Analyzing the Factor That Effects Working Life of Bandsaw Blades Based on Taguchi-Fuzzy Method

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Abstract

The aim of companies in today's competitive environment is to produce high quality products at low cost. The quality is considered substantially in selection of products. Taguchi method greatly reduces the number of tests to be performed by using orthogonal sequences, which consequently yield savings in time, cost and effort. In this study, Taguchi and Taguchi-Fuzzy methods are used to examine the quality factors that effects the working life of bandsaw blades. Firstly, the average and S/N ratio for each experiment that have been performed according to L18 orthogonal array are calculated. Later, ANOVA has been performed in order to determine the factors which significantly affect the quality of bandsaw blades. After determination of the most important factors, numerical data is converted into linguistic variables and rules addressing relationship between inputs (the factors) and output (the working life of blades) are identified for implementing Fuzzy method. Finally, numerical values are converted into crisp value by defuzzification.

Key words: Experimental Design, Taguchi, Taguchi- Fuzzy

1. Introduction

Today, quality stands out as the most influential factor in product selection with more awareness of customers. The Taguchi method of experimental design method is preferred to determine the most effective factors [1]. Taguchi method is a very useful method to determine the best combination of different levels of different parameters. Taguchi method is based on orthogonal arrays to get better results with very little trials instead of applying experiments for all combination of each level of each parameter [2].

The disadvantage of Taguchi method is obtaining results for only predetermined levels of factors. Results for intermediate values of factor levels are not provided by classical Taguchi method. Thus, Taguchi-Fuzzy method can deal this challenge by integrating fuzzy approach to Taguchi method for estimating outputs of intermediate values.

First, the most significant factors influencing the quality or result are determined by Taguchi technique. After that, fuzzy logic method converts numerical data obtained from Taguchi method into linguistic variables. Then rules addressing interrelationships between the most influencing factors and output are identified. Consequently, crisp output values are extracted for any value of factors between given levels by defuzzification process. In this study, Taguchi-Fuzzy method is implemented for determining working life of bandsaw blades under several conditions.

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2. Background and Literature Survey

Taguchi method which advances the process performance with less experiments, is a robust optimization tool [3-6]. Panda and Pandey present a hybrid algorithm (Taguchi combined with membership function) for the optimization of bone drilling process with multiple performance characteristics to minimize the drilling induced bone tissue damage [7].

On the other hand, fuzzy logic is a mathematical theory of inexact reasoning that allows modeling of the reasoning process of human in linguistic terms [8]. Scientists make many studies about fuzzy logic.

In recent years, remarkable studies exists about Taguchi-Fuzzy approach. Tzeng and Chen make scientific studies about fuzzy logic analysis coupled with Taguchi methods to optimize the precision and accuracy of the high-speed electrical discharge machining process [9]. Rajyalakshmi and Venkata Ramaiah use fuzzy logic integrated with the Taguchi method to optimize Wire Electro Discharge Machining (WEDM) process with multiple quality characteristics [10]. Pandey presents a methodology for the simultaneous optimization of multiple quality characteristics in laser cutting process by developing the software 'CATFMO' Computer Aided Taguchi-Fuzzy Multi-Optimization [11]. Laxman and Raj optimized model to investigate the effects of peak current, pulse on time, pulse off time and tool lift time in Electrical Discharge Machining (EDM) process using Fuzzy Taguchi [12]. Lan showed that the attributes from the fuzzy Taguchi deduction optimization parameters are all significantly advanced comparing to from benchmark [13].

3. Taguchi and Taguchi-Fuzzy Methods

Although the experimental design was developed by Sir Ronald Fisher in the 1930s, experimental design is first applied to reduce variation Taguchi. Taguchi has defined a criterion that called a signal/noise (S/N) ratio to reduce variability in experimental design and used as a performance criterion. Practice problems were divided into three groups according to the type of target and for each, different S/N ratio is defined by Taguchi. Identified S/N ratios are shown in Table 1 [14].

Table 1. Calculation of Signal-to-Noise (S/N) Ratio

Characteristic Type	S/N Ratio
Lower-the-better	$-10\log((1/n)\sum y_i^2)$
Nominal-the-better	$-10\log(\bar{y}/s^2)$
Higher-the-better	$-10\log((1/n)\sum (1/y_i^2)$

Whichever S/N ratio type is used in evaluation, bigger S/N ratio means better experiment result. Thus, factor levels of the experiment with the greatest S/N ratio value gives the best performance among all combination of factor levels [15].

Factors combination that process to reach its optimum performance is determined with the help of S/N ratio as well as variance analysis. The other important point is that a balanced experimental design, namely, is to be evaluated independently of the factors and thus, an equal number of sampling is performed for different levels of the factors in the design. Taguchi's standard design is based on this system [16].

The stages of the Taguchi method are given as followings [17]:

- Determination of the problem
- The choice of the factors that affecting of the performance characteristics
- Determination the level of each factor
- The separation of factors as control and noise
- Determination of interactions between factors to be examined
- Selection of the appropriate orthogonal array
- Assigned factors to the column
- Determination of experiment application order
- Realization of experiment

On the other hand, to overcome the challenge of obtaining performance result for intermediate values Taguchi-Fuzzy method is proposed. The Taguchi-Fuzzy method is obtained by the integration of fuzzy logic to the Taguchi method. After determination of the most important factors by classical Taguchi method, numerical data is converted into linguistic variables and rules addressing relationship between inputs (the factors) and output (performance characteristic) are identified by implementing fuzzy logic. Finally, crisp output values are extracted for any value of factors between given levels by defuzzification process.

4. Application

This study was carried out in a company that manufactures metal cutting machines with bandsaw blades. To be competitive in its market, the firm required to analyze the factors affecting performance of the blades. Many researches have been done on this issue and Taguchi and Fuzzy Taguchi methods are preferred to be performed.

Firstly, factors that have impact on the life of the bandsaw are detected. These factors are boron oil ratio, rotation speed, downstroke (feeding) speed, blade tension, tooth number, bandsaw type and material type. Boron oil ratio has two levels and the rest of the factors have three levels. Levels of these factors are shown in Table 2.

Table 2. Level of the specified factors for the experiment

Factor	Symbol	Levels	
Boron oil ratio	**A**	1	7%
		2	12%
Rotation speed	**B**	1	30 m/min
		2	60 m/min
		3	90 m/min

Downstroke (feeding) speed	**C**	1	30 mm/min
		2	60 mm/min
		3	90 mm/min
Blade tension	**D**	1	200 N/mm2
		2	300 N/mm2
		3	400 N/mm2
Tooth number	**E**	1	5/8
		2	4/6
		3	3/4
Bandsaw type	**F**	1	bi-alfa cobalt
		2	bi-alfa profile
		3	bi-alfa master
Material type	**G**	1	plenteous
		2	tube
		3	structure

L18 orthogonal array has been chosen for experiments according to the defined factors and levels, and shown in Table 3.

Table 3. L18 orthogonal array table with factors

Experiment No.	Boron oil ratio A	Rotation speed B	Downstroke speed C	Blade tension D	Tooth number E	Bandsaw type F	Material type G
1	1	1	1	1	1	1	1
2	1	1	2	2	2	2	2
3	1	1	3	3	3	3	3
4	1	2	1	1	2	2	3
5	1	2	2	2	3	3	1
6	1	2	3	3	1	1	2
7	1	3	1	2	1	3	2
8	1	3	2	3	2	1	3
9	1	3	3	1	3	2	1
10	2	1	1	3	3	2	2
11	2	1	2	1	1	3	3
12	2	1	3	2	2	1	1
13	2	2	1	2	3	1	3
14	2	2	2	3	1	2	1
15	2	2	3	1	2	3	2
16	2	3	1	3	2	3	1
17	2	3	2	1	3	1	2
18	2	3	3	2	1	2	3

For each experiment type five experiments and in total ninety experiments were realized to test the working life of bandsaws. The results of the experiments are shown in Table 4.

Table 4. Experimental results

Experiment No.	Experimental results (m²/band) Y1	Y2	Y3	Y4	Y5
1	3.80	3.53	3.76	3.89	3.71
2	2.50	2.76	2.45	2.30	2.55
3	2.32	2.15	2.23	2.36	2.36
4	2.06	2.10	2.11	2.15	2.06
5	5.85	5.78	5.74	5.74	5.30
6	3.22	3.06	3.17	3.17	3.32
7	7.10	7.21	7.14	7.32	7.24
8	3.65	3.87	3.60	3.75	3.95
9	5.30	5.32	5.25	5.08	5.04
10	3.12	3.25	3.21	3.23	3.25
11	3.56	3.50	3.45	3.65	3.61
12	2.10	2.11	2.10	2.21	2.16
13	2.98	2.79	2.58	2.84	2.92
14	5.98	5.94	5.96	5.97	5.89
15	3.47	3.32	3.37	3.47	3.27
16	5.65	5.62	5.60	5.55	5.52
17	3.54	3.50	3.45	3.41	3.56
18	5.10	5.20	5.13	5.24	5.26

In this study, factors, levels and test results of problem were analyzed using Minitab software. "Higher-the-better" criterion is used to calculate of S/N ratio. The obtained results are shown in Figure 1.

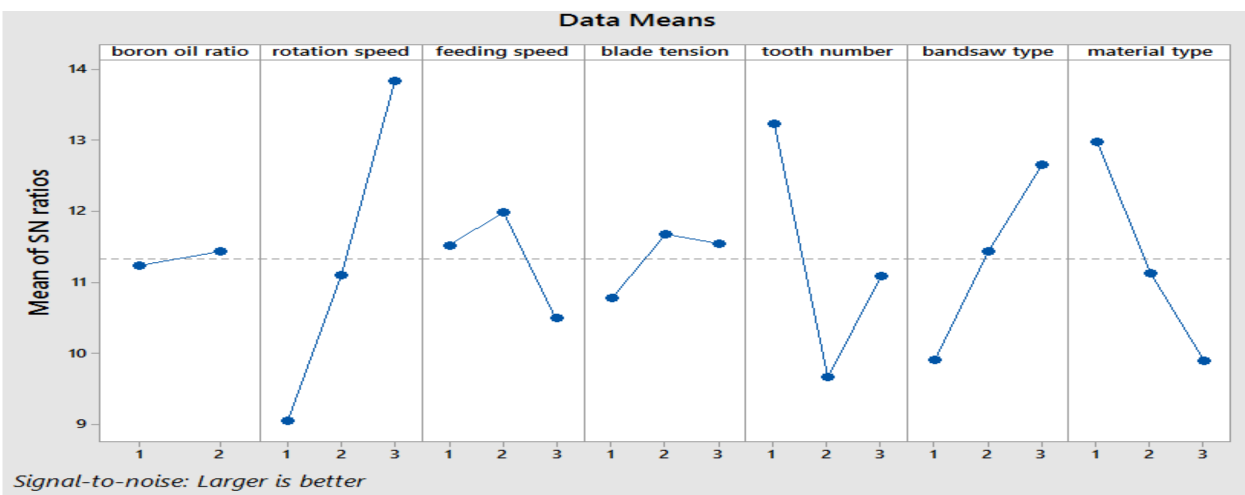

Figure 1. Main effects plot for S/N ratios

Figure 1 gives that; second level for factor A, third level for factor B, second level for factor C, second level for factor D, first level for factor E, third level for factor F and first level for factor G is the most appropriate combination.

After finding the most appropriate levels of factors, analysis of variance has been implemented. The ANOVA results are shown in Figure 2.

Source	DF	Seq SS	Adj SS	Adj MS	F	P
boron oil ratio	1	0,179	0,1794	0,1794	0,07	0,810
rotation speed	2	69,468	69,4679	34,7339	12,82	0,018
feeding speed	2	6,897	6,8974	3,4487	1,27	0,373
blade tension	2	2,877	2,8767	1,4384	0,53	0,625
tooth number	2	38,915	38,9146	19,4573	7,18	0,047
bandsaw type	2	22,733	22,7333	11,3666	4,19	0,104
material type	2	28,851	28,8510	14,4255	5,32	0,075
Residual Error	4	10,839	10,8386	2,7096		
Total	17	180,759				

Figure 2. Analysis of variance for S/N ratios

Considering Figure 2, "rotation speed" and "tooth number" are the most important factors for bandsaw performance, since F test values are greater and probability values are less than 0.05 for these two factors. That is why, the rotation speed and tooth number are input variables, while the life of the bandsaw is output variable for fuzzy logic approach. Fuzzy logic model of the problem is built using MATLAB software as shown in Figure 3.

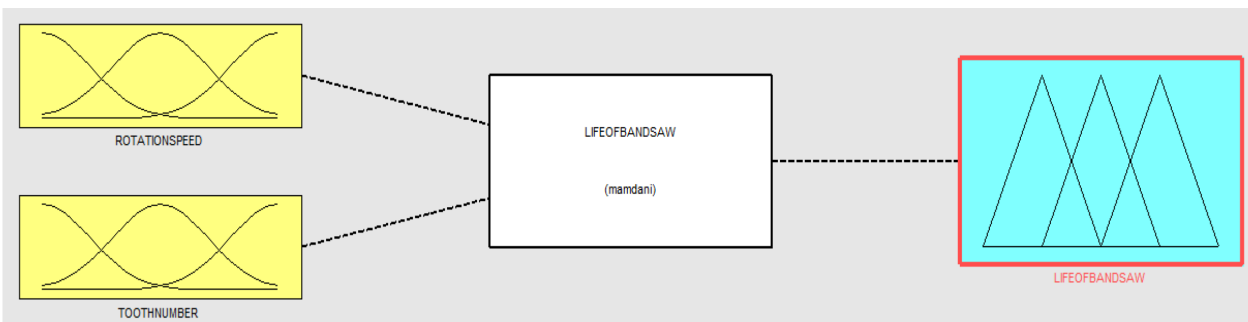

Figure 3. FIS editor screen of the life of bandsaw

Each input and output is expressed with 5 linguistic variables. Linguistic expressions for the rotation speed are; very slow, slow, medium, fast and very fast. The linguistic expressions for the tooth number are; too few, few, medium, much and too much. Life of bandsaw which is output performance is also with 5 linguistic variables, namely; too little, little, medium, much and too much. Figure 4 (a), (b) and (c) show triangular membership functions for each input and output variables.

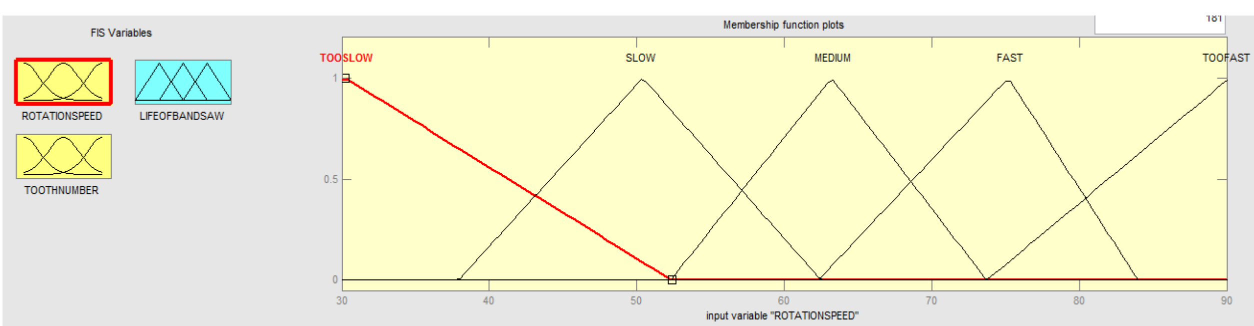

Figure 4 (a). Rotation speed membership functions

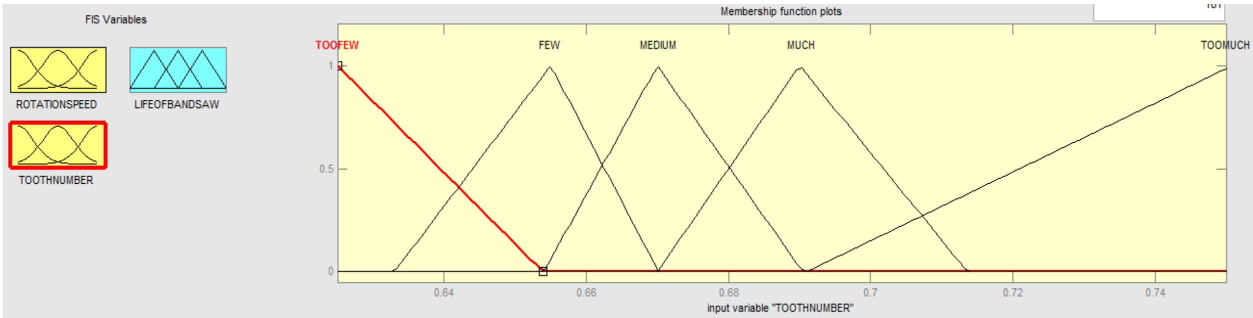

Figure 4 (b). Tooth number membership functions

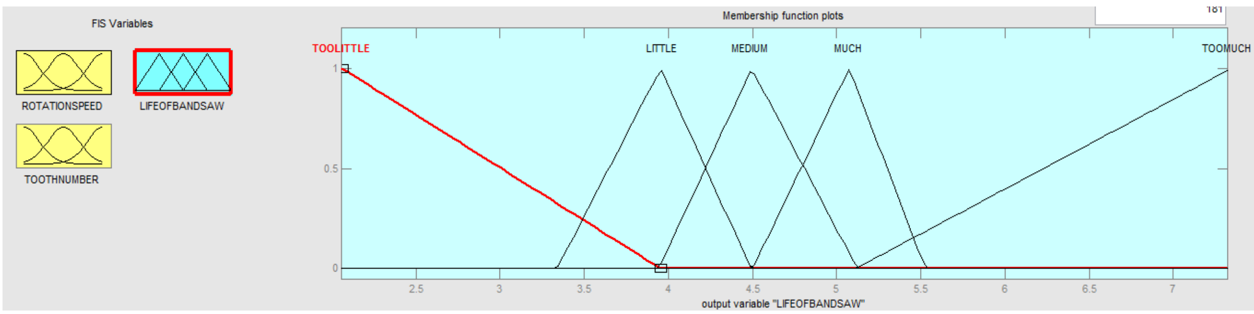

Figure 4 (c). Life of bandsaw membership functions

Upper and lower limit values of the variables are set as the largest and the smallest values of factor levels which are used in Taguchi method. Triangular membership functions has been utilized which is commonly used because of its simplicity (see Table 5).

Table 5. Input and output linguistic variables and ranges

Input Variables	Lower	Upper	Membership Function	Value Ranges				
Rotation speed (A)	30	90	Triangular	Too Slow	Slow	Medium	Fast	Too Fast
Tooth number (B)	0.625	0.75	Triangular	Too Few	Few	Medium	Much	Too Much
Output Variable								
Life of bandsaw	2.06	7.32	Triangular	Too Little	Little	Medium	Long	Too Long

The rules indicating interrelationship between inputs and output have also been determined and entered to the inference engine of the fuzzy logic model. Some examples of the rules are given below and the whole list is given in Table 6.

Rule 1: If rotation speed is too slow and tooth number is too few then life of bandsaw is medium.
Rule 2: If rotation speed is too slow and tooth number is few then life of bandsaw is medium.
Rule 25: If rotation speed is too fast and tooth number is too much then life of bandsaw is much.

Table 6. Fuzzy logic rules

Rotation speed	**Tooth number**	**Life of bandsaw**
Too Slow	Too Few	Medium
Too Slow	Few	Medium
Too Slow	Medium	Much
Too Slow	Much	Too Much
Too Slow	Too Much	Too Much
Slow	Too Few	Medium
Slow	Few	Medium
Slow	Medium	Much
Slow	Much	Too Much
Slow	Too Much	Too Much
Medium	Too Few	Little
Medium	Few	Medium
Medium	Medium	Much
Medium	Much	Too Much
Medium	Too Much	Too Much
Fast	Too Few	Little
Fast	Few	Little
Fast	Medium	Medium
Fast	Much	Much
Fast	Too Much	Much
Too Fast	Too Few	Too Little
Too Fast	Few	Too Little
Too Fast	Medium	Little
Too Fast	Much	Medium
Too Fast	Too Much	Much

Center of gravity method is used to defuzzify the output variable in fuzzy systems. Surface characteristics of the developed fuzzy logic model is shown in Figure 8.

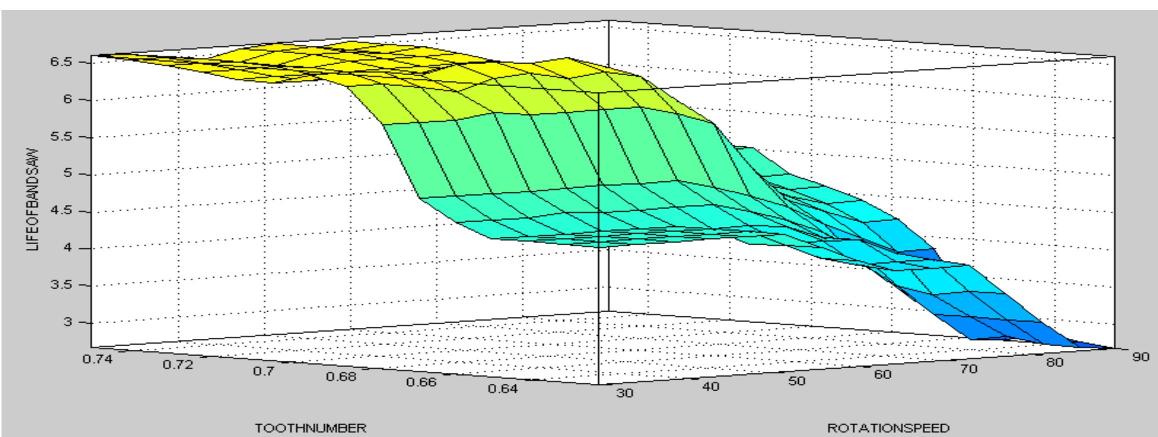

Figure 8. Surface graphics display of the change of bandsaw's life depending on the tooth number and rotation speed

According to Figure 8, it is seen that the life of bandsaw increases when tooth number increases and the rotation speed decreases.

Figure 9 shows defuzzification mechanism of the model. For example, if rotation speed is set to 60 (m/min) and tooth number is set to 0.688 (mm) then the life of bandsaw is calculated as 6.4. Different values for working life performance of bandsaw blades could be obtained by changing values of input variables.

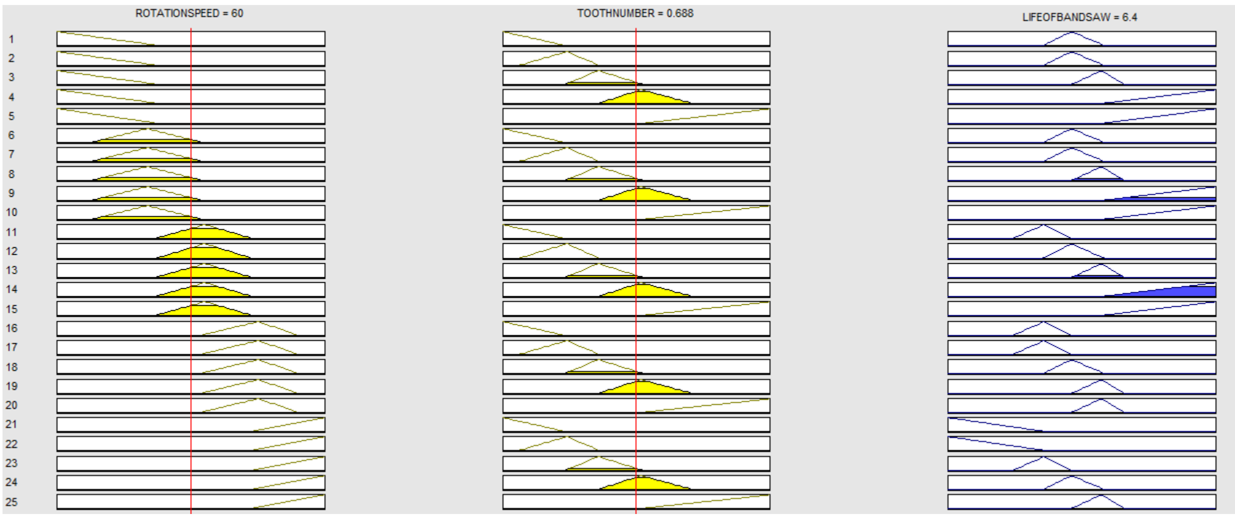

Figure 9. Life of bandsaw rule base

Conclusions

This paper has presented the use of fuzzy logic and Taguchi method in an integrated manner to estimate the working life of bandsaw blades. The factors that affect life of bandsaw blade were determined and then levels for each factor were decided. Based on number of factors and levels, L18 orthogonal array has been chosen for Taguchi implementation. Minitab software was used to analyze Taguchi experiment results. ANOVA test results showed that rotation speed and tooth number are the most influencing factors for bandsaw working life. Thus, rotation speed and tooth number were used as input variables and life of bandsaw was used as output variable in Fuzzy logic model which was built by MATLAB software. For each variable, 5 triangular membership functions were defined and rules indicating relationship between input variables and output variable were entered to the inference engine of the model. As a result defuzzification was available for obtaining performance result of bandsaw blade by changing the values of input variables. Fuzzy approach was used to enhance Taguchi method so that, performance results for intermediate values of factors are able to be obtained. This approach could be used for several quality improvement application.

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