

High Performance P/M Stainless Steels

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ABSTRACT

Powder Metallurgy (P/M) automotive exhaust flanges are in volume production for several US automobile and light truck engines. However competing technologies continue to improve and may threaten the anticipated increase in applications of P/M stainless flanges. This paper examines the properties of stainless steel powders, particularly a stabilised ferritic steel that should improve the processing and competitiveness of P/M stainless steels in automotive applications.

INTRODUCTION

Recent automotive applications of pressed and sintered P/M stainless steel parts have resulted in significant growth in the market for stainless parts and powders. However competition from other metal forming processes requires that powder and part producers further improve the performance and consistency of P/M stainless steels if the growth is to continue.

This paper examines the properties of improved "High Performance" stainless steels powders that offer one means to improve the efficiency of the P/M production process.

PERFORMANCE REQUIREMENTS

The recent rapid growth in consumption of stainless steel powders has been driven by two automotive applications: the "HEGO" boss and exhaust flanges. The exhaust flange is the critical application for P/M parts and powder producers since it demonstrates the ability of P/M processing to displace fully dense wrought steels on both price and performance. The performance of the P/M exhaust flange requires: Corrosion resistance, high sintered density, thermal shock resistance and hot strength¹.

The exact mechanical properties required vary with part design and application and the grade of stainless steel specified. However, successful exhaust flange production requires process conditions that are close to the limits of conventional pressed and sintered technology for ferrous parts.

Table 1: Typical Process Requirements for Exhaust Flange Production

Sintered Density	>7.15 g/cm ³
Compaction Pressure	40-50 tsi
Sintering Temperature	2300-2400 °F
Atmosphere	Hydrogen
Time at Temperature	>30 mins.

These powder and process requirements are more demanding, and more expensive, than those for the majority of ferrous pressed and sintered components.

Table 2: Comparison of Stainless and Conventional P/M Production

	Stainless Flange	Conventional P/M
Compaction Pressure (tsi)	40-50	30-50
Green Density (g/cm ³)	6.5	6.7-7.2
Sintered Density (g/cm ³)	>7.15	6.7-7.2
Green Strength (psi)	1000-1200	1500-3000
Temperature (°F)	2300-2400	2050
Atmosphere	hydrogen	nitrogen/hydrogen
Time at temperature (mins.)	>30	20-30
Furnace	pusher/ceramic belt	conventional belt

To meet these requirements stainless steel powders require: high compressibility and high shrinkage during sintering. Additionally, as parts become more complex, the powder should possess consistent flow for good die fill and good green strength to minimize cracking during part ejection and edge loss during handling. These requirements are challenging and somewhat contradictory. High shrinkage during sintering is favored by high surface area hence fine powders, but fine powders possess poor flow and die fill characteristics. The compressibility and green strength of fine powders are often inferior to those of conventional P/M powders. These characteristics offset some of the benefits of fine powders when producing parts by die compaction and sintering.

POSSIBLE IMPROVEMENTS

If conventional processing is close to the limits of conventional pressing and sintering technologies, further improvements to part performance and process efficiencies will dictate improvements to powder characteristics coupled with improved powder production processes such as arc-furnace melting. These advances will enable P/M to compete with improvements in wrought technologies. The current paper illustrates the

properties of ferritic stainless steel powders that incorporate some of the potential improvements to powder properties.

HIGH PERFORMANCE (HP) STAINLESS STEEL POWDERS

High Performance stainless steel powders have been developed through changes to the melting, powder production and secondary processes. The goal of the HP program is to produce stainless steel powders that possess higher green properties than current water-atomized powders combined with greatly improved production efficiencies.

GREEN PROPERTIES

The first product of the HP program was Ancorsteel 434HP. This powder possesses higher compressibility than conventional powder particularly at higher compaction pressures.

Table 3: Green Density (g/cm³) of Ancor 434 Stainless Steel Powders

Pressure (tsi)	434HP	434L
30	5.85	5.81
40	6.25	6.12
50	6.50	6.35

lubricant 0.75 w/o lithium stearate

HP processing improves the green strength of stainless steel powders . As shown in table 4, the green strength of Ancorsteel 434HP is approximately 50% higher than that of the conventional grade.

Table 4: Green Strength (psi) of 434 Stainless Steel Powders

Pressure (tsi)	434HP	434L
30	644	350
40	1090	700
50	1580	1000

lubricant 0.75 w/o lithium stearate

This combination of good compressibility and improved green strength (Fig. 1) provides a powder that is more forgiving to the parts producer during compaction and handling operations, leading to a reduction in the number of damaged parts and an improvement in process efficiency.

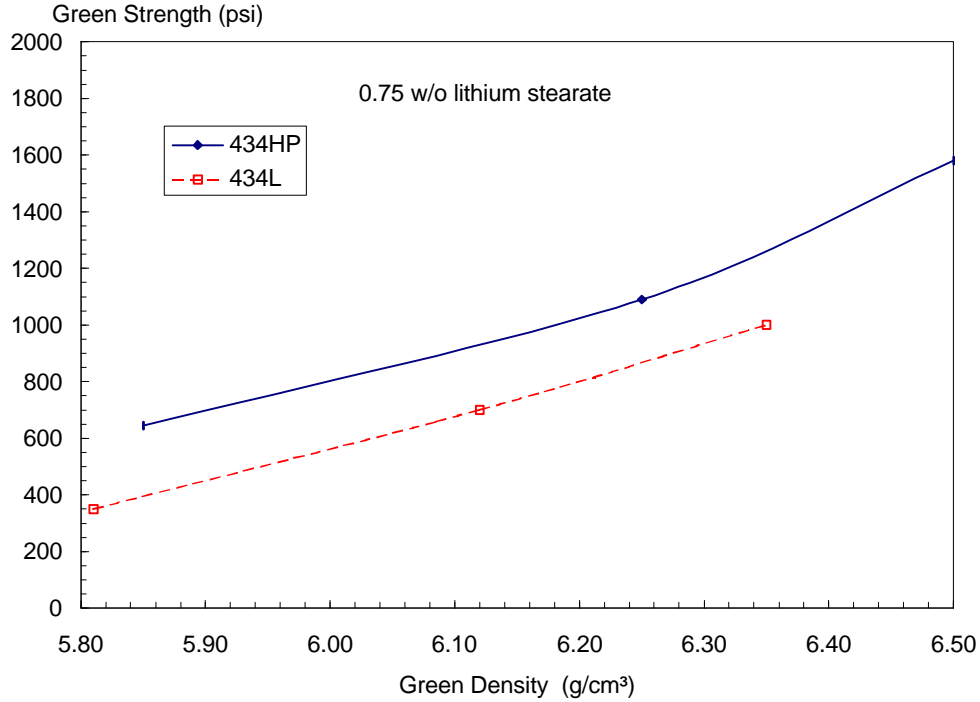


Fig. 1: Green Strength vs. compressibility of Ancor 434HP

Stabilized Grades

Although considerable development was devoted to 434 stainless steels, stabilized such as 409 and 410 plus columbium have been more widely specified for exhaust applications where the improved weldability offered by columbium offers a performance advantage over non-stabilized grades.

HP processing can be applied to stabilized grades with similar results to those observed in 434. The compressibility of 410Cb is equivalent to that of the conventional grade (Fig. 2).

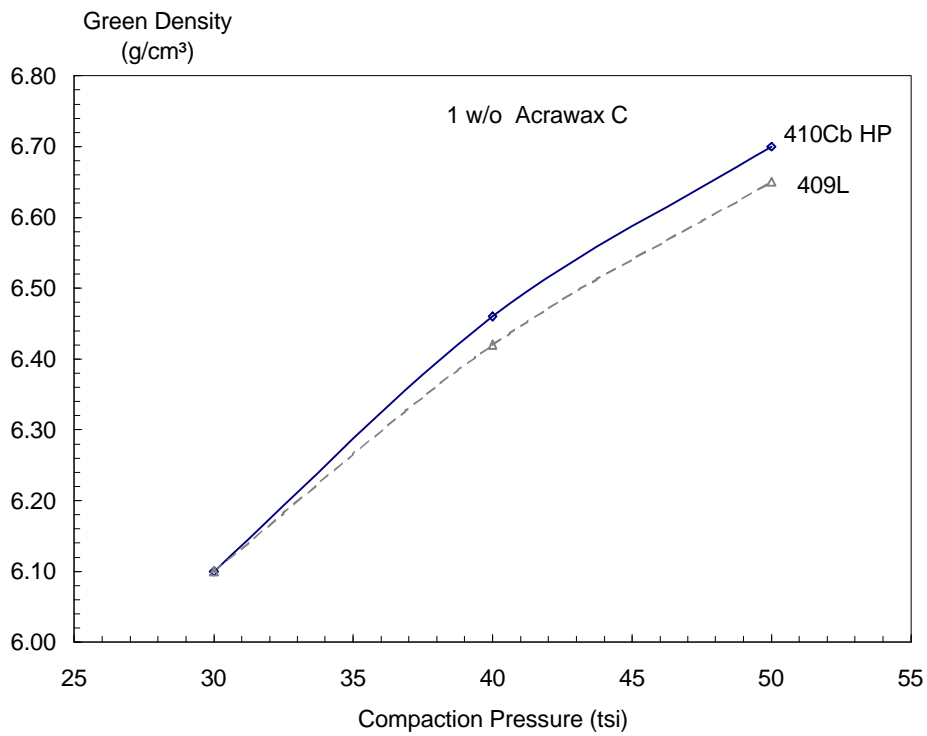


Fig. 2: Compressibility of 410Cb HP

However HP processing increases green strength significantly particularly at higher

Table 5: Green Strength of 410Cb HP

Pressure (tsi)	410CbHP	409L
30	700	547
40	1245	892
50	1700	1240

1w/o Acrawax C

compaction pressures such that the HP processed grade offers a superior combination of green strength and compressibility than the conventional grade (Fig. 3).

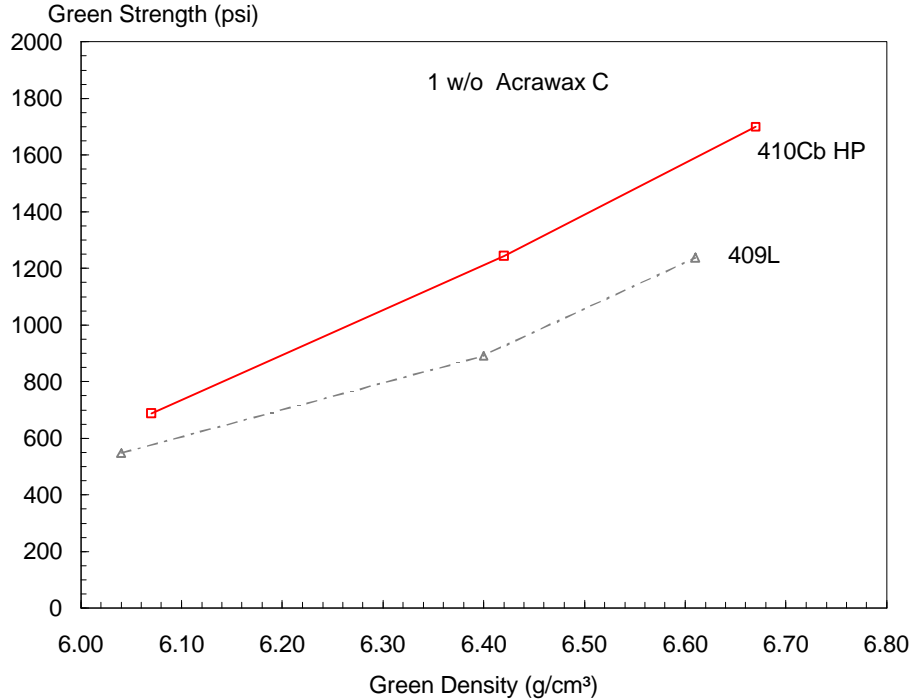


Fig. 3: Green Strength vs. Green Density of Ancor 410Cb HP

SINTERED PROPERTIES OF HP STAINLESS STEELS

The sintered properties of stainless steels depend strongly upon sintering temperature, atmosphere and time at temperature²). Testing results show the sintered strength and macro hardness of the HP stainless steels are the same as those of conventionally produced grades, although they experience less shrinkage during sintering. These results are illustrated at sintering temperatures of 2050°F and 2350°F.

Low Temperature Sintering

The sintered properties of the 410Cb HP are illustrated in figures 4 and 5 below. The results illustrate that the sintered strength of the HP processed material is equivalent to that of the 409L. In both materials TRS, sintered at 2050°F in 75 v/o hydrogen/ 25v/o nitrogen TRS increases from approximately 45×10^3 psii when compacted at 30 tsi to 80×10^3 psi when compacted at 50 tsi. However, the HP processed material shows slightly less shrinkage during sintering than the 409L and shows slightly greater growth from die size at all compaction pressures.

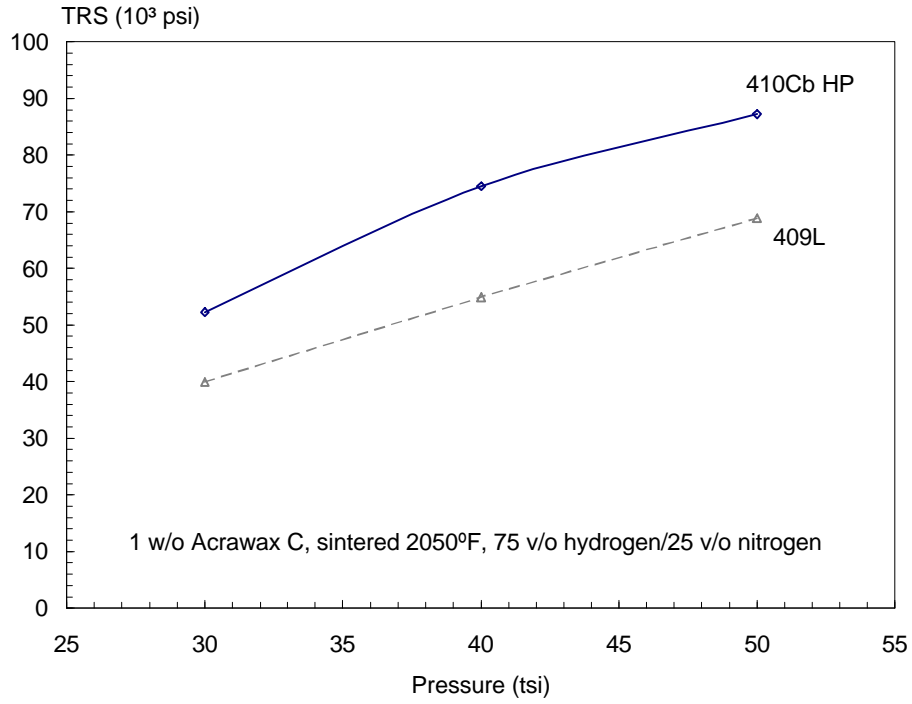


Fig. 4: TRS of 410Cb HP sintered at 2050°F

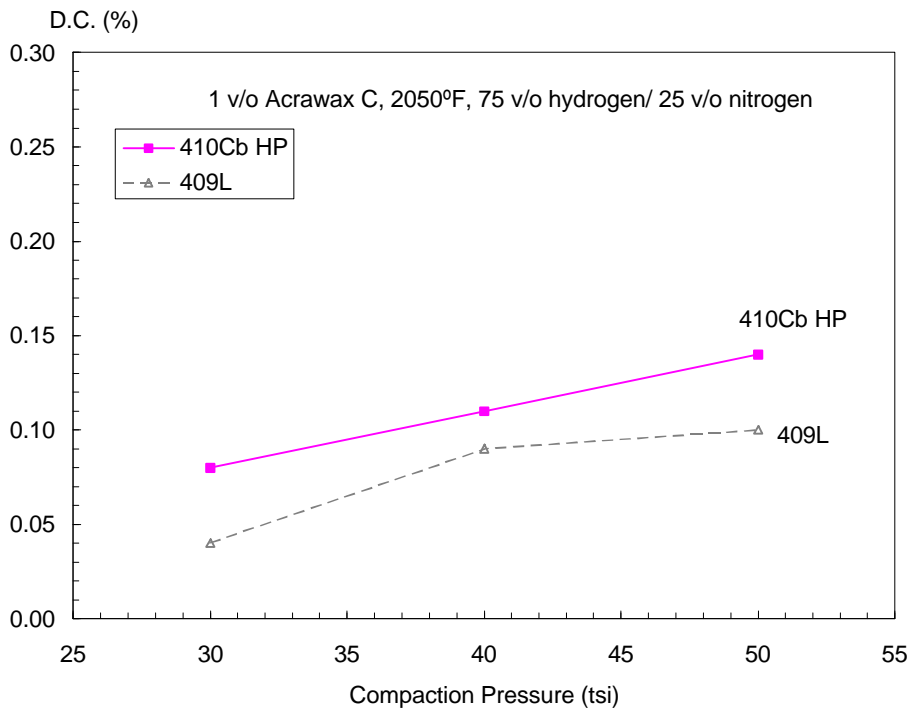


Fig. 5: Dimensional Change of 410Cb HP sintered at 2050°F

HIGH TEMPERATURE SINTERED PROPERTIES

The response of stainless steels sintered at low temperatures is interesting for less critical applications and comparative purposes. However, those intended for exhaust flanges, particularly stabilized grades, should be sintered at high temperatures in atmospheres of low nitrogen content.

The results show (Table 6) that the mechanical properties of the Ancor 410CbHP sintered at 2350°F under 100 v/o hydrogen atmosphere are equivalent to those of the conventionally produced 409L.

Table 6: High Temperature Sintered Properties of Ancor 410CbHP

Grade	P (tsi)	GD (g/cm ³)	SD (g/cm ³)	D.C. (%)	TRS (10 ³ psi)	Hard. (HRA)
HP	30	6.09	6.60	-2.99	98.5	24
	40	6.44	6.97	-2.87	149.9	31
	50	6.66	7.11	2.36	129.5	34
L	30	6.10	6.76	-3.50	99.5	27
	40	6.41	7.10	3.70	139.4	34
	50	6.54	7.23	3.04	129.4	34

compacted 1w/o Acrawax C
sintered 2350°F, 100 v/o hydrogen, 30 mins.

For both alloys TRS increases from 99 x 10³ psi to 130 x 10³ psi with increasing compaction pressure. The data show that the Ancor 409L shows greater shrinkage during sintering than the Ancor 410HP.

Tensile Properties

High temperature sintering produces significant densification and also reduces carbon, nitrogen and oxygen contents of stainless steels. These effects combine to increase ductility significantly such that tensile tests are a better indicator of mechanical properties than three point bend tests. Tensile testing showed that the tensile properties of the Ancor 410HP are equivalent to those of the Ancor 409L despite the slightly lower density.

It can be seen that both yield strength (Fig.6) and ultimate tensile strength (Fig. 7) do not change significantly with increasing compaction pressure. Yield strength increases from about 25 x 10³ psi to 28 x 10³ psi despite an increase in density from about 6.65 to 7.2 g/cm³.

Ultimate tensile strength shows a larger increase with increasing density from about 39 x 10³ psi to 47 x 10³ psi over the same range of compaction pressures.

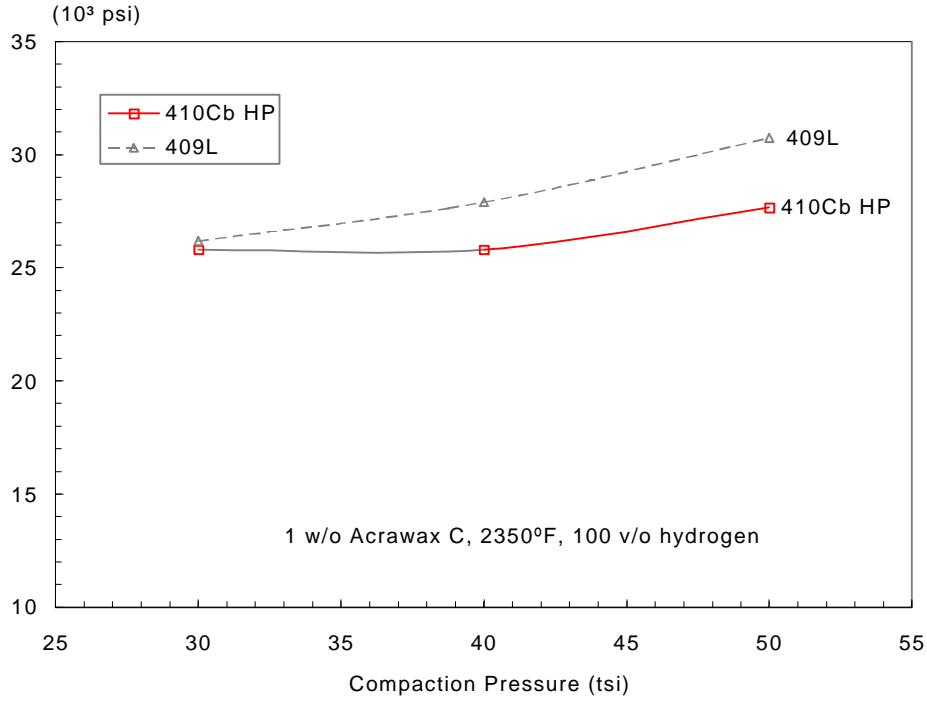


Fig. 6: Yield Strength of High Temperature Sintered Ancor 410Cb HP

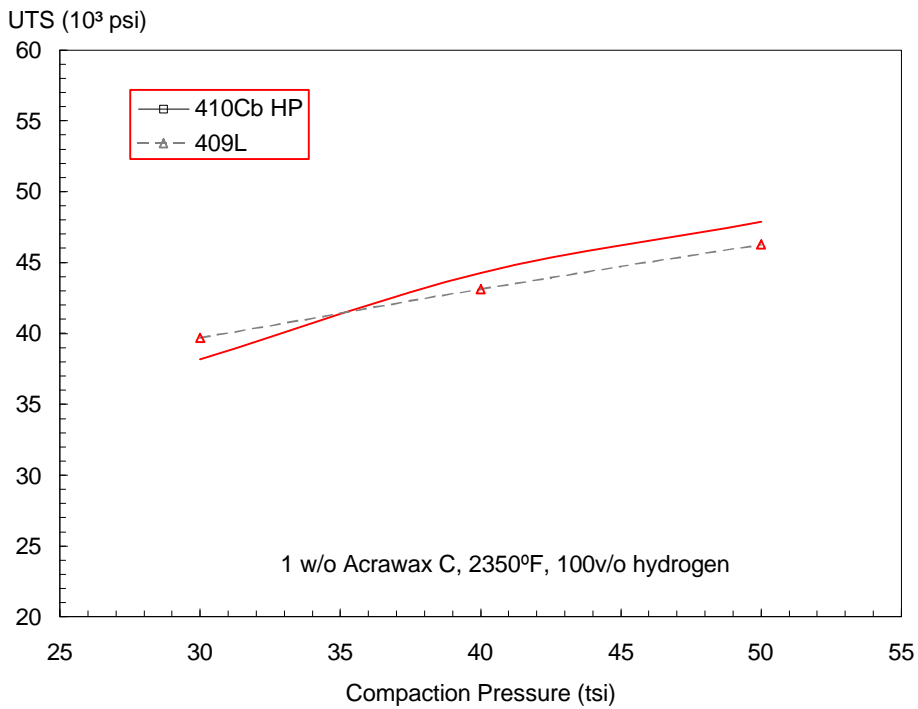


Fig. 7: UTS of High Temperature Sintered Ancor 410Cb HP

Both the conventional 409L and m HP processes 410Cb HP are very ductile for P/M steels (Fig. 8). Elongation at break increases from about 13% when compacted at 30tsi to about 17% when compacted at 50tsi.

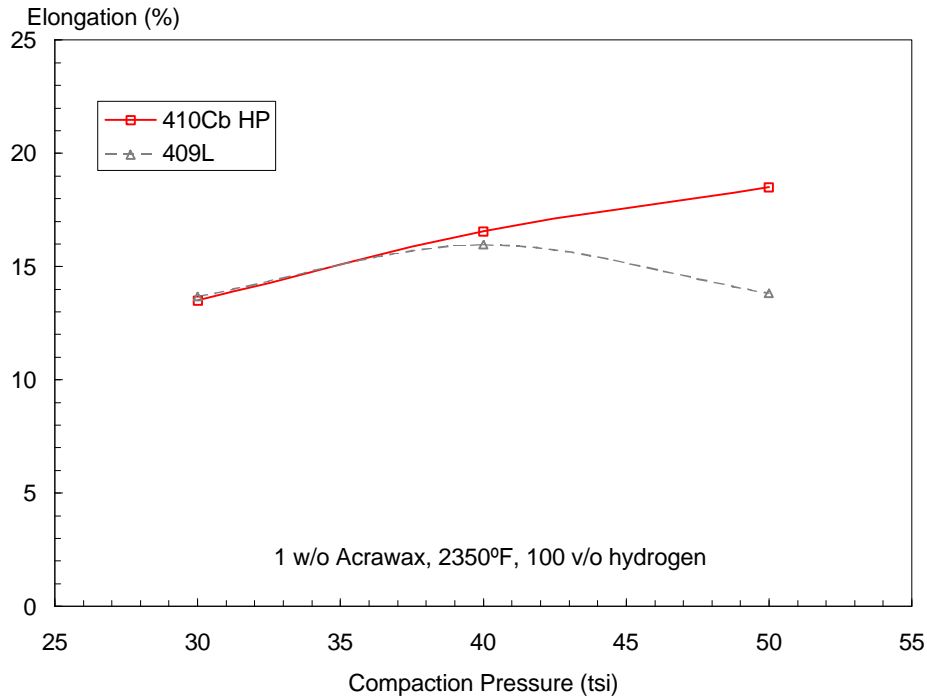


Fig.8: Elongation of High Temperature Sintered Ancor 410Cb HP

APPLICATION TO OTHER ALLOYS

Although the test program above concentrated upon the sintered properties of Ancor 410CbHP, testing has shown that the process can be extended to other ferritic stainless steels. Testing under production conditions shows that the sintered densities

Table 7: Sintered Density of High Performance Stainless Steels

Grade	Sintered Density (g/cm ³)
410	7.25
410Cb	7.33
434	7.20

Compaction 50tsi , Sintered 2400°F

can be increased further with higher sintering temperatures or longer sintering times.

CONCLUSIONS

HP stainless steels provide a better combination of green strength and green density than is available with conventional grades.

The sintered properties of the HP stainless steels are equivalent to those of conventional grades.

The HP grades show slightly less shrinkage and densification than the equivalent composition.

REFERENCES

Ref. 1: Requirements for Stainless Steel P/M Materials in Automotive Exhaust System Applications, Pamela Lee, PM²TEC 97.

Ref. 2: High Temperature Sintering , Section II, MPIF, Princeton N.J. 1990