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RESEARCH ARTICLE

FUZZY SET THEORY APPROACH TO MODEL TURNING OF HARDFACED COMPONENTS USING WEIGHTED COMPENSATORY OPERATOR

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ABSTRACT

This paper deals with application of fuzzy set theory in turning of hard-faced components as various parameters such as cutting speed, feed rate, depth of cut are not defined precisely. Decision maker may use the weighted compensatory operator to model the hardfacing problem and a better solution may be obtained.

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INTRODUCTION

"Hardfacing" or "Hardsurfacing", 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 can be deposited on the component surface, especially at the areas which are subjected to wear through different welding processes such as Arc Welding, Gas Welding, and TIG Welding etc. In a hard-faced part, the base material is selected to impart strength and economy, and the hard-facing material is selected for the specific wearing conditions to which the areas of the part will be subjected in service. Hard-facing can also be applied to a new component during its production, or it can be used to re-establish a worn out surface (Gregory, 1978). Welding deposits can help to regain the components by improving their service life (Agustín Gualco *et al*., 2010). Hard-facing extends the life of parts used in machinery or equipment very efficiently (Badisch and Kirchgaßner, 2008; Kirchgaßner *et al*., 2008). Hard-surfacing 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.

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Weld hard facing techniques are mainly used to improve the service life of engineering parts by rebuilding in such a way that it produces a metallic/alloy wall section to resist wear, corrosion, 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 (Neural network, Fuzzy logic, Genetic algorithm and their hybridizations) is used for prediction of important parameters in manufacturing (Grzesik and Brol, 2003; Ho *et al*., 2002; Mainsah and Ndumu, 1998). In this paper fuzzy logic technique using compensatory operator has been used to find the surface roughness of hard-faced component.

Fuzzy logic (Burnwal *et al*., 2014; Burnwal *et al*., 2013) is a part of artificial intelligence. It is based on the theory of fuzzy sets, where an objects membership of a set is continuing rather than just member or not a member. Fuzzy logic uses the whole interval of real numbers between zero (false) and one (true) to develop logic as a basis for rules of inference. Particularly the fuzzified version of the modus ponens rule of inference enables computers to make decisions using fuzzy reasoning rather than exact. Fuzzy logic has great capability to capture human common sense reasoning, decision making and other aspects of human cognition. It can be performed in hardware or software or by combination of both of them. Medicine was one of the first field in which it was applied.

Many Authors (Santosh Kumar Das *et al*., 2015; Santosh Kumar Das *et al*., 2015; Santosh Kumar Das *et al*., 2015 and Kumar Das *et al*., 2013) used fuzzy logic in different fields. Fuzzy logic system, a successful application of fuzzy set theory (Zadeh, 1965) is a potential tool for dealing with imprecision and uncertainty. Islam *et al*. (2011) predicted feed rate has a dominant effect on surface finish.Hashmi *et al*. (1998) applied fuzzy set theory logic for selection of cutting conditions in machining. Lee, Yang, and Moon (Lee *et al*., 1999 used fuzzy set theory-based non-linear model for a turning process as a more effective tool than conventional mathematical modeling techniques if there exists 'fuzziness' in the process control variables.

Kamatala *et al*. (1996) developed a fuzzy set theory-based system for predicting surface roughness in a finished turning operation. Chen *et al*. (1998) used a hybrid approach of fuzzy set and ANN-based technique for designing a grinding process and its control. Lalitha *et al*. (2015) dealt with three soft computing techniques namely Adaptive Neuro Fuzzy Inference System (ANFIS), Neural Networks (NN) and Regression in predicting the surface roughness of AA6063 Aluminium alloy in turning process considering spindle speed, feed rate and depth of cut as input parameters analysed that surface roughness value increases as the feed and depth of cut increases and as the spindle speed increases the surface roughness value decreases.

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:

Table 1. Range of Input Parameters

Input Parameters	Notations	Units	Levels		
			Low(L)	Medium(M)	High(H)
Cutting speed	V	m/min	30-52	52-98	98-120
Feed rate	FR	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

Mathematical Description

The turning system of hard-faced component is designed for three fuzzy input variables. The membership functions 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 FR: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

Table 2. Surface Roughness Selection

Ranges	Linguistic values (μm)
Low	0.50-0.575
Medium	0.575-0.725
High	0.725-0.80

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

$X_1*p_1 + Y_1*q_1 + Z_1*r_1= S_1$; $X_1*p_1 + Y_1*q_1 + Z_2*r_1= S_2$;$X_1*p_1 + Y_1*q_1 + Z_3*r_1= S_3$
$X_1*p_1 + Y_2*q_1 + Z_1*r_1= S_4$;$X_1*p_1 + Y_2*q_1 + Z_2*r_1= S_5$; $X_1*p_1 + Y_2*q_1 + Z_3*r_1= S_6$
$X_1*p_1 + Y_3*q_1 + Z_1*r_1= S_7$;$X_1*p_1 + Y_3*q_1 + Z_2*r_1= S_8$; $X_1*p_1 + Y_3*q_1 + Z_3*r_1= S_9$
$X_2*p_1 + Y_1*q_1 + Z_1*r_1= S_{10}$;$X_2*p_1 + Y_1*q_1 + Z_2*r_1= S_{11}$; $X_2*p_1 + Y_1*q_1 + Z_3*r_1= S_{12}$
$X_2*p_1 + Y_2*q_1 + Z_1*r_1= S_{13}$;$X_2*p_1 + Y_2*q_1 + Z_2*r_1= S_{14}$; $X_2*p_1 + Y_2*q_1 + Z_3*r_1= S_{15}$
$X_2*p_1 + Y_3*q_1 + Z_1*r_1= S_{16}$;$X_2*p_1 + Y_3*q_1 + Z_2*r_1= S_{17}$; $X_2*p_1 + Y_3*q_1 + Z_3*r_1= S_{18}$
$X_3*p_1 + Y_1*q_1 + Z_1*r_1= S_{19}$;$X_3*p_1 + Y_1*q_1 + Z_2*r_1= S_{20}$; $X_3*p_1 + Y_1*q_1 + Z_3*r_1= S_{21}$
$X_3*p_1 + Y_2*q_1 + Z_1*r_1= S_{22}$;$X_3*p_1 + Y_2*q_1 + Z_2*r_1= S_{23}$; $X_3*p_1 + Y_2*q_1 + Z_3*r_1= S_{24}$
$X_3*p_1 + Y_3*q_1 + Z_1*r_1= S_{25}$;$X_3*p_1 + Y_3*q_1 + Z_2*r_1= S_{26}$; $X_3*p_1 + Y_3*q_1 + Z_3*r_1= S_{27}$

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

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 .If any solution S_i>ϕ, than result will be accepted otherwise result will be rejected.

The sequence <S_i> of accepted solution will be given in descending order of their values. The set of solutions is {S_1, S_2, S_3,………, S_{27}} and <S_i>may contain less than 27 accepted solutions in which first solution is inferior and last is most superior.{ S_{i1}, S_{i2}, S_{i3}………………………S_{i27}}

Sample Problem

The system is designed for fuzzy input variables .The valueof 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}=50, 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

Solution of Problem

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.

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

$X_1*p_1 + Y_1*q_1 + Z_1*r_1=50*0.6+0.10*0.3+0.20*0.1=30.050=S_1$
$X_1*p_1 + Y_1*q_1 + Z_2*r_1= 50*0.6+0.10*0.3+0.21*0.1 =30.051=S_2$
$X_1*p_1 + Y_1*q_1 + Z_3*r_1=50*0.6+0.10*0.3+0.22*0.1 =30.052= S_3$
$X_1*p_1 + Y_2*q_1 + Z_1*r_1=50*0.6+0.11*0.3+0.20*0.1 =30.053= S_4$
$X_1*p_1 + Y_2*q_1 + Z_2*r_1=50*0.6+0.11*0.3+0.21*0.1 =30.054= S_5$
$X_1*p_1 + Y_2*q_1 + Z_3*r_1=50*0.6+0.11*0.3+0.22*0.1 =30.055= S_6$
$X_1*p_1 + Y_3*q_1 + Z_1*r_1= 50*0.6+0.12*0.3+0.20*0.1 =30.056=S_7$
$X_1*p_1 + Y_3*q_1 + Z_2*r_1= 50*0.6+0.12*0.3+0.21*0.1 =30.057=S_8$
$X_1*p_1 + Y_3*q_1 + Z_3*r_1= 50*0.6+0.12*0.3+0.22*0.1 =30.058=S_9$
$X_2*p_1 + Y_1*q_1 + Z_1*r_1= 90*0.6+0.10*0.3+0.20*0.1 =54.050=S_{10}$
$X_2*p_1 + Y_1*q_1 + Z_2*r_1=90*0.6+0.10*0.3+0.21*0.1 =54.051= S_{11}$
$X_2*p_1 + Y_1*q_1 + Z_3*r_1=90*0.6+0.10*0.3+0.22*0.1 =54.052= S_{12}$
$X_2*p_1 + Y_2*q_1 + Z_1*r_1=90*0.6+0.11*0.3+0.20*0.1 =54.053= S_{13}$
$X_2*p_1 + Y_2*q_1 + Z_2*r_1=90*0.6+0.11*0.3+0.21*0.1 =54.054= S_{14}$
$X_2*p_1 + Y_2*q_1 + Z_3*r_1= 90*0.6+0.11*0.3+0.22*0.1 =54.055=S_{15}$
$X_2*p_1 + Y_3*q_1 + Z_1*r_1= 90*0.6+0.12*0.3+0.20*0.1 =54.056=S_{16}$
$X_2*p_1 + Y_3*q_1 + Z_2*r_1=90*0.6+0.12*0.3+0.21*0.1 =54.057= S_{17}$
$X_2*p_1 + Y_3*q_1 + Z_3*r_1= 90*0.6+0.12*0.3+0.22*0.1 =54.058=S_{18}$
$X_3*p_1 + Y_1*q_1 + Z_1*r_1=120*0.6+0.10*0.3+0.20*0.1 =72.050= S_{19}$
$X_3*p_1 + Y_1*q_1 + Z_2*r_1= 120*0.6+0.10*0.3+0.21*0.1 =72.051= S_{20}$
$X_3*p_1 + Y_1*q_1 + Z_3*r_1= 120*0.6+0.10*0.3+0.22*0.1 =72.052=S_{21}$
$X_3*p_1 + Y_2*q_1 + Z_1*r_1=120*0.6+0.11*0.3+0.20*0.1 =72.053= S_{22}$
$X_3*p_1 + Y_2*q_1 + Z_2*r_1= 120*0.6+0.11*0.3+0.21*0.1 =72.054=S_{23}$
$X_3*p_1 + Y_2*q_1 + Z_3*r_1= 120*0.6+0.11*0.3+0.22*0.1 =72.055= S_{24}$
$X_3*p_1 + Y_3*q_1 + Z_1*r_1= 120*0.6+0.12*0.3+0.20*0.1 =72.056=S_{25}$
$X_3*p_1 + Y_3*q_1 + Z_2*r_1=120*0.6+0.12*0.3+0.21*0.1 =72.057=S_{26}$
$X_3*p_1 + Y_3*q_1 + Z_3*r_1= 120*0.6+0.12*0.3+0.22*0.1 =72.058=S_{27}$

RESULT

The set of normalized weight of solutions(in ascending order) is { $S_1, S_2, S_3, S_4, S_5, S_6, S_7, S_8, S_9, S_{10}, S_{11}, S_{12}, S_{13}, S_{14}, S_{15}, S_{16}, S_{17}, S_{18}, S_{19}, S_{20}, S_{21}, S_{22}, S_{23}, S_{24}, S_{25}, S_{26}, S_{27}$}

Use of Threshold Value

A threshold value denoted by ϕ is considered according to the choice of decision maker. Suppose its value is 70, that means if any S_i>70 than result will be accepted otherwise it will be rejected. The sequence of accepted normalize weight of solutions will be given in ascending order of their values. The sequence of normalize weight of solutions is{$S_{19}, S_{20}, S_{21}, S_{22}, S_{23}, S_{24}, S_{25}, S_{26}, S_{27}$}.

Modeling of Data Using Fuzzy Logic Approach

Since, {S_{19} ………… S_{27}} are the accepted normalize 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.

Assigning membership functions to each linguistic variable in MATLAB using fuzzy logic

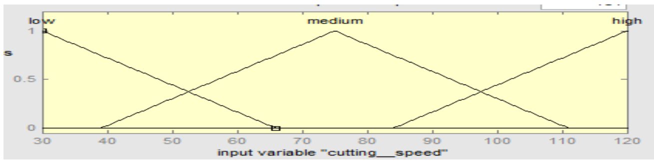

Figure (1a). Cutting Speed vs. Membership Function

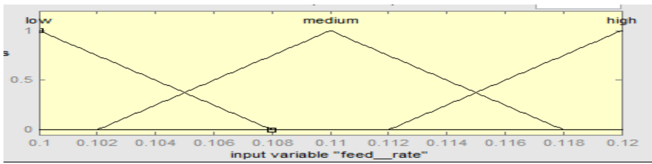

Figure (1b). Feed Rate vs. Membership Function

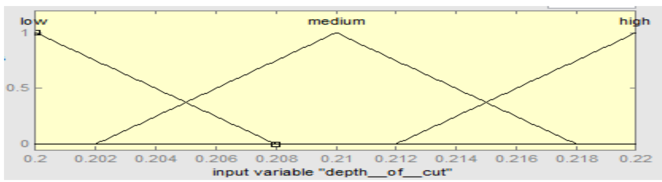

Figure (1c). Depth of Cut vs. Membership Function

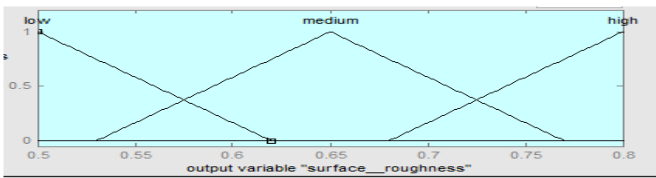

Figure (1d). Surface Roughness vs. Membership Function

Creating Fuzzy Rule Base

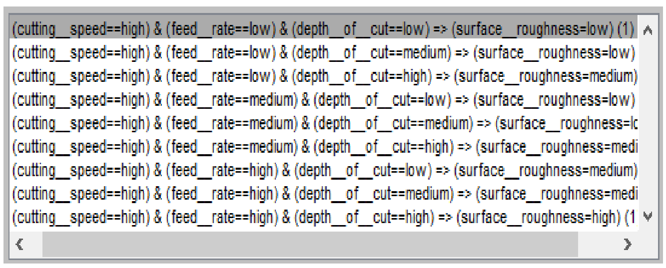

Figure (2) Fuzzy Rule Base Created In MATLAB

Fuzzy Rule Viewer

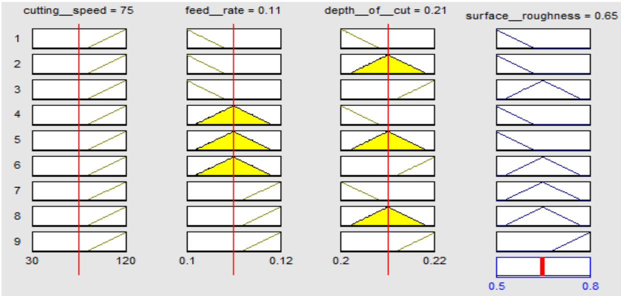

Figure (3a) Rule Viewer of Fuzzy Rule Base

Optimum result obtained by proposed fuzzy logic model in figure (4)

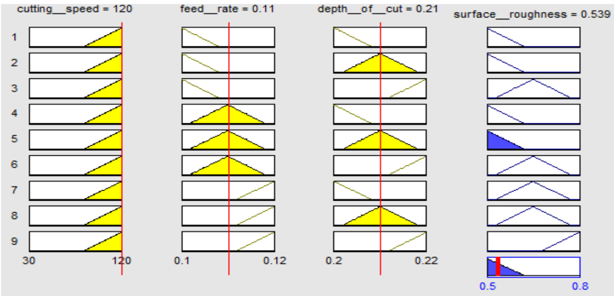

Figure (4a). Optimum Values of V= 120m/min, FR=0.11mm/rev, DOC=0.21mm Yields R_a = 0.539 µm

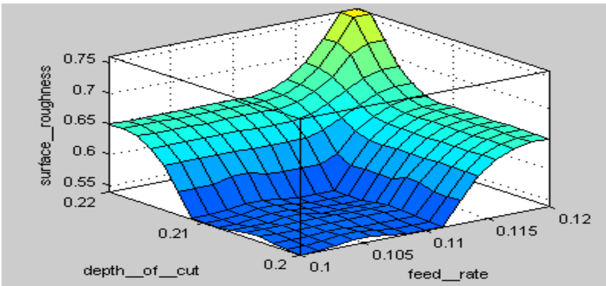

Figure (4b). Surface View of Optimum Result

Conclusion

A fuzzy logic approach has been applied to study the effect of various cutting parameters in turning of components subjected to hard-facing process. Whereas 27 rules were obtained using fuzzy logic but the weighted compensatory operator made it possible to reduce the number of these rules to 9 only. This, in turn, reduce the time consumed in making the rule base in the fuzzy logic system. As a result of these productivity may be enhanced. The optimum surface roughness 0.539µm was obtained at the cutting speed 120m/s, feed rate 0.11mm/rev. and depth of cut 0.21mm. As a future work some more linguistic variables such as tool geometry, tool wear mechanism etc. may also be used or incorporated.

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