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FINDING OUT GOOD GRINDING QUALITY THROUGH THE AHP BASED SELECTION OF APPROPRIATE PROCESS PARAMETERS

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Abstract: Grinding uses hard, abrasive grits of a wheel for removing micro-volume of work material to finish/semi-finish it. Parametric optimization is tried in this investigation on surface grinding through the analytical hierarchy process (AHP). Data observed during grinding under different parametric combinations and environmental conditions are utilized to construct the AHP model. It is observed that the choice of desired grinding quality through proper machining condition can be made successfully using the AHP.

Keywords: Grinding, Analytical Hierarchy Process, Grinding Quality, Environment.

1. INTRODUCTION

Achieving proper ground surface quality is essential in manufacturing. Grinding is a high speed machining process and it is complex and often fails to achieve desired accuracy. Appropriate control of grinding zone temperature is of utmost importance, else there would be the possibility of thermal damage to the workpiece. So, grindability should be high; operation should be safe; there should be time saving and it should cause minimum damage to workpiece, wheel and machine tool. The limitation of this high speed machining/grinding is thermal damage [1-3]. Many researchers tried in the past various methods to effectively reduce grinding zone temperature while some attempted to improve effectiveness of usual water-soluble oil or some other conventional/ eco-friendly fluids [1-6] utilizing different methods including small or minimum quantity lubrication (SQL/MQL). Application of liquid nitrogen was explored by some others [1-2, 7-9].

Rowe et al. worked [10] on the importance of thermal properties of wheel and explored surface integrity of ground workpiece. Some other researchers tried to formulate relationships between grinding forces and temperature with the related process variables [11]. For the estimation of good grinding quality, proper experimental condition was tried to find out using the Analytical Hierarchy Process (AHP). The AHP makes a rank of each alternative through a logical multi-criteria decision-making procedure.

Patil and his team applied [12] the AHP for finding out the best vitrified bonded wheel parameters. Type of abrasive grit was found to have the highest influence followed by grade of wheel considering finish of the workpiece. On the other hand, Shi et al. [13] employed fuzzy-synthetic theory combined with the AHP to estimate grinding quality through selection of optimum grinding parameters.

The AHP is a simple ranking tool for solving multi-criteria decision-making (MCDM) problems introduced by Saaty [14, 15] and the ranking may vary depending on assigning weights by a person. So, person to person, ranking may vary. In different applications, Das et al. applied [16, 17] the AHP for estimating the state of tool wear. Kazi et al. [18] did optimization in GMAW by applying the AHP to achieve good weld-bead when Mondal et al. [19] evaluated optimal spot welding of 17-4 PH stainless steel using the AHP and Biswas and Das [20] applied the AHP for P91 steel pipe welding for similar purpose. Bologa et al. [21] used the AHP for appropriate selection of manufacturing process. In some other applications in manufacturing area, Bhowmick et al. used [22] the AHP for exploring optimal condition in die-sinking EDM of Inconel workpiece with graphite tool electrode when Acharya et al. [23] employed the AHP in ATIG (activated-flux tungsten inert gas) welding successfully. Chaudhury et al. employed [24] the AHP to select suitable fluid delivery system for grinding titanium work material. Different types of nozzle systems were used. The criteria were wheel load, surface characteristics and force. They noticed compound nozzle setup of fluid delivery to have penetrated the air layer around the wheel. The AHP results were agreeable to the experimental findings. Recently, optimisation in grinding of a nickel-base super alloy was tried using both the AHP and TOPSIS in tandem [25].

This work is undertaken to explore whether the Analytic Hierarchy Process (AHP) would be effective to find out the process parameters to obtain desired grinding quality. The AHP model is developed for grinding of mild steel under different environment by varying different grinding parameters.

2. BASIC STEPS OF THE AHP

The AHP has the ability to solve [14-16] a variety of multi-criteria decision-making problems. First, a hierarchy structure is to be constructed where the goal, or the objective to achieve, is put on the top followed by the criteria and decision alternatives in the consequent descending level as depicted in Fig.1. A form of pairwise comparison matrix is shown in equation (1).

$$\mathbf{A} = \begin{array}{c|cccc} C & E_1 & E_2 & \cdots & E_n \\ \hline E_1 & a_{11} & a_{12} & \cdots & a_{1n} \\ E_2 & a_{21} & a_{22} & \cdots & a_{2n} \\ \vdots & \vdots & \vdots & & \vdots \\ E_n & a_{n1} & a_{n2} & \cdots & a_{nn} \end{array} \quad (1)$$

In Eq. (1), a_{ij} (for i, j = 1, 2, …, n) are strengths of preference of the alternative E_i over E_j with regard to criterion, C selected from 1–9 ratio scale of Table 1, $a_{ji} = 1/a_{ij}$ and $a_{ii}=1$, for all values of i and j.

Table 1: Numerical rating based on relative preference [14, 15]

Judgement	Rating
Extremely preferred	9
Very strongly preferred	7
Strongly preferred	5
Moderately preferred	3
Equally preferred	1
Intermediate values between the two adjacent judgments	2, 4, 6, 8

MatrixA in Eq. (1) is consistent when

$$a_{ij} = w_i/w_j; \quad i,j = 1, 2, \ldots, n \tag{2}$$

and

$$a_{ij}\, a_{jk} = a_{ik} \text{ when } i, j, k = 1, 2, \ldots, n. \tag{3}$$

Here, w_i (I1, 2, ..., n), are priority weights of the respective alternatives that can be computed by solving Eq. (4).

$$Aw = nw; \text{ when } w = (w_1, w_2, \ldots, w_n)^T \tag{4}$$

Matrix A is rarely found to be consistent, and then, Eq. (4) is modified as:

$$Aw = \lambda_{max} w$$

Here, λ_{max} is the largest eigen value of matrix A. (5)

When matrix is inconsistent, λ_{max} n. Inconsistency is measured by consistency index, C.I. given by: $C.I. = (\lambda_{max} - n)/(n-1)$ (6)

Consistency ratio (C.R.) is found by the ratio of C.I. and R.I. (random Index). R.I. is evaluated from a randomly generated matrix of rank n. C.R. ≤10% is usually accepted. Having obtained λ_{max}, local weights are calculated by Eq. (7).

$$w_i = \sum_{j=1}^{n} (a_{ij}\, w_j)/\lambda\max,\ i=1,2,\ldots n \tag{7}$$

Alternatively, the principal right eigenvector, w, can be directly computed by raising the matrix A to an increasing power of k and then normalizing the resulting system as

$$w = \lim_{k\to\infty} \frac{A^k e}{e^T A^k e} \tag{8}$$

If p_j, j = 1, 2, ..., m, are weights of the m criteria and q_{ij}, i = 1, 2, ..., n are local weights of n alternatives with respect to the jth criterion, then global weights of alternatives are computed by Eq. (9).

$$r_i = \sum_{j=1}^{m} p_j\, q_{ij}\ , \qquad i = 1, 2, \ldots\ldots, n \tag{9}$$



Fig. 1. Typical hierarchy structure of AHP

Table 2. Experimental Observation [7,9]

ALTERNAIVE			CRITERIA				
Expt. No.	*Environment*	*Infeed (μm)*	*Grinding Temp. (°C)*	*HAZ (μm)*	*Tangential Grinding Force, F_T (N/mm)*	*Inner Residual Stress (N/mm^2)*	*Surface roughness (μm)*
1	*Dry*	*10*	*948*	*588.5*	*3.8*	*340*	*0.75*
2	*Wet*	*10*	*698*	*477.5*	*4.2*	*300*	*0.55*
3	*Lq. Nitrogen*	*10*	*133*	*100*	*2*	*50*	*0.75*
4	*Dry*	*20*	*1066*	*625*	*6.5*	*480*	*0.875*
5	*Wet*	*20*	*877*	*551*	*7*	*500*	*0.625*
6	*Lq. Nitrogen*	*20*	*313*	*183*	*3.5*	*210*	*0.75*
7	*Dry*	*30*	*1497*	*661.5*	*7.9*	*520*	*0.55*
8	*Wet*	*30*	*1175*	*624.5*	*9.3*	*510*	*0.55*
9	*Lq. Nitrogen*	*30*	*227*	*266*	*4.5*	*310*	*0.9*
10	*Dry*	*40*	*1044*	*698*	*10.5*	*560*	*0.875*
11	*Wet*	*40*	*1000*	*698*	*11*	*520*	*0.65*
12	*Lq. Nitrogen*	*40*	*389*	*349*	*5.5*	*350*	*0.8*

3. Materials and Method

3.1 Experimental details

S. Paul, A.B. Chattopadhyay and P.P. Bandyopadhyay conducted [7-9] several grinding experiments where they used liquid nitrogen along with other grinding environment. Experiments were performed using a Jung made surface grinder employing an AA60K5V8 grinding wheel. Mild steel (AISI 1020) was used as workpiece material with hardness, Rc 14 and carbon content of 0.15%. Cutting velocity taken was 23.5 m/s and table speed was chosen to be 8m/min. Infeed was maintained to be within 10 μm and 40 μm in steps of 10 μm. Grinding was done under dry, soluble oil (wet) and liquid nitrogen environment. Grinding force components were measured by them. Ground surface and chips were studied under Scanning Electron Microscope (SEM). Observations made [7, 9] out of the twelve experimental runs are shown in Table 2.

The AHP is applied in this work based on the experimental data reported by Paul et al. [7, 9] as described in the following section.

3.2 Methodology of applying the AHP on the experimental results

First, hierarchy structure of the AHP is made as shown in Fig. 2. The goal is set to be: "To find out the desired grinding quality by appropriately choosing grinding process parameters". The data of temperature, HAZ, force and surface residual stress have been taken from the observation already reported by Paul and Chattopadhyay [7]. The data of surface roughness have been taken from paper authored by Paul et al. [8]. At 10 μm and 30 μm infeed, temperature and surface roughness were not measured through experiment. Values of temperature and surface roughness have been described by Chattopadhyay [1] and these are used in the AHP model.

Five criteria have been selected. These are:

a) Grinding temperature (C1),
b) HAZ (C2),
c) Grinding force (C3),
d) Surface residuai stress (C4), and
e) Surface roughness (C5).

Tweive aiternatives are considered in the system iike experiment run 1 to experiment run 12. Twelve experiments were conducted under dry, soluble oil and liquid nitrogen environment by varying grinding parameters, such as infeed 10 - 40 µm in steps of 10µm with wheel speed and table feed rate kept constant.

Elements of Table 3 are chosen through pairwise comparison of criteria against the goal to achieve. The pairwise comparison matrix for alternatives for each of the five criteria are constructed as indicated in Tabie 4 through Table 8 keeping in mind the observations indicated in Table 2.

Diagonal elements of pairwise comparison matrix always become unity as one item here is compared with itself only. Based on the experimental data, judgemental rating 1-9 scale is inserted in the comparison matrix. The component of principal eigen vector of the matrix gives the priority weights of the criteria calculated using equation (7). Consistency Index is found out to check the consistency of such a matrix and it should be less than or equal to 10% to make the AHP model acceptable.

4. SELECTION OF APPROPRIATE GRINDING CONDITION UTILIZING THE AHP

Appropriate grinding condition is tried to be selected in this work utilizing the AHP. Observations made out of the twelve experimental runs, as shown in Table 2, are considered for taking the decision. Fig. 2 shows full hierarchy structure of the AHP for

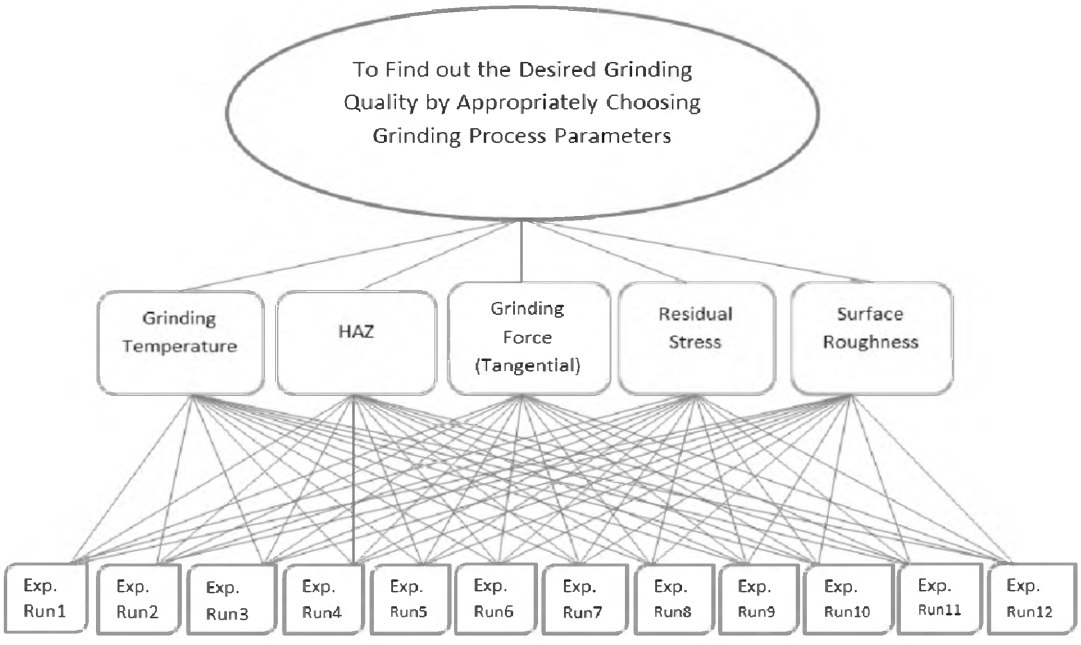


Fig. 2. The developed AHP model

this particular grinding problem. Five criteria are chosen in the present hierarchy structure of the AHP. Table 3 shows the pairwise comparison matrix for criteria considering the Goal to achieve. Similarly, considering each criterion, pairwise comparison matrices for alternatives are decided as given in Table 4 through Table 8. Expertise of authors in the area of grinding was utilized to determine the value of each element of the criterion matrix and the alternative matrices through several brainstorming sessions. Authors think assignment of weights in these matrices is quite reasonable.

Table 3. Pairwise comparison matrix for the criterion with regard to the goal

Goal	C1	C2	C3	C4	C5	Criteria Wt.
C1	*1*	*3*	*5*	*7*	*9*	*0.51704*
C2	*1/3*	*1*	*2*	*4*	*8*	*0.24224*
C3	*1/5*	*1/2*	*1*	*2*	*6*	*0.13623*
C4	*1/7*	*1/4*	*1/2*	*1*	*3*	*0.07315*
C5	*1/9*	*1/8*	*1/6*	*1/3*	*1*	*0.03132*

R.I.= 1.12, C.R.= CI/RI= 0.0355<0.1; so, matrix is acceptable and correct.

Table 4. Pairwise comparison matrix for alternatives with regard to grinding temperature (C1 criterion)

C1	E1	E2	E3	E4	E5	E6	E7	E8	E9	E10	E11	E12	Local Wt.
E1	*1*	*1/5*	*1/9*	*2*	*1/2*	*1/6*	*4*	*2*	*1/6*	*2*	*2*	*1/6*	*0.0309*
E2	*5*	*1*	*1/6*	*6*	*3*	*1/4*	*8*	*7*	*1/5*	*7*	*7*	*1/5*	*0.0822*
E3	*9*	*6*	*1*	*9*	*7*	*5*	*9*	*8*	*2*	*8*	*8*	*5*	*0.2743*
E4	*1/2*	*1/6*	*1/9*	*1*	*1/3*	*1/7*	*2*	*2*	*1/8*	*1*	*1*	*1/6*	*0.0212*
E5	*2*	*1/3*	*1/7*	*3*	*1*	*1/5*	*6*	*4*	*1/6*	*4*	*4*	*1/4*	*0.0494*
E6	*6*	*4*	*1/5*	*7*	*5*	*1*	*8*	*7*	*1/2*	*7*	*7*	*1*	*0.1393*
E7	*1/4*	*1/8*	*1/9*	*1/2*	*1/6*	*1/8*	*1*	*1/2*	*1/9*	*1/2*	*1/3*	*1/8*	*0.0120*
E8	*1/2*	*1/7*	*1/8*	*1/2*	*1/4*	*1/7*	*2*	*1*	*1/8*	*1*	*1/2*	*1/7*	*0.0171*
E9	*6*	*5*	*1/2*	*8*	*6*	*2*	*9*	*8*	*1*	*8*	*8*	*2*	*0.1952*
E10	*1/2*	*1/7*	*1/8*	*1*	*1/4*	*1/7*	*2*	*1*	*1/8*	*1*	*1*	*1/7*	*0.0192*
E11	*1/2*	*1/7*	*1/8*	*1*	*1/4*	*1/7*	*3*	*2*	*1/8*	*1*	*1*	*1/7*	*0.0211*
E12	*6*	*5*	*1/5*	*6*	*4*	*1*	*8*	*7*	*1/2*	*7*	*7*	*1*	*0.1375*

C.R.= 0.0676<0.1; so, matrix is acceptable and correct.

Table 5. Pairwise comparison-matrix for alternatives with regard to HAZ (C2 criterion)

C2	E1	E2	E3	E4	E5	E6	E7	E8	E9	E10	E11	E12	Local Wt.
E1	1	1/2	1/6	2	1	1/5	3	2	1/4	4	9	1/3	0.0525
E2	2	1	1/5	3	2	1/4	4	3	1/3	5	5	1/2	0.0728
E3	6	5	1	7	6	2	8	7	3	9	9	4	0.2613
E4	1/2	1/3	1/7	1	1/2	1/6	2	1	1/5	3	3	1/4	0.0323
E5	1	1/2	1/6	2	1	1/5	3	2	1/4	4	4	1/3	0.0491
E6	5	4	1/2	6	5	1	7	6	2	8	8	3	0.1977
E7	1/3	1/4	1/8	1/2	1/3	1/7	1	1/2	1/6	2	2	1/5	0.0219
E8	1/2	1/3	1/7	1	1/2	1/6	2	1	1/5	3	3	1/4	0.0323
E9	4	3	1/3	5	4	1/2	6	5	1	7	7	2	0.1450
E10	1/4	1/5	1/9	1/3	1/4	1/8	1/2	1/3	1/7	1	1	1/6	0.0153
E11	1/4	1/5	1/9	1/3	1/4	1/8	1/2	1/3	1/7	1	1	1/6	0.0153
E12	3	2	1/4	4	3	1/3	5	4	1/2	6	6	1	0.1039

C.R.= 0.0392<0.1; so, matrix is acceptable and correct.

Table 6. Pairwise comparison matrix for alternatives with regard to grinding force (for C3 criterion)

C3	E1	E2	E3	E4	E5	E6	E7	E8	E9	E10	E11	E12	Local Wt.
E1	1	2	1/2	4	5	1	6	7	2	8	8	3	0.1606
E2	1/2	1	1/3	3	4	1/2	5	6	1	7	7	2	0.1085
E3	2	3	1	5	6	2	7	8	3	9	9	4	0.2261
E4	1/4	1/3	1/5	1	2	1/4	3	4	1/3	5	5	1/2	0.0518
E5	1/5	1/4	1/6	1/2	1	1/5	2	3	1/4	4	4	1/3	0.0367
E6	1	2	1/2	4	5	1	6	7	2	8	8	3	0.1606
E7	1/6	1/5	1/7	1/3	1/2	1/6	1	2	1/5	3	3	1/4	0.0262
E8	1/7	1/6	1/8	1/4	1/3	1/7	1/2	1	1/6	2	2	1/5	0.0189
E9	1/2	1	1/3	3	4	1/2	5	6	1	7	7	2	0.1085
E10	1/8	1/7	1/9	1/5	1/4	1/8	1/3	1/2	1/7	1	1	1/6	0.0137
E11	1/8	1/7	1/9	1/5	1/4	1/8	1/3	1/2	1/7	1	1	1/6	0.0137
E12	1/3	1/2	1/4	2	3	1/3	4	5	1/2	6	6	1	0.0741

C.R.= 0.0323<0.1; so, matrix is acceptable and correct.

Table 7. Pairwise comparison-matrix for alternatives with regard to inner surface residual stress (for C4 criterion)

C4	E1	E2	E3	E4	E5	E6	E7	E8	E9	E10	E11	E12	Local Wt.
E1	1	1/2	1/5	2	2	1/4	4	3	1/2	5	4	1	0.0698
E2	2	1	1/4	3	3	1/3	5	4	1	6	5	2	0.1060
E3	5	4	1	6	6	3	8	7	4	9	8	5	0.2760
E4	1/2	1/3	1/6	1	1	1/5	3	2	1/3	4	3	1/2	0.0453
E5	1/2	1/3	1/6	1	1	1/5	3	2	1/3	4	3	1/2	0.0453
E6	4	3	1/3	5	5	1	7	6	3	8	7	4	0.1957
E7	1/4	1/5	1/8	1/3	1/3	1/7	1	1/2	1/5	2	1	1/4	0.0205
E8	1/3	1/4	1/7	1/2	1/2	1/6	2	1	1/4	3	2	1/3	0.0301
E9	2	1	1/4	3	3	1/3	5	4	1	6	5	2	0.1060
E10	1/5	1/6	1/9	1/4	1/4	1/8	1/2	1/3	1/6	1	1/2	1/5	0.0145
E11	1/4	1/5	1/8	1/3	1/3	1/7	1	1/2	1/5	2	1	1/4	0.0205
E12	1	1/2	1/5	2	2	1/4	4	3	1/2	5	4	1	0.0698

C.R. = 0.0305<0.1; so, matrix is acceptable and correct.

Table 8. Pairwise comparison matrix for alternatives with regard to surface roughness (for C5 criterion)

C5	E1	E2	E3	E4	E5	E6	E7	E8	E9	E10	E11	E12	Local Wt.
E1	1	1/5	1	4	1/4	1	1/5	1/5	5	4	1/3	3	0.0474
E2	5	1	5	7	3	5	1	1	8	7	4	6	0.1943
E3	1	1/5	1	4	1/4	1	1/5	1/5	5	4	1/3	3	0.0474
E4	1/4	1/7	1/4	1	1/6	1/4	1/7	1/7	3	1	1/5	1/3	0.0181
E5	4	1/3	4	6	1	4	1/3	1/3	7	6	3	5	0.1181
E6	1	1/5	1	4	1/4	1	1/5	1/5	5	4	1/3	3	0.0474
E7	5	1	5	7	3	5	1	1	8	7	4	6	0.1943
E8	5	1	5	7	3	5	1	1	8	7	4	6	0.1943
E9	1/5	1/8	1/5	1/3	1/7	1/5	1/8	1/8	1	1/3	1/6	1/4	0.0119
E10	1/4	1/7	1/4	1	1/6	1/4	1/7	1/7	3	1	1/5	1/3	0.0181
E11	3	1/4	3	5	1/3	3	1/4	1/4	6	5	1	4	0.0800
E12	1/3	1/6	1/3	3	1/5	1/3	1/6	1/6	4	3	1/4	1	0.0282

C.R. = 0.0613<0.1; so, matrix is acceptable and correct.

By combining criteria weight with the weight for alternatives, global weights are computed. Excel tool was used by formula to calculate the weights. Largest value of global weight corresponds to the most preferable alternative, meaning a particular experimental run, of the others within the present experimental domain. Table 9 gives global weights obtained. Fig. 3 is constructed with the data shown in Table 9 representing global weights in decreasing order. Fig. 3 shows that the E3 alternative is the best and it corresponds to 10 μm infeed under liquid nitrogen environment. It gives grinding quality best than the other experimental conditions. Then the global weights of E6 and E9 are near about the same. At 20 μm infeed under liquid nitrogen and 30 μm infeed under liquid nitrogen, better grinding quality can be obtained. Values of temperature, HAZ, force, residual stress and surface roughness are near about the same for E6 and E9 alternatives. After that according to global weight, E12 gets preference. E12 at 40 μm depth of cut and under liquid nitrogen environment gives grinding quality to be good. Fig. 3 shows that E10 alternative at the experimental condition of 40 μm depth of cut, under dry environment without using coolant gives the worst grinding quality.

Table 9. Global Weight for Alternatives

Alternatives	*Global Weights*
E1	*0.0572*
E2	*0.08879*
E3	*0.25765*
E4	*0.02978*
E5	*0.04947*
E6	*0.15763*
E7	*0.02273*
E8	*0.0276*
E9	*0.15905*
E10	*0.01719*
E11	*0.02052*
E12	*0.11239*

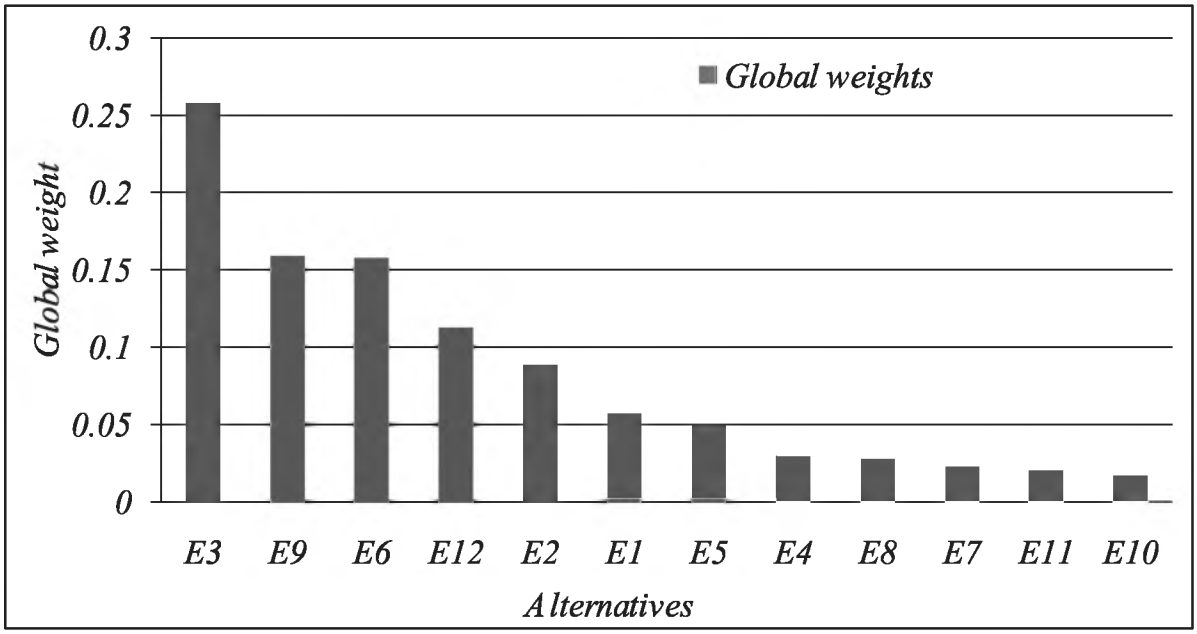


Fig. 3. Alternatives representing decreasing global weight

5. CONCLUSION

Results through the AHP show that grinding quality is the best when depth of cut is less and under cryogenic cooling treatment. When soluble oil is used as a coolant, at that time less temperature rise occurs and the area of HAZ is narrow. If grinding force acting on the workpiece is more, then residual stress within the surface will be more. So, results through the AHP show that grinding quality is good under a wet environment. All experimental conditions under dry environment are ranked at a lower level of the AHP model. In a dry environment, heat generation is more and surface roughness is the highest. The AHP process shows close estimation to find out the best quality of grinding and hence, the success. Further research can be done by varying more alternative environmental conditions on different types of materials and criteria to go towards green manufacturing, and to improve surface quality through applying MCDM for appropriate judgement.

REFERENCE

1. Chattopadhyay, A. B., Machining and Machine Tools, Wiley Publication, New Delhi. 2011.
2. Das, S., Improving Grinding Performance through Appropriate Grinding Fluid Application, Proceedings of the National Conference on Investment Casting (NCIC-2003), Durgapur, September 22-23 2003, pp.97-103, 2003.
3. Mahata, S., Mistri, J., Mandal, B. and Das, S., Coolants and Their Role in Grinding, Reason- A Technical Magazine, Vol.10, pp.41-44, 2011.
4. Mandal, B., Sing, R., Das, S. and Banerjee, S., Improving Grinding Performance by Controlling Air Flow around a Grinding Wheel, International Journal of Machine Tools and Manufacture, Vol.51, No.9, pp.670-676, 2011.
5. Mahata, S., Mistri, J., Mandal, B. and Das, S.,A Comparative Study of Grinding Performance Using Different Fluid Delivery Techniques, Journal of the Association of Engineers, India, Vol.83, No.3-4, pp.63-70, 2013.
6. Majumdar, S., Kumar, S., Roy, D., Chakroborty, S. and Das, S., Improvement of lubrication and cooling in grinding, Materials and Manufacturing Processes, Vol. 33, No.13, pp.1459-1465, 2018.
7. Paul, S. and Chattopadhyay, A. B., A Study of Effects of Cryo-Cooling in Grinding, International Journal of Machine Tools and Manufacture, Vol. 35, No.1, pp.109-117,1995.
8. Paul, S., Bandyopadhyay, P. P. and Chattopadhyay, A. B., Effects of Cryo-Cooling in Grinding Steels, Journal of Materials Processing Technology, Vol. 37, pp.791-800, 1993.
9. Paul, S., Das, S., Bandyopadhyay, P.P. and Chattopadhyay, A.B., Effect of Cryogenic Cooling on Wheel Loading in Grinding Steels, Proceedings of the 16th all India Manufacturing Technology Design and Research Conference, Bangalore, December 8-10 1994, pp.478-484, 1994.
10. Rowe, W., Black, S., Mills, B., Qi, H. and Morgan, M., Experimental Investigation of Heat Transfer in Grinding, Annals of the CIRP, Vol. 44, No.1, pp.329-332, 1995.
11. Biswas, A.K. and Das, S., Comparative study of force analysis and heat generation in grinding, Reason- A Technical Magazine, Vol.10, pp.17-20, 2011.
12. Patil, S. and Bhalerao, J., Ranking of Vitrified Grinding Wheel Parameters by

Using Analytical Hierarchical Process for Surface Roughness of Workpiece in Grinding Operation, Proceedings of the International Conference on Advances in Mechanical, Industrial, Automation and Management Systems, pp.185-188,2017.

13. Shi, X., Liu, G., Wang, Q. And Kang, R., Study on a Grinding Quality Assessing Method Based on Fuzzy Decision Combined with Analytic Hierarchy Process, Engineering Materials, Vol. 359-360, pp.543-547, 2008.
14. Saaty, T. L., A Scaling Method for Priorities in Hierarchical Structures, Journal of Mathematical Psychology, Vol.15, pp.234-281,1977.
15. Saaty, T. L., The Analytic Hierarchy Process, McGraw-Hill, New York, 1980.
16. Das, S., Islam, R. and Chattopadhyay, A. B., A Simple Approach for On-Line Tool Wear Monitoring Using the Analytic Hierarchy Process, Proceedings of the Institution of Mechanical Engineers, Part B, Journal of Engineering Manufacture, Vol. 211, No.B1, pp.19-27, 1997.
17. Das, S., Datta, S., Mondal, P., Das, S. K. and Sinha, S., Application of the Analytic Hierarchy Process as an Optimization and Predictive Tool, Proceeding of the Conference on Intelligent Computing and VLSI, Kalyani, February 16-17 2001, pp.55-100, 2001.Sabiruddin, K., Das, S. and Bhattacharya, A., Application of the Analytic Hierarchy Process for Optimization of Process Parameters in GMAW, Indian Welding Journal, Vol. 42, No.1, pp.38-46, 2009.
18. Kazi, S., Das, S. and Bhattacharya A., Application of the analytic hierarchy process for optimisation of process parameters in GMAW, Indian Welding Journal, Vol.42, No.1, pp.38-46, 2009.
19. Mondal, C., Bhattacharya, S. and Das, S., Parametric Optimisation of Spot Welding of 17-4 Ph Stainless Steels Using the Analytic Hierarchy Process, Indian Welding Journal, Vol. 44. No.4, pp.69-77, 2011.
20. Biswas, N. and Das, S., Selection of Process Parameters for Welding P91 Steel Pipes Using The Analytic Hierarchy Process, Reason-A Technical Magazine, Vol. 10, No.1, pp.7-12, 2011.
21. Bologa, O., Breaz, E.R., Racz, S. And Crenganis, M., Using the Analytic Hierarchy Process in Evaluating the Decision of Moving to a Manufacturing Process Based upon Continuous 5 Axes CNC Machine-Tools, Procedia Computer Science, Vol. 91, pp.683-689, 2016.
22. Bhowmick, R., Chattaraj, P., Das, S. and Mondal, B., The AHP Based Evaluation of Optimal Condition for Electric Discharge Machining of Inconel Workpiece Using Graphite Electrode, Proceedings of the 63rd National Convention & International Conference on Evolution of Industrial Engineering in Covid Era, Indian Institution of Industrial Engineering, December 4-5 2021.
23. Acharya, S., Gonda, D., Das, S., Bose, D. and Islam, R., Augmentation of Depth of Penetration and Productivity Benefits of ATIG Welds Using the AHP, International Journal of the Analytic Hierarchy Process, Vol. 15, No.3, pp.1-20, 2023.
24. Chaudhury, A., Mandal, B. and Das, S., Selection of appropriate fluid delivery technique for grinding titanium grade-1 using the Analytic Hierarchy Process, International Journal of Analytic Hierarchy Process, Vol. 7, No.3, pp.454-469, 2015.
25. Azizi, A., Seidi, M., Bahrami, P. and Rabiei, F., Nickel-Based Super Alloy Grinding Optimisation Using a Hybrid Multi Attribute Decision Making Method Based on Entropy, AHP and TOPSIS, Advances in Materials and Processing Technologies, pp.1-20, 2024