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MATHEMATICAL MODEL OF CUTTING FORCES WHEN WIDENING HOLES IN STAINLESS STEEL X15CrNiSi20-12

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Lucrarea prezintă un set de date experimentale obținute la operația de lărgirea oțelului inoxidabil X15CrNiSi20-12, şi modalitățile şi instrumentele de determinare a forțelor de aşchiere în anumite condiții de prelucrabilitate. Acest studiu reprezintă o contribuție personală a autorilor la estimarea exponenților politropici şi determinarea structurii ecuațiilor forțelor de aşchiere. Lucrarea mai oferă şi graficele de variație a componentelor forțelor de aşchiere funcție de parametrii tehnologici de aşchiere. Rezultatele obținute pot fi folosite în cercetări viitoare, în vederea îmbunatățirii productivității de prelucrare a otelurilor.

The paper presents a series of experimental data concerning the widening of the stainless steel X15CrNiSi20-12 and the ways and means to determine the cutting forces with respect to the specific working conditions. It represents the contribution of the authors to the estimation of the polytrophic exponents and to the assessment in terms of structure of the cutting forces equation. Afterwards, the paper presents the graphs for the variation of the cutting force components with the parameters of the cutting technology. The obtained results can be implemented in further research, in order to increase the productivity of steel machining.

Keywords: widening, cutting force, stainless steel, polytrophic exponents.

1. Introduction

The researches in cutting domain have as purpose the cutting process economic optimization. In time, these allowed to create new materials for cutting tools and sensible choice for the geometric parameters of tools and cutting regime [1]. The use of stainless steels is increasing at a rapid rate in various technical fields: building construction materials; hospital facilities in medicine; laboratories equipment and instruments and home appliances or kitchen utensils in industries.

It is well known that, owing to some specific physical-mechanical properties, it is often very problematic in practice to cut stainless steels in industry in terms of deciding the optimal cutting conditions and consume of materials and time [2]. At the same time, due to the high costs of these steels, their

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machinability should be studied using rapid cutting methods, capable of assuming minimum tool and material requirement [3].

The purpose of this paper is analyze a particular type of material during the cutting process, and to obtain the values of the cutting forces. This will be done while widening the stainless steel X15CrNiSi20-12. A series of experimental studies where carried out in order to determine the above mentioned cutting forces. In the equations used to determine these forces, a new element introduced, the speed, which, together with the previous indicators, significantly contribute to a more precise calculus [4]. In time, many researchers have experimented cutting various materials by changing the cutting conditions, but it seems that their influence was not significant, and only speed is bringing an important change when modified. The new equation is to be used this way for any other future determination of forces while processing other materials, especially in steels applications.

2. Method, means and conditions

The tests were performed using a special dynamometer for determination of forces and moments [5]. On the perimeter of the elastic detecting element four equidistant strain ganges were placed, inclined at 45º with respect to generatrix, in opposite, alternative successively. By using this placement of the transducers, and by connecting them to a bridge, a higher measurement sensitivity has been achieved.

The cutting conditions during the experiments are given below:

- The machine tool: a GC_0 32 DM_3 drilling device, the dimensions of the mass are 480×420 (mm) and a Morse cone 4 was used.
- The cutting equipment: Rp5 high-speed steel spiral drill with Rockwell Hardness Number equal to 62.
- The geometric features of the drill have met the requirements of the R1370/2-74 standard, A1 type cutting, with diameters between 10 to 30 mm.
- The cooling and lubricating fluid: P 20% emulsion.
- The tools have been cut by means of the UAS-200 machine equipped with a stone wheel 50x20x20 E_N 40 M7C, using a special cutting device.

Table 1 shows the chemical characteristics of the steel X15CrNiSi20-12.

Table 2 shows the mechanical characteristics of this studied stainless steel.

Table 1

Chemical Composition, %

C	Cr	Ni	Si	S	P
0.15	20	12	0.8	0.015	0.03

Table 2

Mechanical Characteristics

Tensile strength R_m (N/mm^2)	0.2 offset limit R_{02} (N/mm^2)	Ultimate Elongation δ (%)	Hardness HB
710	270	28	223

3. Experimental results

Technical literature [1] provided equation (1), which has been the starting point in the analysis of the cutting forces:

$$F = C_F \cdot D^{x_F} \cdot f^{y_F} \cdot a_p^{u_F} \quad \text{(N)}. \tag{1}$$

where D is the drill diameter, f is the cutting feed, a_p is the cutting depth, x_F, y_F, u_F, are constants exponents and C_F a constant.

This equation has proved to be inappropriate since after the practical estimation of the polytrophic exponents and constants, several tests determinations have been performed and have showed a wide scattering of results under the same cutting conditions. The problem is that during the steel machining at various speeds, different parameter values were recorded even if all the other machining conditions were kept constant [5]. This led to the introduce a speed factor: v

The new equation with the cutting speed has the form:

$$F = C_F \cdot D^{x_F} \cdot f^{y_F} \cdot a_p^{u_F} \cdot v_c^{z_F} \quad \text{(N)}. \tag{2}$$

In order to estimate the constant C_F and the polytrophic exponents x_F, y_F, u_F, z_F, equation (2) has been linearized by using the logarithm, as shown below:

$$\lg F = \lg C_F + x_F \lg D + y_F \lg f + u_F \lg a_p + z_F \lg v_c \ . \tag{3}$$

Table 3 shows a selection of the most conclusive machined steel samples of the stainless steel X15CrNiSi20-12.

If data for the first five experiments included in Table 3 are substituted in the equation (3), a linear inhomogeneous system of five equations with five unknowns (lgC_F, x_F, y_F, u_F, z_F) is obtained, for every cutting force component, F_x, F_y and F_z .

Table 3

Experimental Results

Exp. Nr	D_i (mm)	D_f (mm)	a_p (mm)	f (mm/rot)	n rot/ min	v_c (m/ min)	F (N)
1	12	16	2	0.20	224	11.25	438
2	12	24	6	0.20	224	16.88	1960
3	16	24	4	0.32	224	16.88	1761
4	16	24	4	0.20	355	26.75	1338
5	12	16	2	0.12	355	17.83	321
6	16	24	4	0.12	224	16.88	765
7	12	24	6	0.32	355	26.75	3309

The system for the force component F_z has the form:

$$\begin{cases} \lg C_F + x_F \lg 16 + y_F \lg 0.20 + u_F \lg 2 + z_F \lg 11.25 = \lg 438 \\ \lg C_F + x_F \lg 24 + y_F \lg 0.20 + u_F \lg 6 + z_F \lg 16.88 = \lg 1960 \\ \lg C_F + x_F \lg 24 + y_F \lg 0.32 + u_F \lg 4 + z_F \lg 16.88 = \lg 1761 \\ \lg C_F + x_F \lg 24 + y_F \lg 0.20 + u_F \lg 4 + z_F \lg 26.75 = \lg 1338 \\ \lg C_F + x_F \lg 16 + y_F \lg 0.12 + u_F \lg 2 + z_F \lg 17.83 = \lg 321 \end{cases} \quad (4)$$

It has the following solutions $C_F = 436$; $x_F = -0.07$; $y_F = 0.88$; $u_F = 1.28$ and $z_F = 0.3$

Using these values, we have to verify equation (3) with data for the experiments 6 and 7 in Table 3 we observe that the error ε is very low: ε < 3%.

Therefore, the formula of the cutting force component F_z for the widening of the stainless steel X15CrNiSi20-12 is obtained by inserting these solutions in the equation (2):

$$F_z = 436 \cdot D^{-0.07} \cdot f^{0.88} \cdot a_p^{\ 1.28} \cdot v_c^{\ 0.3} \quad \text{(N)}. \quad (5)$$

By tracing the cutting forces components variation diagrams with respect to the work parameters, the resulted diagrams are shown in figures 1 to 6, and they are valid only for stainless steel X15CrNiSi20-12.

Fig. 1 shows the variation of the cutting force F_z depending on the diameter, for different values of the feed. The two parameters kept fixed were the cutting depth and the cutting speed, and we varied the drill diameter and the cutting feed. The later was given three main values, 0.1, 0.2 and 0.3 mm/rot. The value of the force increases with the feed and decreases with the drill diameter.

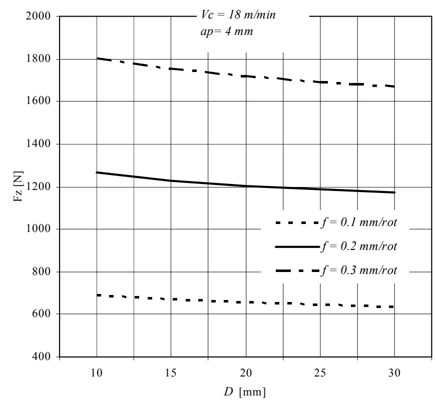

Fig. 1. The force F_z variation depending on the diameter for different feeds.

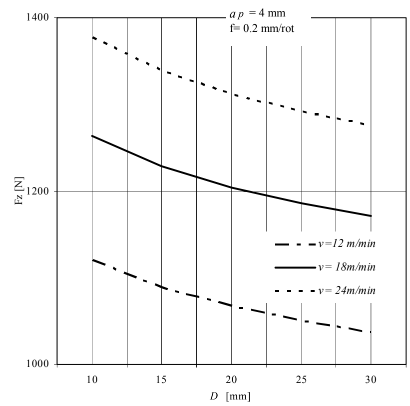

Fig. 2. The force F_z variation depending on the diameter for different speeds.

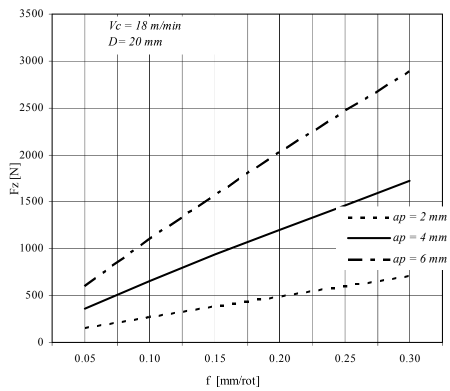

Fig. 3. The force F_z variation depending on the feed for different depths.

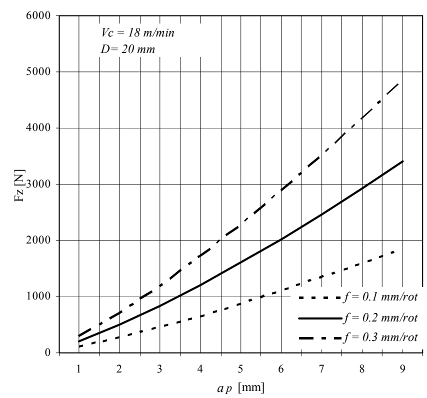

Fig. 4. The force F_z variation depending on the depth for different feeds.

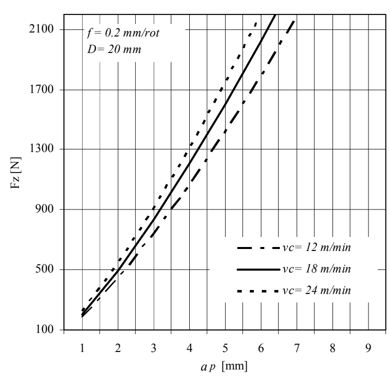

Fig. 5. The force F_z variation depending on the depth for different speeds.

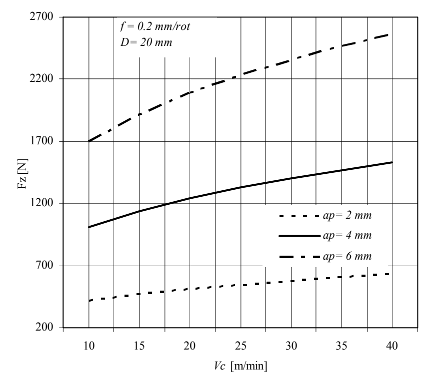

Fig. 6. The force Fz variation depending on the speed for different depth.

Fig. 2 shows the variation of the cutting force F_z depending on the drill diameter for different values of the cutting speed. The value of the force increases with the speed and decrease with the diameter. Fig. 3 shows the variation of the cutting force F_z depending on the cutting feed, for different values of the cutting depth. The force increases with the depth and the feed. Fig. 4 shows the variation of the cutting force F_z depending on the cutting depth, for different values of the cutting feed. The value of the force increases with the feed and the depth. Fig. 5 shows the variation of the cutting force F_z depending on the cutting depth, for different values of the cutting speed. The value of the force increases with the depth and the speed. Fig. 6 shows the variation of the cutting force F_z depending on the cutting speed, for different values of the cutting depth. The value of the force increases with the speed and the depth.

4. Conclusion

The analysis of the experimental data has led to the following conclusions:

1) For the cutting force determination at stainless steel widening, a special dynamometer was designed and manufactured; the strain ganges were attached to an elastic element.

2) By many experimental tests, it the necessity of modifying the structure of the cutting force calculation relation found in the technical literature was demonstrated, meaning that the speed has to be included with respect to equations (2) and (5).

3) The experimental results prove the variation of the cutting forces values depending on the parameters of the cutting technology.

4) The results of the present study can be readily implemented and/or used in further research activity concerning technological parameters for the widening of the stainless steels.

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