

LOW ALLOY STEEL POWDERS FOR SINTER HARDENING APPLICATIONS

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Sinter hardening enables the production of P/M parts with high strength and apparent hardness at lower cost than conventional heat treatment. This process is particularly attractive for parts that are difficult to quench because of their size and shape. Various types of low alloy steel powders have been developed for sinter hardening. These provide sufficient hardenability to make the martensite transformation possible during the cooling portion of the sintering cycle.

Three low alloys steel powders with different compositions were evaluated at various levels of graphite and 2% copper at a density of 6.9 g/cm³. Specimens were sintered 25 minutes at 1120°C in a nitrogen based atmosphere and cooled at either 0.4 or 1.5°C/s in the temperature range of 650 to 400°C. The mechanical properties were determined in the as-sintered condition and after tempering 60 minutes at 200°C.

KEYWORDS: SINTER HARDENING, STEEL POWDERS.

I. INTRODUCTION

P/M parts often require secondary quench and tempering treatments to increase their strength and apparent hardness. However, these treatments increase production costs because of added handling and processing steps. Also, quenching P/M parts generates high stresses and part distortion, making it difficult and sometimes impossible to maintain the dimensional tolerances required for the application. Sinter hardening offers a significant advantage over the quench-and-temper process because P/M parts are hardened during the cooling portion of the sintering operation. This process may reduce the number of operations by as much as 50% [1], but requires base powders with enough hardenability to generate a high amount of martensite when the parts are cooled from the sintering temperature, because of the slower cooling rate encountered by the parts as compared to the quenching treatment [2]. This slower cooling rate also makes tighter control of part dimensions because of the reduced distortion.

Many low alloy steel powders can be used for sinter hardening and the final properties will depend on the mix formulation, the size of the parts and the cooling efficiency of the sintering furnace. The objective of this study is to compare the mechanical properties of three low alloy steel powders that can be used for sinter hardening and determine their properties for various carbon concentrations and cooling rates.

II. EXPERIMENTAL PROCEDURE

The base low alloy steel powders used in this study were ATOMET 4601, ATOMET 4701 and MSP 4. The chemical properties of these powders are given in Table 1. Four mixes of each powder grade containing 2% copper and 0.75% zinc stearate were prepared with various

graphite additions to reach carbon concentrations of 0.35, 0.55, 0.75 and 0.95% after sintering.

Table 1. Chemical properties of the low alloy steel powders.

	Mn, %	Mo, %	Ni, %	Cr, %
ATOMET 4601	0.18	0.5	1.75	-
ATOMET 4701	0.45	1.0	0.9	0.45
MSP 4	0.18	0.5	4.0	-

Sixteen transverse rupture strength bars and sixteen dog bone specimens were pressed from each mix to a green density of 6.9g/cm³. Half of the specimens were sintered at 1120°C for 25 minutes in a 90% nitrogen based atmosphere with a post-sintering cooling rate of 0.4°C/s in the temperature range of 650 to 400°C. The other half of the specimens were sintered for 20 minutes at 1120°C in a 90% nitrogen based atmosphere in a furnace equipped with a fast cooling unit in order to achieve a post-sintering cooling rate of 1.5°C/s in the temperature range of 650 to 400°C. A tempering treatment was then carried out at 200°C for 60 minutes on half of each series of specimens. Apparent hardness and tensile properties were determined according to MPIF Standards 43 and 10 respectively. Microstructural characterization was performed by optical microscopy.

III. RESULTS AND DISCUSSION

Figure 1 illustrates the evolution of apparent hardness of the three materials as a function of combined carbon, for cooling rates of 0.4 and 1.5°C/s, in the as-sintered condition and after tempering for 60 minutes at 200°C. Specimens cooled at 0.4°C/s generally show lower apparent hardness than those cooled at 1.5°C/s. ATOMET 4601, which is the material with the lowest hardenability, requires a minimum combined carbon of about 0.8% to

reach an apparent hardness of 40 HRC at 0.4°C/s in the as-sintered condition. The minimum required carbon content is reduced to about 0.6% C with ATOMET 4701 and MSP 4 because of their superior hardenability. It is worth noting a slight reduction in hardness values with MSP 4 when the combined carbon concentration is raised from 0.7 to 0.9% and the cooling rate is increased from 0.4 to 1.5°C/s. This is probably related to a higher quantity of retained austenite in this material. This occurrence of retained austenite is favored when the carbon and other alloying element concentrations are increased [3]. Particularly, the high concentration of nickel in this alloy strongly contributes to the retention of austenite in high carbon steels [4]. Therefore, the true cooling rate encountered by the parts after sintering is required to better select the base powder and the mix composition to optimize the mechanical properties. Indeed, the cooling rate depends first on the cooling efficiency of the sintering furnace and, secondly on the section thickness of the parts and, finally, on the belt load. Large section thickness and belt loading reduce the cooling rate. Therefore, materials with better hardenability are required to reach high apparent hardness in these conditions. On the other hand, a material with high hardenability processed with a fast cooling rate because of either better furnace cooling efficiency, thinner section thickness or light belt loading, will have a greater tendency to retain austenite with a possible reduction of apparent hardness and strength. A reduction of the combined carbon concentration will help correct this situation.

Tempering reduces apparent hardness, particularly for materials sinter hardened above 30 HRC. This is better illustrated in Figure 2. The difference between the values reached in the as-sintered and tempered conditions achieves a maximum at about 0.7% C for ATOMET 4701 and MSP 4 and about 0.9% C for ATOMET 4601. The largest differences between these two conditions are generally observed for the fastest cooling rate. This is related to the larger amount of martensite produced at this cooling rate which increases the softening effect due to the increased proportion of tempered martensite [5]. The largest hardness difference between the as-sintered and tempered conditions is observed with MSP 4 at 0.7% combined carbon with a value of 10 HRC.

Figure 3 illustrates the microstructure obtained with the three materials for a combined carbon of about 0.9%. Figures 3a and b shows the effect of raising the cooling rate for the ATOMET 4601 material. For the slowest cooling rate, the microstructure is composed of martensite with few areas of bainite while it is almost fully martensitic when the cooling rate is raised from 0.4 to 1.5°C/s. Figure 3c represents the microstructure obtained with ATOMET 4701 which is also fully martensitic and Figure 3d illustrates the microstructure obtained with MSP 4. In the latter case, plate martensite with evidence of retained austenite is observed and confirms the previous observations regarding the reduction of apparent hardness

at this carbon level due to higher concentration of retained austenite.

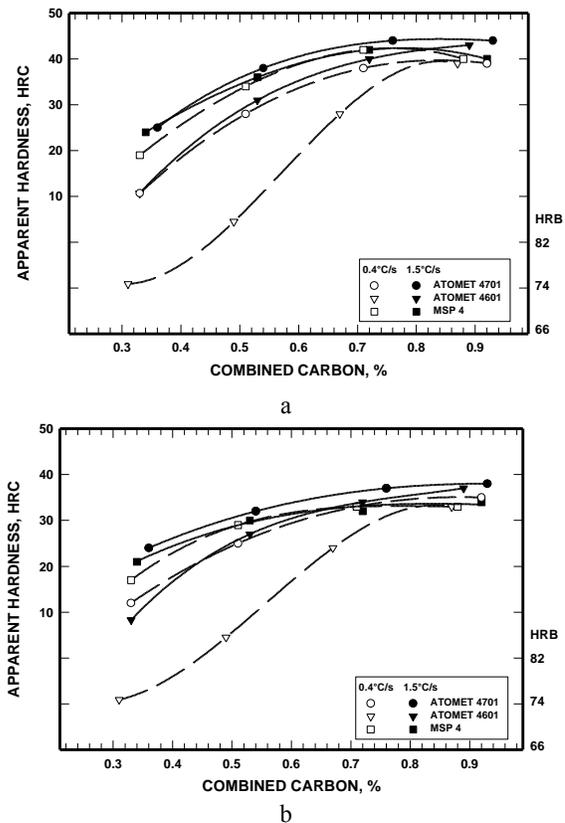


Figure 1. Effect of combined carbon and cooling rate on apparent hardness of the three materials: a) as-sintered and b) after tempering 60 minutes at 200°C (Specimens pressed to 6.9 g/cm³; all mixes contained 2% Cu).

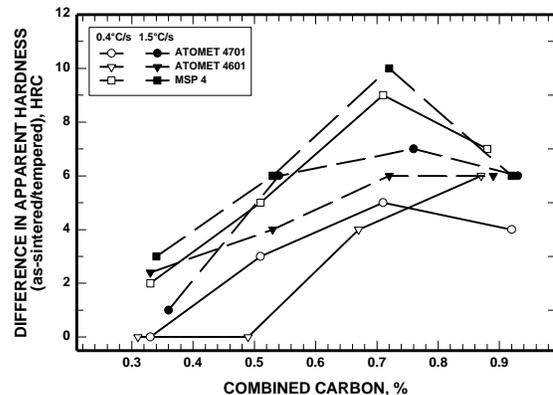


Figure 2. Difference in apparent hardness between the as-sintered and tempered conditions for the three materials for cooling rates of 0.4 and 1.5°C/s.

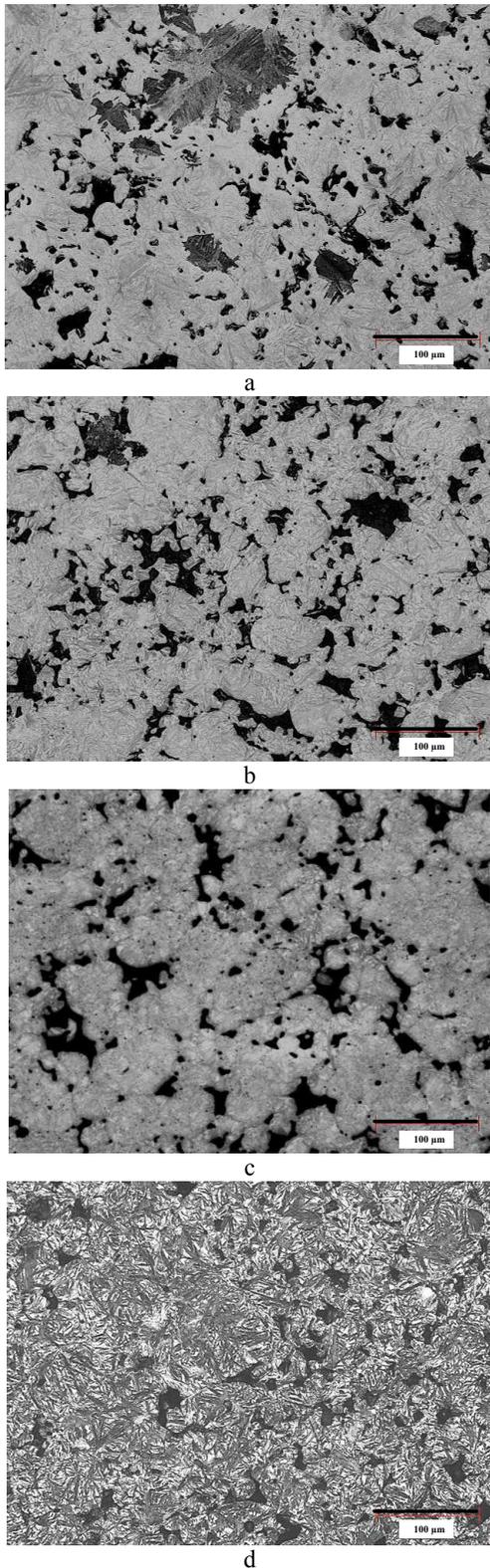


Figure 3. Micrographs of the materials with 0.9%C-2%Cu in the as-sintered condition: a) ATOMET 4601, 0.4°C/s, b) ATOMET 4601, 1.5°C/s, c) ATOMET 4701, 1.5°C/s and d) MSP 4, 1.5°C/s.

Figure 4 illustrates the evolution of tensile strength of the three materials as a function of combined carbon, for cooling rates of 0.4 and 1.5°C/s, in the as-sintered condition and after tempering 60 minutes at 200°C. In the as-sintered condition, the maximum tensile strength is reached in a combined carbon concentration range of about 0.4 to 0.5% C for ATOMET 4701 and MSP 4 for the two cooling rates and for ATOMET 4601 cooled at 1.5°C/s with values ranging from 800 to 900 MPa. In the case of ATOMET 4601 cooled at 0.4°C/s, the maximum tensile strength is reached at about 0.6% C with a value of 600 MPa. It is worth noting that this material also showed the lowest apparent hardness values at this cooling rate.

Tempering improves tensile strength and shifts maximum tensile strength values toward higher carbon concentrations. The highest tensile strength value, about 950 MPa, is obtained with ATOMET 4701 at about 0.6 to 0.7% C cooled at either 0.4 or 1.5°C/s.

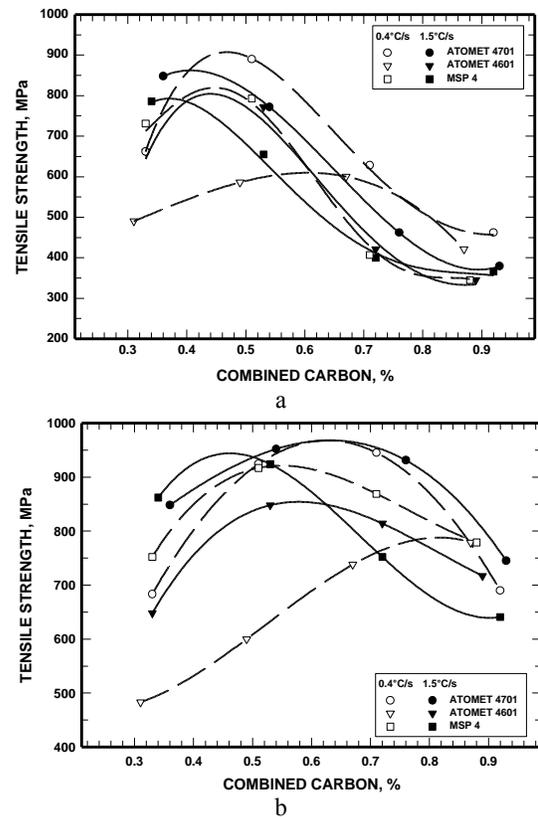


Figure 4. Effect of combined carbon and cooling rate on tensile strength of the three materials: a) as-sintered and b) after tempering 60 minutes at 200°C (Specimens pressed to 6.9 g/cm³; all mixes contained 2% Cu).

Figure 5 shows the effect of combined carbon on yield strength. No yield point is observed above 0.5% C for MSP 4 for the two cooling rates and for ATOMET 4601 and ATOMET 4701 for a cooling rate of 1.5°C/s and above 0.7% C for the two latter materials and a cooling rate of 0.4°C/s. The highest yield strength values, about 650 to 660 MPa, are reached at about 0.5% C for the three

materials cooled at 1.5°C/s and also for ATOMET 4701 cooled at 0.4°C/s.

As for tensile strength, tempering significantly improves yield strength. Also, yield points are observed over the entire range of combined carbon concentrations for the three tempered materials. It is also worth mentioning that below 0.7% C, for a given material, raising the cooling rate generally increases yield strength values. Also, the maximum yield strength for a given material is also observed at different combined carbon concentrations depending of the material hardenability and cooling rate. At 0.4°C/s, ATOMET 4601, which exhibits the lowest hardenability among the three materials, shows a maximum yield strength of about 610 MPa at 0.9% C. Raising the cooling rate to 1.5°C/s lowers the combined carbon concentration where the maximum yield strength is reached to 0.6% C. For ATOMET 4701 and MSP 4, these maximum values are respectively reached at about 0.55-0.60 and 0.40-0.50% C at a cooling rate of either 0.4 or 1.5°C/s. The highest yield strength is observed with ATOMET 4701 containing 0.55% C cooled at 1.5°C/s with a value of 850 MPa.

IV. CONCLUSIONS

To optimize the apparent hardness and mechanical properties of sinter hardening parts, it is essential to have a good understanding of the cooling rate seen by the parts. Powders with lower hardenability can show good sinter hardened properties if the cooling rate is fast enough to avoid the formation of pearlite and minimize the production of bainite during cooling. In this study:

- ?? ATOMET 4601 required higher combined carbon than ATOMET 4701 and MSP 4 to reach 40 HRC in the as-sintered condition.
- ?? Tempering sinter hardened parts with apparent hardness above 30 HRC resulted in a reduction of the apparent hardness from the as-sintered condition of 4 to 10 HRC. The largest difference was observed at 0.7% C with MSP 4 cooled at 1.5°C/s.
- ?? Almost fully martensitic structure has been obtained with ATOMET 4601 with 0.9% C and 2% Cu cooled at 1.5°C/s. For similar carbon and copper contents, the largest amount of retained austenite was observed with MSP 4.
- ?? The highest tensile strength values for the three materials were reached after tempering at about 0.5% C for MSP 4 and 0.6% C for ATOMET 4701 at either 0.4 or 1.5°C/s and at 0.6% C for ATOMET 4601 cooled at 1.5°C/s with values of respectively 950, 925 and 850 MPa.

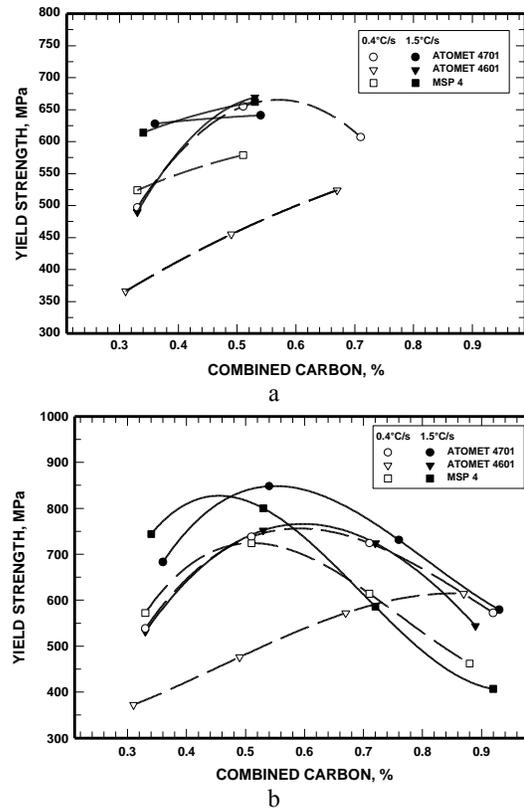


Figure 5. Effect of combined carbon and cooling rate on yield strength of the three materials, a) as-sintered and b) after tempering 60 minutes at 200°C (Specimens pressed to 6.9 g/cm³; all mixes contained 2% Cu).

IV REFERENCES

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