Influence of Sintering Temperature and Component Density on the Properties of Prealloyed PM Steel Grades Containing Cr, Mo and Mn

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Abstract

Chromium, molybdenum and manganese are effective alloying elements suitable for low-alloyed structural steel components. Efficient use of these alloying elements in PM steels will make the PM technology more competitive in high performance applications. This study demonstrates mechanical properties obtained with prealloyed powder grades containing Cr, Mo and Mn after application of different press-sinter process routes. Astaloy CrL (Fe-1.5%Cr-0.2%Mo) with 0.7%C obtains tensile strength values of 714/880 MPa combined with elongations of 1.2/1.8% at density levels 7.0/7.2 g/cm^3 after conventional sintering at 1120°C. Corresponding tensile strength and elongation values for two development grades with more ductile property profiles are 632/736 MPa combined with 2.2/3.0% for Fe-1.8%Cr, and 586/662 MPa combined with 3.3/4.0% for Fe-0.8%Cr-0.4%Mn, both with 0.7%C after sintering. Application of higher sintering temperature is beneficial for the mechanical performance of the studied materials. Sintering at 1250°C leads to increased tensile strength values by 15-25% compared to the properties obtained after sintering at 1120°C.

Introduction

Molybdenum and nickel are commonly used as alloying elements in low-alloyed PM steel grades for structural steel components. However, high and volatile prices of these elements in recent years are making the PM technology less competitive towards conventional steel making techniques, such as forging and casting. Therefore, increased usage of the low cost and effective alloying elements chromium and manganese in steel powder grades would be beneficial for the PM industry. The oxidation sensitivity of Cr and Mn has historically been a limiting factor, but improvements in production processes for powders and PM components have changed the situation. Water-atomized powder grades prealloyed with Cr (1.5-3%) and low amounts of Mo (0.2-0.5%) have now been available for some years and these materials are continuously finding new applications. Using them as base in production of PM structural parts is a cost efficient way to reach the mechanical properties needed for high performance applications [1,2]. The usage of Mn in PM steel grades is still very limited. However, results from a recent investigation show that good mechanical properties are achievable for PM steels based on powder grades prealloyed with Mn [3].

This study demonstrates mechanical properties obtained with prealloyed powder grades containing Cr, Mo and Mn after application of different press-sinter process routes. The materials included in the investigation are the commercial grade Astaloy CrL, which is prealloyed with 1.5%Cr and 0.2%Mo, and two development grades, one prealloyed with 1.8%Cr and the other with 0.8%Cr and 0.4%Mn. Test specimens have been produced with two different compaction pressures (600/800 MPa) and sintering was performed at two different temperatures (1120/1250°C) in N_2/H_2 atmosphere. Conventional cooling was applied after sintering. Standard tensile and impact testing has been conducted on the sintered specimens and the results have been correlated to the microstructures of the materials.

Experimental procedure

Three different water-atomized powder grades were used as test materials (see Table 1). Oxygen contents of the used powders are in the range 0.10-0.15% O. Powders A and B were mixed with 0.75% C-UF4 (graphite from Kropfmühl) for sintering at 1120°C and 0.8% C-UF4 for sintering at 1250°C. Powder C was mixed with 0.8% C-UF4 for both sintering temperatures. Lubricant amount was 0.6% Kenolube in all mixes.

Grade	Fe (%)	Cr (%)	Mo (%)	Mn (%)
A	Base	0.8	-	0.4
B	Base	1.8	-	-
C	Base	1.5	0.2	-

Table 1. Nominal chemical compositions of investigated powder grades.

Standard tensile test specimens (ISO 2740-1986) and un-notched impact test specimens (ISO 5754) were produced with two different compaction pressures (600/800 MPa). Heated tool (60°C) was used for the highest pressure. Specimens of both density levels were sintered in a laboratory mesh belt furnace at 1120°C for 30 minutes in $95N_2/5H_2$ atmosphere. High temperature sintering at 1250°C for 30 minutes in $95N_2/5H_2$ atmosphere was done in a laboratory batch furnace for specimens compacted at 600 MPa. The cooling rate was in the range 0.5-1°C/s in both sintering processes. An overview of the applied process routes is given in Table 2. Evaluation of the sintered specimens consisted of mechanical testing, metallography (LOM) and chemical analysis (of C and O in LECO instruments).

Process route	Compaction	Sintering
1	600 MPa	1120°C, 30 min, $95N_2/5H_2$
2	800 MPa, heated tool	1120°C, 30 min, $95N_2/5H_2$
3	600 MPa	1250°C, 30 min, $95N_2/5H_2$

Table 2. Process routes applied on the test mixes.

Results

Sintered properties are summarized in Table 3. Carbon contents are close to 0.7% C for all materials. Carbon loss was 0.05-0.09% C for the materials sintered at 1120°C and 0.11-0.13% C for the materials sintered at 1250°C. Material C has higher carbon contents than the other two materials after 1120°C sintering due to higher graphite content in the test mix. Oxygen contents are very similar for the different material types, with 0.04-0.07% O after 1120°C sintering and 0.01% O after 1250°C sintering. Sintered density (SD) levels are in the range 7.0-7.1 g/cm^3 after process routes 1 & 3, and in the range 7.2-7.3 g/cm^3 after process route 2. The densities are slightly higher for materials A and B than for material C.

Grade	Process route	C (%)	O (%)	SD (g/cm^3)	HV10	UTS (MPa)	YS (MPa)	A (%)	IE (J)
A	1	0.66	0.04	7.04	163	586	388	3.3	19
	2	0.68	0.06	7.26	191	662	422	4.0	30
	3	0.67	0.01	7.06	193	658	443	3.2	33
B	1	0.68	0.04	7.03	192	632	448	2.2	19
	2	0.69	0.06	7.23	220	736	496	3.0	28
	3	0.67	0.01	7.08	198	733	505	3.2	32
C	1	0.74	0.05	6.98	209	714	570	1.2	19
	2	0.75	0.07	7.19	250	880	630	1.8	23
	3	0.69	0.01	7.06	255	892	705	2.4	30

Table 3. Sintered properties obtained for powders A/B/C mixed with 0.75-0.8% graphite after different process routes.

The ultimate tensile strength (UTS) of the materials increases as much with higher density as with higher sintering temperature (see Figure 1). Material C has highest UTS values, with 714 MPa after process 1 and close to 900 MPa after processes 2 and 3. Correspondingly, the UTS values increase with change in process route (1 → 2/3) from 632 MPa to around 735 MPa for material B and from 586 MPa to around 660 MPa for material A. The yield strength (YS) of the materials is enhanced with change in process route in similar way as the UTS (see Figure 2). However, the YS values are higher after process 3 than after process 2.

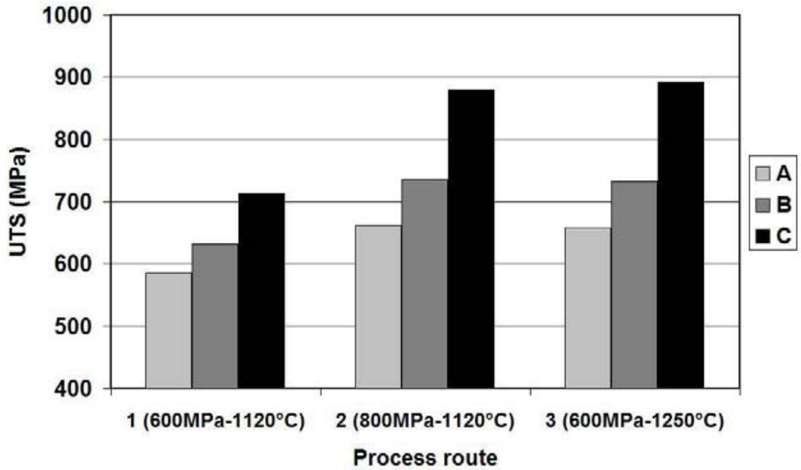


Figure 1. Tensile strength values obtained for powders A/B/C mixed with 0.75-0.8% graphite after different process routes.

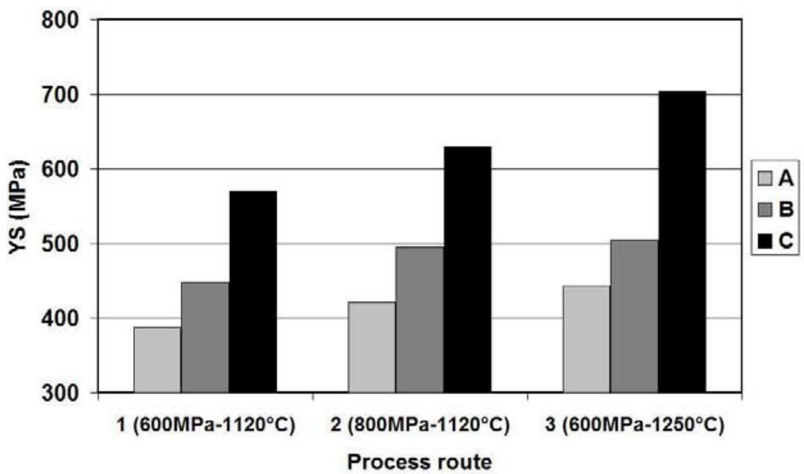


Figure 2. Yield strength values obtained for powders A/B/C mixed with 0.75-0.8% graphite after different process routes.

Material A has high elongation (A) in the range 3.2-4.0% after all three process routes, as illustrated in Figure 3. Also material B has high elongation values, ranging from 2.2% after process 1 to around 3% after processes 2 and 3. Material C has lower elongation than the other two materials after all process routes, with a maximum value of 2.4% after process 3. All three materials have an impact energy (IE) value of 19 J after process 1 (see Figure 4). After process 2, the impact strength is considerably higher for materials A (IE = 30 J) and B (IE = 28 J) but only somewhat higher for material C (IE = 23 J). Process 3 leads to high and equivalent IE values in the range 30-33 J for all materials.

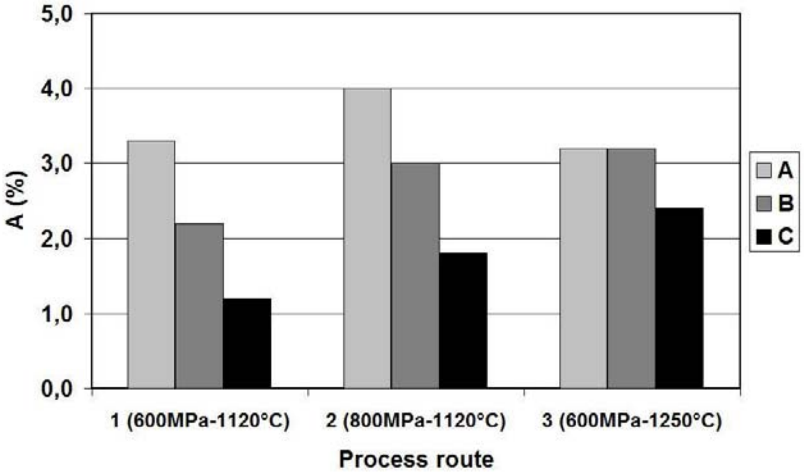


Figure 3. Elongation values obtained for powders A/B/C mixed with 0.75-0.8% graphite after different process routes.

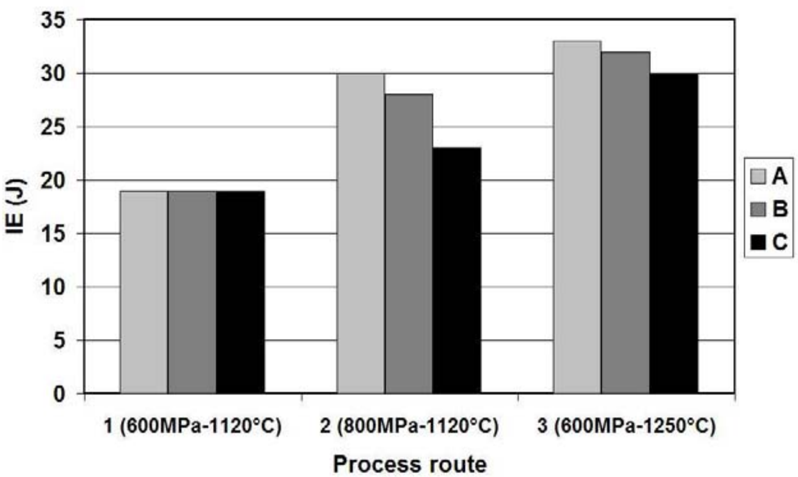
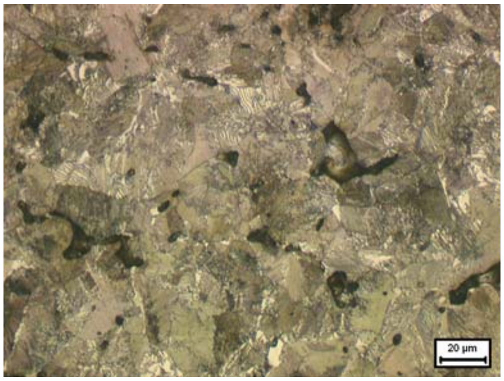


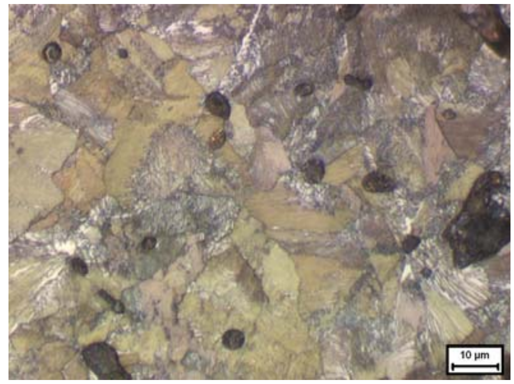
Figure 4. Impact energy values obtained for powders A/B/C mixed with 0.75-0.8% graphite after different process routes.

Etched microstructures of the sintered materials are displayed in Figure 5. The microstructure of material A contains a mix of fine and coarse pearlite after processes 1 and 2. After process 3, the structure of the material contains mainly fine pearlite. There are also traces of ferrite in all the structures of material A. Material B has a microstructure consisting of fine pearlite with only small amounts of coarse pearlite after all three process routes. In material C, the microstructure consists of upper bainite after process 1 and a mix of upper bainite and fine pearlite after processes 2 and 3. The amount of fine pearlite in the structure is higher after process 3 (~50%) than after process 2 (~20%).

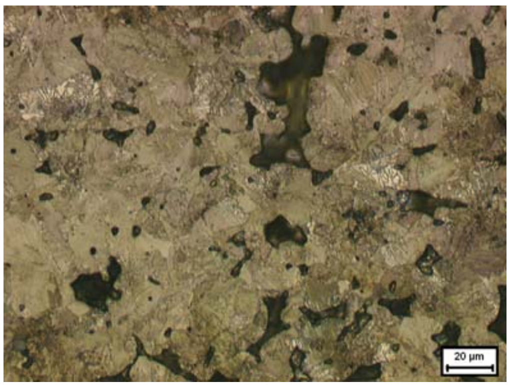
Examination of as-polished microstructures of the sintered specimens shows that there are small oxides (typically of submicron size) throughout the structures of all three materials after processes 1 and 2. After process 3, all materials have clean microstructures with only traces of oxides present.



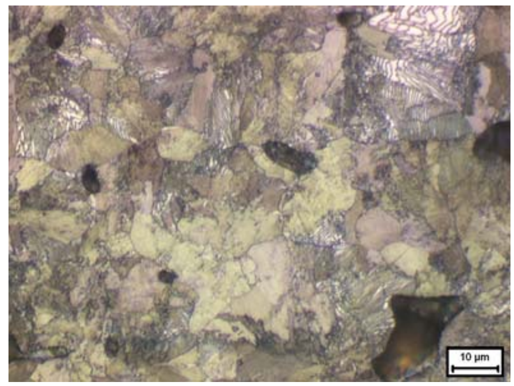
Material A (Process 1): Fine & coarse pearlite



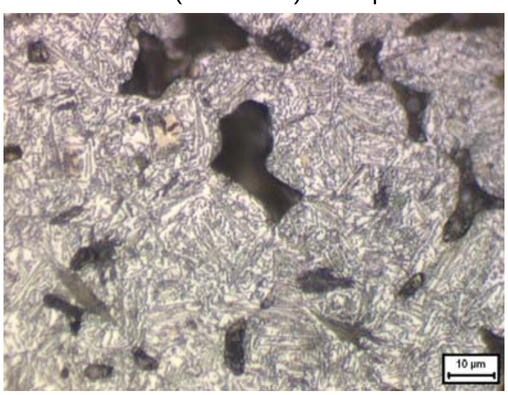
Material A (Process 3): Fine pearlite



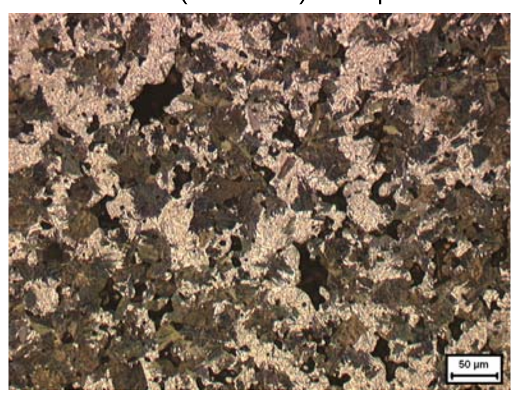
Material B (Process 1): Fine pearlite



Material B (Process 3): Fine pearlite



Material C (Process 1): Upper bainite (UB)



Material C (Process 3): UB & Fine pearlite

Figure 5. Etched microstructures of sintered specimens (based on powders A/B/C mixed with 0.75-0.8% graphite) after different process routes.

Discussion

The performed investigation demonstrates differences in mechanical property profile between the studied materials after sintering. These differences are linked to the microstructures of the materials. Material C, which is based on a 1.5%Cr-0.2%Mo prealloyed powder grade, has bainitic or mixed bainitic/pearlitic microstructure resulting in high strength but relatively low ductility. The other two materials have pearlitic microstructures that give lower strength but better ductility compared to material C. Material B (based on 1.8%Cr prealloyed powder) has somewhat finer pearlitic structures than material A (based on 0.8%Cr-0.4%Mn prealloyed powder), which leads to higher strength but lower ductility for material B in comparison with material A.

The application of higher compaction pressure in process 2 leads to increase in sintered density by ~0.2 g/cm^3 compared to process 1 for all materials. Thereby, the tensile strength is raised about 15% for materials A and B. These materials also exhibit large gain in both elongation and impact strength due to the increased density levels. For material C, the tensile strength is almost 25% higher after process 2 than after process 1, which should be a combined effect of increased density and change in microstructure (from bainite to mixed bainite/pearlite). Material C also shows a relatively large gain in elongation at the higher density level, while the increase in impact strength is only moderate.

Material B has almost identical tensile properties (UTS, YS, A) and impact strength after process routes 2 and 3. Hence, sintering at higher temperature (process 3) has the same beneficial effect on the mechanical properties as using higher compaction pressure (process 2) in this case. The behaviour of material A is similar, except that no gain in elongation is obtained after high temperature sintering compared to after sintering at 1120°C (process 1). This should be a consequence of the difference in microstructure composition after the two processes, with finer pearlitic structure after high temperature sintering. Material C also responds well to higher sintering temperature and the mechanical performance is improved relatively much compared to after process 1. Here, the change in microstructure from bainite (process 1) to mixed bainite/pearlite (process 3) should contribute to the gain in performance.

The beneficial effect of higher sintering temperature on the mechanical properties of the materials is mainly due to rounding of pores and slight increases in density. More efficient oxide reduction during sintering may also contribute, although remaining oxides in the materials after sintering at 1120°C should have no significant effect on the properties. The high density specimens from process 2 have only slightly higher oxygen contents than the specimens with lower density from process 1, showing that influence of porosity level on the oxide reduction process during sintering is relatively small.

Conclusions

High mechanical performance is achievable with cost efficient prealloyed powder grades after conventional press-sinter process routes. The investigated materials provide different property profiles with regard to combination of strength and ductility:

- Astaloy CrL (Fe-1.5%Cr-0.2%Mo) with 0.7%C obtains tensile strength and elongation values of 714MPa/1.2% at density 7.0 g/cm^3 and 880MPa/1.8% at density 7.2 g/cm^3 after sintering at 1120°C. Corresponding values after sintering at 1250°C are 892MPa/2.4% at density 7.1 g/cm^3. Microstructures are bainitic or mixed bainitic/pearlitic.
- For a Cr-alloyed grade (Fe-1.8%Cr) with 0.7%C, tensile strength and elongation values are 632MPa/2.2% at density 7.0 g/cm^3 and 736MPa/3.0% at density 7.2 g/cm^3 after sintering at 1120°C. Corresponding values after sintering at 1250°C are 733MPa/3.2% at density 7.1 g/cm^3. Microstructures are pearlitic in all cases.
- For a Cr/Mn-alloyed grade (Fe-0.8%Cr-0.4%Mn) with 0.7%C, tensile strength and elongation values are 586MPa/3.3% at density 7.0 g/cm^3 and 662MPa/4.0% at density 7.3 g/cm^3 after sintering at 1120°C. Corresponding values are 658MPa/3.2% at density 7.1 g/cm^3 after sintering at 1250°C. The microstructures are pearlitic.

References

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