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Sintering of AISI M3:2 High Speed Steel – Part II

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Abstract: Liquid phase sintering of high speed steels seems to be a cheaper processing route in the manufacturing of tool steels if compared to the well-known and expansive hot isostatic pressing high speed steels process. In a previous work a M3:2 high speed steel was vacuum sintered from irregular water atomized powders and had its sintering temperature determined. In this work the same powder was uniaxially cold compacted and vacuum sintered by adding some small quantity of graphite (0.3%C in weight) to prevent porosity and loss of carbon which result from the sintering cycle. The samples from all these experimental procedures were uniaxially cold compacted and vacuum sintered at five different temperatures and had its densities evaluated. The microstructure was evaluated using optical-electronic techniques in order to investigate the best range of sintering temperature. At least five parallel samples were tested to each condition of sintering.

Keywords: High speed steels, sintering, water atomized powders, near full density.

Introduction

High speed steel components manufactured by the powder metallurgy route are both well known and developed. Good sintering properties combined with excellent wear resistance have enabled the manufacture of sintered high speed steel tools for many years but little effort has yet been spent on exploiting such properties for other applications. Wear resistant automotive components such as cams, valve guides, valves seats, or valve tappets appear to be ideally suited to manufacture in high speed steel materials by powder metallurgy processes. The applications of high speed steels to wear resistant components requiring high volume production could be enhanced by this process. The main aim of this work was to develop an economically competitive sintering process for producing M3:2 high speed steels through cold compaction and vacuum sintering of irregular water atomized powders by adding some quantity of 0.3 wt% C (graphite). This technique allows the production of components sintered to near full density, i.e density equal to 99% of the theoretical value [1-7]. In a previous work M3:2 water atomized powders supplied by Coldstream Inc. was cold uniaxially pressed and vacuum sintered to near full density at temperature of 1263 °C (± 3 °C)[8]. In this work 0.3% C (graphite) was added to the same powder in order to correct the carbon content and to prevent eventual loss that result from the sintering cycle.

Experimental procedure

One grade of water atomized M3:2 high speed steel powder was used for this study as a base material, the composition is shown in Table 1. The graphite was added first as a means of correcting the carbon content and to compensate any carbon loss caused by its reaction with oxide contamination in the powder during the sintering treatment. The graphite additions were made by blending into the base material for 15 min using a Turbula mixer. Green compacts were produced from the powder by cold pressing, without lubricant, in a simple acting die at a pressure of 700 MPa to form square blanks, 6.35 × 12.7 × 31.7 mm. Compact green densities were all greater than 70% of theoretical and were calculated by mean of geometric density Densities were calculated in $g.cm^{-3}$ using the relationship $\rho = M/V$, where M is the mass of the specimen (g) and V is the volume (cm^3).

Table 1 - Chemical composition of M3 class 2 high speed steel powder object of this work (base material). Weight percent and iron balance.

Material	C	Si	Mn	Cr	Mo	W	V	S	P
M3:2 Powder	0.98	0.2	0.3	3.97	6.2	5.68	2.92	-	-

Green specimens were sintered under vacuum atmosphere (minimum 5×10^{-5} Torr) for one hour and the sintering cycle used is presented in figure 6. Sintering densities were evaluated by the same method used for the green compacts.

Results and discussion

After the cycles of sintering the results for the densities and fractions of full densities could be evaluated and the results are presented.

Table 2 shows the densities and the fractions of full densities which resulted from the sintering cycles for the five distinct temperatures of sintering used in this study. The density of M3 class 2 high speed steel was taken as 8.16 g/cm^3. Figures 1, 2, 3, 4 and 5 show the SEM micrographs which present the microstructures of the M3 class 2 high speed steel with additions of 0.3%C (graphite). The evaluation of these microstructures leads to a better attainment of full density for the sintering temperature of 1240 °C. The other sintering temperatures studied presented some porosity in some cases and large porosities for the higher temperatures and an excess of liquid phase can be also observed.

Table 2 – Results of densities and fractions of full densities as a function of the sintering temperatures.

Temperature of sintering (°C)	1230	1240	1250	1260	1270
Density ($g \times cm^{-3}$)	7.94 ± 0.04	8.07 ± 0.04	8.01 ± 0.02	7.79 ± 0.07	7.71 ± 0.12
Fraction of full density (%)	98.0 ± 0.5	98.9 ± 0.5	98.9 ± 0.2	96.2 ± 0.9	95.2 ± 1.5

Vacuum sintering for 1 hour showed that the M3 class 2 material first attained full density at 1263 °C without any graphite addition as object of a previous work [8] and that this was lowered to 1240 °C by adding 0.3% of graphite powder. The M3:2 + 0.3%C material was considered adequate for this study as its post-sintered carbon content was closest to that required by the standard composition while still maintaining an acceptable sintering temperature [9].

Microstructures typically seen in the material at an optimum sintering temperature (1240 °C), i. e. that at which there was no porosity and an acceptable microstructure, was produced (Fig. 2). The structure of this material in as-sintered condition was composed typically by martensitic matrix (α') plus retained austenite (γ) (detected by X-ray diffraction), together with MC and M_6C carbides, both as rounded carbide particles within the grains and as angular or continuous carbides at prior austenite grain boundary. Grain boundary MC carbides retained their globular morphologies throughout the complete range of studied sintering temperatures. The changes in microstructure at progressively higher were basically consistent with the literature [10]. Figure 9 shows a pattern of X-ray diffraction of M3:2 + 0.3%C high speed steel at optimum sintering temperature of 1240 °C.

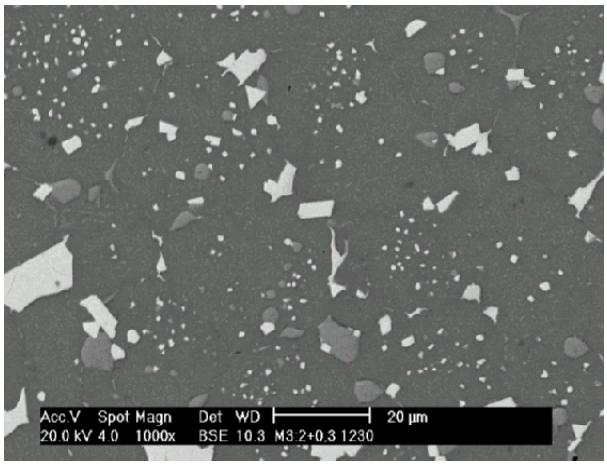

Fig. 1 - SEM micrograph of vacuum sintered M3:2 high speed steel with addition of 0.3%C vacuum sintered at 1230 °C.

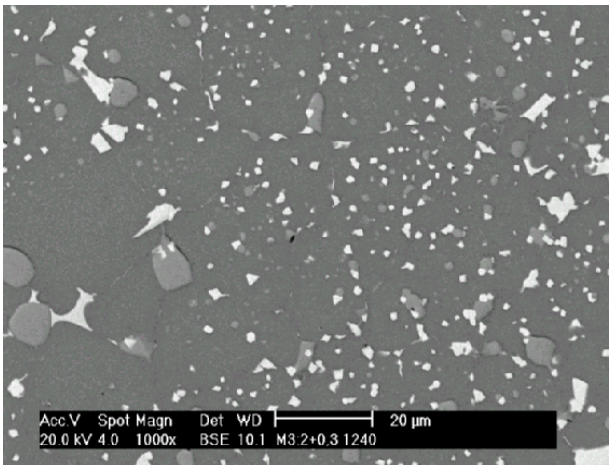

Fig. 2 - SEM micrograph of vacuum sintered M3:2 high speed steel with addition of 0.3%C vacuum sintered at 1240 °C.

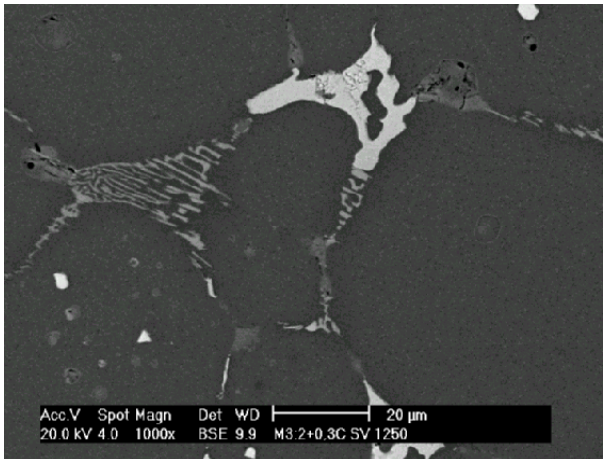

Fig. 3 - SEM micrograph of vacuum sintered M3:2 high speed steel with addition of 0.3%C vacuum sintered at 1250 °C.

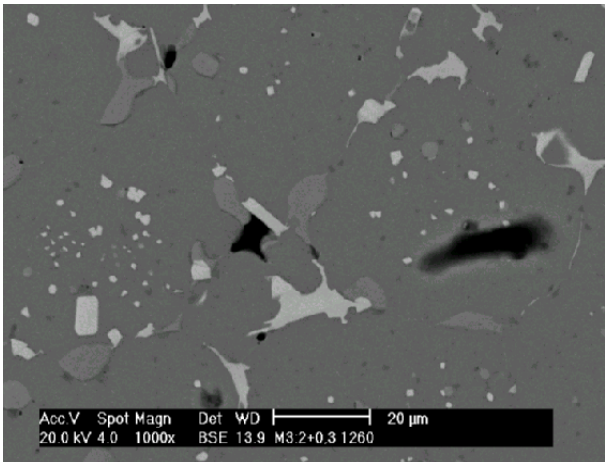

Fig. 4 - SEM micrograph of vacuum sintered M3:2 high speed steel with addition of 0.3%C vacuum sintered at 1260 °C.

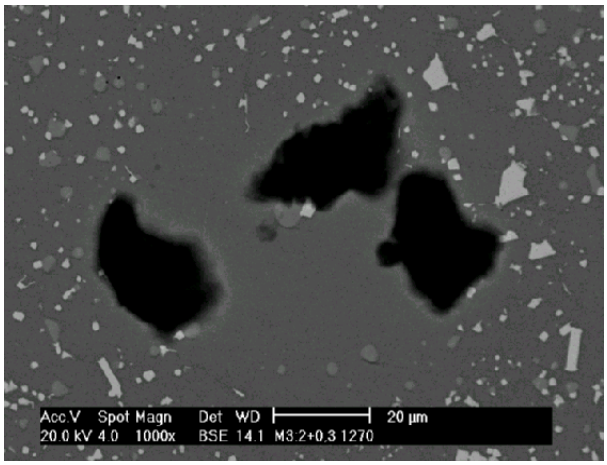

Fig. 5 - SEM micrograph of vacuum sintered M3:2 high speed steel with addition of 0.3%C vacuum sintered at 1270°C

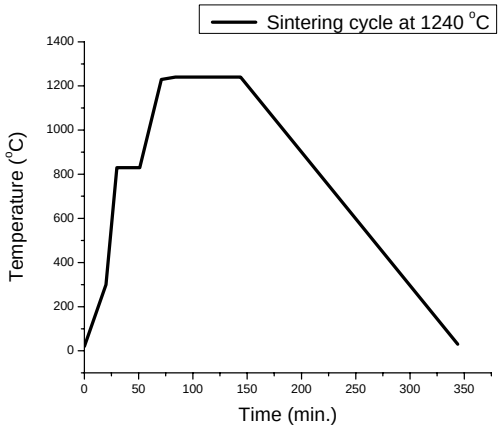

Fig. 6 – Sintering cycle used for sintering M3:2 + 0.3%C at 1240°C

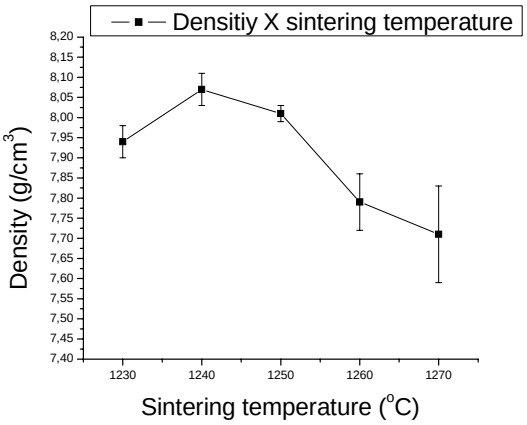

Fig. 7 – Density as a function of sintering temperature

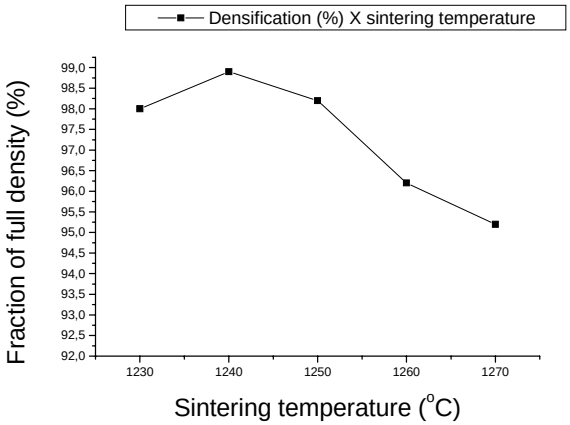

Fig. 8 – Fraction of full density as a function of sintering temperature

Typical compositions for the martensitic matrix and carbide phases found in the M3:2 high speed steel are given in Table 3, and showed that M_6C carbides were basically rich in iron, tungsten, and molybdenum. MC carbides also appeared were rich in vanadium and molybdenum which is consistent with compositions recently reported [11].

Table 3 – Typical as sintered of matrix and carbides in M3:2 +0.3%C high speed steel (at optimum sintering temperature of 1240 °C)

	Normalized alloying element content, wt%				
Phase	Fe	Cr	V	Mo	W
Matrix	Bal.	3.87	1.78	2.69	4.56
M_6C	29.41	2.98	4.34	22.01	41.25
MC	22.56	3.29	32.38	16..35	22.42

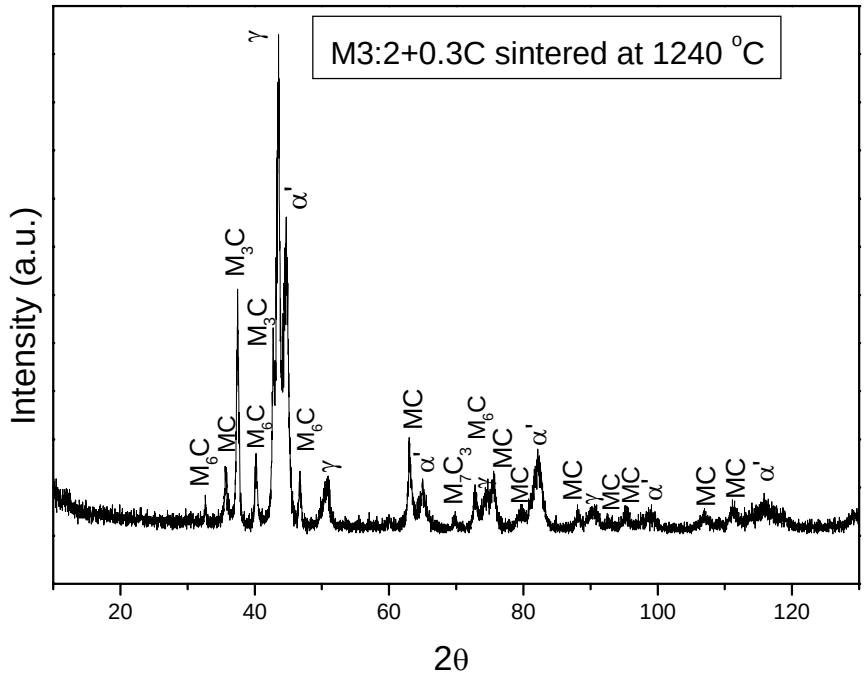

Fig. 9 – X-ray diffraction pattern of M3:2 + 0.3%C high speed steel at optimum sintering temperature of 1240 °C. Cu-kα

The hardness of the as-sintered samples showed high levels for this property (about 53 HRC) and this can attributed to the martensite phase present in this material, detected by means of x-Ray diffraction. Before the hardening heat treatment (austenitizing, quenching and subsequent tempering) it is necessary to submit the material to an annealing treatment in order to reduce its hardness at a lower level (about 20 HRC). If annealing is not performed before hardening an undesired microstructure (fish-scale type) can be resulted producing intergranular fractures and grain growth in the material.

Conclusions

1. M3 class 2 high speed steel + 0.3%C could be vacuum sintered to near full density at 1240 °C.

2. The addition of 0.3%C (graphite) lowered the optimum sintering temperature to 1240 °C if comparison with the M3 class 2 without any addition which presents an optimum sintering temperature of 1263 °C.

3. Microstructures typically observed in this material (M3 class 2 high speed steel + 0.3%C) showed no porosity and an acceptable microstructure was produced.

4. The structure of this material in the as-sintered condition was composed typically by a martensitic matrix (α') plus retained austenite (γ), with MC and M_6C carbides.
5. Since the hardness of the as-sintered material presented high levels (about 53 HRC) due to the martensite phase it is necessary to submit the material to the heat treatment of annealing before hardening to prevent grain growth and intergranular fractures (fish-scale fractures).

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