# Transfer Case Sprocket Production through the Sinter Hardening Process

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Abstract : Sinter hardening can produce powder metal parts with high strength and apparent hardness in a single pass through the sintering furnace. This process eliminates the need for a post-sintering heat treatment with the inherent related drawbacks such as part distortion, oil contamination and added processing costs. Low alloy steel powders have been developed for sinter hardening applications. These materials, combined with the availability of sintering furnaces equipped with enhanced cooling capacity, make sinter hardening particularly attractive for parts that are difficult to quench because of their size or shape. The transfer case sprocket, recently developed by MascoTech Sintered Components, is a good example of a successful application of the sinter hardening process using these low alloy powders. This paper describes the influence of the mix formulation and the sintering parameters on mechanical properties of selected sinter hardenable materials and the approach taken to convert a major line of sprockets from a traditional mold, sinter, size and quench process to a cost effective mold and sinter harden process.

## INTRODUCTION

Sinter hardening is defined as a process where martensitic transformation takes place during the cooling stage of the sintering cycle. This implies that the hardenability of the material and the cooling rate from the sintering temperature are high enough for that transformation to occur. Under appropriate cooling conditions, the face-centered cubic (FCC) structure of austenite suddenly transforms into a supersaturated solid solution of carbon trapped in the body-centered tetragonal (BCT) structure of martensite by a combination of shearing actions. This creates a distorted lattice and the degree of distortion increases with the concentration of carbon. This distorted lattice accounts for the high hardness and the brittle nature of martensite [1]. A tempering treatment may be carried out, if necessary, to restore resilience in the material. The part density and its microstructure govern the material mechanical properties.

The alloy content of the base powdered material, the diffusion state achieved during sintering, the cooling rate and the tempering conditions are parameters which will dictate the material microstructure. Obviously, maximum values of mechanical properties such as hardness and yield strength cannot be achieved simultaneously; some compromises are required when selecting the material and process parameters for a new application. Numerous studies on materials and processing conditions are available to help the designer in his selection [2 to 10]. However, it is important to realize that materials with a high martensite content can hardly be sized and are difficult to machine. Therefore, the control of the dimensional change through the manufacturing process becomes a critical requirement for many new applications, hence the importance of understanding the interaction between material formulation and processing conditions on size change. Ideally, the dimensional change relating to the material selected should be robust to minor variations in alloy content and process conditions.

## POWDERED MATERIAL SELECTION

Basically there are two types of steel powders available for sinter hardening applications. First, there are the unalloyed iron powders used in combination with admixed elements. Graphite, copper and nickel are the most commonly used. Copper and nickel can also be bonded to iron powders by either partial diffusion or binder treatments. Because of its slow diffusion in iron, admixed nickel alone does not sufficiently improve hardenability to obtain a large amount of martensite after sintering at conventional temperature. High temperature sintering and extended time at temperature are required to enhance the diffusion rate [11, 12, 13]. The use of manganese, chromium and molybdenum, in either their elemental forms or as ferroalloys, combined with high temperature sintering to get these elements into solution, makes sinter hardening feasible with unalloyed powders as base materials [11, 14].

The second and most widely used type of powders available for sinter hardening applications is the low alloy steel powders. Manganese, molybdenum, nickel and chromium are used in the preparation of these low alloy powders. Because the alloying elements are in solid solution in the iron, the hardenability of the material is increased and a homogeneous microstructure can be achieved after sintering. Particular material selection and powder manufacturing techniques are necessary to optimize powder compressibility, hardenability and cost. The approach taken by Quebec Metal Powders Ltd to develop these alloys is discussed elsewhere [7, 8]. Graphite and copper can be admixed to further increase material hardenability and strength. These elements will rapidly diffuse in the matrix at conventional sintering temperature i.e. 1120°C.

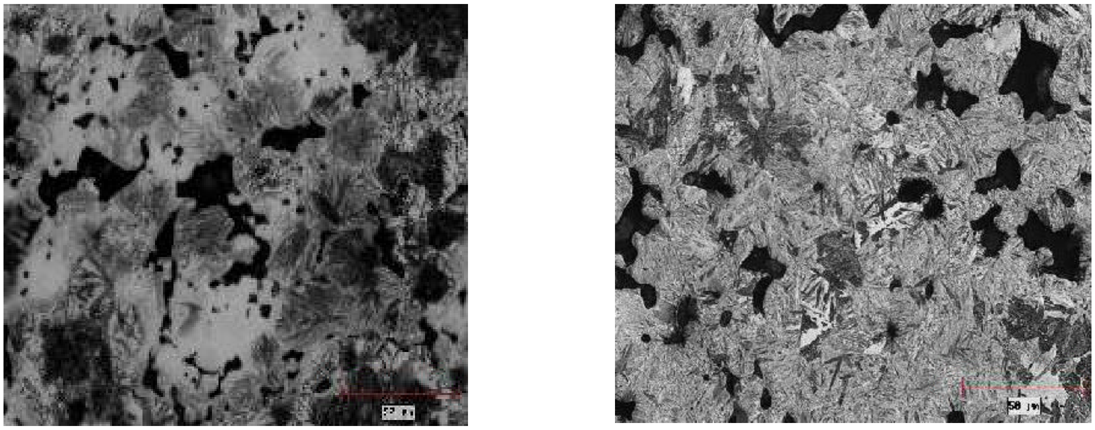

a ) FD-0408 b) FLC-4608

**Figure 1. Microstructure of sinter hardened materials. [9].**

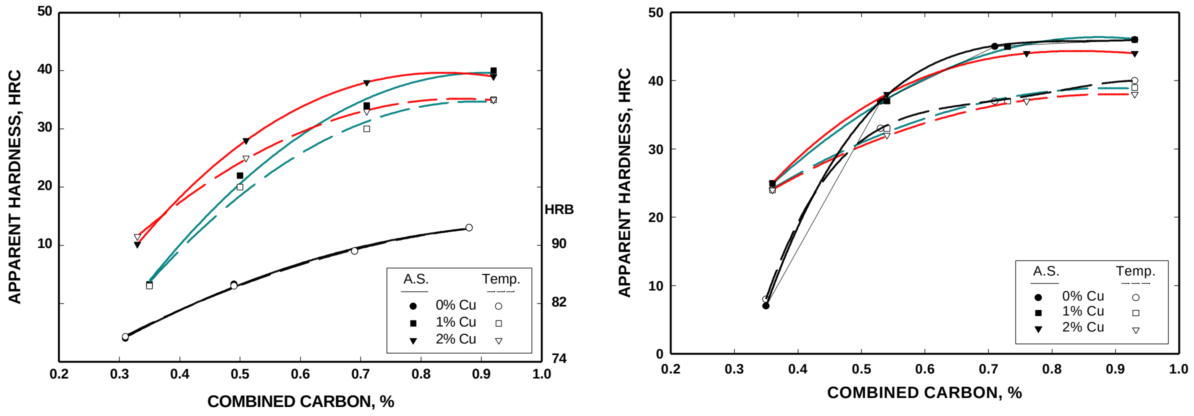
Figure 1 compares the microstructure of a diffusion-bonded alloy powder FD-0408 (ATOMET DB 48[1] containing 4% Ni and 1.5% Cu) at 0.8% carbon to that of a fully alloyed powder FLC-4608 (ATOMET 4601[1] admixed with 2% Cu) at the same carbon level. The heterogeneous structure of the diffusion-bonded alloy is evident with the presence of martensite, bainite, pearlite and both nickel rich and retained austenite phases. For the FLC-4608 material, the microstructure is essentially martensitic with few areas of bainite.

Low alloy powders such as ATOMET 4601 (0.20% Mn, 0.55%Mo, 1.8%Ni) and ATOMET 4701[1] (0.45%Mn, 1.00%Mo, 0.9%Ni, 0.45%Cr) are materials that are well suited for these applications.

## MIX FORMULATION AND PROCESSING CONDITIONS

The main goal of using sinter hardenable materials is to favor the formation of martensite and therefore maximize apparent hardness after sintering. With the development of sintering furnaces equipped with fast cooling units, graphite and copper contents can be lowered while maintaining a martensitic microstructure. Therefore, the cooling rate can be adjusted to tailor the microstructure and hence the mechanical properties to a given powder mix formulation. This leads to the opportunity of adjusting the mix formulation to stabilize the dimensional change occurring during the sinter hardening process.

A study was carried out at the QMP R&D facilities [10] to evaluate the effect of graphite and copper concentrations as well as post-sintering cooling rates on apparent hardness, strength, and dimensional change. In this study, transverse rupture strength bars and dogbone specimens were pressed at 6.9 g/cm$^3$ from mixes of ATOMET 4701 with 0, 1 or 2 % copper and the amount of graphite required to reach 0.3, 0.5, 0.7 and 0.9% combined carbon. The test pieces were sintered for 20 to 25 minutes at 1120°C in a nitrogen based atmosphere and cooled at rates of 0.4 and 1.5°C/s respectively in the temperature range of 650 to 400°C. The fast cooled test specimens were sintered at MascoTech Sintered Components in Ridgway, PA. Tempering was carried out at 200°C for 60 minutes. Material properties were evaluated on specimens in both as-sintered and tempered conditions. The mechanical properties measured for these specimens were found to be consistent with the relative amount of martensite, retained austenite and pearlite/bainite present in the microstructure. The detailed analysis of these microstructures is presented elsewhere [10].



**a) 0.4°C/s** **b) 1.5°C/s**

**Figure 2. Effect of Combined Carbon and Copper Contents on Apparent Hardness [10].**

The effect of combined carbon and copper concentrations on apparent hardness is illustrated in Figure 2. As expected, apparent hardness increases with combined carbon but the rate of increase and the maximum apparent hardness vary with the cooling rate. For a cooling rate of 0.4°C/s, the addition of copper and a minimum combined carbon of 0.7% are required to achieve apparent hardness values above 30 HRC. For a combined carbon of 0.9%, raising the copper content from

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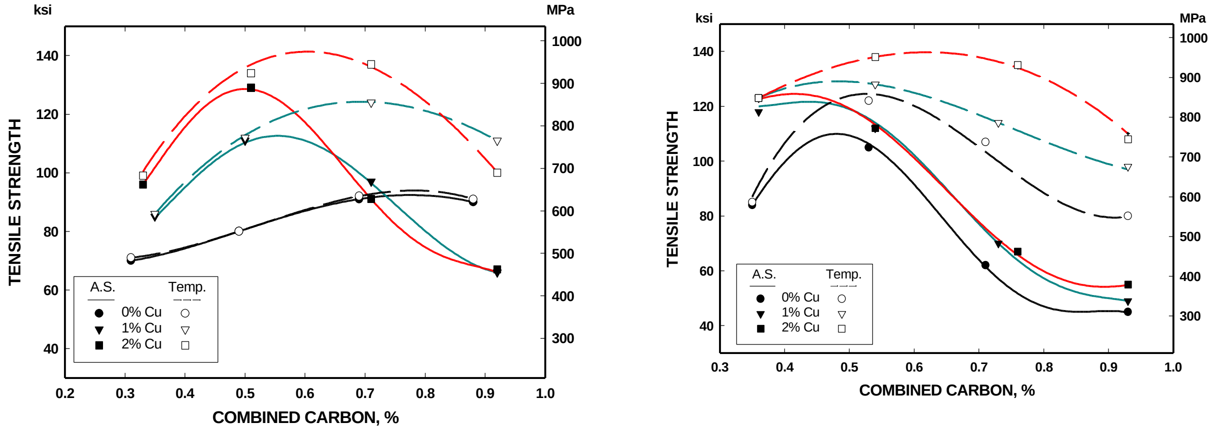
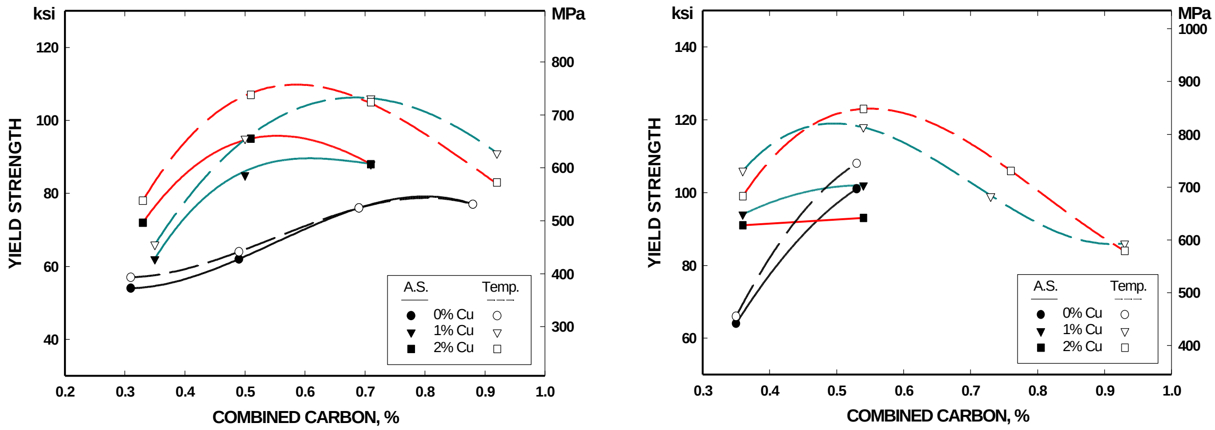
[1] Manufactured by Quebec Metal Powders Ltd

1% to 2% does not contribute to further increase the apparent hardness, which reaches a maximum of about 41 HRC in the as-sintered condition.



**a) 0.4°C/s** **b) 1.5°C/s**

**Figure 3. Evolution of Ultimate Tensile Strength with Carbon and Copper Contents [10].**



**a) 0.4°C/s** **b) 1.5°C/s**

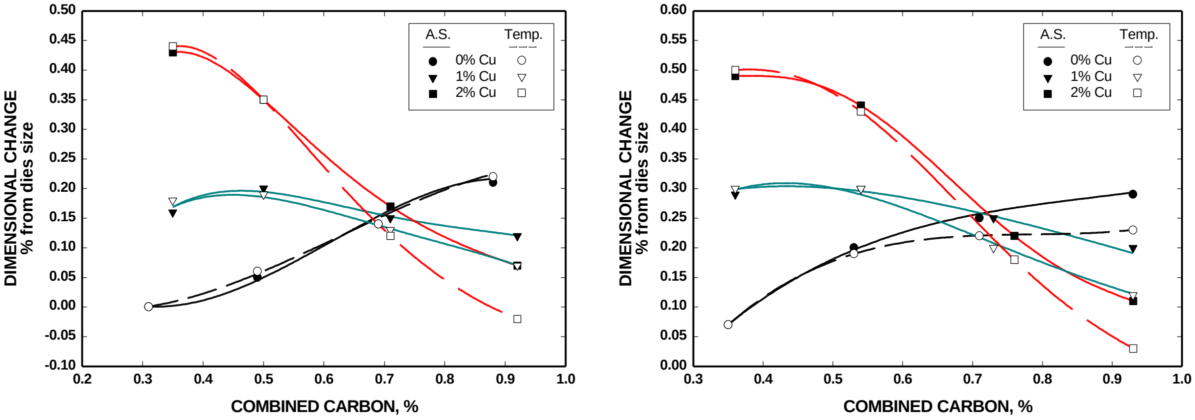
**Figure 4. Evolution of Yield Strength with Carbon and Copper Contents [10].**

Increasing the cooling rate to 1.5°C/s significantly increases the apparent hardness of the sinter hardened steel, particularly for copper free materials. The addition of copper improves the apparent hardness of the 0.35% carbon material. Above 0.7% carbon, apparent hardness values tend to level off at about 46 HRC. It is worth noting that, for applications requiring a minimum hardness of 30 HRC, the carbon and copper contents and the cooling rate can be varied to possibly adjust the dimensional change during sinter hardening while maintaining comparable hardness.

The effect of combined carbon and copper concentrations on the tensile strength is presented in Figures 3 and 4. Tempered specimens with 0.5 or 0.7% carbon and with 2% copper have maximum ultimate and yield strength values of around 950 MPa and 850 MPa respectively. For applications requiring lower strength values a wide spectrum of mix formulations and cooling rates can be used.

## SINTER HARDENING AND DIMENSIONAL CHANGE CONTROL

Of particular interest for the transfer case sprocket conversion program was the effect of combined carbon and copper concentrations and cooling rates on dimensional change. This information, obviously required for tool and die design, could also be used to identify formulation ranges that are robust to variation in additive contents or processing conditions. Selecting such a formulation may become critical since sinter hardened parts cannot be sized after sintering to meet tighter dimensional tolerances.



**a) 0.4°C/s** **b) 1.5°C/s**

**Figure 5. Evolution of Dimensional Change from Die Size with the Combined Carbon and Copper Contents for Cooling Rates of 0.4°C/s and 1.5°C/s . [10].**

Figure 5 illustrates the effect of combined carbon and copper contents on dimensional change from die size of the TRS bars. The same trends are observed for both cooling rates. At a combined carbon of 0.3%, the copper content has a significant effect on the specimen growth. A similar behavior, but to a lesser extent, is observed when the carbon content reaches 0.9%. At 0.7% C, the dimensional change of the specimens from die size is similar for the three copper levels and therefore robust to the variation of copper content. Similarly, it can be concluded that dimensional change of specimens containing around 1% copper will be robust to carbon content variations. At low martensite content, the dimensional change of the specimens is not affected by tempering at 200°C. However, as the carbon and copper contents in the specimen increase, the formation of martensite is promoted. When the tempering treatment is carried out at 200°C, martensite loses its BCT (body-centered tetragonal) structure due to the precipitation of transition carbides. This is accompanied by a modification of the BCT to a BCC structure, which accounts for the size change [16].As illustrated in Figure 6, the relaxation is enhanced with increased martensite content, particularly for carbon concentrations above 0.5%, with differences as high as 0.09% between the as-sintered and tempered conditions.

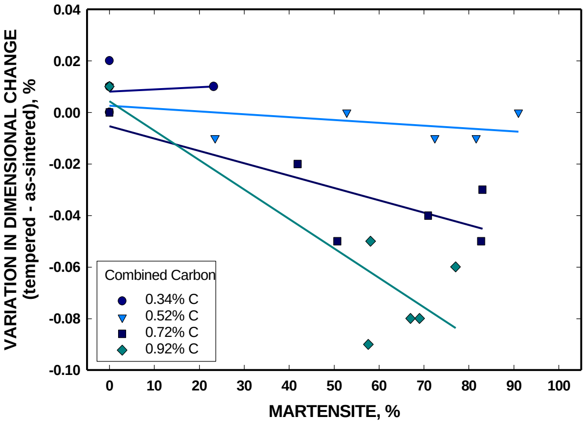


**Figure 6. Dimensional Change from As-Sintered to Tempered Conditions as a Function of the Martensite and Combined Carbon Content. [10].**

Based on the information above, it becomes evident that several material formulations and cooling rate conditions are available to the designer to meet various mechanical property requirements while maintaining robustness with regards to dimensional control.

## APPLICATION

An example of the benefits of the sinter hardening process is illustrated by the conversion of a major product line of transfer case sprockets at MascoTech Sintered Components in Ridgway, PA[**17**]. One of these sprockets is shown in Figure 7. The actual production steps for the sprockets include molding, sintering, sizing, and heat treating. The conversion aimed at reducing the number of steps from four to two: only molding and sintering, resulting in a significant cost reduction. Sprockets were manufactured using two sinterhardening powder grades : ATOMET 4601 mixed with 2% copper and 1% graphite and ATOMET 4701 mixed with 1% copper and 1% graphite. The properties of the sinter hardened parts were compared to those obtained with the existing process consisting of quenching and tempering a FN0408 material (iron mixed with 4% Ni and 0.9% graphite). Hardness measurements, dimensional change evaluation, mechanical testing and microstructural characterization were performed on both series of sprockets in the as sintered and tempered conditions. The results were compared to those obtained with the sprockets manufactured with the existing process. Hardness and strength test results are summarized in Figure 8. A simple single tooth loading device was designed to evaluate the strength. The load applied at tooth failure is reported in figure 8 as the crush strength.

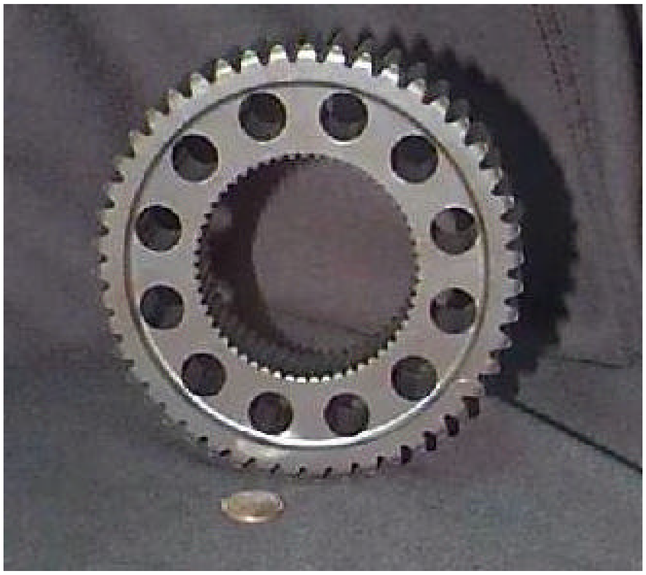


**Figure 7. Transfer case sprocket** [**17**].

No significant difference in hardness was found between the sinter hardenable grades in both as-sintered and tempered conditions, despite their different copper contents. However, the difference with the quenched sprockets manufactured using the current process is significant.

The crush test results clearly showed that a significant improvement in strength is obtained by tempering the sprockets manufactured with the sinter hardenable powders. The ATOMET 4701 mix with 1% copper exhibits a higher strength than the ATOMET 4601 mix with 2% copper. The crush resistance of the sprockets manufactured using sinter hardenable powders in the as-sintered condition is comparable to that of the quenched and tempered sprockets. As shown in Figure 9, the microstructure of the sprockets produced from the ATOMET 4701 mix was uniform and essentially martensitic with some islands of bainite.

Dimensional change measurements were carried out on three groups of parts (50 parts per group) manufactured as follows: 1) mold, sinter, size, and quench; 2) mold, sinter, and quench; and 3) mold and sinter harden. The results of part size measurements are shown in Figure 10. The nominal dimension required for the application is 141.186 mm (5.5585 inch) with a tolerance of 0.145 mm (0.0057 inch). Table 1 compares the statistical data and process capability indexes of the three processing conditions. The quenched parts with a 6 $\sigma$ range at 0.159 mm (0.0063 inch) do not meet the tolerance, so sizing is required in the current process.

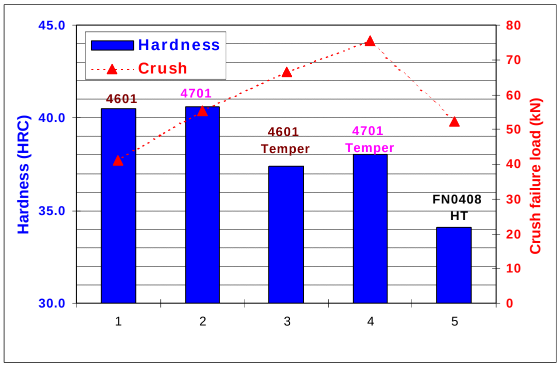


**Figure 8. Summary of hardness measurements and crush test results.** [17]

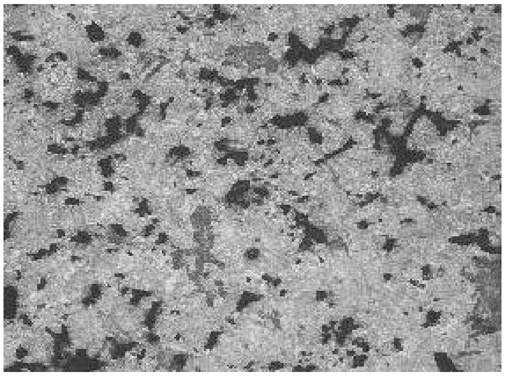


**Figure 9. Microstructure of the sprocket (4% picral, 2% nitral)** [17].

On the other hand, the sinter hardened parts in the as-sintered condition satisfy the requirement with a capability index of 1.37. Therefore, the sizing operation is no longer necessary when using the sinter hardening process. The difference in the 6σ value is 40% lower in the case of the sinter hardened sprockets when compared to that of the quenched parts. The sinter hardened parts are equivalent or even superior in size control than the sized and quenched parts.

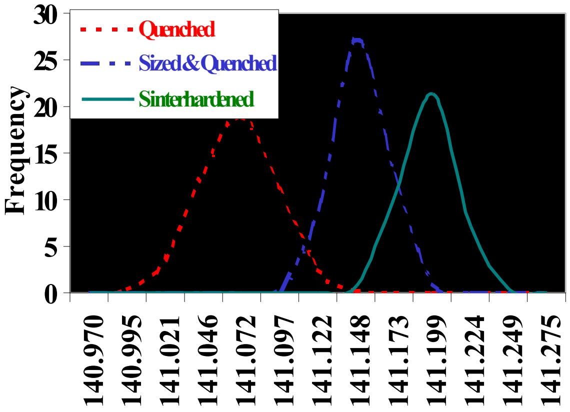


**Figure 10. Distribution part diameter measurements, mm.** [17].

| | Quenched | Sized & Quenched | Sinter hardened |
|---|---|---|---|
| **X-Bar** | 141.069 | 141.150 | 141.196 |
| **Sigma** | 0.027 | 0.019 | 0.018 |
| **High** | 141.153 | 141.209 | 141.260 |
| **Low** | 141.023 | 141.122 | 141.163 |
| **Range** | 0.130 | 0.086 | 0.097 |
| **Cp** | 0.91 | 1.31 | 1.37 |
| **-3?** | 140.990 | 141.096 | 141.143 |
| **+3?** | 141.150 | 141.206 | 141.249 |
| **6?** | 0.159 | 0.111 | 0.106 |

**Table 1. Effect of processing route on dimensional control, mm.** [17].

Several experiments were performed to determine the effect of sinter hardening process parameters on dimensional change control [**17**]. The sintering temperature and belt speed were retained as the most important parameters. Parts were produced from the same material lot, compacted on the same press and sintered in the same furnace. All size measurements were taken at the ID mark on the part to minimize the effects of size variation within the part. A multiple regression analysis was used to generate an equation to predict pitch diameter change for a given belt speed and sintering temperature. The equation was then used to generate the graph shown in Figure 11. It shows that the pitch diameter can be reduced by 0.018 mm (0.0007 “) for each increment in sintering temperature of 2.75 $^{o}$C (5 $^{o}$F). Similarly, an increment in belt speed of 12.7 mm/min (0.5 in/min) will increase the pitch diameter by 0.020 mm (0.0008 “). It was later demonstrated, in mass production, that the above control parameters were useful for process adjustment. These additional tools to the material formulation further confirm the feasibility of eliminating the sizing operation.

The sprockets manufactured at MascoTech Sintered Components, using the sinter hardening process, successfully passed all application tests and generated the expected cost savings. Millions of these sprockets have since been produced.

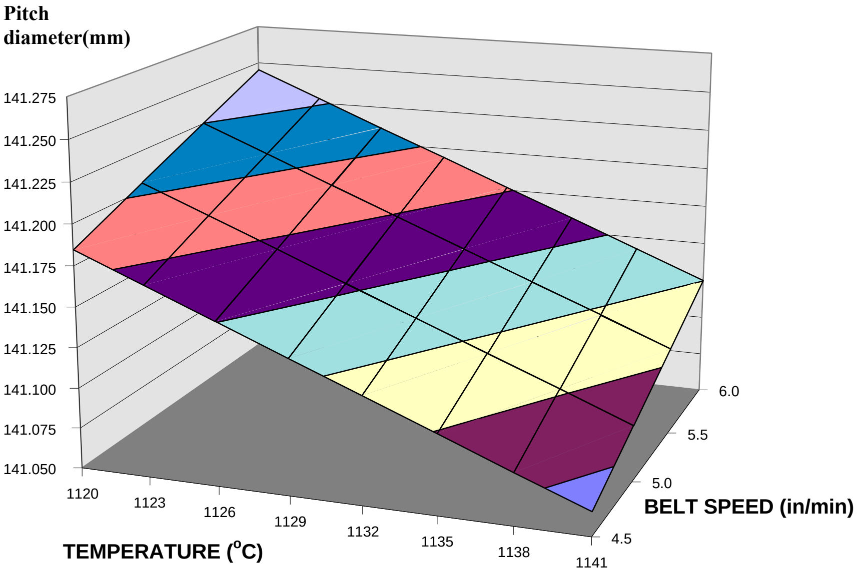


**Figure 11. Combined belt speed and sintering temperature effect on the dimensional change of sinter hardened sprockets.** [**17**].

## CONCLUSIONS

Using low alloy powder products, the production of parts with high apparent hardness can be reduced to a simple mold and sinter process, eliminating post sintering sizing and heat treatment operations.

The cooling rate during sintering can be adjusted to tailor the microstructure and hence the mechanical properties to a given powder mix formulation.

Proper selection of carbon and copper content can be made to improve the dimensional change stability.

* The sintering temperature and belt speed are useful process parameters to adjust the dimensional change during sintering.

The sinter hardening process can be beneficially used for the manufacture of automotive transfer case sprockets.

## REFERENCES

1. Avner, S.H., “Introduction To Physical Metallurgy”, McGraw-Hill, New York, 1974, pp 249-347.
2. Trudel Y. Gagné and Racicot F., “Design Criteria For The Manufacturing Of Low Alloy Steel Powders”, Advances in Powder Metallurgy & Particulate Materials, Vol. 5 Metal Powder Industries Federation, Princeton, NJ, 1991, pp 45-58.
3. M. Gagne, Y. Trudel. “Effects of post-sintering cooling on the properties of low alloy sintered materials”, 1991 P/M Conference and Exhibition, Chicago, June 9-12.

4. R. Ratzi, “Modern Methods for the Heat Treatment of High Strength Sintered Parts”, In-House P/M Seminar on Advanced P/M Components for the Automotive Industry, Adam Opel AG, EPMA, June 21, 1993.

5. H. Ferguson, “The Heat Treatment of P/M Steels-an Overview”, Proceedings of the 16th ASM Heat Treating Society Conference & Exposition, 19-21 March 1996, Cincinnati, OH.

6. F. Chagnon, Y. Trudel. “Effect of sintering parameters on mechanical properties of sinterhardened materials”, 1997 International Conference on Powder Metallurgy & Particulate Materials, June 29 - July 2, Chicago.

7. C. Ruas, F. Chagnon. “Development and characteristics of low alloy steel powders for sinterhardening applications”, 1997 International Conference and Exhibition on Powder Metallurgy for Automotive Components, February 10-12, Delhi.

8. Chagnon F. and Trudel Y., “Designing Low Alloy Steel Powders For Sinter Hardening Applications”, Advances in Powder Metallurgy & Particulate Materials, Vol. 4 Metal Powder Industries Federation, Princeton, NJ, 1996, pp 13-211 to 13-220.

9. Chagnon F., Danaher J., Ilia E., .Krise S., “Cost Reduction Processes for Transfer Case Sprockets : Part 1 : Metallurgical Aspects.” SAE 2000 World Congress, Detroit March 6-9, 2000, SAE Technical paper 2000-01-1000

10. Chagnon F. and Gagné M., “Effect Of Graphite And Copper Concentrations And Post Sintering Cooling Rate On Properties Of Sinter Hardened Materials”, paper presented at the PM2TECH 2000 conference, New York, May 31, 2000.

11. Danniger H., “Sintering Of Low Alloy Steels Prepared From Elemental Powders”, Powder Metallurgy Science & Technology-Vol.-4, July 1993, pp 22-36.

12. Kawase K., Morimoto K., Kohno T. and Yanagawa H., “High Temperature Sintering Of Low Alloy Steel Powders”, SAE International Congress & Exhibition, Detroit February 26-29, 1996, SAE Technical Paper 960381.

13. Miura H., Baba T. and Honda T., “The Effect Of Heterogeneous Structure On The Properties Of Sintered Low Alloy Steels”, Advances in Powder Metallurgy & Particulate Materials, Vol. 4 Metal Powder Industries Federation, Princeton, NJ, 1996, pp 13-42 to 13-49.

14. Shivanath R., Jones P.K. and Lawcock R., “On The Synergies Of High Temperature Sintering And Alloy Development For High Endurance P/M Powertrain Components”, Advances in Powder Metallurgy & Particulate Materials, Vol. 4 Metal Powder Industries Federation, Princeton, NJ, 1996, pp 13-427 to 13-437.

15. Avner, S.H., “Introduction To Physical Metallurgy”, McGraw-Hill, New York, 1974, pp 349-385.

16. Krauss G., “STEELS: Heat Treating And Processing Principles”, American Society for Metals, Materials Parks, OH, 1990, pp43-85.

17. Ilia E., Krise S., Frawley R., Chagnon F., Danaher J., “Cost Reduction Processes for Transfer Case Sprockets : Part 2 : Processing Variables.” SAE 2000 World Congress, Detroit March 6-9, 2000, SAE Technical paper 2000-01-1001