

## The Sintering Behaviour of Fe-Mn-C Powder System, Correlation between Thermodynamics and Sintering Process, Mn Distribution, Microstructure

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### Abstract

*Sintering behavior of the Fe-0.8Mn-0.5C powder system was studied on the specimens with a density of ~7.0 g/cc sintered at 1120°C for 30 min in a gas mixture of 7%H<sub>2</sub>/93%N<sub>2</sub> with the inlet dew point of -60°C. During the atmosphere monitoring (CO/CO<sub>2</sub>-content and dew point) was showed, that carbothermical reduction occurs in two different temperature ranges; three peaks of dew point profile also can be distinguished during sintering cycle as well. Following sintering the Mn-content distribution and microstructures around the Mn-source were micro-analytical evaluated; the results showed that manganese travels through porous iron matrix up to ~60 μm.*

**Keywords :** Fe-Mn-C system, sintering, atmosphere monitoring, carbothermical reduction

### 1. Introduction

Manganese, which increases the strength of ferrite and hardenability of steels, is an effective and cheap alloying element, which is widely employed in wrought alloys [1]. But in spite of its perfect characteristics, manganese has been traditionally avoided in ferrous powder metallurgy. Several previous attempts to develop Mn sintered steels were unsuccessful due to the high affinity of Mn for oxygen leading to the formation of continuous oxide network when sintering conditions employed may favour oxidation of manganese [2-4]. Mitchell et al. [5] postulated that the only effective way for a “good” sintering of Mn containing steels is an active “micro-climate” around and within the compacts. The contribution deals with an investigation of sintering behavior of the Fe-0.8Mn-0.5C admixed and prealloyed powder systems.

### 2. Experimental and Results

The raw materials employed were: prealloyed atomized iron powders A and B with manganese content 0.3% and 0.8%, respectively. For experiment were prepared two mixtures (wt. %): A+0.5Mn+0.5C+0.8AW and B+0.5C+0.8AW. Sintering was carried out in laboratory tube furnace LAC “LHR A-type” at 1120°C for 30 min in an atmosphere of 93%N<sub>2</sub>/7%H<sub>2</sub> with the inlet dew point of -60°C; the flow rate was ~8 l/min. The heating and cooling rates were ~10°C/min. The dew point and exhaust

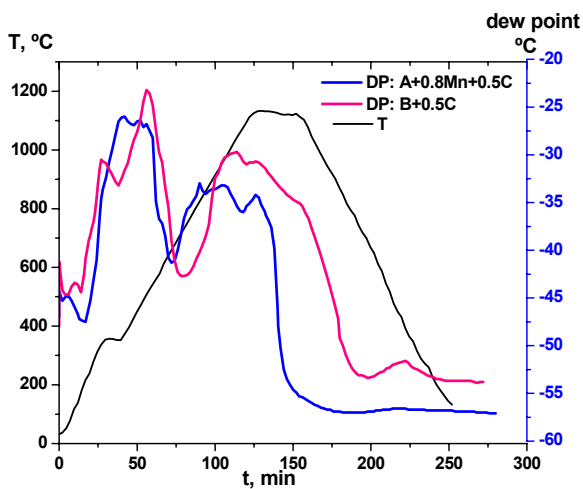
gases CO/CO<sub>2</sub> were monitored during the sintering in the different parts of the furnace (atmosphere within the container, flowing atmosphere above the container and at the exit from the furnace).

Green and sintered densities, dimensional changes Δl, mass changes Δm (the values after the deduction of mass of amide wax) and C-content in sintered specimens are given in Table 1. The R<sub>FR</sub> values were obtained utilizing a “button” tensile test on the same cylindrical samples.

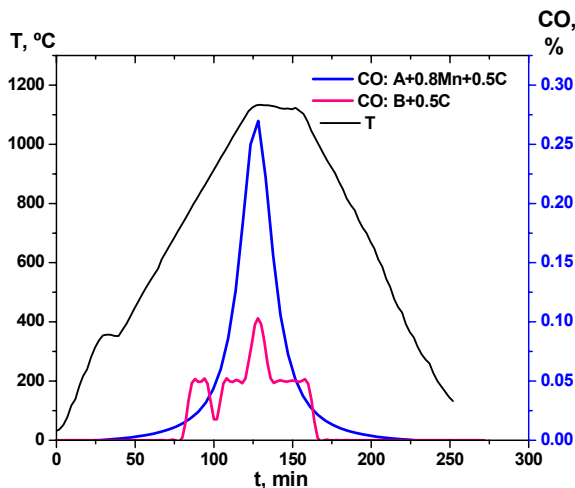
**Table 1. Processing characteristics of sintered specimens**

	density [g/cc]		Δl, [%]	Δm, [%]	C [%]	R <sub>FR</sub> [MPa]
	gr	sint				
A+0.5Mn+0.5C	7.03	6.98	-0.31	-0.19	0.38	364
B+0.5C	7.07	7.04	-0.32	-0.05	0.47	401

The mass change values, Δm, are in accordance with the values of carbon loss. Surface iron oxides, which are prevailing in case of powder A, are better reducible during the sintering than predominating internal and complex Mn-Si-O oxides in case of powder B. The higher values of mass loss and carbon loss for powder A were confirmed by atmosphere monitoring, Figs.1, 2, which show higher values of the dew point and CO content in the atmosphere for the system based on powder A. Obtained monitoring of the dew point and CO content in different part of furnace indicate that accurate information about the atmosphere changes can be achieved only within the container with specimens.



**Fig. 1. Dew point profiles in the container during sintering for both admixed and prealloyed systems.**



**Fig. 2. CO-content profiles in the container during sintering for both admixed and prealloyed systems.**

### 3. Summary

For both admixed and prealloyed Fe-Mn-C systems can be seen three peaks in the dew point profile, (Fig.1): i) at  $\sim 120^{\circ}\text{C}$ , which is attributed with the water removal from the samples, ii) the largest peak at  $\sim 350^{\circ}\text{C}$  during the degassing which is linked with the desorption of physically bonded water by particles, lubricant and graphite, moisture, and hydroxides dissociation; for the system based on powder B the second peak split at two peaks which also show the contribution of surface iron oxides reduction by  $\text{H}_2$  that starts at this temperature, iii) the peak, linked with the reduction of surface iron oxides. Above  $720^{\circ}\text{C}$  the carbothermic reduction begins to play a dominant role. Two peaks are observed on the CO-content profile (Fig.2): i) the first in the range of  $720\text{-}850^{\circ}\text{C}$ , which is linked with the reduction of the surface iron oxides by plain graphite; ii)

the second peak at the beginning of sinter-holding is associated with the reaction of dissolved carbon with internal iron oxides. Higher Mn content in as-prealloyed powder retards the reduction processes (second peak for B+0.5C system is three times less than for system A+0.8Mn+0.5C) because of internal oxygen mostly forms manganese oxides that are more stable than iron oxides which results in a more complicated and slower reduction processes. CO peaks for both systems are accompanied by traces of  $\text{CO}_2$ . The atmosphere monitoring profiles are in good agreement with results obtained during degassing experiments by Danninger et al. [6].

The microstructure of the A+0.5Mn+0.5C specimens, consists mostly of ferrite and pearlite. Complicated sequence of microstructure constituents around FeMn residuals - austenite, which in direction to the particle centre changes to martensite and bainite, is a consequence of Mn concentration gradient due to diffusion processes. Ferrite, which forms the centre of the prior Fe particles, is surrounded by small areas ( $10\text{-}20\ \mu\text{m}$ ) of pearlite. The results of SEM+WDX analysis show that Mn travels through iron matrix up to  $\sim 60\ \mu\text{m}$ . Linear EDX analysis shows that FeMn residuals are complex contaminations, formed by MnS and complex Fe-Mn-Si-O oxides. It is also significant to note the presence of dots inclusions at the grain boundaries in areas near to FeMn residuals. The microstructure of the prealloyed system B+0.5C consists of evenly distributed pearlite and ferrite in nearly equal proportion. Oxides inclusions on the grain boundaries and microstructure heterogeneity due to manganese distribution effect during sintering cycle in admixed system based on powder A result in lower values of the rupture strength  $R_{FR}$  (Table 1) than for prealloyed system based on powder B.

### Acknowledgement

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