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# Fuzzy Expert System Design for Determining Wearing Properties of Nitrided and Non Nitrided Steel

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***Abstract*—**This paper proposes a Fuzzy Expert System design to determine the wearing properties of nitrided and non nitrided steel. The proposed Fuzzy Expert System approach helps the user and the manufacturer to forecast the wearing properties of nitrided and non nitrided steel under specified laboratory conditions. Surfaces of the engineering components are often nitrided for improving wear, corosion, fatigue specifications. A major property of nitriding process is reducing distortion and wearing of the metalic alloys. A Fuzzy Expert System was developed for determining the wearing and durability properties of nitrided and non nitrided steels that were tested under different loads and different sliding speeds in the laboratory conditions.

**Keywords**—Fuzzy Expert System Design, Rule Based Systems, Fatigue,Corrosion

## I. INTRODUCTION

TODAY, lots of mechanical systems operate in severe and difficult conditions and wearing of the metallic systems is a significant problem for mechanical manufacturing industry. Designers develop their metallic systems by doping different elements to stretch the limits of endurance and wearing properties of metallic alloys to overcome the problems of wearing on the metallic mechanical parts [1]. One of the techniques used for this problem is Nitriding (a surface treatment technique) used to introduce nitrogen into metallic materials to improve their surface hardness, mechanical properties, wear and corrosion resistance, as well as life [2]. Salth Bath Nitrocarbuzing improves the wear resistance properties of the metallic alloys and compounds and also this process helps the designer to improve the metallic fatigue strength and corrosion resistance by means of adding iron nitrid compounds to the surface of metallic systems. For the reasons mentioned above the "Nitriding" process is one of the most widely used thermo-chemical methods which produce durable and shallow case with high compressive residual stresses on the surface of steel components such as gears, crankshafts, dies and tools [3]. When used for a long time, lots of metallic machine components enter the threat zone of fatigue failure and for overcoming this fatigue and wearing problem, nitriding process is performed on the sensitive surfaces of the metallic alloys to form a protective layer [4]. A Fuzzy Expert System based software was constructed for determining the wearing weight loss of nitrided and non nitrided AISI 5140 type steel under the specified laboratory conditions. The applied load and the sliding speed (m/s) were accepted as the input parameters and the wearing property (weight loss (g)) of nitrided and non nitrided AISI 5140 type steel were accepted as the output parameters. The Rule Base of the FES (Fuzzy Expert System) consists of 25 rules and the rules were constructed by the help of the experimental results that showed the wear characteristics of salt bath nitrided AISI 5140 steel and non-heat treated AISI 5140 steel under the test conditions of block-on-cylinder test system located in dry conditions. In this study, a FES based software was developed for determining the wear characteristics of a salt bath nitrided AISI 5140 steel and non-heat treated AISI 5140 steel with block-on-cylinder test system in dry conditions.

## II. RESEARCH METHOD

In the laboratory tests made for determining the wearing properties of nitrided and non nitrided steels, different loads with different sliding speeds were applied to the test materials placed in a block on cylinder test system. The cylinder on the wearing test mechanism was rotated with different sliding speeds with the specified load for testing the wearing properties of test materials. The general structure of the FES (Fuzzy Expert System) that determines the wearing properties (the weight loss) of nitrided and non nitrided AISI 5140 type under laboratory test conditions. The applied load and the speed of rotation were accepted as the input parameters of Fuzzy Expert Determination System. The weight losses of the nitrided and non nitrided AISI 5140 type steel were accepted as the output parameters. The block on cylinder test mechanism was used for determining the wearing properties of nitride and non nitrided AISI 5140 type steel. The block on cylinder test mechanism was used for 1000 m of sliding distance for different sliding speeds and applied loads. The wearing properties of nitrided and non nitrided AISI 5140 type steel were investigated by the help of the laboratory tests and developed FES software gave successful results for determining wearing weight losses of nitrided and non nitrided AISI 5140 type steels.

The input variables were defined by five linguistic degrees as "Very Low, Low, Medium, High and Very High" and these linguistic degrees were expressed by the abbreviations "VL, L M, H and VH" respectively. The output variables were defined by seven linguistic degrees as "Extremely Low, Very Low, Low, Medium, High, Very High and Extremely High". And these linguistic variables were abbreviated as "EL, VL, L, M, VH and EH". Rule base was developed according to the laboratory experimental results. Mamdani inference system was used as the Inference Method and Centroid Method was used for defuzzification mechanism.

## III. The General Structure Of Fuzzy Expert System

A fuzzy expert system consists of four main parts. These parts can be listed as the fuzzifier, fuzzy rule base, fuzzy inference system and defuzzifier [6]. In the fuzzification process fuzzifier part uses membership functions to convert the crisp input values to fuzzified linguistic values as low, medium, high etc [7]-[8]. The usage of fuzzy expert and decision systems are increasing because fuzzy logic supplies human thinking and intuition system [9]-[10]. The general structure of the fuzzy expert system is shown in the Figure 1. In the Figure 2 membership functions of the FES are shown. The mathematical functions of the membership functions and the rule table were constructed with the help of the experimental results. The Figure 2.a depicts the “Applied Load” and Figure 2.b depicts “The Speed of Rotation”. Figure 2.c and 2.d shows the membership function of the output variables which are depicting the wearing weight loss (g) of the Nitrided and Non Nitrided AISI 5140 type steel. The membership functions of the input variables are depicted by five linguistic degrees named as “Very Low, Low, Medium, High and Very High”. The output membership functions are depicted by seven linguistic degrees named as “Exremely Low, Very Low, Low, Medium, High, Very High, Exteremely High.

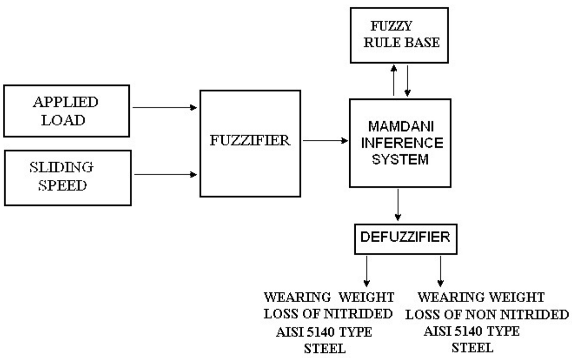
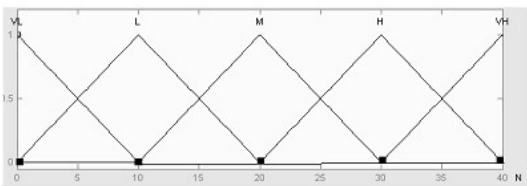
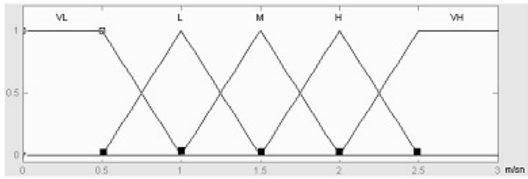


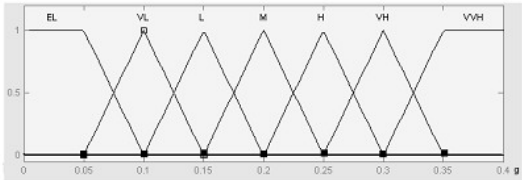

Fig. 1 The membership functions of the fuzzy expert system



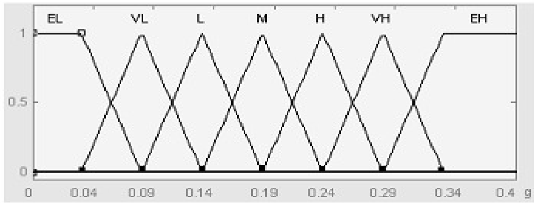

a. The membership functions of the Applied Load (Newton)




b. The membership functions of the Sliding Speed (m/sn)




c. The membership functions of the fist output variable named as the wearing weight loss of non nitrided AISI 5140 type steel




d The membership functions of the second output variable named as the wearing weight loss of nitrided AISI 5140 type steel

Fig. 2 The membership functions of input and output variables of Fuzzy Expert System.

## IV. The Rule Base Of Constructed Fuzzy Expert System

The rule base of the constructed fuzzy expert system consists of 25 rules and the rules were constructed according to the experimental results and the wearing property of AISI 5140 type steel. Some of the rules are shown below.

Rule 1 If applied load is very low and sliding speed is very low then the wearing weight loss of non nitrided AISI 5140 type steel is very low and the wearing weight loss of nitrided AISI 5140 type steel is extremely low.

Rule 3 If applied load is very low and sliding speed is medium then the wearing weight loss of non nitrided AISI 5140 type steel is low and the wearing weight loss of nitrided AISI 5140 type steel is very low.

Rule 5 If applied load is very low and sliding speed is very high then the wearing weight loss of non nitrided AISI 5140 type steel is high and the wearing weight loss of nitrided AISI 5140 type steel is medium.

Rule 8 If applied load is low and sliding speed is medium then the wearing weight loss of non nitrided AISI 5140 type steel is medium and the wearing weight loss of nitrided AISI 5140 type steel is low.

Rule 14 If applied load is medium and sliding speed is very high then the wearing weight loss of non nitrided AISI 5140 type steel is very high and the wearing weight loss of nitrided AISI 5140 type steel is high.

Rule 22 If applied load is very high and sliding speed is low then the wearing weight loss of non nitrided AISI 5140 type steel is high and the wearing weight loss of nitrided AISI 5140 type steel is medium.

Rule 25 If applied load is very high and sliding speed is very high then the wearing weight loss of non nitrided AISI 5140 type steel is extremely high and the wearing weight loss of nitrided AISI 5140 type steel is very high.

## V. The Mamdani Inference Mechanism

Mamdani Inference Mechanism was used as the selected Inference Mechanism for developing the fuzzy expert system because best results were obtained by this inference system when compared with other inference mechanisms. In this inference system the implication operator is accepted as "minimum" and the aggregation operator is accepted as "maximum". In the implication step of the system of this inference system, the minimum of the fuzzified values of the inputs are taken for all the fired rules. In the aggregation step, maximum operator is applied to the rule lines which have the same output linguistic variable. The Mamdani Inference System can be expressed by the equations 1-4 [11]-[12].

R If x is Ai and y is Bi then z = C
İ= 1, 2…..n x ∈ U

$$\alpha_i = \mu_{Ai}(x_o) \wedge \mu_{Bi}(y_o) .... \quad ..............(1)$$

$$\mu_{CI}(z) = \alpha_i \wedge \mu_{Ci}(z) \quad ..............(2)$$

The total result is obtained by the fired rules of the Fuzzy Infrence System

$$\mu C'(z) = \vee_{i=1}^{i=n} [\alpha_i \wedge \mu_{Ci}(z)] \quad .........................Eq(3)$$

$$C' = \bigcup_{I=1}^{n} C'_i \quad .......................... Eq(4)$$

## VII. The Centroid Defuzzifier

The last step of the Fuzzy Expert Sytem is defuzzification process.The defuzzification process is used for obtaining a crisp output value from Fuzzy Expert Sytem. Centroid defuzzifier is used as defuzzifier operator because optimum results were obtained by this defuzzificatioın mecahnism when compared with other defuzzification mechanisms [11]. The centroid defuzzifier calculates the center of gravity of the union of the area of the output membership functions formed by the triggered rules of FES rule base [12]-[13]. In the centroid defuzzifier the overlapping areas are taken once. In this study we used the centroid method for getting the optimum desired resultant crisp values. The centroid defuzzification system is depicted by the Eq. 5 shown below. In the equation 5 below, "μ" represents the membership function of the output variables [14].

$$Center\ Of\ Gravity = \frac{\int_a^b \mu(x) x\, dx}{\int_a^b \mu(x)\, dx} \quad ............................Eq.5$$

## VI. Results And Conclusions

The results derived from the FES were approximately the same as the results obtained from the laboratoty experiments with the tolerance ±2%. The two dimensional Figures shown in Figure 3-4 depict the difference between the output values "the weigt loss of the nitrided and the non nitrided" according to the input variables named as the sliding speed and applied load. In the laboratory tests and the constructed predicting FES, the real and calculated weight loss of the nitrided AISI 5140 type is less than the non nitrided AISI 5140 type steel. In the Figure 3, the wearing weight loss of non nitrided AISI 5140 type steel versus the input variables sliding speed and the applied load is shown and in the Figure 4, the wearing weight loss of non nitrided AISI 5140 type steel versus the input variables sliding speed and the applied load is shown . Table 1 shows the comparison between the results calculated by the FES software and the laboratory experiments made for determinming the wearing properties of nitrided and non nitrided steel.

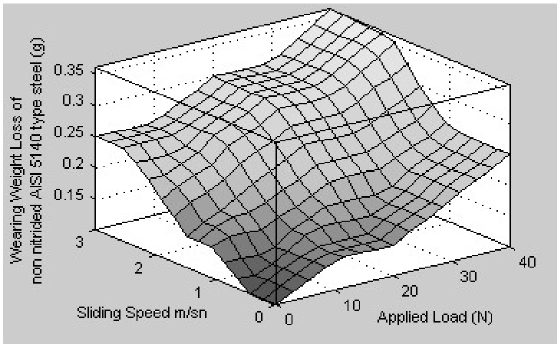



Fig. 3 The wearing weight loss of non nitrided AISI 5140 type steel versus the input variables sliding speed (m/s) and the applied load (N)

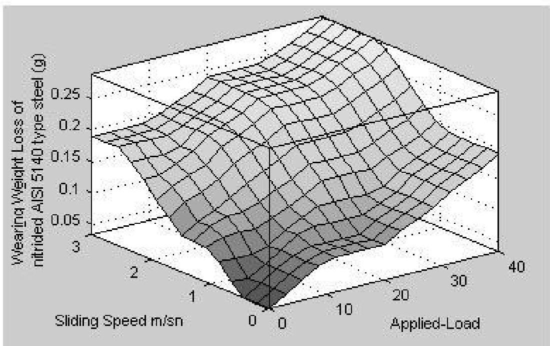



Fig. 4 The wearing weight loss of nitrided AISI 5140 type steel versus the input variables sliding speed (m/s) and the applied load (N)

TABLE I
THE COMPARISON BETWEEN THE RESULTS CALCULATED BUY THE FES AND THE LABORATORY EXPERIMENTS MADE FOR DETERMINMING THE WEARING PROPERTIES OF NITRIDED AND NON NITRIDED STEEL

| | Applied Load (N) | Sliding Speed (m/sn) | Non Nitrided AISI 5140 type steel (g) (FES) | Nitrided AISI 5140 type steel (g) (FES) | Non Nitrided AISI 5140 type steel (g) (Lab.) | Nitrided AISI 5140 type steel (g) (Lab.) |
|---|---|---|---|---|---|---|
| 1 | 20 | 1.5 | 0,25 | 0,19 | 0,24 | 0,19 |
| 2 | 12 | 2,5 | 0,262 | 0,202 | 0,25 | 0,2 |
| 3 | 30 | 2,5 | 0,3 | 0,24 | 0,28 | 0,23 |
| 4 | 8 | 2,5 | 0,25 | 0,19 | 0,24 | 0,18 |
| 5 | 10 | 1.0 | 0,15 | 0,09 | 0,14 | 0.08 |
| 6 | 9 | 2 | 0,243 | 0,183 | 0,25 | 0,17 |
| 7 | 6 | 1.5 | 0,179 | 0,119 | 0,18 | 0,13 |
| 8 | 10 | 2 | 0,25 | 0,19 | 0,23 | 0,20 |
| 9 | 20 | 3.5 | 0,3 | 0,24 | 0,29 | 0,21 |
| 10 | 27 | 2.5 | 0,3 | 0,24 | 0,29 | 0,25 |

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