Comparison with Experimental Results of Models and Modelling with Fuzzy Logic of the Effect on Surface Roughness of Cutting Parameters in Machining of Co28Cr6Mowrought Steels

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Abstract. This study includes comparison with experimental results of models and modelling with fuzzy logic of the effect on surface roughness of cutting parameters (rotational speed (n), feed rate (f), depth of cut (a) and tool tip radius (r)) in CNC turning of Co28Cr6Mo wrought steels. Fuzzy logic models were established that can determine the optimum rotational speed, feed rate, depth of cut and tool tip radius for surface roughness (Ra) according to the hardness of material and type of cutting tool. In the model created using fuzzy logic, membership functions and foot widths of input parameters and output parameter were utilized. In the rule base, triangular (trim-f) membership functions were selected by the Mamdani approach. The results obtained using this fuzzy model and experimental results were interpreted and compared with 2dimensional graphics.

1. Introduction
The surface roughness is important in design. Many researchers have been dealing with the establishment of models in recent years due to the increased number of applied materials and tool materials. These models provide a connection between the cutting parameters and the surface roughness. At the beginning of these models are artificial intelligence techniques. One of these artificial intelligence techniques is fuzzy logic. Professor Zadeh invented fuzzy logic in 1964. The concept of fuzzy logic came from the idea of grade of membership function, which became the backbone of fuzzy set theory. Fuzzy logic is a basic concept which refers to all theories and technologies that employ fuzzy set [1-2]. It allows intermediate values to be defined between evaluations like low/high, slow/fast, small/large etc. Many authors have done some research on surface roughness with fuzzy logic;

A fuzzy based method was proposed by Fei and Jawahir [3] for predicting the achievable levels of surface roughness in finish turning operations. They created the rules from a new method for predicting surface roughness values under cutting conditions. The surface roughness minimization was carried out using fuzzy approach by Gok [4] for nodular cast iron. L16 (3⁵) Taguchi plan was used to define the experimental run, in which the three input parameters were changed in four levels (Vc=50-100-150-200 m/min; f=0.05-0.075-0.01-0.125 mm; ap=0.5-1-1.5-2 mm). The cutting ability of die cast alloy Al-Si-Cu-Fe for four kinds of materials: normal, Bismuth reinforced (Bi),
Strontium-reinforced (Sr), and Antimon-reinforced (Sb) was examined by Barzani et al. [5]. In the study, a TiN coated tool was used insert VBGTT110302F. The cutting speed and the feed were changed in three levels (Vc=70-130-250 m/min; f=0.05-0.01-0.15 mm), while the depth of cut was held at a constant value (ap=0.5 mm). They performed 36 experiments, and they have defined the membership functions of the input and the measured output (surface roughness) parameters. Finally, they have constructed a predictive model using fuzzy approach to estimate the surface roughness. Rajasekaran et al. [6] investigated the effect of cutting parameters on the estimation of surface roughness values by using CBN cutting tool to obtain good surface quality and fuzzy modelling for turning CFRP composites. A fuzzy model to predict surface roughness and cutting power for drilling Aluminum AA1050 was used by Nandi et al. [7]. Lo [8] concluded that an adaptive network based fuzzy inference system for prediction of workpiece surface roughness in end milling. Ray et al. [9] investigated the effects of cold deformation on the cutting force, surface roughness and chip characteristics in machining of ASME 12L14 free cutting steel using fuzzy set theory. A fuzzy logic model was developed by Ilkaz [10] for turning. He determined cutting parameters depending on hardness of workpiece and tool material and power of machine tool. He used Matlab Fuzzy Toolbox to prepare of fuzzy logic models. Wong et al. [11] created the general fuzzy model for the selection of cutting parameters in machining. Several fuzzy models for different cutting tools were created and compared. The results showed that the accepted model was formed with an average error of 6%. Chungchoo and Saini [12] estimated tool wear in CNC turning using the fuzzy and neural network model. For this, classification of tool wear is done with fuzzy logic, inputs are normalized, network is set to at least squared fault, and crater wear is estimated with high accuracy.

In the present work, fuzzy logic models will be developed to determine the optimum rotational speed (n), feed rate (f), depth of cut (a) and tool tip radius (r) for surface roughness. The developed model can be effectively used to predict the surface roughness in the machining of Co28Cr6Mo within the ranges of variables studied.

2. Experimental Work

2.1. Machining conditions and roughness measurements

In the experimental study, Co28Cr6Mo ASTM F 1537 wrought steel having hardness of 40 HRC was used as workpiece material. The dimensions of the sample are Ø50x500 mm. Turning process was carried out on a TC25-L type Sogotec CNC lathe and surface roughness values were measured on a SJ-201 Mitutoyo device. The tests were performed under dry machining conditions. The tool holder of used was MTJNR-L2525 M16, the cutting tools were TiCN coated TNMG 160404, 160408 and 160412 MT by PVD method. The average of surface roughness values measured from three different parts of the surface after each cutting operation was used. A total of 27 experiments were carried out in accordance with L27 (3^4) Taguchi standard orthogonal test design for four parameters and three levels used in this study. Finally, the cutting parameters were modeled with fuzzy logic as 4 inputs (n,f,a,r) and a single output (Ra).

2.2. Modelling of cutting parameters with Fuzzy Logic

Limit values of the membership functions of the output parameter and input parameters are shown in Table 1. In Figure 1, membership functions and foot widths of input parameters and output parameter are shown.

| Table 1. Limit values for input (n, f, a, r) and output (Ra) parameters |
|-----------------------------|-----------------------------|-----------------------------|
| Rotational speed, (rpm)     | Degree of speed             | Feed rate, (mm/rev)         | Degree of feed |
| 314-477: Slow               | 0.1-0.15: Low               | 0.5-0.7: Little             |
| 314-477: Regular            | 0.1-0.2: Middle              | 0.5-0.9: Middle             |
| 0.7-0.8: Fast               | 0.1-0.2: High                | 0.7-0.9: High               |
| Tool tip radius, (mm)       | Degree of depth             |
| 0.1-0.2: Small              | 0.1-0.3: Medium              |
| 0.4-0.5: Large              | 0.4-0.7: Medium              |
| 0.8-0.9: Medium             | 0.8-1.2: Large               |
| Ra, (μm)                    | Degree of roughness         |
| 0.1-1.3: Excellent          | 0.11-1.3: Good               |
| 1.3-3.5: Average            | 3.5-3.7: Bad                 |
| 5.5-10.7: Terrible          |


3. Results and Discussion
In this study, which aims to model cutting parameters with fuzzy logic in CNC turning, 222 rule bases were created to apply cutting parameters to provide the best surface quality.

3.1. Effect of cutting parameters on surface roughness
In this section, the surface roughness values of predicted are shown with 2-dimensional graphics by fuzzy logic in relation to changes of the input parameters in Figure 2. For example, for \( n = 318, f = 0.25, a = 0.7 \) and \( r = 0.4 \);
3.2. The comparison of experimental data and Fuzzy output

Table 2 shows the comparison of experimental data and the fuzzy output Ra values.

Table 2. Comparison of experimental and fuzzy output Ra values.

| No. | Experimental | Fuzzy Output | $n$ (rpm) | $f$ (mm/min) | $a$ (mm) | $r$ (mm) | Surface Roughness, $R_a$ (um) | Surface Roughness, $R_a$ (um) | $\Delta R_a$ (um) |
|-----|--------------|--------------|----------|--------------|--------|--------|-------------------------------|-------------------------------|------------------|
| 1   | 318          | 0.1          | 0.5      | 0.4          | 3.66   | 2.92   | 0.74                          |                               |                  |
| 2   | 318          | 0.1          | 0.5      | 0.8          | 0.81   | 1.26   | 0.46                          |                               |                  |
| 3   | 318          | 0.15         | 0.9      | 1.2          | 1.87   | 1.35   | 0.48                          |                               |                  |
| 4   | 318          | 0.15         | 0.9      | 0.8          | 1.959  | 2.22   | 0.63                          |                               |                  |
| 5   | 318          | 0.25         | 0.9      | 0.4          | 4.923  | 4.23   | 0.59                          |                               |                  |
| 6   | 318          | 0.25         | 0.9      | 0.8          | 4.923  | 4.23   | 0.59                          |                               |                  |
| 7   | 318          | 0.25         | 0.7      | 0.4          | 7.11   | 6.75   | 0.36                          |                               |                  |
| 8   | 318          | 0.25         | 0.9      | 0.8          | 4.923  | 4.23   | 0.59                          |                               |                  |
| 9   | 477          | 0.1          | 0.5      | 0.8          | 3.9    | 2.22   | 0.45                          |                               |                  |
| 10  | 477          | 0.1          | 0.9      | 1.2          | 0.987  | 2.94   | 1.95                          |                               |                  |
| 11  | 477          | 0.15         | 0.9      | 1.2          | 0.987  | 2.94   | 1.95                          |                               |                  |
| 12  | 477          | 0.15         | 0.7      | 0.4          | 4.4    | 2.45   | 1.95                          |                               |                  |
| 13  | 477          | 0.15         | 0.9      | 1.2          | 0.987  | 2.94   | 1.95                          |                               |                  |
| 14  | 477          | 0.15         | 0.7      | 0.4          | 4.4    | 2.45   | 1.95                          |                               |                  |
| 15  | 477          | 0.25         | 0.9      | 1.2          | 1.95   | 1.95   | 0.25                          |                               |                  |
| 16  | 477          | 0.25         | 0.7      | 0.8          | 7.11   | 6.75   | 0.36                          |                               |                  |
| 17  | 477          | 0.25         | 0.9      | 1.2          | 1.94   | 1.94   | 0.02                          |                               |                  |
| 18  | 477          | 0.25         | 0.9      | 1.2          | 1.94   | 1.94   | 0.02                          |                               |                  |
| 19  | 656          | 0.1          | 0.5      | 1.2          | 0.987  | 2.94   | 1.95                          |                               |                  |
| 20  | 656          | 0.1          | 0.9      | 0.4          | 4.923  | 4.23   | 0.59                          |                               |                  |
| 21  | 656          | 0.25         | 0.9      | 0.8          | 4.923  | 4.23   | 0.59                          |                               |                  |
| 22  | 656          | 0.25         | 0.7      | 0.4          | 7.11   | 6.75   | 0.36                          |                               |                  |
| 23  | 656          | 0.25         | 0.9      | 1.2          | 1.94   | 1.94   | 0.02                          |                               |                  |
| 24  | 656          | 0.25         | 0.9      | 1.2          | 1.94   | 1.94   | 0.02                          |                               |                  |
| 25  | 656          | 0.25         | 0.7      | 0.8          | 7.11   | 6.75   | 0.36                          |                               |                  |
| 26  | 656          | 0.25         | 0.7      | 1.2          | 2.193  | 2.193 | 0.03                          |                               |                  |
| 27  | 656          | 0.25         | 0.9      | 0.4          | 4.923  | 4.23   | 0.59                          |                               |                  |
4. Conclusions
In the present work, fuzzy logic models were developed to determine the optimum rotational speed ($n$), feed rate ($f$), depth of cut ($a$) and tool tip radius ($r$) for surface roughness. Apart from this work, the results of fuzzy logic can be compared to the results of other artificial intelligence methods such as (Neural networks, ANFIS, MANFIS, Genetic Algorithms, etc.) in the future. This work will contribute to the academic work and the manufacturing sector for predictive force model, tool wear model, tool cost, etc.

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