

## Performance Assessment of Spray Formed AISI M2 High-speed Steel Tools

Jesus, E. R. B.; Jesus Filho, E. S.; Rossi, J. L.

Instituto de Pesquisas Energéticas e Nucleares, IPEN/CNEN-SP  
Av. Lineu Prestes, 2242- Cidade Universitária - 05508-000 - São Paulo - Brazil  
jelrossi@ipen.br

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**Abstract.** Machining tools (interchangeable inserts) were manufactured from spray formed AISI M2 high-speed steel. The spray formed materials were mechanical and microstructural characterised. An assessment of the machining performance of the spray formed high-speed steel was attained. These results were compared to materials obtained by conventional and powder metallurgy techniques. The results showed that under the used process conditions (hot rolling and heat treating), the spray formed material showed a machining behaviour near closed to other materials; and highlight the potential of the spray forming technique for the obtention of materials with adequate properties for machining tools manufacturing.

### Introduction

In the manufacture process about 50% of the production cost is related to resources and materials needed to the course of process, where are included the tools used in machining [1]. The tool steel is a materials choice, among several other options, for machining tools manufacturing. There are basically three processes for obtainment of tool steel: conventional casting, powder metallurgy and spray forming.

The spray forming process has showed to be technically and economically feasible for obtainment of a range of materials, including tool steels [2-4]. This process involves the continuous atomization of a metallic alloy and deposition of droplets in a substratum before all are in the solid state; and, can be better described by the incorporation of the advantages proportionate by the powder metallurgy process, without the disadvantages associated with the consolidation. The material obtained by the process in general, presents a refined microstructure and important characteristic are the absence of large segregations, low levels of fine microsegregations, refinement of intermetallic particles, secondary and eutectic phases.

### Materials and methods

In this study, it was considered basically four materials variation for AISI M2 high-speed steel, regarding to obtainment methods and subsequent applied thermo mechanical process, see Table 1. Table 2 shows the chemical composition of the used high-speed steels in comparison to the nominal composition of the AISI M2 steel.

A 35 kg spray formed preform was obtained in a pilot plant installed at IPEN. The atomising gas was N<sub>2</sub>. After spray forming, the material (MCS) was soft annealed to improve its workability (machining). For this annealing, the parameters found at literature [5,6], (880 °C for 1 h), was efficient to provide enough hardness reduction in order to allow the machining of the material. Slabs were removed from the annealed material, which were hot rolled at 50% (MCSR50) and 72% (MCSR72) thickness reduction ratio that correspond to areas reductions of about 20% and 67%,

respectively. The hot rolling was performed at 1150 °C and the rolling passes were 1 mm. After each pass the slab returned to the furnace for reheating.

The conventional cast material (MConv) was purchased commercially. Details of the manufacturing methods were not supplied by vendor; however, the literature [5] indicates a reduction ratio of the 94% and over is necessary, with respect to these materials, for attaining a suitable microstructure. Long and onerous esferoidization heat treatments are also needed, for the obtainment of these materials.

Table 1. Used AISI M2 high-speed steels regarding the manufacturing process and subsequent applied thermo mechanical process.

Designation	Obtainment	Post processes
MCSR50	Spray formed	Annealing + hot rolling (50%) + heat treatment
MCSR72	Spray formed	Annealing + hot rolling (72%) + heat treatment
MConv	Conventionally cast	Heat treatment
MP	Powder metallurgy	Heat treatment

The material made by powder metallurgy (MP), was supplied in the shape of sintered square shape 13 x 13 x 5 mm<sup>3</sup>, with dimensions close to that necessary for the manufacture of machining test inserts, see Fig. 1. The sintered inserts were prepared from water atomized powder, which was uniaxially pressed at 800 MPa followed by vacuum sintering at 1249 ± 3 °C [7].

Table 2. Chemical composition (mass%) of the high-speed steels used in this work.

Material	C	Mn	Si	Cr	Ni	Mo	W	V	P	S	N
AISI M2 nominal	0.78-0.88 0.95-1.05	0.15 -	0.20 -	3.75 4.50	0.30 max.	4.50 5.50	5.50 6.75	1.75 2.20	0.03 max.	0.03 max.	-
MCS	1.03	0.18	0.22	3.29	0.29	4.98	6.19	1.87	...	...	0.0340
MConv	0.90	0.29	0.36	3.94	0.20	5.17	6.28	1.77	0.018	0.001	...
MP	0.80	0.20	0.30	4.20	...	5.25	6.38	1.90	...	0.007	...

... Not measured.

The samples and testing specimens from MCSR50, MCSR72 and MConv were heat treated in a salt bath and consisted of pre-heating at 880 °C (9 min), austenitising at 1210 °C (3 min), intermediary cooling at 520 °C (6 min), quenching at room temperature and double tempering at 560 °C (2 h). Specimens were prepared for the transverse rupture strength (TRS) testing [8]. After the flexion test, the broken parts were hardness tested. In the case of MP material, the hardness values were taken direct from insert surface.

For the observation of carbides distribution and size, samples were prepared using standard metallographic technique. The samples were analysed using a scanning electronic microscope (SEM) for microstructure observation, in the as polished and etched conditions. The used etching was a solution of HCl (10 mL), HNO<sub>3</sub> (5 mL) and ethanol / methanol 95% (85 mL) [2], aiming to reveal the austenitic grain boundary.

From mentioned materials, it was manufactured interchangeable inserts for performance evaluation, i.e., machining test. The inserts were coarse machined, heat-treated and at last, finished (rectified and sharpened), resulting in inserts ready to use (Fig. 1). For machining tests, CNC lathe was used. The machining tests were made on specimens of 49 mm (diameter) and 260 mm (length), prepared from SAE 1045 steel according to recommendations of ISO 3685 [9]. The specimens were machined at constant values of cut depth (p) and feed rate (f) equal 1.5 mm and 0.2 mm/rot, respectively. The corner radius (r) was equal 0.8 mm according to ISO 3685. It was used 34 m/min cutting speed during machining operation. During machining it was considered several stops, for flank and crater wear evaluation. At each stop the insert was removed from the tool holder and

carried to an optic microscope for photographic record of wear evolution. Following, the insert was remounted on the tool holder for testing continuity.

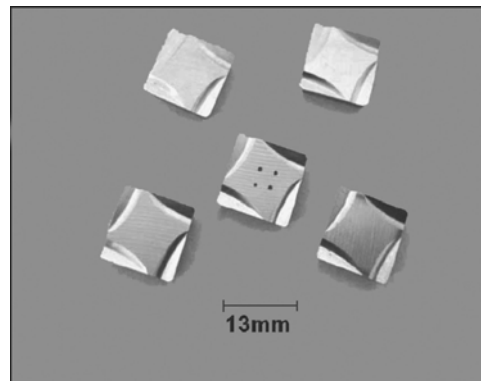


Figure 1. Detail of finished, ready to use, interchangeable inserts for performance evaluation.

## Results and discussion

The hardness measurements results after quenching and tempering showed a small value (720 HV30) for MP material and similar values (770 HV30) for MCSR50 and MCSR72 materials. The higher hardness value (800 HV30) was encountered in MConv material, however, it is important to comment, that higher hardness value is not connected to a better machining performance, as verified by Jesus [2] and Santos [10] in works with conventional, sintered and spray formed high-speed steels.

The results of the transverse rupture strength tests showed that when the spray formed material is submitted to a hot rolling reduction about 50%, the strength value, is higher than the conventional materials. When the reduction ratio is increased to 72% the results are comparable to materials obtained by powder metallurgy. Fig. 2 shows the results of transverse rupture strength tests made in the present work, in comparison to published data for AISI M2 high-speed steel.

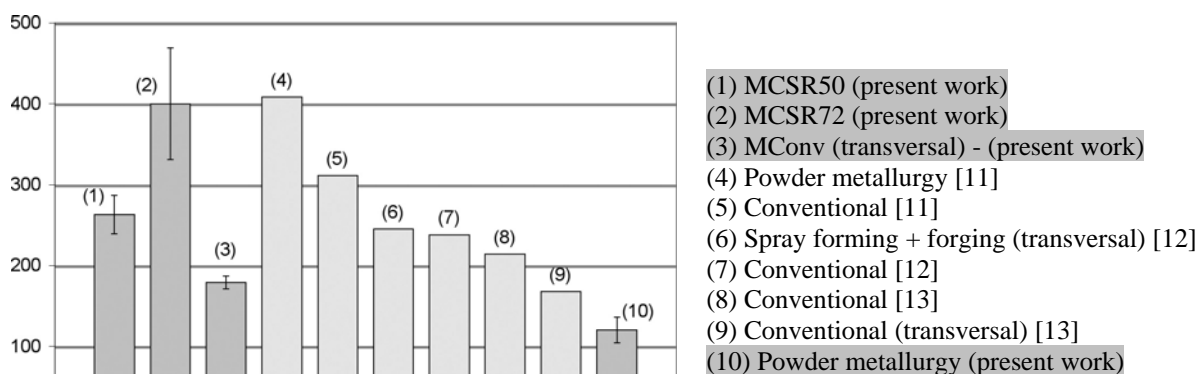


Figure 2. Results of transverse rupture strength testing (TRS) of evaluated materials, in comparison to data obtained by others researchers after heat treatment.

The initial analysis after the machining testing, was about the flank wear performance of each tool material. In this case, the analysis was based mainly on data obtained with cutting speed of 34 m/min. It was machined a major quantity of specimens in two complete session tests, showing acceptable reproducibility results.

From a mean wear curve (maximum flank wear) between two session tests (Fig. 3), it is possible to verify that all materials demonstrated a wear behaviour near close in terms of final values; i.e., neither case presented a divergence so meaningless that could carry out a definitive rejection of the evaluated materials, for the application proposed in present work. This observation

is a sound sign of the potential of the spray formed tool steels, when compared to others consecrated materials.

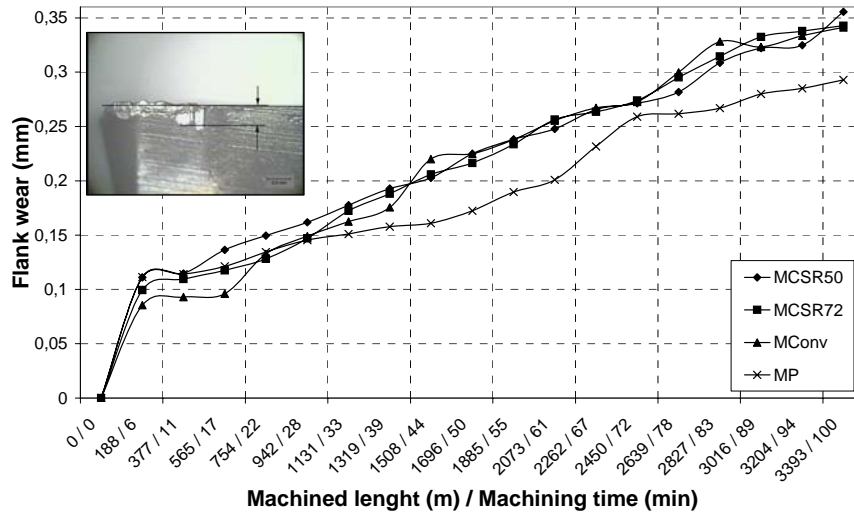


Figure 3. Wear curves for cutting speed of 34 m/min (mean values relating to two session tests). The insert shows a measure of the maximum flank wear.

The machining results presented in Fig. 3 point out a better performance showed by the material obtained by powder metallurgy (PM), followed by the conventionally cast material (MConv), which presented a near close advantage in comparison to spray formed material hot rolled at 72% thickness reduction ratio (MCSR72), followed by the spray formed material hot rolled at 50% thickness reduction ratio (MCSR50).

Compatible results were come across proceeding a similar analysis, based on values of crater wears verified during machining tests, and also when specific Taylor's equation for each material is predicted from data of the tests. Table 3 show an estimation of cutting speed (Vc) for each tool material based on a tool life of 15 minutes.

Table 3. Estimation of the cutting speed for a tool life of 15 minutes.

Tool material			
MCSR50	MCSR72	MConv	MP
Vc = 34 m/min	Vc = 38 m/min	Vc = 39 m/min	Vc = 51 m/min

Microstructurally, if the micrographs showed in Fig. 4 were evaluated aiming the identification of the better material in terms of the microstructural refinement (better distribution and small carbides), characteristics that usually promote better mechanical properties; the MCSR72 material would be chosen. However, when dealing with materials aiming machining tools, there are another significant characteristic that need be considered: the abrasive wear resistance. According to Schruff et al. [14,15], the better microstructural condition that promotes a good material performance regarding wear resistance, is that where the carbides are homogeneously distributed and with coarse sizes. In this condition, in any region and direction there are anchors points which has enough resistance to obstruct the passage of an abrasive element; this resistance will be higher, the higher the carbide size is.

Carrying on a comparative analysis among micrographs of Fig. 4, and establishing a correlation with the results of the machining tests, it follows: a) The MCSR50 microstructure is very similar to the MConv microstructure. However, the MCSR50 material presented worse results in terms of wear resistance during machining tests when compared to the MConv material. b) The MCSR72 presents a homogeneous carbides size distribution and smaller carbide size than MConv, hence, with a microstructure much more refined. However the machining tests showed that both

materials have a very close performance condition, with narrow advantage for the MConv material. c) The MCSR72 material presented a microstructure as refined as the MP material, including very small carbides size. However, the MP material presented the best result during machining testing, among all evaluated tool materials.

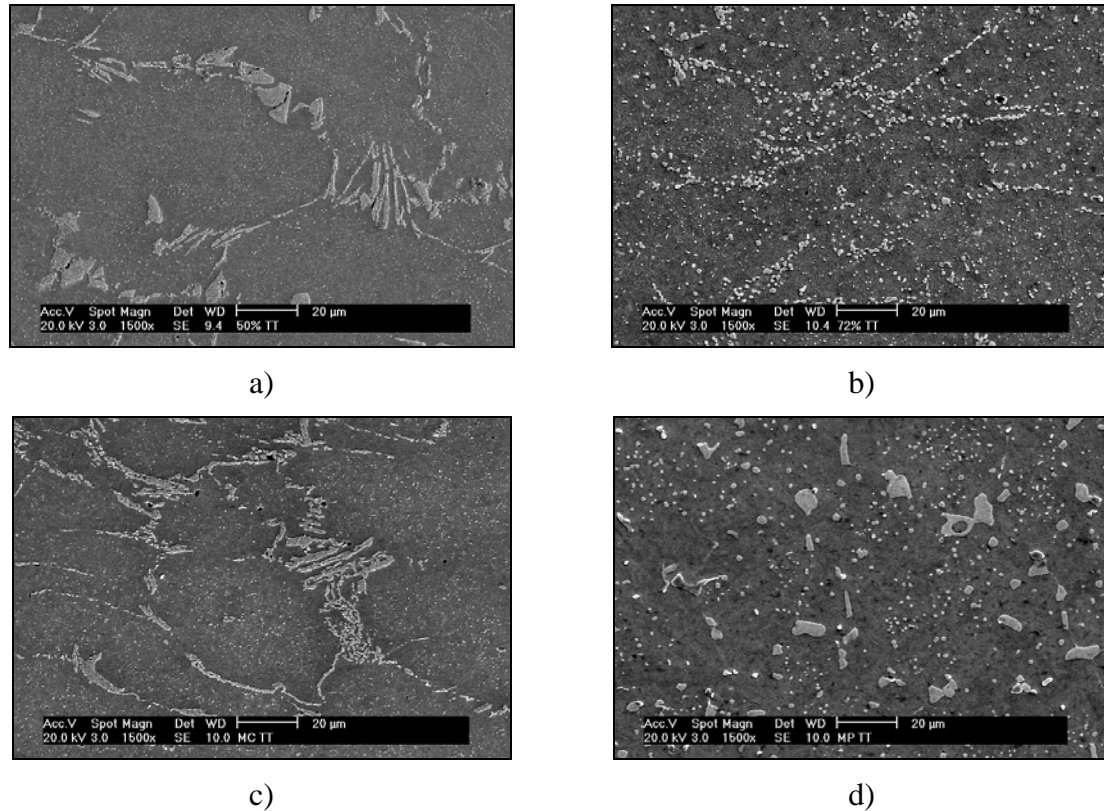


Figure 4. SEM micrographs showing the microstructures of AISI M2 high-speed steels after heat treatment (without etching). a) Spray formed material hot rolled 50% height reduction - MCSR50. a) Spray formed material hot rolled 72% height reduction – MCSR72. c) Conventionally cast material - MConv. d) Powder metallurgy material - PM.

The affirmation of Schruff et al. [14,15], perhaps not the unique neither the most adequate justification for all cases (items a, b and c) mentioned previously, is certainty is that one that can better explain the superior performance of the material obtained by powder metallurgy, in comparison to the others materials.

Regarding the austenitic grain size, analysis on all samples using the scanning electron microscope (SEM) after heat treatment (quenching and tempering), revealed a mean grain size  $22 \pm 3$   $\mu\text{m}$  for the powder metallurgy (MP) sample, in comparison to the samples of the others materials; this can in part explain the small hardness and transverse rupture strength (TRS) values measured in this material. In the case of MCSR50 and MCSR72, the grain size was smaller than the MP material,  $15 \pm 4$   $\mu\text{m}$  and  $17 \pm 2$   $\mu\text{m}$ , respectively. This fact can partially explain the higher hardness and transverse rupture strength values in relation to MP material. For the MConv material, it was measured the smallest grain size  $13 \pm 4$   $\mu\text{m}$ , that can be associated with the higher hardness values encountered in this material.

## Conclusions

The 50% thickness reduction ratio and post thermo mechanical process of spray formed material, not was enough to turn possible a good distribution of broken and disaggregate carbides net formed during spray forming.

The 72% thickness reduction ratio and post thermo mechanical process of spray formed

material was not adequate because presented evidences of reduction in wear resistance in comparison to MConv and MP materials.

In the processing conditions used in present work, the analysis of the machining tests revealed behaviour near closed among all materials. However, it was possible to verify a minimal superior performance of the material obtained by powder metallurgy technique (MP), followed by material obtained by conventional metallurgy (MConv), which presented a minimum advantage in relation to the material obtained by spray forming hot rolled at 72% thickness reduction ratio (MCSR72).

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