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

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Key words: spray forming; machining; high-speed steel, tool.

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. This results were compared to materials obtained by conventional and powder metallurgy techniques. The results showed that under the used process 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.
Key words: spray forming; machining; high-speed steel, tool.

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, 2]. 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. This last (spray forming process), has showed technically and economically feasible for obtainment of a large range of materials, including tool steels. According to the American Iron and Steel Institute – AISI, classification, the M2 high-speed steel is only one among several types of existing tool steels, and the reason for the present study.

Materials and methods

Materials

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 1. – Variation for AISI M2 high-speed steel, regarding to obtainment methods and subsequent applied thermo mechanical process, used for manufacturing machining tool inserts.

Designation	Obtainment method	Post processes
MCSR50	Spray formed	Annealed and hot rolled at 50% thickness reduction ratio
MCSR72	Spray formed	Annealed and hot rolled at 72% thickness reduction ratio
MConv	Conventionally cast	-
MP	Powder metallurgy	-

The spray formed material (MCS) was obtained in a pilot plant installed at IPEN/SP. After obtainment, the material was soft annealed to improve its workability (machinability). For annealing, the parameters found at literature [3-11], 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 at area reduction of about 20% and 67% respectively.

The conventional cast material (MConv) was purchased commercially. Details of the manufacturing methods were not supplied by vendor, however, the literature [12,13] indicates a reduction ratio of the 94% and over, with respect to these materials, for attaining a suitable microstructure. Long and onerous esferoidization heat treatments are also necessary, for the obtainment of these materials.

The material made by powder metallurgy (MP), was supplied in the shape of sintered square shape, with dimensions 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 [14,15].

Methods

Mechanical and microstructural analysis

Samples from MCSR50, MCSR72 and MConv materials were prepared for the transverse rupture strength (TRS) testing [16]. 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 mounted in Bakelite, ground and polished until diamond paste of 1 μm, followed by final finishing in colloidal silica 0.25 μm. 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_3 (5 mL) and ethanol / methanol 95% (85 mL) [3,10,11], aiming to reveal the austenitic grain boundary.

Inserts manufacturing

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).

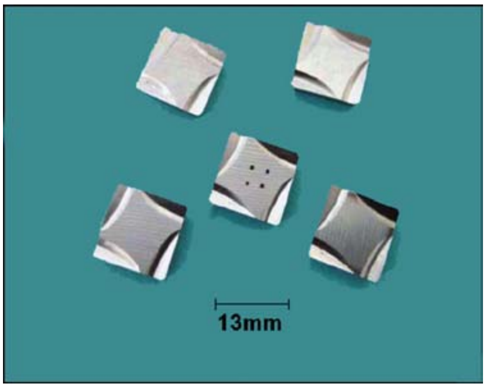


Figure 1. Detail of finished, ready to use, interchangeable inserts for performance evaluation.

Machining tests

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 [17].

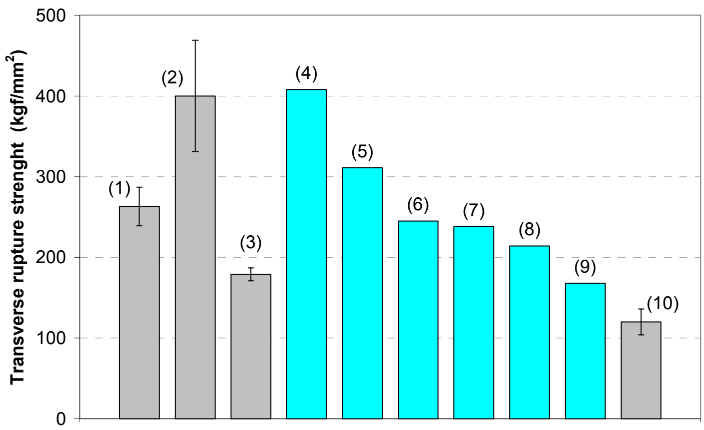
The specimens were machined at constant values of cut depth (p) and feed rate (f) equal 1.5 mm and 0.2 mm/rot, respectively. The corner radius (r) was equal 0.8 mm according to ISO 3685 [17]. Besides the material from which the tool was made, the cutting speed was another evaluated parameter. It was used four distinct cutting speeds (30, 32, 34 and 36 m/min) during machining operation, for each one of the four types of used tool material. During machining for of each specimen, 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.

Results and discussion

Mechanical and microstructural properties of materials

The hardness measurements results after quenching and tempering showed a small value (721 HV30) for MP material and similar values (774 HV30) for MCSR50 and MCSR72 materials. The higher hardness value (804 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 [3] and Santos [18] 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 show the results of transverse rupture strength tests made in the present work, in comparison to published data obtained by others researches for AISI M2 high-speed steel.



(1) MCSR50 (present work) [3,19,20]
(2) MCSR72 (present work) [3,19,20]
(3) MConv (transversal) - (present work) [3]
(4) Powder metallurgy (MP) - Haberling and Weigand [21]
(5) Conventional - Haberling e Weigand [21]
(6) Spray forming + forging (transversal) - Igharo and Wood [22]
(7) Conventional - Igharo and Wood [22]
(8) Conventional - Mesquita and Barbosa [23]
(9) Conventional (transversal) - Mesquita and Barbosa [23]
(10) Powder metallurgy (present work) [3]

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

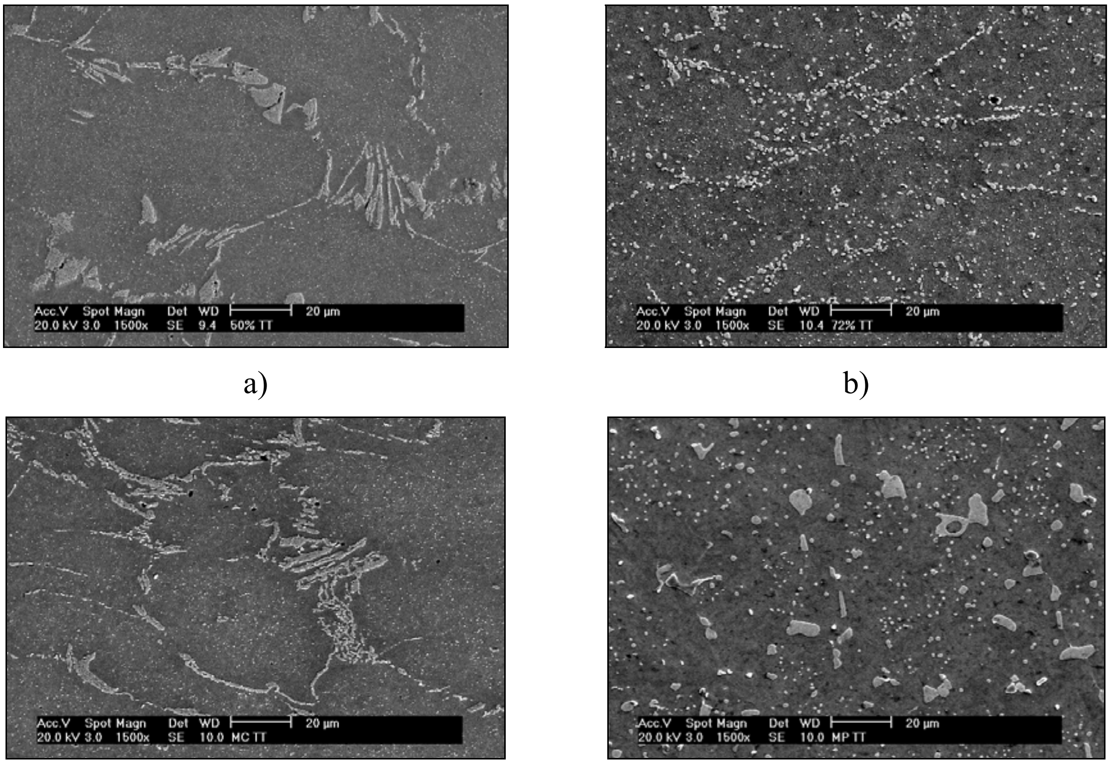
Microstructurally, if the micrographs showed in Fig. 3 were evaluated aiming the identification of the better material in terms of the microstructural refinement (better distribution and small carbides), characteristics that usually promote better mechanical properties; the MCSR72 material would be chosen. 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. [24,25], 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 (see Fig. 4).

Carrying on a comparative analysis among micrographs of Fig. 3, and establishing a parallel with the results of the machining tests, which will be showed later, it follows:

a) The MCSR50 microstructure is very similar to the MConv microstructure. 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.

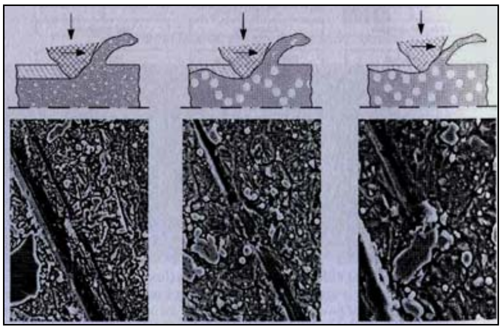
c*)* The MCSR72 material presented a microstructure as refined as the MP material, including very small carbides size. However, the MP material presented the best result during machining testing, among all evaluated tool materials.



a) b) c) d)

Figure 3. Secondary scanning electron micrographs of AISI M2 high-speed steels, after quenching and tempering (without etching). a) Spray formed material hot rolled 50% height reduction. a) Spray formed material hot rolled 72% height reduction. c) Conventionally cast material. d) Powder metallurgy material.

The affirmation of Schruff et al. [24,25], 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.



a) b) c)

Figure 4. Effect of carbides size and distribution on the wear resistance of tool steels [24,25].

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 (about 22 μm) for the powder metallurgy (MP) sample, 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 e 17 μm, 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 (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 two complete session tests, showing exceptional reproducibility results.

From a mean wear curve between two 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 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.

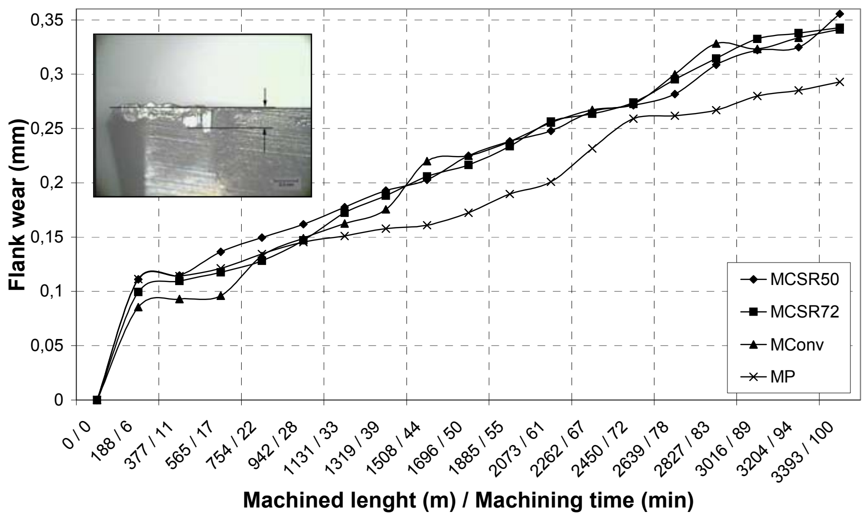


Figure 5. Wear curves for cutting speed of 34 m/min (mean values relating to two session tests). The insert shows a measure of the flank wear.

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 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.

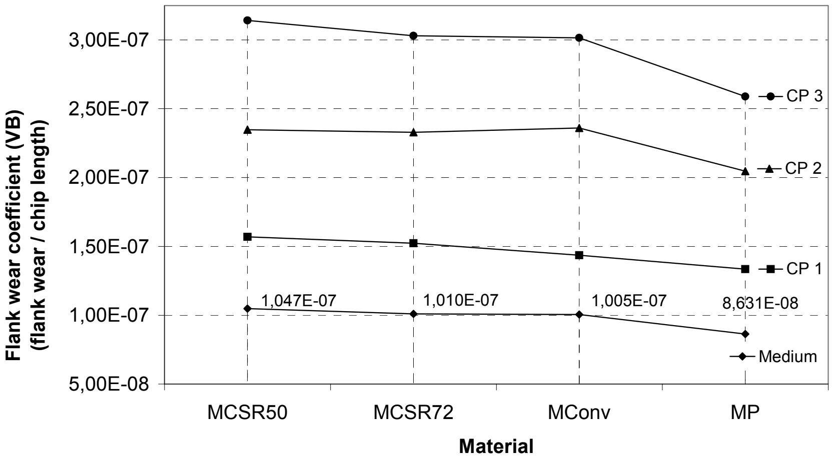


Figure 6. Flank wear coefficient relative to tests with cutting speed of 34 m/min (cumulative data).

Analytically, the results presented in Fig. 6 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 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 post thermo mechanical process of spray formed material, not was enough to turn possible a good distribution of broken and disaggregate of carbides net formed during spray forming.

The 72% thickness reduction ratio and post thermo mechanical process of spray formed material not was adequate because presented evidences of reduction in wear resistance in comparison to MConv and MP materials.

In the processing conditions utilized in present work, the analysis of the machining tests revealed behaviour near closed among all materials. However, proceeding a detailed analysis, 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).

AKNOWLEDGMENTS: The authors are greatly indebted to CNPQ by a scholarship provision to E. R. B. Jesus; to Hurth Infer for heating treating the samples; to Petroleum Precisa for sharpping the inserts and to Laboratory of Powder Metallurgy of IPEN for supplying the sintered inserts.

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