POLİTEKNİK DERGİSİ

JOURNAL of POLYTECHNIC

ISSN: 1302-0900 (PRINT), ISSN: 2147-9429 (ONLINE)
URL: http://dergipark.org.tr/politeknik

Stelit kaplamalı valf yüzeylerinin oda sıcaklığında ve 300 ^{0}C'de adhesif aşınma davranışının bulanık mantık yöntemi ile analizi

Analysis of adhesive wear behavior of stellite-coated valve surfaces at room temperature and 300 ^{0}C by fuzzy logic method

***Yazar (Author)**: Uğur ARABACI*

ORCID[1]: 0000-0003-4850-3275

Bu makaleye şu şekilde atıfta bulunabilirsiniz: Arabacı U., "Stelit Kaplamalı Valf Yüzeylerinin Oda Sıcaklığında ve 300 ^{0}C'de Adhesif Aşınma Davranışının Bulanık Mantık Yöntemi İle Analizi", ***Journal of Polytechnic***, 27(1): 419-427, (2024).

To cite to this article: Arabacı U., "Analysis Of Adhesive Wear Behavior Of Stellite-Coated Valve Surfaces At Room Temperature And 300 ^{0}C By Fuzzy Logic Method", ***Politeknik Dergisi***, 27(1): 419-427, (2024).

Erişim linki (To link to this article): http://dergipark.org.tr/politeknik/archive

DOI: 10.2339/politeknik.1427665

Stelit Kaplamalı Valf Yüzeylerinin Oda Sıcaklığında ve 300 ^{0}C'de Adhesif Aşınma Davranışının Bulanık Mantık Yöntemi İle Analizi

Analysıs of Adhesive Wear Behavıor of Stellite-Coated Valve Surfaces at Room Temperature and 300 ^{0}C by Fuzzy Logic Method

Highlights

- *Fuzzy Logic*
- *Stellite Coats*
- *Adhesive Wear*
- *Valves*
- *Wear Behaviour*

Graphical Abstract

With this study, it has been determined that experimental studies will yield results with the help of fuzzy logic without the need for intermediate experimental studies

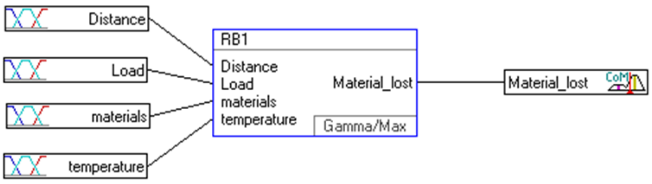


Figure 1: Structure of the Fuzzy Logic System

Aim

It is aimed to prove that fuzzy logic and experimental studies will support each other. (EN).

Design & Methodology

After the experimental studies on the main criteria were verified with fuzzy logic, the intermediate criteria were made entirely with fuzzy logic. made (EN).

Originality

In this study, attrition and fuzzy logic studies were evaluated together. (EN).

Findings

Experimental studies and fuzzy logic results completely coincide with each other. (EN).

Conclusion

When the experimental study results and fuzzy logic results are evaluated, the results of the experimental study in all criteria and the results obtained in the fuzzy logic studies conducted in connection with this support each otherXXX (EN).

Etik Standartların Beyanı (**Declaration of Ethical Standards**)

Bu makalenin yazar(lar)ı çalışmalarında kullandıkları materyal ve yöntemlerin etik kurul izni ve/veya yasal-özel bir izin gerektirmediğini beyan ederler. / The author(s) of this article declare that the materials and methods used in this study do not require ethical committee permission and/or legal-special permission.

Stelit Kaplamalı Valf Yüzeylerinin Oda Sıcaklığında ve 300°C'de Adhesif Aşınma Davranışının Bulanık Mantık Yöntemi İle Analizi

Araştırma Makalesi / Research Article

Uğur ARABACI[1]

[1]Metalurji ve Malzeme Mühendisliği Bölümü, Teknoloji Fakültesi, Gazi Üniversitres. Türkiye

(Geliş/Received : 13.12.2023 ; Kabul/Accepted : 02.02.2024 ; Erken Görünüm/Early View : 28.02.2024)

ÖZ

Çalışmam kapsamında, özellikle otomotiv valflinin üretiminde kullanılan çelik (1.4718) yüzeyi, Nikel 60 ve kobalt esaslı Stellite 1, Stellite 6, Stellite F alaşımları ile TIG kaynak yöntemiyle kaplanmıştır. Belirtilen kaynak parametreleri ile kaplanan numuneler, 4400 metre boyunca metal aşındırıcı disk üzerinde oda sıcaklığında ve 300 0C'de 10, 25 ve 40 N yükler altında aşındırılmıştır. Her 1100 metrede ağırlık kayıpları ölçülerek numunelerin aşınma dirençleri belirlenmeye çalışılmıştır. Deneysel çalışma sonuçları ile bulanık mantık tahminlerinin birbiriyle örtüştüğü, test edilmeyen ara değerlerde aşınma davranışının belirlenmesinde bulanık mantık tahminlerinin kullanılabileceği belirlenmiştir.

Anahtar Kelimeler: Bulanık mantık, valf kaplama, adhezif aşınma, TIG kaynağı, stelit kaplama.

Analysis Of Adhesive Wear Behavior Of Stellite-Coated Valve Surfaces At Room Temperature and 300°C By Fuzzy Logic Method

ABSTRACT

Within the scope of my study, the surface of steel (1.4718), especially used in the production of automotive valves, has been coated with Nickel 60 and cobalt-based Stellite 1, Stellite 6, Stellite F alloys using the TIG welding method. The samples coated with the specified welding parameters were subjected to abrasion tests on a metal abrasive disk for 4400 meters at room temperature and 300°C under 10, 25, and 40 N loads. Weight losses were measured at every 1100 meters to determine the wear resistance of the samples. The experimental results aligned with fuzzy logic predictions, indicating that fuzzy logic predictions could be used to determine wear behavior in untested intermediate values.

Keywords: Fuzzy logic, valve coating, adhesive wear, TIG welding, stellite coating.

1. INTRODUCTION

Numerous studies focus on enhancing the wear properties of materials, but these efforts often face limitations inherent in experimental methodologies. Wear tests, though foundational, are constrained by specific test criteria and working conditions [1-3]. To address these limitations, the fuzzy logic method is employed to broaden the criteria in obtaining experimental results. By establishing a foundation using data derived from predetermined experimental conditions, fuzzy logic facilitates the expansion of experimental study results across multiple criteria [4-6]. Artificial Intelligence (AI) methods are becoming increasingly prominent in diverse research fields, such as FSSW, owing to their outstanding performance, ease of implementation, and adaptability [7-10]. The framework for fuzzy logic control simplifies parameters by converting them into binary values, represented as 1 (true) or 0 (false) attributes. Fuzzy sets play a crucial role in classifying objects based on registration, adding significant value to prediction models. Fuzzy Logic Control Systems (FLCS) utilize guidelines for determining yields and are contingent on the probability of information states. If-Then rules are preferred for their efficacy in designing FLCS [11-13].

This study consists of two parts. In the first part, the experimental studies and their results will be examined, while in the second part, the intermediate values not found in the experiments will be evaluated with the fuzzy logic method. In the results part, the results obtained in the experimental studies and the intermediate value results obtained with fuzzy logic were compared and evaluated together.

In the experimental section of my study, the surfaces of steels coded as 1.4718 were coated with Stellite F, Stellite 1, Stellite 6, and cobalt-based Ni60 alloys using the TIG welding method. The wear properties of the coatings were attempted to be determined by evaluating the results of experiments conducted at different loads

**Sorumlu Yazar Uğur ARABACI*
e-posta : uarabaci@gazi.edu.tr

and abrasion distances, microstructure photographs, XRD analyses, hardness, and Scanning Electron Microscope (SEM). Subsequently, predictions for untested intermediate values were generated using a fuzzy logic system prepared based on the results of the experimental study.

1.1. Literature Studies

Fuzzy logic is extensively employed to support experimental studies, determine intermediate values, and regulate experimental outcomes. Consequently, it finds widespread usage in academic research.

In a study conducted by Maha M. A. Lashin and others, a fuzzy logic controller has been developed. They attempted to optimize the power of friction stir spot welding (FSSW) by managing welding parameters. In this study, the design of two fuzzy models aimed to enhance the strength of FSSW in Al 1050 alloy. One of these models monitors static, while the other monitors dynamic welding parameters. The results obtained by fuzzy logic indicate that it is a suitable technology for predicting and optimizing the strength of FSSW, both in terms of cost and accessibility. The obtained results emphasize the effectiveness and sufficiency of the proposed fuzzy logic control systems [14].

In the study conducted by P.M. Rudenko et al., an analysis of the fundamental parameters of rail welding was performed using data obtained from reports generated by the computer control system during the rail welding process. Various statistical analysis methods, including correlation and regression analysis based on welding process parameters, were utilized. As a result, a model predicting the output quality index of a welded rail, specifically focusing on the fracture load and deflection characteristics of the weld, was developed [15].

Kuchuk et al., in their research, suggested that Flash Butt Welding (FBW) of rails could be dynamically controlled within specified limits of key parameters. Thus, the control algorithm facilitated the real-time identification of subpar welding and unfavorable trends in the process at the lower level [16].

In a separate study, SI. Kuchuk-Yatsenko et al. discussed a contemporary approach to establishing a control system for the flash butt welding process of rails, utilizing statistical analysis of data characterizing the process. They emphasized that this analysis could reveal previously unknown and valuable interpretations of information (knowledge discovery in databases) crucial for decision-making in process control. The study delved into analyzing reasons that could lead to deviations in the technological process and subsequent degradation of the quality of welded butts. The authors proposed a two-level control system to identify these deviations [17].

In another study by SI. Kuchuk-Yatsenko et al., the authors highlighted that operational control of weld quality is a fundamental aspect of the entire rail production process. They applied real-time systems in practice and introduced a novel method utilizing fuzzy logic to analyze data from mechanical testing and ultrasound examination of connections [18].

Alghannam et al., in their investigation, initially manually measured 30 weld ingots to validate the accuracy of their proposed system in detecting the H.A.Z and fusion radii. The results affirmed the effectiveness of the proposed system in measuring size when the weld ingot shape is nearly circular. Additionally, they compared the topography of each sample with the corresponding 3D model generated by their proposed system, demonstrating high accuracy in detecting troughs, peaks, and side subtractions [19].

Na et al. developed an arc sensor for CO gas metal arc welding of butt joints using electrical signals obtained from the welding arc through fuzzy set theory. They implemented a straightforward fuzzy controller without resource coupling tracking adaptations. The study explored a self-organizing fuzzy controller capable of autonomously developing a set of fixed rules and control rules designed based on experiments [20].

In their research, Nweze et al. aimed to predict the percent dilution (%D) of TIG mild steel welds using fuzzy logic. The results indicated that the fuzzy logic tool serves as a reliable estimator, and the developed model proves to be highly efficient in handling such tasks, thereby saving time, energy, and costs associated with pre-welding procedures [21].

In their study, Bal et al. proposed a fuzzy logic-based switching hybrid controller structure in the MATLAB/Simulink program. They compared the proposed hybrid controller with the PID controller optimized using the Artificial Bee Colony Algorithm and with the results obtained from different controllers based on the Ziegler-Nichols method. Comparison criteria were determined as maximum overshoot amount, rise time and settling time [22].

In the study of Kocakulak and his colleagues, a pre-transmission parallel hybrid vehicle model was created in the MATLAB/Simulink environment. They developed a torque control strategy for the hybrid vehicle on the created model and provided the torque control of the hybrid vehicle with fuzzy logic and traditional rule-based control strategies[23].

In this study, 1.4718 steel material used in valve manufacturing in the automotive industry was coated with cobalt-based Stellite 1, Stellite F, Stellite 6, and Nickel 60 alloys by TIG welding method. The test specimens were abraded on a metal abrasive disc under different loads (10, 25, and 40 N) at room temperature and 300 0C. The wear behaviors of the specimens were examined by measuring the weight losses at regular intervals. A fuzzy logic system was prepared using the results obtained from the experimental studies. The fuzzy logic results were compared with the experimental results, and estimates were produced for the untested intermediate values. It is aimed to estimate the wear amount for the load, temperature, and distance values not used in the experiments.

2. MATERIALS AND METHOD

In this section, information on the experimental studies will be given first. Information about the materials used in the experiments and the test criteria are given. In the second part, studies with fuzzy logic will be evaluated. In

Table 1. the chemical composition of 1.4718 types of steel used in the experiments is given.

	C	Si	Mn	Cr	S
% Weight	0,43	2,73	0,47	8,71	0,001

2.1. Experimental Adhesive Wear Behaviors

Adhesive wear tests were carried out at room temperature using the pin-on disc method under 10, 25, and 40 N loads, which we determined based on previous studies on wear. In Table 2, the total wear loss values (x10-4 mg) depending on the friction distances of the samples and the applied load are given.

In the experiments, the weights of each sample were measured before the wear and after the experiments, these measurements were made again under each load and at the end of each distance, and the wear behavior of the samples was examined by the weight loss method. All the wear loss values obtained are given in the graphs (x10-4 mg). It was determined that the total weight loss in adhesive wear in all samples increased due to the increasing friction distance and the increase in the amount of applied load.

2.2. Analysis of Experimental Studies with Fuzzy Logic

Normally, the rules of a fuzzy controller system are derived from the system's internal structure and system behavior using expert knowledge who has experienced the system. However, it is not possible to derive fuzzy rules based on expert human knowledge for all systems. The need to use different methods to derive fuzzy rules in non-linear systems with highly variable behavior arises [24]. In this section, the results obtained as a result of the experiments were entered, and the data between certain test criteria values were tried to be determined. The experimental results given in Table 1 in the previous section, and the intermediate values in the table are studied with the fuzzy logic method. Intermediate values were entered in the applied load, ambient temperature, and wear distances with fuzzy logic and compared with the experimental values.

2.3. Project Description

Table 3. Project Statistics

Input Variables	4
Output Variables	1
Rule Blocks	1
Rules	192
Membership Functions	18

Table 2. Experimental adhesive wear total weight loss values depending on the load and friction distance of the samples.

		At room temperature			at 300 oC			
		Applied load (N)			Applied load (N)			
	Friction Distance (m)	**10**	**25**	**40**	**10**	**25**	**40**	
Stellite 1	**1100**	6	8	9	12	18	20	**Total weight loss (x10^{-4} mg)**
	2200	15	17	20	22	30	34	
	3300	22	24	28	26	35	42	
	4400	29	31	33	32	38	47	
Stellite F	**1100**	44	57	286	62	87	305	**Total weight loss (x10^{-4} mg)**
	2200	74	112	438	102	157	581	
	3300	100	162	530	143	225	773	
	4400	130	210	602	171	290	906	
Stellite 6	**1100**	10	13	21	14	19	32	**Total weight loss (x10^{-4} mg)**
	2200	19	27	35	22	39	50	
	3300	27	35	49	30	45	66	
	4400	33	41	57	39	59	78	
Nickel 60	**1100**	30	49	124	42	63	142	**Total weight loss (x10^{-4} mg)**
	2200	66	100	274	87	118	302	
	3300	94	137	372	124	161	412	
	4400	118	172	461	157	202	508	

2.4. System Structure

The flow from input variables to output variables is governed by the arrangement of the fuzzy logic system. Transforming analog inputs into fuzzy values occurs through fuzzification at the input interfaces. Rule blocks, which incorporate precise linguistic control rules, host the process of fuzzy inference. Linguistic variables are the result that emerges from these rule blocks. Specific linguistic variables at the output interfaces then undergo a defuzzification process, translating them back into analog variables. The figure below illustrates the comprehensive structure of the fuzzy system. Connecting lines represent the data flow within the system.

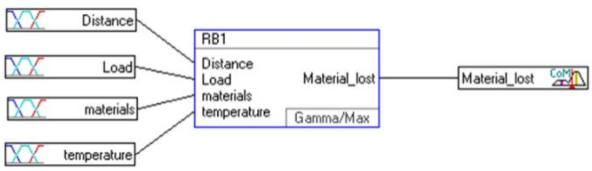


Figure 1. Structure of the Fuzzy Logic System.

2.5. Variables

Linguistic variables play a crucial role in translating real values into linguistic values within the system. The tables below provide a comprehensive list of all variables in the system, along with the corresponding fuzzification or defuzzification methods. Additionally, the properties of all base variables and their associated term names are detailed. The Compute MBF method was employed for the fuzzification process in this system. The inputs for the fuzzy logic system include distance, applied load, materials used, and temperature. In the experimental studies, the friction distances were 1100, 2200, 3300, and 4400 meters. However, in the fuzzy logic system used, the maximum and minimum limits of the distances were assumed as 1000 and 4500 meters, respectively. Similarly, the limits of the other inputs were enlarged. This is to ensure that the variables used remain within the experimental results (Table 4).

Table 4. Variables of Group "Inputs"

#	Variable Name	Type	Unit	Min	Max	Default	Term Names
1	Distance		Units	1000	4500	2200	Low medium_low medium_high high
2	Load		Units	5	45	25	low medium high
3	materials		Units	0	5	0	Stellite_1 Stellite_F Stellite_6 Nickel_60
4	temperature		C	0	320	0	low high

The output of this study is the material loss measured after the experiments. Thus, the output of the fuzzy system was arranged as material loss to compare the experimental and fuzzy results (Table 5).

Table 5. Variables of Group "Outputs"

#	Variable Name	Type	Unit	Min	Max	Default	Term Names
5	Material_lost	CoM	Units	0	950	20	very_low low medium high very_high

The default value of an output variable serves as a fallback if no rule is firing for that specific variable. The defuzzification process, which transforms linguistic variables into crisp values, can employ various methods, aiming to determine the 'most plausible result' or find the 'best compromise.' In this system, the CoM (Center of Maximum) method was employed for the defuzzification process. This method calculates the center of gravity of the aggregated fuzzy set, providing a means to obtain a single crisp output value from the linguistic variables.

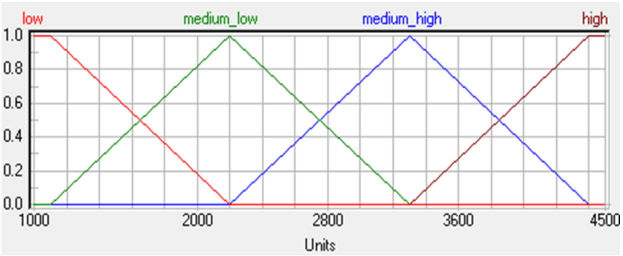


Figure 2. MBF of "Distance"

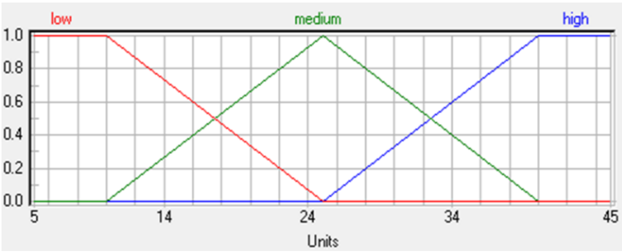


Figure 3. MBF of "Load"

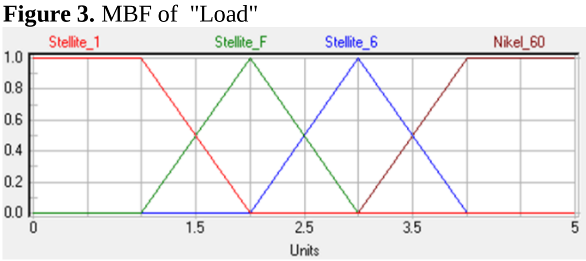


Figure 4. MBF of "materials"

2.6. Rule Blocks

In a fuzzy logic system, rule blocks encapsulate the control strategy, with each block housing rules for the same context. A context is established by the shared input and output variables of the rules within the block. The 'if' part of the rules articulates the situation for which they are designed, while the 'then' part specifies the response of the fuzzy system in that particular situation. To quantify the importance of each rule, the Degree of Support (DoS) is employed as a measure of its weight within the system. This weighting mechanism helps prioritize rules based on their relevance and significance in shaping the system's response.

3. CONCLUSIONS AND DISCUSSION

In this section, the wear values were tried to be estimated by entering intermediate values for both the distance and the applied loads, and then the accuracy was determined by comparing them with the real experimental data. In Table 6, the load criterion has been changed, and results with different intermediate values have been tried to be determined. In all fuzzy logic experiments, firstly, the results in real experimental conditions were verified, and then other intermediate values were started. For this reason, only fuzzy logic has been studied on stellite 1 and stellite F in Table 6. In Table 4, the test results are tried to be determined by taking intermediate values for the friction distances

Table 6. Wear loss values obtained by changing the applied load with the fuzzy logic method.

		At room temperature (20 °C)					**At 300 °C**				
		Applied load (N)					**Applied load (N)**				
	Friction Distance (m)	**10**	**17,5**	**25**	**32,5**	**40**	**10**	**17,5**	**25**	**32,5**	**40**
Stellite 1	**1100**	6,1	7,34	8,38	9,18	9,5	11,78	15,96	18,56	19,28	19,7
	2200	15,18	16,2	16,3	18,36	19,7	21,98	26,6	29,9	32,54	34,44
	3300	21,98	23,94	24,24	26,12	27,64	26,5	30,92	34,44	38,44	42,38
	4400	28,78	30,64	31,04	33,26	34,44	32,16	34,58	37,84	42,44	46,9
Stellite F	**1100**	43,5	51,92	56,38	176,92	287,1	61,64	72,54	82,04	110,6	306,12
	2200	74,08	90,02	112,62	282,54	436,94	102,42	119,88	157,58	367,68	580,28
	3300	99,02	121,66	162,66	343,62	529,68	143,22	204,48	223,62	499,02	774,44
	4400	129,62	184,16	210,92	399,44	602,16	170,28	252,1	289,64	597,72	905,84
Stellite 6	**1100**	9,5	10,66	11,78	17,9	20,84	14,04	17,14	19,7	28,04	32,16
	2200	19,7	23,54	26,5	30,92	34,44	21,98	33,4	38,96	45,02	50,3
	3300	26,5	30,92	34,44	44,34	48,04	29,9	38,98	44,64	58,26	66,16
	4400	33,3	37,38	41,24	51,96	57,1	38,96	51,98	58,24	69,56	78,62
Nickel 60	**1100**	29,9	43,24	48,04	83,08	123,96	42,38	55,66	62,76	93,9	143,22
	2200	66,16	81,66	99,02	203,12	274,42	87,7	98,56	118,28	228,14	305,04
	3300	93,36	106,32	136,42	235,54	384,56	123,96	136,5	160,12	279,36	408,22
	4400	118,28	142,72	172,82	311,82	449,64	158,38	184,02	200,76	344,08	507,8

Table 7. Wear loss values obtained by changing the applied temperature with the fuzzy logic method.

		At room temperature (20 oC)			**At 100 °C**			**At 200 °C**			**At 300 °C**		
		Applied load (N)			Applied load (N)			Applied load (N)			Applied load (N)		
	Friction Distance (m)	**10**	**25**	**40**	**10**	**25**	**40**	**10**	**25**	**40**	**10**	**25**	**40**
Stellite 1	**1100**	6,1	8,38	9,5	7,66	10,32	10,82	10,7	16,14	17,1	11,78	18,56	19,7
	2200	15,18	16,3	19,7	17,56	18,7	23,62	21,2	27,76	31,74	21,98	29,9	34,44
	3300	21,98	24,24	27,64	23,46	29,5	35,4	25,86	32,52	38,94	26,5	34,44	42,38
	4400	28,78	31,04	34,44	29,9	33,06	39,74	31,56	36,36	43,58	32,16	37,84	46,9
Stellite F	**1100**	43,5	56,38	287,1	46,48	65,7	288,5	55,34	74,72	299,18	61,64	82,04	306,12
	2200	74,08	112,62	436,94	83,7	122,66	510,08	94,2	132,74	547,2	102,42	157,58	580,28
	3300	99,02	162,66	529,68	108,64	205,24	642,14	125,14	211,98	691,12	143,22	223,62	774,44
	4400	129,62	210,92	602,16	148,46	242,6	749,46	158,22	262,38	810,34	170,28	289,64	905,84

Table 8. Wear loss values obtained by changing the wear distance with the fuzzy logic method

		At room temperature (20 ºC)			**At 300 ºC**		
		Applied load (N)			Applied load (N)		
	Friction Distance (m)	**10**	**25**	**40**	**10**	**25**	**40**
Stellite 1	**1100**	6,1	8,38	9,5	11,78	18,56	19,7
	1650	12,58	13,72	16,74	18,84	26,1	29,74
	2200	15,18	16,3	19,7	21,98	29,9	34,44
	2750	19,2	21,26	24,46	23,86	31,54	38,44
	3300	21,98	24,24	27,64	26,5	34,44	42,38
	3850	25,7	28,86	31,12	29,16	36,08	45,64
	4400	28,78	31,04	34,44	32,16	37,84	46,9
Stellite F	**1100**	43,5	56,38	287,1	61,64	82,04	306,12
	1650	62,06	82,82	346,4	81,04	108,9	368,54
	2200	74,08	112,62	436,94	102,42	157,58	580,28
	2750	85,24	130,34	487,7	112,86	211,18	688,48
	3300	99,02	162,66	529,68	143,22	223,62	774,44
	3850	107,9	203,06	564,92	162,74	266,04	826,98
	4400	129,62	210,92	602,16	170,28	289,64	905,84

In Table 1, for Stellite 1 under a load of 10N, weight losses of 6 at 1100 meters, 15 at 2200 meters, 22 at 3300 meters, and 29 x10-4 mg at 4400 meters are obtained at room temperature, while in Table 7 these values are 6.1, 6.1, 15.18, 21.98, and 28.78 x10-4mg. Again, when the experimental weight losses of the Stellite F specimen due to load change at 3000C at the end of 1100 meters are examined in Table 1, wear losses of 62 mg under 10N load, 87 mg under 25N load and 305x10-4mg under 40N load are obtained in Table 2. weight losses of 61.64, 82.04 and 306.12x10-4mg were obtained, respectively, under the same criteria.

In this section, the graphical results obtained as a result of experimental studies are evaluated by fuzzy logic method and comparisons are made.

Figure 5(a) shows the measurements of the Stellite 1 sample under 10, 25, and 40N loads at room temperature (20 0C) and 300 °C at 1100 – 4400 m. In the graph given in Figure 1(b), the accuracy and consistency of the system built with fuzzy logic are checked with experimental studies. It has been seen that the results obtained with fuzzy logic are parallel and consistent with the experimental results.

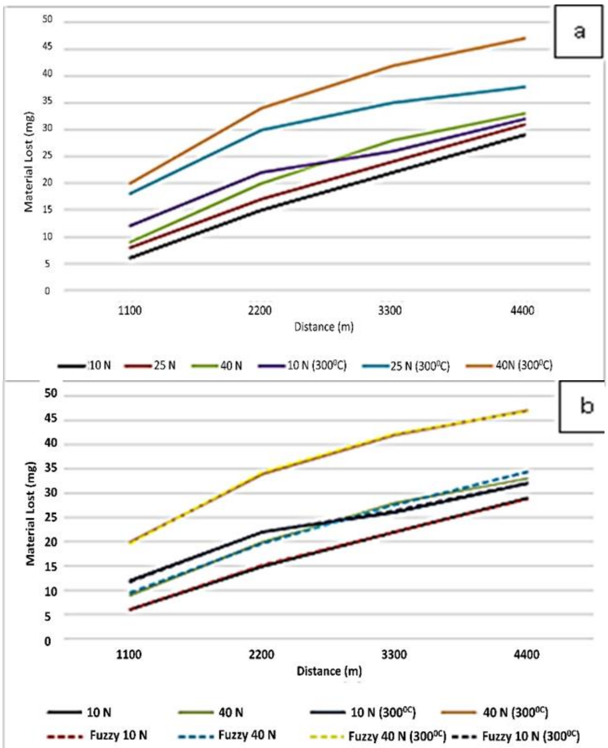


Figure 5. Graphics of Stellite 1 material. (a) Results from the experimental study. (b) Results obtained by fuzzy logic

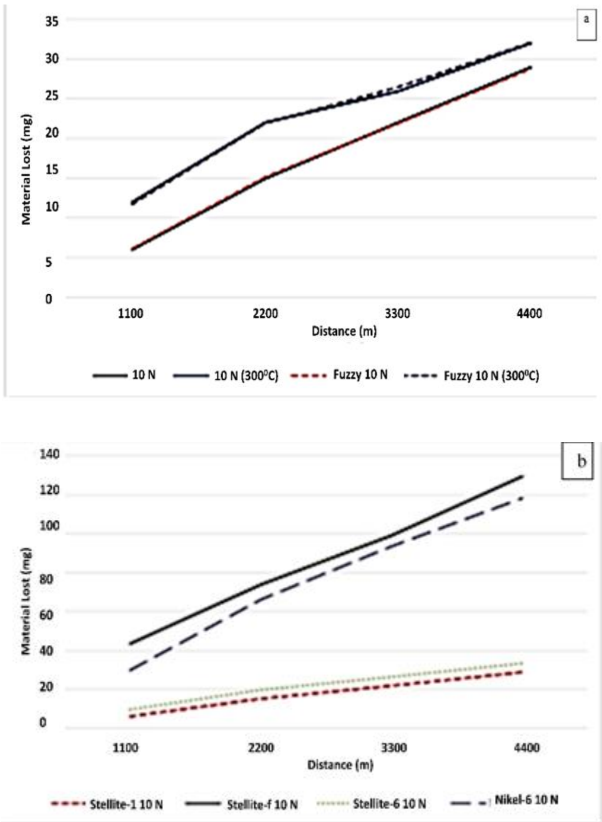


Figure 6. Comparison of experimental results with fuzzy logic results for Stellite 1 material. (a) Depends on temperature, (b) Depends on the material.

The results obtained from the experimental study for the Stellite 1 material are given in Figure 6, comparing the experimental results with the fuzzy logic results. In these studies, the consistency of experimental studies under 10N load and 300 °C temperature with fuzzy logic was compared. It has been determined that the fuzzy logic results obtained are reliable and show parallelism.

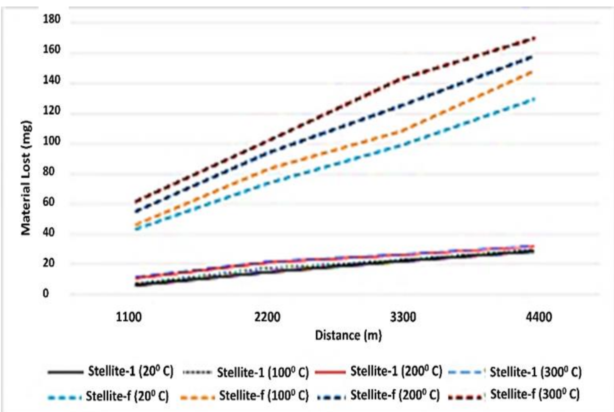


Figure 7. Graph of the fuzzy logic analysis of temperature changes of Stellite 1 and Stellite f samples.

In Figure 7, the weight losses that may occur in the samples at temperatures ranging from room temperature to 300 °C are examined by fuzzy logic method. In experimental studies, it has been determined that the weight losses obtained at room temperature (20 °C) and 300 °C in Stellite 1 and Stellite f samples are similar to the fuzzy logic method at intermediate temperatures (100 °C and 200 °C), and the increase in weight losses continues proportionally.

With the fuzzy logic method, it has been observed that the wear losses that may occur at the intermediate temperature points are determined experimentally due to the wear losses obtained at only two temperature values (20 °C and 300 °C).

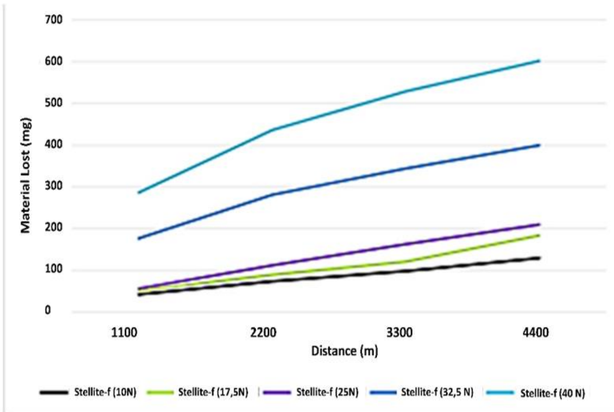
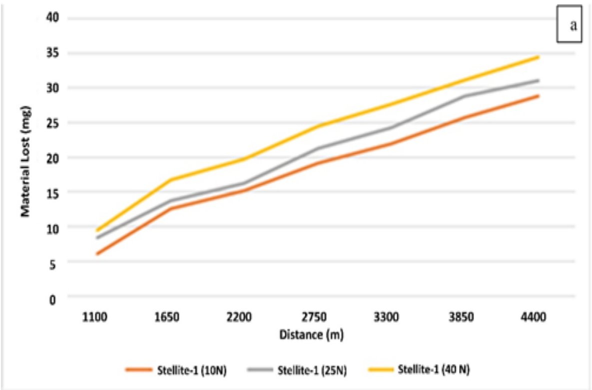


Figure 8. The graph of the fuzzy logic analysis of the load forces applied to the Stellite f sample.

In Figure 8, the graph of wear losses at intermediate loads of the Stellite f sample is given. When this graph was evaluated with the graph obtained from the experimental samples, it was determined that the wear losses increased at 10, 25, and 40N loads. When Figure 4 is examined, it is determined that the intermediate loading values (17.5 and 32.5N) show a similar increase and are consistent with the experimental studies.

In the experimental studies, the samples were etched at 1100, 2200, 3300, and 4400 meters etching distances. Intermediate values were studied for fuzzy logic studies. The wear loss graph obtained from the determined intermediate values is also given in Figure 9. When the graph in Figure 5 is examined, it has been determined that the wear loss values obtained are compatible with those obtained in transverse openings, and as the abrasion distance increases, the wear losses increase in parallel with the experimental studies.



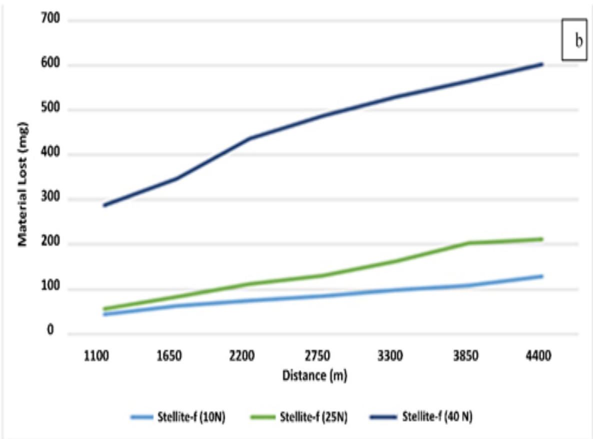


Figure 9. Fuzzy logic graph of wear losses due to wear distances in Stellite 1(a) and Stellite f (b) samples.

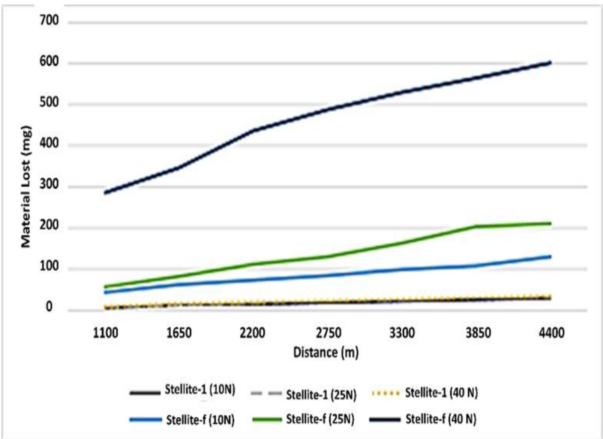


Figure 10. Fuzzy logic graph of wear losses due to comparative wear distances in Stellite 1 and Stellite f samples.

When the fuzzy logic graph of both Stellite 1 and Stellite F samples was examined on the same graph (Figure 10), it was determined that the wear loss curves were compatible with each other and with the experimental studies, and gave healthy results at the determined intermediate values. According to the fuzzy logic results obtained, it is seen that there is an increase in weight loss depending on the increasing wear distance in the intermediate values, but this increase is related to the distance ratio.

4. EVALUATION

When the experimental study results and fuzzy logic results are evaluated, the results of the experimental study in all criteria and the results obtained in the fuzzy logic studies conducted in connection with this support each other.

For the fuzzy logic study, firstly, 10, 25, and 40 N application loads, 1100, 2200, 3300, and 4400 meters of wear distance, which were kept constant under the experimental conditions, and room temperature and 300 °C temperatures were taken as the wear environment. The fuzzy logic study was first tested under these experimental conditions, and then fuzzy logic was applied to other intermediate criteria.When the results obtained under all other specific experimental conditions were examined, it was determined that very close and supportive values were obtained. Since the weight loss measurement results are in terms of 10-4mg, the deviations between fuzzy logic and experimental results are considered to be quite acceptable.

The findings and recommendations obtained as a result of this study are given below.

- Fuzzy logic is a very useful program, especially in areas where each material and criterion develops its own system, such as wear.

- Determination of wear properties is very costly in terms of both time and material. In addition, the limited wear mechanisms limit the experimental parameters and reduce the efficiency of the study. These difficulties are overcome with fuzzy logic.

- Experiments made in line with the most extreme parameters to be determined will create an infrastructure;, fuzzy logic will be built on these robust data and present all data in intermediate values to us.

In this way, both time and material loss and other measurement errors will be minimized, and more efficient work will be provided.

ETİK STANDARTLARIN BEYANI (DECLARATION OF ETHICAL STANDARDS)

Bu makalenin yazar(lar)ı çalışmalarında kullandıkları materyal ve yöntemlerin etik kurul izni ve/veya yasal-özel bir izin gerektirmediğini beyan ederler.

YAZARLARIN KATKILARI (AUTHORS' CONTRIBUTIONS)

Uğur ARABACI: Deneyleri yapmış ve sonuçlarını analiz etmiştir. / Perofrmed the experiments and analyse the results.

ÇIKAR ÇATIŞMASI (CONFLICT OF INTEREST)

Bu çalışmada herhangi bir çıkar çatışması yoktur. / There is no conflict of interest in this study.

5. REFERENCES

[1] Wong, S.V., at all,."Generalized Fuzzy Model For Metal Cutting Data Selection", ***Journal of Materials Processing Technology,*** 50-99, 310-317. (1999).

[2] Babuska, R., "Fuzzy Modeling for Control. Kluwer" ***Academic Publishers***, 257. (1998).

[3] Passino, K.M., Yurkovich, S., "Fuzzy Control", ***Addison Wesley Longman, Inc***., 468. (1998).

[4] Allahverdi, N., Uzman Sistemler, "Bir Yapay Zeka Uygulaması", ***Atlas Yayın Dağ***., 248. (2002).

[5] Klir, G.J., Yuan, B., "Fuzzy Sets and Fuzzy Logic : Theory and Applications", ***Prentice, Hall PTR***, 574 (1995).

[6] Yalçın B., Varol R., Yılmaz N., "Demir Esaslı Toz Metal (T/M) Yatakların Aşınma Özelliklerinin Bulanık Mantıkla (BM) Modellenmesi", ***Makine Teknolojileri Elektronik Dergisi,*** (4) 1-8.(2004).

[7] Tavoosi, J., Zhang, C., Mohammadzadeh, A., Mobayen, S., Mosavi, A.H. "Medical Image Interpolation Using Recurrent Type-2 Fuzzy Neural Network. Front". ***Neuroinform***. 15. (2021)

[8] Tavoosi, J, Suratgar A. A, Menhaj M.B., Mosavi A., Mohammadzadeh A, Ranjbar E., "Modeling Renewable Energy Systems By A Self-Evolving Nonlinear Consequent Part Recurrent Type-2 Fuzzy System For Power Prediction". ***Sustainability.*** 13. (2021).

[9] Sadeghiravesh, M.H., Khosravi, H., Abolhasani, A., Ghodsi, M., Mosavi, A. "Fuzzy Logic Model to Assess Desertification Intensity Based on Vulnerability Indices." ***Acta Polytech. Hung*** 18, 7–24. (2021).

[10] Claywell, R., Nadai L., Felde I., Ardabili S., Mosavi A. "Adaptive Neuro-Fuzzy Inference System And A Multilayer Perceptron Model Trained With Grey Wolf Optimizer For Predicting Solar Diffuse Fraction". ***Entropy*** 22. 1192. (2020).

[11] Jantzen, J. "Foundations of Fuzzy Control", ***Hoboken,*** USA (2007).

[12] Khuntia, S.R., Mohanty K., Panda S., Ardil C. "A. Comparative Study of PI, IP, Fuzzy, and Neuro-Fuzzy Controllers for Speed Control of DC Motor Drive." ***World Academy of Science and Technology.*** Paris France, Volume 68. (2009).

[13] Thaker, S., Nagori V. "Analysis Of Fuzzification Process In Fuzzy Expert System". ***Procedia Comput. Sci.*** 132. 1308–1316. (2018).

[14] Lashin M. M. A., Al Samhan A. M., Badwelan, "A., Control of Static and Dynamic Parameters by Fuzzy Controller to Optimize Friction Stir Spot Welding Strength". ***Coatings.*** 12 (10), 1442.(2022).

[15] P.M. Rudenko, V.S. Gavrish, S.I. Kuchuk-Yatsenko, A.V. Didkovsky and E.V. Antipin. "Influence Of Flash Butt Welding Process Parameters On Strength Characteristics Of Railway Rail Butts". ***Avtomaticheskaya Svarka (Automatic Welding),*** 87-90. (2017).

[16] Kuchuk-Yatsenko S.I., Rudenko P.M., Gavrish V.S., Didkovsky O.V., Antipin, Ye.V., Ziakhor I.V. "Operational Control as a Means of the Evaluation of Quality of Welded Connections for Flash-Butt Welding of Modern High-Strength Steels". ***Science and innovation.*** 16. (2020).

[17] S.I. Kuchuk-Yatsenko, P.M. Rudenko, V.S. Gavrısh, A.V. Dıdkovsky And E.V. Antıpın. "Statıstıcal Control OF Process OF Flash-Butt Weldıng Of Raıls. Two-Level Control System." ***The Paton Welding Journal,*** 5-6. (2016).

[18] S.I. Kuchuk-Yatsenko, P.M. Rudenko, V.S. Gavrysh, A.V. Didkovsky, V.I. Shvets, E.V. Antipin, P. Wojtas, A. Kozłowski.. "Real-Time Operational Control In Information Management System For Flash-Butt Welding Of Rails. Mınıng – Informatıcs," ***Automatıon And Electrıcal Engıneerıng*** No. 1-529. (2017).

[19] Alghannam, Lu, Ma, Cheng, Gonzalez, Zang, & Li. A. "Novel Method of Using Vision System and Fuzzy Logic for Quality Estimating Resistance Spot Welding". ***Symmetry.*** 11(8), 990. (2019).

[20] Na S. J., Kim J. W. "A self-organizing fuzzy control approach to arc sensor for weld joint tracking in gas metal arc welding of butt joints" 72:2. ***Welding Journal.*** United States. (1993).

[21] S. Nweze, J. Achebo. "The Use of Fuzzy Logic in Predicting Percentage (%) Dilution of Weld during Tig Welding Process". ***Materials Sciences and Applications.*** Vol.10, 406-422. (2019).

[22] BAL, G., OZTURK, N., ÖNCÜ, S., ÜNAL, K. "Otomatik Gerilim Regülatörü İçin Hibrit Bir Denetleyici Tasarımı". ***Politeknik Dergisi***, 199-207. 26(1), (2023).

[23] KOCAKULAK, T., SOLMAZ, H., & ŞAHİN, F. "Control and Optimization of Pre-Transmission Parallel Hybrid Vehicle with Fuzzy Logic Method and Comparison with Conventional Rule Based Control Strategy." ***Politeknik Dergisi,*** 1035-1047. 26(3), (2023).

[24] BULUT, M. "Bulanık Ters Model Kullanılarak Doğru Akım Motor Sürücüsü için Referans Model Temelli Uyarlanabilir Bulanık Denetleyici". ***Politeknik Dergisi***, 26(2), 593-602. (2023)