New Materials, Compounds and Applications
Vol.6, No.1, 2022, pp.44-54

APPLICATION OF AHP & FUZZY LOGIC HYBRID FOR EVALUATING MACHINABILITY OF AZ31 ALLOY

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Abstract. The purpose of this research is to apply the AHP & Fuzzy Logic Hybrid to evaluate the machinability of AZ31 magnesium alloy during mechanical machining using AHP-Fuzzy methods. Cutting speed, feed rate, depth of cut, and metal removal rate, as well as tool angles design, were all utilized to determine the weight of numerous parameters that play a role in controlling surface roughness, temperature, chatter, and residual stress. By using this method, a realistic appraisal of the crucial weight as well as a milestone understanding of how to change each parameter correctly can be obtained. Machining factors such as cutting speed have a considerable influence on chatter and surface roughness, temperature, and stress residual, according to the findings. Furthermore, a single adjustment may not yield the intended effect until it is implemented across all parameters.

Keywords: *AZ31 alloy, machining factors, High strength material, AHP-Fuzzy.*

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Received: *14 January 2022;* ***Accepted:*** *28 February 2022;* ***Published:*** *19 April 2022.*

1. Introduction

In the automotive, electrical, and aerospace sectors, magnesium alloys have long been utilized. Because of their attractive characteristics, magnesium alloys have the potential to replace aluminum and steel in structural and mechanical applications (Asal *et al*., 2019). Magnesium alloy has a wide range of uses and is known as a "green metal" material in the twenty-first century due to its various advantages, including high strength-to-weight, high stiffness-to-weight ratios, and its non-polluting feature, among others. Manufacturing is the process of altering the geometry, characteristics, and/or appearance of a starting material using mechanical, physical, and chemical processes in order to create new, completed components or products. Manufacturing industries must choose suitable production strategies, product designs, manufacturing methods, work piece and tool materials, machinery and equipment, and other factors to address problems. There is little research on machining soft materials such as AZ31 Mg alloy, compared to harder-to-cut materials such as Inconel alloy and titanium alloy. According to Musfirah & Jaharah (2012), magnesium alloy is difficult to produce at low temperatures due to its hexagonal closed-packed crystal structure, and must be machined at high temperatures. Another issue is that magnesium alloy has a low melting point of 650°C and could catch fire if the machining temperature is exceeded. In this paper, the nine-point scale technique used to assess each level of the target options in the conventional Analytical Hierarchy Process (AHP) method, and each pair reflects the priority of the target alternatives. (Kong & Liu, 2005) suggested the nine-point scale approach; Equal, Slightly Strong, Strong, and Very Strong are the ratings for the choices. In comparison, the values of these preferences are 1, 3, 5, 7, and 9, and the comparative ratio is a clear actual number. The classic AHP technique, however, cannot correctly estimate the relative weight of target choices since target option selection is typically subjective and inaccurate. The area of decision-making is particularly significant. In terms of the problem-solving space, variables are classified as direct or indirect. Selecting a set of objectives that are directly engaged in the operating process, such as cut-off conditions, and others that obtained during or after the operating process utilized as decision-making techniques. However, AHP and Fuzzy Logics are frequently employed as input and output in our present work; thus, it employed them in my study as well.

2. Methodology

1.1 Machinability of AZ31 alloy

Magnesium and its alloys are resistant to dissolving in aqueous solutions, particularly those containing chloride ion electrolytes, due to their low corrosion potential. Biomaterials engineers have expressed interest in creating magnesium-based biodegradable medical devices in recent years, making use of the corrodible characteristics of magnesium alloys. (Zhang *et al.,* 2010) studied two AZ series alloys; AZ31 and AZ91 were selected and a drilling operation was performed to assess the effect of the secondary phase amount and distribution on machining characteristics. The drilling operation was carried out using different sets of process parameters, the cutting forces were obtained, and the chips which were produced during drilling were analyzed. From the results, it can be clearly understood that the presence of secondary phase (Mg17Al12) has a significant influence on cutting forces. Increase in cutting speed reduced the required cutting force and load fluctuations in all the cases. (Sunil et al., 2016) and Lu et al., 2016 carried out a series of experiments to systematically reveal the effect of cutting parameters on the microstructure, residual stress, hardening behavior, and roughness of AZ31B Mg alloys. Combing the analysis of microstructure and Vickers hardness, the residual stress distribution after high speed cutting was discussed. Meanwhile, the roughness was measured to reflect the surface quality of the work piece, and the new predicted model of roughness was established (Lu *et al.,* 2016). Optimization of surface roughness and cutting force has been studied (Sun, 2010) and Sunil *et al.,* 2016, as also how cutting parameters affect cutting chip, roughness, and residual stress and high-speed cutting (Tuzkaya & Önüt, 2008; Zhang *et al.,* 2010).

3. AHP – Fuzzy Approach

The analytical hierarchy process (AHP) is a particular focus tool created by Saaty in the 1980s to help put things in perspective (Saaty, 1980). It combines qualitative and quantitative techniques and enables the breakdown of complicated situations into smaller ones, allowing for easier evaluation of solutions (Shahin & Mahbod, 2007). It may also be used to evaluate the environmental performance of each life cycle phase (Ng, 2016). The nine-point scale simplifies criteria selection and provides information about one element's dominance over others (Saaty, 1987; Sun, 2010). A discrete scale cannot easily convey information unpredictability (Chan *et al.,* 2013), which is a problem that occurs during the construction of comparison matrixes. More matchings between attributes are necessary as the number of characteristics in a hierarchy rises. Furthermore, the experts are unable to correctly convey their prior understanding of the problems (Jato-Espino *et al.*, 2014). Decisions are getting more subjective and untrustworthy as a result. On the other hand, the fuzzy set theory is chosen to deal with the imprecision of expert judgements. Zadeh (Zadeh, 1965) came up with the concept, which is currently widely used in pair-wise comparison. The Fuzzy AHP technique is represented as triangular fuzzy integers (TFN). With the membership function described in (Chang, 1996), the numbers are represented by the triple M = (l, m, u). According to the findings of Rahimianzarif and Moradi (2017), an organization should develop principles based on criteria and prioritized parameters, and then design a web-based system within the company. (Adetunmbi, 2020) applying Fuzzy strategies with AHP provide baseline information to the construction clients and consultants on the importance of contractor's prequalification decision criteria to be adopted, which will eventually translate to a better decision making and increase project performance.

4. Implementation of the AHP-Fuzzy Approach

The problem at hand is complicated since it involves numerous layers of criterion and sub-criteria. The AHP technique picked because it helps to break down a complicated problem into smaller chunks. Due to the obvious disparities in the parameter combinations that difficult descriptive evaluation rather than numerical marks, it was difficult to pick between numbers grades 1–9. The goal of this research is to rate alternatives in order to identify the best structures for adaption. The research framework for this study was developed in the research layout as shown in Fig 1.

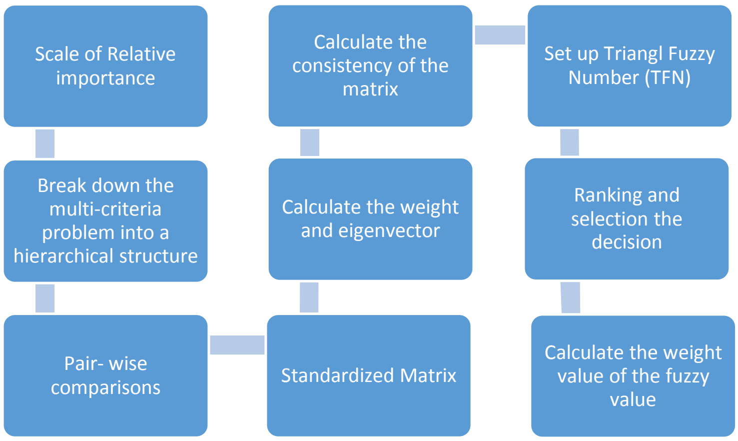

Figure 1. AHP approach research layout

A novel framework for making a safe decision in an emergency decision-making predicament is discussed in this section. There are three steps to the decision-making method that has been introduced: (1) determining the criteria's weight; (2) constructing the weight matrix's group; and (3) determining accurate solutions. First, the significance weights of all criteria must be assessed. The best–worst method (Rezaei, 2015) is used to determine the importance weight of criteria in this paper. We have n criteria in our study, and we wish to perform a pairwise comparison of these criteria using a 1/9 to 9 scale (Keeney *et al.*, 1993). The main objectives are subordinate to the criteria that are important in decision making. The AHP method is of great importance for comparison by pairs of elements in the hierarchy of goal, criteria, and alternatives. The comparison of the elements in pairs, which adopts the top-down direction, forms a square comparison matrix $A = (a_{ij})_{n\times n}$ where a total of (n/2) comparisons, discovers the importance of a specific criterion in comparison to another (Miloševi & Miloševi, 2020). The resultant matrix would look like equation (1):

$$A = \begin{bmatrix} \alpha_{11} & \alpha_{12} & \cdots & \cdots & \alpha_{1n} \\ \alpha_{21} & \alpha_{22} & \cdots & \cdots & \alpha_{2n} \\ \cdots & \cdots & \ldots & \cdots & \cdots \\ \cdots & \cdots & \cdots & \ldots & \cdots \\ \alpha_{n1} & \alpha_{n2} & \cdots & \cdots & \alpha_{\mathrm{nn}} \end{bmatrix}, \tag{1}$$

where α_{ij} shows the relative preference of criterion i to criterion j. α_{11} =1 shows that i and j are of the same importance. α_{ij}>1 shows that i is more important than j with α_{ij}= 9 showing the extreme importance of i to j. The importance of j to i is shown by α_{ij}. In order for matrix A to be reciprocal, it is required that $\alpha_{\mathrm{ij}}= 1/\alpha_{ji}$ and α_{ii}=1, for all i and j. Considering the reciprocal property of matrix A, in order to obtain a completed matrix A, it is necessary to have n(n-1)/2 pairwise comparisons. The pairwise comparison matrix A is considered to be perfectly consistent if (Rezaei, 2015):

$$\alpha_{\mathrm{ik}} * \alpha_{\mathrm{kj}} = \alpha_{ij} * \forall i, j \tag{2}$$

Here, we attempt to clarify the so-called pairwise comparison, which is the cornerstone of our suggested strategy.

a) Scale of Relative importance

Establishing the pairwise comparison matrix using the expert's assessment is a crucial step towards building a fuzzy AHP model. Linguistic words such as ‘equally important/preferable, 'moderately to strongly more important/preferable,' and ‘extremely more important/preferable' express the relative importance of one criterion or option over another (Liu *et al.*, 2020). Table 1 shows the results for the qualities studied in this study. Machining inputs include cutting speed, feed rate, depth of cut, and metal removal rate (MRR), as well as tool geometries including rake angle, approach angle, and nose radius. Four sorts of reactions are available: surface roughness, temperature, chatter, and residual stress.

Table 1. Scale of Relative Importance (Saaty, 1980)

Definition	Weight
Equally importance/preferable	1
Equal to Moderately more importance/preferable	2
Moderately more importance/preferable	3
Moderately to strongly more importance/preferable	4
Strongly different more importance/preferable	5
Strongly to very strongly more importance/preferable	6
Very strongly more importance/preferable	7
Very strongly to extremely more importance/preferable	8
Extremely more importance/preferable	9

Break down the multi-criteria problem into a hierarchical structure in the matrix (3).

$$A = \begin{bmatrix} 1 & \alpha_{12} & \cdots & \cdots & \alpha_{1n} \\ 1/\alpha_{21} & 1 & \cdots & \cdots & \alpha_{2n} \\ \cdots & \cdots & 1 & \cdots & \cdots \\ \cdots & \cdots & \cdots & 1 & \cdots \\ 1/\alpha_{n1} & 1/\alpha_{n2} & \cdots & \cdots & 1 \end{bmatrix}, \tag{3}$$

where $a_{ij} = 1/a_{ji}$, for $a_{ij} \neq 0$; and $a_{ij} = 1$, for i = j and I, j = 1, 2... n.

b) Pair- wise comparisons

The matrix was carried out among the attributes at the same level in the next higher-level for all assessment criteria as a result the data collection and comparison are given in the Table 2 below .

Table 2. Pair – wise comparison results

	Surface roughness	Temperature	Rack Angle	cutting Speed	Feed Rate	Depth of Cut	Approach angle	Chatter	Nose Radius	Residual Stress
Surface roughness	1.00	0.50	0.33	0.20	3.00	1.00	1.00	1.00	0.50	3.00
Temperature	2.00	1.00	3.00	0.50	3.00	1.00	5.00	3.00	5.00	5.00
Rack Angle	3.03	0.33	1.00	0.50	1.00	1.00	7.00	3.00	5.00	3.00
cutting Speed	5.00	2.00	2.00	1.00	3.00	5.00	3.00	5.00	3.00	5.00
Feed Rate	0.33	0.33	1.00	0.33	1.00	3.00	1.00	0.33	1.00	9.00
Depth of Cut	1.00	1.00	1.00	0.20	0.33	1.00	1.00	0.33	1.00	1.00
Approach angle	1.00	0.20	0.14	0.33	1.00	1.00	1.00	0.33	0.50	3.00
Chatter	1.00	0.33	0.33	0.20	3.03	3.03	3.03	1.00	1.00	3.00
Nose Radius	2.00	0.20	0.20	0.33	1.00	1.00	2.00	1.00	1.00	3.00
Residual Stress	0.33	0.20	0.33	0.20	0.11	1.00	0.33	0.33	0.33	1.00

c) Calculate the weight, Eigenvector (λ) and max. Eigenvector (λmax)

Kumar A. & Kumar M. (2019) performed a calculation that involves normalization of the comparison matrix A and transforming it into matrix B. Each element of matrix B is computed as (Sobandi *et. al.,* 2018).

$$b_{jk} = \frac{a_{jk}}{\sum_{l=1}^{m} a_{lk}} \tag{4}$$

Table 3. Standard Matrix B

Standardised Matrix	B									
	Surface roughness	Temperature	Rack Angle	cutting Speed	Feed Rate	Depth of Cut	Approach angle	Chatter	Nose Radius	Residual Stress
Surface roughness	0.06	0.08	0.03	0.05	0.18	0.05	0.04	0.06	0.03	0.08
Temperature	0.12	0.16	0.31	0.12	0.18	0.05	0.20	0.19	0.27	0.14
Rack Angle	0.18	0.05	0.10	0.12	0.06	0.05	0.28	0.19	0.27	0.08
cutting Speed	0.29	0.31	0.21	0.24	0.18	0.26	0.12	0.32	0.16	0.14
Feed Rate	0.02	0.05	0.10	0.08	0.06	0.16	0.04	0.02	0.05	0.24
Depth of Cut	0.06	0.16	0.10	0.05	0.02	0.05	0.04	0.02	0.05	0.03
Approach angle	0.06	0.03	0.01	0.08	0.06	0.05	0.04	0.02	0.03	0.08
Chatter	0.06	0.05	0.03	0.05	0.18	0.16	0.12	0.06	0.05	0.08
Nose Radius	0.12	0.03	0.02	0.08	0.06	0.05	0.08	0.06	0.05	0.08
Residual Stress	0.02	0.03	0.03	0.05	0.01	0.05	0.01	0.02	0.02	0.03

Consistency is expected to be near perfect to produce a decision that is close to valid (Sobandi *et al.*, 2018). The eigenvector (λ) is then calculated, which is known as the criteria weight vector w, which is built by averaging the entries on each row of matrix B, i.e.

$$\lambda = \frac{\sum_{l=1}^{m} b_{jl}}{m} \tag{5}$$

To calculate the maximum eigenvalue according to following equation

$$\lambda_{max} = \frac{1}{m}\sum_{j=1}^{m}\frac{Aw_j}{\lambda}, \tag{6}$$

where λ_{max}= maximum eigenvalue of the comparison matrix.

d) Calculating the consistency of the matrix

When creating each of the pair wise comparison matrices involved in the process, the AHP contains an excellent approach for evaluating the consistency of the assessments. Chang (1996) calculated the Consistency Ratio (CR) to assess the consistency of the matrix as follows:

$$CR = \frac{\lambda_{max}-n}{n-1}, \tag{7}$$

where n is the number of variables.

The consistency Index (CI) is defined as the ratio of the matrix's consistency ratio (CR) to the RI value, the various values of RI are shown in table 4, where the RI value for ten components is 1.4854.

Table 4. RI values (Saaty, 1980)

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
0.00	0.00	0.5247	0.8816	1.1086	1.2479	1.3417	1.4056	1.4499	1.4854	$\boxed{1.514}$	1.5365	1.5551	1.5713	1.5838

The paired comparison matrix's consistency was examined to determine whether or not the decision-makers' comparisons were consistent. If the consistency Index (CI) is less than 0.10, the AHP analysis can continue. If the consistency ratio is more than 0.10 or 10%, it is important to update the judgements in order to identify and rectify the source of the discrepancy. The value of CI = 0.088 in this study is less than 0.10, which is acceptable.

e) Set up Triangular Fuzzy Number (TFN)

The fuzzy set theory, introduced by (Zadeh, 1965) is well suited to dealing with the uncertainty and imprecision associated with knowledge about various parameters. Uncertainty is a fundamental aspect of human understanding. Indefinite terms, as "equally," "moderately," "strongly," "very strongly," "Extremely," and "significantly" are used to describe human judgment. Decision-makers frequently use imprecise and quantitative words to quantify uncertain occurrences and things. Fuzzy set theory offers a variety of ways for representing a decision maker's qualitative opinion as quantitative data. In this work, triangular fuzzy numbers are utilized to analyze decision-makers' preferences. A triple (l,m,u), where $l \leq m \leq u$, is a triangular fuzzy number. The parameters l, m, and u, respectively, signify the least possible value (lower bound), the modal value, and the maximum possible value (upper bound) for a fuzzy event. (l,m,u) is written as (Tuzkaya & Önüt, 2008).

$$\mu_A(x) = \begin{cases} (x-l)/(m-l), & l \le x \le m, \\ (x-u)/(m-u), & m \le x \le u, \\ 0 & otherwise \end{cases} \tag{8}$$

f) Ranking and selection the decision

The method for computing Fuzzy weights was initially discussed by Buckley (1985). The purpose of utilizing fuzzy triangular numbers is to allow the decision makers to make better decisions if there is any doubt in determining which the alternative is dominant over the others. As indicated in Table 5, the Triangular Fuzzy Number (TFN) is now available. The membership function assigns a value between 0 and 1 as the set's membership degree to each element. The mappings between the fuzzy set and the linguistic term must follow a scale such that the same judgment yields the same measurable result. This type of scale is known as a fuzzy scale.

Table 5. Triangular Fuzzy Number (TFN)

	Surface roughness	Temperature	Rack Angle	cutting Speed	Feed Rate	Depth of Cut	Approach angle	Chatter	Nose Radius	Residual Stress
Surface roughness	(1,1,1)	(1/3,1/2,1)	(1/4,1/3,1/2)	1/6,1/5,1/4	(2,3,4)	(1,1,1)	(1,1,1)	(1,1,1)	(1/3,1/2,1)	(2,3,4)
Temperature	(1,2,3)	(1,1,1)	(2,3,4)	(1/3,1/2,1)	(2,3,4)	(1,1,1)	(4,5,6)	(2,3,4)	(4,5,6)	(4,5,6)
Rack Angle	(2,3,4)	(1/4,1/3,1/2)	(1,1,1)	1/3,1/2,1	(1,1,1)	(1,1,1)	(6,7,8)	(2,3,4)	(4,5,6)	(2,3,4)
cutting Speed	(4,5,6)	(1,2,3)	(1,2,3)	(1,1,1)	(2,3,4)	(4,5,6)	(2,3,4)	(4,5,6)	(2,3,4)	(2,3,4)
Feed Rate	(1/4,1/3,1/2)	(1/4,1/3,1/2)	(1,1,1)	(1/4,1/3,1/2)	(1,1,1)	(2,3,4)	(1,1,1)	(1/4,1/3,1/2)	(1,1,1)	(2,3,4)
Depth of Cut	(1,1,1)	(1,1,1)	(1,1,1)	(1/6,1/5,1/4)	(1/4,1/3,1/2)	(1,1,1)	(1,1,1)	(1/4,1/3,1/2)	(1,1,1)	(2,3,4)
Approach angle	(1,1,1)	(1/6,1/5,1/4)	(1/8,1/7,1/6)	(1/4,1/3,1/2)	(1,1,1)	(1,1,1)	(1,1,1)	(1/4,1/3,1/2)	1/3,1/2,1	(2,3,4)
Chatter	(1,1,1)	(1/4,1/3,1/2)	(1/4,1/3,1/2)	(1/6,1/5,1/4)	(2,3,4)	(2,3,4)	(2,3,4)	(1,1,1)	(1,1,1)	(2,3,4)
Nose Radius	(1,2,3)	(1/6,1/5,1/4)	(1/6,1/5,1/4)	(1/4,1/3,1/2)	(1,1,1)	(1,1,1)	(1,2,3)	(1,1,1)	(1,1,1)	(2,3,4)
Residual Strees	(1/4,1/3,1/2)	(1/6,1/5,1/4)	(1/4,1/3,1/2)	(1/4,1/3,1/2)	(1/4,1/3,1/2)	(1/4,1/3,1/2)	(1/4,1/3,1/2)	(1/4,1/3,1/2)	(1/4,1/3,1/2)	(1,1,1)

The comparison of component m (row element) with component n is represented by the element a_{mn} (column element). It is assumed that A is reciprocal if it is a pair-wise comparison matrix (as indicated in Table 5), and the reciprocal value, i.e. $1/a_{mn}$, is assigned to the element a_{nm}.

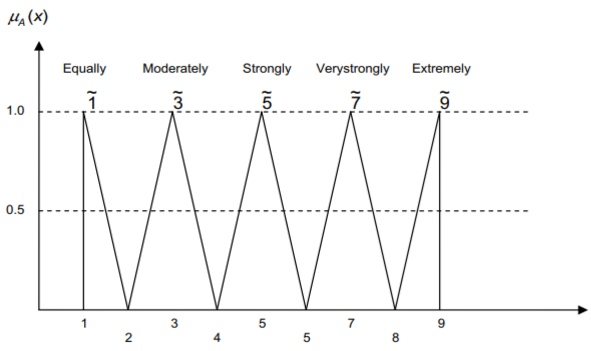

Figure 2. Fuzzy membership function for linguistic values for attributes or alternatives (Ayağ & Özdemir, 2006)

g) Calculate the weight value of the fuzzy value

The logarithmic least-squares approach is used to generate the triangular fuzzy weights that indicate the relative significance of the criterion, the feedback of the criteria, and the alternatives according to each criteria. The following technique for computing triangular fuzzy weights can be used (Tuzkaya & Önüt, 2008).

$$W_k = (w_k^l, w_k^m, w_k^u), \text{ where k=1,2,3,} \tag{9}$$

where

$$w_k^s = \frac{(\prod_{j=1}^n a_{kj}^s)^{1/n}}{\sum_{i-1}^n (\prod_{j=1}^n a_{ij}^m)^{1/n}}, \quad s \in \{l, m, u\} \tag{10}$$

Following the verification of the fuzzy matrices' consistency, the resulting components must be defuzzified to yield a collection of discrete values. This procedure can be developed in a variety of ways, with the one chosen for this study being the one given by (Opricovic & Tzeng, 2003) and results given in Table 6.

Table 6. Weighted average

	Fuzzy Weight (Ŵ)	Weights (ω)
cutting Speed	(0.120755242,0.21965045,0.342994)	20.85%
Rack Angle	(0.082737,0.132625,0.224672369)	13.43%
Feed Rate	(0.04406,0.06856832,0.1336115)	7.51%
Nose Radius	(0.043591,0.07088,0.116554161)	7.05%
Depth of Cut	(0.0424654,0.0592353,0.08962149)	5.84%
Approach angle	(0.03387885,0.0514946,0.0863782)	5.24%
MRR	(0.02203,0.034081,0.0614065)	3.59%

When the procedure is complete, each option will be ranked, and the decision-maker will be able to select which parameter is qualified from the data being compared. Table 5 shows that cutting speed has the highest ideal weight value when compared to the other options. As a result, it is possible to conclude that cutting speed is the highest-quality characteristic among all those considered.

5. Results and discussions

The result obtained after using the suggested combined AHP-FUZZY technique is detailed in this part. As a result, using the Fig. 3 (a, b, c, d), the assessment process based on weights calculated by AHP-Fuzzy techniques on cutting characteristics such as surface roughness, temperature, chatter, and residual stress is explained.

Pairwise comparison matrices for criterion vs criteria with respect to the objective have been constructed based on the data from the aforementioned tables and the criteria under consideration. All of these pairwise comparison matrices result in a priority vector of the criteria in relation to the aim. It is evident that cutting speed has a substantial impact on chatter, residual stresses, surface roughness, and temperature, with values of 32%, 29%, 28%, and 25%, respectively. Chatter, surface roughness, residual stress, and temperature were all substantially impacted by rack angle, although in distinct sequences, with values of 24 percent, 21 percent, 17 percent, and 16 percent, respectively. The feed rate has a 19 percent impact on residual stress, while chatter has a

13 percent affect. Other parameters have values that range from 7% to 11% on the answers.

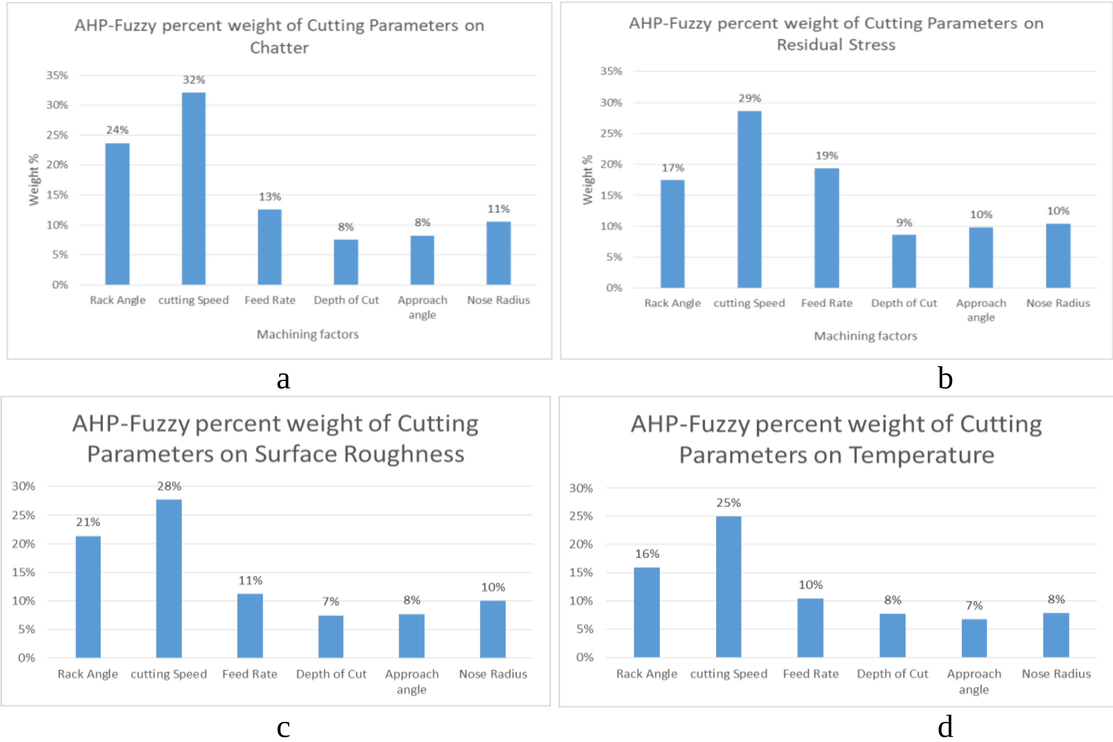

Figure 3. AHP-Fuzzy percent weight of Cutting Parameters on (a: Chatter, b: Residual stress, c: Surface roughness, d: Temperature)

6. Conclusion

The goal of this article was to use the AHP-fuzzy technique to evaluate the weight of all parameters involved in the cutting process of machining of AZ31 alloy. The following are the analysis' contributions and findings:

In the industrial industry, optimal machining parameter selection is a significant topic for improving machining efforts and minimizing machining costs. To identify the ideal parameter values, the weightage of the criterion was determined using the AHP-Fuzzy approach. Surface roughness, which is influenced by cutting speed and rake angle, is the most common issue, followed by chatter. Weight values, on the other hand, must be transformed to digital expressions using intelligent systems that are supported.

References

Adetunmbi, A.O. (2020). Performance Analysis of Fuzzy Analytic Hierarchy Process Multi-Criteria Decision Support Models for Contractor Selection. *Scientific African*, e00471. https://doi.org/10.1016/j.sciaf.2020.e00471

Ayağ, Z., Özdemir, R.G. (2006). A fuzzy AHP approach to evaluating machine tool alternatives. *Journal of Intelligent Manufacturing*, *17*(2), 179–190. https://doi.org/10.1007/s10845-005-6635-1

Ömer, A.S.A.L. (2019). Optimization of Surface Roughness in Turning of AZ31 Magnesium

Alloys With Taguchi Method. *Gazi University Journal of Science Part A: Engineering and Innovation*, *6*(1), 25-32.

Chan, H.K., Wang, X., White, G.R.T., & Yip, N. (2013). An extended fuzzy-AHP approach for the evaluation of green product designs. *IEEE Transactions on Engineering Management*, *60*(2), 327–339. https://doi.org/10.1109/TEM.2012.2196704

Chang, D.Y. (1996). Applications of the extent analysis method on fuzzy AHP. *European Journal of Operational Research*, *95*(3), 649–655. https://doi.org/10.1016/0377-2217(95)00300-2

Jato-Espino, D., Rodriguez-Hernandez, J., Andrés-Valeri, V.C., & Ballester-Muñoz, F. (2014). A fuzzy stochastic multi-criteria model for the selection of urban pervious pavements. *Expert Systems with Applications*, *41*(15), 6807–6817. https://doi.org/10.1016/j.eswa.2014.05.008

Keeney, R.L., Raiffa, H., & Meyer, R.F. (1993). *Decisions with multiple objectives: preferences and value trade-offs*. Cambridge University Press.

Kong, F., Liu, H. (2005). Applying fuzzy analytic hierarchy process to evaluate success factors of e-commerce. *International Journal of Information and Systems Sciences*, *1*(3–4), 406–412.

Liu, Y., Eckert, C. M., & Earl, C. (2020). A review of fuzzy AHP methods for decision-making with subjective judgements. In *Expert Systems with Applications* (Vol. 161). Elsevier Ltd. https://doi.org/10.1016/j.eswa.2020.113738

Lu, L., Hu, S., Liu, L., & Yin, Z. (2016). High speed cutting of AZ31 magnesium alloy. *Journal of Magnesium and Alloys*, *4*(2), 128–134. https://doi.org/10.1016/j.jma.2016.04.004

Miloševi, D. M., & Miloševi, M. R. (2020). *Implementation of Adjusted Fuzzy AHP Method in the Assessment for Reuse of Industrial Buildings*.

Musfirah, A.H., & Jaharah, A.G. (2012). Magnesium and aluminum alloys in automotive industry. *Journal of Applied Sciences Research*, *8*(10), 4865–4875.

Ng, C.Y. (2016). Evidential reasoning-based Fuzzy AHP approach for the evaluation of design alternatives' environmental performances. *Applied Soft Computing Journal*, *46*, 381–397. https://doi.org/10.1016/j.asoc.2016.05.022

Opricovic, S., Tzeng, G.H. (2003). Defuzzification within a multicriteria decision model. *International Journal of Uncertainty, Fuzziness and Knowlege-Based Systems*, *11*(5), 635–652. https://doi.org/10.1142/S0218488503002387

Rezaei, J. (2015). Best-worst multi-criteria decision-making method. *Omega (United Kingdom)*, *53*, 49–57. https://doi.org/10.1016/j.omega.2014.11.009

Saaty. (1980). The Analytic Hierarchy Process Mcgraw Hill, New York. *Agricultural Economics Review*, *70*.

Saaty, T.L. (1987). Concepts, theory and techniques: rank generation, preservation, and reversal in the analytic hierachy decision process. *Decision Sciences*, *18*(2), 157–177.

Shahin, A., Mahbod, M.A. (2007). Prioritization of key performance indicators: An integration of analytical hierarchy process and goal setting. *International Journal of Productivity and Performance Management*, *56*(3), 226–240. https://doi.org/10.1108/17410400710731437

Sobandi, M., Putra, D., Andryana, S., & Gunaryati, A. (2018). *Fuzzy Analytical Hierarchy Process Method to Determine the Quality of Gemstones*. *2018*.

Sun, C.C. (2010). A performance evaluation model by integrating fuzzy AHP and fuzzy TOPSIS methods. *Expert Systems with Applications*, *37*(12), 7745–7754. https://doi.org/10.1016/j.eswa.2010.04.066

Sunil, B.R., Ganesh, K.V., Pavan, P., Vadapalli, G., Swarnalatha, C., Swapna, P., Bindukumar, P., & Pradeep Kumar Reddy, G. (2016). Effect of aluminum content on machining characteristics of AZ31 and AZ91 magnesium alloys during drilling. *Journal of Magnesium and Alloys*, *4*(1), 15–21. https://doi.org/10.1016/j.jma.2015.10.003

Tuzkaya, U.R., Önüt, S. (2008). A fuzzy analytic network process based approach to transportation-mode selection between Turkey and Germany: A case study. *Information Sciences*, *178*(15), 3133–3146. https://doi.org/10.1016/j.ins.2008.03.015

Zadeh, L.A. (1965). Fuzzy Sets. *Information and Control*, *8*, 338–3353. https://doi.org/10.1201/9780429287831-2

Zhang, S., Zhang, X., Zhao, C., Li, J., Song, Y., Xie, C., Tao, H., Zhang, Y., He, Y., Jiang, Y., & Bian, Y. (2010). Research on an Mg-Zn alloy as a degradable biomaterial. *Acta Biomaterialia*, *6*(2), 626–640. https://doi.org/10.1016/j.actbio.2009.06.028