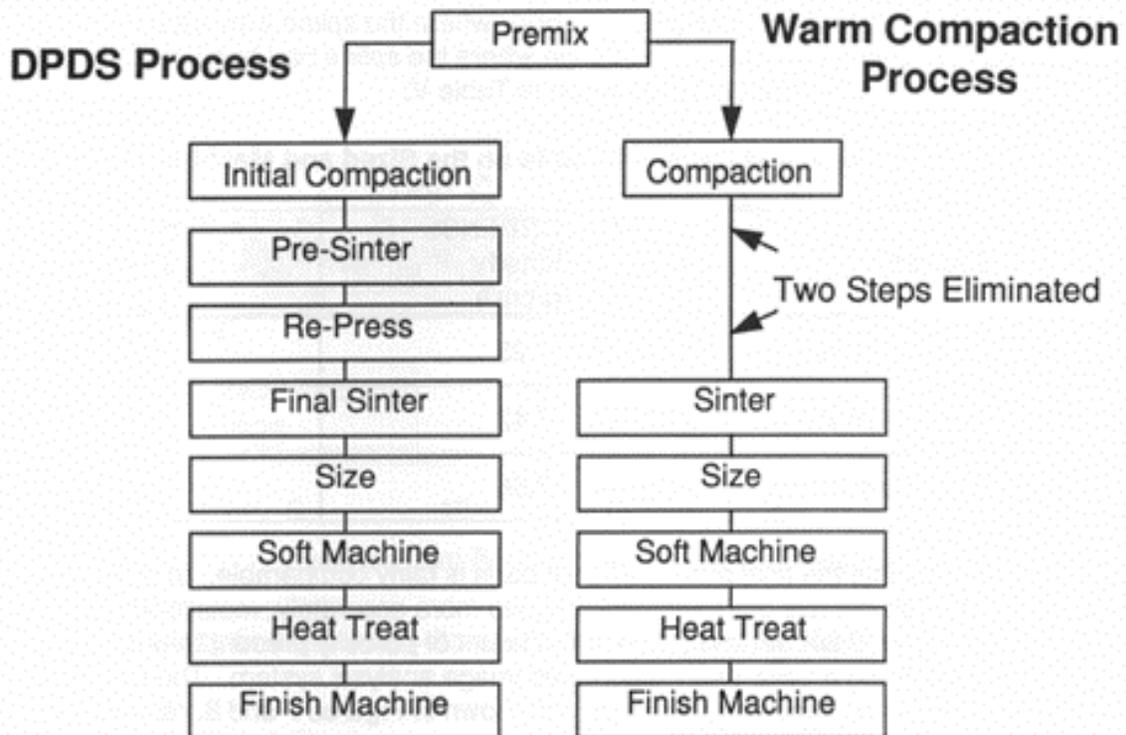


Figure 6: A Comparison of DPDS and ANCORDERSE Manufacturing Processes for the Output Shaft Hub  
 PART RESULTS  
 Sintered Density

Sintered density results prior to the sizing step (after final sintering) for various sections are shown in Table IV. The ANCORDERSE parts had a significantly higher density on the flange sections, whereas the density distribution is slightly more uniform in the boss section for the DPDS part. The overall density of the output shaft hub from both processing routes was in excess of 7.3 g/cm<sup>3</sup>.

Table IV: Sectional Density Results

Section	ANCORDERSE Density (g/cm <sup>3</sup> )	Typical DPDS Density (g/cm <sup>3</sup> )
OD of Flange	7.24	6.99
ID of Flange	7.15	7.09
Top of Boss (Adjacent to the Flange)	7.30	7.32
Middle of Boss	7.22	7.30
Bottom of Boss	7.33	7.35

Following sizing and machining, the density of the parts was re-checked. Three density measurements were made; the bottom of the boss where the spline was left unmachined, the top of the boss to immediately below the flange where the spline had been machined away, and

Table V: Sectional Density Results on the Sized and Machined Parts

Section	ANCORDERSE Density (g/cm <sup>3</sup> )	Typical DPDS Density (g/cm <sup>3</sup> )
Top Boss (Machined)	7.28	7.33
Bottom Boss (Spline)	7.42	7.42
Overall Part	7.36	7.39

The data indicates that the final density of both parts is fairly comparable. In order to define the differences between the two processing techniques more accurately, metallographic sections of the part were prepared and an analysis of the amount of porosity present throughout the part was performed utilizing a Leitz TAS+ automated image analysis system. The results for the sections taken from the flange and the boss are shown in Figures 7 and 8, respectively.

The data indicates that the area near the inside diameter of the flange sections contain about the same level of density. At the section closest to the OD of the flange, the

ANCORDENSE part contains a lower amount of porosity (higher density) than the DPDS part. The variation in the porosity level in the boss sections is slightly higher in the ANCORDENSE part compared to the DPDS part. The density split is slightly more noticeable in the ANCORDENSE part. The ANCORDENSE part indicates higher porosity at the mid-height of the part and lower porosity at the top of the part compared to the DPDS part.

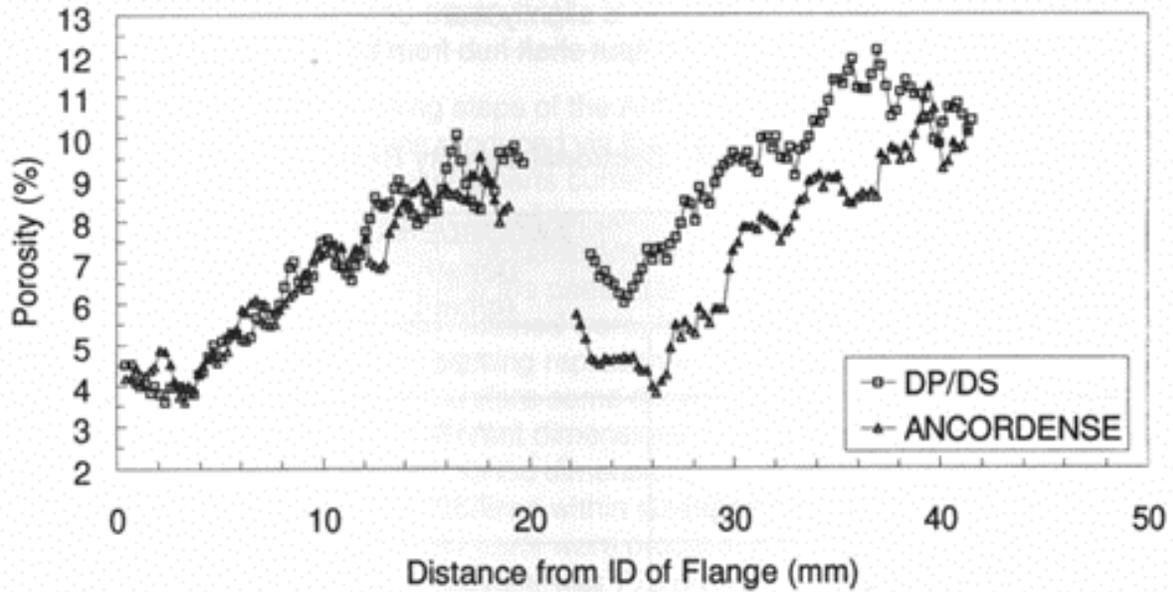


Figure 7: Porosity in Flange Area-Comparison of Processing Routes Figure

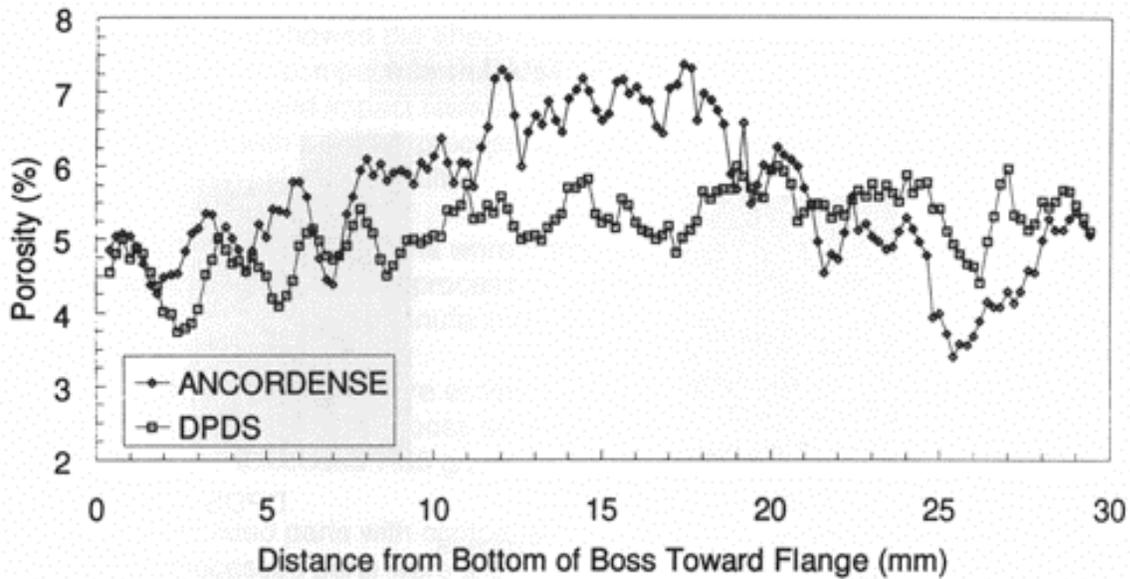


Figure 8: Porosity in Boss Area--Comparison of Processing Routes

## Radial and Axial Crush Testing

Figures 9 and 10 illustrate the radial crush load and the axial crush load, respectively, for three parts made from each of the two processes. The figures illustrate that for this set of tests, the DPDS results are slightly higher than the results for the ANCORDERSE-processed materials. Both processes provide results that were well within historical statistical variation for output shaft hub processed by the existing processing method. Results for both radial and axial crush are approximately twice the part specification for both processing techniques. The part also requires a minimum hardness of 78 HR15N. The ANCORDERSE and DPDS parts tested with an average hardness of 84.5 and 83.5 HR15N, respectively.

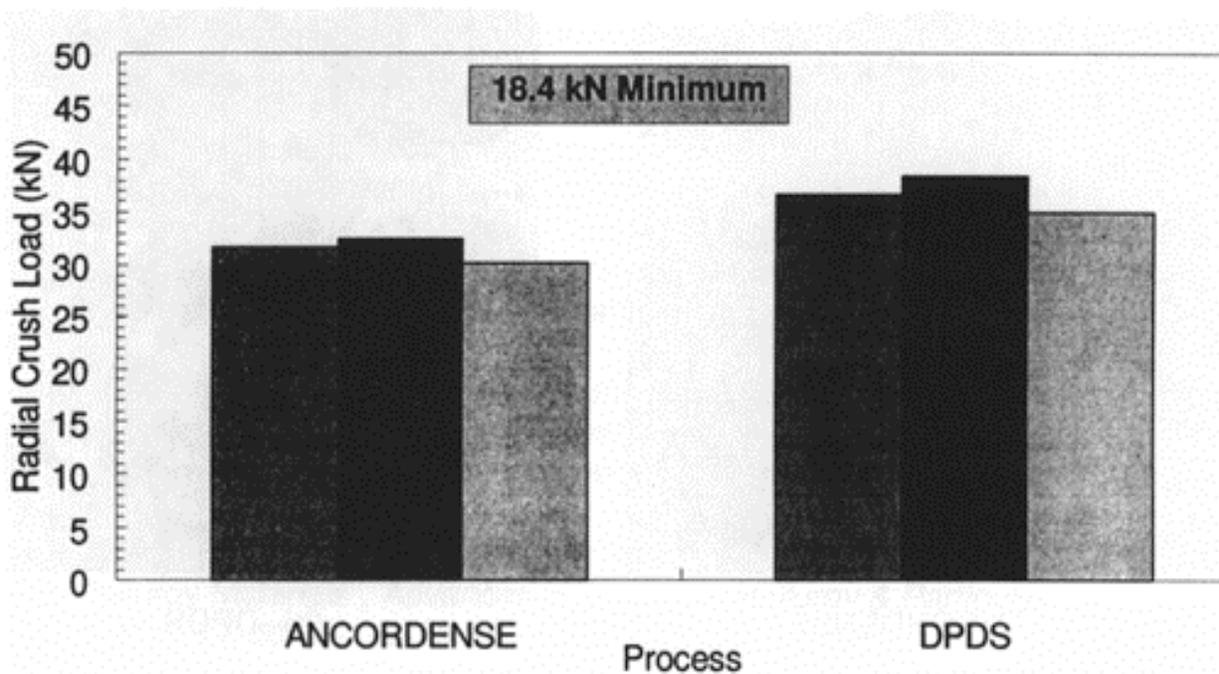


Figure 9: Radial Crush Load

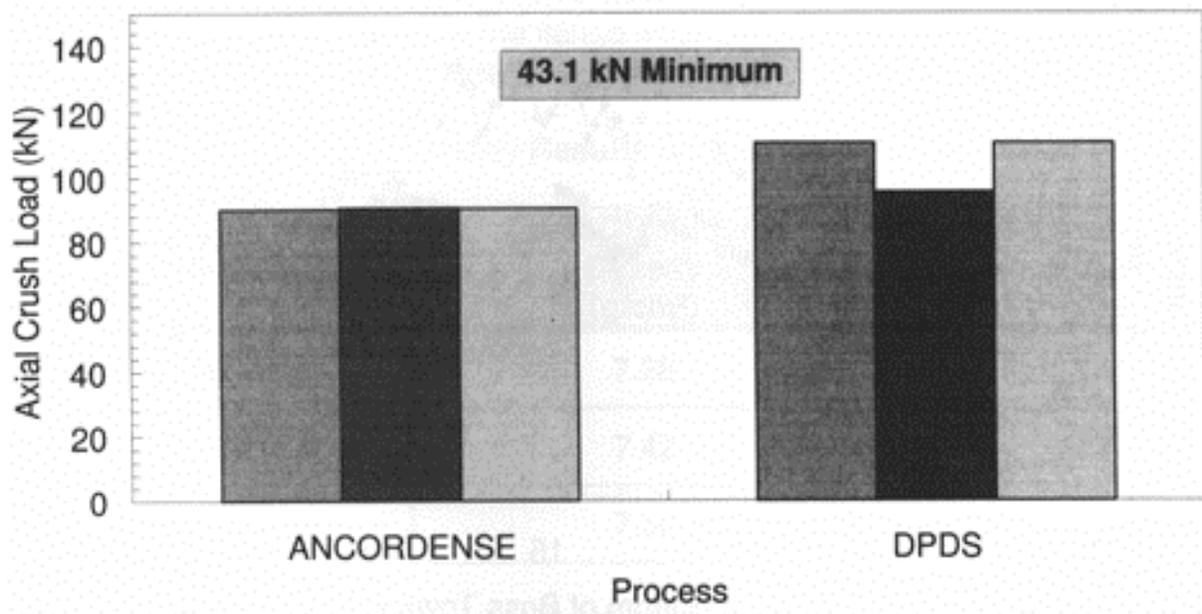


Figure 10: Axial Crush Load

#### Microstructural Examination

The ANCORDERNSE- and DPDS-processed parts were sectioned, prepared and examined utilizing optical metallography. Sections were prepared from the flange, the upper boss, the lower boss and the spline teeth in the lower boss. Figure 11 shows photomicrographs at 500X taken of the spline teeth etched with 2% nital. An analysis indicates that both processing techniques resulted in a similar case of martensite and unresolved pearlite measuring about 1.2 mm at the tip of the teeth on the spline. The martensite hardness in this area was determined to be 899 DPN. The results from other sections of both parts indicate that the microstructure for the majority of the part is similar and consists predominantly of fine pearlite with Ni-rich islands of austenite or martensite. There was also some martensite formation in the structure toward the OD of the flange where the cooling rate was faster.

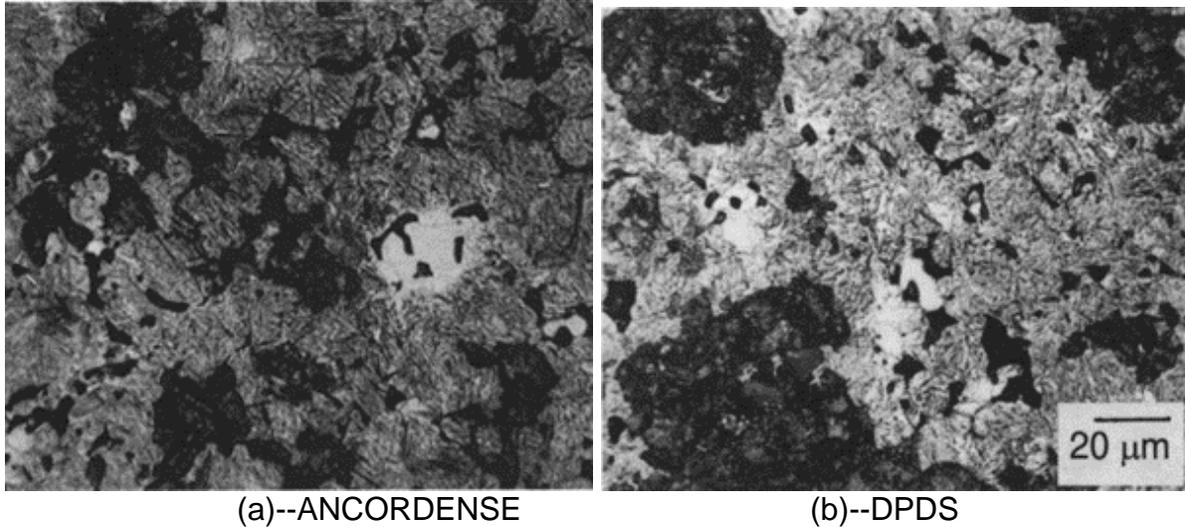


Figure 11: Microstructures of the Spline Teeth of the ANCORDENSE and DPDS Processed Part (Original Photographs at 500X, 2% Nital Etch)

## CONCLUSIONS

A study was presented that showed the effect of density on mechanical properties of an FN-0205 premix. The warm compaction process resulted in achieving high density levels which provided excellent strength and impact resistance. A comparison was made between output shaft hubs manufactured with a DPDS process and a warm compaction process (ANCORDENSE) with the following results:

1. The ANCORDENSE-processed parts were manufactured without the pre-sinter and repress steps required for the DPDS process. By eliminating these steps, a potential cost savings could be realized in the manufacture of this part.
2. The density levels of both parts were essentially the same with the DPDS part showing slightly higher density in the upper boss section. The overall, sized and heat treated, density for both parts exceeded  $7.35 \text{ g/cm}^3$ .
3. Both processes provided parts with comparable performance, although the ANCORDENSE-processed parts were slightly lower in strength compared with the DPDS parts. The variation in strength of both parts was well within the historic statistical variation in properties. Additional ANCORDENSE trials will be required to establish the variability of the new process. The performance of the parts produced by both processes far exceeded the part specifications.

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