

PROPERTIES OF HIGH DENSITY FERROUS P/M MATERIALS
A STUDY OF VARIOUS PROCESSES

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ABSTRACT

Several methods of achieving higher density in ferrous P/M parts are possible. Double press/double sinter allows densities in excess of 7.3 g/cm^3 but is limited by cost and geometry considerations. A new method of single processing high performance materials is evaluated and compared to other methods of processing. The comparison is performed utilizing Ancorsteel 85HP and Distaloy 4800A base materials. Various green and sintered properties are evaluated including; green strength, transverse rupture strength, tensile properties and impact values.

The data clearly demonstrates that the patented (1) ANCORDENSE™* process offers performance comparable to double press/double sinter processing. Green density values of approximately 98.5% of the pore free density limit are achieved with a single compaction step.

INTRODUCTION

The ANCORDENSE process is a patented powder premixing and compaction technology that enables the production of powder metallurgy parts by single press and single sinter operations to densities of approximately 7.4 g/cm^3 . The ANCORDENSE premixes are a derivative of the ANCORBOND®** process (2), thus insuring good flowability and segregation resistance. The ANCORDENSE process utilizes traditional powder metallurgy compaction equipment but requires that the powder and tooling be heated to moderate temperatures in order to achieve high as-compacted densities. The ANCORDENSE process is represented schematically in Figure 1. The press ready powder is heated to a temperature in the range of 265°F to 310°F prior to compaction. It is recommended that the powder temperature be controlled to a maximum variation of $\pm 5^\circ\text{F}$ to insure minimum part to part variability. The ANCORDENSE process utilizes a highly engineered lubricant system to optimize

performance within this temperature range.

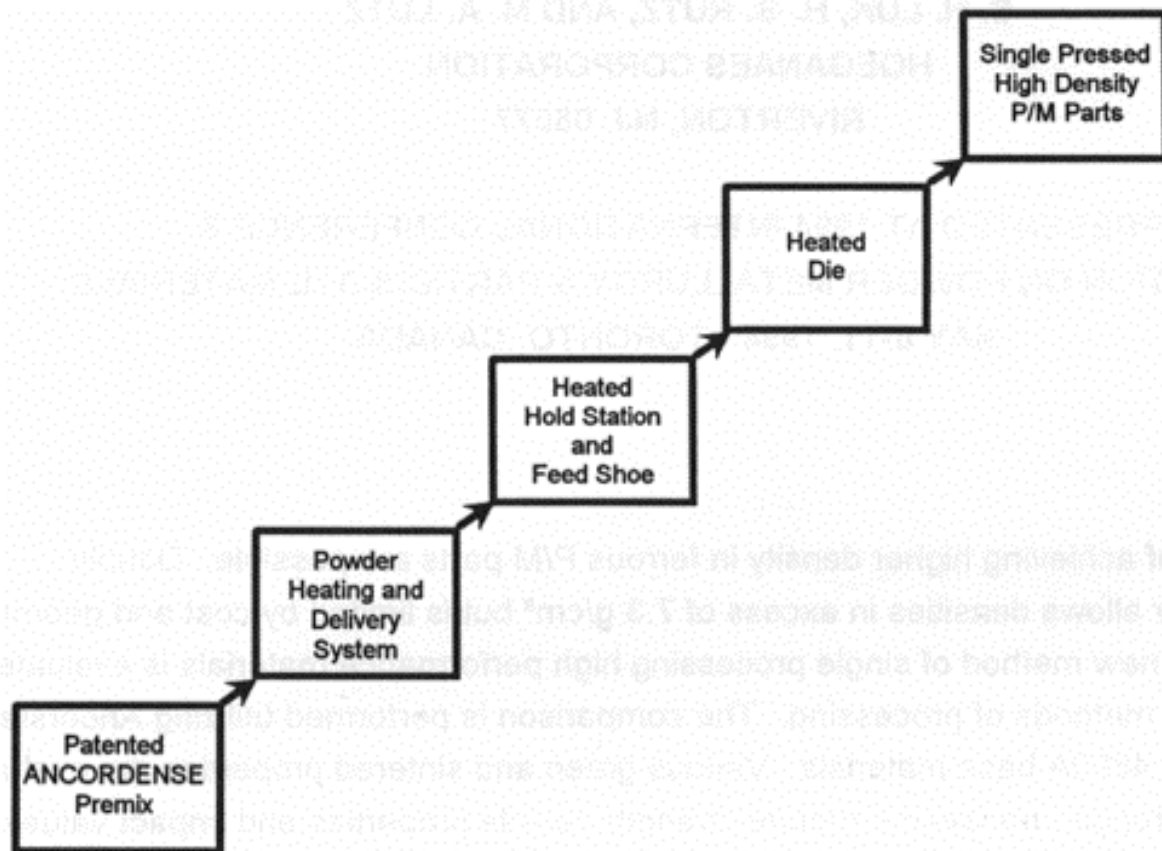


Figure 1: The ANCORDENSE Process

Following heating, the powder is held in a storage container that provides powder to the shuttle. The die, top punch and any large core rod assemblies are heated to the same temperature as the powder. The warm powder is fed into the heated die and compaction proceeds as in normal powder metallurgy processing to provide high density/high performance components. Rutz and Hanejko (3) offer a more detailed description of the compaction process. The ANCORDENSE process has been proven to be capable of commercial production of high performance powder metallurgy parts.

This paper will document various properties obtained by the ANCORDENSE process and compare these results to conventional single and double compaction processes. Two high performance Ancorsteel®*** based premix compositions were chosen for evaluation. Test specimens were prepared and evaluated according to standard procedures (4) for green density, green strength, sintered TRS, sintered tensile and sintered Charpy impact properties. Additionally, data was collected to evaluate the effect of the ANCORDENSE process on dimensional change and ejection characteristics.

PROCEDURE

Two premix compositions were prepared using both the ANCORDENSE process and conventional premix methods. The ANCORDENSE process utilized the newly developed lubricant system while the conventional premix utilized Acrawax as the lubricant. Typical base material chemistries and specific premix additions are listed in Table I.

Table I. Premix Compositions Evaluated

Base Powder	Base Material			Premix Additions		
	Ni (Wt.%)	Cu (Wt.%)	Mo (Wt.%)	Ni (Wt.%)	Graphite (Wt.%)	Lubricant (Wt.%)
Distaloy 4800A	4	1.5	0.50	--	0.5	0.6
Ancorsteel 1 85HP	--	--	0.85	2	0.4	0.6

Test specimens were compacted at 30, 40 and 50 tsi. In all cases, between 5 and 10 test specimens were evaluated for each test condition. The green strength, transverse rupture strength, and tensile test specimens were compacted on a 10-ton hydraulic press while the Charpy impact specimens were compacted on a 22-ton Cincinnati press. On both presses, the conventional mixes were compacted at ambient temperature and specimens were only collected after the die had reached steady state temperature conditions. The ANCORDENSE processed samples were compacted at a powder and die temperature of 290°F.

In addition to the single press/single sinter samples, both TRS and tensile specimens were also prepared using double press/double sinter techniques. Following the first compaction, both the ANCORDENSE and conventionally processed materials were pre-sintered at 1400°F for 30 minutes at temperature in a 25% N₂/75% H₂ atmosphere. These specimens were then repressed at the same pressure used in the first compaction step. The second compaction step was performed at ambient temperature for both the ANCORDENSE and the conventionally prepared materials.

Once compaction was completed, sintering was done in a production sintering furnace. The Distaloy 4800A-based specimens were sintered at 2050°F and the Ancorsteel 85HP-based specimens were sintered at 2300°F. In both cases, a 10% H₂/90% N₂ atmosphere was used.

Green density, green expansion from die size, and green strength were determined from the green strength bars. Density was

determined by immersion techniques for all sintered specimens. Additionally, TRS, sintered hardness and sintered dimensional change from die were determined on the TRS specimens. Values for 0.2% offset yield strength, ultimate tensile strength and tensile elongation were determined from flat unmachined tensile specimens with a 1" gauge length and at a strain rate of 0.1" per minute. Un-notched Charpy impact values were measured on the Charpy bars.

RESULTS AND DISCUSSION

Green Properties

The green properties for the two mixes are listed in Table 2. For both materials, the ANCORDERSE process achieved higher green density than the conventionally processed samples (Figure 2). The increases in green density ranged from 0.08 g/cm³ to over 0.14 g/cm³ for a given compaction pressure.

Table II: Green Properties

Base Material	Processing Technique	Compaction Pressure (tsi)	Green Density (g/cm ³)	Green Strength (psi)	Green Expansion (%)	Peak Ejection (tsi)
Ancorsteel 1	ANCORDERSE	30	7.14	3370	0.19	2.15
		40	7.31	3685	0.26	2.43
		50	7.37	3580	0.29	2.32
85HP	Conventional	30	7.00	1430	0.17	2.70
		40	7.19	1770	0.23	3.68
		50	7.29	1950	0.27	3.90
Distaloy	ANCORDERSE	30	7.07	4100	0.17	1.99
		40	7.29	4445	0.23	2.30
		50	7.36	4515	0.29	2.37
4800A	Conventional	30	6.93	1770	0.19	2.70
		40	7.15	2170	0.24	3.52
		50	7.26	2450	0.28	3.77

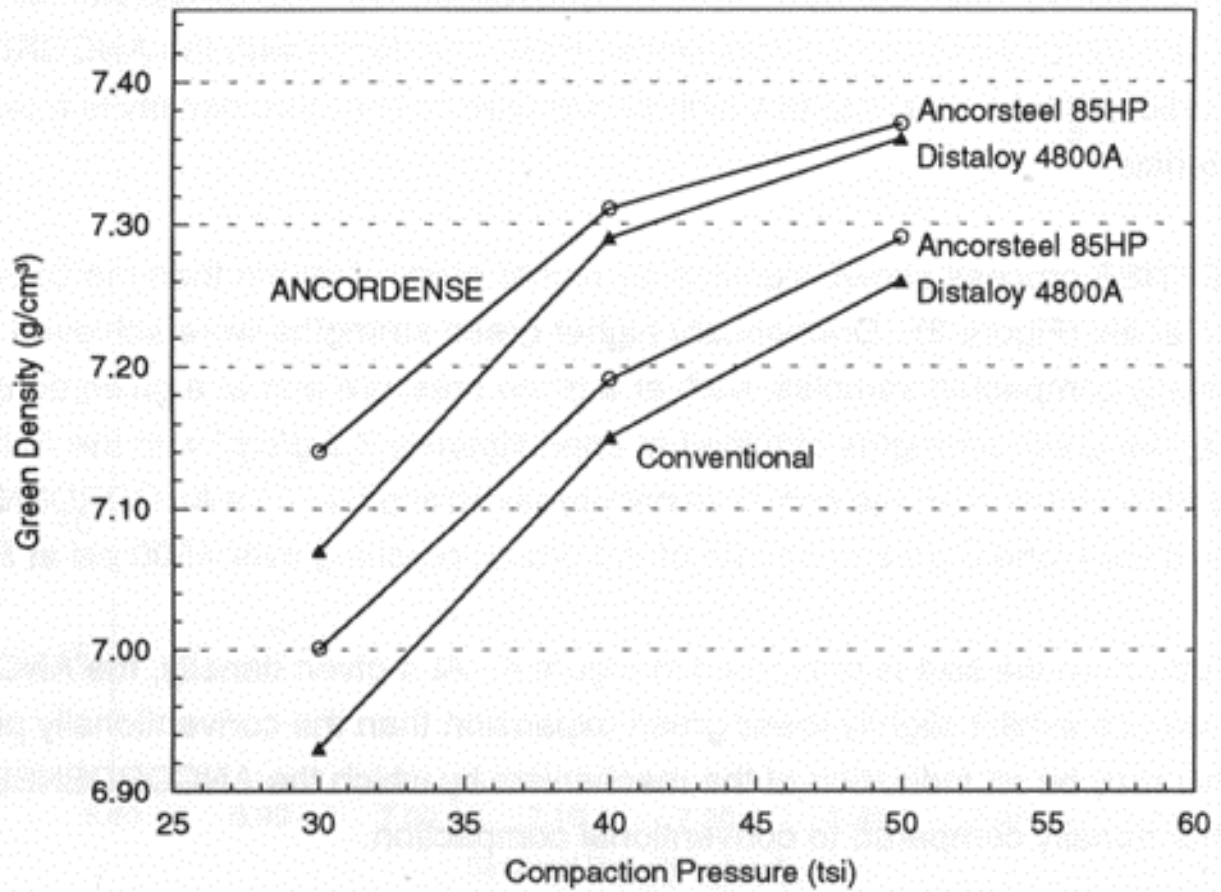


Figure 2: Green Density versus Compaction Pressure for Two Materials (Ancorsteel 85HP+2% Ni+0.4% Graphite +0.6% Lubricant and Distaloy 4800A+0.5% Graphite+0.6% Lubricant) Compacted by ANCORDENSE and Conventional Techniques

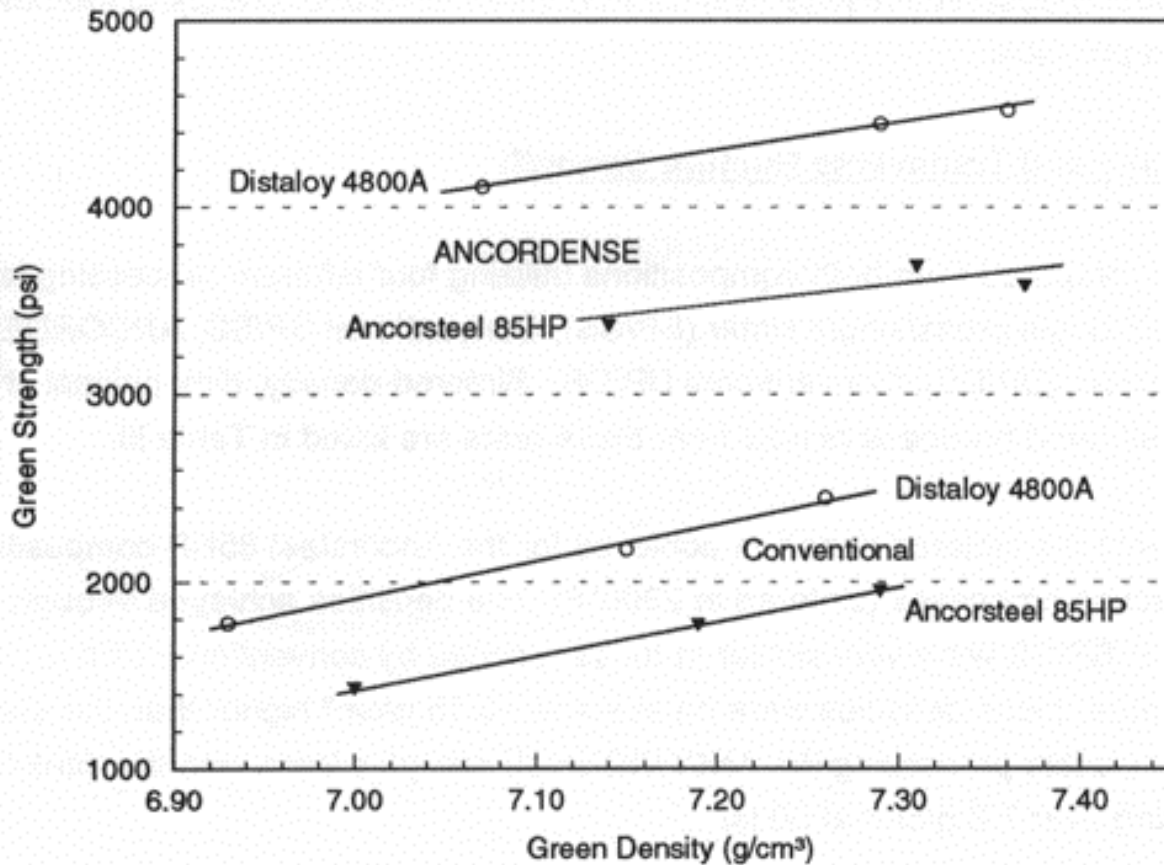


Figure 3: Green Strength versus Green Density Comparing ANCORDERSE and Conventional Processing

For both materials, the ANCORDERSE process achieved higher densities at 40 tsi than the corresponding conventional premix did at 50 tsi. At 50 tsi, both ANCORDERSE premixes attained densities of over 7.35 g/cm³. This density level corresponds to approximately 98.5% of the por-free density for those mix compositions. Past experience with the ANCORDERSE process has indicated that obtaining this high percentage of pore free density is typical for these two base materials.

The ANCORDERSE process shows significantly higher green strength than the conventionally processed materials (Figure 3). Dramatically higher green strengths were achieved relative to the conventionally compacted samples, both at a given pressure and at a given density. For both materials, the green strengths obtained at approximately 7.2 g/cm³ with the ANCORDERSE process were 85% higher than the conventional premix strengths. The ANCORDERSE Distaloy 4800A achieved the highest green strength of the group, reaching over 4500 psi at 50 tsi.

Green expansion from die size is presented in Figure 4. At a

given density, the ANCORDERNSE processed materials exhibit slightly lower green expansion than the conventionally processed materials. This may be an indication of the mechanism by which the ANCORDERNSE process achieves higher density compared to conventional compaction.

While compacting the green density samples, the peak force during ejection was recorded. This measurement should be an indication of lubricant performance. The data is presented in Figure 5. At all compaction pressures and green densities, the ANCORDERNSE process exhibited significantly lower ejection forces than the conventionally compacted materials. This result confirms previously observed results (3) and may provide significant benefits to the powder metallurgy part producer.

Sintered Density and Transverse Rupture Strength

TRS bars were prepared from both compositions utilizing four different processing techniques: ANCORDERNSE single press/single sinter (SP/SS), Conventional SP/SS, ANCORDERNSE double press/double sinter (DP/DS), Conventional DP/DS. Sintered density, dimensional change from die, TRS and sintered hardness results from these tests are listed in Table III.

Figure 6 presents the sintered densities achieved for the Ancorsteel 85HP composition utilizing all four compaction processes (sintered at 2300°F). The densities achieved through ANCORDERNSE SP/SS were very similar to those reached by conventional DP/DS. Over the compaction range, these densities were on average ~0.15 g/cm³ higher than the standard single press results. Double processing the ANCORDERNSE samples increased the density even further, reaching over 7.6 g/cm³ at 50 tsi.

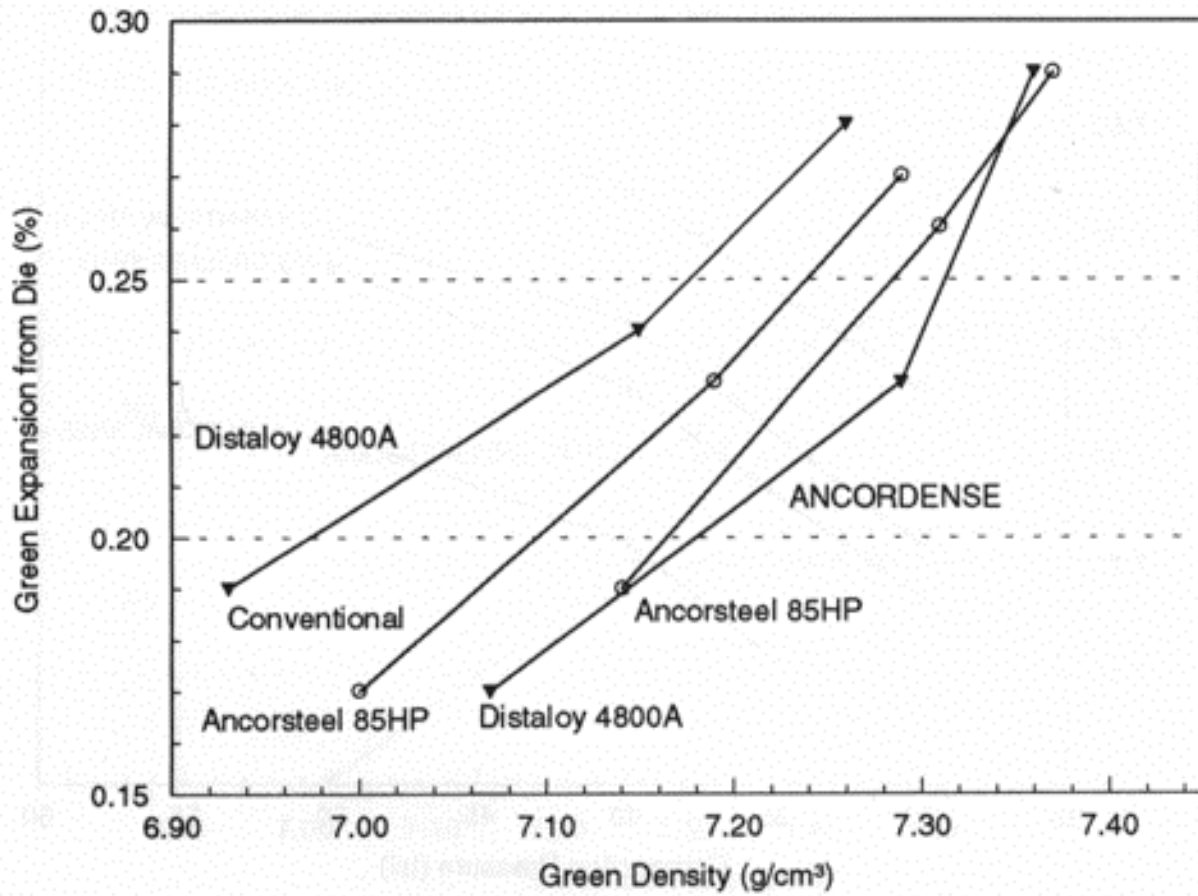


Figure 4: The Effect of Process and Chemistry on Green Expansion from Die Size

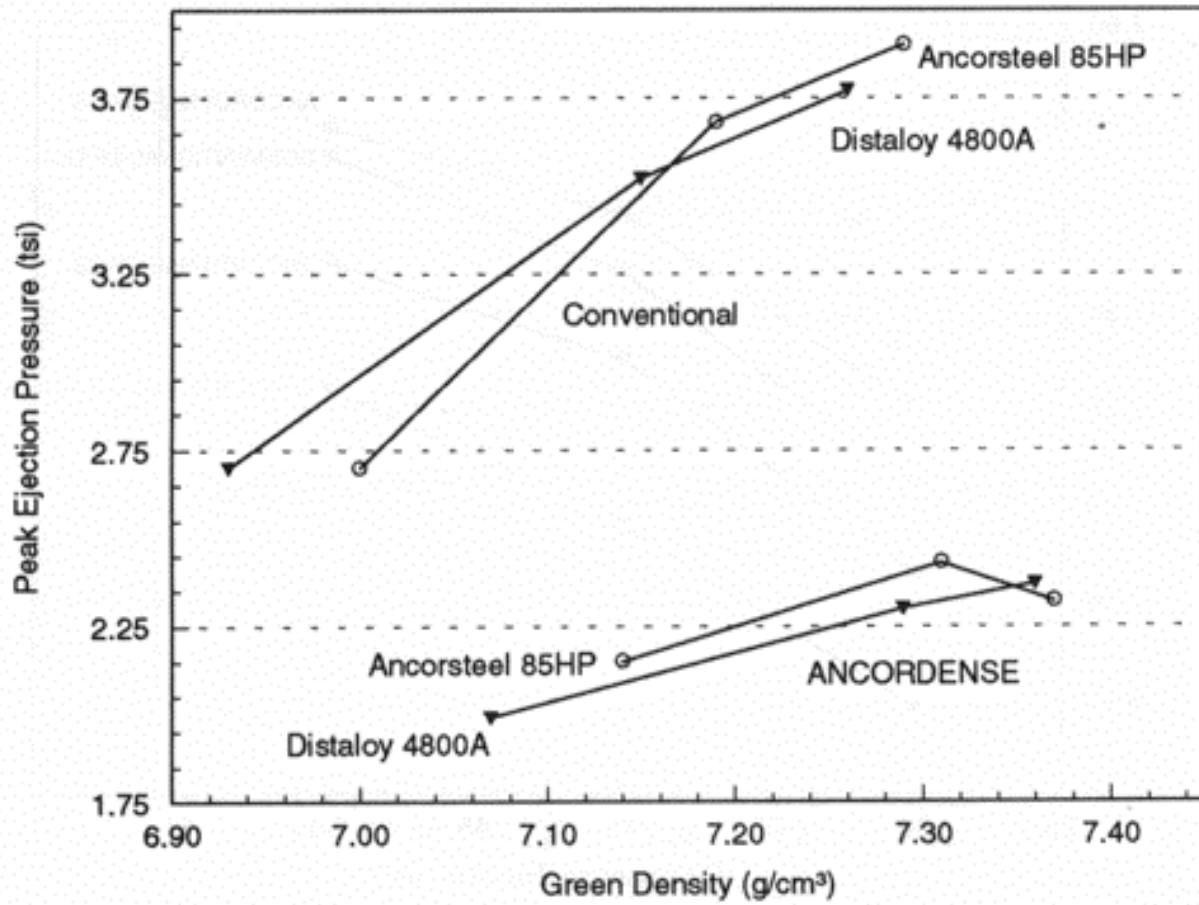


Figure 5: The Effect of Compaction Technique on Peak Ejection Pressure

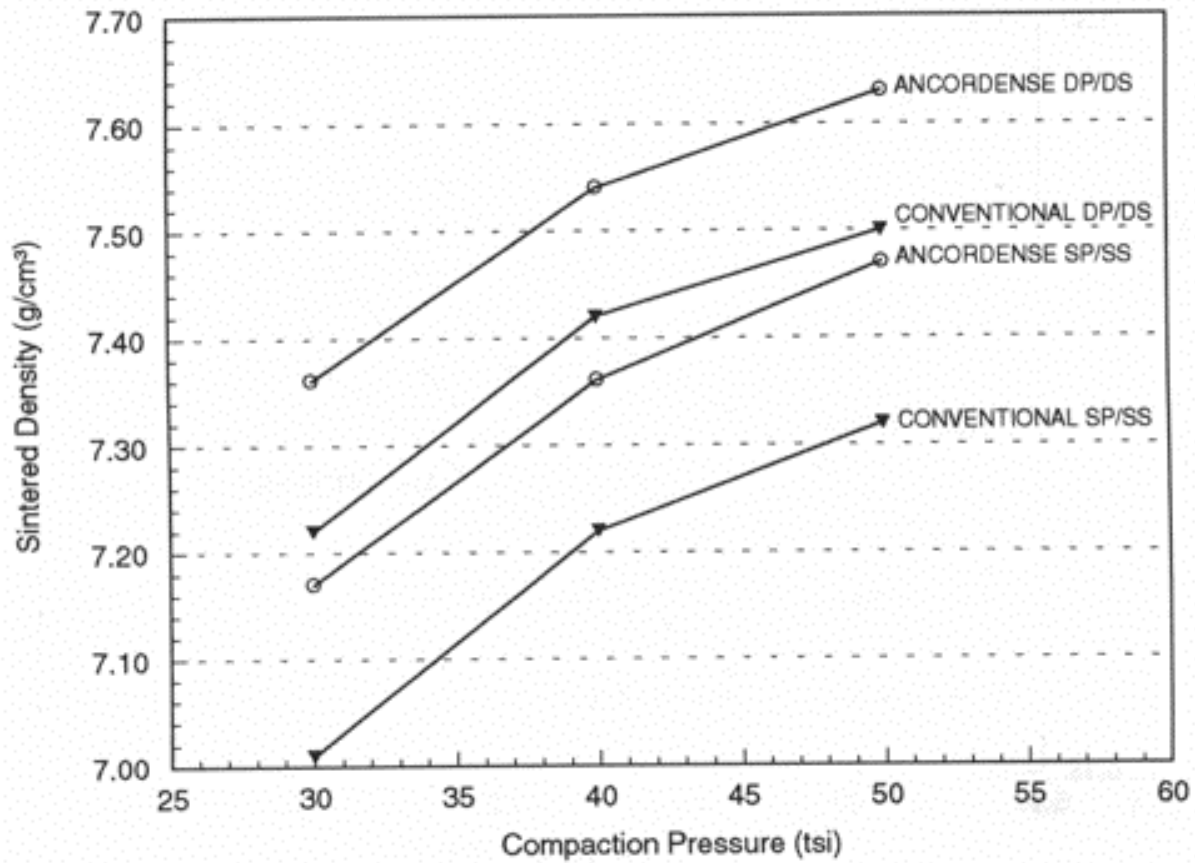


Figure 6: Sintered Density of Ancorsteel 85HP+2% Ni+0.4% Graphite+0.6% Lubricant Utilizing Various Compaction Processes (Sintered at 2300°F for 30 minutes in 10% H₂/90% N₂)

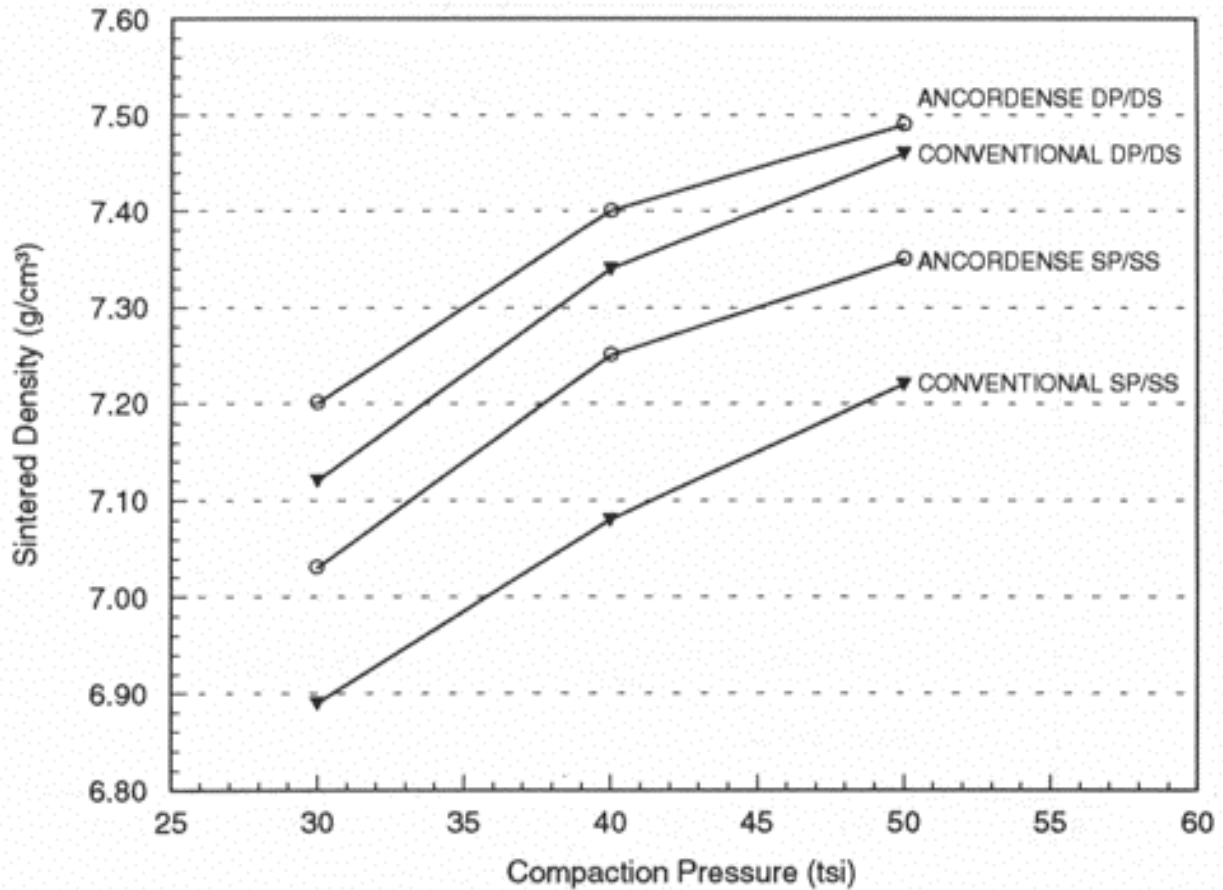


Figure 7: Sintered Density of Distaloy 4800A+0.5% Graphite+0.6% Lubricant Utilizing Various Compaction Processes (Sintered at 2050°F for 30 minutes in 10% H₂/90% N₂)

The sintered densities (2050°F sinter) achieved with the Distaloy 4800A composition are shown in Figure 7. These results indicate that the ANCORDENSE SP/SS densities are once again about 0.15 g/cm³ higher than conventional SP/SS processing. Conventional DP/DS obtains densities of about 0.1 g/cm³ higher than the ANCORDENSE SP/SS for a given compaction pressure. By utilizing ANCORDENSE DP/DS, the sintered density is increased, about 0.06 g/cm³ to 0.12 g/cm³ higher than the density achieved by conventional DP/DS.

Table III: TRS Properties

Base Material	Processing Technique	Compaction Pressure (tsi)	Sintered Density (g/cm ³)	TRS (10 ³ psi)	Dim. Chg. (%)	Hard. (HRB)
Ancorsteel	ANCORDENSE SP/SS	30	7.18	159.5	-0.25	83
		40	7.36	192.1	-0.13	88
		50	7.47	194.6	-0.07	91
85HP	ANCORDENSE DP/DS	30	7.36	194.6		89
		40	7.54	216.7		92

(2300°F Sinter)		50	7.63	221.7		94
	Conventional SP/SS	30	7.01	144.3	-0.27	79
		40	7.22	166.0	-0.16	85
		50	7.32	185.7	-0.09	88
	DP/DS	30	7.22	180.2		87
		40	7.42	212.0		92
50		7.50	221.9		94	
Distaloy	ANCORDENSE SP/SS	30	7.04	174.8	0.17	90
		40	7.27	199.6	0.25	94
		50	7.35	210.1	0.30	97
4800A	ANCORDENSE DP/DS	30	7.20	218.5		94
		40	7.40	245.4		97
		50	7.49	246.0		100
(2050°F Sinter)	Conventional SP/SS	30	6.90	141.4	0.11	81
		40	7.08	183.5	0.24	87
		50	7.20	194.1	0.28	91
	Conventional DP/DS	30	7.12	199.4		90
		40	7.34	238.8		94
		50	7.46	261.1		96

Dimensional change from die size is presented in Figure 8 for both materials. For a given density, the ANCORDENSE processed materials exhibited slightly more shrinkage (Ancorsteel 85HP) or less growth (Distaloy 4800A) from die size than the conventionally processed materials. The difference in dimensional change between the two processes can be correlated back to the difference in green expansion (Figure 4). The results indicate that the two processes obtained the same degree of sintering.

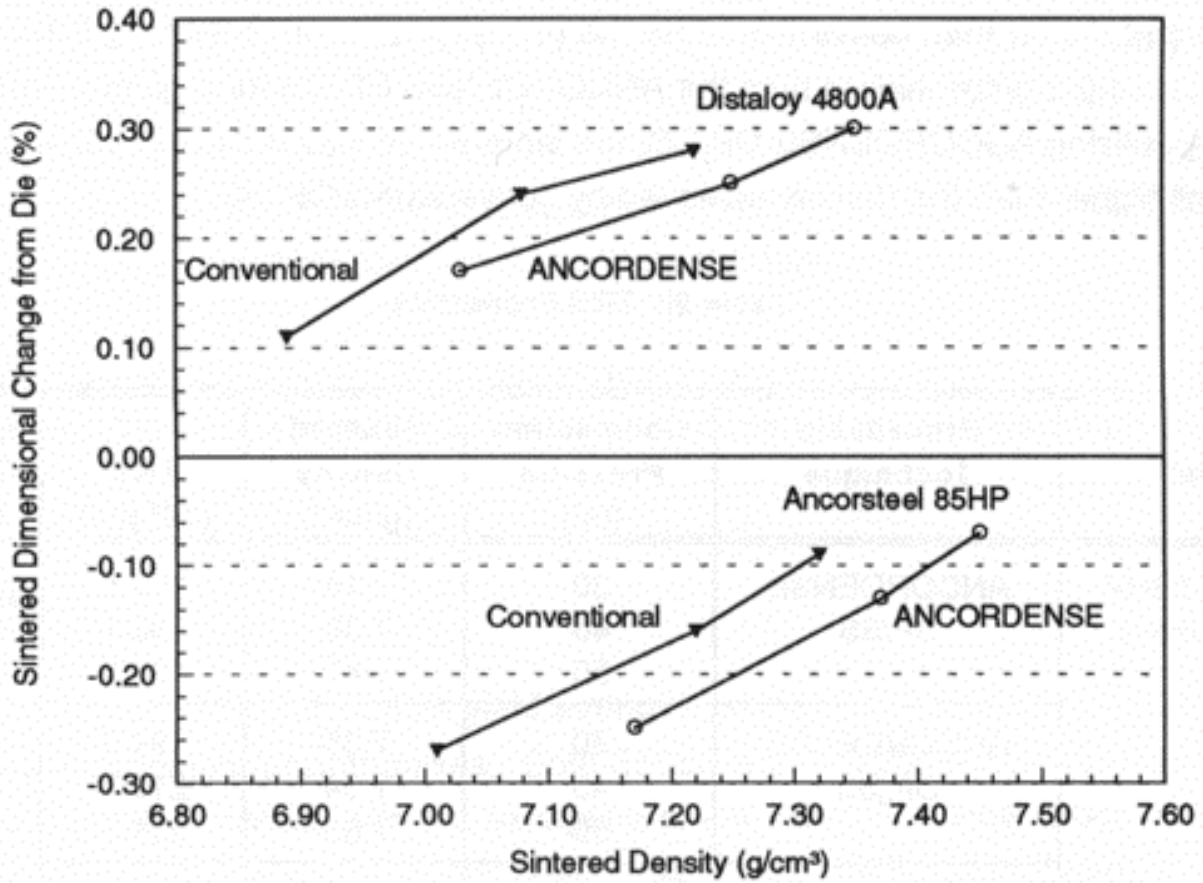


Figure 8: Sintered Dimensional Change from Die (Sintered at 1200°F (Ancorsteel 85HP) and 2050°F (Distaloy 4800A) for 30 minutes in 10% H₂/90%N₂)

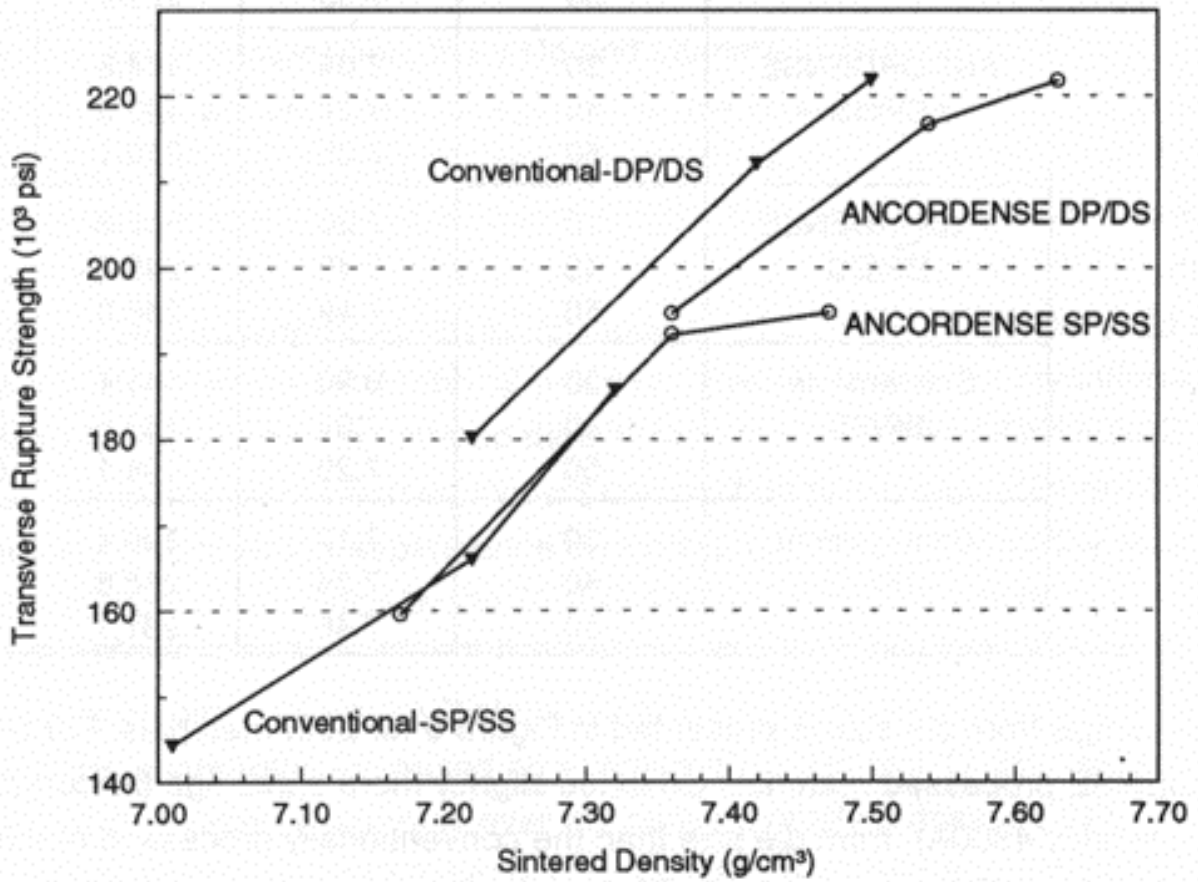


Figure 9: Transverse Rupture Strength for the Ancorsteel 85HP Material Compacted Utilizing ANCORDENSE and Conventional Processes

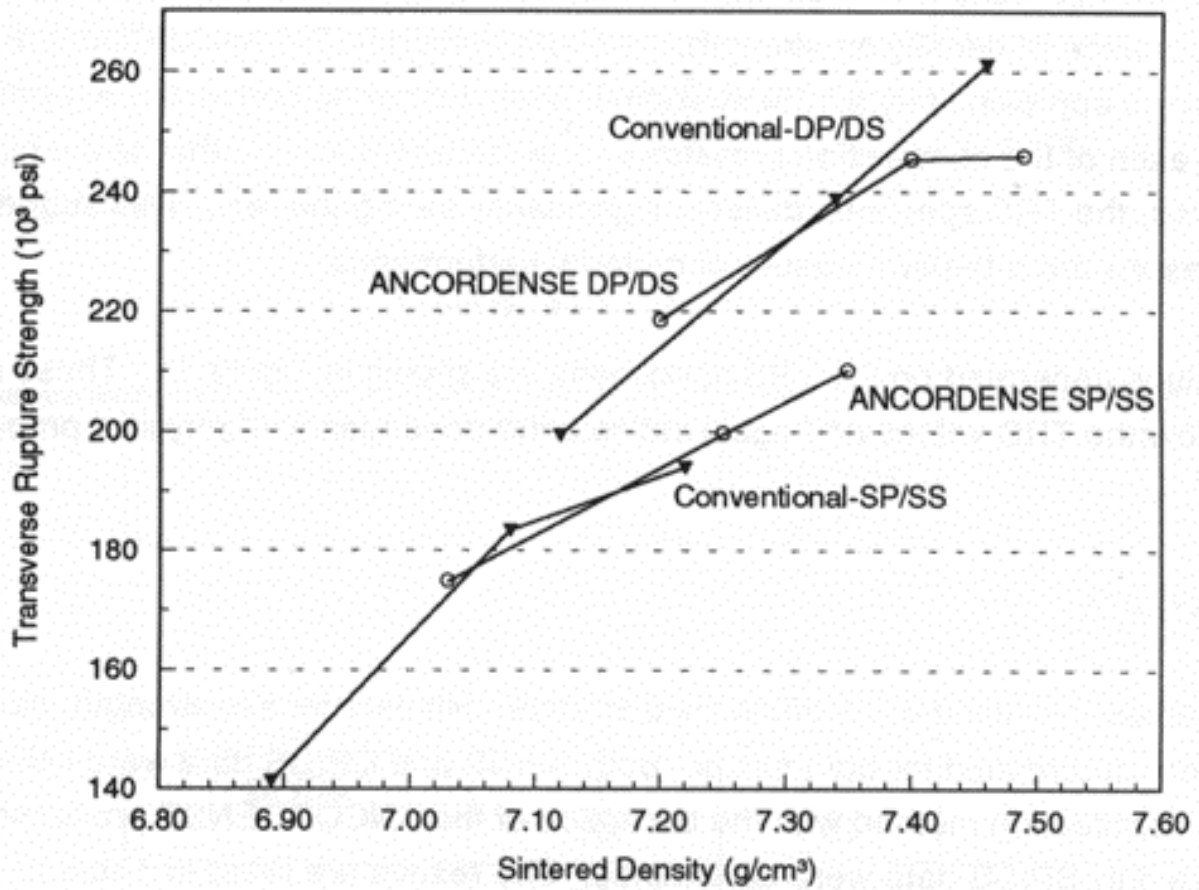


Figure 10: Transverse Rupture Strength for the Distaloy 4800A Material Compacted Utilizing ANCORDERNSE and Conventional Processes

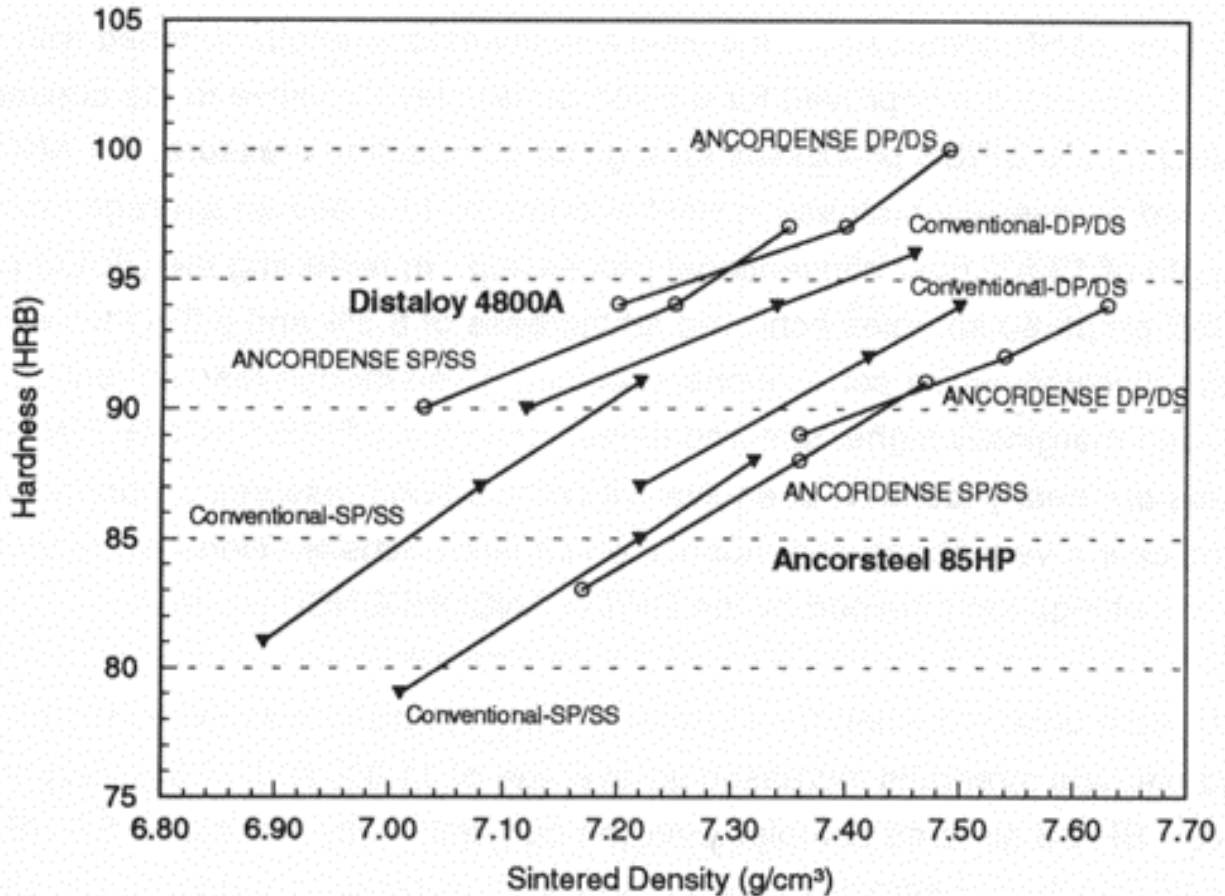


Figure 11: Hardness Values for the Ancorsteel 85HP and the Distaloy 4800A materials Compacted Utilizing ANCORDENSE and Conventional Processes

Transverse rupture values for each of the four processes are shown in Figure 9 for the Ancorsteel 85HP material and in Figure 10 for the Distaloy 4800A material. Both graphs clearly show the importance of density on strength. For both materials, the ANCORDENSE SP/SS process provides approximately a 12% strength increase over the conventionally processed premixes for each of the compaction pressures. It is important to note that at the high density levels achieved, the TRS specimen deflects significantly during the test. This suggests that tensile test results are a better measure of material performance. Hardness values generated on the TRS specimens are shown in Figure 11. These results generally follow the TRS values and again indicate the dependency of physical properties on density.

Tensile Properties

Tensile properties, including 0.2% offset yield strength,

ultimate tensile strength, elongation and hardness, were determined for both mixes. Both SP/SS and DP/DS data were collected for each material and compaction method with the exception of the ANCORDENSE processed Distaloy 4800A, where only SP/SS data were determined. The results are listed in Table IV. The data for ultimate strength, 0.2% offset yield strength and elongation for the Ancorsteel 85HP composition are shown in Figures 12 through 14, respectively, and for the Distaloy 4800A composition in Figures 15 through 17, respectively. In a similar fashion to the TRS results, the strength and elongation values all show a significant dependence on density.

For the Ancorsteel 85HP composition, the yield and ultimate strength obtained with the ANCORDENSE process are improved for a given density level relative to the conventional premix. Evaluating the SP/SS processes for a given compaction pressure, the ANCORDENSE process provided an average increase in yield strength of 11% and an average increase in ultimate strength of 13.5% over conventional processing. In reviewing the DP/DS processes, the ANCORDENSE prepared samples achieved an increase of 8.3% and 8.8% for yield and tensile strength, respectively, over the conventional process. Even though the conventional DP/DS process provided marginally higher sintered density than the SP/SS ANCORDENSE process, the strength values are nearly identical at equivalent compaction pressures. Elongation values (Figure 14) indicate a very strong dependence on sintered density. Noteworthy among the data is the nearly 6% elongation obtained by the DP/DS ANCORDENSE process.

Similar trends were obtained when the Distaloy 4800A chemistry was evaluated (Figures 15-17). The yield and ultimate strengths increased an average of 11.3% and 17.3%, respectively, for the ANCORDENSE SP/SS sintered samples over the conventionally processed SP/SS samples. The SP/SS ANCORDENSE samples indicate only slightly lower yield and tensile strengths compared to the conventional DP/DS samples for a given compaction pressure. However, the ANCORDENSE SP/SS samples do indicate much higher elongation values.

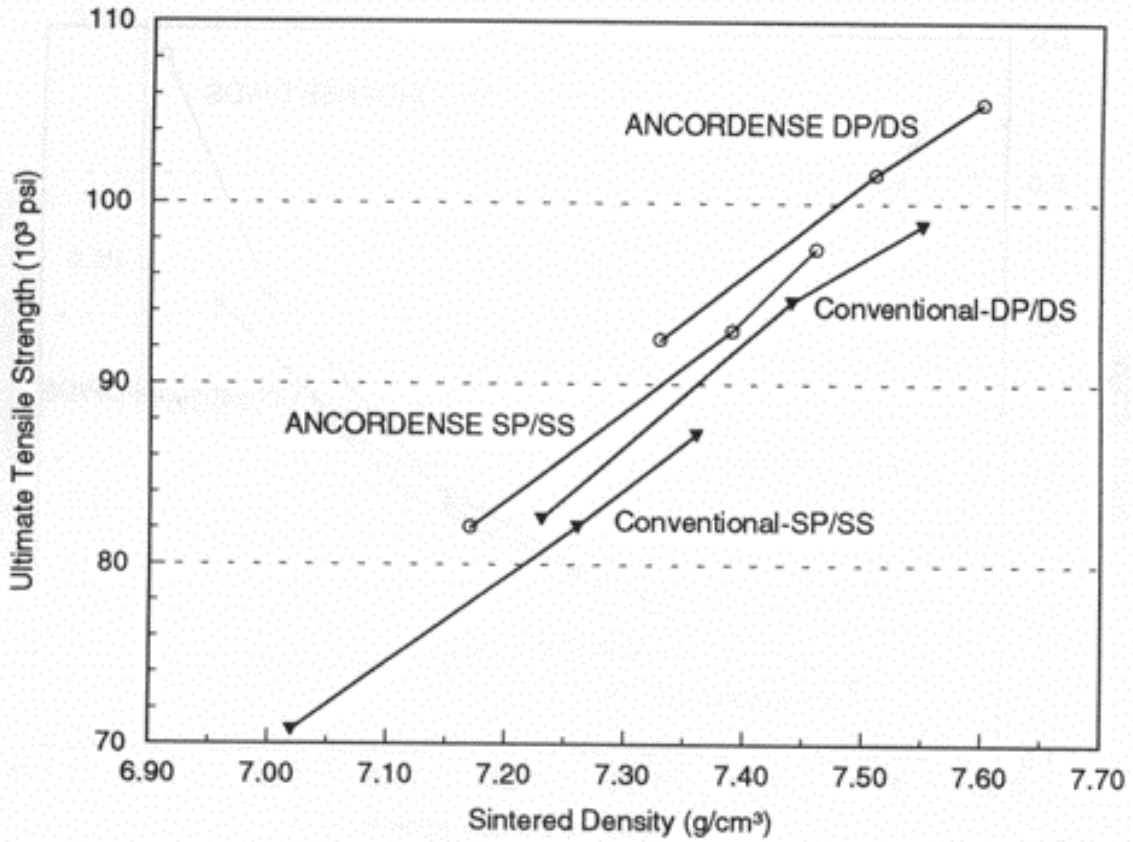


Figure 12: Ultimate Tensile Strength of the Ancorsteel 85HP Material Compacted Utilizing ANCORDENSE and Conventional Processes

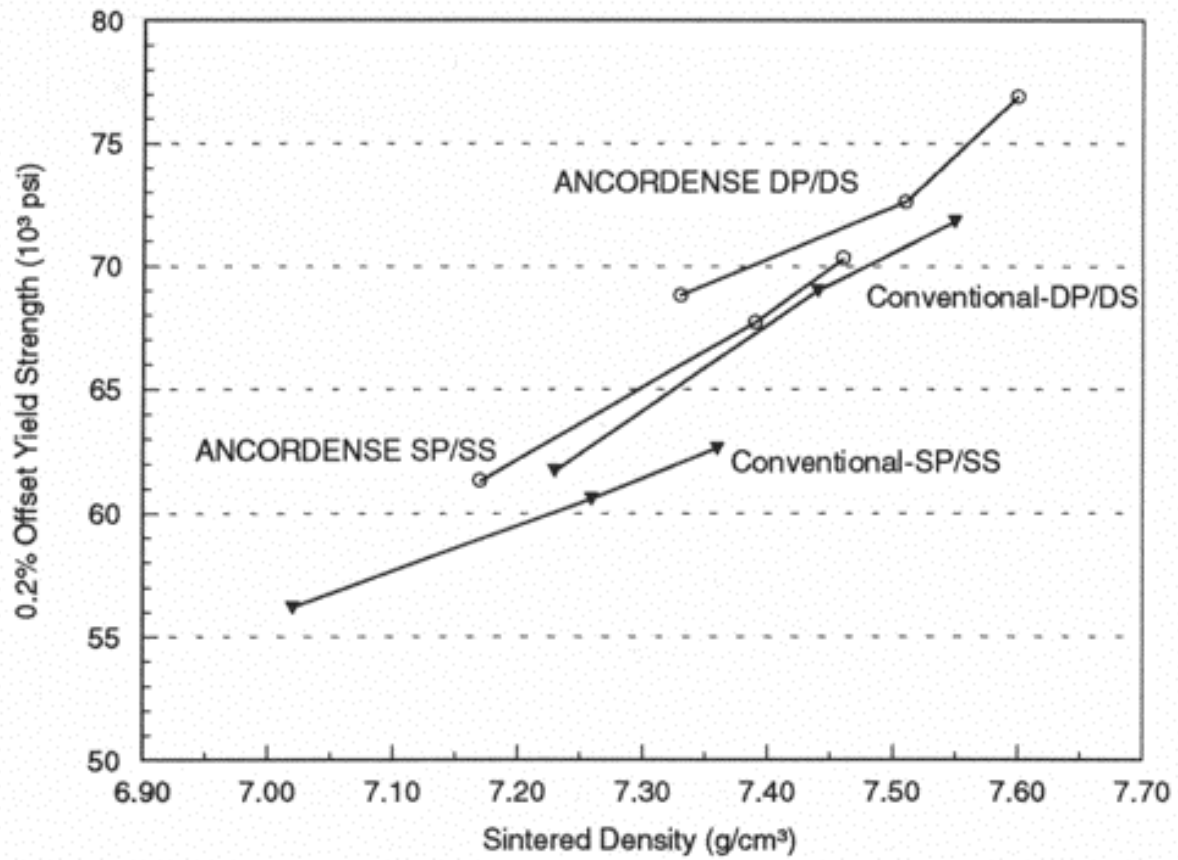


Figure 13: 0.2% Offset Yield Strength of the Ancorsteel 85HP Material Compacted Utilizing ANCORDENSE and Conventional Processes

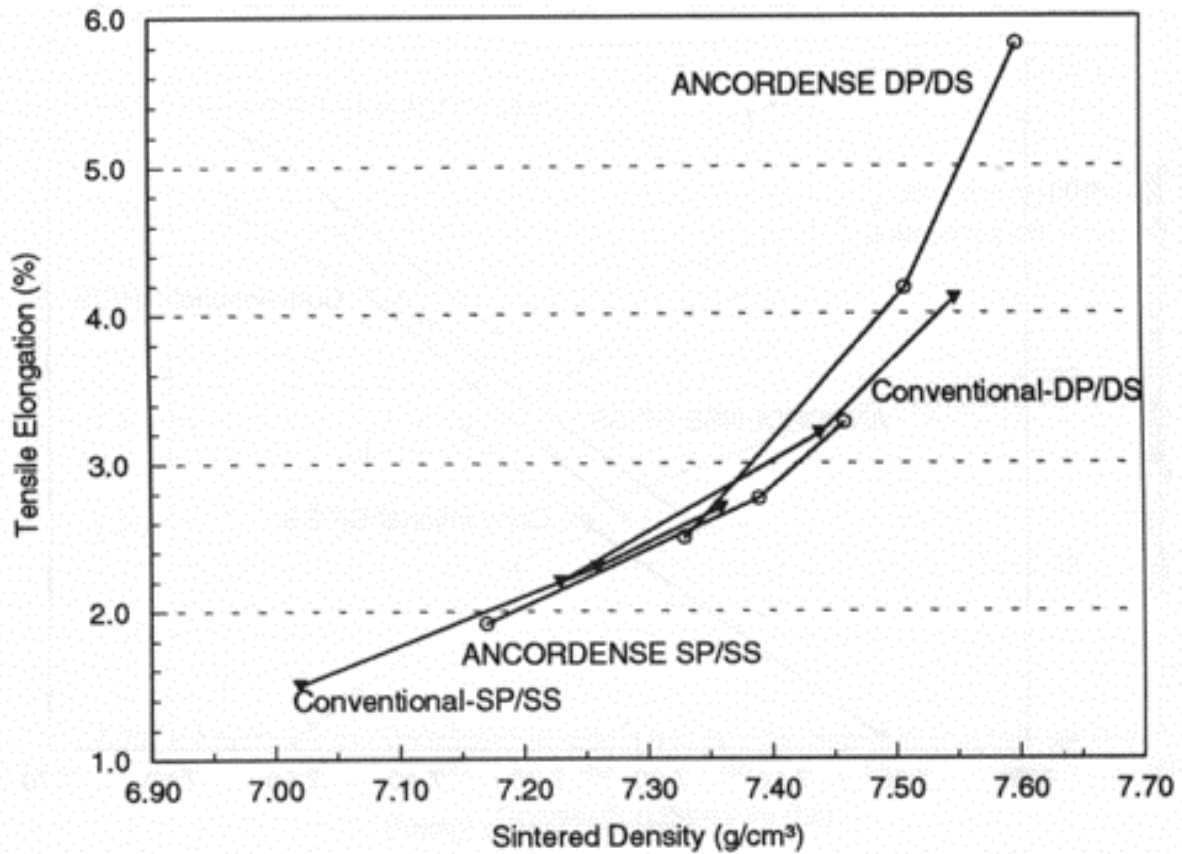


Figure 14: Tensile Elongation of the Ancorsteel 85HP Material Compacted Utilizing ANCORDENSE and Conventional Processes

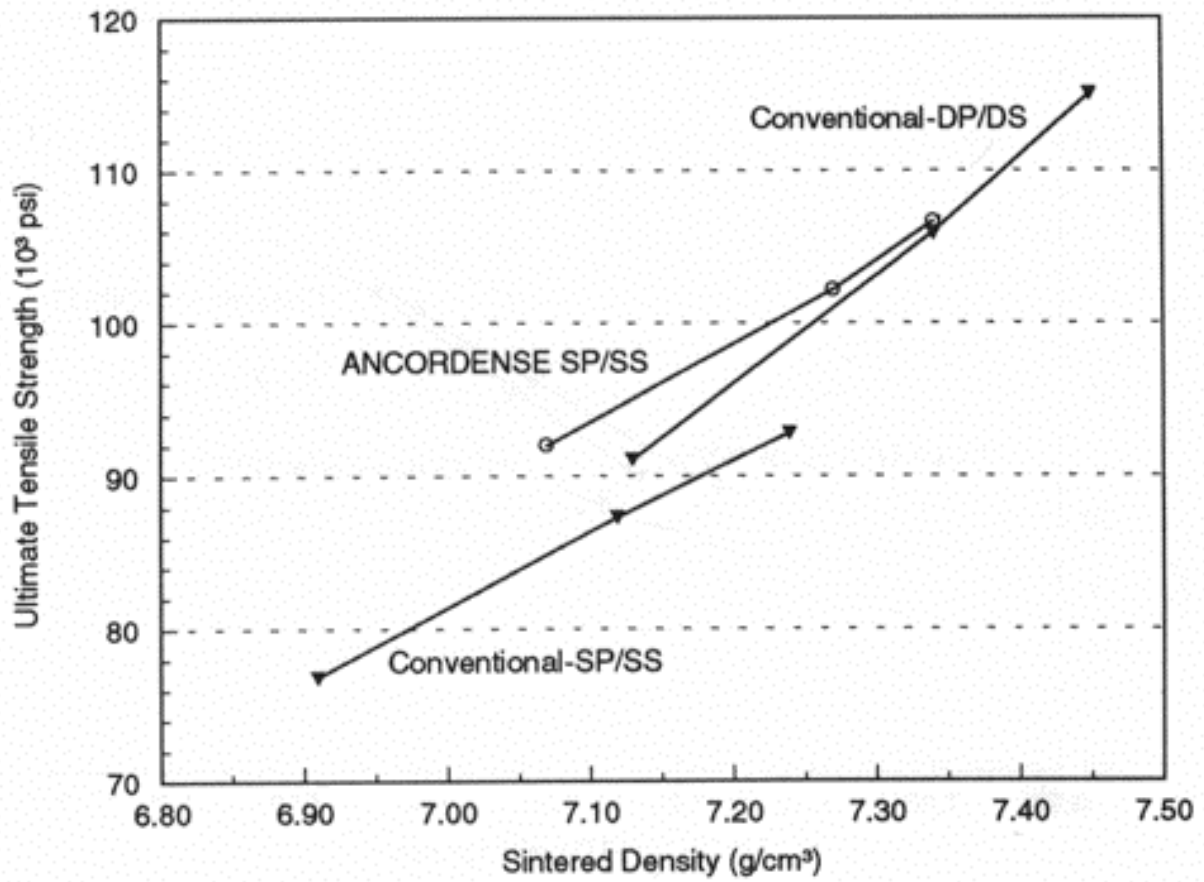


Figure 15: Ultimate Tensile Strength of the Distaloy 4800A Material Compacted Utilizing ANCORDENSE and Conventional Processes

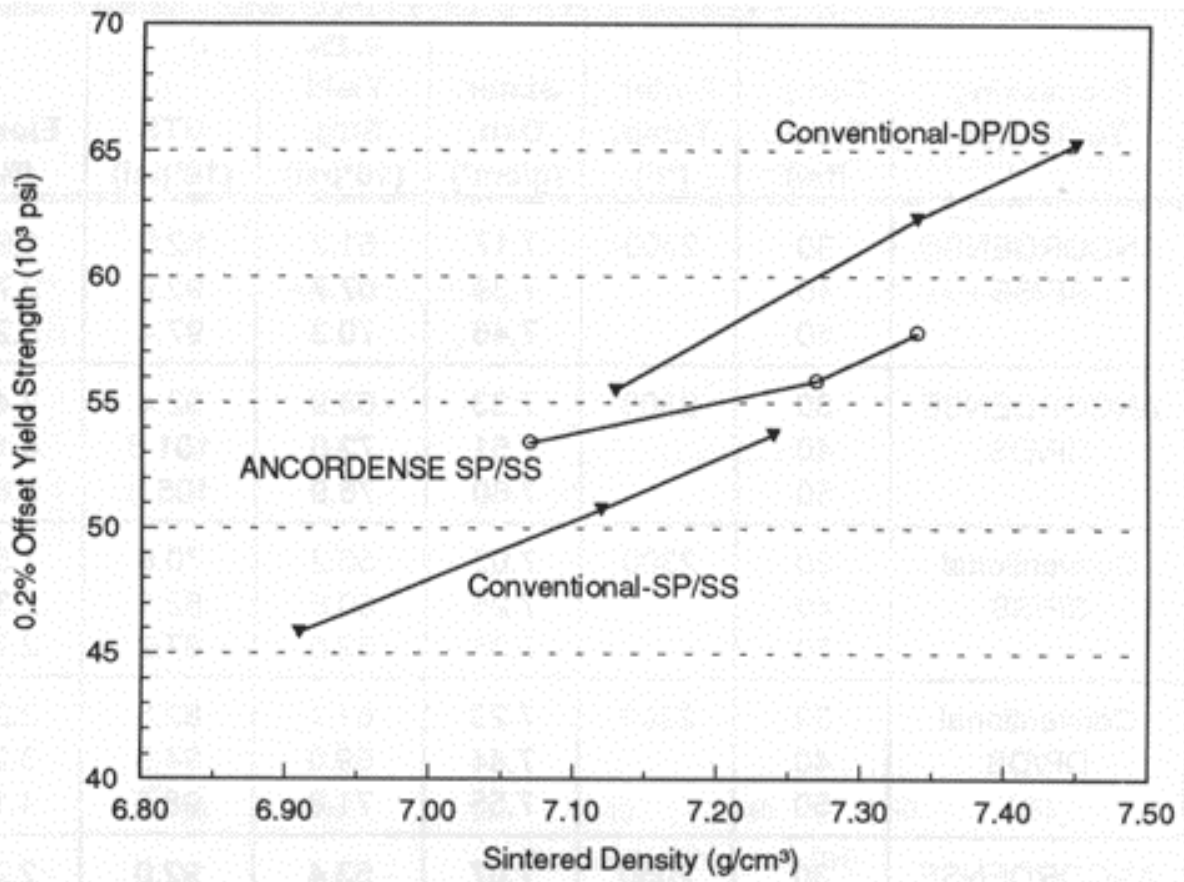


Figure 16: 0.2% Offset Yield Strength of Distaloy 4800A Material Compacted Utilizing ANCORDENSE and Conventional Processes

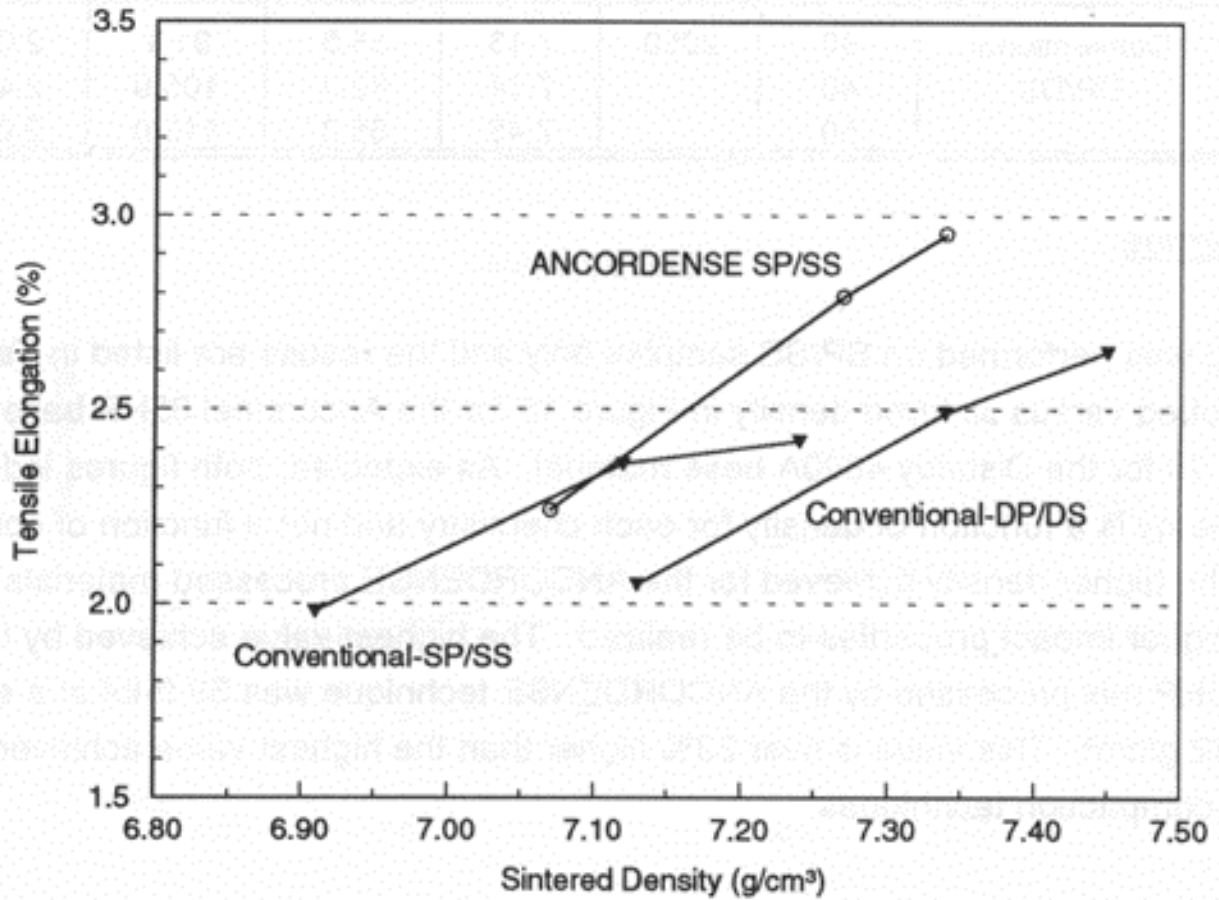


Figure 17: Tensile Elongation of the Distaloy 4800A Material Compacted Utilizing ANCORDERNSE and Conventional Processes

Table IV: Tensile Properties

Base Material	Processing Technique	Comp Press (tsi)	Sinter Temp (°F)	Sinter Den (g/cm³)	0.2% Yield Strg (10³ psi)	UTS (10³ psi)	Elong (%)	Hard (HRB)
Ancorsteel	ANCORDERNSE SP/SS	30	2300	7.17	61.3	82.0	1.91	84
		40		7.39	67.7	92.9	2.76	88
		50		7.46	70.3	97.4	3.27	90
85HP	ANCORDERNSE DP/DS	30	2300	7.33	68.9	92.4	2.49	87
		40		7.51	72.6	101.6	4.17	92
		50		7.60	76.9	105.5	5.81	95
	Conventional SP/SS	30	2300	7.02	56.2	70.8	1.50	79
		40		7.26	60.6	82.1	2.30	87
		50		7.36	62.6	87.2	2.70	88
Conventional DP/DS	30	2300	7.23	61.7	82.5	2.20	85	
	40		7.44	69.0	94.5	3.20	91	
	50		7.55	71.8	98.8	4.10	92	

Distaloy 4800A	ANCORDENSE SP/SS	30	2050	7.07	53.4	92.0	2.24	89
		40		7.27	55.8	102.	2.79	92
		50		7.34	57.7	2	2.95	93
						106.		
						9		
	Conventional SP/SS	30	2050	6.91	45.9	76.8	1.98	83
		40		7.12	50.8	87.4	2.36	89
		50		7.24	53.8	92.8	2.42	90
	Conventional DP/DS	30	2050	7.13	55.5	91.1	2.05	91
40		7.34		62.3	105.	2.49	95	
50		7.45		65.3	9	2.65	97	
					115.			
					0			

Impact Properties

Impact testing was performed on SP/SS samples only and the results are listed in Table V. The results are plotted versus sintered density in Figure 18 for the Ancorsteel 85HP base material and in Figure 19 for the Distaloy 4800A base material. As expected, both figures indicate that the impact energy is a function of density for each chemistry and not a function of compaction technique. The higher density achieved for the ANCORDENSE processed materials allow significantly higher impact properties to be realized. The highest value achieved by the Ancorsteel 85HP mix processed by the ANCORDENSE technique was 39 ft-lbf at a sintered density of 7.42 g/cm³. This value is over 33% higher than the highest value achieved by conventional compaction techniques.

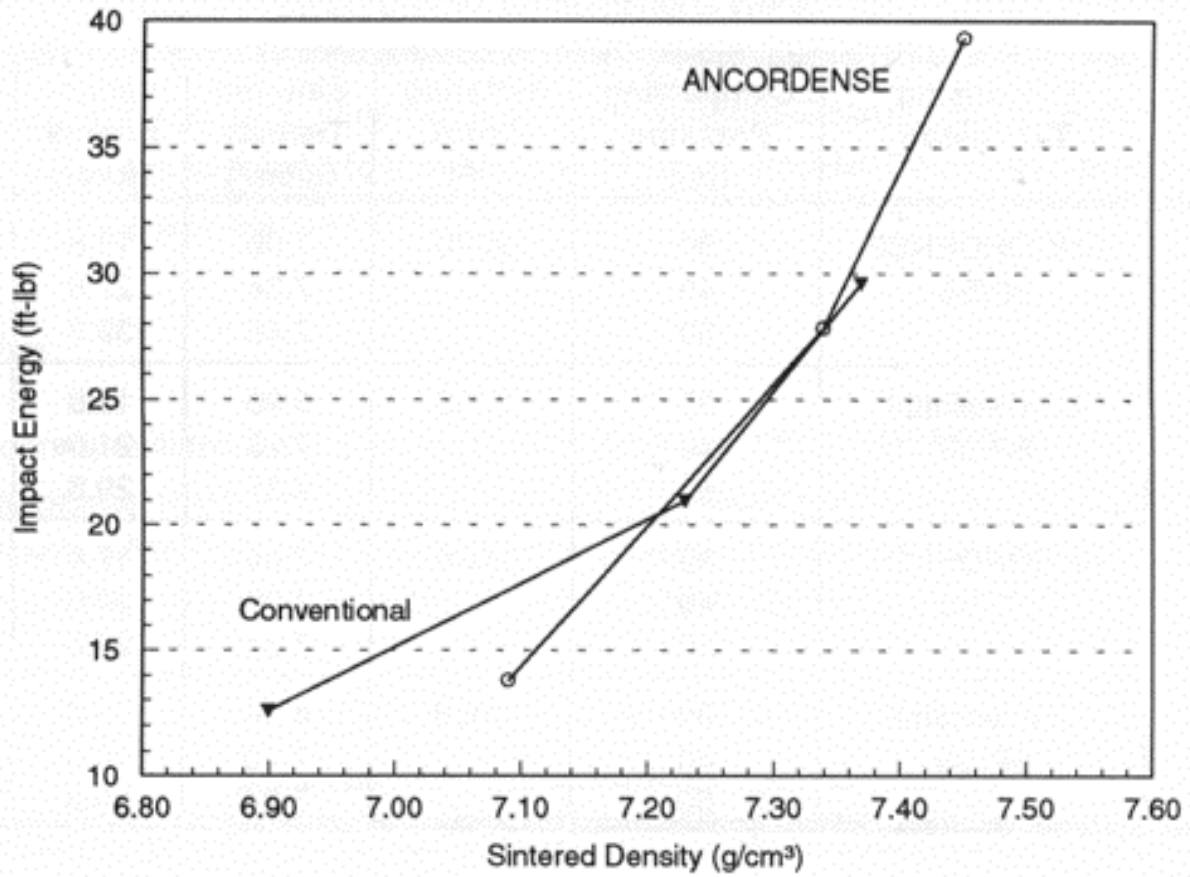


Figure 18: Charpy Impact Values for the Ancorsteel 85HP Material SP/SS by ANCORDENSE and Conventional Processes

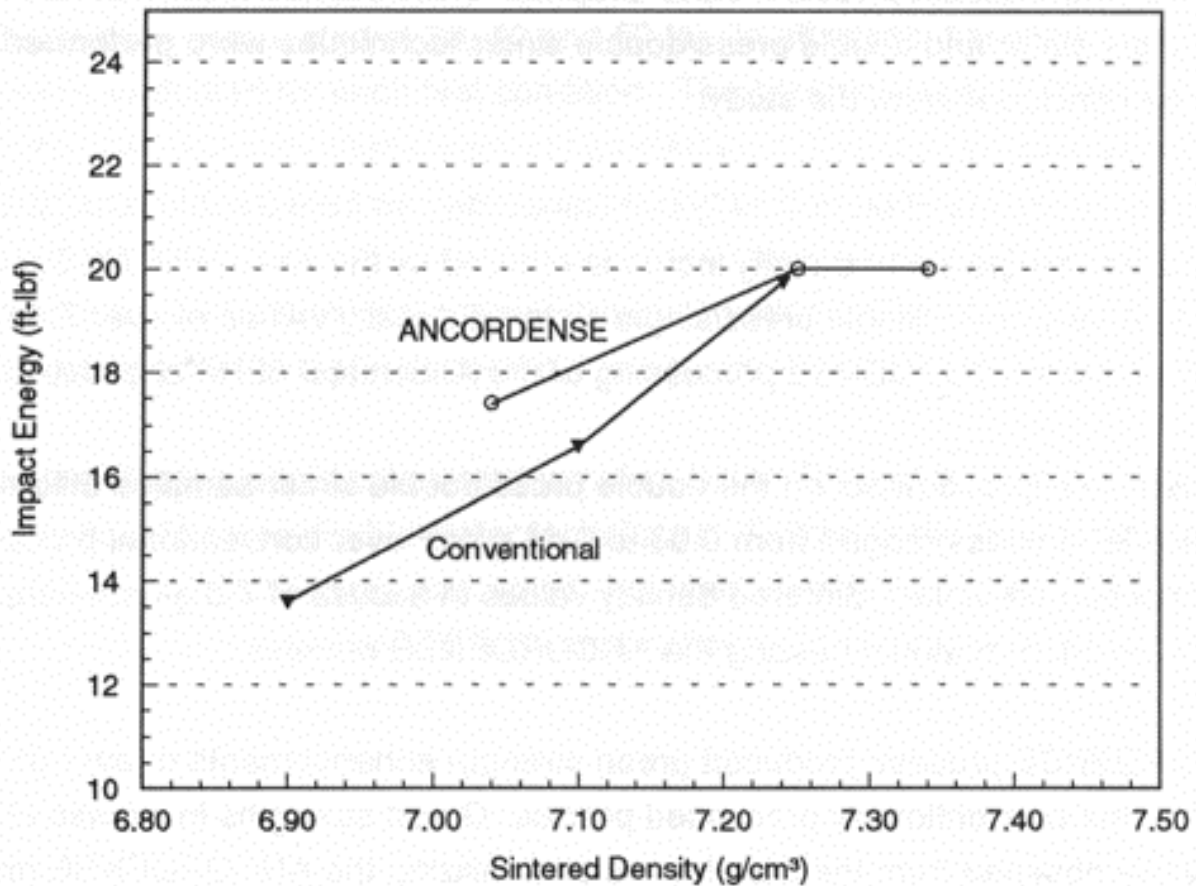


Figure 19: Charpy Impact Values for the Distaloy 4800A Material SP/SS by ANCORDENSE and Conventional Processes

Table V: Impact Properties

Base Material	Processing Technique	Compacting Pressure (tsi)	Sintering Temp (°F)	Sintered Density (g/cm ³)	Impact Energy (ft-lbf)	Hard (HRB)
Ancorsteel	ANCORDENSE SP/SS	30	2300	7.09	13.8	79
		40		7.34	27.8	86
		50		7.45	39.3	90
85HP	Conventional SP/SS	30	2300	6.90	12.6	77
		40		7.23	21.0	82
		50		7.37	29.6	86
Distaloy	ANCORDENSE SP/SS	30	2050	7.04	17.4	84
		40		7.25	20.0	89
		50		7.34	20.0	92
4800A	Conventional SP/SS	30	2050	6.90	13.6	81
		40		7.10	16.6	85
		50		7.24	19.8	87

CONCLUSIONS

A comparison was made between ANCORDENSE processing and conventional compaction techniques utilizing two premixes (Ancorsteel 85HP+2% Nickel+0.4% Graphite+0.6% Lubricant sintered at 2300°F and Distaloy 4800A+0.5% Graphite+0.6% Lubricant sintered at 2050°F). Both single press/single sinter and double press/double sinter techniques were performed. The following can be concluded from the study:

- 1) Green density increases of up to 0.14 g/cm³ were obtained from the ANCORDENSE process. The single press/single sinter density increase realized by the ANCORDENSE process ranged from 0.14 to 0.19 g/cm³. Single press/single sintered density values of over 7.45 g/cm³ were obtained from the ANCORDENSE processing of the Ancorsteel 85HP chemistry.
- 2) Sintered density improvements on the double press/double sinter samples utilizing the ANCORDENSE process ranged from 0.03 to 0.14 g/cm³ over conventional processing for a given compaction pressure. Sintered density values in excess of 7.6 g/cm³ were obtained for the Ancorsteel 85HP material utilizing the ANCORDENSE process.
- 3) The ANCORDENSE process produced green strength enhancements of over 85% when compared to the conventionally processed premix. Green strengths in excess of over 4500 psi were obtained from the Distaloy material utilizing the ANCORDENSE process.
- 4) All physical properties showed a strong dependence on sintered density. For a given compaction pressure, the ANCORDENSE processed materials consistently achieved higher density and thus higher physical properties, than the conventionally processed materials. Of particular note are the impact values of nearly 40 ft-lbf for the ANCORDENSE SP/SS processed Ancorsteel 85HP material and the elongation values of nearly 6% for the ANCORDENSE DP/DS processed Ancorsteel 85HP material.

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Notes

- ANCORDENSE is a trademark of the Hoeganaes Corporation.
- **ANCORBOND is a registered trademark of the Hoeganaes Corporation.
- ***Ancorsteel is a registered trademark of the Hoeganaes Corporation.