



MANGANESE ADDITION INFLUENCE ON THE DENSITY, SIZE, COMPACTIBILITY, AND POROSITY OF MIXED IRON-MANGANESE SINTERED COMPACTS

Cristian SUCIU, George ARGHIR, Ioan PETEAN

Abstract: The influence of manganese addition on the density and size, compactibility, and porosity of sintered compacts is studied. Cylindrical specimens of iron powder mixed with ferromanganese powder (5-15 mass Mn %) were made for analysis of size and density changes. Specimens were pressed at 600 MPa and sintered in H₂ at the temperature of 1120 °C and 1230 °C for 30 minutes. Sintered specimens were analyzed by size and mass measurements. The addition of manganese leads to a linear increase of specimens size, influencing strongly the density and the microstructure, and increasing porosity.

Key words: sintering, manganese steel, density, size change.

1. INTRODUCTION

Since many years the world of PM is searching methods which will bring performance of steel [1].

Manganese has been added to steel for a long time and are the cheapest alloying element with high hardenability. The manganese addition in the sintered parts in form of ferro manganese improves the mechanical properties of alloys such as tensile strength, hardness, and impact energy [2].

There are disadvantages of manganese use as an alloying element, such as high affinity to oxygen and the decrease of powder compressibility [3]. Some of the most intensive researches mention that the difficulties can be eliminated through sintering in atmosphere with low dew point (less than -55 °C) and at temperatures above 1200°C [3].

The swelling of Fe-Mn-C alloys during sintering was investigated by Selecka at all [4,5]. The low dimensional accuracy caused by swelling during the sintering process can be easily solved by sizing [6].

This article describes a study of the size, mass, and density of mixed iron-manganese sintered compacts. The objective of the study is to define and to characterize the physical properties variation after sintering of mixed iron-manganese compacts.

2. EXPERIMENTAL PROCEDURE

Test samples were prepared using following: DWP 400 iron powder and FeMn80C20 ferromanganese powder. Powder grain size is presented in Table 1 according to SR EN 2449. Apparent density was calculated according to SR EN 23923, Table 2. Flow rate was determined according to ISO 4490, using a flow meter with a diameter of 2.54 mm, Table 2. Chemical composition of powders is presented in Table 3.

Tab.el 1. Particle size distribution

Grain size, μm	<63	63-71	71-80	80-100
DWP 400, %	28.09	4.80	3.46	19.23
FeMn80C20,%	9.43	1.66	1.29	4.06
Grain size, μm	100-125	125-250	250-315	>315
DWP 400, %	19.05	24.61	0.38	0.38
FeMn80C20, %	7.21	37.71	24.22	14.42

Iron powder (DWP 400) was mixed with ferromanganese concentrations of 5, 7, 9, 11, 13, 15 mass Mn %, respectively, and 0.14, 0.20, 0.26, 0.32, 0.38, 0.43 mass C % and milled in a planetary mill for 15 min. The pressing was done in a 11.285 mm diameter cavity steel die at bilaterally applied 600 MPa.

Sintering was done at temperatures of 1120°C and, respectively, at 1230 °C in H₂

(99.9 % purity, dew point -40 °C) for 30 minutes. Heating rate was 60 °C/min and cooling rate was 60 °C/min.

Table 2. Apparent density and flow rate of powders

Powder type	Apparent density, g/cm ³	Flow rate, sec/50 g
DWP 400	2.60	43.29
FeMn80C20	3.38	37

Table 3. Chemical compositions of powders

Powder type	C, %	S, %	Mn, %	O, %	Fe, %
DWP 400	0	0.02	0.13	0.17	balance
FeMn80C20	2.00	0	balance	0.17	14.80

The composition of the samples and sintering parameters are shown in Table 4.

Table 4. Compositions and sintering parameters of specimens

Specimens cod	Specimens composition	Sintering temp., °C
Fe5Mn1230	Fe+5%Mn+0.14%C	1230
Fe5Mn1120		1120
Fe7Mn1230	Fe+7%Mn+0.20%C	1230
Fe7Mn1120		1120
Fe9Mn1230	Fe+9%Mn+0.26%C	1230
Fe9Mn1120		1120
Fe11Mn1230	Fe+11%Mn+0.32%C	1230
Fe11Mn1120		1120
Fe13Mn1230	Fe+13%Mn+0.38%C	1230
Fe13Mn1120		1120
Fe15Mn1230	Fe+15%Mn+0.43%C	1230
Fe15Mn1120		1120

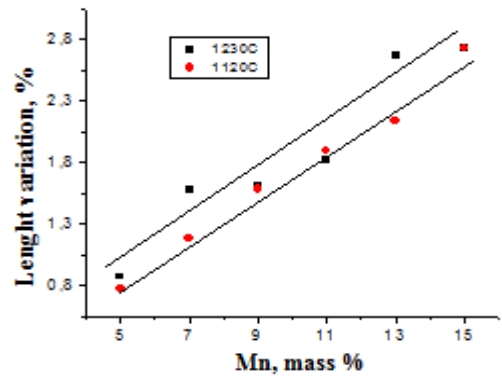
3. RESULTS AND DISCUSSION

Figure 1 a, b shows longitudinal and radial variation versus manganese content. It was recorded a significant swelling of all specimens after sintering. The swelling increases as the manganese content and the sintering temperature increase.

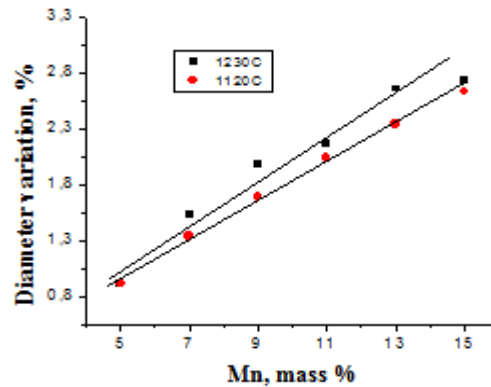
It was recorded a loss of mass and density for all specimens after sintering and are presented in Figure 1 c, d.

The average green density of specimens was between 6.56 and 6.82 g/cm³. Samples (green) with the highest concentration of manganese show the lowest density. The observed a row of low density and mass values, for samples sintered at 1230°C, can be explained by condensation of manganese.

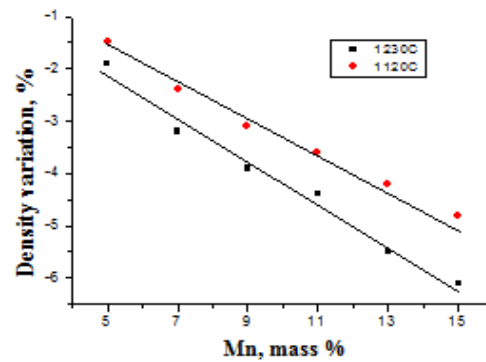
The samples were polished for metallographic investigations. Microstructure analysis and photography was done on an Olympus GX51 microscope.



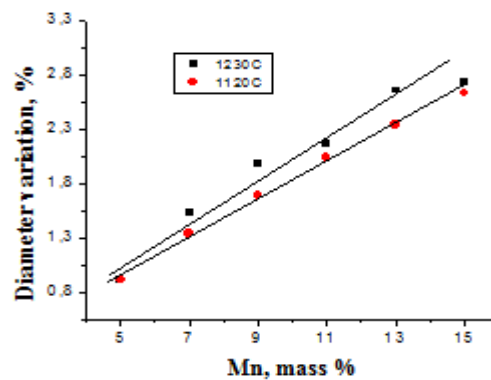
a



b



c



d

Fig. 1. Physical properties variation for sintered samples: a) longitudinal variation, b) radial variation, c) density, and d) mass.

Table 5. Size, mass and density of specimens

Specimens cod	Diameter, mm	Length, mm	Mass, g	Density, g/cm ³
Green specimens				
Fe5Mn1230	11.33	7.23	4.92	6.75
Fe5Mn1120	11.33	7.22	4.96	6.82
Fe7Mn1230	11.33	7.28	4.96	6.75
Fe7Mn1120	11.33	7.24	4.94	6.77
Fe9Mn1230	11.33	7.35	4.97	6.71
Fe9Mn1120	11.33	7.32	4.94	6.70
Fe11Mn1230	11.33	7.42	4.98	6.66
Fe11Mn1120	11.33	7.35	4.98	6.72
Fe13Mn1230	11.34	7.44	4.99	6.65
Fe13Mn1120	11.33	7.38	4.98	6.70
Fe15Mn1230	11.33	7.57	5.00	6.56
Fe15Mn1120	11.33	7.53	4.97	6.56
Sintered specimens				
Fe5Mn1230	11.43	7.29	4.90	6.56
Fe5Mn1120	11.43	7.27	4.97	6.67
Fe7Mn1230	11.50	7.40	4.94	6.43
Fe7Mn1120	11.48	7.32	4.94	6.53
Fe9Mn1230	11.55	7.47	4.94	6.32
Fe9Mn1120	11.52	7.44	4.95	6.40
Fe11Mn1230	11.58	7.56	4.94	6.22
Fe11Mn1120	11.56	7.49	4.99	6.36
Fe13Mn1230	11.63	7.64	4.95	6.10
Fe13Mn1120	11.59	7.53	4.98	6.28
Fe15Mn1230	11.68	7.78	4.96	5.95
Fe15Mn1120	11.63	7.74	4.98	6.08

Microstructures of the investigated materials are presented in Figure 2. High porosity is present specially in the specimen with 11-13 mass Mn %. The high volatility of manganese at sintering temperature can lead to increased porosity and plenty of voids. Finally we observed in Figure 2 a that the average diameter of darker regions (pores) is situated around 50 μm .

For the specimens with 7 and 9 mass Mn % the pores (the darkest areas in Fig. 2 b,d), are considerably increase (maximum 100 μm diameter).

We can also observe that the porosity is increasing and in the Figure 2 d for the samples with 11 mass Mn % the pores are considerably bigger and is around 150 μm .

In the Figure 2 e, f the porosity is increased and the average diameter in this case is around 200 μm , bigger than in the previous sections.

Metallographic investigations showed that the manganese addition had a major effect on the shape and size of pores.

The study of compactibility and porosity was made on sintered samples.

Compactibility was calculated with formula:

$$C = \rho_{\text{sint}} / \rho_{\text{theoretic}} \times 100 \% \quad (1)$$

where ρ_{sint} is the density of sintered sample, $\rho_{\text{theoretic}}$ is the theoretical density of sample.

The porosity was calculated with formula:

$$P = 100 - C \% \quad (2)$$

The values of compactibility and porosity of sintered samples are shown in Table 6.

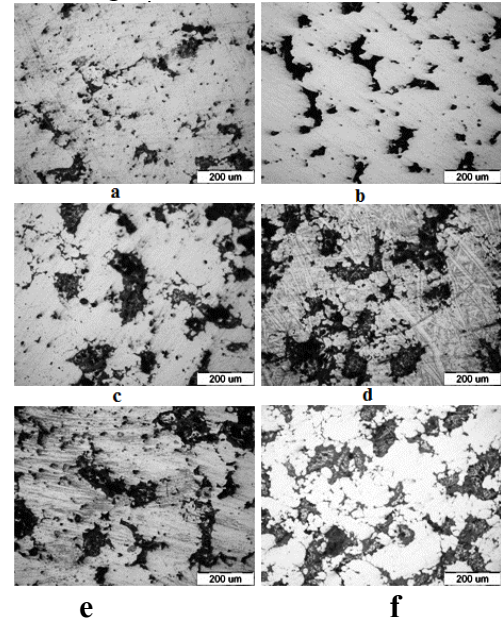


Fig.2. Microstructure of the sample sintered in H₂ at 1120 °C unetched. a) - 5, b) - 7, c) - 9, d) - 11, e) - 13, f) - 15 mass Mn %.

Table 6. Compactibility and porosity of sintered samples from mixed iron-manganese compacts.

Specimens cod	Dens., g/cm ³	Theor. dens., g/cm ³	C, %	P, %
Fe5Mn1230	6.56	7.82	83.7	16.3
Fe5Mn1120	6.67	7.82	85.1	14.9
Fe7Mn1230	6.45	7.81	82.4	17.6
Fe7Mn1120	6.53	7.81	83.4	16.6
Fe9Mn1230	6.32	7.80	80.8	19.2
Fe9Mn1120	6.40	7.80	81.8	18.2
Fe11Mn1230	6.22	7.78	79.6	20.4
Fe11Mn1120	6.36	7.78	81.4	18.6
Fe13Mn1230	6.10	7.77	78.2	21.8
Fe13Mn1120	6.28	7.77	80.5	19.5
Fe15Mn1230	5.95	7.76	76.4	23.6
Fe15Mn1120	6.00	7.76	78.0	22.0

Compactibility and porosity versus manganese content are presented in Figure 3 and 4 (using Table 6).

Compactibility of Fe-Mn steels is decreasing with the increasing of manganese content. We can also observe that the porosity is increasing in the same time with manganese content. Growing the sintering temperature from 1120 °C to 1230 °C leads to a decrease of compactibility and a increase of porosity.

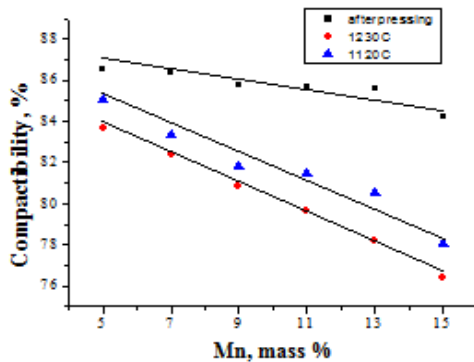


Fig. 3. Compactibility of sintered samples versus manganese content.

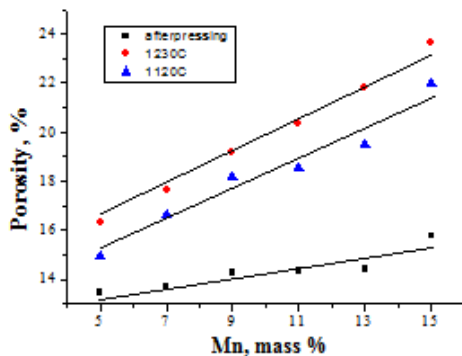


Fig. 4. Porosity of sintered samples versus manganese.

4. CONCLUSIONS

The study outlined the following: addition of manganese in the concentrations of 5-15 mass % Mn leads to a linear decrease of density; samples (green) with the highest concentration of manganese show the lowest density; it was recorded a loss of mass and density for all specimens after sintering; the swelling of mixed iron-manganese compacts is increased as manganese addition and temperature is increased; all samples present open porosity

Influența adăugării de mangan asupra densității, dimensiunilor, compactității și porozității în compactele cu mangan sinterizate

Rezumat: S-a studiat influența adăugării de mangan asupra densității, dimensiunilor, compactității și porozității compactelor sinterizate. S-au preparat probe cilindrice din pulbere de fier amestecată cu pulbere de feromangan (5-15 masă % Mn) pentru analiza modificărilor dimensionale și de densitate în sinterizate. Probele au fost realizate prin presare la 600 MPa și sinterizate în H_2 la temperatura de 1120 °C și 1230 °C pentru 30 minute. Probele sinterizate au fost analizate dimensional și cântărite. Adăugarea de mangan duce la o creștere liniară a dimensiunilor probelor, influențând puternic densitatea și microstructura, crescând porozitatea.

SUCIU Cristian, Drd. Eng., Universitatea Tehnică din Cluj – Napoca, Facultatea de Ingineria Materialelor și a Mediului; **ARGHIR George**, Prof. Dr. Fiz. Eng., Universitatea Tehnică din Cluj – Napoca, Facultatea de Ingineria Materialelor și a Mediului; **PETEAN Ioan**, Dr. Eng., Universitatea Tehnică din Cluj – Napoca, Facultatea de Ingineria Materialelor și a Mediului.

after sintering and the porosity increases with manganese content; the low dimensional accuracy is caused by swelling during the sintering process.

ACKNOWLEDGMENT: This paper was supported by the project "Doctoral studies in engineering sciences for developing the knowledge based society-SIDOC" contract no. POSDRU/88/1.5/S/60078, project co-funded from European Social Fund through Sectorial Operational Program Human Resources 2007-2013.

REFERENCES

- [1] C. Molins, *Update on the status of high performance P/M steels*, Proc. RoPM 2005, vol. 1, Sinaia, Romania, (2005) 5-16.
- [2] A. Salak, M. Selecka, *Effect of manganese addition and sintering conditions on mechanical properties of low carbon 3Cr prealloyed steels*, Research in Powder Metallurgy, (2011) 55-58.
- [3] E. Hryha, E. Dudrová, *The sintering behaviour of Fe-Mn-C powder system, correlation between thermodynamics and sintering process, manganese distribution and microstructure composition, effect of alloying mode*, www.interchopen.com/download/pdf/pdfs_id/13129
- [4] M. Selecka, A. Salak, T. Pieczonka, *Dilatometric study on solid-phase gas-phase sintering and alloying of powder Fe-Mn steels*, Steel Grips, 5, (2008) 355-358.
- [5] M. Selecka, A. Salak, *Manganese gas-phase alloying of sintered steels analysed by dilatometry: Effect of carbon, base powders and manganese carrier*, Powder Metallurgy Progress. 8 (2008) 7-22.
- [6] A. Cias, *Processing and mechanical properties of sintered manganese gears*, Powder Metallurgy Progress. 5 (2005) 147-163.