INFLUENCE TRAVERSE SPEED ON SURFACE QUALITY AFTER WATER-JET CUTTING FOR HARDOX STEEL

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Abstract

In this study, the effect of different traverse speed of abrasive water jet (AWJ) on HARDOX 400 steel was experimentally investigated. In the experiment five different traverse speeds of 20, 40, 60, 80 and 100 mm/min were used. After the cutting the qualitative aspects, especially surface roughness and the analysis of 3D surface topography, were measured. The experiment was carried out on the water-jet machine with pump power of 18.5 kW generating working pressure 280 MPa. Few well-known relations have been proven. First of all, the growth of all surface roughness parameters with increasing traverse speed has been observed. Another relation is that the smallest values of surface roughness parameters are obtained for profile close to the upper edge cutting surface. On the contrary, the profile close to the bottom edge is characterized by a significant increase of surface roughness with increasing traverse speed. The smallest declination angle was obtained for the slowest traverse speed. The good cutting quality is associated with a slower traverse speed but longer time of cutting brings higher costs, since the process consumes more water, electricity and abrasive. Therefore, some optimization is suggested to make process sufficiently precise and economic.

Keywords: water-jet cutting, HARDOX steel, surface roughness, 3D surface topography.

1. INTRODUCTION

The paper is aimed at problems of surface quality, the problems studied many times by various research teams all over the world. The first attempts were performed in the nineties of the twenties century [1]. The striation formation process [2] surface roughness [3] and other quality parameters [4] are studied since the beginning of the twenty first century. In spite of the fact that these studies last more than twenty years, the overall results are still insufficient and, therefore, research is opened for further progress. Some mathematical and statistical methods are introduced to the surface quality research since the end of the last decade [5,6]. Simultaneously with the further studies aimed at striations' process formation and the investigation of the consequences of the jet delay and divergence inside the produced kerf [7,8], the knowledge is pushed to the better prediction and control of the abrasive water jet cutting process.

2. EXPERIMENTAL PROCEDURE AND RESULTS

The experiments were performed using water jet APW 2010BB machine, which is located in the Laboratory of Finishing Treatments at the Kielce University of Technology. The process constant parameters are presented in Table 1.

Table 1 The process constant parameters for abrasive water-jet cutting.

Parameter	**Unit**	**Value**
Water pressure	MPa	280
Abrasive mass flow rate	g/min	360

Abrasive material grain size	mm	0.212 (80 mesh India garnet)
Angle of impact	rad	0 (normal to the sample surface)
Stand-off distance	mm	2
Water orifice diameter	mm	0.3
Focusing tube diameter	mm	1.02
Focusing tube length	mm	76

The experiments were performed with various traverse speeds on the same material, which was HARDOX 400 steel with the thickness of 15 mm. The chemical composition of material is presented in Table 2. HARDOX 400 is an abrasion resistant steel with the nominal hardness of 400 HBW. HARDOX represents a combination of hardness and toughness. It's extremely resistant to wear and it is able to perform as a load-carrying part in many applications. This enables new innovative ways of designing steel structures.

Table 2 Chemical compositions HARDOX 400

C	Si	Mn	P	S	Cr	Ni	Mo	B
≤0.15	≤0.7	≤1.6	≤0.025	≤0.01	0,5	0.25	0.25	0.004

In the first stage of experimental work 3D surface topography were measured on non-contact 3D Profiler Talysurf CCI - Lite. The Talysurf CCI Lite is an advanced type of measurement interferometer, which uses an innovative, patented correlation algorithm to find the coherence peak and phase position of an interference pattern produced by precision optical scanning unit. All the samples were measured in three different areas (Fig.1). All measured surface topography areas had the same measured window 4.25 x 1.6 mm. The aim was to show the differences in surface roughness topography depending on the measurement sites.

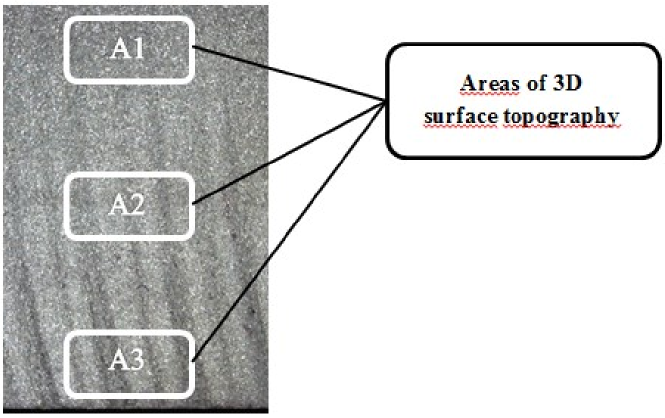

Fig. 1 Three section of surface roughness.

Five basic roughness parameters are compared in this paper, namely *Sa, Sq, Sv, Sp, Sz*. Each area has been thoroughly researched. *Sa* 3D parameter is expanded from the roughness (2D) parameter *Ra* [9]. It expresses the average of the absolute values in the measured area, which is equivalent to the arithmetic mean of the measured region on the three-dimensional display diagram when valleys have been changed to peaks by conversion to absolute values. *Sq* parameter responds to 2D parameter *Rq*. Parameter *Sq* differs from *Sa* as it expresses the root mean squared in the measured area. The valleys have been changed to high peaks by squaring. *Sz* parameter expresses the sum of the maximum value of peak height and the maximum value of valley depth on the surface within the measured area. This is the sum of maximum value of peak heights *Sp* and maximum value of valley depths *Sv* on the surface in the measured area.

The measured characteristics of the surface are summarized in Table 3. Surface roughness parameters (arithmetic mean height *Sa* and root mean squared height *Sq*) were measured for each traverse speed and each measuring area (window). The comparison shows increase of each one parameter with both the traverse speed and depth of jet penetration into material. The measurements are supplied by graphical records of the surface topography (Fig. 2) and the Abbott-Firestone curves with distribution of ordinates for each traverse speed and measures area on the cut wall (see Fig. 3). The characteristic values for these analyses are maximum valley depth *Sv*, maximum peak height *Sp* and maximum height *Sz*. The results are presented in Table 4.

Table 3 Surface roughness parameters, arithmetic mean height (*Sa*) and root mean squared height (*Sq*) (20A1 - measured area A1 for traverse speed 20 mm/min, etc.)

Parameter	20A1	40A1	60A1	80A1	100A1
Sa, μm	3.19	3.72	4.07	4.61	5.57
Sq, μm	4.15	4.73	5.22	5.88	6.97

Parameter	20A2	40A2	60A2	80A2	100A2
Sa, μm	3.13	4.94	6.45	11.80	12.46
Sq, μm	4.02	6.20	8.22	14.10	15.80

Parameter	20A3	40A3	60A3	80A3	100A3
Sa, μm	3.95	7.18	13.88	22.30	33.14
Sq, μm	4.80	8.69	15.91	26.01	38.81

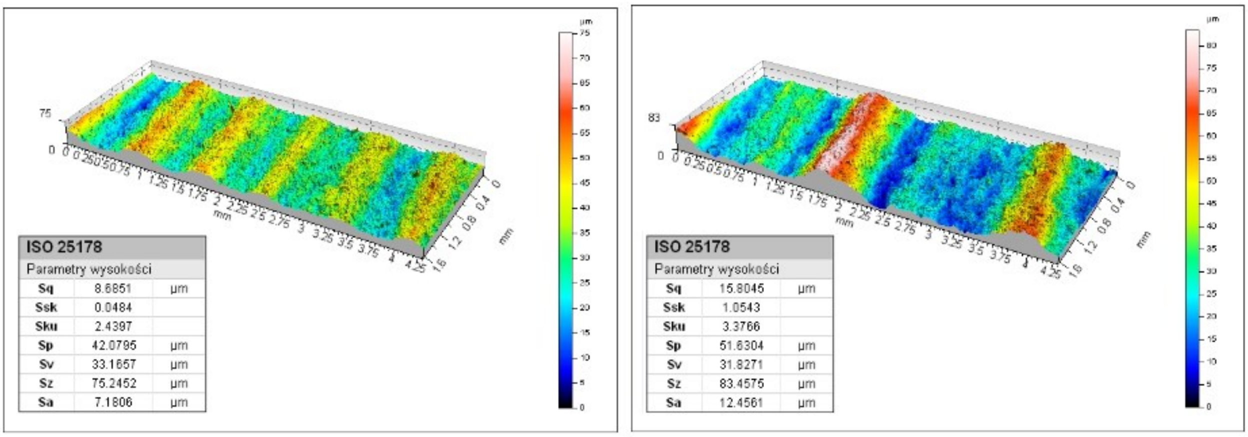

Fig. 2 3D surface topography for traverse speeds a) 40 mm/min (area A3) , b) 100 mm/min (area A2)

Table 4 Surface roughness parameters extended (maximum valley depth *Sv*, maximum peak height *Sp*, maximum height *Sz*): 20A1- traverse speed 20 mm/min for area A1, etc.

Parameter	20A1	40A1	60A1	80A1	100A1
Sv, μm	45.55	30.38	40.77	57.15	51.63
Sp, μm	56.04	48.74	61.55	32.39	32.49
Sz, μm	101.59	79.12	102.32	89.54	84.12

Parameter	20A2	40A2	60A2	80A2	100A2
Sv, µm	49.57	63.14	49.00	46.29	31.83
Sp, µm	26.31	27.70	52.87	39.99	51.63
Sz, µm	75.88	90.84	101.86	86.28	83.46

Parameter	20A3	40A3	60A3	80A3	100A3
Sv, µm	34.64	33.17	85.06	66.96	92.80
Sp, µm	21.70	42.08	79.35	86.22	115.46
Sz, µm	56.35	75.25	164.41	153.18	208.25

The quality of surface can be determined from the *Sz* parameter. If the values are higher the quality is worse, because differences between peaks and valleys (the highest and lowest parts of measured surface) are increasing. The dispersion (variance) of the measured values is a significant parameter (see the bar graphs in Fig. 3) - the narrower the measured distribution the better the surface. It can be observed that in lower parts of the cut walls (close to the bottom of the kerf) the dispersion of measured parameter *Sz* increases dramatically (from about 30 μm near the top to the more than 100 μm). Therefore, the increase of *Sz* over 60 μm is possible to consider as the overcoming of the limit for sufficiently good cutting.

In the second part of experimental work the influence traverse speed on the declination angle has been compared. The angles between the tangents to striations and impinging jet axes are the typical features created by the streams of abrasive water jets. The example of impinging jet axis on the cut walls is presented in Fig. 4. The measurement of the declination angles was performed on the photos of the cutting walls. These “declination angles” can be used for the description of the material cutting parameters. Measured declination angles are shown in the Table 5. The limit for rather good cutting is about 20 degrees. Such declination angle corresponds with the traverse speed being approximately 60% of the limit one for applied water jet characteristics and material thickness and parameters. Therefore, it is possible to determine the limit traverse speed and then control the process through setting of the current traverse speed.

Table 5 Comparison of declination angles determined from direct measurements on cutting edge photos, from regression equation prepared from measured points and from theoretical model before correction and the corrected one

Declination angle	Measured	Regression	Theory	Theory corrected
20 mm/min	8.04	8.00	2.78	5.66
40 mm/min	11.57	11.50	7.86	11.81
60 mm/min	16.08	16.50	14.44	16.97
80 mm/min	23.49	23.00	22.23	22.69
100 mm/min	30.88	31.00	31.07	31.07

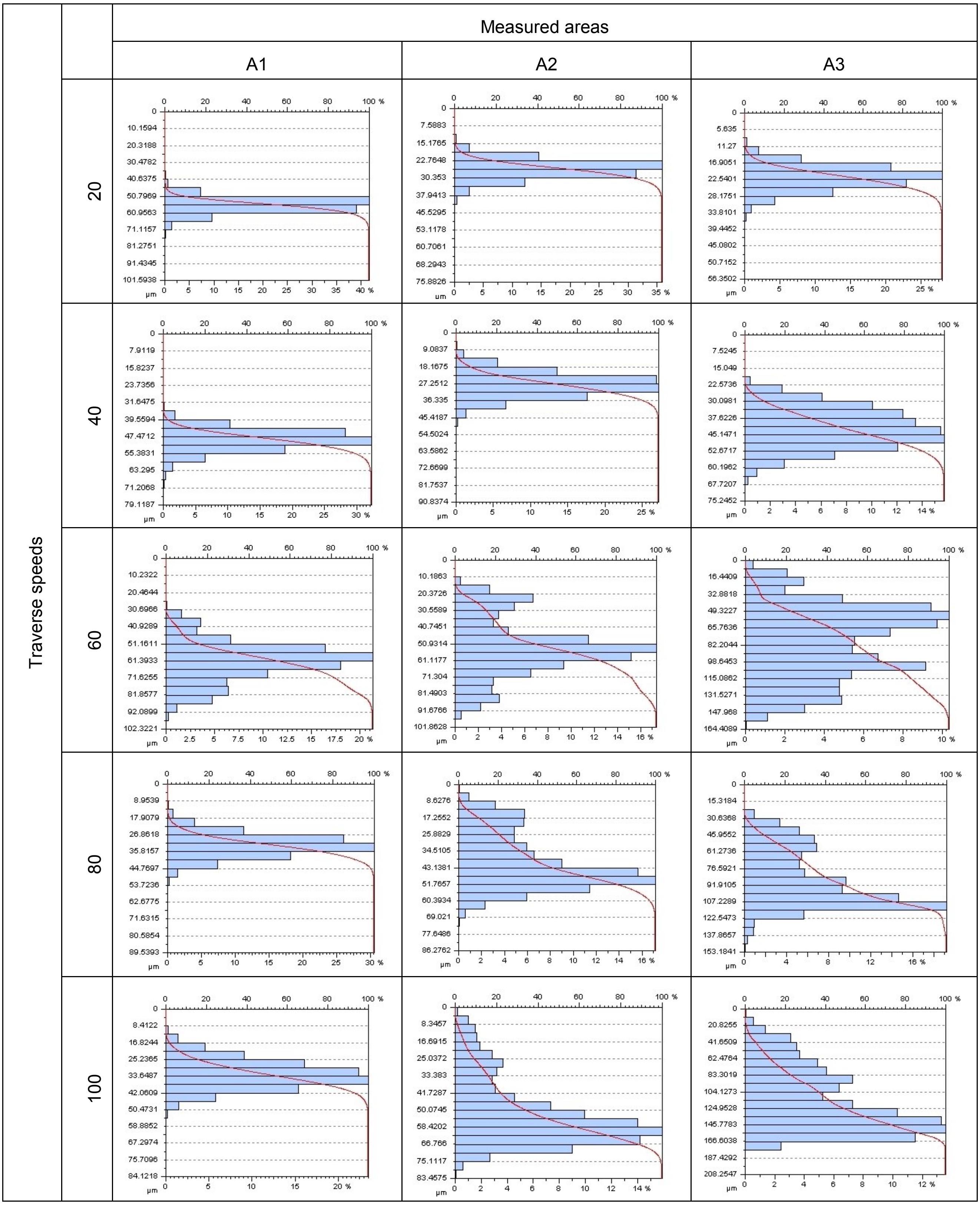

Fig. 3 The Abbott-Firestone curve with distribution of the ordinates for different traverse speeds and measured areas

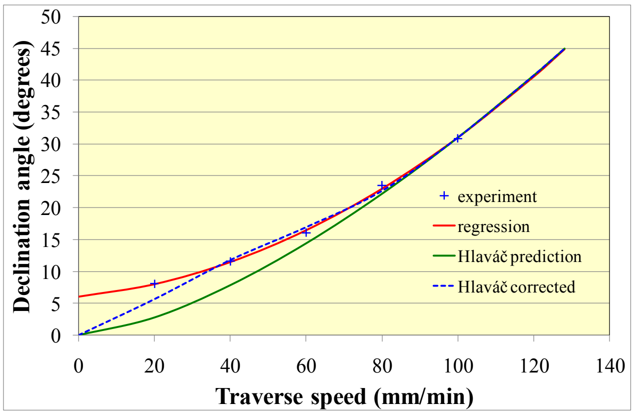

Fig. 4 Comparison of declination angles: measured ones, the ones calculated from regression, the ones calculated from the theoretical model and the ones from the corrected (see [10]) theoretical model.

CONCLUSION

Some new forms of quality evaluation have been presented in this paper. One of them is based on the optical device for surface scanning application and a subsequent determination of the surface quality from measured data. The parameter *Sz*, the total difference of heights in the scanned area, is proved to be a relatively good parameter for quality evaluation. The declination angle of striations is another one, provided that the correction for bigger but slower particles is applied.

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