Contribution on Taguchi’s Method Application on the Surface Roughness Analysis in End Milling Process on 7136 Aluminium Alloy

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Abstract. The resulting surface quality after the cutting process is one of the most important characteristics of product quality and also the most frequent customer requirement. Previous research was focused on the effect investigation of machining parameters: cutting speed [1] and feed per tooth [2] on surface roughness. This paper is in itself a continuation of a previous research [3], in which, with Taguchi’s method it was determined the level of influence of the cutting parameters on surface roughness of 7136 aluminium alloy in end milling process. The purpose of this paper is to highlight the importance of Taguchi’s method use to analyse the surface roughness of 7136 aluminium alloy in end milling process. To conduct the experiments, three cutting parameters were used: cutting speed, feed per tooth and cutting depth. To analyse the surface quality, the surface roughness Ra (the arithmetic average of the absolute values) was measured. It was determined the recommended configuration regarding the optimum values of each machining parameter and the interactions between them, in order to obtain the better cutting process performance and to reduce the surface roughness sensitivity to uncontrollable factors. Based on a full factorial experiment were confirmed the obtained results by applying the Taguchi’s method. Final results are a starting point for further research.

1. Introduction

Both national and international researchers are conducting experiments in almost all fields of research, having the purpose to identify some particular aspects of processes and systems. Literally every experiment is a test. A designed experiment could be defined as a test or series of tests, in which can make changes on the input variables of a process or system, so that through their influence on the process/system, we can identify the reasons for the occurrence of changes which can be seen from the results [4].

Therefore, a mathematical model can be developed which is aimed at achieving these results by the most important input variables and then use this model in the process or system in order to improve taking other decisions. Due to the need of identifying the optimal values of the cutting regime parameters, which affects the end milled surface quality, it was imposed to carry out some research based on experimental plans method. In this research, the construction of experimental plan will be conducted using the Taguchi’s method. The argument for this choice is that, G. Taguchi propose a systematic and effective method for conducting the experiment, a method which leads to a proper solution in terms of performance and cost [3].

The proposed method uses an experimental orthogonal matrix which allows to divide the experimental space and also to select an experimental design matrix which contains a large number of
variables, with a few experiments. Basically, this method allows to make a smart selection in the experimental field of an experimental parameters subset, which allow to study the entire experimental space with a minimum number of experimental determinations. [5], this paper is a continuation of a previous research on the application of Taguchi method in the study of the cutting parameters influence over the surface quality, whose results were published in [3]. Similarly identified research was carried out by: [6] which was focused on the optimization of the cutting regime parameters using the Taguchi’s method on the turning process of 6061 aluminum alloy, and [7] which has the main objective to optimize the process parameters to obtain a better surface roughness on the turning process of 7075 aluminum alloy. Others research in which the Taguchi’s method was investigated are [5], [8] and [9], in which the implementation of this method was analyzed in order to improve the product quality.

2. Research methods

Given the purpose of the Taguchi method - oriented to conduct the experiments, based on this, it was determined the best combinations of the studied parameters. To obtain the expected results, the following steps were followed:

2.1. Process variables and their parameters

1) Identifying the factors involved in the end-milling process of the A7136 aluminum alloy:
   • Cutting speed – v (m/min);
   • Cutting depth – ap (mm);
   • Feed per tooth – fz (mm/tooth).

2) The choice of levels for each machining parameter according to the SECO Tools manufacturer indications and also according to the technological possibilities of the tool, cutting inserts and CNC machine (table 1). The chosen levels reflect the minimum and maximum values of the machining parameters. To carry out the experiments according to Taguchi’s method, the minimum and maximum values of each parameter must be used.

   | Table 1. Cutting process parameters and their values. |
   |-----------------------------------------------------|
   | A – Cutting speed [m/min]                          |
   | 495 530 570 610 660 710                           |
   | B – Cutting depth [mm]                             |
   | 2 2,5 3 3,5 4                                    |
   | C – Feed per tooth [mm/tooth]                      |
   | 0,04 0,06 0,08 0,11 0,14                           |

   3) The column distribution of the parameters with their corresponding levels in the form of a matrix, respecting the rule of settlement. Based on Taguchi’s method, were conducted a reduced number of experiments by combining the set factors using the orthogonal tables
(matrices). The orthogonal matrix for the choice of parameter values for each experiment $L_8(2^7)$ is shown in figure 1.

4) The research experiments according to the Taguchi plan:

2.2. Work Material
This research is focused on the study of arithmetic mean deviation $Ra$, of the Al7136 end-milled surface. The 7136 aluminum alloy is used in the aircraft industry and many of its properties are superior to other materials, including high strength to weight ratio, high wear resistance, low thermal expansion, corrosion resistance, durability, ductility, and conductivity, which make it a versatile material.

To conduct the 8 tests/experiments according to the Taguchi plan, an extruded block of Al7136 was used which comprises 8 rectangular specimens of 100 mm $\times$ 35 mm and 30 mm – figure 2.

2.3. Cutting tool
The experiments were performed by using 16 mm End milling cutter milling with 100% (16 mm) tool engagement - SECO R217.69-1616.0-09-2AN, holding two indexable cutting inserts with ISO coding XOEX090308FR-E05, H15 - figure 3.

2.4. CNC Machine
The machine used for the milling tests is a HAAS VF2 CNC. Copious amounts of Blasocut BC 35 Kombi SW mineral coolant were provided at the cutting zone throughout the experiment. The pressure of the machine coolant pump was 8 bar. Three hoses of Ø6 diameter, have been used to target the jet.

5) The analysis and the interpretation of experimental data.

Figure 2. The experiment on CNC machining center.

Figure 3. Cutting tool type SECO R217.69-1616.0-09-2AN used to conduct the experiments.
2.5. Response
After the machining operations, the surface roughness of each specimen was measured by using a portable surface roughness tester Mitutoyo SURFTEST SJ-210. The covered distance by the measuring device sensor is 5 mm (table 2).

| No. exp. | v [m/min] | ap [mm] | fz [mm/dinte] | Ra [µm] |
|----------|-----------|---------|---------------|---------|
| 1        | 495       | 2       | 0,04          | 0,070   |
| 2        | 495       | 2       | 0,14          | 0,155   |
| 3        | 660       | 4       | 0,04          | 0,412   |
| 4        | 660       | 4       | 0,14          | 0,108   |
| 5        | 495       | 4       | 0,04          | 0,071   |
| 6        | 495       | 4       | 0,14          | 0,342   |
| 7        | 660       | 2       | 0,04          | 0,074   |
| 8        | 660       | 2       | 0,14          | 0,132   |

2.6. Results and discussions
Based on the surface roughness measurements conducted in previous research [3], it was determined the configuration regarding the optimum values of each machining parameter and the interactions between them, in order to obtain the better cutting process performance and to reduce the surface roughness sensitivity to the uncontrollable factors.

6) Determination of the most favorable level of each factor to obtain the best possible surface quality: A2 B1 C1 A1B1 A1C2 B1C1. In other words, to attain that objective, it is recommended to use a higher cutting speed value at a lower value of cutting depth and feed per tooth. A first finding that emerges here is that the cutting speed has the greatest influence on surface roughness. To confirm this aspect, forwards the research is conducted using a full factorial experiment

3. Research approach using factorial experiment
Using the factorial experiments is recommendable and especially very effective in experiments that containing a several influence factors and it is necessary to study the cumulative effect of these factors on the objective function [5]. At this stage they were used to perform the experiments for all the cutting parameters values (Table 1), resulting a total of 150 cutting regimes. 3 blocks of Al7136 were machined under the same cutting conditions, having the dimensions 500 mm x 101 mm x 24.5 mm. After the end milling process, the Ra measurements were performed – figure 4. Based on the results, an evaluation of the experimental data was carried out that consists of a general appreciation of data homogeneity and particularity, using statistical parameters, such as [5]:

- histograms;
- scatter plot diagrams;
- Response surfaces and contours plot diagrams.

The analysis of the resulting experimental data derived from Ra measurements, was approached by the graphics realization based on the aspects mentioned above, using STATISTICA8 application. By the interpretation of the graphs, are seeking the influences of cutting parameters, that they exert on machined surface roughness. So, using the obtained results, a graphical data evaluation with a histogram distribution was carried out (figure 5). Hence, it appears an approximately normal data distribution and, under the established cutting conditions to conduct the experiment (tool, material and cutting regime) the Ra values are rather low at about 0,5 µm. Using the second parameter statistical processing: scatter plot, we evaluated the orthogonality experimental plan in order to track the dispersion of results to identify the types of relationships between factors and responses.
Using the second statistical parameter - scatter plot, the orthogonality of the experimental plan was evaluated in order to find the results dispersion to identify the relationships types between factors and responses. By the Ra scatter plot diagram in which the roughness values are analyzed in function by the cutting speed - figure 6, it is derived that the measurements have an increasing trend with increasing this parameter. This finding confirms the issues mentioned in all studies specialized in this direction. But what is specific to this experiment, is the high values distribution of roughness measured in the middle range of speeds (570 m/min - 610 m/min). After the primary analysis on the system behavior of CNC - tool - workpiece, it was supposed that the vibrations were the cause of these increases.

Figure 7 shows that with the increasing of the cutting depth values also there is also a direct correlation in the increase of the roughness distributions. These values may be caused by the same assumption regarding the effect of vibration and chip breaking phenomenon, due to the large loading on tool (high cutting depth and the maximum value of the cutting edge).

Figure 8 shows a slight decrease of the roughness values related to the cutting feed. This trend is directly influenced by the high dispersion of the roughness values at cutting speeds of 570 m/min and 610 m/min. Further, a tridimensional analysis was performed in order to observe the Ra dimensional variation under the machining parameters influence.
In figure 9, the spatial variation of Ra values depending on the cutting speed and cutting depth influences is presented. It can be observed a fairly large increase of the measurements in the first part of the interval of cutting speeds of 495-570 m/min, on the whole range of cutting depths. However, it appears that the cutting depth has not so great influence on the roughness values at low cutting speeds, but this phenomenon is changing at speeds exceeding 570 m/min.

Figure 10 shows the spatial variation using the contour plots distribution and it can be observed how the roughness values are influenced by the cutting speed and feed per tooth. It is found that the cutting speeds values of 570 to 610 m/min, in combination with a low feed per tooth, have an impact on measured roughness values which increase in whole experimental field. Again, the vibration may be the cause of these increasing. The Ra spatial variation under the cutting depth and feed per tooth influence, is shown in figure 11. After the analysis of this evolution, it appears that the cutting depth related to the cutting feed, influences the surface roughness values of the machined surface, resulting low roughness values. However, at higher feed per tooth values and lower cutting depth values, due to the influence of cutting speeds of 570 to 610 m/min, there is a tendency of roughness increase.

4. Conclusions

Using the Taguchi's method, the number of experiments has been reduced from 150 to 8.

The optimum configuration composed of each machining parameter, aimed to increase the cutting process performance and to reduce the susceptibility to uncontrollable factors, is: A2 B1 C1 A1B1 A1C2 B1C1.
The histogram shows that the arithmetic mean deviation values of the surface profile, obtained by experiment, and fits the milling process with the studied cutting parameters, in the fine precision class – (1.6 μm).

From the scatter plot diagrams it was found that the Ra measured values, have an increasing trend with the cutting speed increasing. The reason could be the vibrations caused by the resonance regime of the system, tool, material, cutting values and the CNC, and the phenomenon of chip breaking caused by high tool loading.

The conducted tridimensional analysis shows that the cutting speed combined with cutting depth expresses the strongest influence on the surface roughness.

The cutting parameter with the greatest influence on the surface roughness is the cutting speed. With its increasing the roughness values have also an increasing trend.

5. Future work

Given the dynamic behavior of the system CNC - tool - workpiece, it must be studied the effect of the vibration in this context.

Methods identification that will lead to obtain some mathematical models of others factors – like tool wear, that influence the surface quality

The study of the tool wear evolution in the aluminum machining, based on the varying of the cutting parameters regime.

Expanding the range of current research on other materials and compared to the studied 7136 aluminum alloy.

Increasing the sustainability of economically and in terms of productivity through the use of mathematical modeling of the cutting process.

Expanding the range of current research on other materials and compared to the 7136 Al alloy studied.

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