

Effect of Tempering Temperature on Sintered Properties of Sinter Hardened P/M Steels

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ABSTRACT: The development of low alloy steel powders specifically designed for sinter hardening applications enables components to reach high sintered strength and apparent hardness in sintering furnaces equipped with either conventional or rapid cooling units. By adjusting the mix formulation, the sintered properties can be tailored to optimize both strength and apparent hardness. Because untempered martensite is a fragile structure, sinter hardened parts are generally given a tempering treatment to restore strength and improve toughness. However, this treatment also affects the apparent hardness of P/M parts. A study was carried out to evaluate the effect of tempering temperature on mechanical properties of sinter hardened steels containing 2% copper and either 0.65 or 0.80% C. Test pieces were pressed to 6.8 g/cm^3 and sintered at 1120°C in a production furnace equipped with a conventional cooling unit. Three tempering temperatures, 150, 175 and 205°C were selected for the test program. A reduction of apparent hardness of about 10 HRC (85 HV) was observed after tempering at 150°C but tensile properties were significantly increased, particularly at high carbon concentration.

INTRODUCTION: The production of P/M parts for high stress applications often requires a secondary heat treatment in order to achieve sufficient strength and apparent hardness. This secondary operation significantly increases the processing costs and generates high thermal stresses and part distortion resulting from quenching. Also, a cleaning operation is required before and after heat treatment if P/M parts contain oil or grease [1,2]. Finally, P/M parts are more difficult to quench than wrought materials, particularly for massive parts and/or large amounts of porosity.

Sinter hardening is an attractive technique for the manufacture of high apparent hardness P/M parts because it eliminates the need for post sintering heat treatment, thus reducing costs and providing improved control on final part dimensions. For similar levels of strength and hardness, prealloyed powders are generally preferred over admixed constituents to obtain optimum microstructures while minimizing the alloying additions [3]. With proper material formulation, sinter hardening can tailor the final microstructure as a function of the size of the parts and the sintering furnace throughput which directly affect the cooling rate.

The objective of this work was to study the effect of tempering temperature on mechanical properties of low alloy steel powders used in sinter hardening applications. Test specimens have been characterized for both mechanical properties and microstructure.

EXPERIMENTAL PROCEDURE: The base powder used in this study was ATOMET 4701, a low alloy steel specifically designed for sinter hardening applications. Table 1 shows the typical physical and chemical properties of this powder. Mixes were prepared with 2% copper, graphite to reach carbon concentrations of respectively 0.65 and 0.80% in the test pieces after sintering and 0.75% zinc stearate as lubricant. Test specimens were pressed to 6.8 g/cm³ and sintered in an industrial belt furnace at 1120°C for 25 minutes in a 90% nitrogen based atmosphere. The cooling rate from 870 to 650°C was 0.7°C/s. All the specimens were tempered one hour in air at either 150, 175 or 205°C. Tensile properties were determined using round machined specimens as per MPIF standard 10 while impact energy was measured using Charpy specimens according MPIF standard 40.

TABLE 1
Physical and chemical characteristics 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	0.009	0.45	0.45	1.00	0.90	Bal.

RESULTS AND DISCUSSION: The mechanical properties of ATOMET 4701 specimens containing 2% copper and 0.65% or 0.80% C pressed to 6.8 g/cm³, sintered 25 minutes at 1120°C and tempered one hour in air at either 150, 175 and 205°C are given in Table 2.

Table 2
Properties of sintered specimens as a function of combined carbon and tempering temperature.

Combined C, %	Tempering Temperature, °C	UTS, MPa	YS, MPa	Apparent Hardness, HRC (HV)	Impact Energy, J
0.65	As-sintered	520	-	34 (335)	9.5
	150	565	-	23 (255)	9.2
	175	685	625	22 (250)	10.2
	205	755	650	22 (250)	11.3
0.80	As-sintered	475	-	40 (390)	8.4
	150	670	555	30 (300)	11.1
	175	650	545	30 (300)	11.3
	205	700	580	27 (280)	10.4

Figure 1 illustrates the effect of tempering temperature on apparent hardness for the two levels of combined carbon. In the as-sintered condition, apparent hardness values of 40 and 34 HRC (390 and 335 HV) are reached for carbon contents of respectively 0.80 and 0.65% C. These are relatively high values considering that the sintered densities range from 6.70 to 6.75 g/cm³. Apparent hardness is reduced by about 10 HRC (85 HV) after tempering at 150°C. Apparent hardness slightly decreases as the tempering temperature increases from 150 to 205°C but the effect is more pronounced at 0.80% C than at 0.65% C, 3 versus 1 HRC.

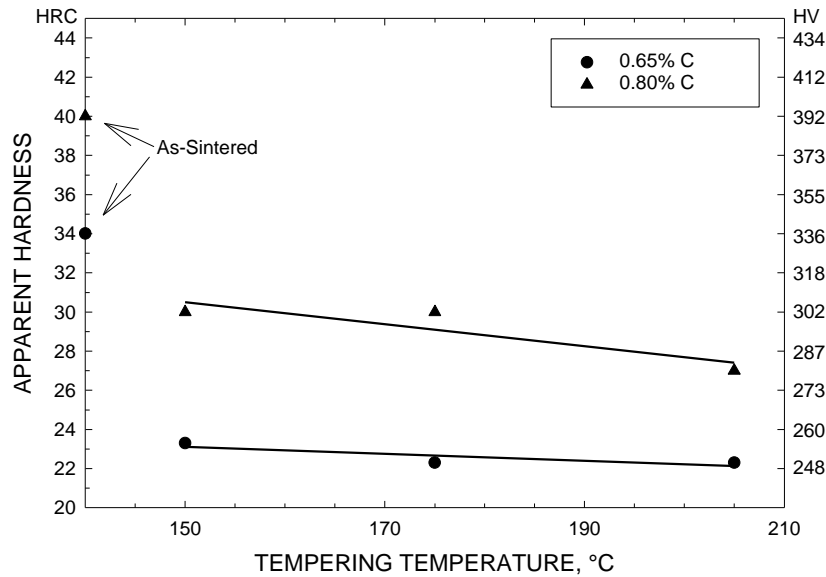


Figure 1. Effect of tempering temperature on apparent hardness of TRS specimens pressed to 6.8 g/cm³ and sintered 25 minutes at 1120°C.

The higher apparent hardness observed with specimens containing 0.80% C is related to the larger amount of martensite compared to specimens with 0.65% C as shown in Figure 2. Both as-sintered materials exhibit a similar microstructure of martensite and bainite but the amount of martensite is slightly greater at 0.80% C. It is also worth noting that the 0.80% C specimen contains more retained austenite than that with 0.65% C. The microstructure after tempering is composed of tempered martensite with some bainite.

The effect of tempering temperature on ultimate tensile strength is illustrated in Figure 3 for the two carbon concentrations. UTS values of 520 and 475 MPa are achieved with specimens containing respectively 0.65 and 0.80% C in the as-sintered condition. The lower strength observed at 0.80% C is related to the larger amount of fragile un-tempered martensite in these specimens. The tempering treatment at 150°C significantly improves UTS and the effect is more notable for the 0.80% C level. On the other hand, increasing the tempering temperature has a more pronounced effect on the 0.65% than on the 0.80% C specimens. As the tempering temperature is raised from 150 to 205°C, UTS increases from 565 to 755 MPa at 0.65% C and from only 670 to 700 MPa at 0.80% C. In previous work [4, 5], the maximum UTS values for this material were reached at combined carbon concentrations ranging from 0.65 to 0.75% after sintering and tempering at 205°C. Above 0.75% C, the strength starts declining. It is however worth noting that at a tempering temperature of 150°C, the 0.80% C specimens exhibit higher UTS than the 0.65% C specimens while at 175°C, UTS is similar for both carbon concentrations. This is an important consideration when optimizing the mechanical properties as a function of specific application requirements. If strength is the key variable, a carbon content of 0.65% with a higher tempering temperature of 205°C should be used. On the other hand, if high apparent hardness is required while maintaining high strength, a carbon content of 0.80% with a tempering treatment at lower temperature, 150°C, would be recommended. If only high apparent hardness is necessary with no specific need for high strength, parts with high carbon content without a tempering treatment should be more appropriate.

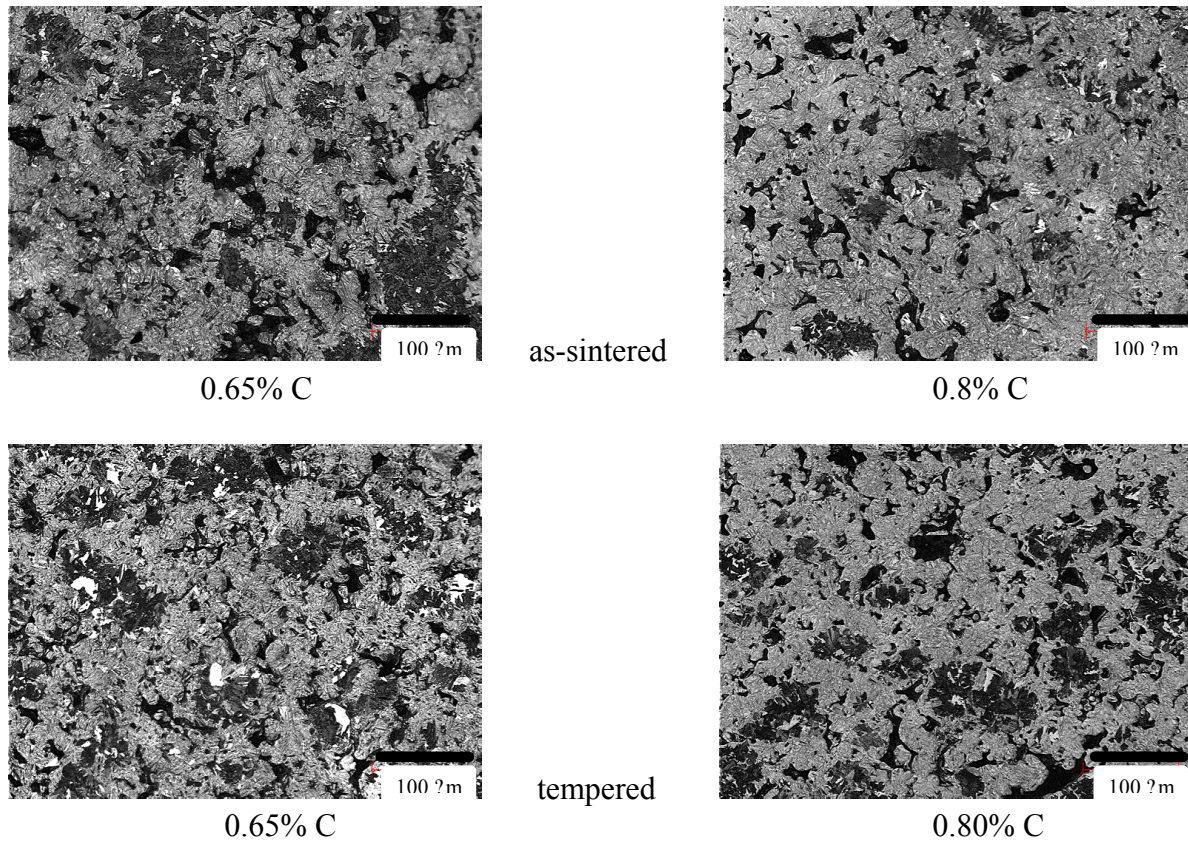


Figure 2. Microstructure of specimens pressed to 6.8 g/cm^3 and sintering 25 minutes at 1120°C and tempered one hour at 175°C (etched with Picral).

Figure 4 illustrates the effect of tempering temperature on yield strength. It is worth noting that no yield point was observed in the as-sintered condition for both carbon concentrations. The same applies to the 0.65% C specimens tempered at 150°C . However, a yield point was observed with the 0.80% C specimens after tempering at 150°C . It is believed that the higher quantity of retained austenite in the high carbon specimens enabled a yield point to be observed. It is also observed that the yield strength increases almost linearly with the tempering temperature for both carbon concentrations. Finally, the yield strength of the 0.65% C specimens is higher than that of the 0.80% C specimens by about 10% after tempering at 175 and 205°C .

The effect of tempering temperature on impact energy is illustrated in Figure 5. For the 0.65% C specimens, a tempering treatment at 150°C does not improve impact energy as compared to the as-sintered condition. However, impact energy increases linearly with the tempering temperature to reach about 11 joules at 205°C , a gain of nearly 20% versus the as-sintered condition. For the 0.80% C specimens, a tempering treatment at only 150°C significantly improves impact energy by approximately 30% as compared to the as-sintered conditions. A further increase of the tempering temperature to 205°C results in a slight reduction of the impact energy.

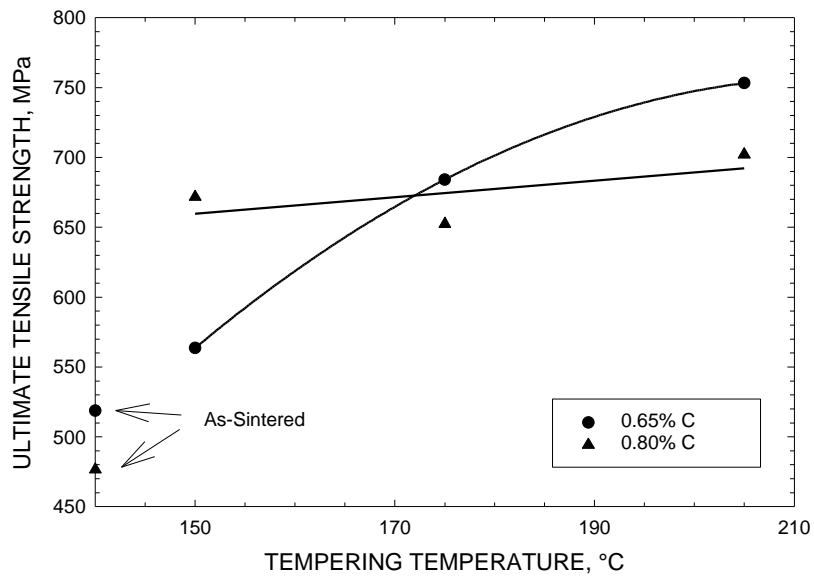


Figure 3. Effect of tempering temperature on ultimate strength of specimens pressed to 6.8 g/cm³ and sintered 25 minutes at 1120°C.

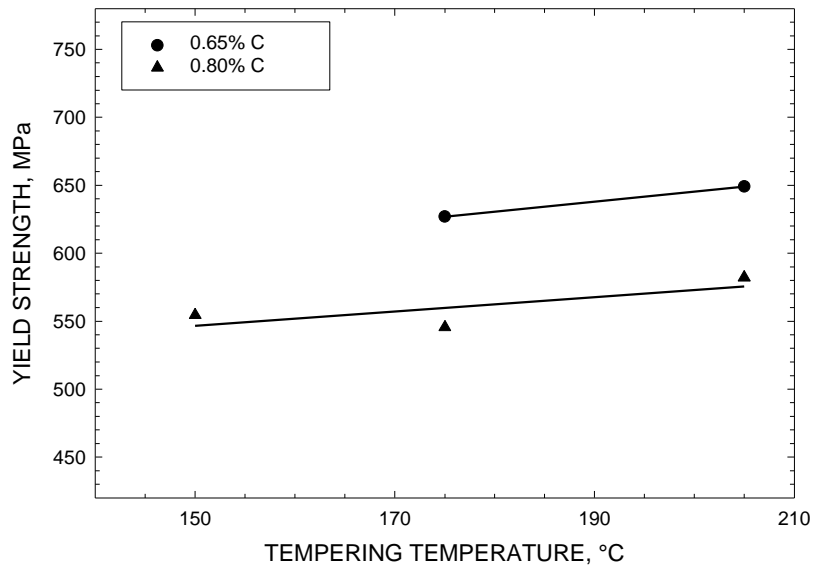


Figure 4. Effect of tempering temperature on yield strength of specimens pressed to 6.8 g/cm³ and sintered 25 minutes at 1120°C.

From these results, it can be observed that:

If high apparent hardness is required for an application requiring good impact resistance, a carbon content of 0.80% and a tempering treatment at 150°C are recommended.

If apparent hardness is less critical but high strength values are required for the application, a lower carbon content of 0.65% is preferable and the tempering treatment must be carried out at a higher temperature of 205°C in order to maximize both the strength and impact resistance.

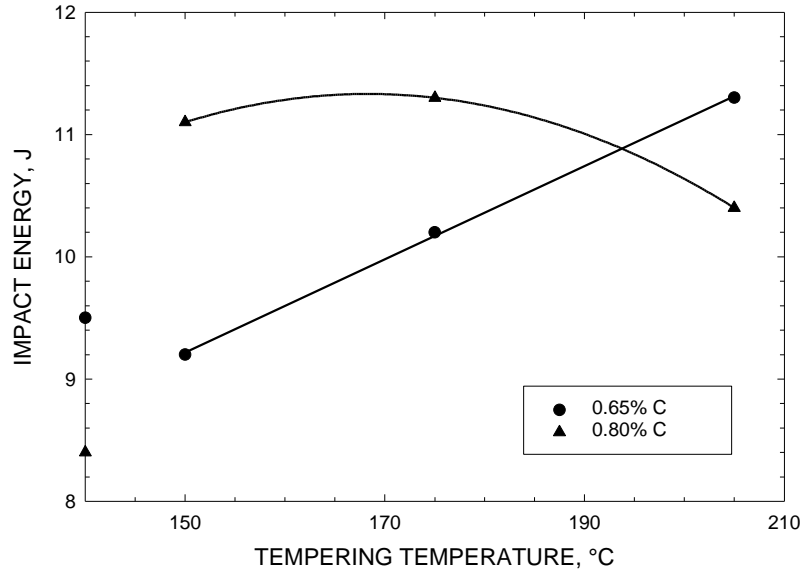


Figure 5. Effect of tempering temperature on impact energy of specimens pressed to 6.8 g/cm³ and sintered 25 minutes at 1120°C.

CONCLUSIONS:

1. A tempering treatment is required to restore the strength and toughness of sinter hardened P/M steels.
2. The detrimental impact through tempering is a loss of about 10 HRC (85 HV) in apparent hardness for carbon concentrations of 0.65 and 0.80%.
3. The carbon concentration and the tempering temperature can be adjusted to tailor specific properties. For a formulation containing 2% admixed copper, pressed to 6.8 g/cm³ and sintered 25 minutes at 1120°C, various strategies can be recommended to meet apparent hardness, strength and impact energy requirements.

To maintain high apparent hardness (40 HRC), a high carbon content (0.80%) should be used and the tempering treatment avoided. The UTS (475 MPa) and toughness (8.4 J) will decrease but may be adequate for the application requirements.

To reach a moderate apparent hardness (27 HRC) along with higher toughness (11.1 J) while maintaining adequate strength (670 MPa), a high carbon concentration (0.80%) with a tempering treatment at a low temperature of 150°C could be more appropriate.

To maximize UTS (755 MPa) and toughness (11.3 J) while maintaining adequate apparent hardness (22 HRC), a medium carbon content (?0.65%) with a tempering treatment at a higher temperature (205°C) would be more suitable.

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