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A Critical Overview on Metal Composites Machining

E.R.B. Jesus and J.L. Rossi

Instituto de Pesquisas Energéticas e Nucleares - IPEN, Powder Processing Centre - CPP,
P. O. Box 11.049, 05422-970, Sao Paulo, SP, Brazil

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ABSTRACT Several articles dealing with machining and machinability of metal matrix composites were reviewed. The objective was to highlight important machining aspects and to suggest procedures and useful attitudes to facilitate testing, allowing results' interpretation and further correlation. It was also the aim of this survey to give an active collaboration to future works in this field.

INTRODUCTION

Metal matrix composites have been an important material issue in the past decades, attracting the attention of many researchers and industrialists, mainly in strategic sectors and more recently in the automotive industry. The MMCs are characterized by having in many instances, superior mechanical properties when compared to more prosaic materials. The tendency for searching cost effective technologies leads to necessary improvements in equipment production, maintenance and safety. An increased demand for metal matrix composites is expected as the number of applications expands. The utilization of such materials implies in the project of specific components that will make part of machines, equipment and structures. In the project stage, shapes are established and the materialization of such can take place by different approaches. Even with the advent of near net shape technology, it is almost essential in practice that for a finished part, at least one machining operation is necessary in order to comply with standards, dimensions and surface finishing, according to project specifications. Roughly, most of all produced parts and components are submitted to some machining process before being considered finished[1]. The study and evaluation of phenomena related to metal matrix composite machining are important to understand the behavior of such materials during parts manufacturing and their interaction with the tooling as a whole. Therefore, it is important to evaluate critically the machinability of these materials for a better understanding of the associated machining mechanisms allowing a previous evaluation of the feasibility of industrial production and, guiding oriented researches.

DISCUSSION

Machining and machinability.

In order to avoid false expectations by undue terminology, it is important to mention the difference between machining and machinability.

Machining: is the operation executed by a machine tool that, by means of removing material and producing chips, confers shape, size and surface finishing for a desired part [2]. The Metals Handbook [3] quotes machining as a term that comprises a large variety of manufacturing processes being characterized by the removal of unnecessary material, usually in chip forms; transforming metal billets casted, forged or preformed into shapes with dimensions and surface finishing according to standards established in project.

Machinability: is a technological dimension that expresses by means of a numeric value (index or percentage), a set of metal machining properties compared to a standard [1]. The machinability index as defined by the Metals Handbook is a number that indicates the facility or the difficulty in machining a specific material.

None of the references that deals with machinability [4-7] had established an indicative number for the machining difficulty of the studied material, in comparison to another material taken as standard, see Table 1. Therefore, nothing can be said about machinability in this case.

TABLE 1. *Some data gathered from literature.*

Ref.	Subject	Fabrication process	Insert geometry	Tool holder geometry	Tool material *	Machinability
(4)	Machinability	yes	yes	no	HM and PCD	no
(5)	Machinability	yes	no	no	HM	no
(6)	Machinability	no	yes	yes	HM and PCD	no
(7)	Machinability	yes	yes	yes	PCD	no
(10)	Machining	no	no	no	HM, Ceramic and PCD	no
(11)	Machining	no	no	no	HM	no

Relevant aspects of the research on machining and the machinability measurement.

According to the definition previously given, when dealing with machining, it is expected that, several aspects regarding the process should be evaluated, including machinability. Then, the results obtained can be applied to other areas such as tool materials development, alternative machining processes and new cutting fluids. These aspects are:

- √ chip formation;
- √ cutting mechanisms evaluation;
- √ cutting fluids influence;
- √ influence of the machining parameters;
- √ influence of the insert geometry and the tool holder;
- √ thermal effect evaluation;
- √ tribological aspects;
- √ wear mechanisms;
- √ wear type;
- √ cutting forces study;
- √ machinability index determination;
- √ surface finishing evaluation.

Regarding machinability, by the definition previously given, it is expected at research level, mainly by the manufacturers, materials consumers and by tool industry, that at least one item should be established; the machinability index. Some researchers when comparing the machinability of composite materials, quote that one material is more or less difficult to machine, but this difficulty is not quantified. Some of the published results could be foresighted intuitively. Chambers [4], for example, concluded that Duralcan (A 356) reinforced with SiC 15 % in volume fraction, was less difficult in machining than the composite Al5Mg reinforced with 5 % alumina plus 15 % SiC. In this case an increase in 5 % alumina for the Al5Mg could explain the increase in the machining difficulty.

Nevertheless, the question is how much is this difference? How much this represents in numbers? Quigley, Monaghan and O'Reilly [5] and Chadwick and Heath [8] used in their testing other materials taken as reference standard but they did not establish the machinability difference between the tested materials; moreover the standards were conventional materials, therefore of a different nature than metal matrix composites.

It is necessary and important to establish reference standards. For metal matrix composites, specific standards should be prepared despite of the adverse conditions that such materials pose when machined, impairing the use of conventional standards (see below). If the machinability index of a material were known, it would be possible for consumers to make final cost projection for the manufacture of some component with a new material. Therefore, the industrial production viability of the material for components manufacture could be considered.

Irrelevant aspects of the research on materials machining and machinability.

In research and mainly for the industry, it is important to stick out that it does not make sense to establish ideal machining parameters for a certain material from the aspect of tool life. It is well known that these parameters may vary significantly. For example, a big component's manufacturer may opt for a substantial increase in cutting speed to produce more items per period, even so this might result in more tool wearing and more frequently tool change, providing this is viable.

Viability is nothing more than a positive relationship cost / benefits. So, who establishes the best machining conditions in each case, is the manufacturer, by means of its technical staff, that tries to obtain a higher production, at the least time, with assured quality, safety and at a low cost. There are optimal parameter combinations, which lead to better results, mainly from surface finishing point of view. But, this can depend on the tolerance specified in the project.

Metal matrix composites machinability reference standards -- the need for.

It is known that the establishment of machinability index for a certain material is difficult. This index is affected by several factors during the machining process [1]. It has been quoted that testing equivalent materials, specified in DIN or ASA standards, but with slight oxide content difference, produced a complete different hard metal tool wearing. For metal matrix composites, there are other factors that will be addressed as follows.

First, these materials demand harder tools than conventionally, as the reinforcement is usually a ceramic or oxide. Second, the microstructure is the main factor responsible for machinability index variation [1, 3, 9-11] . Under these circumstances, metal matrix composites differentiate a lot from the conventional materials. Its microstructure is very complex with the presence of second phase particles and the reinforcement.

The machinability of each material, when it is possible, should be established under the same machining condition as the standard, i. e., by using the same tool material and the same machining parameters. Previously obtained machinability standards, besides using conventional materials as research subject, used testing conditions that have very little in common with the actual necessity imposed by the technological evolution. Moreover, those testings used essentially high-speed steels as tool's material. Chambers [4], in his work, establishes a relation of equality between the studied composite and cast iron, in terms of machining difficult. However, in the Machinery's Handbook [12] tables are presented that show the possibility of machining cast iron with high-speed tools under specific conditions. All references that deal with machining and machinability of metal matrix composites clearly do not use high-speed steels for tools (see Table 1). Even the Metals Handbook [3] in the chapter on composites machining does not refer to the use of high-speed steels for tools in the machining of such materials.

Particularities and such observations justify the need for establishing and adopting reference standards, specific for composite materials. This is not only because of the intrinsic different nature of the material, but also a function of the requirements imposed by the technological development.

Testing methods standardization for metal matrix composites machining and machinability.

In order to facilitate interpretation and comparison among diverse works carried out in this area, it is necessary a standardization of tests for the study of the machining and machinability of composite materials. The Metals Handbook [3], in the chapter "machinability test method" gives a general survey about machining and machinability and other involved aspects. The advantages and disadvantage of the methods for machinability determination are given by Ferraresi [1] in his book. The standard ISO/DIS 3685 [14] could be applied for MMCs machining if an adaptation to this type of material is provided.

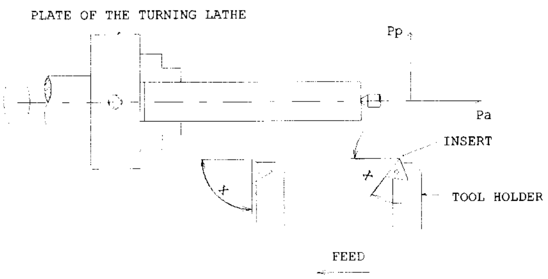
For machinability measurement, besides the adoption of a coherent reference standard, the limited amount of available material should be taken into account in many circumstances. So, the testing method should be of short duration, although the results obtained in short duration testing do not always show a good correlation with long duration results.

Information that should be supplied in this type of work.

As mentioned previously, the machinability of a certain material is very difficult to be established, due to many factors that influence the process. So, it is important that as many as possible information should be supplied to help the interpretation of results and correlation which would allow other researchers to repeat and check their tests.

By analyzing works on MMCs machining, it is verified the lack of many essential information to allow new testing in the same conditions. Tomac and Tønessen [6], Cronjäger and Biermann [9], Weirnert, Biermann and Meister [10], for example, did not mention the material obtainment method in their works (see Table 1). In metal matrix composite the fabrication route has strong influence on the material microstructure, which in turns affects the machining.

From Table 1, it is possible to verify that some researchers [5, 8, 10, 11] when using interchangeable insert tools do not mention insert and tool holder geometry. Chambers [4], Cronjäger and Biermann [9] mention only the insert geometry. For the same insert geometry, there are several positioning possibilities, depending on the tool holder used. The tool holder puts the insert in a position that makes an angle (χ) between the insert and the surface to be machined. This angle (c) variation causes a change in the cutting forces, leading, for example, to differentiated tool wear (see Fig. 1).



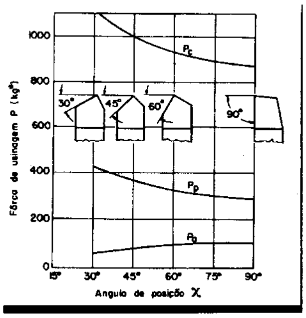


Fig. 1. Influence of the positioning angle χ (abscissa) versus resulting machining power P (ordinates) [1].

For advanced materials, Eliasson and Sandströn [15] divide the most important factors into three major groups depending on its importance: mandatory factors; essential factors and recommended factors. By adapting these conditions to specific machining and machinability studies, a series of other factors could be added and some of the existing ones could be moved to other groups, according to their importance to the machining process. For example, the item "microstructure of the matrix", a recommended factor, according to Eliasson and Sandströn, could be transferred to the mandatory factors group, if the microstructure has a great influence on the materials' machining and machinability as previously mentioned.

As a rule, the factors that must be evaluated in machining and machinability studies, including those established by Eliasson and Sandströn are the following ones, independently from the proposed classification:

A - Related to materials system:
- A.1 - reinforcement characteristics
  - A.1.1 - size
  - A.1.2 - material
  - A.1.3 - type
  - A.1.3.1 - fibres
  - A.1.3.2 - whiskers
  - A.1.3.3 - particles
- A.2 - amount of reinforcement
- A.3 - reinforcement orientation (fibres and whiskers)
- A.4 - characteristics of the matrix
  - A.4.1 - chemical composition
  - A.4.2 - grain size
  - A.4.3 - second phase particles

B - Related to the consolidated material:
- B.1 - mechanical properties
- B.2 - physical properties
- B.3 - heat treatments
- B.4 - microstructural characterization
- B.5 - obtainment method
- B.6 - reinforcement distribution (homogeneous or not)

C - Related to machining tools:
- C.1 - mechanical properties
- C.2 - physical properties
- C.3 - chemical composition
- C.4 - microstructural characterization
- C.5 - geometry
  - C.5.1 - tool holder geometry (for inserts), ISO equivalence and manufacturer code**.
  - C.5.2 - insert geometry, ISO equivalence and manufacturer code **.
  - C.5.3 - in case of using bar tools (welded inserts), geometry, ISO equivalence and schematic drawings if necessary **
  - C.5.4 - principal tool angularities
    - C.5.4.1 - rake angle
    - C.5.4.2 - clearance angle

** see importance on Fig. 1

D - Related to used equipment:
- D.1 - characteristics
- D.2 - type
- D.3 - model
- D.4 - maker

E - Related to machining conditions:
- E.1 - testing method and standard
- E.2 - cutting speed
- E.3 - feed speed
- E.4 - cutting depth
- E.5 - specimen dimension
- E.6 - cutting fluid or cooling
  - E.6.1 - chemical composition
  - E.6.2 - characteristics
  - E.6.3 - standards and maker

After testing, several others informations are obtained and should be given. Some of these informations are closely related to the aim of the proposed work. They are:

F - Related to used equipment:
- F.1 - surface roughness of the specimen
- F.2 - cutting forces
- F.3 - temperature at the cutting region
- F.4 - dimensional variations

G - Related to the observed effects during testing:
- G.1 - formation or not of built-up edge
- G.2 - type of formed chips
- G.3 - machining tool wear
  - G.3.1 - wear mechanisms
  - G.3.2 - wear type

CONCLUSIONS

The absence of machinability index is verified even in articles that deal with machinability. The absence of machinability index can be associated to the lack of a reference standard for metal matrix composite, causing many times superficial correlation with conventional materials.

The machining testing standardization for composite materials would facilitate results' interpretation and correlation for example, by definition of a set of machining parameters, inserts geometry, tool holder. Similarly, the machinability measurement would benefit from this standardization.

The lack of data and information in papers on machining and machinability impairs the interpretation and correlation of the results from diverse studies. Many times these informations are essential to other researchers, and without them it is impossible to perform similar tests and check results.

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erbjesus@net.ipen.br; jelrossi@net.ipen.br

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