Improved Efficiency by Use of Sinter-Hardened P/M Automotive Components

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INTRODUCTION
Sinter-hardening, accelerated cooling, of P/M components directly from the sintering furnace is an increasingly popular production process. Sinter-hardened P/M steels possess similar macrohardness and strength to heat treated P/M steels processed by quenching and tempering. Where design permits, sinter-hardening enables P/M fabricators to improve process efficiencies by omitting a separate heat treatment operation. This paper examines the interaction of material selection and process conditions required to develop a sinter-hardened P/M component for an automotive application.

SINTER-HARDENING PROCESS
The aim of the sinter-hardening process (Fig. 1) is to produce a part with high martensite content without a conventional heat treatment process. This is achieved by accelerated gas cooling of the sintered compact from the sintering furnace.

The process combines press ready premixes of high hardenability with furnace designs that achieve much higher cooling rates in the cooling zone than are normally employed in conventional part production. High cooling rates are achieved by circulation of the atmosphere within the cooling zone through heat exchangers, then recirculation of the cooled gases at high velocity over the sintered parts.

Sinter-Harden	Sinter-Heat treat
Premix	Premix
Compact	Compact
Sinter	Sinter
Rapid Cool	"Slow" Cool
Temper	Austenitize &Quench
	Temper

Fig. 1: Comparison of Sinter-Hardening and Conventional P/M heat treatment.

With the correct combination of powder premix composition and cooling conditions it is possible to produce sintered parts with martensite contents, macrohardness and mechanical properties typical of heat treated P/M steels without a separate austenitizing heat treatment. Thus where part design permits, sinter-hardening improves process efficiencies by omission of the separate austenitizing heat treatment.

POTENTIAL PART
The potential of sinter-hardening to displace heat treatment of P/M steels was assessed by attempting to produce an automotive transmission parking

brake (Fig. 2), that is currently produced in a heat treated P/M steel, by sinter-hardening.

Fig. 2: P/M Transmission Parking Brake

The part is currently produced in a heat treated P/M steel corresponding to MPIF designation FN-0205HT processed to nominal sintered density of 7.1 g/cm³. The part has to meet a specification for macrohardness and pass a proof test in which a minimum load-to-fracture for a heat treated part is specified. The conversion process thus required materials selection, optimization of processing and production of prototype parts for the proof test.

MATERIAL SELECTION
MPIF Standard 35 (Ref. 1) indicates that a heat treated FN-0205 can be anticipated to possess the following mechanical properties when processed to densities in the range of 6.9 to 7.2 g/cm³. Minimum tensile strengths are 100 MPa lower than the typical value

Table 1: Anticipated Properties for FN-0205HT

Desig nation	Density (g/cm³)	YS (MPa)	UTS (MPa)	Elong. (%)
105HT	6.9	*	830	<0.5
130HT	7.0	*	1000	<0.5
155HT	7.2	*	1100	<0.5

* YS and UTS are approx. the same

reported in the standard. It can be seen that all properties increase with increasing density.

Achieving these targets requires finding a compromise between an alloy of high hardenability, high hardness, good sintered strength but sufficient compressibility to maintain density during commercial part production. The approach chosen was:

Select a prealloy steel powder of good hardenability.
Add copper and nickel to increase hardenability
Increase graphite to increase the hardness of the matrix.

The graphite increase was necessary to compensate for the reduction in compressibility of the prealloyed powders compared to the iron powder specified for FN-0205.

Table 2: Compositions of Ancorsteel Prealloy Powders

	Ancorsteel 737 SH	Ancorsteel 150 HP
Mn (w/o)	0.42	0.14
Mo (w/o)	1.25	1.50
Ni (w/o)	1.4	<0.1
Density (g/cm³) at 40 tsi	6.9	7.0

Two different prealloyed steel powders: Ancorsteel 737 SH and

Ancorsteel 150 HP (Table 2) were chosen as the base to which alloy alloy additions additions were made.The presence of prealloyed manganese and nickel in Ancorsteel 737 SH (Ref. 2) increases its hardenability and suitability for sinter-hardening, over that of Ancorsteel 150 HP but reduces its compressibility.

The transmission parking brake has relatively thick cross sections that reduce cooling rates compared to those of the small cross sections used for preparation of test pieces in standards work. Additional copper and nickel were incorporated into the premix to further increase hardenability so as to accomodate the reduction in cooling rates anticipated in sinter-hardening from those obtained attained in oil quenching.

The prealloyed powder possess lower compressibility than the iron powder used in the FN-0205 premix. The graphite content of the sinter-hardening premixes was increased . The aim was that the higher hardness of the martensite formed would compensate for the increased porosity and maintain macrohardness close to that of the current heat treated part.

Evaluation of these effects required preparation of six combinations of alloying additions for each alloy steel powder (Table 3).

Table 3: Premix Additions to Alloy Powders

Copper (w/o)	Nickel (w/o)	Graphite (w/o)	Acrawax C (%)
2	0	0.90	0.75
2	0	0.70	0.75
1	1	0.90	0.75
1	1	0.70	0.75
0	2	0.90	0.75
0	2	0.70	0.75

TEST PROGRAM
Test pieces for property determination were compacted at a pressure of 45tsi. The specimens required for the un notched Charpy test were compacted directly to size. The threaded round test pieces required for tensile testing were machined from an 0.45 inch square by 4 inch long blank. The green densities of the Ancorsteel 737 SH premixes were approximately 6.95 g/cm³. The test pieces produced in Ancorsteel 150 HP possessed slightly higher green densities of about 7.05 g/cm³. Five test pieces were compacted for each process condition. The macro hardness of all test pieces was measured in the as sintered and tempered conditions. The tensile test pieces machined from sintered blanks were stress relived at 195 ⁰C prior to testing. Sections were taken from the fractured test pieces for metallographic examination and microhardness testing.

PROCESS CONDITIONS
The test pieces were sintered at Chicago Powdered Metal Products Company at 1120 ⁰C for 30 minutes (Fig. 3) in an endothermic gas atmosphere using a Drever belt furnace running at rated capacity.
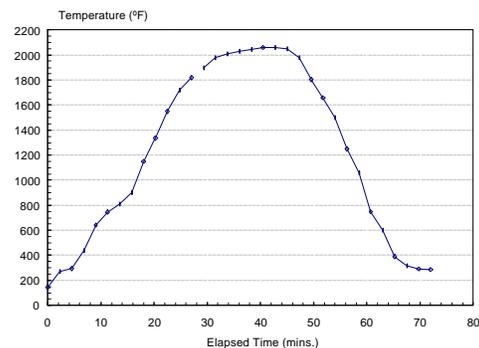

Fig. 3: Temperature vs. Time Profile for a Sinter-hardening Trial.

The furnace was equipped with a Rapid Burn Off zone for lubricant removal and Convecool zones to accelerate the cooling rate from the sintering temperature. The same preheat and sintering set points were employed for all process trials. However, the operating conditions of the Convecool zones were adjusted to change the cooling conditions for the parts.

The test pieces were placed on the belt with routine production parts so as to maintain normal belt loading. The temperature-time profiles were measured by inserting a type K thermocouple into the heaviest cross section of a production part of similar cross section to the transmission parking brake. Two examples of the cooling rates measured are shown in Figure 4.

The conditions employed for Trial B reduced the time required to cool to discharge temperature by about five minutes and produced a lower discharge temperature.
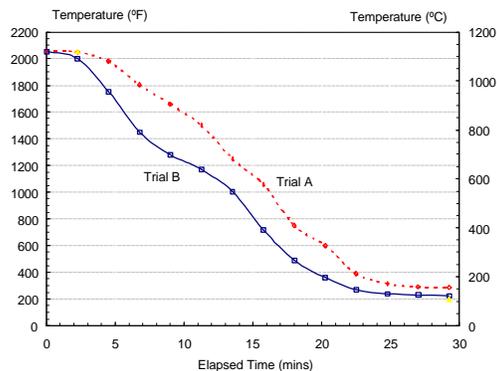

**Fig. 4: Cooling Curves for Part during Sinter-Hardening Trials**

RESULTS
Overall the results showed that the premixes based upon the Ancorsteel 737 SH developed higher hardness and tempered strength than those based upon the Ancorsteel 150 HP. Metallography indicated that the Ancorsteel 737 SH copper,graphite premixes possessed martensitic microstructures whereas those based upon Ancorsteel 150 HP possess significant amounts of pearlite or bainite. Increasing cooling rates increased the martensite contents and hardness of the Ancorsteel 150 HP copper, nickel premixes but did not produce fully martensitic microstructures. Premixes with the 0.7 w/o graphite addition possessed lower hardness, but higher strength than similar premixes with 0.9 w/o graphite. Examples of the results are discussed further below.
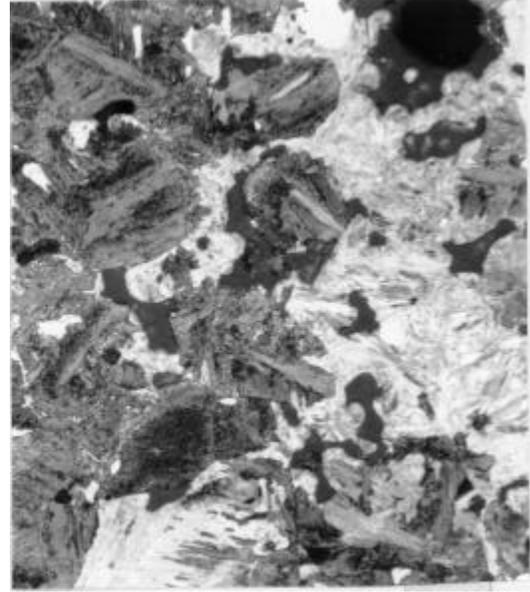
MICROSTRUCTURE
The microstructures of sections cut from the tempered impact test piece are shown in Fig. 5. It is clear that the Ancorsteel 737 SH (5a and 5c) premixes have much higher martensite contents than the equivalent premixes made with Ancorsteel 150 HP.

When only copper (5a and 5b) is added as a premix alloying addition the microstructures are predominately martensite, plus pearlite and bainite in the case of the Ancorsteel 150 HP compositions. When nickel is introduced as a premix alloying element (5c and 5d) light etching nickel rich areas including alloy martensites and possibly retained austenite formed. These nickel rich areas are typical of conventional sintering.
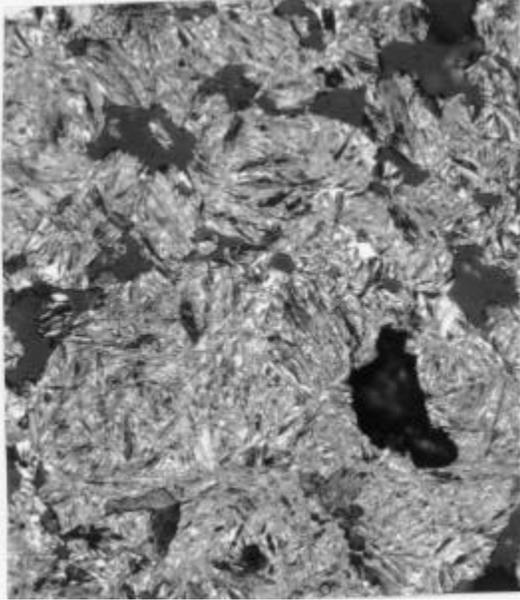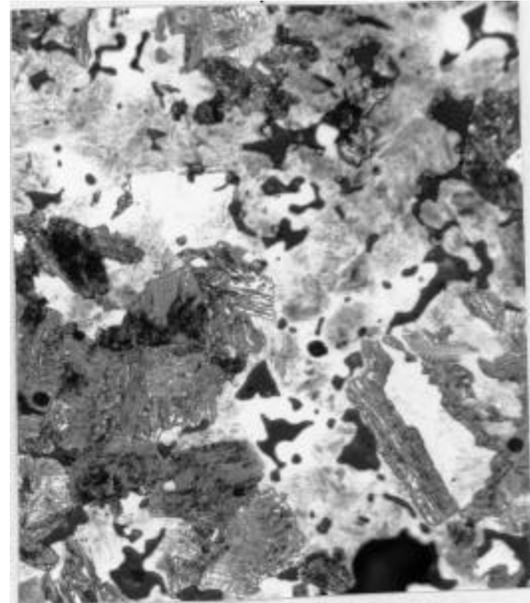
a: Ancorsteel 737 SH

 2 w/o Cu, 0.9 w/o Graphite

b: Ancorsteel 150 HP
 2 w/o Cu, 0.9 w/o Graphite
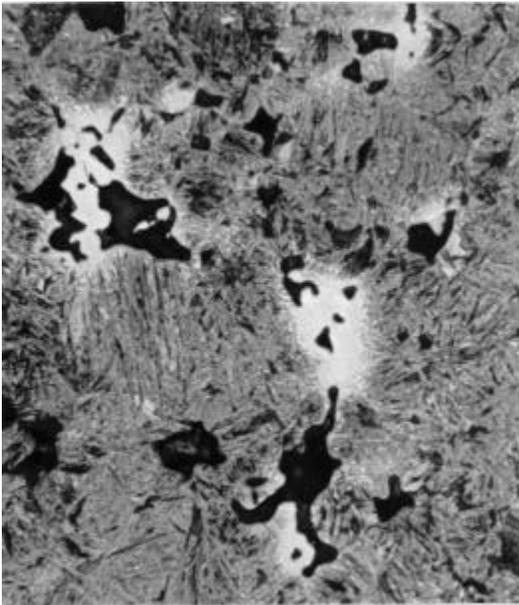
c: Anorsteel 737 SH
 2 w/o Ni, 0.7 w/o Graphite

d: Ancorsteel 150 HP
 2 w/o Ni, 0.9 w/o Graphite

Fig. 5: Microstructure of Sinter-Hardened Test Pieces
Original Magnification 500X, etched with a combination of 2% nital/ 4% picral

MACROHARDNESS

The test pieces produced from the Ancorsteel 737 SH premixes possess significantly higher hardness than premixes produced from Ancorsteel 150 HP (Table 4) .Increasing graphite content from 0.7 w/o to 0.9 w/o increased the tempered hardness of all alloy compositions.

Table 4: Tempered Hardness (HRC) of Sinter-Hardened Preforms made from Ancorsteel Powders

Cu-Ni (w/o)	Graphite (w/o)	737 SH Trial A	150 HP Trial A	737 SH Trial B	150 HP Trial B
2-0	0.9	36.9	27.2	37.7	26.1
2-0	0.7	33.3	22.4	33.6	19.5
1-1	0.9	34.2	25.7	35.4	26.8
1-1	0.7	31.7	19.3	34.0	23.5
0-2	0.9	34.8	21.1	36.0	20.4
0-2	0.7	31.8	18.9	35.3	18.4

Tempered 1hr. at 195º C in air.

The changes in cooling conditions from Trial A to Trial B tended to increase the hardness of the Ancorsteel 737 SH compositions, but their effect upon the Ancorsteel 150 HP compositions was less consistent. The results indicate that a copper addition has a greater effect upon hardenability and hardness than an equivalent nickel addition.

TENSILE STRENGTH

Reducing graphite content of the premixes from 0.9 w/o to 0.7 w/o increases the tensile strength of (Table 5) the Ancorsteel 737 SH compositions. It may slightly reduce the strength of the Ancorsteel 150 HP premixes.

Changing the premix alloy addition from copper to nickel appears to have little effect upon tensile strength.

Table 5. Tensile Strength (MPa of Sintered Hardened Preforms made from Ancorsteel Powders

Cu-Ni (w/o)	Graphite (w/o)	737 SH Trial A	150 HP Trial A	737 SH Trial B	150 HP Trial B
2-0	0.9	895	880	780	820
2-0	0.7	1030	830	1000	740
1-1	0.9	900	960	900	860
1-1	0.7	1030	890	990	850
0-2	0.9	900	850	830	790
0-2	0.7	1030	850	1010	810

Tempered 1hr. at 195º C in air.

The changes in process conditions do not appear to have made a significant change to tensile strength. Although It is possible that the conditions of trial A produce higher tensile strength in the Ancorsteel 150 HP compositions.

IMPACT ENERGY

Generally, the un-notched Charpy impact energy of the test pieces produced from the Ancorsteel 150 HP alloy steels is slightly greater than that of the Ancorsteel 737 SH compositions (Table 6). It appears possible that the the Ancorsteel 737 SH 2 w/o Copper, 0.7 w/o Graphite composition is an exception since its impact energy is closer to the Ancorsrel 150 HP premixes. Adding nickel to the premix appears to increase impact energy

Table 6: Unnotched Charpy Impact Energy (Joules) of Sinter-Hardened Test Pieces made from Ancorsteel Powders

Cu-Ni (w/o)	Graphite (w/o)	737 SH Trial A	150 HP Trial A	737 SH Trial B	150 HP Trial B
2-0	0.9	7.6	7.9	6.2	7.5
2-0	0.7	9.5	6.8	10.3	6.0
1-1	0.9	8.8	9.9	8.4	11.1
1-1	0.7	8.7	10.6	9.2	10.3
0-2	0.9	7.6	9.2	-	10.3
0-2	0.7	7.9	10.6	8.7	9.9

Tempered 1hr. at 195º C in air.

The change in process conditions did not produce a change in impact energy.

MATERIAL SELECTION

Based upon the results above it is clear that the superior hardenability of the Ancorsteel 737 SH produced a better combination of strength and hardness than the Ancorsteel 150 HP with the possible exception of impact strength. The presence of 0.7 w/o Graphite in the 737 SH premixes produces higher tensile strength than 0.9 w/o graphite. It appears that the Ancorsteel 737 SH 2 w/o Copper, 0.7 w/o graphite possesses the best combination of hardness and tensile strength (Fig. 6)
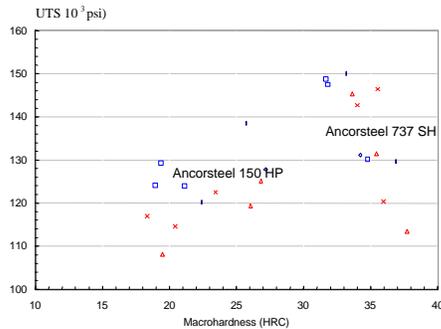

Fig. 6: UTS vs. Macrohardness of Sinter-Hardened and Tempered P/M Steels

Its strength was relatively unchanged by the changes to process conditions. This material was the primary candidate for production part trials.The Ancorsteel 737 SH, 2 w/o Copper, 0.9 w/o Graphite composition was also tested. It was thought that hardness alone, could be a limiting design factor for the part, rather than the combination of strength and hardness.

PROTOTYPE PARTS

Prototype transmission parking brakes were compacted using production tooling at Chicago Powdered Metal

Products. The parts were sinter-hardened using process conditions from trial B with the belt loaded to production capacity.

Parts were selected at random from the belt. The hardness of the parts was measured before and after tempering at 200⁰ C for one hour prior to measuring load to fracture.

Table 7: Macrohardness (HRC) of Sinter-Hardened Transmission Parking Brakes

	0.7 w/o Graphite	0.9 w/o Graphite
No temper	38	43
Temper	32	35

Tempered at 200⁰ C for 1hr in air

The sintered hardness of the 0.9 w/o graphite parts was higher than those of 0.7 w/o graphite content. There was less difference in hardness after tempering.
The results listed in Table 8 show that the sinter-hardened prototypes produced with the Ancorsteel 737 SH, 2 w/o Copper, 0.7 w/o Graphite composition approach the mean properties of the current heat treated FN-0205 parts.

Table 8: Relative Crush Test Results for Sinter-hardened Transmission Parking Brakes

	0.7 w/o Graphite	0.9 w/o Graphite	FN-205HT
No Temper	0.77	0.47	
Temper	0.93	0.65	1.00

The results also confirmed the trend observed in the initial trial that

increasing graphite content from 0.7 to 0.9 w/o reduced strength.

It also confirmed the beneficial effects of tempering upon the strength upon sinter-hardened P/M steels of such high hardness levels.

Metallographic examination of sections cut from a tempered part of 0.7 w/o graphite content showed (Fig. 7) that its microstrucure consisted of about 95 w/o tempered martensite with small amounts of bainite and pearlite.There was little difference between the microstuctures at different cross sections of the part.

CONCLUSIONS

The test program showed that sinter-hardening can be used to produce a P/M automatic transmission parking brake that meets the standard in-process testing requirememts for heat treates P/M parts.

Through a combination of alloy design and process conditions a sinter-hardened P/M steel can be produced that possesses a fully martensitic microstructure.
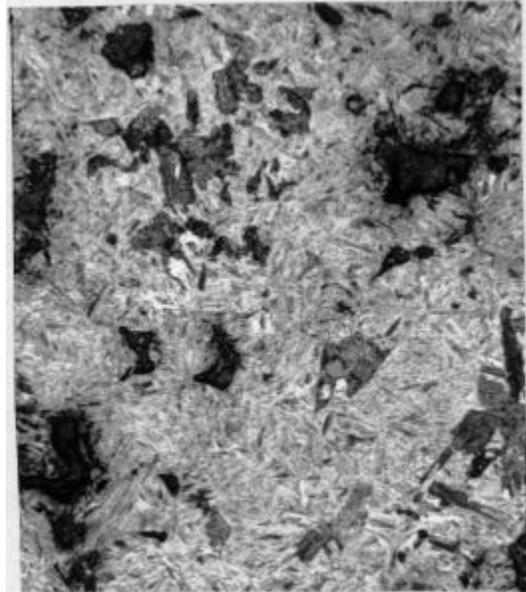

Fig.7: Microstructure of Sinter-Hardened and Tempered Automatic Transmission Parking Brake. Ancorsteel 737SH 2 w/o Copper, 0.7 w/o Graphite Original magnification 500X, etched with a combination of 2 % nital/ 4 % picral

Tempering reduces sintered hardness but increases the strength of sinter-hardened parts.

Ancorsteel 737 SH possesses high hardenability and provides an excellent base for the production of sinter-hardened components.

REFERENCES

Ref. 1: MPIF Standard 35, Materials Standards for P/M Structural Parts, 1997 Edition, MPIF, Princeton N. J.

Ref. 2: M. C. Baran et al "A Superior Sinter-Hardenable Material", , Advances in Powder Metallurgy and Particulate Materials, 1999, Vol. 2, p7, MPIF, Princeton, N. J.