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MECHANICAL STRENGTH IN TWO FERROUS ALLOYS*

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Abstract

This property has been studied to characterize the strength a metallic material exhibits when it is machined so it can be regarded as its typical behaviour. As such, it may even be considered as an intrinsic material property. It is usually measured by an index called Coppini index, which is expressed by the ratio between the removed mass of a cutting tool caused by wear when it is used for machining and its initial one for a certain set of machining parameters. In this investigation, the tests were therefore conducted by an established set of parameters, namely feed rate, cutting and depth rates, in which the same wear mechanism took place in both ferrous alloys: AISI 4140 and AISI 316 steels. They were chosen based upon their increasing ordinary machinability indexes. The initial and final mass of the cutting tool were measured by an analytical scale with 0.01 mg precision. Cylindrical rods of 50-mm diameter were machined and the CI indexes showed a remarkable difference between them: 0.080 for the first steel and 0.049 for the second one, i.e., AISI 316 steel presented better machinability than the first one. It was then possible to conclude that this method presents good results in terms of both reproducibility and adequacy for machine shop conditions and it may be applied in a foreseeable future, mainly for metallic materials that have rather low machinability indices.

Keywords: Machinability; Wear; Ferrous alloys, Machine tool.

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1 INTRODUCTION

Machinability is mostly a very common term used in mechanical industries since it is related to the capacity a certain material has when it is conformed into a given shape by using a cutting tool. It also gives the productivity in industries that uses this process for the higher the machinability, the shorter is the interval to sharpen the cutting tool. Because of this wide spectrum of definitions and applications, there is not a single test or procedure widely accepted by both academy and industry which is simple enough and reproducible for typical machined parts.

In this sense, Coppini and Destro [1] published their first results trying to define a new intrinsic property of a material named machining strength. An index called Coppini index, shortly CI, was proposed, but although it was consistent, it proved to be painstaking to be used in shopping floor conditions; this happened because the test was based upon the measurement of feed rate forces by considering the evolution of tool wear after machining a specifically designed and built specimen. There is also the need of sophisticated instruments to measure such forces as a dynamometer [2]. Such instruments, besides requiring calibration and constant checking, were intrusive when set in the machine to measure the forces involved in the process.

The idea in this work is to determine the CI by the ratio between the removed mass of the tool thanks to its wear and the removed scrap mass of the characterized material. Earlier tests showed that the procedure was very promising, but they were calculated from other papers [3]. The authors of this paper decided to use cylindrical rods in which a selected tool machined them by lathe in a number of cycles. After finishing it, not only the removed scrap mass was weighed but also the lost mass of the tool due to its wear. This procedure was possible thanks to an analytical scale which showed that it was much simpler than the first one proposed and it was clearly not intrusive.

1.1 Machinability

Machinability is a technological property of a material for the index of machinability of a certain material is usually measured by comparison to another one considered as standard, e.g., B1112 steel [4]. This causes machinability to depend on several factors such as machining parameters and shows strong dependence on the shopping floor conditions. When a certain machinability test in long or short term is done by using a specific production scenario, the results cannot be extrapolated to another one with good accuracy or even reproducibility. The main influential factors on machinability are: feed rate, cutting depth, rate and fluid.

Several papers [5-7] have investigated machinability which shows the importance of the present paper about machining strength as an alternative for materials characterization totally independent from the industrial scenario and its operational conditions used to measure it. Al-Ahmari [8] has recently published an investigation creating models that allow predicting the behaviour of this property so strengthened materials may be selected for lathing operations.

1.2 Machining Strength

Machining strength is an intrinsic property of a material that shows the resistance a certain material exhibits when it is machined for a given cutting tool. It may be expressed by an index originally proposed by Coppini and Destro [2]. The CI value

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was determined by a standard test in a specially designed and built specimen, shown schematically in Figure 1.

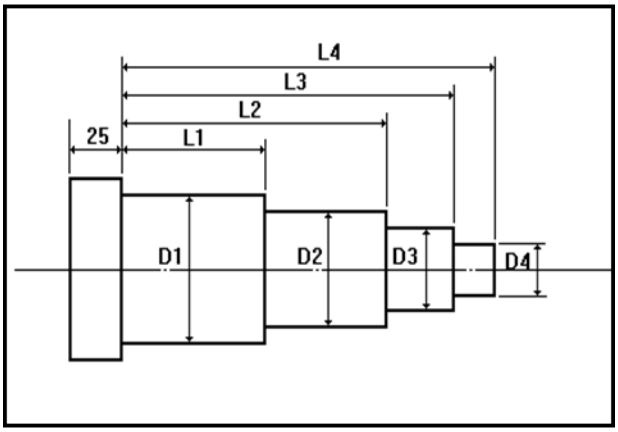

Figure 1. Schematics of the specimen to determine the CI Index.

The test was based on different standardized diameters to determine CI, given by Equation (1):

$$CI = \frac{\sum_{i=1}^{n} F_{fi}}{n} \qquad (1)$$

where: F [N] is the feed force measured by a dynamometer each step “i” shown in Figure 1 and n [mm] are the diameters of the specimen.

The specimen in Figure 1 may be machined almost entirely along its diametrical extension that ensures the wear of the tool and its influence on the forward force measured during the test. The CI value may therefore be understood as an average of the forward forces measured from the test and gives intrinsically the influence of the tool wear. Such measurement was chosen thanks to its lesser influence on the tool wear when compared to the cutting force or other cutting force components.

Despite being painstaking and labor intensive, this way to measure the CI is very precise and adequate enough to be used in laboratories in which scientific approaches are necessary. By considering these investigated aspects, a new test was proposed to measure the CI, but necessarily simple to be used in shopping floor conditions and practical to be used widely in industries [3]. The idea had to be simple, i.e., it had to be simple to be done so people in shopping floor conditions would be able to adopt it. Therefore, Equation (2) was proposed to determine the CI, in which m_{ferr} is the global mass of removed material from the specimen and m_{cp} is the mass of removed scrap as it is the main responsible for the tool wear. The first mass was considered from the area reduction (diameter reduction) after being machined. The tool wear mass, on the other hand, was measured in an analytical scale.

$$CI = \frac{m_{ferr}}{m_{cp}} \qquad (2)$$

As with other technological material properties, machining strength will need different scales as it happens in hardness tests. The authors predict that there will be different scales for materials with different machining behaviour such as non-ferrous and ferrous alloys. Another factor that has to be taken into account is the shape of the specimen to be machined which clearly shows different behaviour in machining operations, such as bars, rods, plates and sheets. Finally, there is also the operation of machining itself

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which varies considerably. It will be necessary to investigate if the machining operation studied in this work will be applicable to other machining operations like drilling and turning. This shows that there is a vast field to be investigated in the future because machining is a technological material property and therefore very important in mechanical industries.

2 MATERIALS AND METHODS

The method used in this work was based on earlier results [9] that showed differences in behaviour between certain types of ferrous alloys. By then, the purpose was to show the reproducibility of the test in stainless steels with different average grain sizes. The present work was developed in the laboratory from Centro Universitário da FEI, in São Bernardo do Campo, that has a CNC ROMI® with 20 kW power, as it is shown in Figure 2.

Figure 2. 20 kW power CNC ROMI® lathe used in this work.

The precision scale used in the present work has a 0.01 mg-precision for weighing the inserts before and after machining as it was highly important for the variation of the masses involved, which was very small.

Another important instrument used in this work was the stereoscope to observe the insert during the test. It helped to check the tool wear and also any minor surface defects in the tool such as a scrap that was randomly adhered to it after machining. This was particularly useful when the masses involved presented any unexpected result. In this case, a short inspection showed that the tool had to be cleaned before being weighed. The procedure for cleaning can be found elsewhere [10]: to avoid any misleading results, the calculation of CI was only done after the last step of machining when the tools were cleaned with nitric acid 10% in an alcoholic solution for 15 minutes to remove, if any, deposited material in the specimen

A triangular insert of hard metal class S, from Sandvik Coromant® TNMG 16-04-04 QM H 13A, was used in this work, as may be seen in Figure 3. It was chosen because it does not have any type of coating for it is very difficult to control the tool wear when it is present [11]. A typical tip radius was used for semi-finished operations despite the fact that the cutting operation parameters selected were for smoothed roughing operations.

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Figure 3. Insert of hard metal, class S, from Sandvik Coromant® TNMG 16-04-04 QM H13A.

The materials used in this work were two ferrous alloys with 50-mm diameter bars and 500 mm length: AISI 316, an austenitic stainless steel, and AISI 4140, a middle-alloyed steel because of their highly different machinability indexes.

The standardized operations conditions were: forward rate 0.2 mm.turn^{-1}; cutting depth 2.0 mm and cutting rate 100.0 m.min^{-1}. These parameters were chosen so that the wear mechanism of the tool should be the same [12]. The CI was calculated slightly different from the original version, Equation (3), as the forward length was standardized in a fixed value, so the removed volume of scrap was the same and it did not have any influence on the final result. The higher the CI value, the higher is the machining strength. As this property is usually related to the material hardness, Table 1 shows the hardness values of these materials.

Table 1. Brinell hardness of the studied materials.

Material	Hardness (HB30)
AISI 316	197
AISI 4140	277

Brinell values are given in kgf.mm^{-2}.

Each cutting edge was used in machining operations for four consecutive times. This procedure was adopted to prevent any wear concentration regions in only one edge and therefore avoiding any unpredictable result. After each step of 150 mm, the insert was weighed as it can be seen in the results presented in Table 2.

3 RESULTS AND DISCUSSION

The results in Table 2 show both the initial and final insert masses after each step of lathing of the AISI 4140 steel. The CI can be seen on its right side. Table 3, on the other hand, show the same quantities for the AISI 316 steel. The numbers on the left side are used for reference; for example, 31.2.1 means the location in the storage box, the face used of the insert, the position of the edge and finally the machining step. The first insert in the storage box was used to clean, faced and referenced the specimen before the test.

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Table 2. Results of the insert masses before and after machining steps and the CI Index calculated for the AISI 4140 steel.

Material	Insert/Edge/Step	Mi - Mf	Mi	Mf	CI
ABNT 4140	21.2.1	0.00054	7.40761	7.40707	0.080
	21.2.2	0.00049	7.40707	7.40658	
	21.2.3	0.00024	7.40658	7.40634	
	21.2.4	0.00034	7.40634	7.40600	
	21.3.1	0.00001	7.40600	7.40599	
	21.3.2	0.00014	7.40599	7.40585	
	21.3.3	0.00084	7.40585	7.40501	
	21.3.4	0.00081	7.40501	7.40420	
	22.1.1	0.00026	7.40420	7.40394	
	22.1.2	0.00088	7.40394	7.40306	
	22.1.3	0.00076	7.40306	7.40230	
	22.1.4	0.00059	7.40230	7.40171	

Table 3. Results of the insert masses before and after machining steps and the CI Index calculated for the AISI 316 steel.

Material	Insert/Edge/Step	Mi - Mf	Mi	Mf	CI
ABNT 316	31.1.1	0.00017	7.40320	7.40303	0.049
	31.1.2	0.00052	7.40303	7.40251	
	31.1.3	0.00043	7.40251	7.40208	
	31.1.4	0.00038	7.40208	7.40170	
	31.2.1	-0.00008	7.40170	7.40178	
	31.2.2	0.00008	7.40178	7.40170	
	31.2.3	0.00039	7.40170	7.40131	
	31.2.4	0.00062	7.40131	7.40069	
	31.3.1	0.00021	7.40069	7.40048	
	31.3.2	0.00026	7.40048	7.40022	
	31.3.3	0.00024	7.40022	7.39998	
	31.3.4	0.00038	7.39998	7.39960	

As can be seen on Table 3, the cutting edge 31.2.1 presented gain in mass (weight), but it was seen in the stereoscope that there was some wear, Figure 4. It is possible to see in this figure that there was a deposition of material from the specimen on the cutting edge, masking the real result of this test. However, in later steps, this effect ceased to occur. As it was mentioned before, to avoid any problems related to it, the calculation of CI was only done after the last step of machining when the tools were cleaned with nitric acid 10% in an alcoholic solution for 15 minutes to eliminate deposited material in the specimen.

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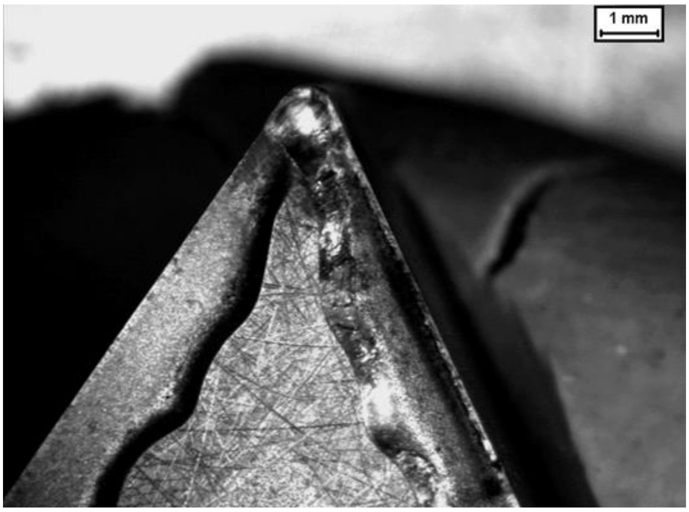
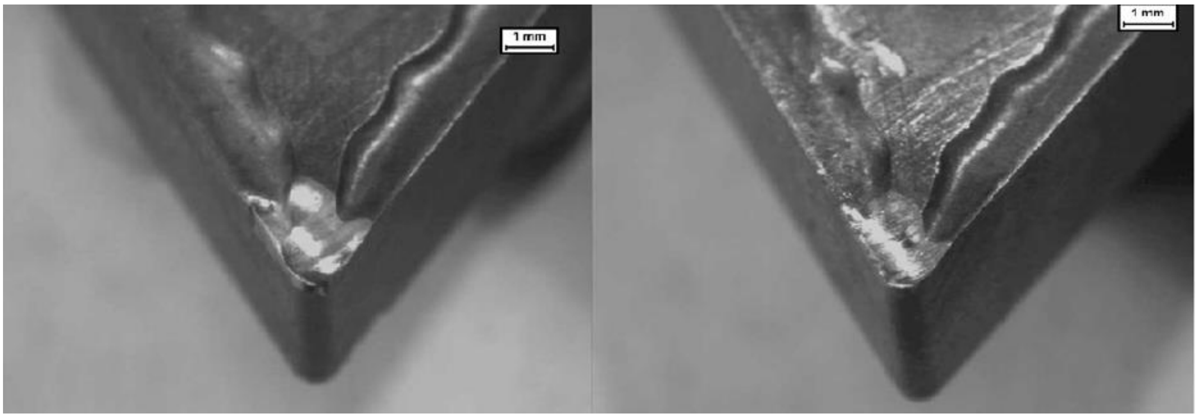


Figure 4. Insert worn with adhesion material.

The CI values above were according to expected since the AISI 4140 steel caused more wear in the tool than the AISI 316 steel and it is the first one which has a higher value of hardness and a lower machinability index. Figure 7 compares the worn edges in the tests for the AISI 4140 (a) and AISI 316 (b) steels, which clearly shows that the cutting edge remained the same in both tools proving that the procedure is consistent and reliable.



(a) (b)

Figure 7. Cutting edges of tool worn after machining (a) AISI 4140 and (b) AISI 316 steels, probably edge rounding.

A scanning electron microscope has been used to investigate in more depth the wear mechanism and to check adhering scrap in the cutting tool edge. Results are yet to be published in future papers.

4 CONCLUSIONS

The following conclusions can be drawn from the present investigation:
- AISI 4140 and AISI 316 steels present different machinability indexes and this was reflected in the CI values calculated by this new technique of measuring a new material property, named machining strength;
- Standardized test to measure the CI index leads to highly reproducible results for materials with low machinability indexes.

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