MATERIAL PROPERTIES OF HEAT TREATED DOUBLE PRESSED/SINTERED P/M STEELS IN COMPARISON TO WARM COMPACTED/SINTER HARDENED MATERIALS

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ABSTRACT

Warm Compaction of Densmix^{TM} powders provides means to produce P/M parts with densities in the range of 7.1 to 7.4 g/cc. As most properties are improved by increased density, the warm compaction method offers possibilities to increase the competitiveness of P/M compared to other manufacturing techniques.

In this paper a comparison of material properties obtained by two different manufacturing routes is presented. Heat treated properties of some P/M steels after double pressing/sintering are compared with properties obtained with sinterhardening of warm compacted Densmix^{TM} powders.

INTRODUCTION

The original purpose of the work was to determine if a gear currently being manufactured by double pressing/double sintering and heat treating could be replaced by a warm compacted and sinter hardened gear. Double press/double sinter is currently used to manufacture a family of gears for an automotive application. Brockway Pressed Metals is interested in reducing the manufacturing cost of the gear without sacrificing any performance. By converting to warm compaction and sinterhardening, three manufacturing processes (pre-press, pre-sinter, heat treat) could be eliminated.

The scope of manufacturing processes to be evaluated was expanded to include conventional sintering and secondary heat treating combined with warm compaction. This alternative still offers a significant cost advantage, although it only eliminates two processing steps.

MATERIALS

Three materials were investigated based on Astaloy 85Mo and D.DC-1. The compositions of the base materials are shown in Table 1 and the composition of the blends is shown in Table 2. The existing material is described below as Pre-mix and is based on Astaloy 85Mo with 0.4 $^{w}/_{o}$ Graphite and 0.6 $^{w}/_{o}$ lubricant.

The materials chosen for the comparison were selected because they were similar to the existing material combination. There are material combinations available that may provide better response to sinterhardening. However, the end user was not interested in exploring these combinations due to the success with the current material. Therefore, the material combinations are not optimized for the sinterhardening process[2].

Table I: Chemical composition of Base Materials

GRADE	MO %	NI %
Astaloy 85 Mo	0.85*	-
D.DC-1	1.47*	2.10**

* Pre-Alloyed
** Diffusion Bonded

Table II: Chemical Composition of Blends

MIX TYPE	BASE MAT'L	GRAPHITE ($^{w}/_{o}$)	NI ($^{w}/_{o}$)	CU ($^{w}/_{o}$)	LUBRICANT ($^{w}/_{o}$)
Pre-mix	Astaloy 85Mo	0.4	-	-	0.8
Densmix™ 1	Astaloy 85Mo	0.4	-	-	0.6
Densmix™ 2	Astaloy 85Mo	0.6	1.0	1.0	0.6
Densmix™ 3	D.DC-1	0.6	-	-	0.6

PROCESSING CONDITIONS

Tables III – V outline the processing conditions for the test specimens. All test specimens were manufactured in the lab in Höganäs AB on the Result semi-automatic press. Sintering and tempering were carried out at Brockway Pressed Metals on production sintering equipment. Heat treatment was performed at Pennsylvania Heat Treaters. The tensile bars were prepared to ISO 2740 and the impact energy bars to ISO 5754.

Table III: Current Processing Conditions

1. Press	2. Pre-Sinter	3. Re-press	4. Sinter	5. Heat Treat	6. Temper
700MPa (50tsi)	750°C (1382°F) 90%N_2/ 10%H_2	400MPa (29tsi)	1138°C (2080°F) 38 minutes @ Temp	843°C (1550°F) 1 hour 0.7% C-pot Oil Quench	177°C (350°F) 1 hour Air

Table IV: Initial Processing Conditions for Densmix™ 1 – 3

1. Warm Compact	2. Sinterharden	3. Temper
700MPa	1132°C	177°C
(50tsi)	(2070°F)	(350°F)
	26 minutes @ Temp	1 hour
	Estimated Cooling Rate:	Air
	1.5 °C/s (2.7 °F/s)	

Table V: Additional Testing for Densmix™ 1 – 3

1. Warm Compact	2. Sinter	3. Heat Treat	4. Temper
700MPa	1138°C	843°C	177°C
(50tsi)	(2080°F)	(1550°F)	(350°F)
	38 minutes @ Temp	1 hour	1 hour
		0.7% C-pot	Air
		Oil Quench	

PROPERTIES

The following section contains the properties achieved with the different materials and processing methods. All testing was performed by Höganäs AB.

Table VI: Densities and Dimensional Change of Test Specimens

Mix Type	Green Density (g/cm^3)	Sintered Density (g/cm^3)	Dimensional Change – From Die (%)
Pre-mix [1,2]	7.33[1]	7.31	0.13
Densmix™ 1[3]	7.35	7.34	0.06
Densmix™ 2[3]	7.33	7.24	0.28
Densmix™ 3[3]	7.33	7.32	0.04
Densmix™ 1[4]	7.35	7.33	0.13
Densmix™ 2[4]	7.32	7.26	0.18
Densmix™ 3[4]	7.33	7.33	0.13

1. Density and dimensional change after second pressing
2. Double Press/double sinter – Heat Treat – Temper
3. Warm Compact – Sinterharden – Temper
4. Warm Compact – Sinter – Heat Treat - Temper

Table VII: Mechanical Properties of Test Specimens

Mix Description	UTS MPa (ksi)	Yield Strength MPa (ksi)	Elongation A %	Apparent Hardness HV10 (HRB, HRC)	Impact Energy J (ft-lbs)
Pre-mix[1]	1114 (162)	1000 (145)	0.3	563 (C45)	15 (11)
Densmix™ 1[2]	568 (82)	440 (64)	2.9	175 (B84)	24 (18)
Densmix™ 2[2]	1062 (154)	918 (133)	0.4	332 (C38)	16 (12)
Densmix™ 3[2]	1100 (160)	862 (125)	0.9	344 (C36)	20 (15)
Densmix™ 1[3]	1170 (170)	1015 (147)	0.3	559 (C45)	12 (9)
Densmix™ 2[3]	1044 (151)	979 (142)	0.7	492 (C44)	13 (10)
Densmix™ 3[3]	1134 (164)	1034 (150)	0.4	522 (C45)	16 (12)

1. Double Press/Double Sinter – Heat Treat – Temper
2. Warm Compact – Sinterharden – Temper
3. Warm Compact – Sinter – Heat Treat - Temper

METALLOGRAPHY

Metallographic analysis was performed on the samples after heat treating and sinterhardening. Percentages of phases present were estimated metallographically.

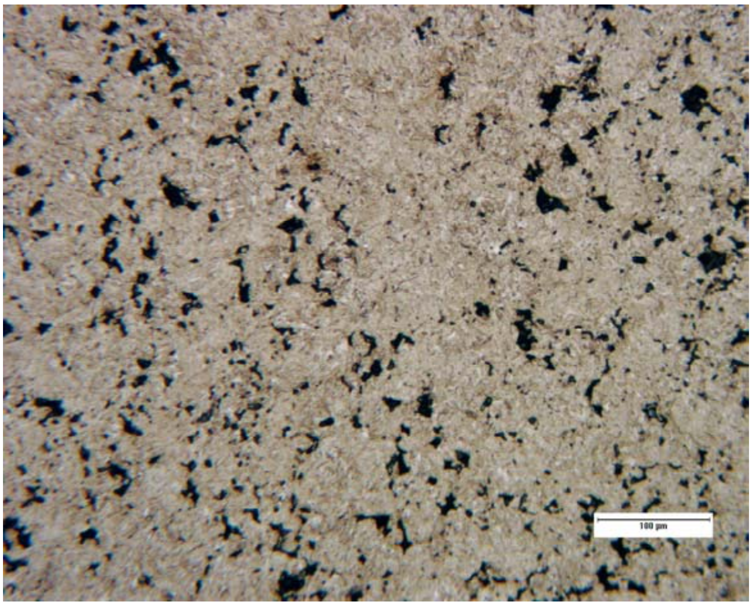

Figure 1 : Pre-mix 1, heat treated, 100% Martensite

Pre-mix exhibits complete martensite transformation due to secondary heat treat and quench. Pore distribution is good, with the presence of some large pores.

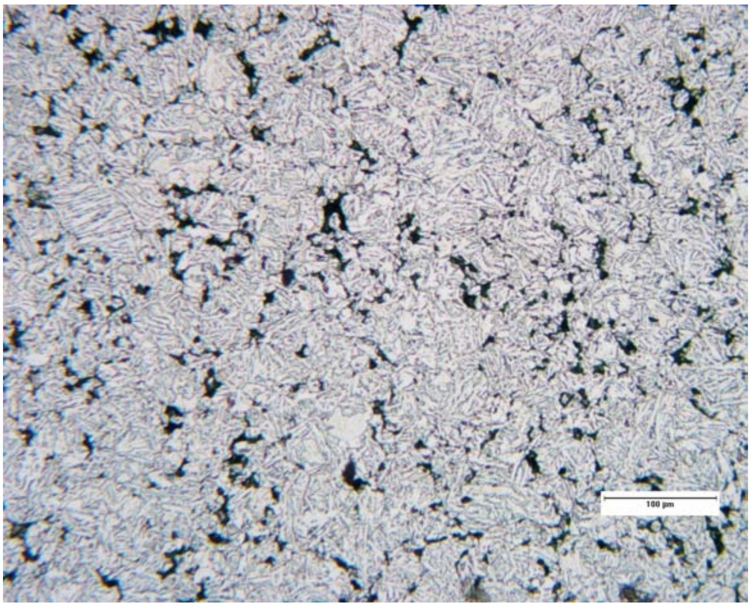

Figure 2: Densmix^{TM} 1, sinterhardened, Bainite

Densmix^{TM} 1 exhibits poor response to sinterhardening at available cooling rate. Microstructure is Bainitic with good pore distribution.

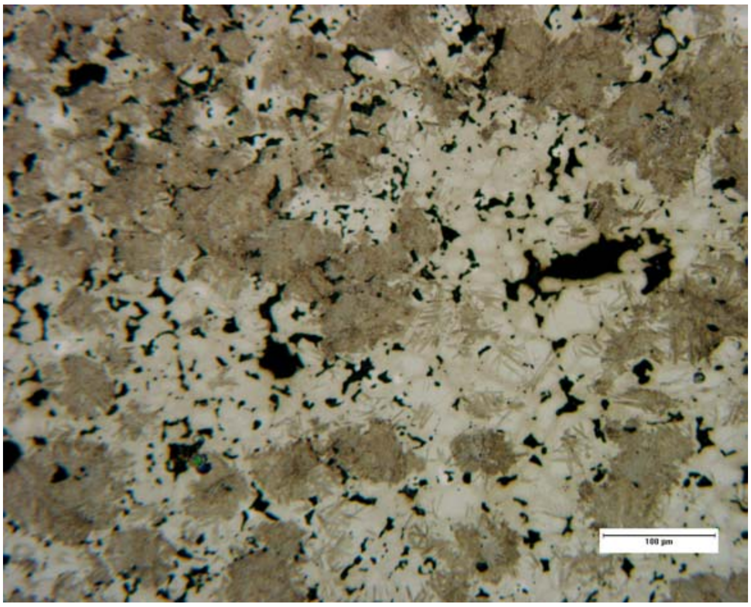

Figure 3: Densmix^{TM} 2, sinterhardened 55 – 60% Martensite + Bainite + Ni-rich Austenite

Densmix^{TM} 2 exhibits higher level of martensite transformation. This can be attributed to the addition of elemental copper[2]. The addition of elemental copper also leaves large pores from the prior copper locations.

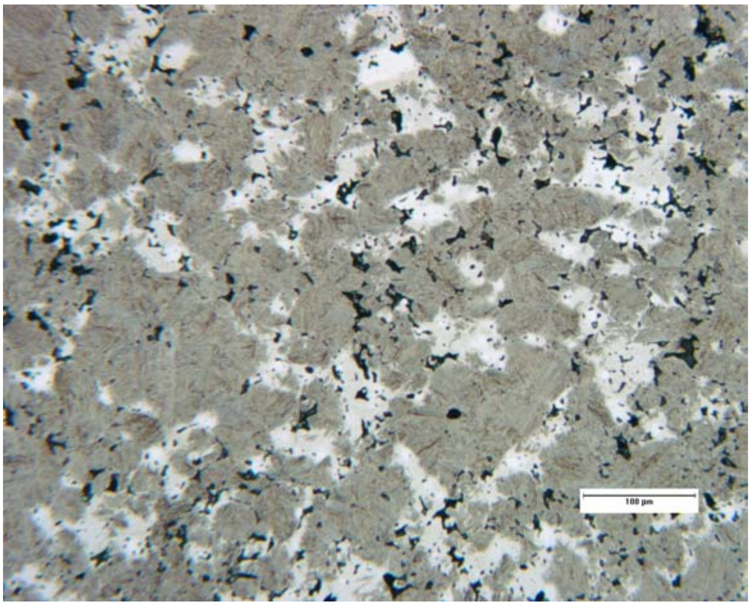

Figure 4: Densmix^{TM} 3, sinterhardened, 25% Martensite + Ni-rich Austenite + Bainite

Densmix^{TM} 3 shows higher martensite transformation than Densmix^{TM} 1. Densmix^{TM} 3 has higher Molybdenum content (1.5% vs. 0.85%) which contributes to better hardening response[2]. There is good pore distribution and an absence of large pores.

DISCUSSION

The green density levels attained by warm compaction are greater than or equal to the density levels achieved by double press/double sinter. The current process reaches green densities of 7.33 g/cm^3 after double press/double sinter. With warm compaction, Densmix^{TM} 1 and 3 reached 7.33 g/cm^3 and Densmix^{TM} 2 admixed copper and nickel reached 7.32 g/cm^3.

The sintered density for the double press/double sinter premix was 7.31 g/cm^3. Densmix^{TM} 1 and 3 reached sintered densities of 7.33 g/cm^3. Densmix^{TM} 2, with admixed copper and nickel, reached a sintered density of 7.26 g/cm^3. This lower density is reflected in the larger dimensional change for this material, likely due to the addition of copper.

The hardness levels achieved by the secondary heat treatment were not achieved during the sinterhardening test. The pre-mix using the double press/double sinter – heat treat process yields an apparent hardness of 563 HV10 (HRC45). The highest apparent hardness achieved with the proposed materials was 332 HV10 (HRC38) Densmix^{TM} 2, which has admixed copper and nickel. The Densmix^{TM} 3 based material reached an apparent hardness of 344 HV10 (HRC36). Densmix^{TM} 1, based on the existing process, only reached a hardness of 175 HV10 (HRB84). The low hardness level was in part due to the low level of admixed graphite (0.4%) and the lack of additional alloying elements such as copper.

In addition to the material combinations, which were not optimized for sinterhardening[2], the production sinterhardening furnace does not have a sufficient rate to reach the amount of martensite transformation required. The cooling rate was estimated metallographically to be approximately 1.5 ^{o}C/s (2.7^{o}F/s). In order to achieve high levels of martensite with Densmix^{TM} 3, a minimum cooling rate of 4 ^{o}C/s (10^{o}F/s) would be required. Densmix^{TM} 1 without copper would require a rate of approximately 50+ ^{o}C/s (90^{o}F/s). With Densmix^{TM} 2 there is a greater level of martensite transformation (approximately 55%), which can be attributed to increased graphite and copper. The required rates of cooling are not currently possible on existing equipment.

The sinterhardening process also failed to achieve the current levels of physical properties. Although the impact energy and elongation exceeded the current process, the ultimate tensile strength and yield strength were lower compared to the current process (see Table VII).

When warm compaction was combined with secondary heat treatment, hardness levels comparable to the existing process were achieved. Hardness levels on the Astaloy 85 Mo without copper and D.DC-1 Densmixes^{TM} reached hardness levels of 559 HV10 (RC45) and 522 HV10 (RC45), respectively. These numbers compare to the 563 HV10 (RC45) achieved by the current process. The Astaloy 85Mo Densmix^{TM} with copper reached a hardness of 492 HV10 (RC44).

The physical properties of the warm compacted – secondary heat treated materials also matched the current double press/double sinter process (see Table VII). The yield strength for all the materials, except for the Astaloy 85Mo with copper, was greater than 1000MPa (145ksi). All other physical properties were comparable, including elongation and impact energy.

The pore structure on Densmix^{TM} 1 and 3 (Figures 2 and 4) consists of smaller, more evenly distributed pores than the double press/double sinter material (Figure 1). This improved pore structure would suggest that the dynamic properties of the warm compacted material would exceed the properties of the double press/double sinter material. Fatigue strength has been shown to increase when warm compaction is used. The increase in fatigue strength would not apply to Densmix^{TM} 2, due to the large pores remaining from the prior copper locations.

CONCLUSIONS

The testing has shown that warm compaction with an Astaloy 85Mo based (matching current material) or a D.DC-1 (with 0.6%C) based Densmix^{TM} allows density levels to be achieved which meet or exceed the levels achieved by the existing double press/double sinter process. By reaching these density levels, the physical properties, including hardness, can match the current process and eliminate the pre-press and pre-sinter operations, offering a significant cost savings.

Further testing will need to be undertaken to determine if sinterhardening is a viable alternative to secondary heat treatment. The alloy system would need to be modified for better hardening response and improving the available cooling rate would also need to be investigated.

REFERENCES

[1] Höganäs Handbook for Sintered Components, 1998, Vol.6

[2] A. Davala, “Development of Sinter-Hardenable Ferrous Powders”, MPIF Sinterhardening Seminar, Nashville, TN, March, 2001.

[3] Höganäs Handbook for Sintered Components, 1998, Vol.4