ANALYSIS AND OPTIMIZATION OF CUTTING PARAMETERS IN DRILLING OPERATION OF EM AW-2007ALUMINUM ALLOY

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***ABSTRACT**: The present work aims to analyze the drilling process of a difficult to cut EN AW-2007aluminum alloy. Traditionally, the machinability of materials involve tool life, cutting forces, surface quality and productivity or chip form, In this work, the authors address the machinability of aluminum alloys including surface roughness, form and dimensional deviations and segmentation, and chip forms. Two parameters, spindle speed and feed, has been taken as control factors. The cutting trials were performed as per Taguchi method to deal with the response from multi-variables using Design Expert soft ware. The Analysis of Variance was carried out to find the significant factors and their individual contribution in the response function i.e. surface roughness, form and dimensional deviations. Additionally the influence of the cutting condition on the chips morphology has been studied.*

***KEYWORDS**: drilling, cutting parameters, aluminum alloyed, surface quality, chip form, ANOVA.*

1 INTRODUCTION

The use of materials with low specific weight is an effective way of reducing the weight of structures. Aluminum alloys are among the most commonly used lightweight metallic materials as they offer a number of different interesting mechanical and thermal properties. In addition, they are relatively easy to shape metals, especially in material removal processes, such as machining. In fact, aluminum alloys as a class are considered as the family of materials offering the highest levels of machinability, as compared to other families of lightweight metals such as titanium and magnesium alloys. The machinability quantifies the machining performance, and may be defined for a specific application by various criteria, such as tool life, surface finish, chip evacuation, material removal rate and machine-tool power. It has been shown that chemical composition, structural defects and alloying elements significantly influence machinability as Konig et al (1983), Andren et al (2004) and Trif et al (2015) demonstrated.

In normal machining operations and, generally, in the manufacturing industry the metal working fluids are still used widely to cool and to lubricate the contact area between work piece and tool. Therefore the cutting fluid can be considered one of the factors that influence the metals cutting process having an important influence on productivity, safety and economy of cutting operations.

Singh et al (2016) have evaluated the performance evaluation of aluminum 6063 drilling under the influence of nano fluid minimum quantity lubrication. In other studies performed (Davoodi et al., 2014), (Bordin et al., 2014), the influence of lubrication and cooling technique on process performance has been analyzed by cutting of several materials using coated or uncoated inserts.

Mahadi H. et al (2017) have analyzed the modern advancements in micro drilling techniques. Some other researchers like Ratna Sunil B., et al. were focused on effect of aluminum content on machining characteristics of AZ31 and AZ91 magnesium alloys during drilling.

The development of aluminum alloys is often conditioned by aeronautical requirements, but aluminum is very interesting for several applications in other sectors. Depending on the nuances, the composition, the treatments and the cutting conditions of these alloys, the material can be classified according to its machinability, recyclability, energy consumption and particle emissions.

Drilling is one of the important machining operations used in the industry. Selection of correct combination of cutting parameters will help to complete the operation in minimum possible time maintaining the required surface quality. The basic objective of this research work is to find the optimized combination of cutting parameters to achieve the best surface quality in drilling operations of aluminum alloys.

Surface quality in drilling is the function of the various factors such as speed, feed, depth of cut, work piece material, tool geometry, work hardness, tool nose radius, stability of machine tools, and cutting fluids. Many researchers have studied the effect of these parameters on the surface quality. Kirby et al (2006) has investigated the effect of speed, feed, depth of cut and tool nose radius on the surface finish of the steel components. Marigoudar and Sadashivappa (2014) have investigated the effect of tool material on the surface finish of the cast iron components. The effect of varying cutting speed on the surface finish due to formation of the built-up edge is investigated by Jin and Liu (2012). Sundaram and Lambert (1984) have studied the effect of speed, feed, and depth of cut, cutting time and tool coating and used multiple regression technique to develop mathematical model.

A number of experimental and analytical studies have done regarding tool vibrations in turning. The higher values of the speed gives better surface finish for the other parameters to be constant has proved through the experiments by Sundaram et.al. (1984) have studied the effect of speed, feed, depth of cut, cutting time and tool coating and used multiple regression technique to develop mathematical model.

Similar kind of study has been carried out by Mital and Mehta (1988) in which they developed the surface finish prediction model as a function of cutting parameters for each individual metal.

They have generated the surface finish data for aluminum alloy 390, ductile cast iron, medium carbon leaded steel 4130 and Inconel 718 alloy for a wide range of machining conditions.

The aim of this to analyze the influence of the cutting parameters and select the combination of optimum cutting parameters which will result in better surface quality in aluminum alloys drill operations.

2 MATERIALS, METHODS AND EXPERIMENTS DESIGN

The experimentation was carried out HAAS VF 2 CNC, available in workshop of Manufacturing Engineering Department.

The vertical machining center used during the experiments has the following technical data: traverse paths of 762 x 406 x 508 mm, SK-40 spindle, 20 PS vector drive (14.9 kW), 7,500 rpm, tools magazine with 20 locations, rapid traverse up to 25.4 m·min^{-1}), and a 208-liters cooling system with continuous coolant supply.

An EN AW-2007 blank with the following dimensions 200x50x50 was used as work piece. The mechanical and chemical properties of EN AW 2007 aluminum alloy are given in Table 1.

Table 1. Properties of EN AW-2007 aluminum alloy

Property	Indications [unit]
Alloying elements of EN AW-2007	AlCu4PbMgMn
Hardness grad	T4, T4510
Tensile yield Rp0,2	210 – 250 [MPa]
Tensile strength	330 – 370[MPa]
Elongation	6 – 8[%]
Hardness HB	95 [2,5/62,5]
Density	2.85[g/cm³]
Young's modulus	~ 70[GPa]

Figure 1 shows the experimental set-up during the drilling process.

Figure 1. Drilling operation of EN AW-2007 on HAAS VF 2

For the experiments, it was used a helical drill ϕ10.2 mm of carbide with cooling channels and point angle 140° from Gühring (Code RT 100U) with a 4318 tool holder (DIN 6535-HA). The cutting parameters which have been taken into account and their levels of variation are given in Table 2.

Parameters	Variation levels	
	Minimum	Maximum
Depth of cut, a_p [mm]	5.1	
Feed, f [mm·rev^{-1}]	0.04	0.4
Cutting speed, v_c [m·min^{-1}]	75	110

Tabel 2. Cutting parameters variation

The experimental results have been analyzed and interpreted using Design Expert software, Response Surface Methodology (RSM) and Analysis of Variance (ANOVA).

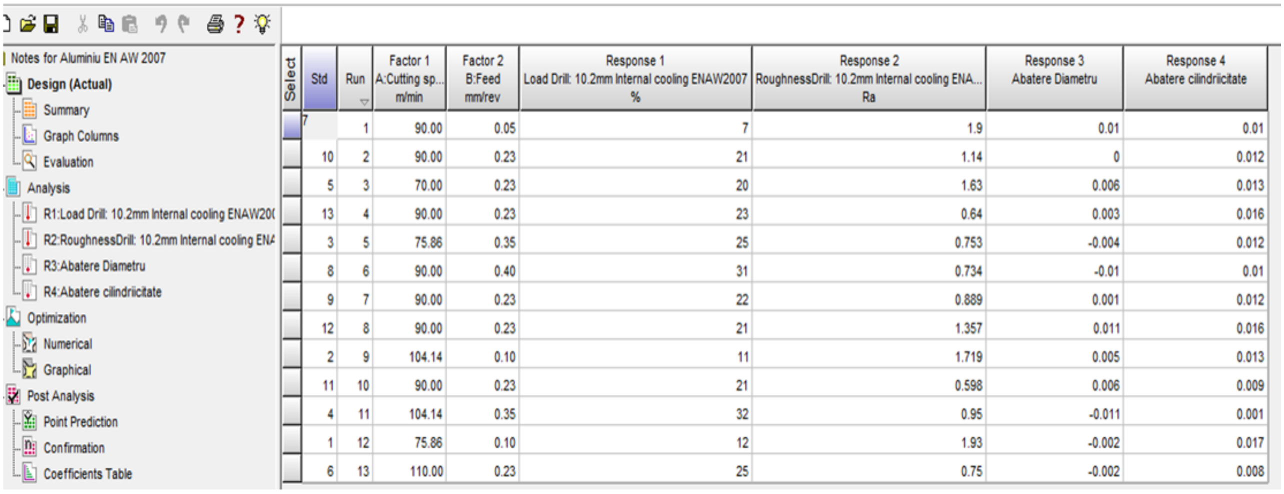
These methods are statistical and mathematical techniques used improving processes in situations where some input independent variables could influence some output variables (responses).The responses can be the quality or performance characteristics of the process.

By such statistical modeling methods, approximating relationships between the responses and the independent variable of the process can be developed. Design Expert software offers also an optimization tool which was applied for finding the best combination of the process variables producing desirable responses (Myers, 2009).

As mentioned before, the number of experiments required to model the response functions can be significantly reduced by using RSM

Considering the Design Expert software suggestion, the orthogonal array (L13) was chosen as there are two control parameters with each having two levels.

Total 13 runs were conducted during one trial. Trials were repeated to check the consistency in the output. L13 orthogonal array is displayed in Figure 2, together with the parameter values of the analysis.



Select	Std	Run	Factor 1 A:Cutting sp... m/min	Factor 2 B:Feed mm/rev	Response 1 Load Drill: 10.2mm Internal cooling ENAW2007 %	Response 2 RoughnessDrill: 10.2mm Internal cooling ENA... Ra	Response 3 Abatere Diametru	Response 4 Abatere cilindriicitate
	7	1	90.00	0.05	7	1.9	0.01	0.01
	10	2	90.00	0.23	21	1.14	0	0.012
	5	3	70.00	0.23	20	1.63	0.006	0.013
	13	4	90.00	0.23	23	0.64	0.003	0.016
	3	5	75.86	0.35	25	0.753	-0.004	0.012
	8	6	90.00	0.40	31	0.734	-0.01	0.01
	9	7	90.00	0.23	22	0.889	0.001	0.012
	12	8	90.00	0.23	21	1.357	0.011	0.016
	2	9	104.14	0.10	11	1.719	0.005	0.013
	11	10	90.00	0.23	21	0.598	0.006	0.009
	4	11	104.14	0.35	32	0.95	-0.011	0.001
	1	12	75.86	0.10	12	1.93	-0.002	0.017
	6	13	110.00	0.23	25	0.75	-0.002	0.008

Figure 2. Ortogonal L13 array and experimental results

3 RESULTS AND DISCUSSIONS

As can be seen in Figure 4, diameter deviation increases along with the two cutting parameters, cutting speed and feed.

The software also provides the analytical model, which can also be used to determine the values of the analyzed quality parameters for each combination of the cutting parameters. Analytical correlation of diameter deviation with cutting parameters considered is given by the equation (1):

$$d_{dev} = 0.02052\text{-}1.414\cdot 10^{-3}\cdot v_c\text{-}5.786\cdot 10^{-3}\cdot f \qquad (1)$$

The circular deviation increases along with the cutting speed and decreases as the value of the feed increases (Figure 5). Analytical correlation of circular deviation with cutting parameters considered is given by the equation (2):

$$form_{dev} = 0.0328\text{-}1.9508\cdot 10^{-3}\cdot v_c\text{-}5.786\cdot 10^{-3}\cdot f \qquad (2)$$

3.1 Machine load

The main influencing parameter is the feed. The load increases in direct proportion to the feed rate and the cutting speed. Analytical correlation of machine load with cutting parameters considered is given by the equation (3):

$$Load_{machine}=24.6163\text{-}0.3778\cdot v_c\text{-}9.4880\cdot f\text{-}1.1428\cdot v_c\cdot f+1.13\cdot 10^{-3}\cdot v_c^{2}\text{-}97.1428\cdot f^{2} \qquad (3)$$

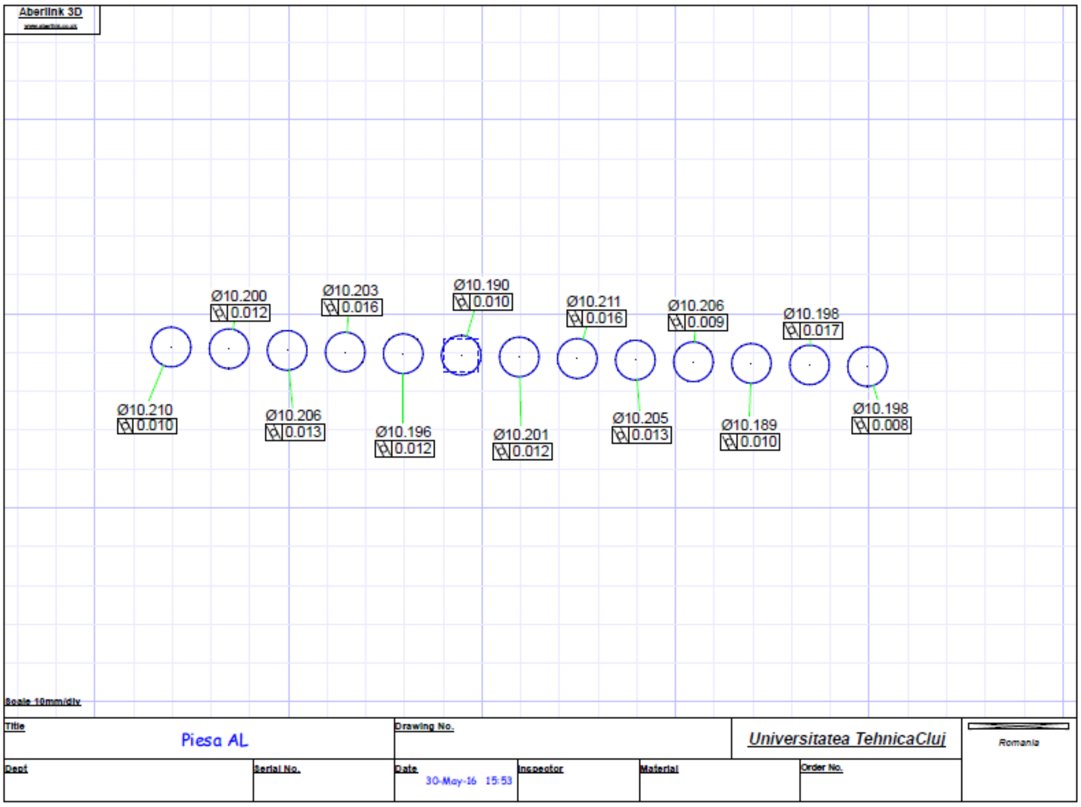


Figure 3. Form and diameter deviations

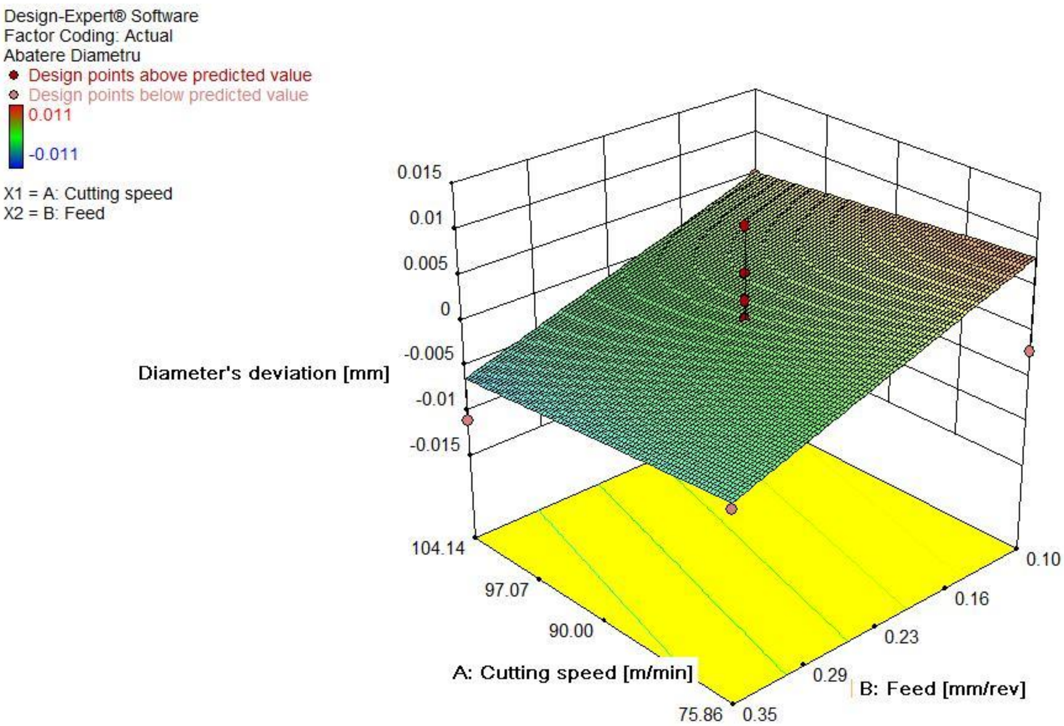


Figure 4. 3D model graphs of diameters' deviations variation

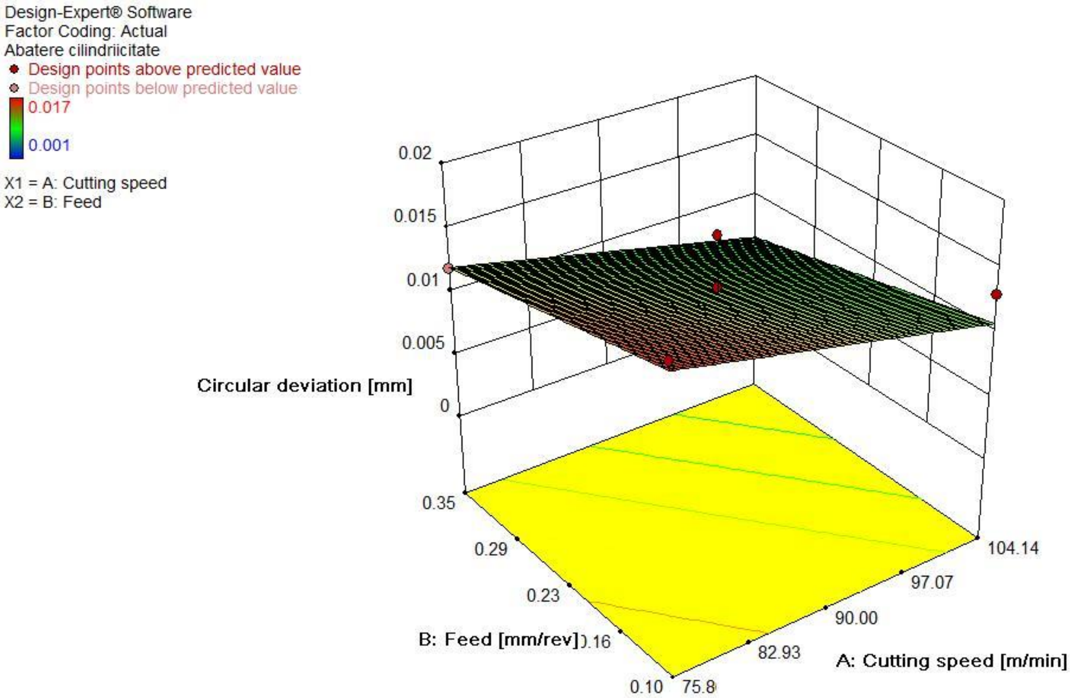


Figure 5. 3D model graphs of circular deviations variation

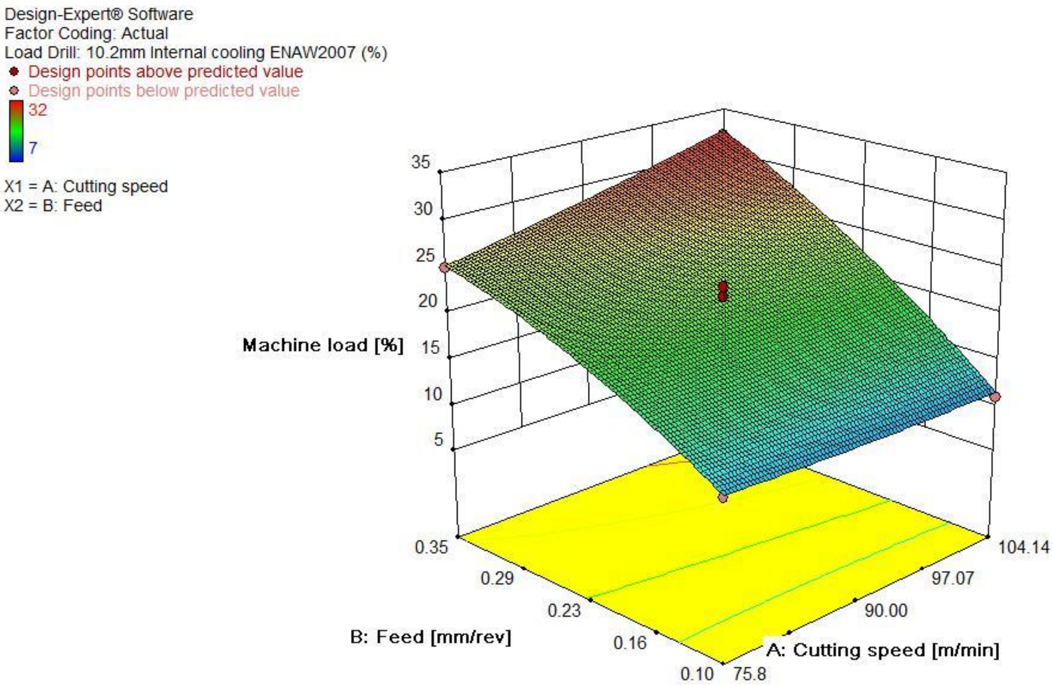


Figure 6. 3D model graph for machine load variation

3.2 Surface roughness

Quality of machined surfaces has been measured with the surface roughness tester Mitutoyo SJ201. Three common parameters have been measured: R_a - arithmetic average of absolute roughness profile; R_z - average length between the lowest valleys and the highest peaks of roughness profile for sampling lengths considered; R_q - root mean squared of surface profile.

Each roughness in Table 3 represents a mean value of tree measurements done for each surface. In the next section only R_a is discussed, since the other parameters (R_q, R_z) are considered to provide similar information on surface profile like R_a.

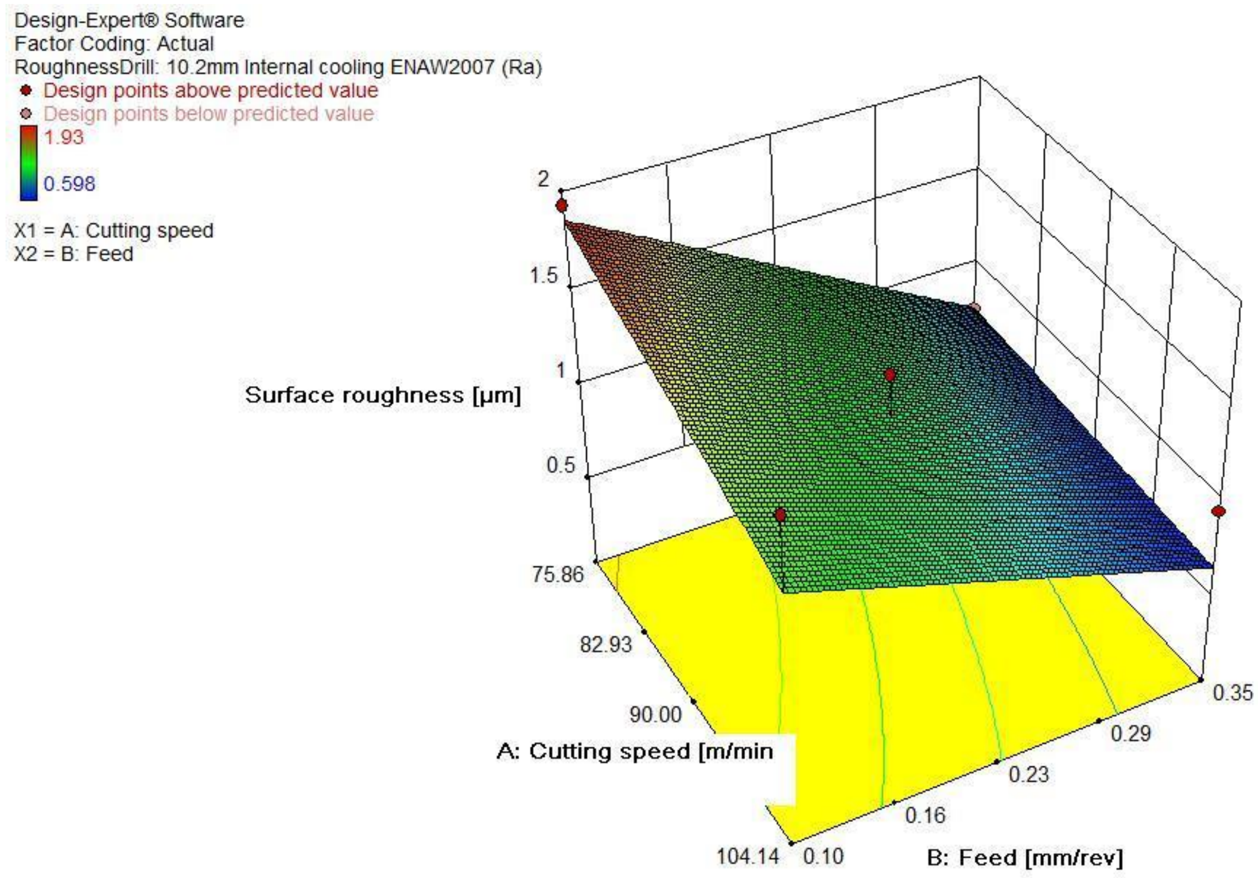


Figure 7. 3D model graph from the roughness variation

The surface roughness is slightly declining when increasing the cutting speed and increases significantly with the feed (Figure 7).

The roughness has mild retrograde tendencies in increasing the cutting speed and increases greatly.

Analytical correlation of surface roughness with cutting parameters considered is given by the equation (4):

R_a=4.1515–0.0242·v_c–8.8771·f+0.0582·v_c·f (4)

3.3 Cutting parameters optimization

From the Design Expert software, Optimization feature was chosen so that the ideal cutting parameters to be further determined. Figure 8 shows the way in which the optimization criteria were established: minimum for roughness, maximum for load, the value of "zero" for diameter and circular form deviations.

Figure 9 shows the optimum solution, which combination of the process parameters values (v_c - cutting speed and *f* - feed rate) should be selected, in order to obtain the best results for drilling the EN AW-2007 aluminum alloy.

As it can be seen, the best parameters combination of cutting speed 104.14 m·min^{-1} and feed 0.31 mm·rev^{-1}, it drives to a machine load of 30%, roughness of 0.755 µm, diameter deviations of 0.004 mm and circular deviations of 0.007 mm.

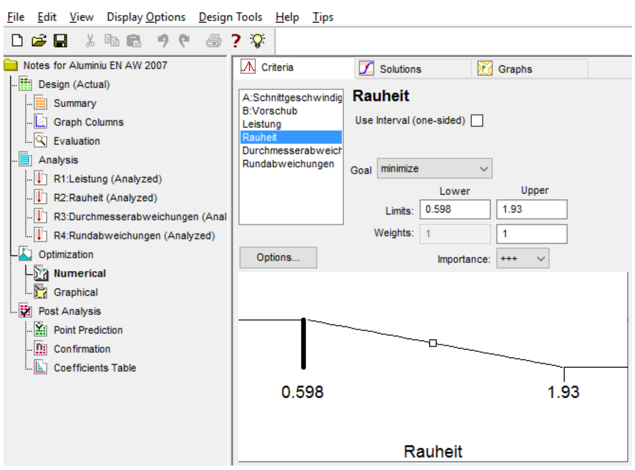


Figure 8. Optimization criteria

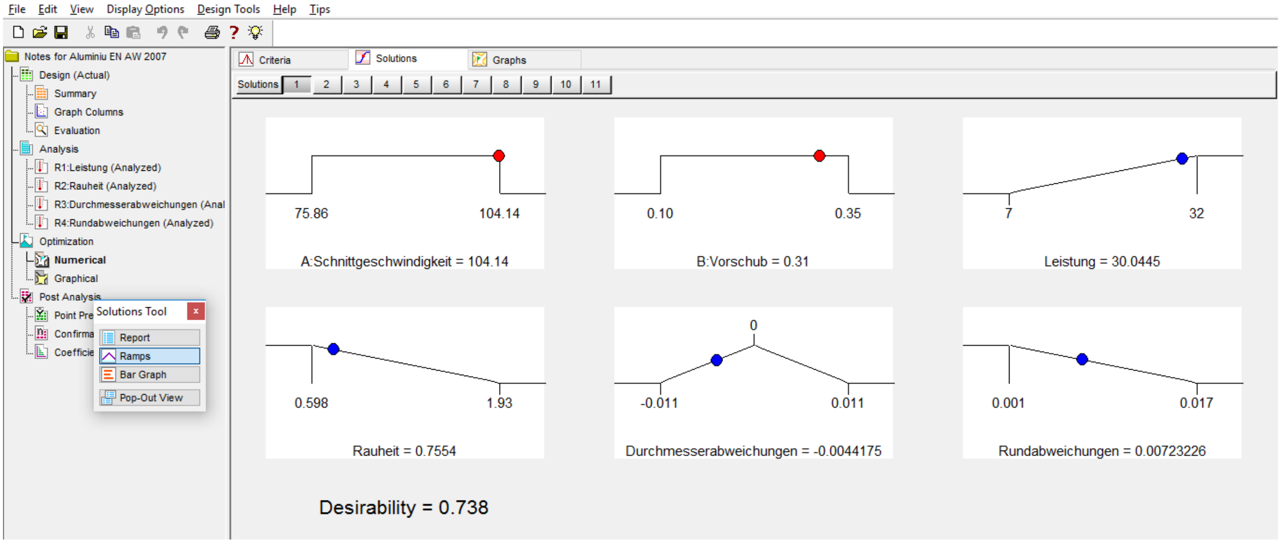


Figure 9. Optimization solution

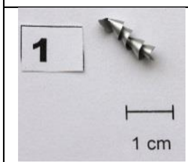
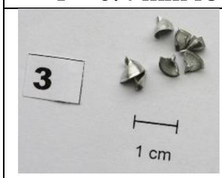
3.4 Chips formation and morphology

To analyze chip segmentation and shape, steel chips were collected after each trial. Different chip types of various shape size and color were produced. Generally, discontinuous chips are desired because they are less dangerous for the operator, and do not damage work piece surface and machine tool. On the other side, these can be easily removed from the work zone, and can be easily handled and disposed.

Production of favorable discontinuous chips is possible by the following principles: proper selection of cutting conditions (e.g. cutting speed, feed rate, material and geometry of the cutting tool), use of chip breakers, work material properties, and selection of machining environment that influence temperature and friction at the chip-tool-part interfaces.

The resulting chips during processing of the EN AW-2007 aluminum alloy, with a drill (code RT 100U have been analyzed for three variation levels of the feed rate by considering a constant cutting speed of v_c =104 m·min^{-1} (Table 3).

Table 3. EN AW-2007 chips types using different feed rates and constant cutting speed

f = 0.04 mm·rev^{-1} => long-spiral shaped chips		
		
f = 0.25 mm·rev^{-1} => fragmented chips		
		
f = 0.4 mm·rev^{-1} => short fragmented chips		
		

Due to the need for machining systems automation, the most desired chip form is loose arcs and short helical segments. Because of tangling around the tool and work piece and removing difficulties from the cutting area, the helical tubular chips or washer long type is less desired.

4 CONCLUSIONS

This study presents an efficient method for determining the optimal turning operation parameters for surface roughness under varying conditions through the use of the Taguchi parameter design process. The study shows that the control factors had varying effects on the response variable.

The use of the Taguchi parameter design method was considered successful as an efficient method to optimize machining parameters in a drilling operation which will tend to reduce the machining time and enhance the productivity.

Related to the chips morphology and formation, the fragmented chips are the preferred ones. These were obtained in the cases of the processing with a large value of feed. Obtaining the desired chip shapes is got by the use of the parameters determined by drilling process optimization. Other factors influencing the process of chip formation are: technological aspects of the material, material and geometry of the cutting tool.

To get a chip form that is easier to remove from the cutting zone is recommended to increase the feed rate and depth. Since the cutting speed needs to be high in order to achieve the desired surface roughness and process productivity, the control of chips formation can be done by choosing appropriate values of cut depth and feed rate.

5 ACKNOWLEDGEMENTS

This research paper is based upon work supported by Romanian National Authority for Scientific Research and Innovation, CNCS/CCCDI–UEFISCDI under Grant No. PN-III-P2-2.1-BG-2016-0216, within PNCDI III.

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