Study of the Mechanical Behaviour of Fe-3.5%Mo Based Sintered Steels Made Through Fractography

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Abstract. Sintered (Powder Metallurgy, P/M) materials usually show brittle behaviour and for this reason its toughness is low if we compare it with wrought materials. Recently mechanical designers need more information about used materials and for this reason the knowledge of the behaviour of P/M materials under dynamic loading must be taken into account. In this work one step in this direction is made, studying the impact toughness behaviour of different P/M steels (Fe-3.5% Mo prealloyed powders as base material) and using the microstructure and fractography as tools for understanding the obtained results.

Résumé. Normalement, les matériaux synthériseurs (P/M) nous montrent une conduite fragile et pour cette raison la résistance est basse si nous les comparons avec le travail du matériel. Récemment les dessinateurs mécaniques ont besoin de plus d'information au sujet de l'usage du materiel et pour cette raison la connaissance du comportement du matériel de poudres métallurgiques soumises aux chargements dynamiques doit être pris en compte. Dans ce travail on a fait un pas dans cette direction. En étudiant l'énergie d'impact des différents aciers P/M Fe-3.5% Mo des poudres prealliage comme base du matériel et employant la microstructure et la fractographie comme un ustensile pour comprendre les résultats obtenus.

1. INTRODUCTION

Impact behavior is one of the most unknown properties in sintered materials, probably due to their high porosity level that produce low values in all properties related to dynamic loads. But if the impact behaviour is not well known, the mechanisms that govern the fracture in these materials under dynamic loads are even more unknown. Porosity acts in P/M materials as the main source of cracks that produces the catastrophic fail in service of the material, and for this reason to achieve a high level of density, as much close as possible to the theoretical one, is the main objective of the P/M materials designer. In[1] there is a complete study on the influence of porosity on the fracture mode, based on the mechanism of deformation as a function of pressure and temperature[2].

On the other hand, fractography could be a very interesting way to study the failure model and it is not a very employed method. Recently, fracture of two P/M steels has been studied: 1.5% (wt.)[3] Mo steels and Cr-Mn steels; in both cases the effect of B additions was analyzed[4].

2. EXPERIMENTAL PROCEDURE

The manufacturing method for the P/M steels was mixing (in a lab mixer during 15 minutes), uniaxial compacting at 700 MPa, sintering in N_2-H_2 atmosphere at 1150 °C and heat treating (quenching from 1175 °C in oil). Based powders (prealloyed Fe-3.5%Mo powders MSC from

Manessmann, Germany) were mixed with copper, nickel and graphite as alloying elements and looking to improve the density and final properties of the materials.

The different compositions studied were the following (% in weight):

%C	%Mo	%Ni	%Cu	%Fe
0.7	3.5	-	-	bal.
0.7	3.5	3	-	bal.
0.7	3.5	-	3	bal.
0.7	3.5	4	2	bal.

Materials were tested (Impact Charpy test according ASTM E23-86) both in as sintered and as heat treated condition. A microstructural study was made using optical microscopy and scanning electron microscopy. The mechanical behaviour of the materials is studied using fractography as main tool, using the fracture surface of tested (under impact test) materials.

3. RESULTS

In figures 1 and 2 the results of the impact Charpy test and the sintering density of the materials can be analyzed. It can be seen how exist a parallelism between the density and the impact behaviour of the materials, being the more alloyed materials those with higher toughness and density. It looks clearly how porosity can affect the toughness in sintered materials.

In figure 3 we can see the microstructure of the different materials in as sintered condition. In all cases a bainitic microstructure can be appreciated due to the high level of Mo. In the case of steels with nickel some austenitic areas can be observed, very well characterized by microporosity due to Kirkendall effect. Materials without nickel exhibit small pearlitic areas connected with grain boundaries.

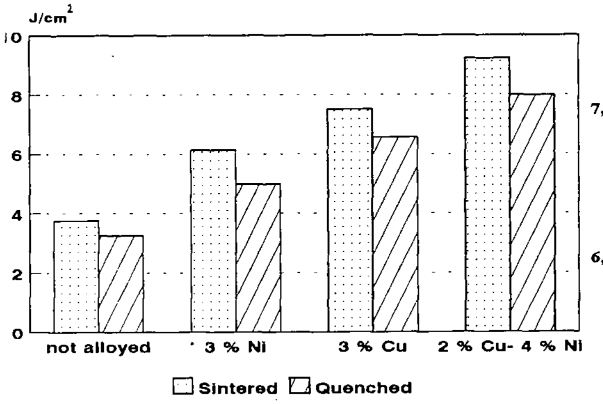

Figure 1: Impact Charpy test results.

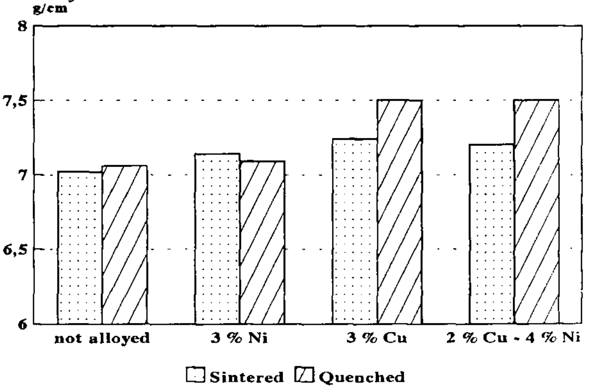

Figure 2: Density of studied materials.

Figure 4 displays the microstructure of materials in as quenched state; here appears martensite and bainite (even quenched materials exhibit a high level of bainite, producing a high toughness level in all materials), being difficult to distinguish between them. In steels alloyed with nickel remains a higher level of porosity of small size and shape close to a circle.

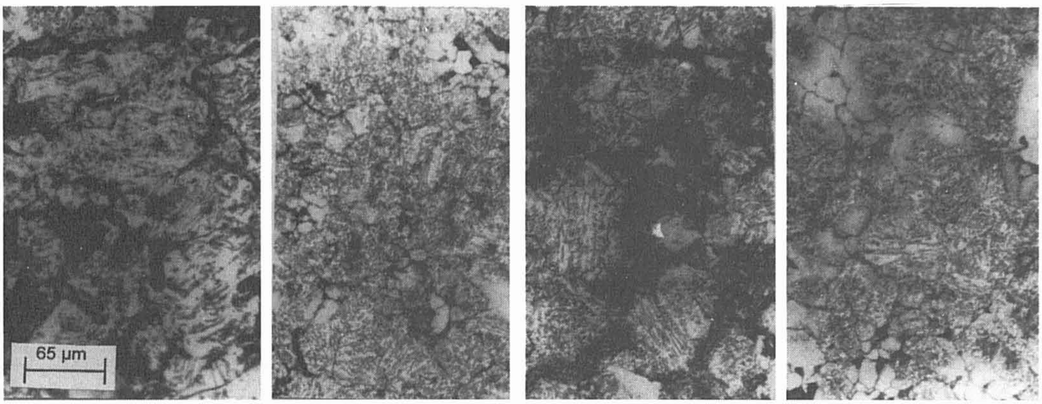

Figure 3: Microstructure of the studied materials in as sintered condition; from left to rigth: Fe-3.5%Mo-0.7%C, Fe-3.5%Mo-3%Ni-0.7%C, Fe-3.5%Mo-3%Cu-0.7%C, Fe-3.5%Mo-2%Cu-4%Ni-0.7%C.

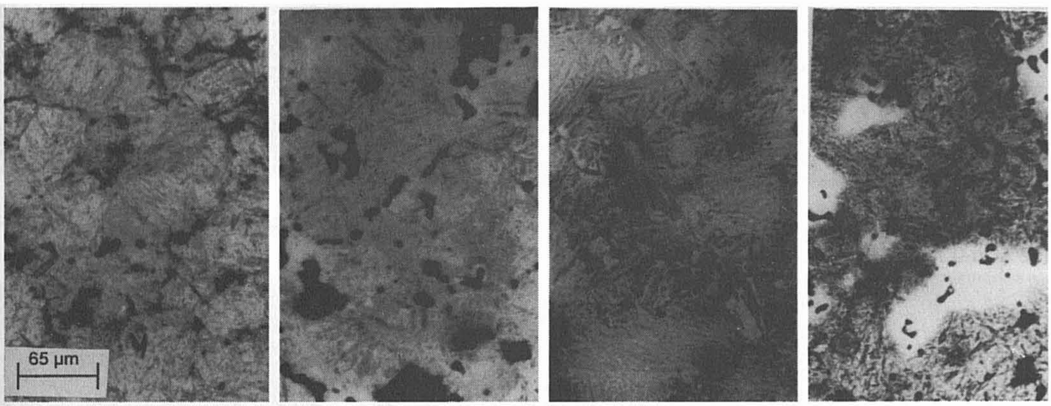

Figure 4: Microstructure of the studied materials after quenching; from left to rigth: Fe-3.5%Mo-0.7%C, Fe-3.5%Mo-3%Ni-0.7%C, Fe-3.5%Mo-3%Cu-0.7%C, Fe-3.5%Mo-2%Cu-4%Ni-0.7%C.

Figure 5 shows the fracture surface, at low magnification of all the materials. The aspect of the surface is wrinkled like is expected in a brittle material. But as much as we increase the magnification level, we can distinguish different microfracture mechanisms. Sometimes it can be distinguished pure ductile fracture in form of several dimples (figure 6). But sometimes the fracture is completely brittle showing cleavage, mainly in transgranular appearance (figure 7, left) or even, in some cases, intercrystaline (figure 7, rigth). The materials with higher densification show a compact surface fracture like it is shown in figure 8 (left). On the opposite hand, the less densified materials show several necks between original particles not being properly sintered (figure 8, right).

4. DISCUSSION

If we analyze all the studied mechanical properties simultaneously, it looks fairly coherent with the expected behaviour. Materials which exhibit higher density have higher impact energy. Moreover, harder materials (quenched) display lower values in toughness. This behaviour has been observed in sintered steels based on Mo: Straffellini et al.[5] studied steels based in a 1.5%Mo prealloyed powders with different carbon contents and they obtained the same correlation between density-hardness-impact energy. In this work, the values obtained for the impact energy are slightly higher in as sintered condition. In a further work[6] in which heat treated steels are studied, the values obtained for quenched steels are lower than those obtained in the present work. The fall of the impact energy after the heat treatment is fully justified if we take into account the microstructural change that experiment the steels (where part of the tough bainite is converted in brittle martensite) and it has been reported by other authors[7].

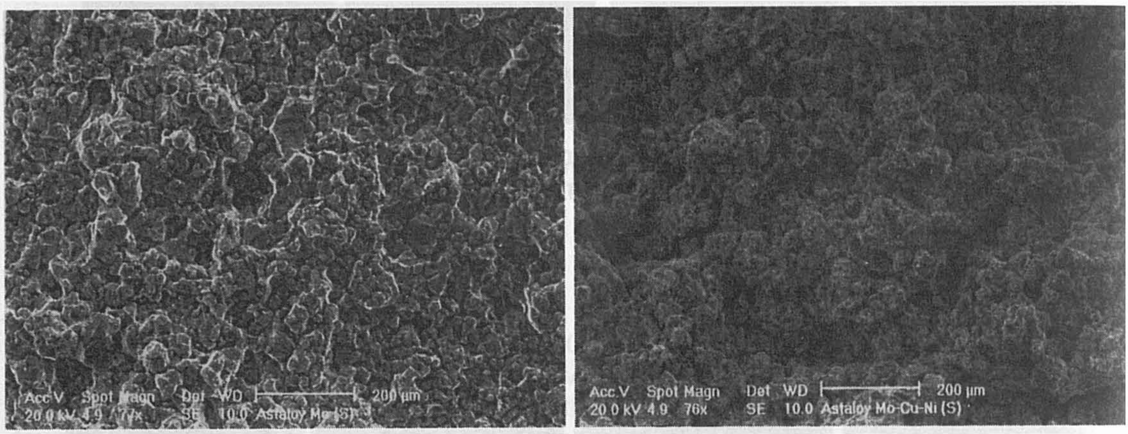

Figure 5: Fracture surface at low magnification in sintered condition; left: Fe-3.5%Mo-0.7%C, rigth: Fe-3.5%Mo-4%Ni-2%Cu-0.7%C.

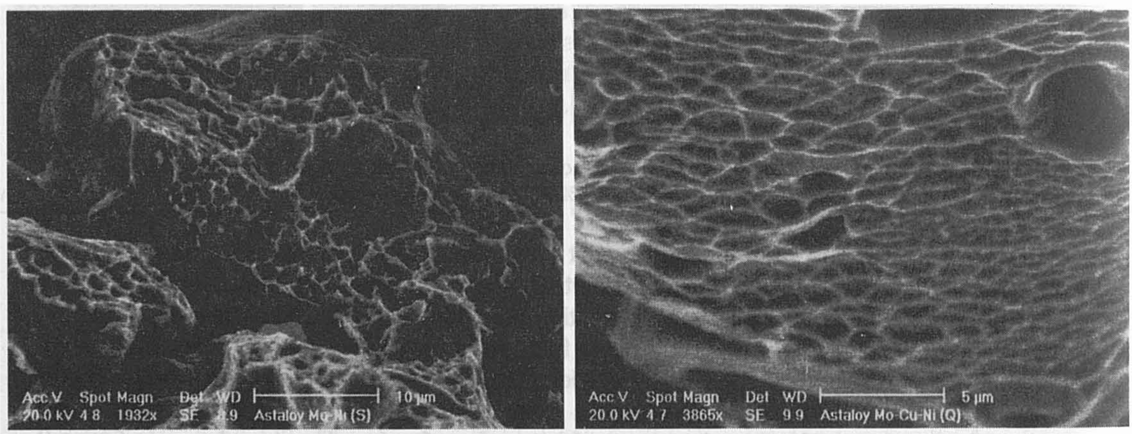

Figure 6: Fracture surface: ductile fracture, dimples.

The brittle behaviour of sintered steels is highly dependent on the density of the materials, and its microstructure. As much as density increases, the impact energy also increases, and in the same way the microstructure help us to explain these results: bainite microstructure produces better answer to dynamic loads than martensite. The brittle behaviour is confirmed when we analyze the fracture surface at low magnification (figure 5). But the analysis of the fracture surface of tested (under impact test) materials at higher magnification reveals two main micromechanisms of fracture: brittle (transgranular cleavage fracture and intercrystalline cleavage fracture) and ductile (dimples). These micromechanisms are not always linked to the ductility (at 'macro' scale) of the materials measured through the impact tests. Figure 9 shows the possible micromechanism of fracture in the more densified materials. On the opposite hand, in figure 10, the fracture mechanism in the less densified materials can be observed and confirmed in figure nº 8. It could be a contradiction that higher densified materials and as a consequence, materials with higher toughness, show brittle micromechanisms of fracture, being the worst materials (under the point of view of it toughness) those which exhibit ductile micromechanisms of fracture (dimple fracture). This contradictory behaviour has been explained previously by[1,8] through mathematical models, that confirm the experimental data obtained in the present work.

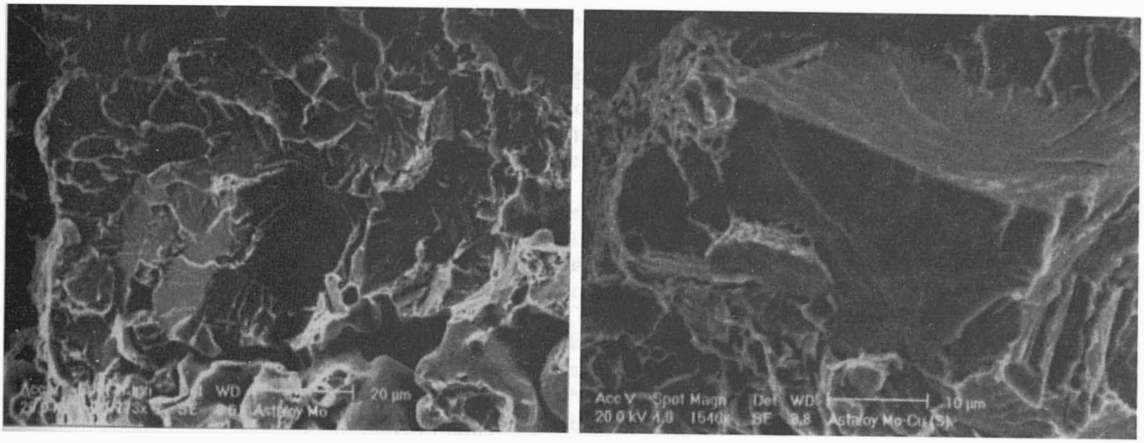

Figure 7: Fracture surface; left: transgranular cleavage, rigth: intercrystaline cleavage.

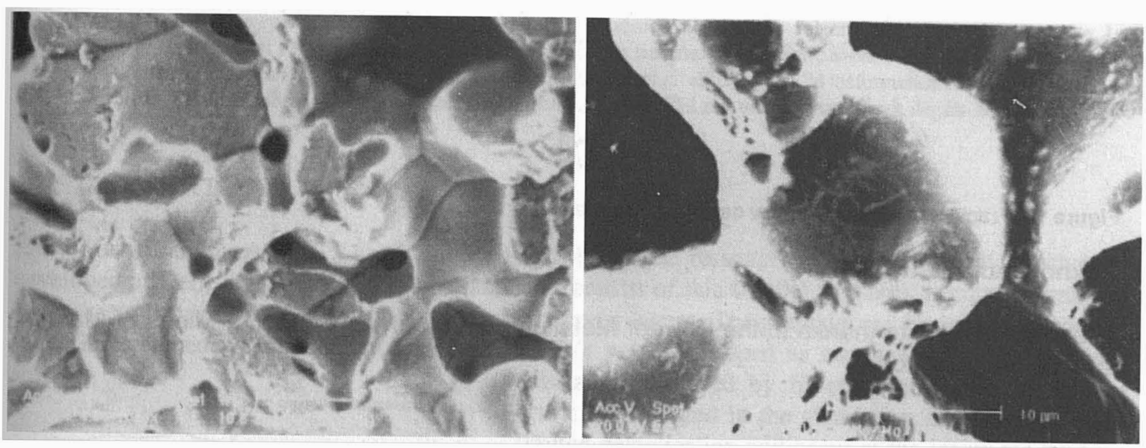

Figure 8: Surface fracture in high densified materials (left) and low densified materials (rigth).

5. CONCLUSIONS

1.- Additions of copper and nickel improve the density of the studied Mo base sintered steels, and as a consequence, the mechanical properties. 2.- Quenching from 1175 °C highly increases the hardness of the studied steels, being the fall in toughness lower than the expected, mainly due to the high level of bainite that remain at microstructural level. 3.- Impact energy of the studied materials reach equivalent levels (9,2 J/cm^2) to those obtained for other steels in better conditions of heat treatment. 4.- Additions of 2% (wt.) Cu and 4% (wt.) Ni to the 3.5% Mo based steel produce the best answer in the studied mechanical properties: hardness and impact energy. Under the point of view of the comprehension of the fracture mechanisms of sintered steels this work propose two simple models for fracture in materials with different level of porosity and confirm experimentally the mathematical model proposed by Malyshenko et al. for sintered steels.

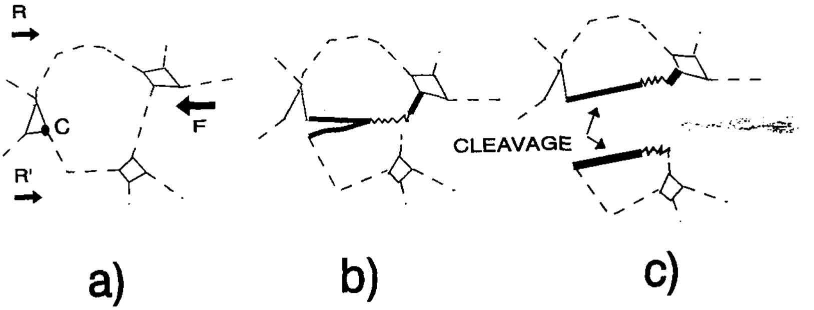

Figure 9: Fracture mechanism in high densified materials.

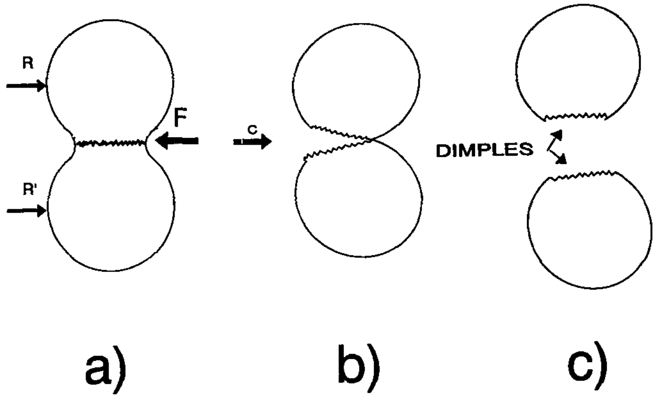

Figure 10: Fracture mechanism in low densified materials.

Acknowledgments

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