Influence of Sintering Parameters on the Mechanical Performance of PM Steels Pre-alloyed with Chromium

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Abstract

Powder grades pre-alloyed with 1.5-3 wt% chromium can be successfully sintered at the conventional temperature 1120 °C, although well-monitored sintering atmospheres are required to avoid oxidation. Mechanical properties of the Cr-alloyed PM grades are enhanced by a higher sintering temperature in the range 1120-1250 °C, due to positive effects from pore rounding, increased density and more effective oxide reduction. Astaloy CrM (Fe-3 wt% Cr-0.5 wt% Mo) with 0.6 wt% graphite added obtains an ultimate tensile strength of 1470 MPa and an impact strength of 31 J at density 7.1 g/cm^3, after sintering at 1250 °C followed by cooling at 2.5 °C/s and tempering.

Keywords : PM steel, chromium, sintering atmosphere, sintering temperature, oxide reduction

1. Introduction

Chromium is a low cost alloying element that gives high hardenability and good recycling possibilities. The fact that chromium is a strong oxide former has earlier obstructed the usage of Cr-containing materials in PM steels. However, in pre-alloyed powders the activity of chromium is lower than in e.g. mixes with ferrochromium, which makes it easier to avoid problems with oxidation during processing.

Guidance on the demands put on sintering atmospheres to avoid oxidation of the PM steel may be obtained from thermodynamic calculations (see Table 1). Conditions are reducing for a steel alloyed with 3 wt% Cr if the oxygen partial pressure is below $4*10^{-18}$ atm at 1120 °C. This agrees well with results from experiments performed on a PM grade pre-alloyed with 3 wt% Cr and 0.5 wt% Mo [1].

The benefits of using high temperature sintering on Cr-alloyed materials have been reported in several studies, where properties are compared after sinterings at 1120 °C and 1250 °C [2-4]. In this paper, results are presented from an investigation where also intermediate sintering temperatures were applied on two different powder grades pre-alloyed with chromium.

Table 1. Critical oxygen partial pressures for oxidation in $90N_2/10H_2$ atmosphere (from Thermo-Calc).

Material [cont. in wt%]	p_{O_2} [atm]	
	1120 °C	1250 °C
Fe-3Cr-0.5C	$4*10^{-18}$	$1*10^{-15}$
Fe-1.5Cr-0.5C	$1*10^{-17}$	$3*10^{-15}$

2. Experimental Procedure

Two water-atomized powder grades pre-alloyed with chromium and molybdenum have been studied in the experimental investigation. Test mixes were prepared as premixes with graphite (Kropfmühl UF4) and lubricant (amide wax) added to the powder grades (see Table 2).

Table 2. Composition of tested premixes.

Test Mix	Powder Grade [cont. in wt%]	Graph. [wt%]	Lubr. [wt%]
M60	Astaloy CrM (Fe-3Cr-0.5Mo)	0.60	0.8
L85	Astaloy CrL (Fe-1.5Cr-0.2Mo)	0.85	0.8

The test mixes were compacted into standard tensile test specimens (ISO 2740-1986) and un-notched impact specimens (ISO 5754) with green density 7.0 g/cm^3. Sintering of the test bars was performed in a laboratory batch furnace for 30 minutes at different temperatures (1120-1250 °C) in a N_2/H_2 (90/10) atmosphere with dew point below -40 °C. Cooling rate after sintering was 0.5 °C/s. All M60 test specimens were re-sintered in a laboratory belt furnace (1120 °C, 30 minutes, $90N_2/10H_2$) with convective cooling capacity, where sinter-hardening was performed with a cooling rate of 2.5 °C/s. The sinter-hardened samples were tempered at 200 °C for 60 minutes in air.

3. Results and Discussion

Carbon loss during sintering is more pronounced in M60 than in L85 and increases with sintering temperature for both materials (see Table 3). The oxygen levels show that oxide reduction during sintering is more efficient at higher temperature. Moreover, both materials experience some density increase with higher sintering temperature.

Table 3. Chemistry and density of sintered materials.

Material	T [°C]	C [wt%]	O [wt%]	SD [g/cm³]
M60	1150	0.51	0.079	7.06
	1200	0.49	0.020	7.09
	1250	0.45	0.006	7.11
L85	1120	0.80	0.075	7.01
	1160	0.79	0.037	7.04
	1200	0.77	0.014	7.07
	1240	0.75	0.007	7.11

Tensile properties and impact strength of sinter-hardened M60 are enhanced by a higher sintering temperature (see Fig. 1 and Fig. 2). Material L85 obtains higher tensile and yield strengths with higher sintering temperature up to 1200 °C. However, sintering at 1240 °C gives slightly lower strength values than sintering at 1200 °C (see Fig. 1). The impact strength increases continuously with the sintering temperature, which is illustrated in Fig. 2.

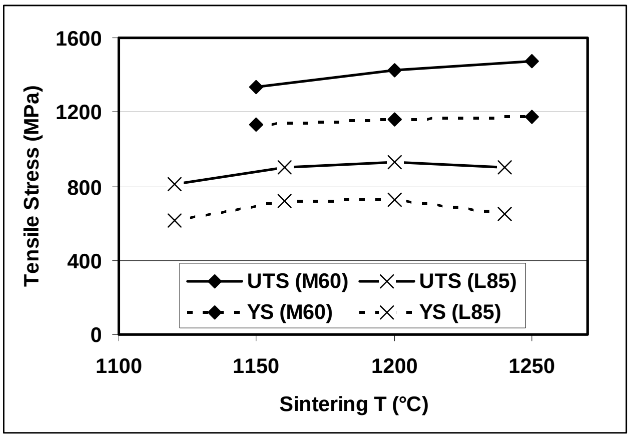

Fig. 1. Tensile and yield strength of sintered materials.

The sinter-hardened M60 materials have fully martensitic microstructures and hardness values around 430 HV10. The microstructures of the sintered L85 materials consist of mixtures of fine pearlite and bainite. Hardness varies between 234 HV10 and 284 HV10. There are somewhat more areas of coarse bainite in the L85 material that was sintered at 1240 °C than in those sintered at lower temperatures, which explains the decline in strength and hardness obtained for the highest sintering temperature.

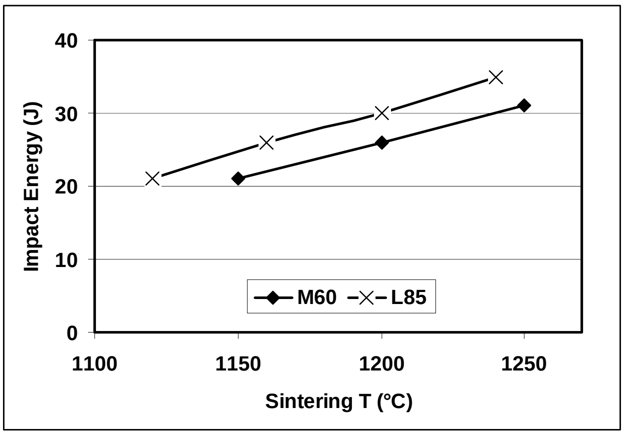

Fig. 2. Impact strength of sintered materials.

The pore structures are slightly irregular and there are some oxides in the materials after sintering at 1120-1160 °C. After sintering at 1200-1250 °C, the pores are rounded and practically all oxides are removed due to faster kinetics and diffusion processes at higher temperatures. These findings are consistent with reports from other studies [5-7].

4. Summary

Critical oxygen partial pressures for oxidation during sintering of powder grades pre-alloyed with 1.5-3 wt% chromium are in the range 10^{-17}-10^{-18} atm at 1120 °C. At higher temperatures, more oxygen is allowed in the sintering atmosphere without having oxidizing conditions.

Mechanical properties of the Cr-alloyed PM grades are enhanced by a higher sintering temperature in the range 1120-1250 °C, due to positive effects from pore rounding, increased density and more effective oxide reduction. The ultimate tensile strength of sinter-hardened Astaloy CrM (with 0.6 wt% graphite added) at density 7.1 g/cm^3, increases from 1330 MPa after sintering at 1150 °C to 1470 MPa after sintering at 1250 °C.

5. References

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