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## Tooling materials and their applications from research to market

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# PERFORMANCE ASSESSMENT OF SPRAY FORMED AISI M2 HIGH-SPEED STEEL TOOLS

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## Abstract
Machining tools (interchangeable inserts) were manufactured from spray formed AISI M2 high-speed steel. The spray formed material was 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 processing conditions, the spray formed material showed 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.

## Keywords
Spray forming; machining; high-speed steel, tool.

# INTRODUCTION

In the manufacture process about 50% of the production cost is related to resources and raw materials needed to the process, where, it is included the tools used for machining [1]. The tool steel is a materials choice, among several other options like hard metals, ceramics and cermets, for machining tools obtention. There are basically three processes for obtainment of high-speed tool steels: conventional casting, powder metallurgy and spray forming. This last, process, spray forming, has been showed to be technically feasible for obtainment of a large range of materials, including high-speed tool steels [2].

# MATERIALS AND METHODS

## Materials

In this study, four series of AISI M2 high-speed steel were considered, regarding the obtainment methods, see Table 1.

**Table 1** : AISI M2 high-speed steels specification regarding the obtainment methods and post processing condition.

| Material | Obtainment method | Post processing |
|---|---|---|
| MCSR50 | Spray formed | Annealed, hot rolled, heat treated |
| MCSR72 | Spray formed | Annealed, hot rolled, heat treated |
| MConv | Conventionally cast | Heat treated |
| MP | Powder metallurgy | Heat treated |

The spray formed material (MCS) was obtained in a pilot plant installed at IPEN/SP. After spray forming, the material was soft annealed to improve its machinability. For this annealing, the parameters found in literature [3], were efficient to provide enough hardness reduction, allowing machining. Slabs were cut from the annealed material and hot rolled at 50% (MCSR50) and 72% (MCSR72) thickness reduction ratio that corresponds to a transversal area reduction of 20% and 67%, respectively. The conventionally cast material (MConv) is currently commercial and vendor did not supply details of manufacturing methods. However, for attaining a suitable microstructure, the literature [5,6] quotes that an area reduction ratio of 94% and over is needed for castings. The Powder Metallurgy Laboratory at IPEN supplied the sintered material (MP), in square shape which dimensions were close to that necessary for the manufacture of machining test inserts. The sintered inserts were prepared from water atomized powder, which was unixially pressed at 800 MPa followed by vacuum sintering at 1249 ± 3 °C [7,8]. All materials were finally heat treated at 1210 °C (3 min), quenched and treble tempered at 560 °C (2 h each).

## Methods

Samples from MCSR50, MCSR72, MConv and MP materials after heat treatment were prepared for the transverse rupture strength testing (TRS) [9]. After the flexion test, the broken parts were hardness tested. For carbides observation (distribution and size), samples were prepared by standard metallographic techniques. The samples were observed using a scanning electron microscope (SEM) in the as polished and etched conditions. The used etching solution was HCl (10 mL), $HNO_3$ (5 mL) and ethanol / methanol 95% (85 mL) [2], aiming to reveal the austenitic grain boundary.

From the mentioned materials, it was manufactured interchangeable inserts for performance evaluation, i.e., machining test. The inserts were coarse machined, heat-treated and finally finished (milled and sharpened), resulting in inserts ready for use (Fig. 1).

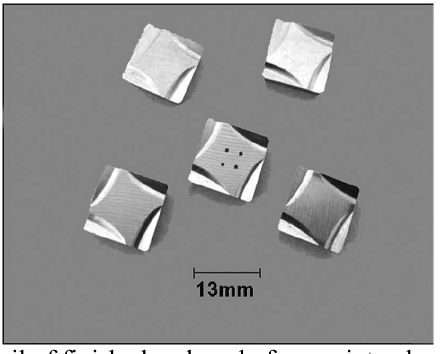



**Figure 1** : Detail of finished and ready for use interchangeable inserts.

For machining tests, a CNC lathe was used. The machining tests were made against specimens of 49 mm in diameter and 260 mm long prepared from SAE 1045, steel according to recommendations of ISO 3685 [10]. 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 tip radius (r) was equal to 0.8 mm. It was used four distinct cutting speeds (30, 32, 34 and 36 m/min). During machining, for each insert it was considered several stops, for flank and crater wear evaluation. At each stop the insert was removed from the tool holder and taken to an optical microscope for photographic record of the wear evolution. Following, the insert was remounted on the tool holder for testing continuity.

# RESULTS AND DISCUSSION

## Mechanical properties and materials microstructure

The hardness measurement results after quenching and tempering showed a smaller value (721 HV30) for MP material and similar values (774 HV30) for MCSR50 and MCSR72 materials. The higher hardness value (804 HV30) was found for the MConv material, however, it is important to comment that high hardness is not always connected to a better machining performance, as verified by Jesus [2] and Santos [11] in works with conventional, sintered and spray formed high-speed steels.

The results of the TRS tests showed that when the spray formed material is submitted to a 50% hot rolling thickness reduction (MCSR50) the strength value is higher than the conventional cast material (MConv). When the thickness reduction ratio is increased to 72% (MCSR72), the results are comparable to materials obtained by powder metallurgy (MP). Fig. 2 show the results of the TRS tests made for the present work, in comparison to published data.

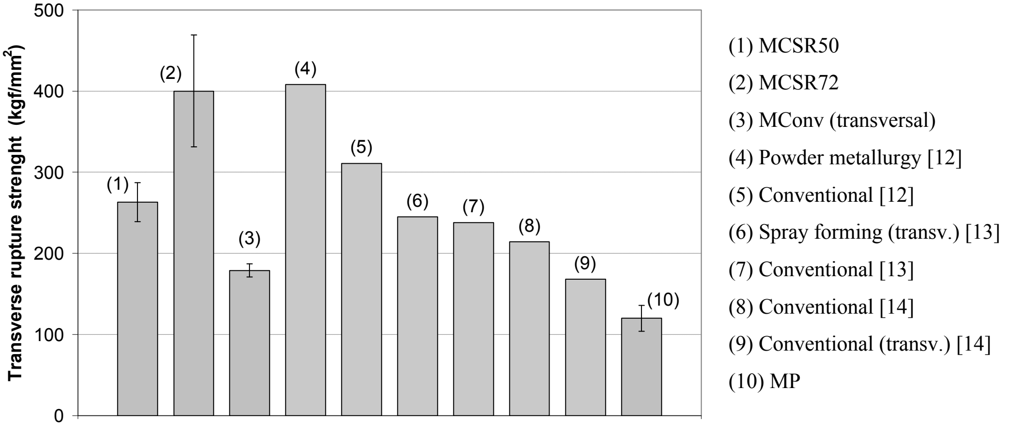



**Figure 2** . Results of transverse rupture strength testing (TRS) of evaluated materials, in comparison to published data

The micrographs showed in Fig. 3 were evaluated aiming a refinement assessment (homogeneous distribution of small carbides), characteristics that usually promote better mechanical properties. However, when dealing with machining tools materials, there is another significant characteristic that need to be considered: the abrasive wear resistance. Carrying on a comparative analysis among micrographs showed in Fig. 3 and establishing a parallel with the results of the machining tests, see Figs. 5 and 6, it follows: a) The MCSR50 microstructure is very similar to the MConv. However, the MCSR50 material presented inferior 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.

According to Schruff et al. [15,16], the best microstructural condition that promotes a good material performance regarding wear resistance, is that one 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 (Fig. 4). The affirmation of Schruff et al. [15,16], perhaps it is not the unique explanation for all cases (items a, b and c) mentioned previously, is certainty that one that can better explain the superior performance of the material obtained by powder metallurgy, in comparison to the others materials.

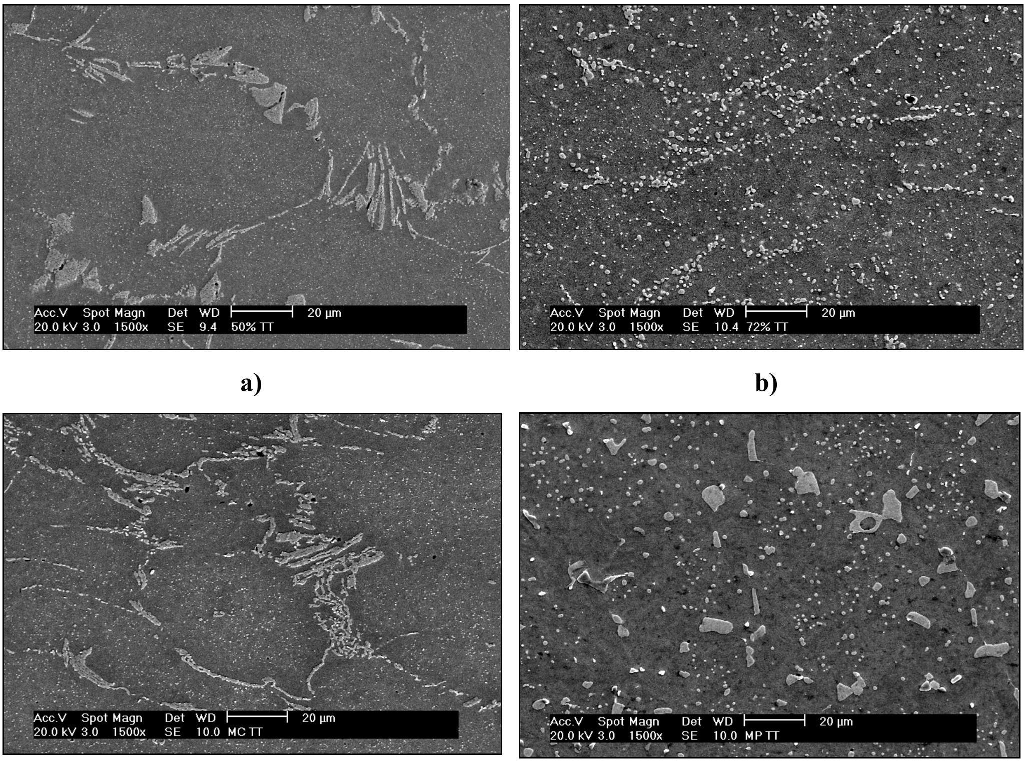
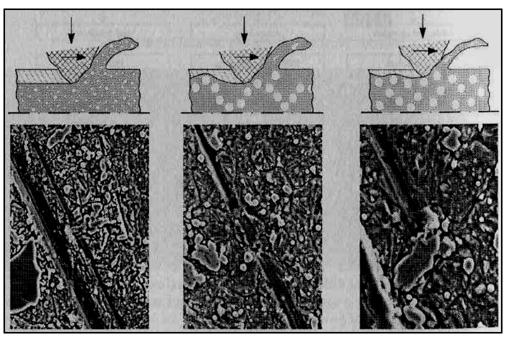



**Figure 3** : Secondary electron scanning micrographs of AISI M2 high-speed steels, after quenching and tempering (without etching). a) MCSR50. b) MCSR72. c) MConv. d) MP.



a) b) c)

**Figure 4** : Effect of carbides size and distribution on the wear resistance [15,16].

Regarding the austenitic grain size, analysis on all samples using the SEM after heat treatment (quenching and tempering), revealed a mean grain size about 22 µm for the powder metallurgy (MP) insert, in comparison to the samples of the others materials; that can 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 µm and 17 µm, respectively. This fact can partially explain the higher hardness and TRS values in relation to MP material. For the MConv material, it was measured the smallest grain size (about 13 µm), that can be associated with the higher hardness values encountered in this material.

## Machining tests

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. In this case it was machined a major quantity of specimens in three complete session tests, showing good reproducibility results (Fig. 5).

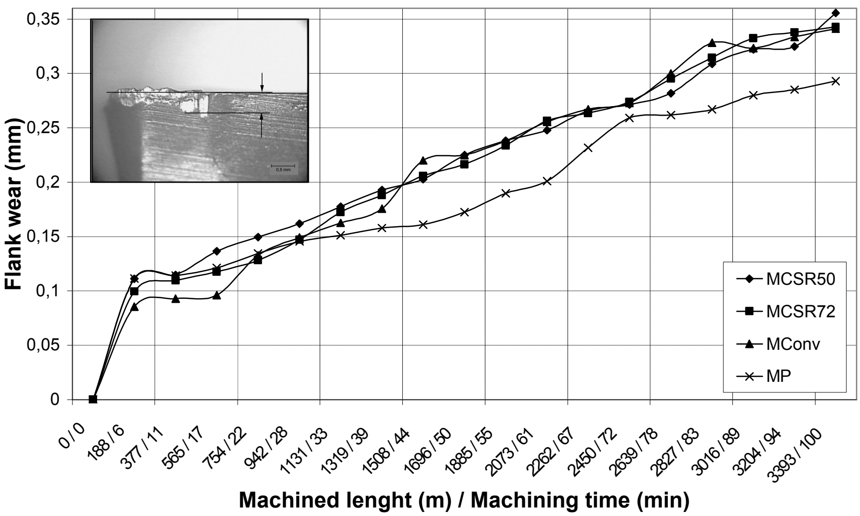



**Figure 5** : Wear curves for cutting speed of 34 m/min (mean values relating to three session tests). The insert shows a measure of the flank wear.

From a mean wear curve among session tests (Fig. 5), 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 meaningful that could lead to a definitive rejection of the evaluated materials. This observation is a sound sign of the potential of the spray formed tool steels, when compared to others consecrated materials.

Preceding a more detailed analysis of the data presented in Fig. 5, a “coefficient of flank wear” (Fig. 6) was calculated aiming to express the performance of each material in terms of a nom dimensional number. Basically, the final value of measured flank wear in meters after the machining of a given specimen was divided by the respective removed chip length in meters.

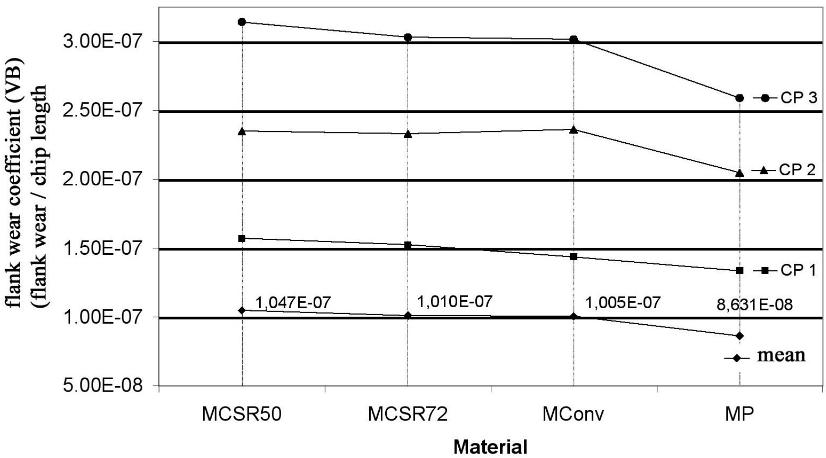



**Figure 6** : Flank wear coefficient relative to tests with cutting speed of 34 m/min (cumulative data for three machined 49 cm specimens - CP).

Analytically, the results presented in Fig. 6 point out a slight better performance showed by the material obtained by powder metallurgy, 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 2 show an estimation of cutting speed (Vc) for each tool material based on a tool life of 15 minutes.

**Table 2** : 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 |

# CONCLUSIONS

The 50% thickness reduction ratio and heat treatment of the spray formed material, not was enough to make possible a good distribution of broken and disaggregate carbides that formed during spray forming.

The 72% thickness reduction ratio and heat treatment of the spray formed material was not adequate, because it presented evidences of wear resistance reduction in comparison to MConv and MP materials.

In the processing conditions used in present work, the analysis of the machining tests revealed behaviour near close to all materials.

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# REFERENCES

[1] DeGarmo EP, Black JT, Kohser RA. Materials and processes in manufacturing. 8th ed., Prentice Hall, 1997, p. 3-5.
[2] Jesus ERB. Machining tools in AISI M2 high-speed steel obtained by spray forming process". 2004. Ph.D. Thesis – IPEN / USP. (In Portuguese)
[3] Bayer, AM, Walton, LR. Wrought tool steels. Metals Handbook, 10th ed., ASM, vol. 1, p. 757-79, 1990.
[4] Jesus ERB, Jesus Filho ES, Gomes EG, Santos WS, ROSSI JL. Properties and microstructure characterisation of spray formed M2 and D2 tool steels. SDMA, 2000, Bremen: 2000, p. 869-78.
[5] Roberts GA, Cary RA. Tool Steels - 4th ed., ASM, p. 628-791, 1980.
[6] Ohja SN, Singh SN. On spray deposition of high-speed steel. Journal of Materials Science Letters, 10, p. 893-95, 1991.
[7] Ambrozio Filho F, Nogueira RA, Ribeiro OS, Neves MDM, Lima LFCP. Influence of heat treatment on microstructures of conventional and sintered AISI-M2 high-speed steel. 20 ASM Conf., 9-12 October 2000, St. Louis, MO, p. 1006-1009.
[8] Nogueira RA, Ribeiro OCS, Neves MDM, Salgado L, Ambrozio Filho F. Effect of heat treatment on microstructure of commercial and vacuum sintered high-speed steels AISI M2 and T15. PTECH 2003, Guarujá-SP, Brazil, 2003, 2003, CD-rom.
[9] METAL POWDER INDUSTRIES FEDERATION. Determination of transverse strength of powder metallurgy materials, 1991. (Standard test method 41).
[10] INTERNATIONAL ORGANIZATION FOR STANDARDIZATION. Tool-life testing with single-point turning tools. 2.ed., 1993. (ISO 3685)
[11] Santos RS. Machining tool made of sintered and conventional: properties analysis. 1998. Master Dissertation – Universidade Federal de Santa Catarina, Brazil. (In Portuguese)
[12] Haberling E, Weigand HH. Correlation between mechanical properties, microstructure and performance of high-speed tool steels. Int. Conf. Towards Improved Performance of Tool Material, Teddington, Middlesex, 28-29 April 1981, p. 170-75.
[13] Igharo M, Wood JV. Investigation of M2 high-speed steel produced by Osprey process. Powder Metallurgy, vol. 32, n° 2, p. 124-31, 1989.
[14] Mesquita RA, Barbosa CA. Evaluation of as-hipped PM high-speed steel for production of large-diameter cutting tools. Materials Science Forum, vol. 416-418, p. 235-240, 2003.
[15] Schruff I, Schüler V, Spiegelhauer C. Advanced tool steels produced via spray forming. 6 Int. Tooling Conf., Karlstad-Sweden, 10-13 September 2002, vol. 2, p. 973-990.
[16] Schruff I, Schüler V, Spiegelhauer C. Spray forming - The new technology for the production of high-grade tool steels. SDMA 2003 e ICSF V, Bremen-Germany, 22-25 June 2003, vol. 1, p. 5-11 a 5-25.