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ESTIMATION OF OPTIMAL CUTTING CONDITIONS FOR AUSTENITIC STAINLESS STEELS MACHINING

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ABSTRACT

Austenitic Stainless Steels have a low machinability in comparison to the rest of stainless steel. Optimum cutting conditions such as cutting speed and feed rate should be known for increasing this type of steels machining performance. In the present work a method for optimum cutting parameters calculation is developed. This method determines optimum cutting conditions for a machinability test and is related to steel characteristics of composition and mechanical properties. In view of the results some conclusions about the machinability of the different types of steel can be drawn. Furthermore, the effect of different additives of the steel and mechanical properties in machinability can be observed.

INTRODUCTION

Stainless steels represent a great part of the world steel production due to their good properties regarding corrosion resistance and mechanical strength.

Austenitic Stainless Steels are the ones which represent the largest production volume among Stainless Steels, by 65 to 70%. At the same time, they present the worst machinability values, due to their high rate of hardening by deformation, low thermal conductivity, high expansion coefficient and high ductility.

Machinability of steels is difficult to standardize, as a lot of variables are involved in the process of cutting, including the machine and the testing method. Working conditions can be very different in industrial practice. Therefore, the goal of this work is to make a research with technological and industrial validity to set the maximum performance conditions in Austenitic Stainless Steels machining.

Optimization of machining variables have been developed in some works by several methods, such as graphic procedure [1], analytical models [2] and [3], neural networks [4], etc. Nevertheless, these optimization methods were made according to isolated criteria, without taking into account all the practical conditions present in the industry. These criteria are the ones considered in the present work and can be summed up in the following: maximum tool life, minimum cost, best surface finish and dimensional accuracy. Furthermore these studies have not been carried out in the field of Austenitic Stainless Steels, so there was a void in this aspect of the subject.

Therefore, this study has a great field of application in the industry of machining, especially in décolletage industry.

In this work a method to determine the relationship between optimal cutting parameters (cutting speed and feed rate) obtained from industrial simulation test and steel properties is developed.

EXPERIMENTAL PROCEDURE

Industrial Simulation Tests were carried out by a CNC Lathe Multi-Turret MUPEM, model ICIAR / 1 / 42, showed in figure 1.

Figure 1. Automatic Lathe used for the tests

Dimensional control of the workpieces was carried out by a 3-D Coordinates Measuring Machine DEA, model MISTRAL-070705.

10 types of Austenitic Stainless Steels were tested, with different compositions and microstructure, so that the effect of some additives and mechanical properties in machinability could be analyzed.

The workpiece machined in the tests is shown in figure 2. Turning, grooving, drilling and parting operations were performed. All of them are very common in the décolletage industry.

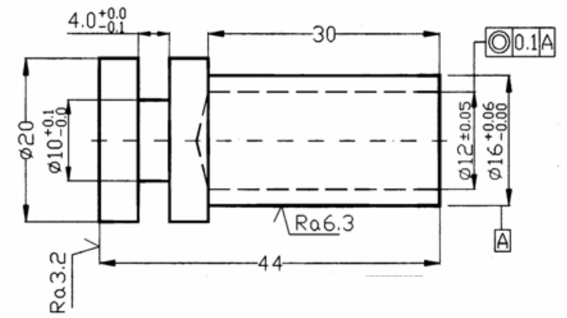

Figure 2. Workpiece machined

The goal of this machinability test was to obtain the conditions for optimal production and profit. Therefore it was necessary to vary continuously the parameters and cutting conditions, so that a large range of values were tested.

The time for the test was set in 6 ± ½ hours. The goal of the test was achieved by varying the cutting conditions to obtain a maximum number of pieces machined within the time set. Values of cutting speed and feed rate that make maximum the production rate will be the results of the test for each type of steel.

DETERMINATION OF OPTIMAL CUTTING CONDITIONS

Method description

From test results empirical expressions can be deduced that allow us to obtain the optimal values of cutting conditions related to the steel properties, by using the method of linear regression of variables.

The data used in the regression are the optimal values of cutting speed and feed rate for the four operations obtained in the tests on one hand, and the composition characteristics and mechanical properties of steels tested on the other hand.

As the number of steel characteristics is very high, taking into account composition values and mechanical properties, it is easier to apply the method independently to small groups of variables, which have special influence in the results of machinability. First the method will be applied to certain composition characteristics and then to some mechanical properties.

According to this procedure, the following expressions for cutting speed and feed rate were outlined.

$$v_c = K_v \cdot (\%A_1)^{a_v} \cdot (\%A_2)^{b_v} \cdot (\%A_3)^{c_v} \cdot \ldots \quad (1)$$

$$f_n = K_f \cdot (\%A_1)^{a_f} \cdot (\%A_2)^{b_f} \cdot (\%A_3)^{c_f} \cdot \ldots \quad (2)$$

where A_1, A_2, A_3, etc. are the additives of the steel which are taken into account.

In the same way, the following expressions for the mechanical properties can be outlined.

$$\mathrm{v_c} = \mathrm{K_v} \cdot (\mathrm{P_1})^{\mathrm{a_v}} \cdot (\mathrm{P_2})^{\mathrm{b_v}} \cdot (\mathrm{P_3})^{\mathrm{c_v}} \cdot \ldots \quad (3)$$

$$\mathrm{f_n} = \mathrm{K_f} \cdot (\mathrm{P_1})^{\mathrm{a_f}} \cdot (\mathrm{P_2})^{\mathrm{b_f}} \cdot (\mathrm{P_3})^{\mathrm{c_f}} \cdot \ldots \quad (4)$$

where P_1, P_2, P_3, etc. are the mechanical properties considered.

The variables which most affect the optimum cutting conditions are those showed in the following expressions of the cutting speed. The linear regression method was carried out in these expressions to determine constant and exponents values:

$$\mathrm{v_c} = \mathrm{K_a} \cdot (\%\mathrm{C})^{\mathrm{a}} \cdot (\%\mathrm{S})^{\mathrm{b}} \cdot (\%\mathrm{Cr})^{\mathrm{c}} \cdot (\%\mathrm{Ni})^{\mathrm{d}} \cdot (\%\mathrm{Ti})^{\mathrm{e}} \quad (5)$$

$$\mathrm{v_c} = \mathrm{K_p} \cdot \mathrm{R}^{\mathrm{f}} \cdot \mathrm{R_A}^{\mathrm{g}} \cdot \mathrm{HB}^{\mathrm{h}} \cdot (\%\mathrm{C})^{\mathrm{l}} \quad (6)$$

These are the expressions regarding the cutting speed for the turning process. For the rest of the processes the expressions are similar. However, in the drilling operation, the percentages of C and Ti have been left out in order to obtain a better adjust.

Regarding the expression of the feed rate, a better adjust is obtained in the regression if it is made for the product $v_c \cdot f_n$, instead of the variable f_n. This difference may be due to the fact that the product $v_c \cdot f_n$ indicates directly the material removal rate, and therefore the optimum value of this product will depend directly on the steel characteristics. So, the expressions outlined for the regression will be the following:

$$v_c \cdot f_n = K_a \cdot (\%C)^a \cdot (\%S)^b \cdot (\%Cr)^c \cdot (\%Ni)^d \cdot (\%Ti)^e \quad (7)$$

$$v_c \cdot f_n = K_p \cdot R^f \cdot R_A{}^g \cdot HB^h \cdot (\%C)^l \quad (8)$$

RESULTS

Tables 1 and 2 present some of the values of the constants and the exponents of the expressions obtained with the linear regression method.

	Variable	Parameter	Turning	Grooving
Additives		**K_a**	$4.16 \cdot 10^{22}$	$4.64 \cdot 10^{13}$
	%C	**a**	-0.315	-0.244
	%S	**b**	0.038	0.020
	%Cr	**c**	-15.022	-7.691
	%Ni	**d**	-2.334	-2.424
	%Ti	**e**	-0.099	-0.007
M. Properties		**K_p**	$6.95 \cdot 10^{10}$	$4.96 \cdot 10^{6}$
	R	**f**	-2.706	-4.173
	R_A	**g**	-2.360	-0.757
	HB	**h**	1.231	3.608
	%C	**l**	-0.352	-0.195

Table 1. Values obtained of the parameters of the optimum cutting speed expressions

	Variable	Parameter	Turning	Grooving
Additives		**K_a**	$1.69 \cdot 10^{26}$	$2.78 \cdot 10^{18}$
	%C	**a**	-0.526	-0.446
	%S	**b**	0.062	0.096
	%Cr	**c**	-18.129	-11.564
	%Ni	**d**	-2.982	-3.581
	%Ti	**e**	-0.110	-0.084
M. Properties		**K_p**	$1.19 \cdot 10^{13}$	$9.32 \cdot 10^{16}$
	R	**f**	-5.119	-12.121
	R_A	**g**	-2.985	-2.664
	HB	**h**	3.305	9.936
	%C	**l**	-0.602	-0.405

Table 2. Values obtained for the parameters of the optimum product $v_c \cdot f_n$ expressions

With these parameters it is possible to estimate the optimum cutting speed and feed rate for any Stainless Steel, by introducing its composition characteristics or its mechanical properties in the expressions mentioned above and using the value of the parameters. Since there will be 2 possible expressions for each variable, the best choice to use in the machining the mean value between them.

ANALYSIS OF RESULTS

A test of validity of the method consisted on using the expressions to predict the optimum cutting conditions and contrasting them with the real value obtained in the industrial simulation test. This test was carried out on two steels: RM-143 (1st Concast) and RDN 495.

Tables 3 and 4 show the comparative values of the cutting conditions for turning from the predictions and the real values

	v_c		
Steel	Predicted (m/min)	Real (m/min)	**Error (%)**
RM – 143	143.9	155	**-7.16**
RDN 495	194.8	200	**-2.60**

Table 3. Comparative results of optimal cutting speed for turning obtained from the empirical prediction and the real values from the tests

	f_n		
Steel	Predicted (m/min)	Real (m/min)	**Error (%)**
RM – 143	0.25	0.26	**-3.84**
RDN 495	0.26	0.28	**-7.14**

Table 4. Comparative results of optimal feed rate for turning obtained from the empirical prediction and the real values from the tests

A good adjust is observed, as the error is smaller than 10% in all cases. This error can be assumed without problems, as the cutting conditions choice will be complemented with other methods, which will decrease even more this error.

It can also be observed that predicted values are always below the real data. It will be convenient, therefore, to take into account this trend when the choice of cutting conditions is done.

A checking for the grooving process was also made. The steels tested were RM-143 (3rd Concast) and RM-314. As it happened with the turning operation, some similar steels to these two were taken to carry out the method of regression, and therefore, for the prediction, so that the characteristics of the steels may be reflected in the expressions worked out. Tables 5 and 6 show comparative values of the checking.

	v_c		
Steel	Predicted (m/min)	Real (m/min)	**Error (%)**
RM – 143	130.1	125	**4.08**
RM – 314	129.1	130	**-0.69**

Table 5. Comparative results of optimal cutting speed for grooving obtained from the empirical prediction and the real values from the tests

	f_n		
Steel	Predicted (m/min)	Real (m/min)	**Error (%)**
RM – 143	0.14	0.15	**-6.67**
RM – 314	0.16	0.12	**33.33**

Table 6. Comparative results of optimal feed rate for grooving obtained from the empirical prediction and the real values from the tests

As it can be observed in the last table, good results are obtained also for the grooving process, since the error values are all smaller than 7%, except for the case of the optimum feed rate for ROLDAMAX – 314 steel. This result can be due to the fact that the real value is quite small and any little deviation causes high relative errors.

Unlike for the turning process, the error sign in this case changes from some values to other, so a general trend cannot be pointed out.

IMPLICATIONS FOR MACHINABILITY OF STEELS

In view of the results, some conclusions can be drawn regarding machinability of steels, since the influence of some characteristics of the steel in the optimum cutting conditions can be figured out.

The attention here will be focused on the expressions of the product $v_c \cdot f_n$, since it represents the metal removal rate. Returning to the table 2 the values of the parameters for the expressions can be seen.

For example, it can be observed that the exponents of the variables %C, %Cr, %Ni y %Ti have negative sign, whereas that of the variable %S is positive. Therefore, we can state that an increase in any of the first group of additives cause a decrease in the optimum metal removal rate, thus worsening machinability, as the number of pieces done in the test will also decrease.

On the contrary, S improves the machinability, as its presence cause an increase in the optimum metal removal rate. This feature is consistent with some other studies performed in which it was observed that S gives place to the compound SMn with the Mn present in the steel that lubricates the tool-piece contact, thus reducing the friction [5].

It can be also observed that the highest exponent in absolute value is that of the variable %Cr, followed by that of %Ni (both negative), which are precisely the characteristic additives of the stainless steels. This effect of decreasing machinability caused by these two elements is in relation to the lower value of machinability characteristic of stainless steels [5]. The more amount of these elements in the steel, the worse the characteristics in the steel.

CONCLUSIONS

The method carried out lets us set the optimum cutting conditions for any type of Austenitic Stainless Steel, though results can be extended to any other type of steel, as the conditions are given according to the material characteristics, i.e. additives and mechanical properties.

Summing up the study, two main conclusions can be drawn:

1.- Optimum cutting conditions for a material are very related to its mechanical properties and therefore, they can be predicted if these properties are known on the basis of the values obtained in machinability tests.

2.- The method used is valid for the prediction of optimum cutting conditions and confirm what other experimental studies have concluded about factors that affect machinability of steels.

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