STUDY ON THE INFLUENCE OF WEDM PROCESSING REGIMES ON THE QUALITY OF ARMOR STEEL

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Abstract: The aim of the current paper is to analyze the influence of process parameters on the dimensional accuracy of parts manufactured by Ramor 550 and Ramor 400 armored steel, using the wire electrical discharge machining (WEDM). Two working regimes were used and the processing quality were quantified by measuring the dimensional accuracy of four parameters (three lengths, an angle and a radius). The obtained results emphasized that working regime 002 leaded to larger dimensional deviations compared to working regime 001. Related to the material, the dimensional deviations were larger in case of Ramor 550 armored steel.

Keywords: WEDM, filiform electrode, dimensional precision, hardness of the surface, deviation, shielding steel

1. INTRODUCTION

The wire electric discharge machine (WEDM) process is extremely used in the manufacture of tools, SDVs, molds, punches, stamping dies, die casting dies and injection molds, being increasingly applied for prototyping and small series productions especially in the aerospace and electronics industry.

It is an advanced non-traditional thermal manufacturing technique that is efficient in producing different parts with great accuracy. Possible applications with WEDM are those that process miniature parts, or made of thin or fragile walls, which cannot be processed with conventional technologies, or complicated round or irregular shapes with larger dimensions [1-4].

One of the benefits of this process is that the wire electrode does not touch the workpiece during the process, so there is no physical pressure on the workpiece compared to the grinding stones and the milling cutter. The principle of spark at wire-shaped electrode erosion is practically the same as that of the process a solid-electrode discharge machine (EDM).

In WEDM the conductive materials are processed with a series of electric discharges (sparks) which are precisely produced between the moving filiform electrode and the workpiece. High frequency pulses of alternating or direct current are discharged from the electrode to the workpiece, with a very small spark through an isolated dielectric fluid.

The most important parameters that can make the process unstable, limit the productivity of the WEDM process and have a negative impact on the quality of the machined part are: *peak current (IP), servo voltage (SV), pulse off-time (Toff), and pulse on-time (Ton).*

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2. EXPERIMENTAL SETUP

2.1. Description of equipment used

During the experiments, a WEDM machine of the Sodick AQ535L type electrode, shown in Figure 1, and an OKI OB-25PN filament electrode were used to perform the experimental study.

Fig. 1. Sodick AQ535L used for experiments.

To determine the dimensional accuracy of the parts, a Zeiss Contura coordinate measuring machine was used (Figure 2a) while the hardness of the machined surface was measured with a Proceq Equotip 550 Leeb equipment (Figure 2b).

a. Zeiss Contura coordinate measuring machine [5]

b. Durimeter Proceq Equotip 550 Leeb

Fig. 2. Used equipment for the experimental tests.

2.2. Used materials

RAMOR 400 and RAMOR 550 steels for armour produced by RAMOR - Ruukki Metals Oy, Suolakivenkatu, Finland [6] were used to carry out the experimental study. The materials are used for blast protection in the industry of armored vehicles, weapon systems, and safety structures. The technical characteristics are presented in Table 1. The thickness of the material is 6.7 mm.

2.3. Experimental conditions

The processing regimes recommended by the company producing the equipment (Sodick AQ535L) were used without changing any parameter (Tables 2 and 3) to be able to analyse the processing quality for the two materials.

The first regime 001 is a roughing regime that can be used to process the part and the second regime 002 is a finishing regime. Normally, in order to obtain the best possible roughness and dimensional tolerance, these regimes are used one after the other, first roughing and then finishing.

To perform the experimental study, a shape of the piece was chosen that would include both straight, inclined surfaces and a radius. The shape of the piece and its dimensions are shown in Figure 3.

Table 1. Chemical composition and mechanical properties of the main shield plates Ramor 400 and Ramor 550 [6].

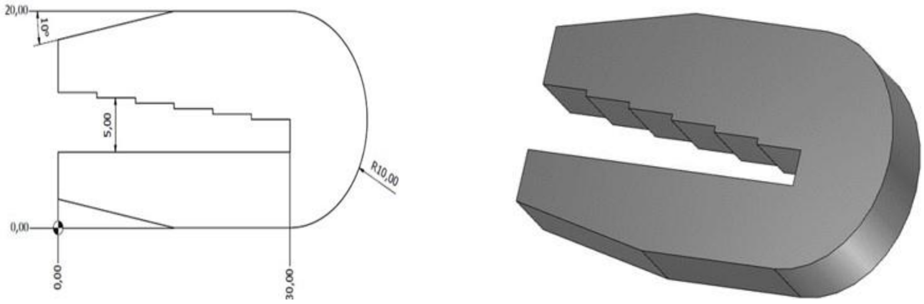
Armor steel	Chemical composition [max%]	Thickness s [mm]	Flow resistance RP02 [MPa]	Breaking strength Rm [MPa]	Hardness [HB]	Elongation A5min [%]	Resilience [Joule]
Ramor 400	C=0.24 Si=0.70 Mn=1.5 Cr=1.0 Ni=1.0 B=0.005	6-30 (6.5)	1100	1300	360-450	8	20
Ramor 550	C=0.36 Si=0.60 Mn=1.0 P=0.012 S=0.003 Al=0.06 Cu=0.3 Cr=1.50 Ni=2.50 B=0.005	3-15 (6.5)	1550	1850	540-600	7	16

Table 2. Parameters considered in the experiments.

Nature	Factor	Symbol	Unit
Input	Pulse on time	Ton	µs
Input	Pulse off time	Toff	µs
Input	Peak current	IP	Amp
Input	Auxiliary power circuit	HRP	Volt
Input	Pulse duration	MAO	µs
Input	Servo voltage	SV	Volt
Input	Main power supply voltage	V	Volt
Input	Servo speed	SF	mm/min
Input	Radius correction of the filiform electrode	OFFSET	mm

Table 3. Processing conditions and parameters values used in the experiments.

Wire electrode diameter: ϕ 0.25										
Regime	Ton (µs)	Toff (µs)	IP (A)	HRP (V)	MAO (µs)	SV (V)	V (V)	SF (mm/min)	OFFSET (mm)	Velocity (mm/min)
001	004	024	2215	000	290	035	6	0110	0.224	09.2 ~10.5
002	000	023	2215	000	750	048	8	6100	0.224	12.0 ~13.5



a. dimensions of the machined part b. 3D part

Fig. 3. Shape and dimensions of parts used for the experimental tests.

The dimensions of pthe art that were measured are the following: l1 - size 20 mm (inclination length), angle 10˚, l2 - size 5 mm, l3 - size 30 mm and radius R10.

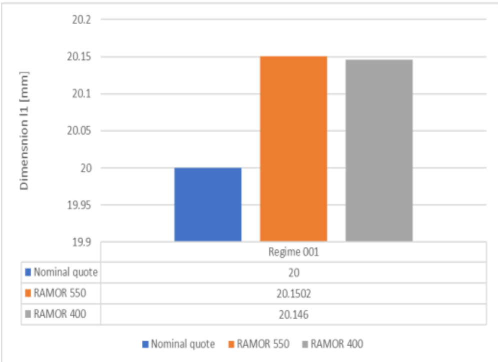
3. RESULTS AND DISCUSSION

3.1. Determining the dimensional accuracy of machined parts

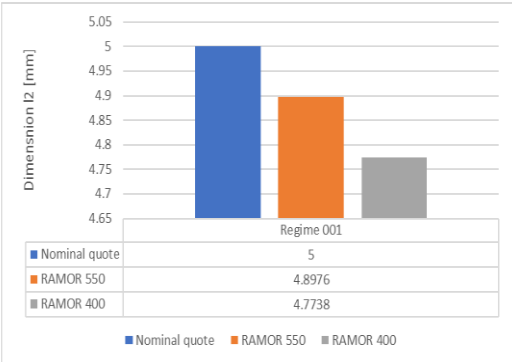
After performing the experimental study on the processing of Ramor materials by WEDM, the obtained parts were measured by using the Zeiss Calypso program of the coordinate measuring machine. The parts were measured at the same reference point without positioning errors.

The processing quality of parts was quantified by measuring the dimensional accuracy of four parameters (three lengths, an angle and a radius).

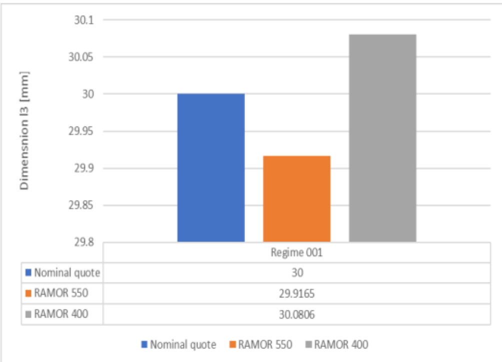
The graphical representations of the measured dimensions for both materials (Ramor 550 and Ramor 400), processed with regime 001, are presented in Figure 4.



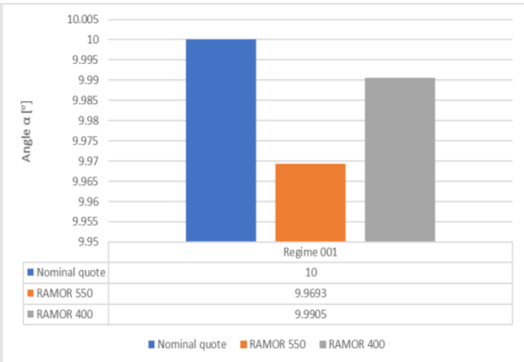
a. dimension l1



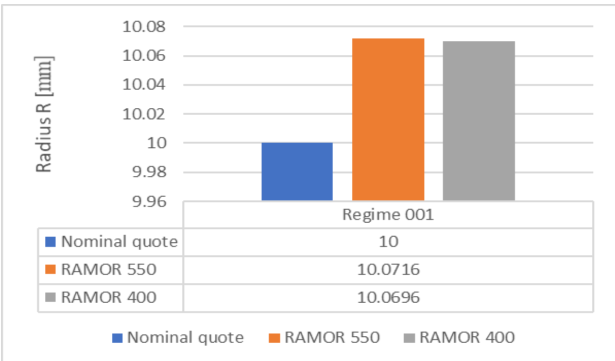
b. dimension l2



c. dimension l3



d. dimension of angle α

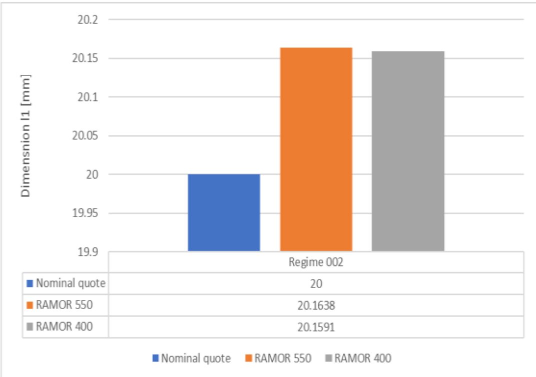


e. dimension of radius R

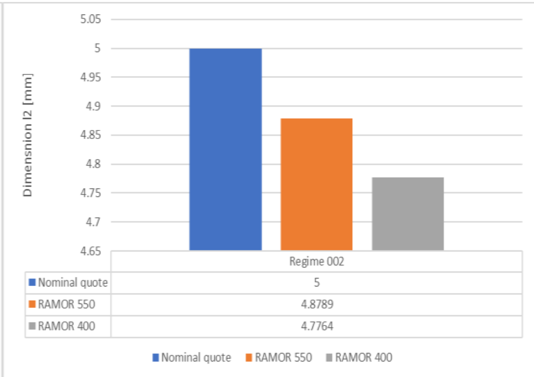
Fig. 4. Dimensional accuracy of parts processed with the 001 working regime.

Related to the l1 dimensions, it can be seen that, when processing the Ramor 550 material, a slightly bigger deviation from the nominal size was obtained compared to the other material. In both materials the deviation from the nominal size (20 mm) is positive. As concern the l2 dimension, it is observed that a deviation from the nominal quota was obtained, for both materials. In the case of the l3 dimension, the deviation was bigger than the nominal value for the Ramor 400 steel and smaller than the nominal value for the Ramor 550 steel. The size of the angle α resulted in smaller than the nominal quote, for both materials, with a bigger deviation in the case of the Ramor 550 material. The processed R radius resulted in bigger than the nominal quote for both materials.

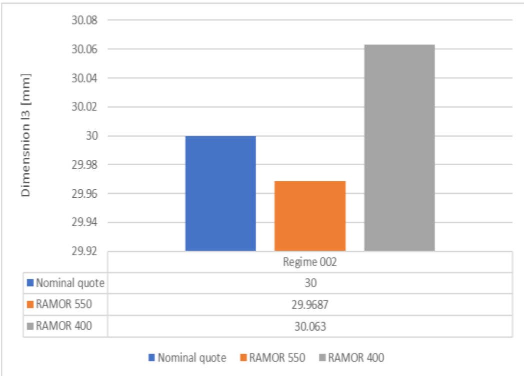
The graphical representations of the measured dimensions for both materials (Ramor 550 and Ramor 400), processed with regime 002, are presented in Figure 5.



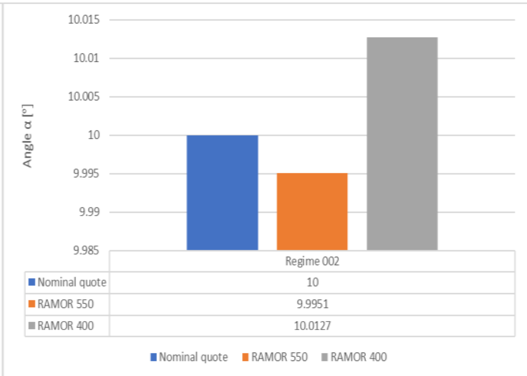
a. dimension l1



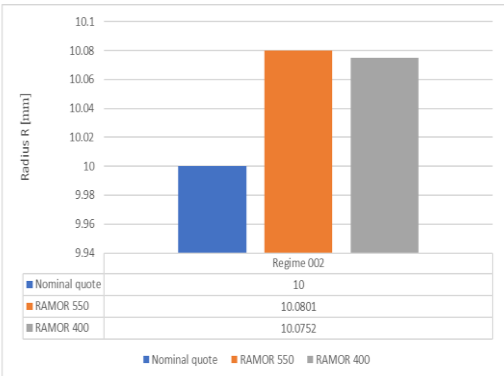
b. dimension l2



c. dimension l3



d. dimension of angle α



e. dimension of radius R

Fig. 5. Dimensional accuracy of parts processed with the 002 working regime.

By analyzing the graphs, it can be seen that the dimensions l1, l2 and l3 have a similar variation tendency as for regime 001. As concern the angle α, the processing of Ramor 550 and Ramor 400 materials with regime 002 led to a size closer to the nominal size. In the case of Ramor 400 material, the size is larger than the nominal size resulting in a positive deviation. The size of the radius R has the same tendency as in case of regime 001 for both materials, being larger than the nominal size.

3.2. Determination of the hardness of the processed surface

At first the hardness of the materials was measured with Durimeter Proceq Equotip 550 Leeb equipment and then the hardness of the machined side surface of the parts for both materials was measured. The results obtained for the hardness of parts are presented in Table 4. It can be observed that the hardness decreases after the processing by WEDM and the tendency is similar in the case of both materials.

Table 4. Hardness of the processed surfaces.

Armor steel	Initially hardness (HV)	Regime 001	Regime 002
Ramor 550	462 HV	172,8 HV	169,5 HV
Ramor 400	398 HV	137,3 HV	122,1 HV

3.3. Discussion

The experimental study on the wire EDM processing of RAMOR 550 and RAMOR 400 materials, highlighted the following aspects:

- In the case of dimensional accuracy, for dimension l1 the dimensional deviations are positive and increase at regime 002 compared to regime 001 in the case of both materials but they are almost insignificant. For l2 the dimensional deviations are large and out of tolerance due to the fact that in both processing regimes the OFFSET of 0.224 was used. These are negative and are higher for Ramor 550 material in both processing regimes. For l3 the dimensional deviations are positive for the Ramor 550 material in the case of both processing regimes and negative for the Ramor 400 material in the case of both processing regimes. In the case of the angle α, of 10˚, the dimensional deviations are larger at the processing mode 002 than at the processing mode 001, and the deviations of the Ramor 400 material are larger than those of the Ramor material 550. The dimensional deviations for R10 are larger in the case the processing regime 002 compared to the regime 001 and the deviations of the Ramor material 550 greater than those of the Ramor material 400.
- In case of hardness, wire EDM machining decreases the initial hardness of the part, but this decreases more when the 002 regime is used, the finishing regime compared to 001, the roughing regime.
- In the case of processing times, they increase with the modification of the processing regime as well as the hardness of the material, so that in the case of Ramor 550 material, the part processed with regime 001 (roughing) lasted 1h and 10min and the processed one with regime 002 (finishing) 3h and 10min. In the case of Ramor 400 material, the part processed with regime 001 (roughing) lasted 1h, and the one processed with regime 002 (finishing) 2h and 15min.
- During the process of cutting with WEDM, the surface layer will be damaged by heat, internal stress or other factors. The Ramor materials are hardened steels and it is known that improper cutting parameters can affect the surface of the material, due to the processing temperature and the dielectric environment in which the part is processed, the depth of the heat affected layer can be up to 0.4mm.

4. CONCLUSIONS

After analysing the influence of the working regime (001 and 002), it was deduced that in this process a very good dimensional accuracy can be obtained, for example, the smallest deviation from the nominal elevation was 0.0045mm. The working regime 002 leaded to larger dimensional deviations compared to the working regime 001.

Related to the material, the dimensional deviations were larger in case of Ramor 550 armored steel. In the case of hardness, the WEDM process decreases the initial hardness of the parts and in the case of processing times, they increase with the modification of the processing regime.

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