DEVELOPMENT OF HIGH SPEED AND HIGH TORQUE GEARS BY SINTER HARDENING

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Abstract - Sinter hardening enables P/M parts to be hardened in conventional sintering furnaces, eliminating the need for post-sintering heat treatments. A pre-alloy powder (0.45Mn, 0.45Cr, 0.90Ni, 1.0Mo), ATOMET4701, admixed with 2.0% copper and 0.9% graphite was tested to develop high speed and high torque gears used for rechargeable power hand tools. The parts were pressed to a green density of 6.85 g/cm^3 and sintered in an endothermic atmosphere at 1120 °C for 30 minutes. The apparent hardness of as-sintered parts reached 37 HRC at 6.8 g/cm^3. The microstructure analysis revealed a full martensite transformation occurred in the cooling zone of the sinter furnace. The parts were subsequently tempered at 180-210 °C for 0.5 to 4 hours. The sinter hardening material yielded the optimal combination of mechanical properties and gear tooth accuracy after tempering at 180 °C for 2 hours, which were superior to the heat-treated low alloyed material.

KEYWORDS: SINTER HARDENING, PREALLOYED POWDER, GEARS AND POWER TOOLS

1. INTRODUCTION

Sinter hardening is an attractive way of manufacturing high hardness P/M parts by eliminating the need for the post sintering heat treatment, thus reducing part costs and improving dimensional tolerance by avoiding heat treatment distortion. A pre-alloyed steel powder, ATOMET 4701, was specifically developed to promote the sinter hardening of P/M parts in the sintering furnaces [1,2]. The pre-alloyed powder contains nickel, manganese, chromium and molybdenum alloying elements, which greatly enhance powder hardenability (Table 1). Since its introduction, the sinter hardening material, ATOMET4701, has been used for power tools, home appliances, business machines and automotive applications around the world [3].

Table 1. Physical and chemical properties of ATOMET 4701.

Apparent Density g/cm^3	Flow s/50g	C %	O %	S %	Cr %	Mn %	Mo %	Ni %	Fe %
2.92	26	0.01	0.25	0.007	0.45	0.45	1.00	0.90	Bal.

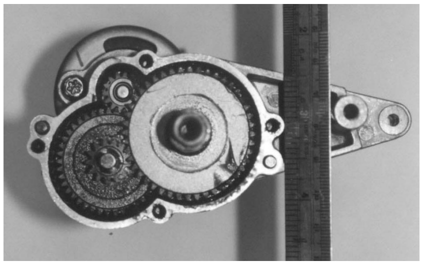
The present study focuses on the development of high speed and high torque gears for the electric power tools using the sinter hardening material. There is a set of six P/M parts used in the 14.4 V rechargeable power hand tools, as shown in Figure 1. The important requirements for these gears are: (1) wear resistance, (2) high torque and (3) low noise level at high speed, which specify the need for high hardness, high strength/tooth crush load and tight dimensional tolerance respectively. Traditionally, diffusion-bonded or low molybdenum alloyed materials are used for this type of applications.

2. EXPERIMENT

Two P/M materials, a sinter hardening (Material A) and low alloyed (Material B), were used for the study, as shown in Table 2.

Material A is the ATOMET4701 admixed with 2.0% Cu and 0.90% graphite, while Material B is a low molybdenum alloyed powder admixed with Ni, Cu and graphite.

(a)



(b)

Figure 1. Gears (a) and a power hand tool unit (b)

Table 2. Chemistry (%wt) of the two P/M materials

Material	Mn	Cr	Mo	Ni	Cu	C	Fe
A	0.45	0.45	1.0	0.9	2.0*	0.9*	Bal.
B	0.15	-	0.85	1.5*	1.25*	0.6*	Bal.

* Admixed as elements.

Tensile test bars (dog bone specimens) were used for testing the tensile strength and elongation. An actual gear, 34.40mm in diameter, 41 teeth, module 0.8 and pressure angle 20°, was used for testing the hardness, tooth crush load, as shown in Figure 2, and gear tooth accuracy, i.e. the total composite tolerance, using the CNC Double Flank Gear Rolling Tester.

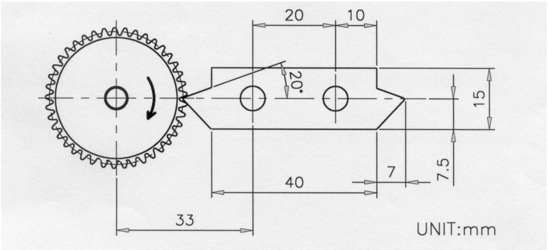


Figure 2. Illustration of the tooth crush load testing

The specimens, both tensile bars and gears, were pressed to a green density of 6.85 g/cm^3, and then sintered in an endothermic atmosphere at 1120 °C for 30min. The furnace was equipped with a gas-quenching zone in the cooling section, assuring that a minimum cooling rate of 0.8 °C /sec was achieved. The sintered specimens had a density of 6.8 g/cm^3. The specimens made with Material B were subsequently subjected to a heat treatment at 850 °C for 30min and oil quenched. The sinter hardened and heat-treated specimens were tempered at different temperatures for 0.5 to 4 hours, then characterized for the apparent hardness, strength, elongation, crush load, tooth dimension tolerance and microstructures.

3. RESULTS AND DISCUSSIONS

3.1 AS-Sintered and Heat Treated Properties

The as-sintered results for the two materials are listed in Table 3. The apparent hardness reached HRC 37 at 6.8 g/cm^3 density for the sinter hardening material, while the hardness was HRC 11 for the low alloyed material. The microstructure of Material A was almost full martensitic with a small amount of retained austenite, Figure 4.b, indicating the martensite transformation occurred in the cooling section of the furnace. In comparison, Material B showed a typical pearlite/ferrite microstructure (Figure 4.a). Due to the brittleness of the martensite phase, the as-sintered Material A had lower strength, elongation and tooth crush load than Material B.

The heat treatment of Material B raised the hardness to HRC 31 from HRC 11 and showed a martensite microstructure, Figure 4.c, similar to Material A.

3.2 Tempered Properties

The sinter hardened Material A and heat treated Material B were tempered at 150, 180 and 210°C respectively for 0.5 to 4 hours, the results are listed in Table 3 and shown in Figure 3 & 5.

Figure 3 illustrates the effects of the tempering temperature on the mechanical properties of Material A, in terms of the apparent hardness and tooth crush load. The hardness decreased with the increase in tempering temperature and decreased more for longer tempering time (2 hours) at a given temperature. While the tooth crush strength showed a maximum at 180 °C, and the highest crush load was obtained after tempering for 2 hours. Judging from the three tempering temperatures, the best combined properties were obtained at 180 °C.

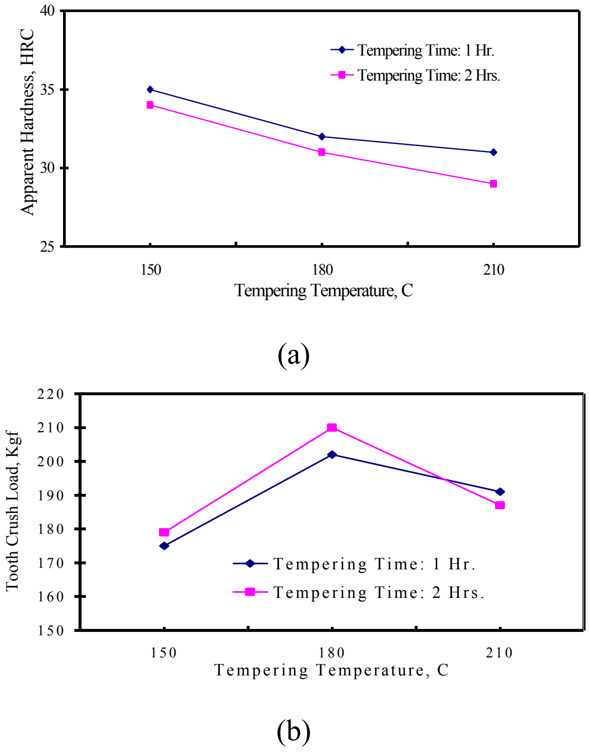


Figure 3. Effects of tempering temperature on hardness (a) and tooth crush load (b) of Material A

A temperature of 180 °C was selected for studying the effects of tempering time, 0.5-4 hours, on the mechanical properties (Table 3). For both materials (A&B), the hardness decreased with increasing tempering time, but the effect was less significant after 2 hours (Figure 5.a). The tooth crush load increased with the tempering time up to 2 hours, but started to deteriorate for tempering time longer than 2 hours (Figure 5.b).

Table 3. The effects of tempering on the properties of sinter hardening Material A and low alloyed Material B

Material	Tempering Time (Hrs.)		Tensile strength MPa (Ksi)	Elongation (%)	Tooth Crush Load (Kgf.)	Apparent Hardness (HRC)	Total Composition Error of Gear Accuracy (mm)
A*	As-sintered		436 (63.2)	0.214	137	37	0.041
	0.5		-	-	179	34	0.044
	1.0		689 (99.9)	0.279	202	32	0.034
	2.0		692 (100.3)	0.300	210	31	0.037
	3.0		-	-	210	31	0.046
	4.0		-	-	207	31	0.046
B**	As-sintered		547 (79.3)	0.378	153	11	0.046
	H.T.	0	-	-	156	31	0.066
		0.5	-	-	174	28	0.059
		1.0	669 (97.0)	0.228	181	26	0.063
		2.0	673 (97.5)	0.243	183	26	0.063
		3.0	-	-	177	26	0.070
		4.0	-	-	175	26	0.067

* Material A: Sintering at 1120 °C for 30 min and tempering at 180 °C.

**Material B: Heat treating at 850 °C for 30 min, oil quenching and tempering at 180 °C.

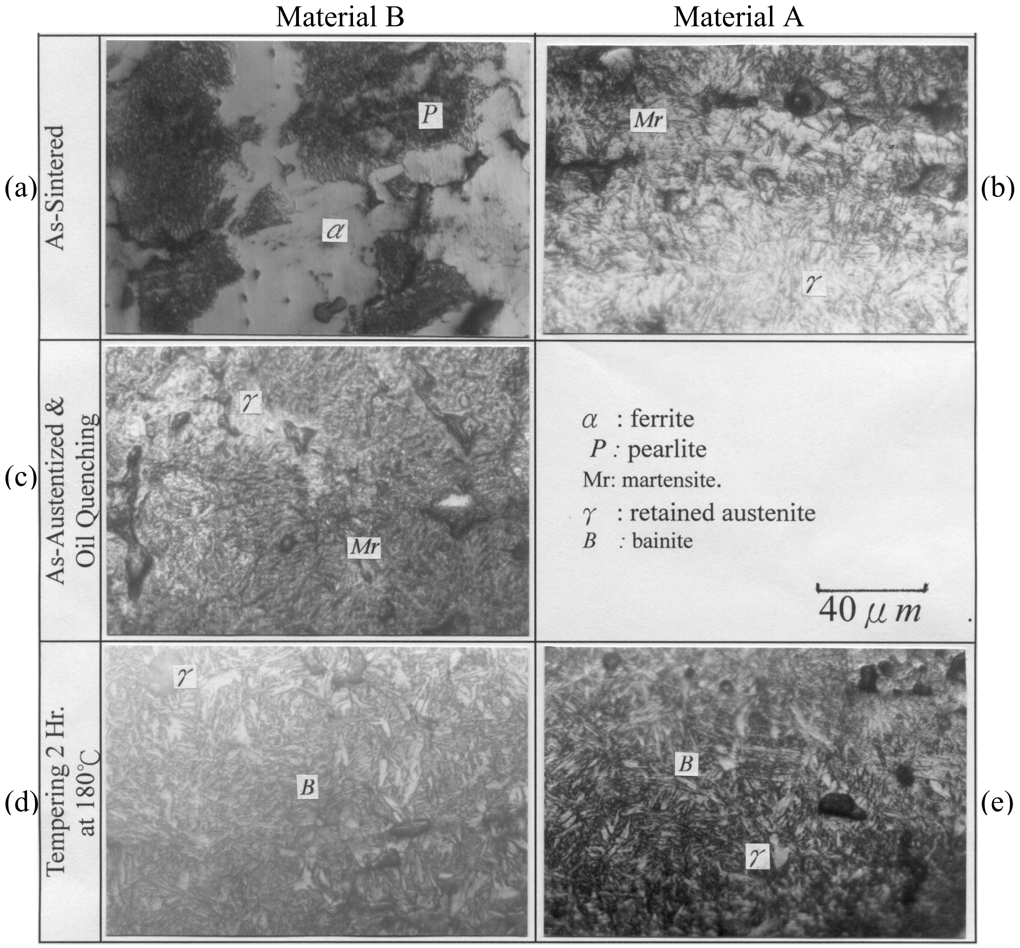


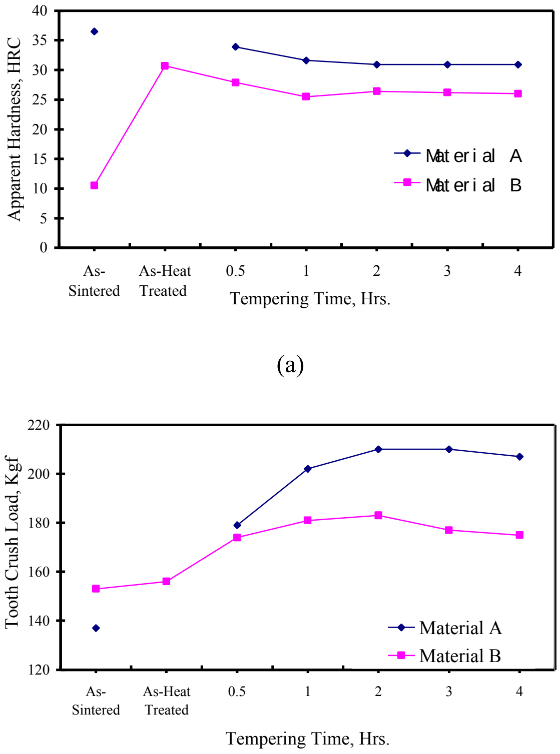
Figure 4. Microstructures of Material A and B

3.3 <u>Material A vs. Material B</u>

In general, Material A showed better mechanical properties than Materials B in terms of tensile strength, hardness and tooth crush load after tempering (Table 3). The tempered microstructures were similar for Materials A &B (Figure 4. d & e). At the optimal tempering condition, 180 °C for 2 hours, Material A achieved a hardness of HRC 31 and reached a crush load of 210 kgf, which were much higher than those of Material B (Figure 5). Therefore, gears developed with Material A would yield a superior performance over those developed with Material B.

3.4 Gear Tooth Accuracy

The noise level at high speed is determined by the gear tooth accuracy. The accuracy can be described by the total composite tolerance, as shown in Table 3 and Figure 6.



(a)

(b)

Figure 5. Effects of tempering time on the apparent hardness (a) and tooth crush load (b)

Based on JGMA 116-02 Standards, for the gear of module 0.8 with 41teeth, the gear accuracy with a total composite tolerance of 0.04-0.056 mm is classified as Class 3, and a total composite tolerance of 0.056-0.080 mm classified as Class 4. For the as-sintered gears, the gear accuracy of the two materials was similar and classified as Class 3. But the heat treatment of Material B caused tooth distortion and degraded the gear accuracy to Class 4. Therefore, the sinter hardened material provides a tighter dimensional tolerance for the final products, which is more desirable for the high-speed gears.

3.5 Cost-Effectiveness

Besides the superior mechanical properties and tight dimension tolerance of the sinter hardening material, it is also very cost-effective by eliminating the need for the heat treatment. The cost of heat treatment is estimated to be around US $650/metric ton in Taiwan. If the heat treatment counted as the material cost, using the sinter hardening material would reduce the cost by 30%, as compared with the heat treated low alloyed or diffusion bonded materials.

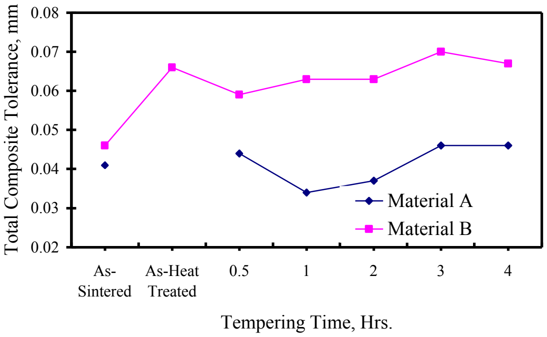


Figure 6. The gear tooth accuracy for Material A & B

4. CONCLUSIONS

1. The as-sintered hardness of the sinter hardening material reached HRC37 at 6.8 g/cm^3 , and a martensite microstructure was obtained, while heat treatment was required for the low alloyed material to yield similar results.
2. Among the tempering conditions tested in the present study, tempering at 180 °C for 2 hours was considered to be optimal for the combined properties in terms of tensile strength, hardness, tooth crush load and gear tooth accuracy.
3. Tempering at 180°C for 2 hours, the sinter hardening material yielded much more desirable strength, hardness, tooth crush load and tooth accuracy than the heat-treated low alloyed material.
4. The sinter hardenable material provides a superior performance and economical benefits for the high speed and high torque gears.

5. REFERENCES

[1] F. Chagnon and Y. Trudel, “Designing Low Alloyed Steel Powders for Sinterhardening Applications”, Advance in Powder Metallurgy & Particulate Materials, Metal Powder Industries Federation, Princeton, NJ, 1996 pp 13-211 to 13-220.

[2] C. Ruas and F. Chagnon, “The development and Characterization of Low Alloyed Steel Powders for Sinterhardening Applications”, Powder Metallurgy in Automotive Applications, Oxford & IBH Publishing Co., New Delhi, 1997, PP 65-74.

[3] F. Chagnon, J. Danaher, E. Ilia and S. Krise, “Cost Reduction Processes for Transfer Case Sprockets”, Powdered Metal Applications, SAE, SP-1535, pp. 143-158.