

Fuzzy Logic Approach with Weighted Compensatory Operator to Predict Surface Roughness of Hardfaced Components

Shamita Murmu¹, S.K.Jha², and A.P.Burnwal³

M. Tech Student, Dept. of Mechanical Engineering, B.I.T. SindriDhanbad, Jharkhand, India¹

Associate Professor, Dept. of Production Engineering, B.I.T. SindriDhanbad, Jharkhand, India²

Assistant Professor, Dept. of Mathematics, GGSESTC Bokaro, Jharkhand, India³

ABSTRACT: This paper deals with application of fuzzy logic system in turning of hard-faced components as various parameters of turning process such as cutting speed, feed rate, depth of cut are not defined precisely. Decision maker may use the weighted compensatory operator to select the most suitable rules to model the fuzzy logic system for the hard-facing problem and a better solution may be obtained with less computational effort.

KEYWORDS: Hard-facing Process, Turning Parameter, Fuzzy set theory, Weighted Compensatory Operator, Threshold Value.

I. INTRODUCTION

Hard-facing is the application of depositing specialized alloys by means of a welding process to resist wear due to abrasion, impact, corrosion, high temperature etc. These alloys deposited on the component surface, especially at the areas which are subjected to wear through different welding processes such as Arc Welding, Gas Welding, TIG Welding etc.. It can also be applied to a new component during its production, or to re-establish a worn out surface [6]. Welding deposits can help to regain the components by improving their service life [1] Hard-facing of industrial components by welding processes is widely adopted among different surface treatment techniques available, as they require less time, help in effective deposition of extra material only in the worn out area, impart better strength and wear properties, equipment portability, cost effectiveness etc.

Hard-faced parts contain irregular surface after welding process, hence it needs subsequent machining process which should be operated in controlled manner for optimum surface finishing. So from the above facts it is obvious that for utilizing the benefits of hard-facing such as reduction in cost, machine downtime and spare parts inventories, extension in equipment service life etc. a subsequent suitable machining process have to be operated in a controlled manner using soft computing techniques because for a skilled operator too it is not possible to set correct cutting parameters each time.

Typically, selected cutting operations have limited capability of attaining the required surface roughness. However, it is necessary to determine optimal cutting parameters in order to achieve minimal expenses or minimal cost/production time. Different methods for prediction of optimal cutting parameters have been done by many Researchers. Due to non-linearity of the cutting parameters, tool work combination and rigidity of machine tool, soft computing is used for prediction of important parameters in manufacturing [2, 3, 4].

In this paper fuzzy logic technique using compensatory operator has been used to find the surface roughness of hard-faced component.

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II. INPUT AND OUTPUT VARIABLES

This system has been designed for three fuzzy input variables and one output fuzzy variable in table 1 and 2 respectively [5, 7]:

Table 1: Input Parameters

Input Parameters	Notations	Units	Levels		
			Low (L)	Medium (M)	High (H)
Cutting speed	V	m/min	60-75	75-105	105-120
Feed rate	f_r	mm/rev.	0.10-0.105	0.105-0.115	0.115-0.120
Depth of cut	DOC	Mm	0.20-0.205	0.205-0.215	0.215-0.220

Table 2: Output Parameter (Surface Roughness)

Ranges	Linguistic values (μm)
Low	0.50-0.55
Medium	0.55-0.65
High	0.65-0.75
Very high	0.75-0.80

III. MATHEMATICAL DESCRIPTION

The turning system of hard-faced component is designed for three fuzzy input variables. The membership functions (MFs) for the three variables such as V, FR and DOC are given below

Different values of V: $V_{11}-V_{13}=V_1$, $V_{13}-V_{14}=V_2$, $V_{14}-V_{15}=V_3$,

Different values of f_r : $V_{21}-V_{22}=f_1$, $V_{22}-V_{23}=f_2$, $V_{23}-V_{24}=f_3$, and

Different values of DOC: $V_{31}-V_{32}=d_1$, $V_{32}-V_{33}=d_2$, $V_{33}-V_{34}=d_3$

(a) Solution procedure

Let us consider that X_i , Y_i and Z_i denote different values of V, FR and DOC which belong to

$X_i \in [V_{11}, V_{12}]$, $Y_i \in [V_{21}, V_{22}]$, $Z_i \in [V_{31}, V_{33}]$ & S_1, S_2, \dots denote corresponding normalize weight values of surface finishing (S_i) given by weighted compensatory operator as

$$X_1 * p_1 + Y_1 * q_1 + Z_1 * r_1 = S_1; X_1 * p_1 + Y_1 * q_1 + Z_2 * r_1 = S_2; X_1 * p_1 + Y_1 * q_1 + Z_3 * r_1 = S_3$$

$$X_1 * p_1 + Y_2 * q_1 + Z_1 * r_1 = S_4; X_1 * p_1 + Y_2 * q_1 + Z_2 * r_1 = S_5; X_1 * p_1 + Y_2 * q_1 + Z_3 * r_1 = S_6$$

$$X_1 * p_1 + Y_3 * q_1 + Z_1 * r_1 = S_7; X_1 * p_1 + Y_3 * q_1 + Z_2 * r_1 = S_8; X_1 * p_1 + Y_3 * q_1 + Z_3 * r_1 = S_9$$

$$X_2 * p_1 + Y_1 * q_1 + Z_1 * r_1 = S_{10}; X_2 * p_1 + Y_1 * q_1 + Z_2 * r_1 = S_{11}; X_2 * p_1 + Y_1 * q_1 + Z_3 * r_1 = S_{12}$$

$$X_2 * p_1 + Y_2 * q_1 + Z_1 * r_1 = S_{13}; X_2 * p_1 + Y_2 * q_1 + Z_2 * r_1 = S_{14}; X_2 * p_1 + Y_2 * q_1 + Z_3 * r_1 = S_{15}$$

$$X_2 * p_1 + Y_3 * q_1 + Z_1 * r_1 = S_{16}; X_2 * p_1 + Y_3 * q_1 + Z_2 * r_1 = S_{17}; X_2 * p_1 + Y_3 * q_1 + Z_3 * r_1 = S_{18}$$

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$$X_3 * p_1 + Y_1 * q_1 + Z_1 * r_1 = S_{19}; X_3 * p_1 + Y_1 * q_1 + Z_2 * r_1 = S_{20}; X_3 * p_1 + Y_1 * q_1 + Z_3 * r_1 = S_{21}$$

$$X_3 * p_1 + Y_2 * q_1 + Z_1 * r_1 = S_{22}; X_3 * p_1 + Y_2 * q_1 + Z_2 * r_1 = S_{23}; X_3 * p_1 + Y_2 * q_1 + Z_3 * r_1 = S_{24}$$

$$X_3 * p_1 + Y_3 * q_1 + Z_1 * r_1 = S_{25}; X_3 * p_1 + Y_3 * q_1 + Z_2 * r_1 = S_{26}; X_3 * p_1 + Y_3 * q_1 + Z_3 * r_1 = S_{27}$$

Where, normalized weights are p_i, q_i and $r_i \in [0,1]$ & $p_i + q_i + r_i = 1$

(b) Results

We have finite number of solution out of which some are less useful some are more useful this can be categorized according to threshold value. A threshold value is consider according to choice of decision maker suppose its value is θ . If any solution $S_i > \theta$, than result will be accepted otherwise result will be rejected. The sequence $\langle S_i \rangle$ of accepted solution will be given in descending order of their values. The set of solutions is $\{S_1, S_2, S_3, \dots, S_{27}\}$ and $\langle S_i \rangle$ may contain less than 27 accepted solutions in which first solution is inferior and last is most superior. $\{S_1, S_2, S_3, \dots, S_{27}\}$

IV. SAMPLE PROBLEM

The system is designed for fuzzy input variables .The value of triangular membership functions for the three variables namely as cutting speed, feed rate and depth of cut is given below:

Different values of cutting speed (m/min.): $V_{11}-V_{13}=60, V_{13}-V_{14}=90, V_{14}-V_{15}=120$

Different values of feed rate (mm/rev.): $V_{21}-V_{22}=0.10, V_{22}-V_{23}=0.11, V_{23}-V_{24}=0.12$

Different values of depth of cut (mm): $V_{31}-V_{32}= 0.20, V_{32}-V_{33}=0.21, V_{33}-V_{34}=0.22$

(a) Solution

Since V is the most significant, FR is the second most significant and DOC has the negligible effect on surface roughness hence these have assigned the following normalized weights respectively $p_i=0.6, q_i = 0.3, r_i= 0.1$ and it has been used in the following weighted compensatory operator.

$$X_i \in [V_{11}, V_{12}], Y_i \in [V_{21}, V_{22}], Z_i \in [V_{31}, V_{33}]$$

$$X_1 * p_1 + Y_1 * q_1 + Z_1 * r_1 = 60 * 0.6 + 0.10 * 0.3 + 0.20 * 0.1 = 36.050 = S_1$$

$$X_1 * p_1 + Y_1 * q_1 + Z_2 * r_1 = 60 * 0.6 + 0.10 * 0.3 + 0.21 * 0.1 = 36.051 = S_2$$

$$X_1 * p_1 + Y_1 * q_1 + Z_3 * r_1 = 60 * 0.6 + 0.10 * 0.3 + 0.22 * 0.1 = 36.052 = S_3$$

$$X_1 * p_1 + Y_2 * q_1 + Z_1 * r_1 = 60 * 0.6 + 0.11 * 0.3 + 0.20 * 0.1 = 36.053 = S_4$$

$$X_1 * p_1 + Y_2 * q_1 + Z_2 * r_1 = 60 * 0.6 + 0.11 * 0.3 + 0.21 * 0.1 = 36.054 = S_5$$

$$X_1 * p_1 + Y_2 * q_1 + Z_3 * r_1 = 60 * 0.6 + 0.11 * 0.3 + 0.22 * 0.1 = 36.055 = S_6$$

$$X_1 * p_1 + Y_3 * q_1 + Z_1 * r_1 = 60 * 0.6 + 0.12 * 0.3 + 0.20 * 0.1 = 36.056 = S_7$$

$$X_1 * p_1 + Y_3 * q_1 + Z_2 * r_1 = 60 * 0.6 + 0.12 * 0.3 + 0.21 * 0.1 = 36.057 = S_8$$

$$X_1 * p_1 + Y_3 * q_1 + Z_3 * r_1 = 60 * 0.6 + 0.12 * 0.3 + 0.22 * 0.1 = 36.058 = S_9$$

$$X_2 * p_1 + Y_1 * q_1 + Z_1 * r_1 = 90 * 0.6 + 0.10 * 0.3 + 0.20 * 0.1 = 54.050 = S_{10}$$

$$X_2 * p_1 + Y_1 * q_1 + Z_2 * r_1 = 90 * 0.6 + 0.10 * 0.3 + 0.21 * 0.1 = 54.051 = S_{11}$$

$$X_2 * p_1 + Y_1 * q_1 + Z_3 * r_1 = 90 * 0.6 + 0.10 * 0.3 + 0.22 * 0.1 = 54.052 = S_{12}$$

$$X_2 * p_1 + Y_2 * q_1 + Z_1 * r_1 = 90 * 0.6 + 0.11 * 0.3 + 0.20 * 0.1 = 54.053 = S_{13}$$

$$X_2 * p_1 + Y_2 * q_1 + Z_2 * r_1 = 90 * 0.6 + 0.11 * 0.3 + 0.21 * 0.1 = 54.054 = S_{14}$$

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$$\begin{aligned}
 X_2 * p_1 + Y_2 * q_1 + Z_3 * r_1 &= 90 * 0.6 + 0.11 * 0.3 + 0.22 * 0.1 = 54.055 = S_{15} \\
 X_2 * p_1 + Y_3 * q_1 + Z_1 * r_1 &= 90 * 0.6 + 0.12 * 0.3 + 0.20 * 0.1 = 54.056 = S_{16} \\
 X_2 * p_1 + Y_3 * q_1 + Z_2 * r_1 &= 90 * 0.6 + 0.12 * 0.3 + 0.21 * 0.1 = 54.057 = S_{17} \\
 X_2 * p_1 + Y_3 * q_1 + Z_3 * r_1 &= 90 * 0.6 + 0.12 * 0.3 + 0.22 * 0.1 = 54.058 = S_{18} \\
 X_3 * p_1 + Y_1 * q_1 + Z_1 * r_1 &= 120 * 0.6 + 0.10 * 0.3 + 0.20 * 0.1 = 72.050 = S_{19} \\
 X_3 * p_1 + Y_1 * q_1 + Z_2 * r_1 &= 120 * 0.6 + 0.10 * 0.3 + 0.21 * 0.1 = 72.051 = S_{20} \\
 X_3 * p_1 + Y_1 * q_1 + Z_3 * r_1 &= 120 * 0.6 + 0.10 * 0.3 + 0.22 * 0.1 = 72.052 = S_{21} \\
 X_3 * p_1 + Y_2 * q_1 + Z_1 * r_1 &= 120 * 0.6 + 0.11 * 0.3 + 0.20 * 0.1 = 72.053 = S_{22} \\
 X_3 * p_1 + Y_2 * q_1 + Z_2 * r_1 &= 120 * 0.6 + 0.11 * 0.3 + 0.21 * 0.1 = 72.054 = S_{23} \\
 X_3 * p_1 + Y_2 * q_1 + Z_3 * r_1 &= 120 * 0.6 + 0.11 * 0.3 + 0.22 * 0.1 = 72.055 = S_{24} \\
 X_3 * p_1 + Y_3 * q_1 + Z_1 * r_1 &= 120 * 0.6 + 0.12 * 0.3 + 0.20 * 0.1 = 72.056 = S_{25} \\
 X_3 * p_1 + Y_3 * q_1 + Z_2 * r_1 &= 120 * 0.6 + 0.12 * 0.3 + 0.21 * 0.1 = 72.057 = S_{26} \\
 X_3 * p_1 + Y_3 * q_1 + Z_3 * r_1 &= 120 * 0.6 + 0.12 * 0.3 + 0.22 * 0.1 = 72.058 = S_{27}
 \end{aligned}$$

(b) Result

The set of normalized weight of solutions (in ascending order) is { S₁, S₂, S₃, S₄, S₅, S₆, S₇, S₈, S₉, S₁₀, S₁₁, S₁₂, S₁₃, S₁₄, S₁₅, S₁₆, S₁₇, S₁₈, S₁₉, S₂₀, S₂₁, S₂₂, S₂₃, S₂₄, S₂₅, S₂₆, S₂₇}

(c) Use of threshold value

A threshold value denoted by θ is considered according to the choice of decision maker. Suppose its value is 70, that means if any normalized weight of solution is greater than 70%, i.e. $S_i > 70$ then result will be accepted otherwise it will be rejected. The sequence of accepted normalized weight of solutions will be given in ascending order of their values. The sequence of normalized weight of solutions is { S₁₉, S₂₀, S₂₁, S₂₂, S₂₃, S₂₄, S₂₅, S₂₆, S₂₇}.

V. MODELING OF DATA USING FUZZY LOGIC APPROACH

Since, {S₁₉ S₂₇} are the accepted normalized weight of solutions. Hence, in fuzzy logic system rules will be created using these 9 sets of equations only i.e. there will be required number of rules will be 9 only.

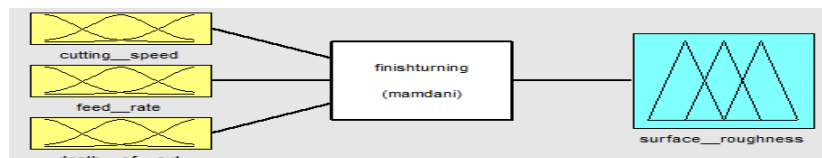


Figure 1: FLS in MATLAB

Membership functions for each input parameters and output parameter have been defined are shown in figure 2(a), (b), (c) and (d) respectively.

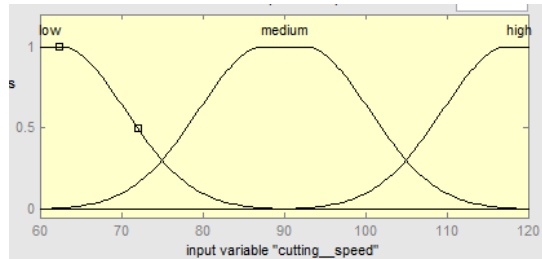


Figure 2(a): Membership Function vs. Cutting speed

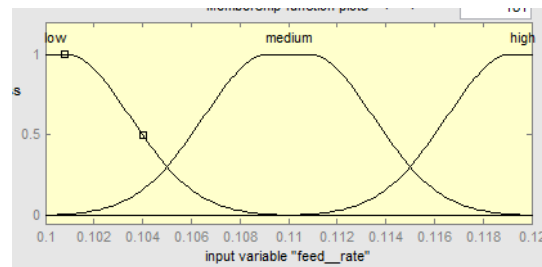


Figure 2(b): Membership Function vs. Feed rate

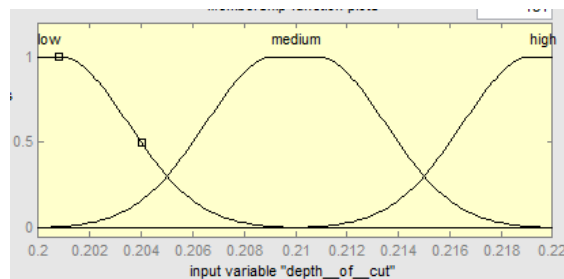


Figure 2(c): Membership Function vs. Depth of Cut

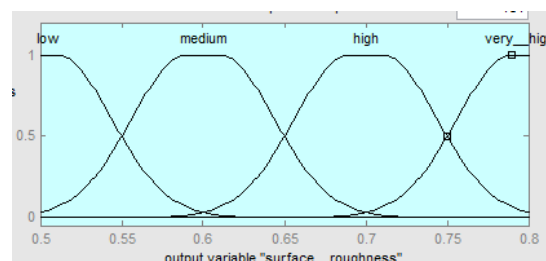


Figure 2(d): Membership Function vs. Surface Roughness

Rule base gives the inter-relations among input parameters to yield output parameter value. This is called the heart of fuzzy logic system. Desired output is based on the rule base generated in fuzzy.

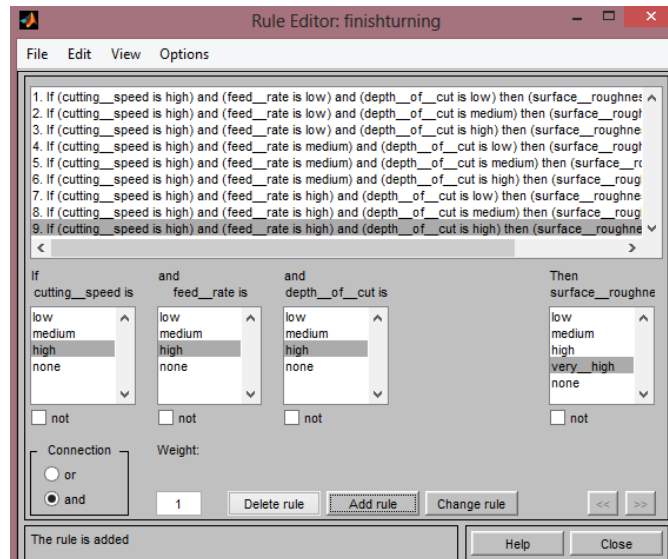


Figure 3: Fuzzy rule base created In MATLAB using [9, 11, 12]

Rule viewer shows the all rules created in fuzzy rule base graphically.

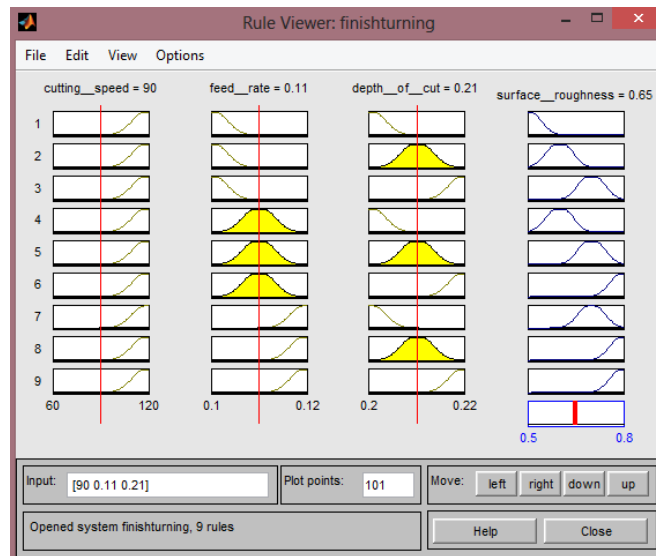


Figure 4: Rule viewer of fuzzy rule base

Figure 5(a) shows the optimum value of cutting speed, feed rate and depth of cut which yields surface roughness 0.532 μ m.

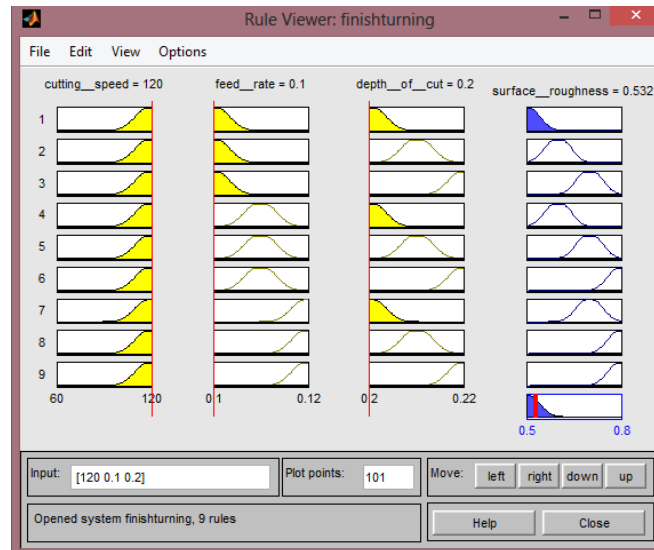


Figure 5(a): Optimum values of $V=120\text{m/min}$, $f_r=0.10\text{mm/rev}$, $\text{DOC}=0.20\text{mm}$ Yield $R_a = 0.532\ \mu\text{m}$

Figure 5(b) shows the three dimensional view of surface roughness with respect to feed rate and depth of cut. Dark blue colour is the indication of optimum surface.

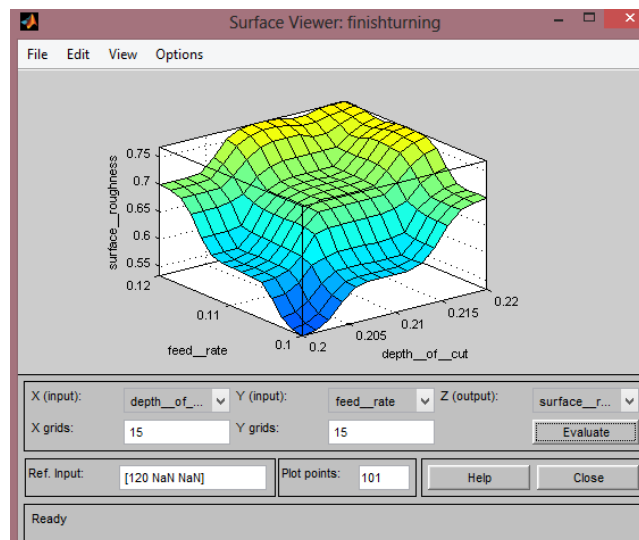


Figure 5(b): Surface view of optimum result

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VI. RESPECTIVE GRAPHS OF INPUT PARAMETERS WITH RESPECT TO OUTPUT SURFACE ROUGHNESS

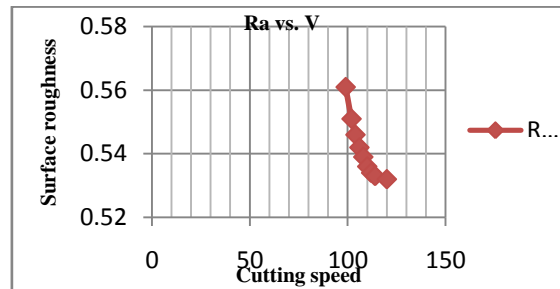


Figure 6(a): Surface roughness vs. Cutting speed

Here surface roughness improves with increase in cutting speed.

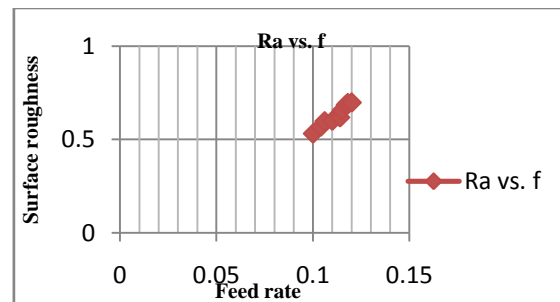


Figure 6(b): Surface Roughness vs. Feed Rate

Surface roughness deteriorates with increment in feed rate.

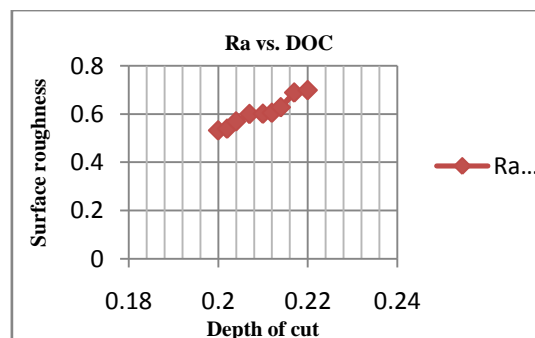


Figure 6(c) Surface Roughness vs. Depth of Cut

Depth of cut also showing the same nature as feed rate. With the increment in DOC, there is deterioration in Ra.

VI. CONCLUSION

The proposed model of surface finishing hard-faced component/components has been designed using fuzzy logic approach with weighted compensatory operator. Total 27 rules were obtained, but with the help of weighted compensatory operator number of rules reduced to 9 only. Hence, it is more suitable to select the optimum combination of cutting parameters by decision maker over trial and error method. It enhances the productivity of industries. The

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optimum value of $R_a = 0.532\mu\text{m}$ is obtained at $V=120\text{m/min}$, $f_r= 0.10\text{ mm/rev}$, and $\text{DOC}=0.20\text{mm}$. In this approach we may use four or more linguistic variables such as tool geometry, coolant, machining environment etc. for getting fast and appropriate value of the result, which may be part of future research work. Other operators in place of compensatory operator may be used.

REFERENCES

- [1] AgustínGualco, Hernán G. Svoboda, Estela S. Surian and Luis A. de Vedia, *Effect of Welding Procedure on Wear Behaviour of a Modified Martensitic Tool Steel Hardfacing Deposit*, Materials & Design, 2010, Volume 31, Issue 9, 2010, pages 4165–4173.
- [2] W. Grzesik and S. Brol, *Hybrid Approach to Surface Roughness Evaluation in Multistage Machining Processes*, Journal of Materials Processing Technology, Volume 134, pp. 265-272, 2003.
- [3] S. Ho, K. Lee, S. Chen and S. Ho., *Accurate Modeling and Prediction of Surface Roughness By Computer Vision in Turning Operations using an Adaptive Neuro-Fuzzy Inference System*, International Journal Machine Tools andManufacture, Volume 42, pp. 1441-1446, 2002.
- [4] E. Mainsah and D.T. Ndumu., *Neural Network Applications in Surface Topography*,Int.Journal of Machine Tools and Manufacture, Volume 38, pp. 591-598, 1998.
- [5] Gost 26101- 84, *ProvolkaPoroshkovayaNaplavochanya*, TekhnicheskayaUsloviya, M, 1984, pp. 14 (In Russian)
- [6] E.N. Gregory, *Hardfacing*, Tribology International, 1978, pages 129-134.
- [7] Grinberg N. A. , Dzikovich N. N. , Nikolovenko M. P. , *Khimicheskaya, SmrukurnayaNiodnorodnosch, SvarchnoyeProizvodsmva*, SvarchnoyeProizvodsmva, 1974, No. 4 pp. 7-9 (In Russian).
- [8] Zadeh, L A, *Fuzzy Sets*, Information & Control, Vol. 8, pp. 338 - 353, 1965.
- [9] MATLAB 7.11.0 (R2010b).