

DILATOMETRIC INVESTIGATION OF Fe-Mn-Cr-Mo PM STEELS WITH DIFFERENT CARBON CONCENTRATIONS

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Abstract

Sintering behaviour in high purity hydrogen, nitrogen and mixture of 5% H₂-95% N₂ of Fe-Mn-Cr-Mo-C system containing 3% Mn was investigated. Three mixtures, differing in chromium, molybdenum and carbon contents, were prepared in a Turbula mixer. Then, using single-action pressing in a rigid die at 600 MPa, green compacts with density level 6.4-6.5 gm/cm³ were prepared. Sintering was carried out in a horizontal push rod dilatometer Netzsch 402E at 1120 and 1250°C for 60 min. Pure hydrogen, nitrogen and mixture of 5% H₂-95% N₂ were employed as sintering atmospheres. The influence of isothermal sintering temperature, chromium, molybdenum and carbon contents was investigated by dilatometry. The aim of investigations was to determine transformation temperatures, especially B_s and M_s. The effect of sintering atmosphere on the apparent surface hardness was also examined.

It was shown that the dimensional changes occurring during heating and isothermal sintering and the final density of sintered compacts are influenced by sintering parameters and concentrations of the alloying elements in the powder mixture. There is dependence between hardness and chemical composition of sintering atmosphere – the highest values of hardness were recorded for the samples sintered in pure nitrogen. The B_s and M_s temperatures depend slightly on the sintering atmosphere in contrast to the effect of sintering temperature.

Keywords: *sintered Mn steels, dilatometry, carbon content, Fe-Mn-Cr-Mo-C PM steels*

INTRODUCTION

Nickel and copper, and in some cases molybdenum, are the alloying elements which have traditionally been used in sintered steels. Copper in steel presents recycling problems and nickel, because of its high price and carcinogenic and allergenic effects [1], nowadays are substituted by combination of Fe-Mn-Mo-Cr-(Si)-C [2]. In terms of cost effectiveness, the advantage of Mn over Ni is clear. In ferrous alloys Ni diffuses about 1/3 as fast as Mn. The effect of Mn on the tensile strength of ferrous alloys is higher than that of Ni. As a solid solution strengthener, Mn is approximately four times more effective than Ni [3]. However Mn has an extremely high affinity to oxygen and compacts with addition of Mn have to be sintered in special conditions [4].

Molybdenum is one of the important alloying elements in ferrous metallurgy. The beneficial effect of Mo on the properties of PM steels can be explained mainly by solid solution hardening [3]. It was observed that Mo diffuses about three times slower than Mn, although diffusion rate of Mn was slowed to the speed of Mo when both Mo and Mn were

contained in the admixed powder [5]. Molybdenum, as an alloying element, has high affinity to the carbon, but low affinity to the oxygen. Sintered steels containing Mo can be prepared mainly as premixes of plain iron with molybdenum donor addition as well as on the basis of Mo-prealloyed powders (e.g. Astaloy Mo, CrM, CrL). The main advantage of the last ones is their full homogeneous microstructure in the base on iron powder matrix [6].

Mn and Cr tend to form stable oxides, which are hardly reduced at lower sintering temperatures. For Mn and Cr the redox line, for example at dew point -40°C, is crossed at 1250°C and 1000°C, respectively [7]. Addition of Mn and Cr in the form of ferroalloy decreases the temperature at which oxides are reduced.

EXPERIMENTAL

The Astaloy CrM- and Astaloy CrL-based compositions (Table 1) with constant Mn concentration (3% Mn) were manufactured and examined. Manganese was added in the form of low-carbon, low-silicon (1.3% C, 77% Mn) ferromanganese powder, having nominal particle size, as measured by sedimentation method, of 12 µm. Elemental carbon in amounts of 0.3, 0.6 and 0.8% was added to powder mixtures in the form of ultra fine Höganäs C-UF graphite powder.

Tab.1. The chemical composition of powder mixtures.

Element [mass %]	Mixture base					
	Astaloy CrL			Astaloy CrM		
	A	B	C	D	E	F
C	0.3	0.6	0.8	0.3	0.6	0.8
Mn	3	3	3	3	3	3
Cr	1.5	1.5	1.5	3	3	3
Mo	0.25	0.25	0.25	0.5	0.5	0.5

The powders were mixed in a Turbula T2F mixer for 30 min to produce a mixture of the required uniform particle distribution of ferromanganese and graphite. Any lubricant was added to the mixture during mixing.

The blended powders were compacted into rectangular specimens of size 5mm x 5mm x 15 mm using uniaxial pressing at 600 MPa. This resulted in green densities of about 6.4-6.5 g/cm³.

Sintering was carried out in a horizontal push rod dilatometer NETZSCH 402E. The measuring direction (length of the specimens) was chosen perpendicular to the pressing direction of the compacts. Pure dry hydrogen, nitrogen and mixture of 5%H₂-95%N₂ with a dew point below -60°C and the flow rate of about 10 ml/min were used as the sintering atmospheres. Heating and cooling rates were 10°C/min and 20°C/min. respectively. Isothermal sintering was carried out for 60 min. at two temperatures: 1120°C and 1250°C. As-sintered densities of samples were in the range of about 6.5-6.6 /cm³. Dilatometric curves were afterwards analysed by Netzscht Thermal Analysis computer program.

RESULTS AND DISCUSSION

The results of dilatometric investigation and hardness test of Fe-3%Mn-(Cr)-(Mo)-(0.3-0.8)%C PM steels are presented in Tables 2 and 3 and Figs.1 and 2. During isothermal sintering the shrinkage was recorded in the range of - 0.30% to -1.70% and - 0.32% to -

1.11% for CrM- and CrL-based materials, respectively. Total dimensional changes are higher for specimens with addition of 3 mass % Mo and 1.5 mass % Cr.

Taking into account the effect of sintering atmosphere on dimensional stability, there is no clear relation between shrinkage/swelling and chemical composition of sintering atmosphere.

The $\alpha \rightarrow \gamma$ transformation in these PM steels is in the range of 790°C - 850°C and no effect of chemical composition of sintering atmosphere on this transformation were recorded. Small effects of Cr and Mo contents on the $\alpha \rightarrow \gamma$ transformation were recorded.

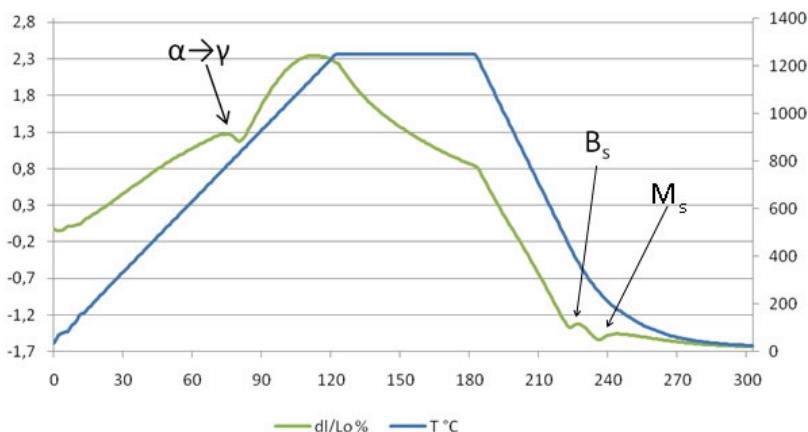


Fig.1. Dilatometric curve of sintered Fe-3%Mn-1.5%Cr-0.2%Mo-0.8%C PM steel; this curve schematically presents the way of calculating the M_s and B_s temperature.

Tab.2. The temperatures of M_s and B_s for Fe-3%Mn-(Cr)-(Mo)-(0.3-0.6)%C PM steels sintered at 1120°C.

Atmosphere	pre-alloyed powder	C [wt.%]	B_s [°C]	M_s [°C]	C [wt.%]	B_s [°C]	M_s [°C]	C [wt.%]	B_s [°C]	M_s [°C]	
100H ₂	CrL	0.3	475	300	0.6	375	275	0.8	300	200	
5H ₂ -95N ₂			475	300		275	225		200	150	
100N ₂			400	275		250	190		200	125	
100H ₂			500	300		200	ND	0.8	400	ND	
5H ₂ -95N ₂	CrM	0.3	400	ND		200			300		
100N ₂			300			200			175		

ND – not determined

Tab.3. The temperatures of M_s and B_s for Fe-3%Mn-(Cr)-(Mo)-(0.3-0.6)%C PM steels sintered at 1250°C.

Atmosphere	pre-alloyed powder	C [wt.%]	B_s [°C]	M_s [°C]	C [wt.%]	B_s [°C]	M_s [°C]	C [wt.%]	B_s [°C]	M_s [°C]	
100H ₂	CrL	0.3	300	250	0.6	300	250	0.8	200	100	
5H ₂ -95N ₂			300	250		250	200		200	100	
100N ₂			300	250		200	170		175	75	
100H ₂	CrM	0.3	400	200	0.6	375	ND	0.8	375	ND	
5H ₂ -95N ₂			300	ND		300			275		
100N ₂			275			200			200		

ND – not determined

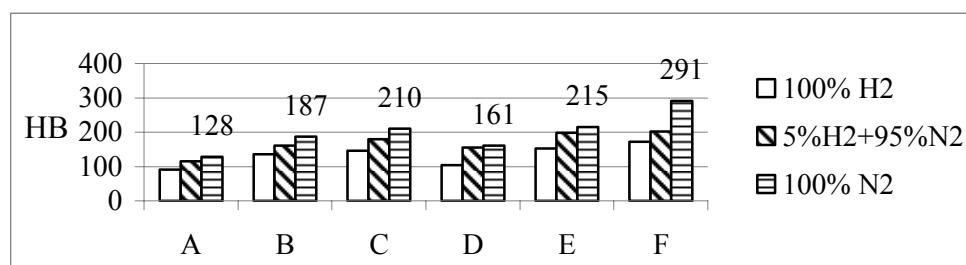


Fig.2. Apparent surface hardness of investigated Fe-Mn-Cr-Mo-C steels vs. chemical composition of sintering atmosphere.

As presented in Tables 2 and 3, an effect of carbon concentration on M_s and B_s of the investigated steels was observed. It could be explained by the favourable effect of carbon on the hardenability of steels. Also the M_s and B_s temperatures depend on sintering temperature; increasing the sintering temperature generally decreases the temperatures of bainite and martensite transformations.

Apparent surface hardness of investigated Fe-Mn-Cr-Mo-C steels depended on the chemical composition of sintering atmosphere; the highest values were recorded for steels sintered in a nitrogen atmosphere. This effect is probably connected with a process of nitrides creation on the surface of steel.

CONCLUSIONS

This work has contributed to studies of sintering Fe-Mn-Cr-Mo-C steels in chemically different atmospheres. On the basis of present work the following conclusions can be drawn:

1. Increasing the nitrogen content in sintering atmosphere decreasing the B_s and M_s temperatures.
2. Using nitrogen as a sintering atmosphere increases surface hardness of Fe-Mn-Cr-Mo-C steels.
3. Alloying elements improve the hardness of steel and decrease the temperature of bainite and martensite transformations.

4. Sintered steels based on Astaloy CrM pre-alloyed powder can be called self-hardening steels because of the low cooling rate necessary to obtain bainitic/martensitic or martensitic structure.

Acknowledgements

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