ENHANCING THE MACHINABILITY OF POWDER-FORGED COMPONENTS

by

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Paper submitted for presentation at 1998 World P/M Conference, Granada, Spain, October 1998.

ABSTRACT

Manganese sulphide powder is added as a machinability enhancer to ferrous powder mixes destined to powder-forging applications such as connecting rods for automobile engines. During machining, the soft MnS particles deform to create planes along which the energy for microvoid and microcrack formation is low. These microdefects increase the shear angle and chip curl and reduce chip thickness, tool-chip contact, length, frictional forces and cutting temperatures. In addition, MnS is reported to build a lubricating film at the tool-chip interface. The machinability improvement obtained with MnS additions is, however, dependent on the properties of the MnS particles, particularly the particle size and purity level.

An evaluation test capable of detecting minute differences in the machinability behavior of materials was used to determine the performance of three series of FC-0205 powder-forged specimens containing different grades of MnS. Significant differences in thrust force, torque and tool life which were related to the difference in particle size and chemical composition of the MnS powders were noted.

1.- INTRODUCTION

To successfully compete with wrought steels in many automotive applications, powder-forged metals must match, and often surpass, the properties of these materials including machinability. Copper steel connecting rods are typical examples of such components. A detailed study carried out by Chernenkoff et al [1] confirmed that a P/F FC-0205 material admixed with 0.3% MnS exhibits tensile and fatigue properties that exceed those of wrought resulphurized steels. Moreover, the presence of an even dispersion of fine MnS particles is more effective than endogeneous MnS stringers present in resulphurized steel to enhance the machinability of connecting rods [2,3]. However, the improvement in machinability obtained with MnS addition is dependent on the properties of the MnS particles. In this study, the machinability behavior of FC-0205 forged materials admixed with MnS powders of different chemical and physical characteristics was evaluated and the results related to various machining parameters.

2.- EXPERIMENTAL PROCEDURES

2.1 Description of the specimens

Table 1 describes the powder-forged materials tested in this study. All mixes were based on ATOMET 1001 P/F, a high cleanliness powder designed for powder-forging applications. As seen in this table additions of graphite and copper were made to obtain nominal copper and carbon contents of 2% and 0.5%, respectively. Three of the blends were admixed with different grades of manganese sulphide powders whose characteristics are presented in Section 3.1. Specimens without MnS were prepared for comparison purpose

Table 1
Description of the Test Materials

Material	% C	% Cu (nominal)	% S	MnS Grade	Hardness HRB
A	0.59	2.0	0.11	A	93
B	0.59	2.0	0.11	B	93
C	0.52	2.0	0.12	C	95
D	0.49	2.0	0.008	None	93

The detailed manufacturing procedures of the powder-forged specimens are described elsewhere[4]. The specimens which consisted in discs of 100mm in diameter and of 32 mm thickness exhibited similar hardness values, Table 1; the typical microstructure of the discs consists in a mixture of 70% pearlite/30% ferrite.

2.2 Machinability Evaluation

Figure 1 shows a schematic of the drilling set-up used to evaluate the machinability of the materials. It consists of a high power press drill with automatic feed rate control instrumented to continuously monitor the feed rate, the rotating speed, the torque applied on the tool and the thrust force transmitted to the specimen. A dedicated data acquisition system enables the measurement of the four parameters nine times per second. The cutting tools were high speed steel drills of 6.35 mm in diameter with a helix angle of 118?. One drill per material was used, each drill being verified through a validation process prior to usage [5]. All tests were carried out at a speed of 2220 rpm and a feed rate of 0.08mm/rev.

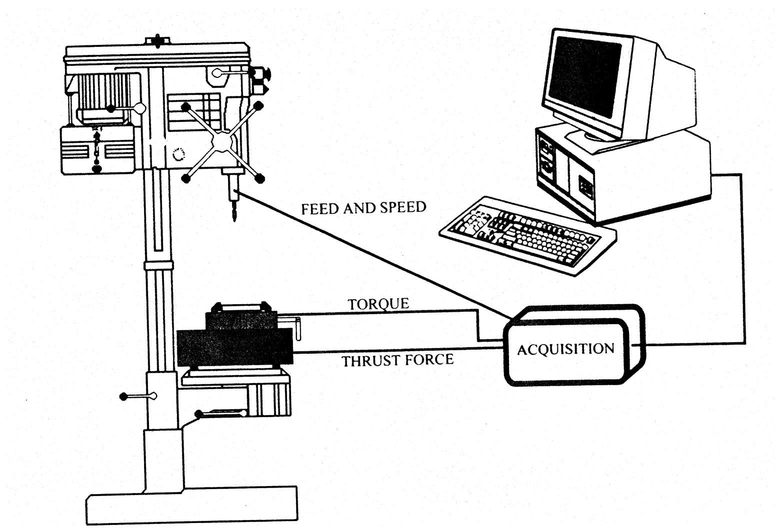


Figure 1. Machinability Evaluation Set-Up.

3.- RESULTS AND DISCUSSION

3.1 Characterization of the MnS Powders

The typical characteristics of the three MnS powders are given in Table 2. Grade "C" MnS distinguishes itself from the others by its coarseness ($d_{95} \sim 39?m$) and its lower purity level.

Table 2

Typical Characteristics of the MnS Grades

Grade	A	B	C
MnS, %	93	99	82
Others, %	7	1	18
D_{50}, ?m	6.4	4.9	8.8
D_{95}, ?m	15.6	11.6	39.0

Figure 2 compares the unetched structures of materials B and C; the difference in particle size is clearly seen. Moreover, it is noted that the MnS present in material C features secondary dark phases embedded in the MnS particles. These are clearly seen in Figure 3 which shows SEM micrographs of polished cross sections of grade "C" MnS. Particles identified with a "2" are pure MnS while the others are oxides whose compositions as analyzed by energy dispersive x-ray spectroscopy are listed in Table 3. Oxides of such compositions (with SiO_2, MgO, Al_2O_3...) are typically hard and brittle.

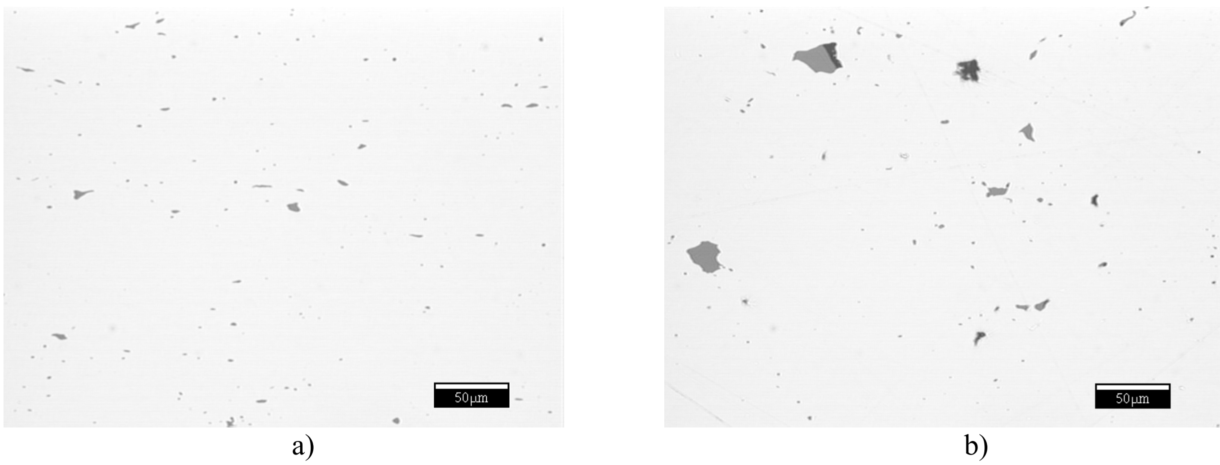


Figure 2. Unetched Structures of Material B (a) and Material C (b).

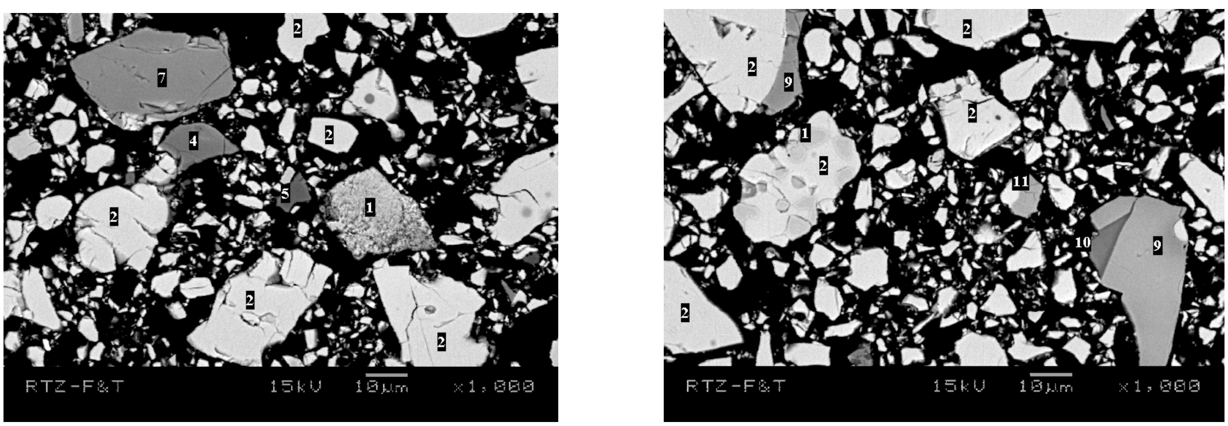


Figure 3. SEM Micrographs of Polished Cross-Sections of Grade "C" MnS.

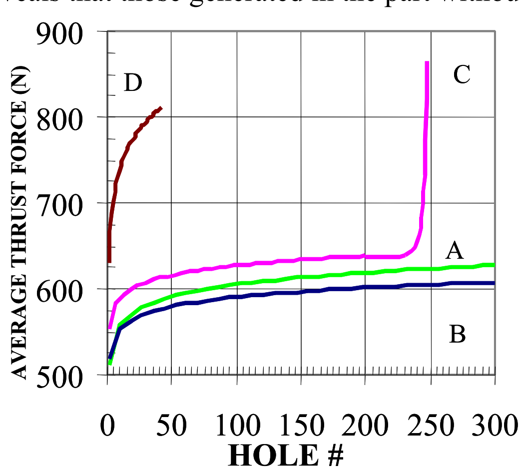
Table 3
Chemical Composition of Secondary Phases
Present in Grade "C" MnS

Compound	Phase no. 1	2	4	5	6	7	8	9	10
MnS	-	100	-	-	-	-	-	-	-
MnO	100	-	34	90	40	30	6	65	35
MgO	-	-	9	9	18	1	19	-	-
SiO_2	-	-	36	0.5	36	57	-	33	50
K_2O	-	-	-	-	-	12	-	-	14
CaO	-	-	-	-	6	-	-	-	-
Cr_2O_3	-	-	-	-	-	-	41	-	-
FeO	-	-	-	-	-	-	16	-	-
Al_2O_3	-	-	-	-	-	-	16	-	-

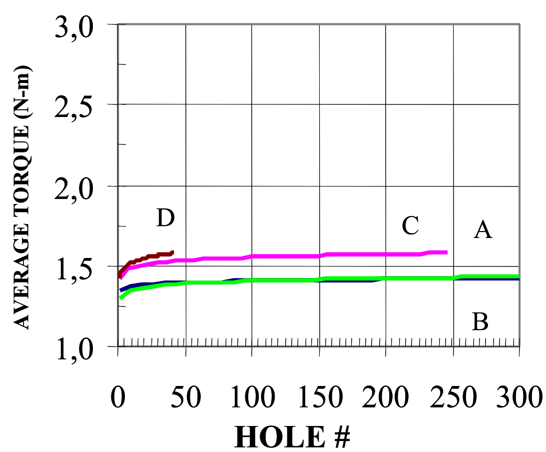
The metallographic examination of the other MnS grades confirmed the difference in particle size as well as in chemical composition vis-à-vis grade "C" MnS. No secondary phase was found in grade "B" MnS while the few ones observed in grade "A" MnS were manganese and iron oxides.

3.2 Machinability

Figures 4a and b present the evolution of the average thrust force and torque measured when drilling holes in the forged specimens at a feed rate of 0.08 mm/rev and a speed of 2220 rpm. The typical 3-stage tool wear curve reported in the literature [6] is clearly seen in the behavior of material "C". Stage I during which thrust force and torque increase rapidly corresponds to the rapid break down of the initial cutting edge and the development of a finite wear land on the tool. This is followed by stage II during which a uniform wear rate is observed and finally by stage III which is characterized by an accelerated wear. The addition of MnS significantly decreases the thrust force and torque values during drilling. The examination of the chips, Figure 5, reveals that those generated in the part without MnS are highly oxidized due to overheating of the tool



a)



b)

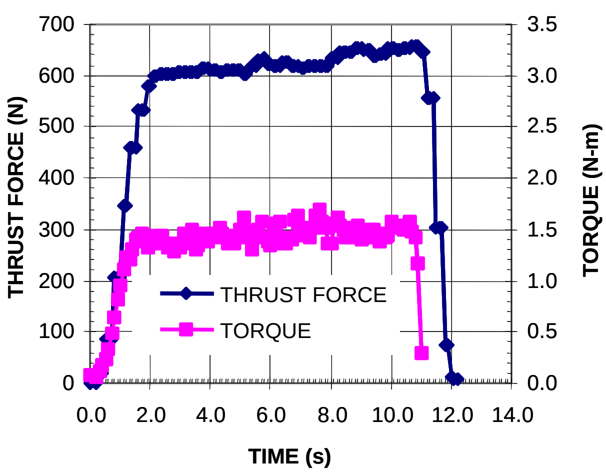
Figure 4: Average Thrust Force (a) and Torque (b) for Each Hole as a Function of the Hole Number.

a)

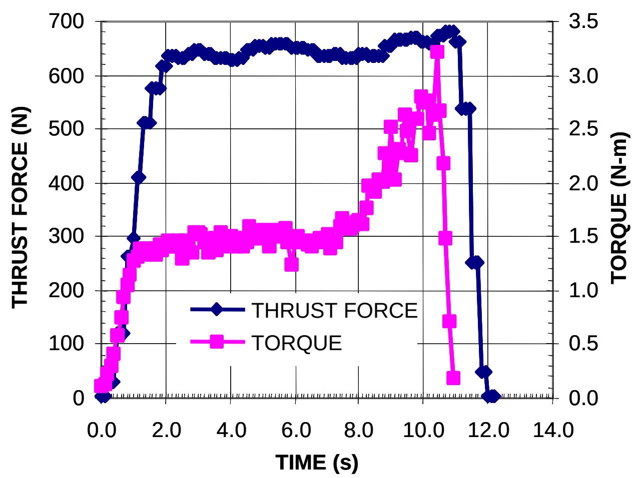
b)

Figure 5. Drilling Chips from Material C (a) (300 holes) and Material D (b) (50 holes).

Differences in machinability related to the various MnS grades are also revealed in Figure 4. Tool life when drilling in the material containing grade "C" MnS is 247 holes while it exceeds 300 holes for the others. This shorter tool life is accompanied by higher thrust force and torque values which indicate that higher stresses are needed for the formation of the chips. It was also noted during the test that the torque values for material C vary significantly from hole to hole which is probably symptomatic of an unstable cutting process during drilling. This is illustrated in Figure 6 which compares the thrust and torque curves generated during drilling a hole in materials B and C. The increase in torque at the end of the drilling test in material C is believed to be related to the increase in temperature at the tool/piece interface as drilling progresses.



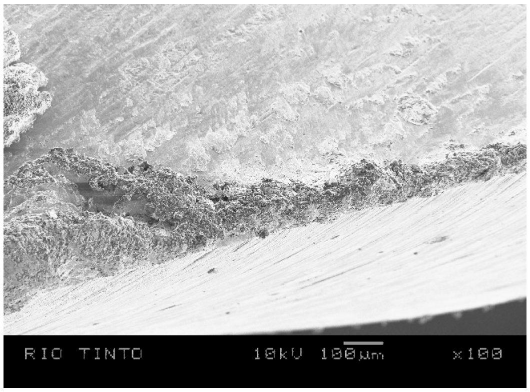
a)



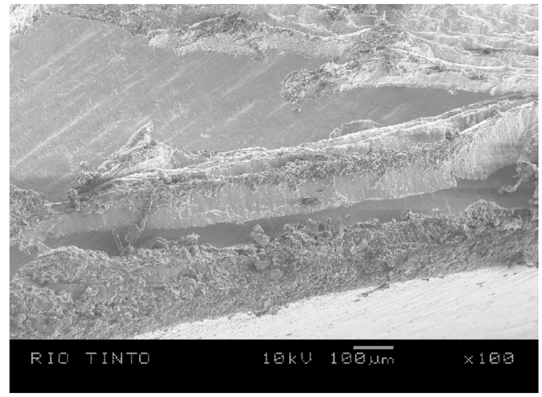
b)

Figure 6. Typical Thrust and Torque Curves When Drilling a Hole in Material B (a) and Material C (b).

The increased difficulty to drill in material "C" is also seen by comparing the wear lands of the tools. As seen in Figure 7, significantly larger wear land and debris built-up are seen on the tool utilized in material C.



a)



b)

Figure 7. Wear Land Developed After Drilling 250 Holes In Material A (a) and 247 Holes in Material C (b).

The poor machinability of Material C might be related to the following factors:

a) Coarse particle size: As seen in Table 2, grade "C" MnS is significantly coarser than grades "A" and "B"; therefore the mean path between the MnS particles is longer as seen in Figure 2. This may result in an interrupted lubrication of the tool. However, it is not clear that such a phenomenon could explain the difference in thrust force measured between materials A and B although grade "B" MnS is slightly finer than grade "A".

b) Chemical Purity: Chemical and microstructural analyses showed that grade "C" MnS contains a significant quantity of phases other than MnS identified as complex metallic oxides, Table 3. Such oxides are very hard inclusions which, rather than lubricating the tool/face interface as does MnS, cause micro-chipping of the tool and the deterioration of the cutting surface. It is worth noting that the machinability of the materials as ranked by the drilling thrust force curves follows the same order as the chemical purity of the MnS grades, i.e. the purest MnS grade (B) exhibits the lowest thrust force. It is also seen on these curves that the curves of material B exhibits the lowest slope and then, rate of tool wear.

4.- CONCLUSION

1.- Drilling thrust force and torque are indices that are related to tool wear and tool life and may be used to characterize the machining behavior of a material.

2.- Manganese sulphide is an effective machinability promoting compound in P/F FC-0205 material.

3.- The machining behavior of MnS containing materials is influenced by the particle size and the chemical composition of the MnS powders.

4.- Using a coarse MnS grade increases the mean path between the particles and is believed to result in an interrupted lubrication at the tool/workpiece interface.

5.- The higher the chemical purity of the MnS powder, the stronger its machinability enhancing effect.

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