ANNALS of Faculty Engineering Hunedoara – International Journal of Engineering
Tome XIII [2015] – Fascicule 1 [February]
ISSN: 1584-2665 [print]; ISSN: 1584-2673 [online]
a free-access multidisciplinary publication of the Faculty of Engineering Hunedoara

[1.] Kharola ASHWANI

APPLICATION OF FUZZY LOGIC REASONING MODEL FOR DETERMINING ADHESIVE STRENGTH OF THIN FILM COATINGS

[1.] Govt. Of India, Ministry of Defence, Institute of Technology Management (ITM), Defence R&D Organisation, Uttarakhand, INDIA

Abstract: In this paper a new approach for determining the Adhesive Strength of thin film coating using fuzzy logic reasoning is proposed. This approach mainly focuses on nano and micro thin films using established International Standards for evaluating adhesion strength. The influence of various coating parameters on adhesion strength is considered. Modeling and Simulation is done in Matlab and the results are also shown in the end.
Keywords: Adhesive, Matlab-Simulink, ANFIS, Fuzzy inference system

1. INTRODUCTION

The emergence of the new field of nanotribology, which pertains to the experimental and theoretical investigations of interfacial processes occurring during adhesion, friction, wear and thin film lubrication of sliding surfaces on the scales ranging from the atomic and molecular scale to the microscale, and its associated techniques have provided a viable means of addressing the tribological issues on the nanoscale [1-3]. In recent industry, nano and micro-thin layers are a popular choice in many of its branches, for its practical adhesion as one of the most important mechanical properties, which is a key parameter for every coating [4,5]. The main purpose of the thin film coating application is to improve the surface properties of the materials while maintaining its bulk properties.

The two main challenging issues that needed to be encountered in the coating process are cost and optimisation [6]. The practical adhesion strength, i.e. the work done to separate the thin film from the substrate, is very sensitive to the measurement and evaluation conditions, such as the strain rate, roughness, thickness, etc[7].Scratch test was chosen from among a wide choice of adhesion strength measurement methods. The surfaces of samples in scratch tests undergo pulling a (mostly diamond) stylus against them under a normal force [8,9]. The recommended shape of stylus is spherical Rockwell C, 200 μm radius or alternatively a smaller one [10]. Progressive loading scratch test mode (PLST), constant load scratch test mode and multi-pass scratch test mode were modes of measurement used in the scratch tests [11]. Recently non-destructive evaluation (NDE) have become

Ubiquitous in manufacturing systems because the technology is an inexpensive and reliable method to measure product requirements [12].

Currently there are already in use internationally recognized industrial standards [13] for evaluating adhesion of macro and micro-layers. The scratch test procedures are described in the national/international standards, which are usually enforced also in the European, American, Japanese or other national standards [14,15]. The standards are designed for a wide range of different coating materials. The most important standards for quantitative single point scratch testing are shown in Table 1.0

Table 1. Standards for quantitative single point scratch testing

S.NO	STANDARD	PURPOSE
1	ISO 1071-3	Test method for adhesion and other mechanical failure modes of thin advanced technical ceramics.
2	ISO 20502	Test method for adhesion of fine ceramics (advanced ceramics, advanced technical ceramics)
3	ISO N269	Test method for adhesion of fine ceramics coatings
4	ISO 1518	Test method for adhesion of paints and varnishes
5	ASTM C1624	Test method for adhesion strength and mechanical failure modes of ceramic coatings
6	ASTM D7027-05	Test method for evaluation of scratch resistance of polymeric coatings and plastics.
7	ASTM D7187	Test method for measuring mechanistic aspects of scratch/mar behaviour of paint coatings by nano scratching
8	JIS R 3255	Test method for adhesion of thin films on glass substrate

Table 2 presents the most important conditions for the evaluation according to these standards. The standards are designed mainly for macro-scratch testers, as these are commonly used to measure the nano- and micro-layers.

Table 2. Measuring conditions in accordance with appropriate international standards designed for nano and micro-films testing

	ISO 1071-3	C 1624-05	D7187
Film material	ceramic coating and other	ceramic coating	paint coating
Film thickness	to 20 μm	from 0.10 μm to 30 μm	to 500 nm
Preload	1 N	1 N for $L_{max} < 10$ N; 5 N for $L_{max} > 20$ N;	0.1 to 1 mN
Progressive loading scratch test mode – loading rate	100 N/min	10 N/min for $L_{max} < 20$ N; 100 N/min for $L_{max} > 20$ N; minimum 5 N/min	5 to 200 mN/min
Progressive loading scratch test mode – displacement speed	10±0.1 mm/min	10±0.1 mm/min	0.5 to 10 mm/min
Constant load scratch test mode – loading rate	20% of L_{max}	20%, 40%, 60%, 100% of L_{max}	–
Constant load scratch test mode – displacement speed	10 mm/min	10±0.1 mm/min	–
Multi-pass scratch test mode – loading rate	50% of L_{max}	–	–
Multi-pass scratch test mode – displacement speed	–	–	–
Stylus geometry	Rockwell C	Rockwell C	spherical, 1 to 100 μm
Surface roughness	$Ra < 0.5$ μm	$Rq < 1$ μm	–
Film hardness	–	$HV > 5$ GPa	–
Min. number of test operations	5×	5×	3×
Optical microscope	100 to 500×	100 to 500×	–
Temperature	22±2 °C	20±5 °C	23±2 °C
Relative humidity	50±10%	50±10%	50±5%

2. FUZZY REASONING APPROACH FOR THE EVALUATION OF ADHESION STRENGTH OF THE NANO AND MICRO FILMS

Fuzzy logic reasoning approach can be used as an effective tool for determining the Adhesion Strength of the nano and micro films. The existing International standards and knowledge of adhesion can be used as models/patterns for setting the fuzzy expert system, which could be used to identify the quality of practical adhesion strength. Also, artificial intelligence methods implemented in Matlab toolboxes [16] can be used in the process. The use of fuzzy logic, as a kind of "soft" computing techniques, enables us to overcome the problems encountered using "hard" computing techniques [17]. The basis for fuzzy logic is the basis for human communication [18]. The purpose of fuzzy control is to influence the behaviour of a system by changing an input or output to that system according to a rule or set of rules that model how the system operates [19]

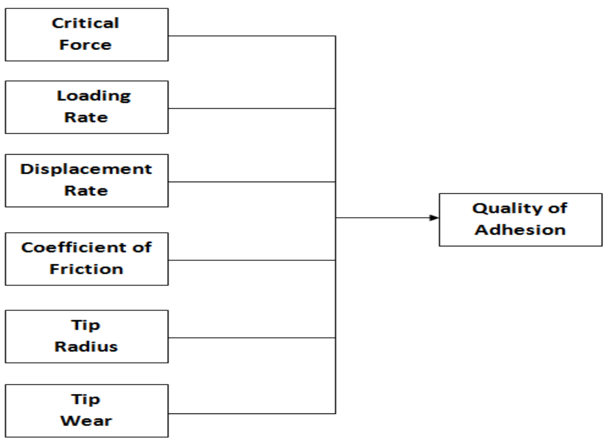

Figure 1. Structure of Fuzzy Inference System (FIS)

2.1. Designing of fuzzy reasoning model

The fuzzy expert system uses a fuzzy if-then rule base consisting of a set of intuitive fuzzy rules, interpreting an input and producing a crisp output. In this study output (quality of adhesion) is significantly influenced by the input variables, which are: critical force, coating thickness, loading rate, displacement rate, substrate roughness, coefficient of friction, tip radius, tip wear and tip damage. Figure 1.0 shows the structure of Fuzzy Inference System (FIS) created in Matlab using Fuzzy Logic Toolbox [20]

If we look at the figure 1 then we can see that inputs are combined to build Adhesion analysis. Structure of Fuzzy Inference System (FIS) in Fuzzy logic toolbox is shown in Figure 2.

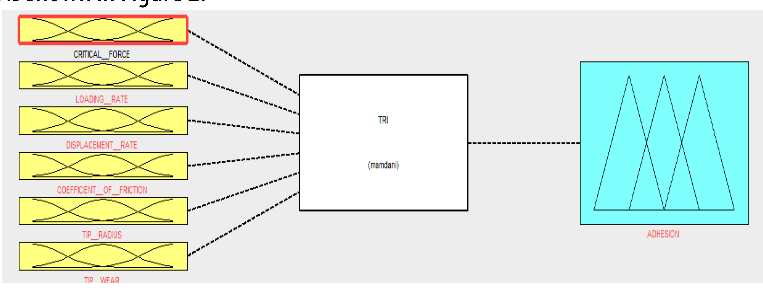

Figure 2. Structure of Fuzzy Inference System (FIS) in Fuzzy logic toolbox

2.2. Defining Universe of Discourse (UOD), Fuzzification of constraints and Membership function's (MF's)

In this research we have fuzzified each of the constraints i.e. Input/Output with four linguistic variables using triangular MF's. The MF's for each of the constraint along with UOD are shown in figure 2 to figure 9.

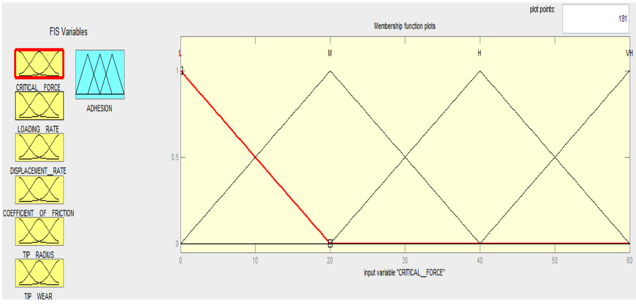

Figure 3. Fuzzified Input parameter 'Critical Force'

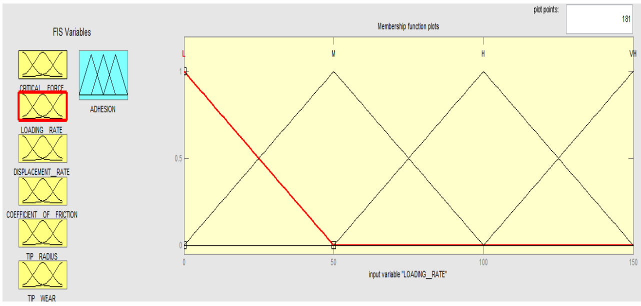

Figure 4. Fuzzified Input parameter 'Loading Rate'

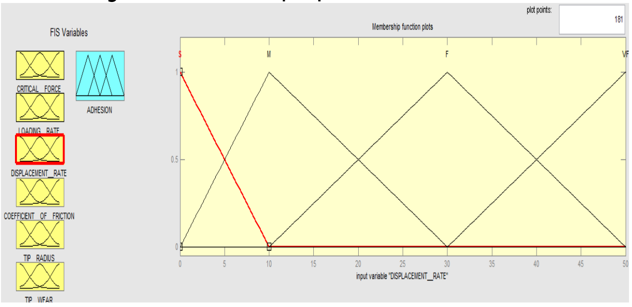

Figure 5. Fuzzified Input parameter 'Displacement Rate'

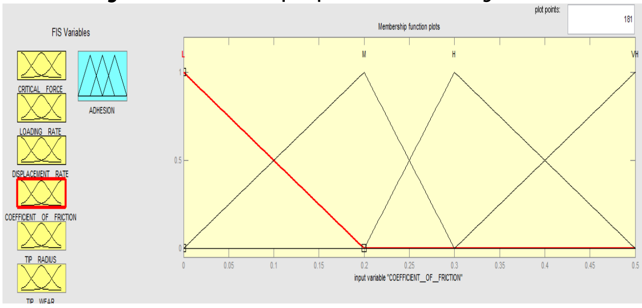

Figure 6. Fuzzified Input parameter 'Coefficient of Friction'

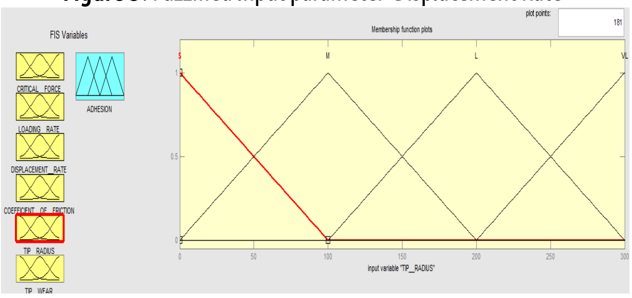

Figure 7. Fuzzified Input parameter 'Tip Radius'

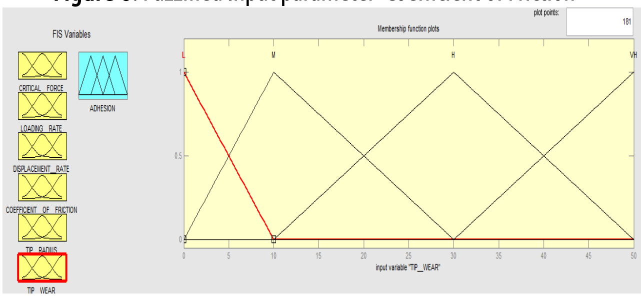

Figure 8. Fuzzified Input parameter 'Tip Wear'

2.3 Defining Fuzzy control rules

In this study we have used fuzzy ordinal approach [21] to develop fuzzy if then rules[22] which has significantly reduced the number of rules. The rules are given different degree of support (DOS) or weights which explains the relative importance of each rule[23]. The fuzzy rules are defined and based on experience of experts. The fuzzy control rules along with DOS for the controller are given below:

(1) If 'Critical Force' is 'Low' then 'Adhesion' is 'Poor' (1)
(2) If 'Critical Force' is 'Medium' then 'Adhesion' is 'Moderate' (1)
(3) If 'Critical Force' is 'High' then 'Adhesion' is 'Good' (1)
(4) If 'Critical Force' is 'Very High' then 'Adhesion' is 'Excellent'(1)
(5) if 'Loading Rate' is 'Low' then 'Adhesion' is 'Excellent'(0.2)
(6) if 'Loading Rate' is 'Medium' then 'Adhesion' is 'Good'(0.2)
(7) if 'Loading Rate' is 'High' then 'Adhesion' is 'Moderate'(0.2)
(8) if 'Loading Rate' is 'Very High' then 'Adhesion' is 'Poor'(0.2)
(9) if 'Displacement Rate' is 'Small' then 'Adhesion' is 'Poor' (0.2)
(10) if 'Displacement Rate' is 'Medium' then 'Adhesion' is 'Moderate'(0.2)
(11) if 'Displacement Rate' is 'Fast' then 'Adhesion' is 'Good' (0.2)
(12) if 'Displacement Rate' is 'Very Fast' then 'Adhesion' is 'Excellent' (0.2)
(13) if 'Tip Radius' is 'Small' then 'Adhesion' is 'Excellent'(0.3)
(14) if 'Tip Radius' is 'Medium' then 'Adhesion' is 'Good'(0.3)
(15) if 'Tip Radius' is 'Large' then 'Adhesion' is 'Moderate'(0.3)

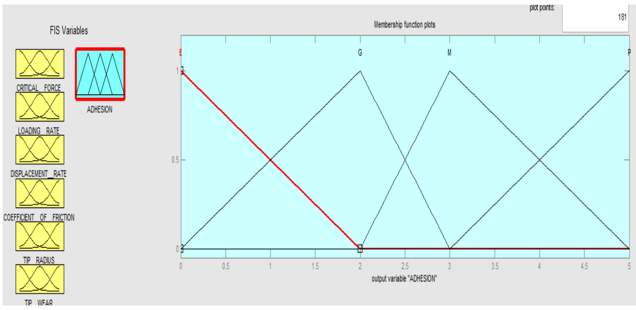

Figure 9. Fuzzified Output parameter 'Adhesion Strength'

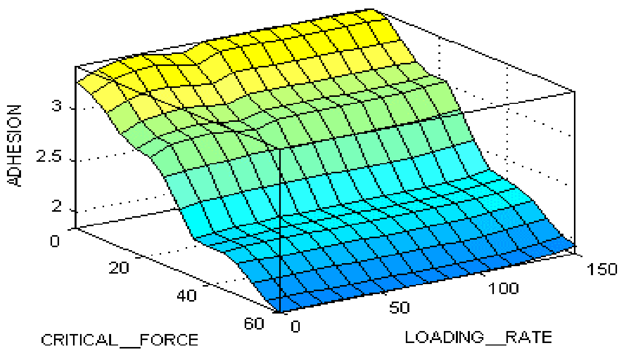

Figure 10. A Surface Viewer for FIS

(16) if 'Tip Radius' is 'Very Large' then 'Adhesion' is 'Poor'(0.3)
(17) if 'Tip Wear' is 'Low' then 'Adhesion' is 'Excellent'(0.4)
(18) if 'Tip Wear' is 'Medium' then 'Adhesion' is 'Good'(0.4)
(19) if 'Tip Wear' is 'High' then 'Adhesion' is 'Moderate'(0.4)
(20) if 'Tip Wear' is 'Very High' then 'Adhesion' is 'Poor'(0.4)

As can be seen from above there are total 20 rules. As an example consider rule number 6. In this rule if 'Loading Rate' is 'Medium' then 'Adhesion' is 'Good' with DOS equal to 0.2.

A Surface Viewer for FIS is shown in Figure 10 which demonstrates the relationship between the input variables Critical force, loading rate and output variable Adhesion strength.

As can be seen from the figure 1.9 if we have numerical value of Critical force and Loading rate in the scale of 0-60 and 0-150 respectively, then we can get the value of Adhesive strength in the range of 0-5.

3. SIMULATION RESULTS

Results of simulations for different set of Inputs i.e. critical force (a), Loading rate (b), Displacement rate (c), Coefficient of friction (d), Tip radius (e) and Tip wear (f) are shown below:

Set 1: a=20; b=50; c=10; d=0.2; e=100; f=25 (Figure 11); Set 2: a=50; b=100; c=30; d=0.3; e=200; f=50 (Figure 12);

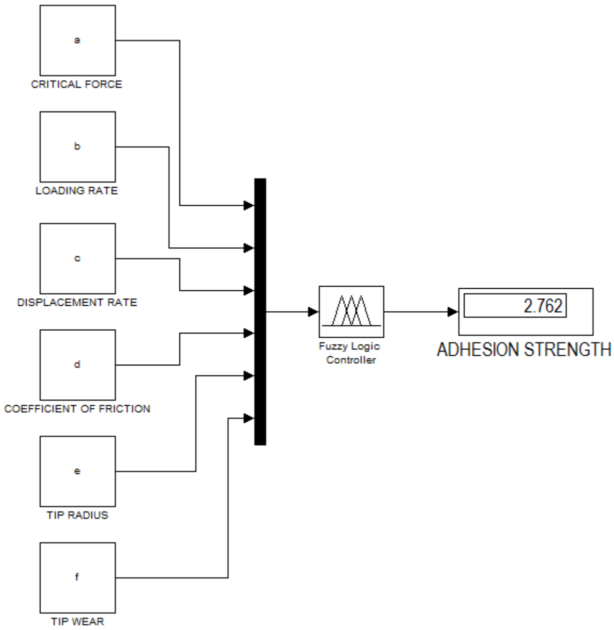

Figure 11. Simulation results

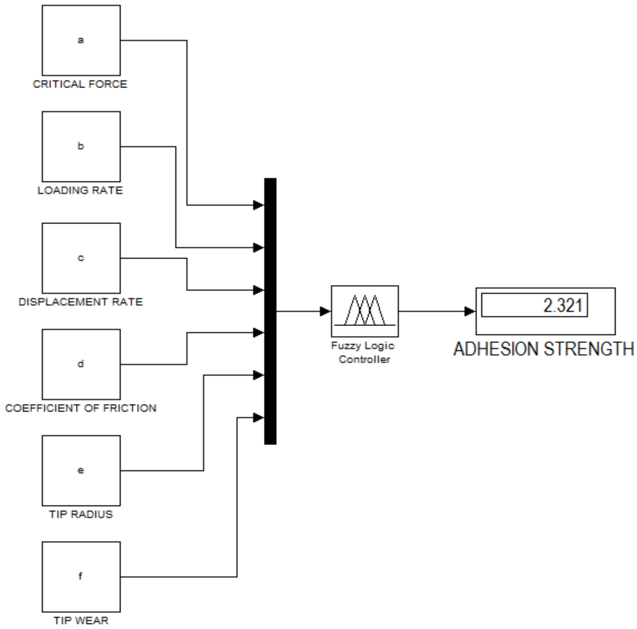

Figure 12. Simulation results

4. CONCLUSION

A new approach for evaluation of Adhesive Strength of nano and micro thin films using fuzzy logic reasoning has been proposed. The fuzzy reasoning provides a logical approach to adhesive strength evaluation. The fuzzy ordinal approach proves to be an effective technique thus reducing the number of fuzzy If-then rules. A Matlab Simulink model has been developed and the proposed framework optimises the related constraints.

As an extension for future work Adaptive Neuro fuzzy inference system (ANFIS) approach can also be implemented which can learn through the training data and hence shows better results? We can also consider other constraints which further determine the Adhesive strength.

5. References

[1.] Nikhil S Tambe and Bharat Bhushan, "Nanoscale friction and wear maps", Phil. Trans. R. Soc. A (2008) 366, 1405–1424
[2.] B Bhushan. 1999a Handbook of micro/nanotribology, 2nd edn. Boca Raton, FL: CRC Press
[3.] B. Bhushan1999b Principles and applications of tribology. New York, NY: Wiley.
[4.] EN 1071-3, Advanced Technical Ceramics – Method of Test for Ceramic Coatings - Part 3: Determination of Adhesion and other Mechanical Failure Modes by a Scratch Test. Brussels: International Organization for Standardization, (2006).
[5.] International Standard ISO 20502: Fine Ceramics (Advanced Ceramics, Advanced Technical Ceramics) - Determination of Adhesion of Ceramic Coatings by Scratch Testing. Geneva: International Organization for Standardization, (2005).
[6.] Abdul Syukor Mohamad Jaya, Abd Samad Hasan Basari, Siti Zaiton Mohd Hashim, Habibollah Haron, Muhd. Razali Muhamad and Md. Nizam Abd. Rahman, "Application of ANFIS in Predicting of TiAlN Coatings Hardness", Australian Journal of Basic and Applied Sciences, 5(9): 1647-1657, 2011,ISSN 1991-8178

[7.] Vladimır Socha, Patrik Kutliek, Slavka Viteckova, "The evaluation of the practical adhesion strength of biocompatible thin films by fuzzy logic expert system and international standards", Journal of electrical engineering, vol. 64, NO. 6, 2013, 354–360
[8.] Standard C1624 (C1624-05) Test Method for Adhesion Strength and Mechanical Failure Modes of Ceramic Coatings by Quantitative Single Point Scratch Testing. Conshohocken: ASTM International, (2005).
[9.] Standard ASTM D7187, "Test Method for Measuring Mechanistic Aspects of Scratch/Mar Behaviour of Paint Coatings by a Nano scratching", Conshohocken: ASTM International, (2005).
[10.] P.Steinmann, H.Hintermann, "Adhesion of TiC and Ti(C,N) Coatings on Steel", J. Vac. Sci. Technol. 3 No. 6 (1985), 2394–2400.
[11.] J.Valli, "TiN Coating Adhesion Studies Using the Scratch Test Method", J. Vac. Sci. Technol. 3 No. 6 (1985), 2411–2414.
[12.] Jay Tillay Johnson, "Defect and thickness inspection system for cast thin films using machine vision and full-field transmission densitometry", A Thesis Presented to The Academic Faculty, School of George W. Woodruff School of Mechanical Engineering
[13.] Patrik kutilek, Jan miksovsky, "The procedure of evaluating the practical adhesion strength of new biocompatible nano- and micro-thin films in accordance with international standards", Acta of Bioengineering and Biomechanics*,* Vol. 13, No. 3, 2011
[14.] EN 1071-3, Advanced technical ceramics – Method of test for ceramic coatings – Part 3: Determination of adhesion and other mechanical failure modes by a scratch test, Brussels, 2006.
[15.] ASTM International, Standard ASTM D7187: Test Method for Measuring Mechanistic Aspects of Scratch/Mar Behaviour of Paint Coatings by a Nano scratching, Conshohocken, 2005.
[16.] S.Sivanandam, S.Sumathi, S.Deepa," Introduction to Fuzzy Logic Using MATLAB", Springer, Berlin, 2010.
[17.] L.Zadeh: Fuzzy sets, Information Control 8 (1965), 338–353.
[18.] V. K. Dwivedi, " fuzzy based decision making for selection of fluid film journal bearing, International Journal of Fuzzy Logic Systems (IJFLS) Vol.2, No.3, July 2012
[19.] Nabil Ibrahim El Sawalhi, "Modelling the Parametric Construction Project Cost Estimate using Fuzzy Logic", International Journal of Emerging Technology and Advanced Engineering Website: (ISSN 2250-2459, Volume 2, Issue 4, April 2012).
[20.] Fuzzy Logic Toolbox: User's Guide MathWorks, www.mathworks.com/help/pdf_doc/fuzzy/fuzzy.pdf
[21.] Asunobu Naitoh, Takeshi Furuhash and Yose Uchikawa, "A Variable Ordinal Structure Model for Fuzzy Reasoning and its Application to Decision Problem of Working Order" 1991 IEEE
[22.] Adnan Shaout and Jaldip Trivedi, "Performance Appraisal System Using a Multistage Fuzzy Architecture", International Journal of Computer and Information Technology (ISSN: 2279 – 0764) Volume 02– Issue 03, May 2013.
[23.] Dr. SB Singh , Ashwani Kharola, "Development of fuzzy logic model for performance rating (PR) of employee's", AMO - Advanced Modelling and Optimization, Volume 15, Number 3, 2013

ANNALS of Faculty Engineering Hunedoara – International Journal of Engineering