

RESEARCH ARTICLE

THE INFLUENCE OF MICROALLOYING ELEMENTS ON CUTTING FORCE AND ROUGHNESS OF AUSTENITE STAINLESS STEEL

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Manuscript Info Abstract

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*Key words:-*Steel Microalloying, Boron, Zirconium, Tellurium, Machinability, Cutting Force, Roughness More recently a modified stainless steels have been used to produce various structural elements that work in complex operating conditions. Stainless steel X8CrNiS18-9 is the most commonly used austenitic stainless steel due to its good machinability. This steel has high mechanical and working properties thanks to a complex alloying, primarily with the elements such as chromium and nickel. The content of sulphur present in the steel from 0.15 to 0.35% improves machinability. The aim of this work is to determine the influence of microalloying with boron, zirconium and tellurium on the cutting force and roughness the mentioned steel.

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Introduction:-

Improved cutting steels are intended for the production of parts on high-performance automatic machines, so they are often called steel for automatic machines. The most important property of steel for automatic machines is better machinability by particle separation compared to other steels. Better cutting is characterized by slower tool blade wear and high surface quality [1].

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In order to produce steels with the best machinability, such as X8CrNiS18-9, a number of inclusions with a carefully designed composition are required [2].

The machinability of these steels is achieved by using a modified chemical composition which promotes the formation of inclusions. The basic characteristics of the chemical composition of steel with improved cutting are increased content of sulphur (0.15-0.45%), phosphorus (0.07-0.11%) and manganese (0.5-1.5%). Sulphur by creating sulphide inclusions reduces friction and resistance to cutting, and increases the brittleness of shavings. Better cutting can be achieved by the addition of selenium, *zirconium*, *tellurium* or bismuth. The inclusions allow the creation of brittle and short shavings. However, due to the presence of inclusions, these steels are more prone to brittle fractures, cracks during heat treatment, fractures due to fatigue, etc. Consequently, steels for automatic machines are mainly used for less mechanically loaded parts, because their toughness and dynamic durability are lower than with other structural steels [1].

Manganese sulphide inclusions tend to elongate in the rolling direction, and elongated manganese sulphide inclusions are less desirable from a machinability standpoint than globular manganese sulphide inclusions. Non-metallic inclusions adversely affect many properties sensitive to the continuity of the steel structure, while they have little or no effect on other properties [3].

Cutting Force And Roughness

In the process of chip removal, several forces acting on the tool and resulting from the resistance of the cut material occur. All these forces can be considered equal to the resultant F_R cutting force [4].

The resultant cutting force can be broken down into components in the axis direction of the rectangular coordinate system F_x , F_y , F_z (which most often coincides with the machine coordinate system), or to forces acting in the direction of the tool movement, where:



Figure 1:- Cutting forces [5].

 $\mathbf{F}_{\mathbf{x}}$ – the force of penetration of the tool into the workpiece that is normal to the work surface;

 $\mathbf{F}_{\mathbf{v}}$ – the main cutting force that is collinear with the cutting speed;

 $\mathbf{F}_{\mathbf{z}}$ – auxiliary movement force (see Figure 1).

The resultant cutting force is calculated according to relation (1) [5]:

$$F_R = \sqrt{F_x^2 + F_y^2 + F_z^2}$$
(1)

Technical surfaces are those surfaces of machine parts which have been obtained by processing with chip removal or with one of processing without removing material. During the processing and exploitation of machine parts, they are exposed to the effects of various types of loads, such as e.g. mechanical, thermal, electrical, chemical or biological. However, mechanical and chemical loads are the most significant, and their frequent consequence is abrasion (wear) of parts and corrosion [6].

Technical surfaces are not ideally smooth geometric surfaces separating two media, but from a microscopic point of view, rough surfaces characterized by a series of irregularities of different sizes, shapes and arrangements. The size of the roughness of the technical surfaces can affect:

- reduction of dynamic strength;
- increased friction and wear frictionally (tribological) loaded surface;
- reduction of overlap at the clamping joints and thus reducing the load-bearing capacity of the clamping joint;
- accelerating corrosion [7].



Figure 2:- Parameters of machined surface [4].

The roughness represents the microgeometric irregularities of the surface, i.e. unevenness at the small reference length (l) of a given direction of the surface (Figure 2). The simplified observed surface roughness represents traces of cutting tool blades [4].

In order for the roughness to be examined with a view to identifying the conditions under which would be moving in the permitted limits, the roughness itself must be defined. The roughness parameters are defined in the center line system (M-medium system), where the center line represents the baseline of the nominal profile. The center line is determined so that within the limits of the reference length l the square deviation of the profile ($y_1, y_2, ..., y_n$) is minimal.

The following parameters (Figure 2) can be defined for the machined surface profile [4]:

- the maximum height of the irregularities (\mathbf{R}_{max}) as the distance between two parallel planes which, within the limits of the reference length, touch the highest and lowest point of the profile and are parallel to the center line;
- mean arithmetic deviation of profile height $(\mathbf{R}_{\mathbf{a}})$ as mean arithmetic magnitude of distance of absolute values of all points of effective profile within the limits of reference length:

$$R_a = \frac{1}{l} \int_0^l y \, dx \, \dots (2);$$

• mean height of the irregularities (\mathbf{R}_z), as the difference between the arithmetic mean of the five highest and five lowest points of the profile within the limits of the reference length, measured from an arbitrary straight line parallel to the center line:

$$R_z = \frac{(R_1 + R_3 + \dots + R_9) - (R_2 + R_4 + \dots + R_{10})}{5} \dots \dots (3)$$

The basic roughness criterion is R_a while R_{max} and R_z are additional criteria.

Experimental Research and Test Results:-

The melting and casting of austenitic stainless steel X8CrNiS18-9 was carried out in a vacuum induction furnace with a capacity of 20 kg. Eight meltings were done. The first melt was basic type of austenitic stainless steel X8CrNiS18-9, without any modifiers. Subsequently, in the next seven melt, the composition with the corresponding contents of boron, zirconium and tellurium was modified. Each of the above elements was added independently, then in combination with two, and finally with all three alloying elements.

In all experimental melts after rolling and after heat treatment, the presence of type A inclusions (sulphides) according to ASTM E45-11 was detected.

The influence on the shape and size of the nonmetallic inclusions is especially shown by zirconium and tellurium. Addition of tellurium with zirconium and boron improves the globularization of austenitic stainless steel X8CrNiS18-9, in this respect tellurium is particularly dominant.

Chemical analysis of the eight melt variants are given in Table 1.

Type of X8CrNiS18-9	Chemical composition (%)									
	С	Si	Mn	Р	S	Cr	Ni	В	Zr	Te
Basic type X	0.03	0.42	0.61	0.021	0.18	18.3	9.4	_	_	_
Type X + B	0.05	0.47	0.66	0.021	0.19	18.5	9.5	0.004	_	_
Type X + Zr	0.04	0.35	0.75	0.021	0.17	18.8	9.4	-	0.016	_
Type X + Te	0.05	0.40	0.80	0.010	0.16	18.9	9.3	-	_	0.033
Type $X + B$ and Zr	0.04	0.49	0.69	0.012	0.17	18.5	9.1	0.004	0.009	_
Type $X + B$ and Te	0.04	0.35	0.78	0.011	0.18	18.8	9.3	0.004	_	0.039
Type $X + Zr$ and Te	0.03	0.47	0.72	0.012	0.18	18.5	8.9	-	0.007	0.040
Type $X + B$, Zr and Te	0.04	0.44	0.78	0.012	0.19	17.1	9.3	0.006	0.012	0.042

 Table 1:- Chemical analysis of melt variants [8].

In the Laboratory for metal cutting and machine tools of the Faculty of Mechanical Engineering in Zenica, the machinability test of the samples was done, based on the estimation of parameters of the cutting force and roughness. The test was carried out on all samples under the same treatment with the following parameters:

n = 600 rpm; s = 0.1 mm/r; d = 1.0 mm,

where n - number of rounds; s - displacement and d - tool penetration depth.

Processing was performed on a universal lathe PA-501 M Potisje (Figure 3) with max speed 2000 rpm. The Kistler 5070 dynamometer (Figure 4) was used to measure the cutting forces. The dynamometer can calculate in real time the three components of the generated forces, as the three components of the resulting vectors at that moment.



Figure 3:- Universal lathe from the Laboratory for metal cutting and machine tools [8].



Figure 4:- Cutting force measuring device Dynamometer Kistler 5070 [8].

The manual perthometer M1 (Figure 5), which was used to measure surface roughness, belongs to the group of devices with a feeler and works on the contact principle. The action between the needle and the measuring disc plays a key role and affects the quality of surface measurement tasks.



Figure 5:- Application of Perthometer M1 on measuring pieces [8].

The diagrams of the individual forces F_x , F_y , and F_z are given in Figure 6.















g) type X + Zr + Te

h) type X + B + Zr + Te

Figure 6:- Diagrams of the individual forces F_x, F_y, and F_z for various steel types of X8CrNiS18-9 [8].

The results of the cutting force tests, the resultant forces F_R , are given by diagram in Figure 7.

In the melt microalloyed with only one element, favorable impact on the cutting force, has tellurium. The melts microalloyed with combinations of the two, and with all three alloy elements, the smallest cutting force, and therefore the best machinability, showing melt microalloyed with zirconium and tellurium, that and overall, is the best variant in terms of cutting forces.

Zirconium microalloyed melt slightly increases the cutting force, while microalloyed with boron and tellurium has by far the highest value of the cutting force, therefore the most negative effect on machinability. All other variants reduce the value of the cutting force, and this has a positive effect on machinability compared to the melt without the addition of alloying elements.



Figure 7:- Diagram of the resultant forces F_R for various steel types of X8CrNiS18-9 [8]

The results of the surface roughness test, the roughness parameters R_a for various steel types of X8CrNiS18-9, are given by diagram in Figure 8.



Figure 8:- Diagram of mean arithmetic deviations of profile height R_a for various steel types of X8CrNiS18-9 [8].

When we analyze the influence of microalloying elements on surface roughness, ie. the mean arithmetic deviation of profile height R_a , as its reference parameter, we can conclude that in the melts microalloyed with only one element,

the most favorable effect was observed in the melt microalloyed with tellurium. In melts microalloyed with combinations of two and with all three alloying elements, the most favorable effect was observed in the case of melt microalloyed with all three alloying elements.

The melt microalloyed with boron and the melt microalloyed with boron and tellurium have a marked increase in surface roughness (parameter Ra), so it can be concluded that the most negative effect was observed in melt microalloyed with boron and tellurium. All other variants reduce the value of the parameter Ra (surface roughness), which has a positive effect on machinability compared to the melt without the addition of alloying elements.

Conclusions:-

The aim of this work is to determine the influence of microalloying with boron, zirconium and tellurium on the cutting force and roughness of austenitic stainless steel X8CrNiS18-9.

The smallest cutting force, and therefore the best machinability, showing the melt microalloyed with zirconium and tellurium, and that is the best variant in terms of cutting forces.

The best variant in terms of reduction of surface roughness represents the melt microalloyed with tellurium.

Addition of tellurium improves the globularization of nonmetallic inclusion of X8CrNiS18-9 austenitic stainless steel and improves the machinability of stainless steel, and its addition also leads to decrease of the surface roughness.

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