MACHINABILITY OF THREE DIFFERENT STEELS FOR PLASTIC INJECTION MOULD CONSIDERING THE CUTTING FORCES IN TURNING

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Abstract. *During manufacture of a mould, machining is certainly the most important process. The composition required to provide important properties in the steels used, such as hardness, wear and corrosion resistance, results in a low machinability and great cutting forces and high power consumption. This work aims evaluating the machinability of three different mould steels (VP50IM, DIN1.2711 and VP20) applied in the manufacturing of plastic injection moulds, through measurements of the machining forces components generated in the process of turning under several cutting conditions. The VP50IM and DIN1.2711 steels are harder than VP20. The latter is the most employed in manufacturing of plastic injection moulds and therefore will be the benchmark for comparison. The results showed that there are significant differences in the machining forces, and consequently in the machinability between the three materials.*

Keywords*: Machinability, steels for plastic injection moulds, machining force components, turning*

1. INTRODUCTION

The plastic injection steel moulds industry is an increasing sector, due to the great utilization of plastic parts. The moulds are made from forged or hot rolled steel bars, where the machining of cavities represents the major part of manufacturing time and a large percentage of the final cost. Steel has more influence on the overall cost of a mould through its machinability than through the raw material cost itself and therefore the optimization of the machining conditions is a key hole to reduce the manufacturing costs of a mould [Recht et al, 2004].

Machinability is generally defined in terms of forces, power consumption, tool wear and surface finish and surface integrity. Thus, a material with good machinability means low power consumption during machining, with low tool wear rate and good surface finish [Kalpakjian, 1985]. The type of surfaces that a machining operation generates and their characteristics are of great importance in manufacturing. In turning operations, it is possible to obtain the desired surface quality by selecting the appropriate cutting parameters [Dan, 1990].

Current studies show that the improvement in the output variables such as tool life, cutting forces, surface roughness, through the optimization of the cutting parameters, such as feed rate, cutting speed and depth of cut, may result in a significant economical performance of machining operations [Armarego, 1994].

1.1. Plastic Injection Mould Steels

Some plastic parts are produced in series, in very short cycles, using moulds with many cavities. Others having large size are manufactured in small scale and much longer cycles. Regardless the type of production, a mould to be used for plastic injection needs to look perfectly. To achieve good results quality moulds should be used since any imperfection will be reproduced onto the plastic product. An important decision to have a good mould is to select a proper steel to be applied. In the Brazilian mould industry, the most steel used is the ISO P20, a chromium-molybdenum alloyed steel. This material is classified as tool steel used to build plastic injection moulds, extrusion dies, blow moulds, forming tools and other structural components [Abou-El-Hossein et al, 2007]. The VP20 steel, developed by Villares Metals, which comes in a range of hardness between 30 and 34 HRC, has an improved machinability in relation to the standard ISO P20. Tests proved that the tool life in machining of the VP20 is about 30% higher than that of the standard ISO P20 [Plástico Moderno Magazine, 2009]. This means a gain of up to 77% in the volume of material removed by the tool.

The hardness of the material is the most important property to be taken into account when selecting a steel. The steels with hardness in the range between 38 and 42 HRC are indicated for moulds that require more strength. Higher hardness implies a better polibility of the steel. The high levels of good polishing allow obtaining dies of plastic parts that need to look translucent. This is the case of the lenses of headlamps and flashlights in cars, which have to be as high as the transparency shown by the glass.

The DIN 1.2711 is a medium carbon and low alloyed steel usually supplied in the heat treated condition, with hardness of 40HRC. It is used in moulds with up to 1000 mm of thickness, because its hardness is homogenous up to the nucleus. On the other hand, the VP50IM is supplied with low hardness, for subsequent hardening via aging [Mesquita and Barbosa, 2005]. This leads to many advantages during the mould production, especially those related to its machinability and polibility. The VP50IM steel is used in the manufacture of moulds for non-chlorinated thermoplastic and resins reinforced. The comparison of properties is important for the decision during the selection of the mould material. The choice is made in accordance with the degree of abrasiveness of the plastic to be injected, the appearance of the part required and desired strength of the tool [Pinedo and Barbosa, 1995].

This research aims to compare the machinability of steels VP50IM, DIN 1.2711 and VP20 used for manufacturing of moulds for plastic injection. The machinability here is expressed by the machining force components measured during turning operation with cemented carbide tools.

2. MATERIALS AND EXPERIMENTAL PROCEDURES

Three different steels are used in this study: VP20, VP50IM and DIN 1.2711. These materials were supplied by Villares Metals S.A. in bars with 100 mm of diameter. The chemical compositions of the workpieces are presented in Table 1. Their microstructures are shown in Fig. 1.

Table 1. Chemical composition of the workpieces used in the tests (weight percentage)

Material	C	Mn	Cr	Mo	Ni	Si	Al	Cu	S	V
VP20	0.36	1.06	1.80	0.20	0.70	-	-	-	-	-
VP50IM	0.15	1.55	-	0.30	3.00	0.30	1.00	1.00	0.10	-
DIN1.2711	0.56	0.70	0.70	0.30	1.65	-	-	-	-	0.075

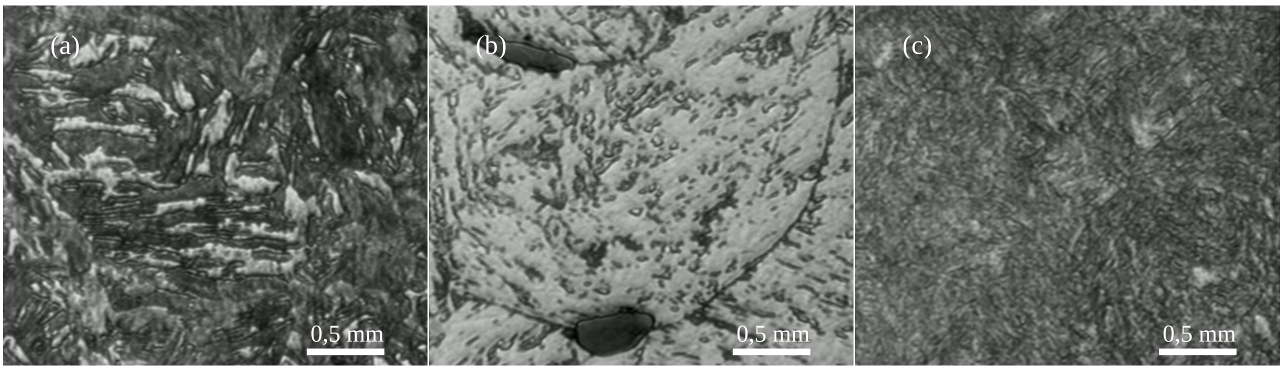

Figure 1. The microstructures of the workpieces materials: (a) VP 20; (b) VP 50 IM; (c) DIN 1.2711

Table 2 presents the average hardness for the three work materials. The average hardness of the VP20 steel is lower than the hardness of the two other steels that showed similar average values of this property.

Table 2. Rockwell C Hardness test results

Rockwell C Hardness Test					
Universal Wolpert Hardmeter - Load: 150 Kg					
VP20	HRC	VP50IM	HRC	DIN 1.2711	HRC
1ª indentation	29	1ª indentation	37.2	1ª indentation	38
2ª indentation	29.6	2ª indentation	40	2ª indentation	39
3ª indentation	28	3ª indentation	39	3ª indentation	39
4ª indentation	31	4ª indentation	39.5	4ª indentation	39
5ª indentation	30	5ª indentation	38	5ª indentation	39.5
Mean	29.52	Mean	38.74	Mean	38.9

In order to check the statistic effect of individual parameters and the interaction between them [Box and Hunter, 1978] a 2^kfactorial design was used. The parameters or independent variables analyzed were cutting speed feed rate, depth of cut and work material. Table 3 shows the levels of these parameters considered.

Table 3. Levels of independent variables

Factors	Level	
	-1	+1
Cutting Speed (m/min)	100	200
Feed Rate (mm/rev)	0.1	0.2
Depth of Cut (mm)	1	2
Work Material (1)	VP20ISO	VP50IM
Work Material (2)	VP20ISO	DIN1.2711
Work Material (3)	VP50IM	DIN1.2711

The use of four input variables resulted in a 2^4 factorial design with sixteen tests for each cutting condition, as shown in Table 4. Two replicates for each condition were made, comprising a total of 48 tests. This methodology was repeated for each work material comparisons (1), (2) and (3) of Tab. 3.

Table 4. Test Conditions according to factorial 2^4 design

Test Number	Cutting Speed (m/min)	Feed (mm/rev)	Depth of Cut (mm)	Material
1	100	0.1	1	-1
2	200	0.1	1	-1
3	100	0.2	1	-1
4	200	0.2	1	-1
5	100	0.1	2	-1
6	200	0.1	2	-1
7	100	0.2	2	-1
8	200	0.2	2	-1
9	100	0.1	1	+1
10	200	0.1	1	+1
11	100	0.2	1	+1
12	200	0.2	1	+1
13	100	0.1	2	+1
14	200	0.1	2	+1
15	100	0.2	2	+1
16	200	0.2	2	+1

It was used a three dimensional dynamometer, Kistler 9265-B, for measuring the machining force components. A data acquisition board and a computer managed the system with a acquisition rate of 1000Hz for a period of 7 seconds during each test. A schematic diagram of the experimental setup is shown in Fig. 2.

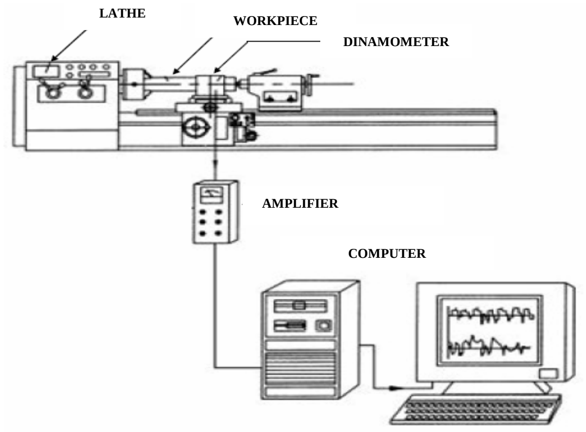

Figure 2. Schematic diagram of the experimental setup

The lathe used was a Multiplic 35 D manufacture by Industrias Romi S.A., with 11 kW of power, variable spindle speed from 3 to 3000 rpm and equipped with a GE Fanuc Series 21i – TB CNC control. The tools used were cemented carbide inserts with ISO specification SNMG 120404 – PM 4235 and a toolholder with specification DSBNR 2525 M 12 both supplied by Sandvik Coromant. No cutting fluid was used in the tests.

2. RESULTS AND DISCUSSION

To show the effects of the independent variables on the cutting forces the Pareto charts were used for each combination of materials work materials, as shown in Figs. 3 to 5.

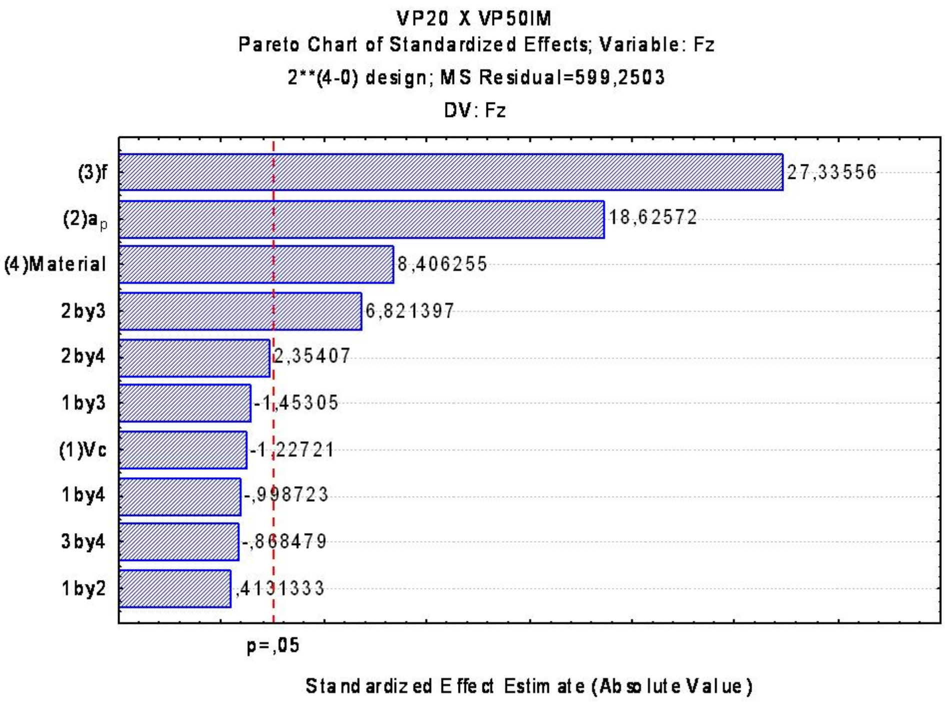

Figure 3. Estimate effects for cutting force (Fz) in the comparison between the VP20 and VP50IM work materials

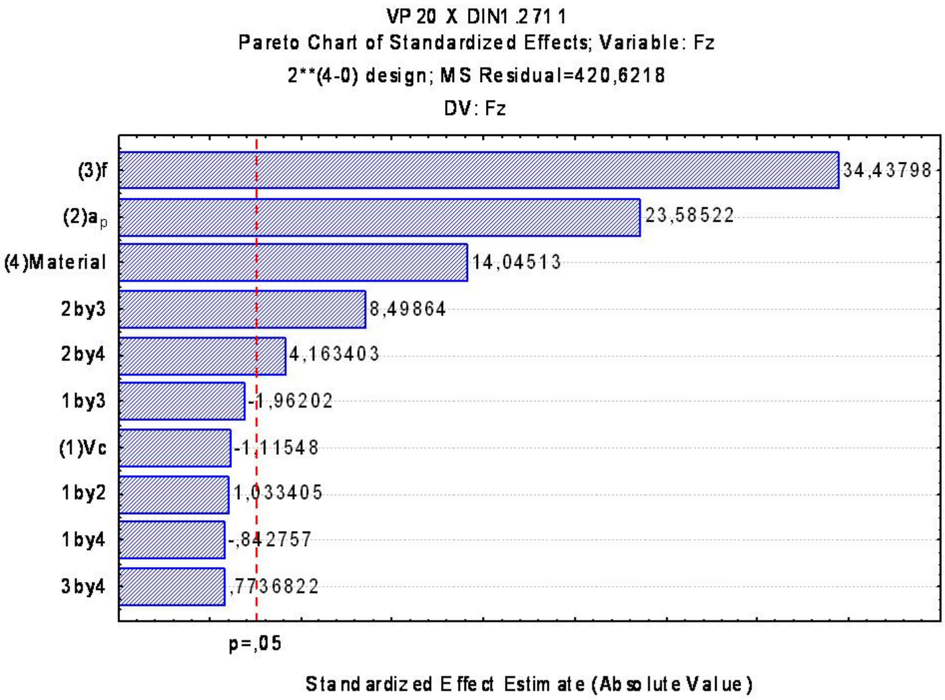

Figure 4. Estimate effects for cutting force (Fz) in the comparison between the VP20 and DIN1.2711 work materials

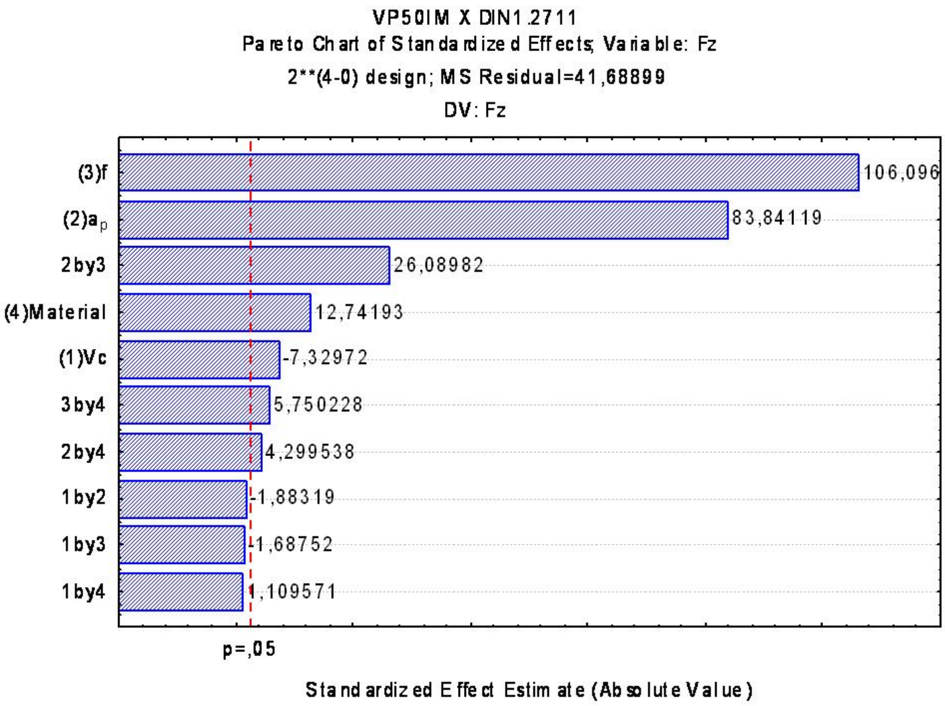

Figure 5. Estimate effects for cutting force (Fz) in the comparison between the VP50IM and DIN1.2711 work materials

By these Pareto's charts the material has always had significant effect on the cutting force, regardless the combination of the work materials. With respect to the cutting conditions, it was observed in all the charts that the significant parameters were the feed rate, the depth of cut and the interaction between the depth of cut and the feed rate. In the chart of Fig. 4, that compares the VP20 with the DIN 1.2711 work materials the effects of the interaction between the depth of cut and the work material was also noticed. In the chart of Fig. 5, that compares the VP50IM with the DIN1.2711 work materials, in addition to the significant effects of the interaction between the depth of cut and the work material and of the interaction between the feed rate and the work material. The effect of the cutting speed alone was detected, with negative influence. This is expected because with increasing cutting speed the cutting forces tend to decrease due to increased cutting temperature [Machado et al, 2009].

Feed rate and depth of cut were the most significant factors. This is because the increase of these parameters causes immediate increase in the cutting area which in turn increases the force level required to machine the material [Luiz, 2007]. There are also significant interactions involving these two parameters, and interactions between them and the work material. These interactions confirm the same trend of the isolated effects of these parameters.

The Pareto charts of the feed force (Fx) and thrust force (Fy) showed the similar behavior of the cutting force for all combinations of work materials tested and therefore they will not be presented here.

Figures 6 to 8 show the mean effect of the work material on the cutting force, the feed force and the thrust force for all combinations of work materials tested.

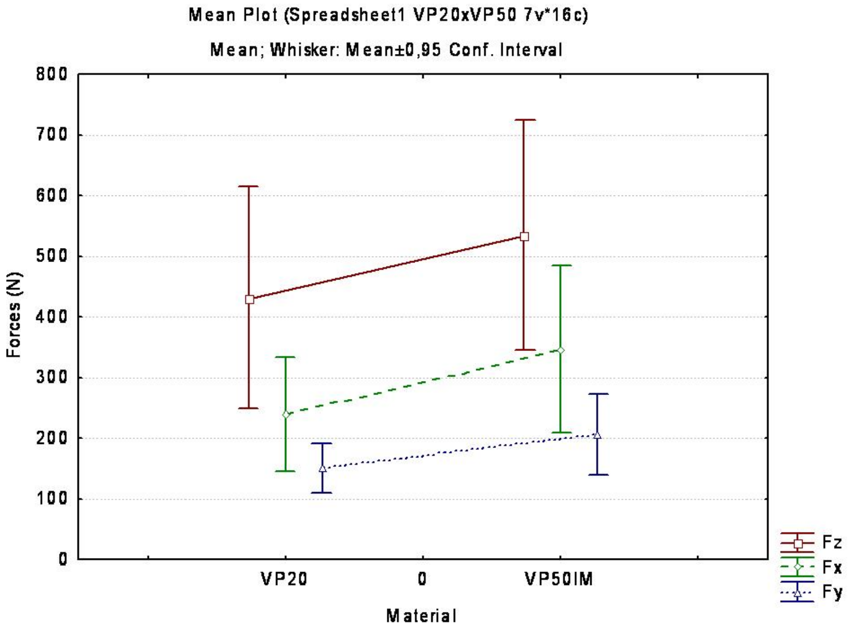

Figure 6. Mean effect of the work material on the cutting force, feed force and thrust force when comparing the VP20 with the VP50IM steels

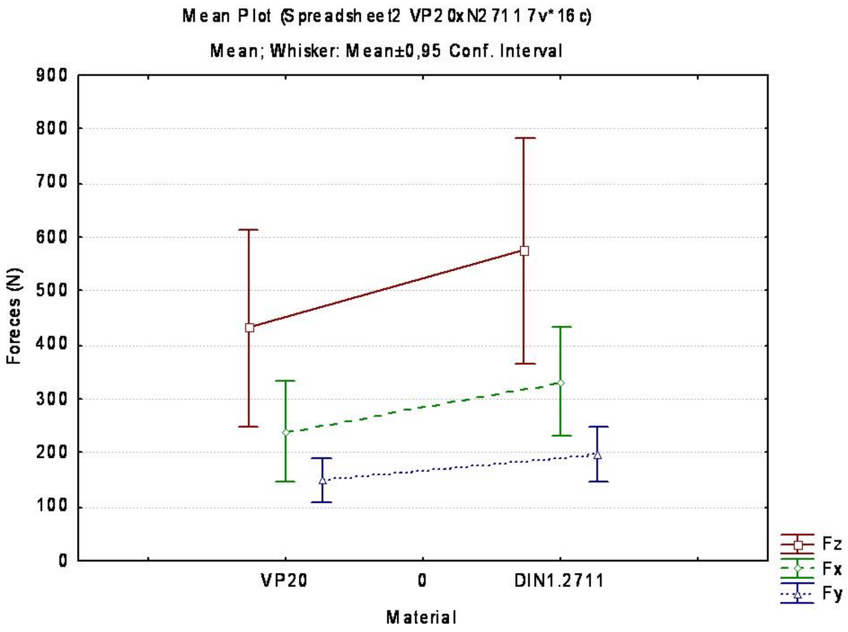

Figure 7. Mean effect of the work material on the cutting force, feed force and thrust force when comparing the VP20 with the DIN1.2711 steels

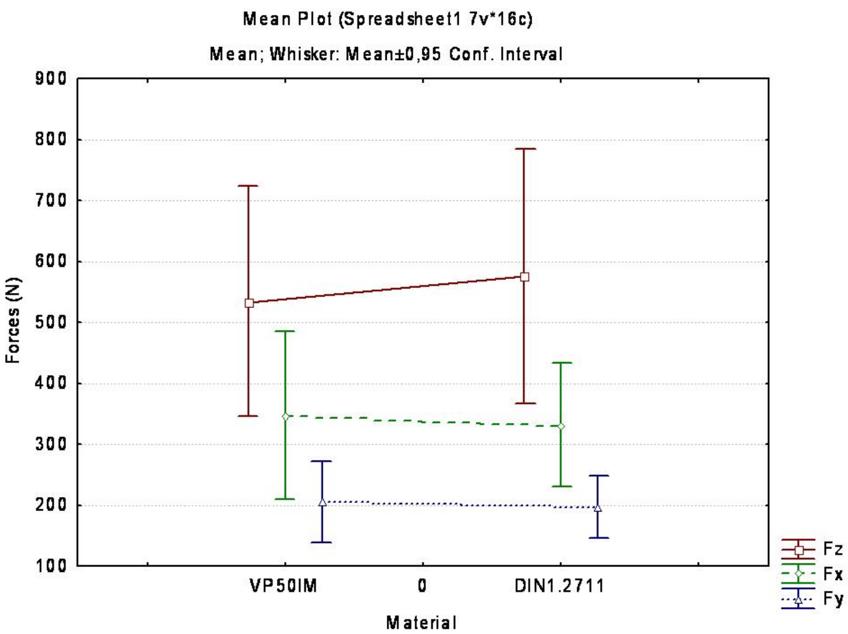

Figure 8. Mean effect of the work material on the cutting force, feed force and thrust force when comparing the VP50IM with the DIN1.2711steels

It is clear from these figures that the machining forces are smaller for the machining of the VP20 benchmark steel than when machining both the VP50IM and the DIN 1.2711 steels. When machining either of these two steels instead of the VP20 the average increases in the cutting and feed forces are of 100 N and in the thrust force of 50 N. This was expected since an increase in the material hardness causes an increase in its shearing resistance which consequently increases the machining force [Machado et al, 2009].

When comparing the cutting force of the VP50IM with the DIN1.2711 steels an average increase of approximately 40 N is seen. Although these work materials have the same average hardness, the hardness of the DIN1.2711 steel is slightly higher and homogenous up to the nucleus, what could explains the fact that the cutting force to be higher for this material. Feed force and thrust force show a decrease in its value. However, it is a slight decrease and thus machining force for these two materials have very similar values.

3. CONCLUSIONS

The following conclusions can be drawn from this study:

- The effect of the material in the cutting forces is significant from a statistical point of view and seems satisfactory to explain the difference in machinability between the materials used in this study;
- There is a good agreement between the work materials hardness and the machining forces when turning them with cemented carbide tools;
- The feed rate and depth of cut are the main variables influencing the machining forces and their interactions also have significant effects;
- The cutting speed shows a negative effect on the cutting forces, as was expected, but this effect was not statistically significant.

4. ACKNOWLEDGEMENTS

The authors are grateful to CAPES, CNPq and FAPEMIG for financial support and to Villares Metals S.A. for supplying the work materials for this research.

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