Nominally Equivalent Powders for P/M Steels: Analysis of Response to Sintering and Differences at Various C Content

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Abstract

Raw materials from different sources, produced by a given process and having equal chemical composition, are supposed to be equivalent. The differences in sintering behavior have been investigated on P/M steels obtained from four diffusion-bonded powders (Fe + Ni + Cu + Mo) on atomized iron base, at the same alloy contents. Two levels of carbon and two sintering conditions have been investigated. Dimensional changes, C content, hardness, microhardness pattern, universal hardness, fractal analysis, pore features, microstructure features, and rupture strength have been compared to characterize different raw materials. The results show that the claimed equivalence is not confirmed by experimental data.

Keywords: diffusion bonding, fractal dimension, microstructure, sintering, universal hardness

1. Introduction

Different iron powder producers offer "equal" or equivalent powder grades. The majority of powder users must rely on powder suppliers or limit any comparison to some prime aspects. On this ground, four diffusion-bonded powders, on atomised base, which are presented -at least in Europe- as nominally equivalent, have been compared in a two-steps investigation. This report presents the results of different comparisons on the response to sintering and carbon content carried out in industrial equipment.

2. Experimental and Results

The nominal composition of investigated powders is: Ni 1.75%; Cu 1.5%, Mo 0.5%. For each base grade, two mixes have been prepared with addition of 0.75% of lubricant, and 0.3 % or 0.6 % graphite. The powders have been compacted at 6.7 ÷ 6.8 g/cm^3 and sintered as follows:

a) belt conveyor furnace, under endogas from methane, at 1125 °C (standard temperature), for 25 minutes;
b) combined-transfer furnace, under N_2/H_2 (90/10) atmosphere, at 1180 °C (high temperature), for 30 minutes.
c) In each material code, the first digit indicates the powder grade, the second digit indicates the nominal C content and the letter indicates the sintering temperature.

Table 1. Coding system of samples.

Powder	1	2	3	4	1	2	3	4
C %	0.3%				0.6%			
1125 °C	13S	23S	33S	43S	16S	26S	36S	46S
1180 °C	13H	23H	33H	43H	16H	26H	36H	46H

The main results of different measurements are collected in Table 2. Bending tests have been carried out to measure the mechanical strength. The average pore area increases as the sintering intensity increases. The "sensible" roundness has been achieved as weighted average, by grouping the pores into 12 classes, by the formula $Ro = P^2/4\pi A$, where P is the perimeter and A is the area of the cross section of a pore.

Table 2. Experimental results.

Mat. code	D	C %	DC %	HV10	B S	FD	SR
			av	av	av	av	av
13S	6.73	0.32	-0.05	120	640	n.d.	1.74
23S	6.74	0.30	-0.08	125	742	n.d.	1.65
33S	6.72	0.32	-0.02	118	655	n.d.	1.75
43S	6.73	0.32	+0.00	124	682	n.d.	1.76
13H	6.74	0.29	-0.12	122	618	n.d.	3.02
23H	6.75	0.31	-0.15	128	668	n.d.	3.04
33H	6.74	0,31	-0.11	116	629	n.d.	2.98
43H	6.74	0.30	-0.10	125	648	n.d.	3.03
16S	6.65	0.59	-0.01	153	752	1.18	1.83
26S	6.66	0.56	-0.05	142	828	1.20	1.68
36S	6,66	0.55	+0.01	149	688	1.17	1.87
46S	6.70	0.56	+0.03	143	770	1.16	1.80
16H	6.72	0.59	-0.09	145	743	1.17	1.81

26H	6,70	0.59	-0.11	144	789	1.18	1.70
36H	6,72	0.58	-0.07	142	711	1.16	1.84
46H	6.70	0.58	-0.07	134	690	1.17	1.80

D = Density [g/cm^3]; C = carbon; DC = dimensional change (referred to green samples); BS = bending strength [MPa]; FD = fractal dimension; SR = "sensible" roundness; av = average

The investigated materials present typically "mottled" microstructures. Each micro-constituent is characterised by a specific micro-hardness. The pattern of micro-hardness distribution enables to distinguish different statistical populations and to find a homogeneity index [1, 2], defined by the expression H.I. = ($f_{max} \cdot n_r / n_h \cdot 40 \cdot 6$) ^ 0.5, where:

n_h is the number of points of maximum, or "humps" on the frequency curve;

f_{max} is the highest frequency of the curve joining the points, %;

n_r is the number of ranges within which the experimental results have been broken-down.

An example of micro-hardness distribution, based on 100 random measurements on each sample, is plotted in Figure 1. The curves indicate that the pattern is affected by base powder, carbon content, sintering temperature. An increase of the sintering temperature shifts towards higher values the frequency of peaks and the average value. Materials 13 and 33 differ from 23 and 43 (S or H); analogously, materials 16 and 36 differ from 26 and 46 (S or H).

Table 3. Results of microhardness measurements.

Mat.code	13S	23S	33S	43S	13H	23H	33H	43H
H.I.	0.43	0.60	0.60	0.71	0.50	0.80	0.66	1.03
Average	158	138	164	141	137	127	167	110
Mat.code	16S	26S	36S	46S	16H	26H	36H	46H
H.I.	0.68	0.68	0.90	0.73	0.84	0.54	0.61	0.55
Average	244	191	228	199	196	192	216	199

The microstructures of two samples are presented in Figs 2 and 3. Upper bainite, with different morphologies, is always the prevailing micro-constituent. Small amounts of fine and very fine pearlite are also present. Ferrite, always present in the microstructure of the 0.3 % C samples, is absent or present in small quantity in the specimens with higher carbon content. The change of microhardness distribution agrees with the observed evolution of microstructures as functions of processing conditions.

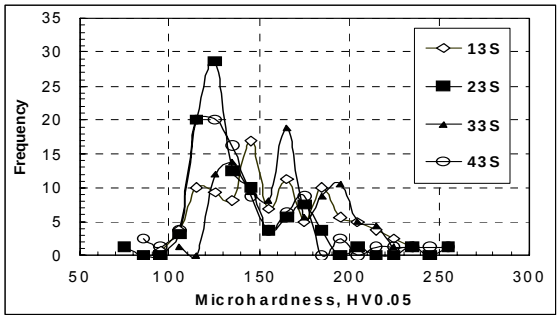

Fig. 1. Microhardness distribution, 1125 °C, 0.3 %C.

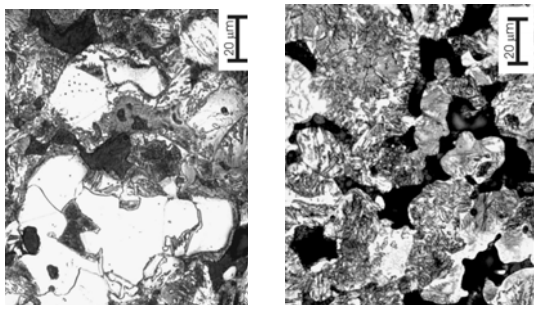

Fig. 2, 3. Materials 13S and 36H.

3. Summary

The results of this investigation show that diffusion-bonded powders available in Europe, claimed as equivalent, differently respond to sintering. The "macroscopic" values (dimensional change, HV10 hardness, bending strength) appear little sensitive to remarkable differences of microstructure and microhardness distributions. More sophisticated approaches, such as microstructure and microhardness analyses, enable to detect that iron-base diffusion-bonded powders, proposed as equivalent to comparable grades, as a matter of fact, notably differ.

4. References

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