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Selection of Optimal Parameters for Reduction of Forging Defect using AHP-TOPSIS Technique

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ABSTRACT: The objective of current experimental study is to minimize underfill defect in one of the leading gear forging industry in India. There are various types of defects occuring in this industry but the underfill defect is the main concern for research due to its high percentage of occurrence. Five months experimental data was collected and analyzed. The percentage of rejection due to underfill defects in gear forging was found to be 2.73 %. Therefore, trials have been conducted for the range of input parameters such as billet weight varied form 2.000-2.275 kg, billet temperature from 1180-1210℃, forging time from 12-21 seconds and die temperature from 195-250℃. To overcome this problem and to find the most excellent set of input parameter AHP-TOPSIS approach is used which gives maximum efficiency and minimum rejection of gear forgings in this industry. Present study provides a platform for researchers working in the field of manufacturing to find an optimum set of parameters to minimize the rejection rate in distinct industries. By implementing this technique in the current research work the minimum rejection of gear forging due to underfill defect has been minimized to 1.48% corresponding to billet weight of 2.275 kg, billet temperature of 1190℃, forging time of 12 seconds and die temperature of 250℃ respectively.

Keywords: Forging, Forging defects, Underfill, AHP, TOPSIS.

Abbreviations: AHP, analytical hierarchy process; MCDM, multi-criteria decision making; NM, normalized matrix; PCD, parameter defining criteria; WNM, Weighted normalized matrix; PWCM, pair wise comparison matrix; TOPSIS, order of preference by similarity to ideal solution; ET-1, experimental Trial-1; ET-2, experimental Trial-2; ET-3, experimental Trial-3; WB, weight of billet; TB, temperature of billet; TF, temperature of forging; TD, temperature of die; CR, consistency ratio; RI, random consistency index; CI, consistency ratio; FEM, finite element methods; NN, neural network; RFM, radial forging machine; AFRC, Advanced frame rate converter; RSM, response surface method; FEA, finite element analysis; ANOVA, analysis of variance; BSC, balance score card; FAHP, fuzzy analytical hierarchy process; ANP, analytical network process; DEA, data envelopment analysis; SQC, statistical quality control; ADRC, active disturbance rejection control; NDM, normalized decision matrix; WNDM, weighted normalized decision matrix; CM, comparison matrix.

Nomenclature: W_l, comparative weight; d_{hl}, normalize decision matrix; $\bar{d}_{hl}$, weighted normalize decision matrix; $\emptyset_{\boldsymbol{h}}$, closeness index; β_h^+, β_h^-, eculidian distance; E_{hl}, constituent of matrix; R, alternative; S, criterion; G, positive and negative ideal solution.

I. INTRODUCTION

Forging is the earliest metal working process used to shape a metal in desired shape by applying compressive load. During forging process there are many defects occurs in the forging industries like underfill, crack, bend and lap etc. These defects are responsible for heavy loss in the industries [1]. Forging imperfection is studied and analyzed by Non-linear FEM process modeling on crankshaft with the help of DEFORM. They predicted the forging imperfection such as laps, folds and under fill by analyzing velocity vectors. They also studied the stream stress of crankshaft material to recognize the imperfection and improved design process [2-4]. Hawryluk and Ziemba (2015) utilized 3D reverse scanning method and appraisal of the wear of the forging tool and choosing forging defects by means of the utilization of a laser scanner incorporated among a measuring arm [5]. The utilized method may be helpful for immediate evaluation of the present tool condition and forging superiority. Also, this method is utilized for the examination of the constancy and precision of the manufacturing method. Gerin *et al.*, (2018) studied the effect of surface imperfection on the fatigue behavior of a connecting rod [6]. For identification of the imperfections the products were scanned prior to fatigue test and fatigue model was developed by examining the fatigue outcomes. Huang *et al.,* (2017) suggested a comprehensive 3D model for development of the forging process [7]. This model has application on process optimization and gives complete insight into the forging process. Pang *et al.,* (2017) developed a approach for manufacture of hollow axle shaft for heavy duty vehicles [8]. For achieving this target non-isothermal forging process is utilized and its viability is examined with finite element software. Outcomes show that there is no need of too much forming loads for non-isothermal forming process. Richter *et al.,* (2017) experimentally examined the thin flash generation and developed an analytical simulation technique [9]. Narita *et al*., (2017) analyzed the influence of spring back on diameter of shaft in cold forging process [10]. Kinematic hardening and isotropic models with FE analysis were executed and they concluded that both the models presented the identical tendency on the variation in diameter [11].

investigated the causes of forming flow found in spur gear. They employed RSM technique for increasing the quality of forming and optimization of die structure and extrusion speed and this is the viable ways to make spur gears in the field of plastic forming. Kilicaslan and Ince (2016) experimentally and numerically analyzed the crack creation on the steel bolt prepared by cold forging process [12]. They developed numerical models for the simulation of forging process and malfunction growth was predicted with the help of Cockroft-Latham model. Also, the forging experiments were used to confirm the numerical predictions on crack creation. Zhang *et al*., (2016) analyzed the void of hot axial forging operation which depends on internal temperature [13]. They proposed a two-dimensional model for hot forging with void. Hence, experimental outcomes were used to ensure the viability of the detection analysis. Behrens *et al*., (2016) numerically examined the two distinct geometric changes of two hot forging die outfitted with inside cooling channels [14]. They investigated the stress states within the die during their examination. Soyaliya *et al*., (2015) studied the reasons of forging imperfection happening in the forging process and proposed their remedial action [15]. They found that appropriate forging practice, modified die design, suitable heating temperature of billet decrease the unfilling imperfection. They also proposed a FEM based DEFORM 3D which helps to detect the imperfection occurring in the forging process and provide the optimal solution for removal of this imperfection. Guo *et al.,* (2016) reported an examination of an unusual crack formation in the forging plate in their study. They found that the main cause of crack formation is fragility caused by phosphorus isolation around crack zone [16]. Hawryluk and Jakubik (2015) studied the forging imperfections i.e. under fills because of tool and air pockets happening in the die forging operation [17]. They proposed FEM software for analyzing the forging operation and concluded that numerical modeling outcome received to be in excellent accord with the consequences of the macroscopic, micro structural and defectoscopic investigation. Zhang *et al*., (2014) [18] applied multi objective design approach to optimize the operation of rib-web forgings by combining Taguchi and FEM approach. The outcomes show that the reasons of the poor quality of forging in the examined region are starting temperature and ratio of height-width of the billet. Patel *et al.,* (2014) examined the causes of forging imperfections occurring in the forging process and illustrate the corrective measures to minimize these imperfections [19]. They reported that forging imperfections are minimized by improving manufacturing process and optimization of the input parameter. Solek *et al.,* (2014) examined the material flow to obtain the superior-quality forgings from unwrought stock [20]. They performed the numerical simulation of the forging operation with Q Form 3D under different thermo-mechanical situation. Outcomes obtained from the numerical simulation were applied to decide the suitable parameters for the forging operation. Liu *et al.,* (2014) investigated the effect of model-parameters like forming temperature material of material, reduction rate etc on inside defects of cross wedge rolling process [21]. They developed a technique for parameter and deformation allotment and utilized in manufacturing of the shafts. Outcomes obtained shows that the highest reduction rate possible without defects is 75% which may be achieved through one time rolling if more reduction rate is required then split once deformation into two times. Abdullah *et al.,* (2013) studied the creation of defects occurring in the cold forging process depending upon the material flow pattern and stress allocation [22]. DEFORM-2D model was used to examine the defects. They found that cause responsible for the creation of forging defect was distance to the edge. Also, they concluded that the finite element method outcomes are in excellent accord among experimental consequence. Kakimoto *et al.,* (2010) examined the role of inner voids of steel ingot in the forging process through 2-D finite element method (FEM) [23]. Experimental outcomes were compared with the analytical outcomes and concluded that it was favorable to simulate the inner void behavior through this analysis. Kumar *et al*., (2019) developed a model to assist managers impartially to evaluate the suppliers [24]. This model was used by two Indian heavy locomotive manufacturers for evaluation and selection of supplier. Gupta *et al.,* (2015) appraised the sustainable manufacturing methods by developing AHP-based model. AHP technique was used for development of this model and utilized for significant weights calculation [25]. Galankashi *et al*., (2016) gives a BSC–FAHP technique for choosing of supplier in the automobile industry [26]. Primarily, a BSC framework was anticipated for the planning of suppliers' performance computation that contains precise procedures of automobile industry in every perception. Also, this work can be incorporated with other MCDM tools such as ANP and DEA. Azimifard *et al.,* [27] conducted the three levels study to find out the supplier countries of steel industry. Bergeron *et al*., [28] used a vacuum heat treated stock for dies, the material evaluation of the pre-hardened and vacuum heat treated materials revealed no signs of any defects. No signs of fatigue were present on the dies and the failures occurred in a brittle manner. The failure mode was determined to be low cycle, high stress fatigue. Investigation into possible surface defects induced during the machining operation revealed no such defects. Khare *et al.,* (2011) show how performance analysis demonstrates significant improvement that can be achieved from optimization of vertical Hand-off in heterogeneous wireless system, also the vertical handoff as important elements in the emerging heterogeneous wireless networks [29]. Mustafin and Vevrek (2019) focus on usage of one of MCDM methods - TOPSIS technique - as a tool for comprehensive evaluation in self-government in Slovakia [30]. This method is applied on a sample of 276 municipalities of Trencin self-governing region. 8 criteria are used and their weight was calculated based on Equal importance method and Fuller triangle method with 25 experts from public sector. Konstantinos *et al*., (2019) presents a methodology which is based on the combination of a MCDM methodology called Analytical Hierarch Process (AHP) and Geographic Information Systems in order to determine the most suitable locations for wind farms installation [31]. The calculated locations are then ranked using the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) in order to rank the locations based on installation suitability. Baswaraj *et al.,* (2018) prioritize parameters for steel recycling using AHP, in the context of Indian steel recycling industries [32]. Understanding these priorities help secondary steel industries to develop strategies to improve quality of steel produced. This approach has been implemented in a prototype for checking in practice. A systematic approach to evaluate quality has been developed using the analytical hierarchy process, which enables the combination of tangible and intangible criteria and checking the consistency of decision-making and also helps to improve agility of secondary steel recycling industries.

Previous study done by distinct researchers reveals that many of research work done on the analysis and removal of forging defects with distinct approaches like SQC tools, Taguchi technique, ANOVA etc, but these approaches are lengthy and less efficient as compared to AHP-TOPSIS technique. AHP-TOPSIS technique is much accurate and efficient as compare to other approaches used in the field of manufacturing till now. The purpose of current experimental work is to select suitable input parameter for forging process with AHP-TOPSIS approach and input parameters are designed by Taguchi L16 orthogonal array to minimize percentage of rejection. In present examination AHP-TOPSIS approach has been utilized to determine the superlative set of input parameters that are designed by means of Taguchi L16 orthogonal array. The influence of variations that is PDC (ET-1, ET-2 & ET-3) standards have been delivered with AHP model and each one of the option of information sets are ranked with TOPSIS approach.

II. MATERIALS AND METHODS

Procedure adopted for current experimental work as follows:

– Study the forging defects responsible for the rejection of gear forging
– Data collection
–Data Analysis
(i) Determination of rejection rate
(ii) Analyze the major contribution
– Causes and effect diagram
– Experimental trial setup

Study of the forging defects responsible for the rejection of gear forging: The following defects are responsible for the rejection of gear forging in the industry.

– Underfill
– Pitmark
– Cold shut
– Die shift
– Lap
– Flakes
– Mismatch.

Data collection and analysis: The five months data of gear have been collected from the company as shown in Table 1 and then the statistical analysis of this data of gear under investigation is carried out. The defects responsible for rejection of gear forging are shown in Fig. 1.

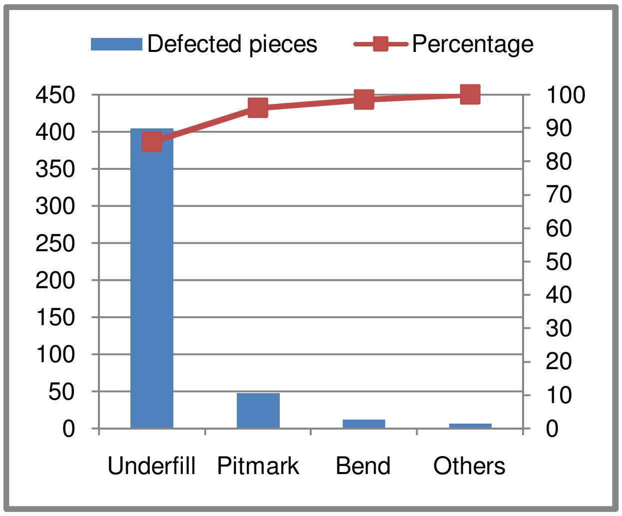

Fig. 1. Parreto analysis of forging defects.

Table 1: Monthly data of gear under investigation.

Month	**Manufactured Components**	**Accepted Components**	**Rejected Components**	**Defects**					
				Under Fill	**Pit mark**	**Bend**	**Others**	**Σ Rej.**	**Percentage Rejection due to underfill**
Jan.	4446	4326	120	96	20	2	2	120	2.7
Feb.	3298	3181	115	98	10	5	2	115	3.48
Mar.	1584	1537	47	46	1	0	0	47	2.96
Apr.	4929	4823	106	95	7	3	3	106	2.15
May.	3030	2946	84	70	10	2	2	84	2.8
Total	17287	16815	472	405	48	12	7	472	2.73
Percentage Contribution				85.8	10.2	2.52	1.48		

All the rejected parts are analyzed to identify the zone/region of the defects. The defects are then arranged in order of priority as shown in Table 2. Where underfill defect has percentage contribution of 85.6%, Pitmark 10.6 %, Bend 4.06 % and others 1.6 % respectively. From Table 2 it has been found that underfill defect has major contribution to the rejection of gear forging.

Table 2: Percentage contribution of defects.

Defects	Priority
Underfill	85.6
Pitmark	10.6
Bend	4.06
Others	1.6

Fishbone (Ishikawa) diagram: Fishbone (Ishikawa) diagram is used for problem diagnosis. The diagram lists out in a classified and systematic manner all causes which are responsible for the problem (called effect).

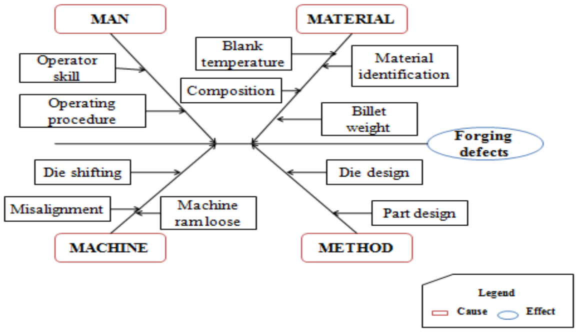

Fig. 2. Fishbone (Ishikawa) diagram.

Fishbone (Ishikawa) diagram (Underfill): The main causes of the underfill defects are:
- Under weight
- Material of die
- Shortcuts in process
- Lack of skills
- Scale deposited in die
- Die wear
- Insufficient heating
- Improper manufacturing method
- Improper material flow
- Improper design.

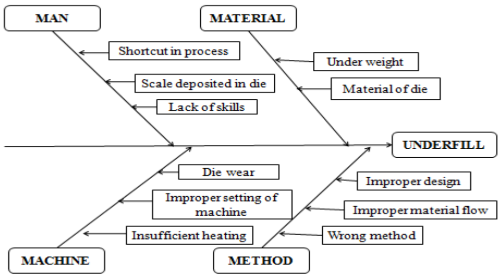

Fig. 3. Fishbone (Ishikawa) diagram of underfill.

Experimental trial setup: The schematic diagram of experimental trial setup is shown in the (Fig. 4) a material used is 20MnCr5 for gear7437. The billet from the raw material bar and bar was first sheared by the shearing machine to the rough weight and dimensions and it was cut to the final size and weight by the band saw. The billet is then heated in the induction furnace to the forging temperature. The hot billet is then put on the blocker die to remove the scaling and make the preform; the preform is then put on the finisher die to make the forging of the desired shape and size. The hot forging is then cooled and heat treated to relieve the stresses and strains induced during forging. The oil fired heat treatment furnace is used for annealing and normalizing. The forged components are then cleaned by the shot blast cleaning machine by using the metal ball blast and the air blast. To assess the quality of the forging parts the parts are examined 100 percent visually for the forging defects and 5 percent with the assistance of vernier caliper and height gauge for dimensional accuracy. In this study the percentage of rejection because of the forging defect like under filling, crack, lap, pitmark are the quality characteristics of the forgings. To achieve the better quality of the forging the forged parts should be defect free and dimensionally accurate.

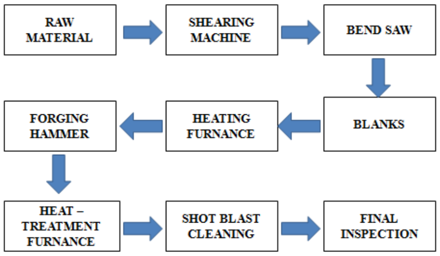

Fig. 4. Experimental setup.

The experimentally analyzed input parameters of gear forging incorporates four data of each such as weight of billet (WB), temperature of billet (TB), Time of forging (TF) and temperature of die respectively. The array L16 is taken dependent on number of parameters and their level.

Table 3: Parameters and range of experiment.

S. No.	Parameters	Symbol	Range
1.	Weight of billet	WB	2.000 – 2.275 kg
2.	Temperature of billet	TB	1180 – 1210℃
3.	Time of forging	TF	12 – 21 Sec
4.	Temperature of die	TD	195 – 250℃

Methods for optimization: AHP-TOPSIS is extremely conspicuous MCDM which positions various option and built up ideal outcomes. The outcomes accomplished are closer to the ideal outcomes and far as of the nastiest. Worried to the quick improve in uses of AHP-TOPSIS, we have utilized this procedure for optimization in the present investigation moreover.

AHP Approach: AHP strategy is useful to organize reaction among assigning weight and after that at last gives the position of all option. AHP is a structured strategy built up by Saaty [33]. The AHP method comprises the accompanying Stage:

Stage-I: Hierarchy structure in this condition, a multiple decision creation is planned as a hierarchy. Hierarchy is framed so that on the whole plan objective is at the top position, basis PDC (T-1, T-2 & T-3) are in the center stage and alternative (A-1 to A-16) are at the base stage as shown in Fig. 5.

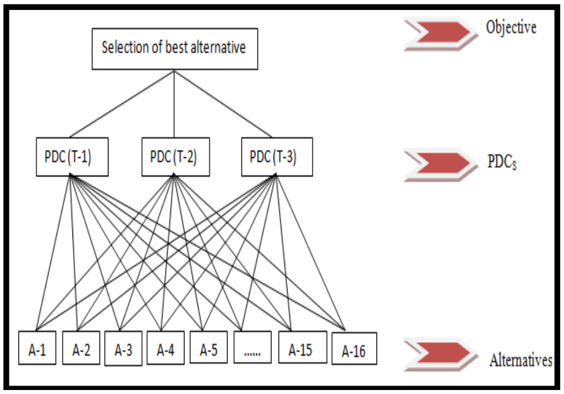

Fig. 5. Hierarchy arrangement used for best option selection.

Stage II: Comparative significance prioritization strategy begins to decide near significance of criterion. The similar significance of choices within every rank of the hierarchy's decided among PWCM and that is determined by Saaty's relational 1–9 point scale as shown in Table 6.

Let B = (B_{hl} = 1, 2,…, S) be the set of criterion and size of comparison matrix (D) will be R × S.

$$D_{RS} = \left\{ \begin{matrix} D_{11} & D_{12} \ldots\ldots & D_{1S} \\ D_{21} & D_{22} \ldots\ldots & D_{2S} \\ \vdots & \vdots \;\; \ldots\ldots & \vdots \\ D_{R1} & D_{R2} \ldots\ldots & D_{RS} \end{matrix} \right\}$$

$$D_{hh}=1,\ D_{lh}= 1/D_{hl}\ ,\ D_{hl} \neq 0 \tag{1}$$

Stage III: Measurement of weight

The Eqn. (2) is utilized to calculate the comparative weight (w_l)

$$w_l = \frac{\left(\prod_{l=1}^{S} D_{hl}\right)^{\frac{1}{S}}}{\sum_{h=1}^{R} \times \left(\prod_{l=1}^{S} D_{hl}\right)^{\frac{1}{S}}}\ , \quad l = 1, 2, \ldots S \tag{2}$$

Stage IV: Consistency ratio (CR)

Consistency Ratio is calculated as follows:

$$CR = \frac{CI}{RI} \tag{3}$$

Table 4: Pair-wise comparison AHP inclination.

Scale	Explanation
1	Two exercises contribute similarly to the target.
2	One exercise is similarly to slightly ideal over other exercise.
3	One exercise is slightly ideal over other exercise.
4-9	One exercise is slightly to solidiy ideal over other exercise.
Reciprocal	If exercise A has one of the above numbers select to it at the point when correlated with exercise B, at that point B has the reciprocal value when correlated with A.

The Eqn. (4) is used to determine the consistency index (CI):

$$CI = \frac{\sigma_{\max} - S}{S-1} \tag{4}$$

TOPSIS Approach: Hwang and Yoon (1981) suggested a MCDM, termed as TOPSIS. This procedure is critical as well as straightforward strategy which gives effortlessness during the computation [34]. The diverse strides to ascertain the issue by TOPSIS are given below:

Step I. Decision matrix design

Assume that R alternative to be thought about other than S criterions. The decision matrix (D) proves the important evaluations of alternatives along with criterion. The decision matrix following an arrangement of R× S given as:

$$D_{R\times S} = \left\{ \begin{matrix} E_{11} & E_{12} \cdots & E_{1l} & \cdots & E_{1S} \\ E_{21} & E_{22} \cdots & E_{2l} & \cdots & E_{2S} \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ E_{h1} & E_{h2} \cdots & E_{hl} & \cdots & E_{hS} \\ \vdots & \vdots & \vdots & \vdots & \\ E_{R1} & E_{R1} & E_{Rl} & \cdots & E_{RS} \end{matrix} \right\}$$

Now, a constituent E_{hl} (for h=1, 2, 3... R; l = 1, 2, 3... S), of decision matrix $D_{R\times S}$ show the actual values of the h^{th} alternative with respect of l^{th} criterion. Profit $(d_{hl})_{max}$ and cost $(d_{hl})_{min}$ criterion has been achieved by manufacturing of decision matrix.

$(d_{hl})_{max} = h^{max}\, d_{hl} = \max[d_{hl}\ ,\ h = 1, 2 \ldots\ldots R]$

$(d_{hl})_{min} = h^{min}\, d_{hl} = \min[d_{hl}\ ,\ h = 1, 2 \ldots\ldots\ldots R]$

Step II. Decision matrix normalization

The decision matrix (d_{hl}) is determined by the normalization

$$d_{hl} = \frac{E_{hl}}{\left[\sum_{h=1}^{R} \times \left(E_{hl}^{2}\right)\right]^{1/2}} \tag{5}$$

Step III. Find out the weighted normalized decision matrix (WNDM)

$(\bar{d}_{hl})$ is determined by multiplying each column of d_{hl} among the $\overline{w}_{hl}$ equivalent to that column as given below:

$$\bar{d}_{hl} = d_{hl} \times \overline{w}_l \tag{6}$$

Step IV. The positive and negative ideal solutions calculation

The positive (g) and the negative best result are calculated the $\bar{d}_{hl}$ is used to calculate the positive (g) and the negative best results as given below:

$g = (\bar{d}_1^+, \bar{d}_2^+ \ldots\ldots \bar{d}_s^+)$ and $= (\bar{d}_1^-, \bar{d}_2^- \ldots\ldots \bar{d}_s^-)$
Here

$$\bar{d}_l^+ = \begin{cases} \overset{R}{\underset{h}{\mathrm{Max}}}\ \bar{d}_{hl} \text{ if l is a benefit criterion} \\ \overset{R}{\underset{H}{\mathrm{Min}}}\ \bar{d}_{hl} \text{ if l is a cost criterion} \end{cases}$$

$$\bar{d}_l^- = \begin{cases} \overset{R}{\underset{h}{\mathrm{Min}}}\ \bar{d}_{hl} \text{ if l is a benefit criterion} \quad \text{for } l = 1, 2 \ldots S \\ \overset{R}{\underset{h}{\mathrm{Max}}}\ \bar{d}_{hl} \text{ if l is a cost criterion} \end{cases} \tag{7}$$

Step V. Determine Euclidian distances

$$\beta_h^+ = \sqrt{\sum_{l=1}^{S} \times \left(\bar{d}_l^+ - \bar{d}_{hl}\right)^2}$$

$$\beta_h^- = \sqrt{\sum_{l=1}^{S} \times \left(\bar{d}_{hl} - \bar{d}_l^-\right)^2}$$

For h = 1, 2…R (8)

Step VI. Closeness index determination

The closeness index ($\emptyset_h$) data of the alternatives is determined as follow:

$$\emptyset_h = \frac{\beta_h^-}{\beta_h^+ + \beta_h^-}$$

For h = 1, 2, 3…R (9)

At last, the alternatives be put in decreasing order as per the data of there $\emptyset_h$.

III. RESULTS AND DISCUSSION

Trial results: The experimental result have been perform for under-fill defect in Gear forging along with sets of alternatives as shown in Table 5. After trial every sixteen alternatives which are the arrangements of forging parameters, the values have been taken and calculated for PDC (ET-1), PDC (ET-2) & PDC (ET-3). The optimum value could not be estimated by PDC (ET-1), PDC (ET-2) and PDC (T-3) hence we take average of {PDC (ET-1), PDC (ET-2) & PDC (ET-3)} to discover ideal values to minimize rejection due to underfill defect in Gear forging. Fig. 6. shows that the minimum rejection value of PDC (ET-1, ET-2 & ET-3) is obtained at A-14 alternative which is equivalent to 1.481483 and most extreme rejection value of PDC (ET-1, ET-2 & ET-3) is obtained at A-5 alternative equivalent to 2.925927. While PDC (ET-1, ET-2 & ET-3) achieved ideal value at A-14 alternative with least rejection rate and greatest rejection rate is obtained at alternative A-5. Weight of billet, temperature of billet, time of forging and temperature of die were selected as the input parameter for the forging process. It was found that optimum values of these parameters were 2.275 kg, 1210℃, 12 second and 250℃ respectively. The variation of input parameters from optimum values may during production cause underfill, over sized, restriction of metal flow and burning. Hence Along with above values the optimization has been completed by means of AHP-TOPSIS to acquire the ideal arrangement of alternatives.

AHP-TOPSIS Implementation

Numerical simulation of AHP for optimization

The Random consistency index depends upon size of the matrix. Table 6 demonstrates value of Random consistency index for the PWCM among the Saaty scale (1-9) [33]. The column sum divided every component of weighted sum matrix among their specific need vector component and after that figure the normal of these data to accomplish σ_{max} as shown in Table 8.

Table 5: Trial results for the underfill defect in gear forging.

Alternatives	Input parameters				Criterion			
	BW	BT	FT	DT	PDC (T-1)	PDC (T-2)	PDC (T-3)	Average (T-1, T-2, T-3)
A-1	2.000	1180	12	195	1.22223	2.77778	1.99999	2
A-2	2.000	1190	15	210	2.77778	1.99999	2.77778	2.518517
A-3	2.000	1200	18	230	2.33334	2.77778	1.99999	2.37037
A-4	2.000	1210	21	250	1.99999	1.22223	2.77778	2
A-5	2.225	1180	15	230	3.22222	2.77778	2.77778	2.925927
A-6	2.225	1190	18	250	2.77778	1.22223	3.22222	2.40741
A-7	2.225	1200	21	195	1.99999	3.22222	1.22223	2.148147
A-8	2.225	1210	12	210	3.22222	1.99999	1.99999	2.4074
A-9	2.250	1180	18	195	1.33334	2.77778	2.77778	2.2963
A-10	2.250	1190	21	210	1.22223	1.22223	1.99999	1.481483
A-11	2.250	1200	12	230	2.77778	1.99999	3.22222	2.666663
A-12	2.250	1210	15	250	1.22223	2.77778	1.99999	2
A-13	2.275	1180	21	230	3.22222	1.99999	2.77778	2.666663
A-14	2.275	1190	12	250	1.99999	1.22223	1.22223	1.481483
A-15	2.275	1200	15	195	1.99999	1.99999	2.77778	2.259253
A-16	2.275	1210	18	210	1.99999	1.99999	2.77778	2.259253

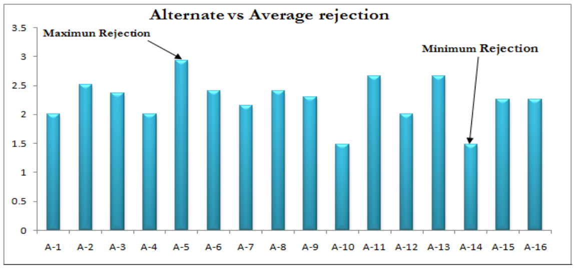

Fig. 6. Average variations PDC (ET-1, ET-2 & ET-3) along with alternatives.

Table 6: Random consistency index (RI).

N	1	2	3	4	5	6	7	8	9
RI	0	0	0.5	0.9	1.58	1.24	1.32	1.41	1.45

To decide the consistency of this matrix, a few extensive consistency procedure has been determined for example σ_{max}= 3.001534, consistency index = 0.000767, Random consistency index = 0.58 and consistency ratio = 0.001323. At the point when the value of consistency ratio seems littler than 0.1, at that point matrix judgment is considerable.

Numerical simulation of TOPSIS for optimization: The measures of sets are estimated as alternatives (A-1 to A-16) as well as response average of PDC (T-1), PDC (T-2) and PDC (T-3) model for execution estimation of underfill defect. A decision matrix ($D_{R\times S}$) is made in which alternatives described with R and criterion with S. Simultaneously, every element of matrix is shown with d_{hl} (for h = 1, 2, 3… R; l = 1, 2, 3… S). Decision matrix is given as pursue:

$$D_{R\times S} = \begin{pmatrix} 1.22223\ (e_{11}) & 2.77778(e_{12}) & 1.99999(e_{13}) \\ 2.77778(e_{21}) & 1.99999(e_{22}) & 2.77778(e_{23}) \\ 2.33334(e_{31}) & 2.77778\ (e_{32}) & 1.99999(e_{33}) \\ 1.99999(e_{41}) & 1.22223(e_{42}) & 2.77778(e_{43}) \\ 3.22222(e_{51}) & 3.22222(e_{52}) & 2.77778(e_{53}) \\ \vdots & \vdots & \vdots \\ 1.99999(e_{R1}) & 1.99999(e_{R2}) & 2.77778(e_{RS}) \end{pmatrix}$$

After making the decision matrix, advantage (d_{hl}) maximum and cost (d_{hl}) minimum rule are determined as pursue:

$(d_{hl})max = (max)d_{hl}$ = {3.22222, 3.22222. 3.22222}

$(d_{hl})min = (min)d_{hl}$ = {1.22223, 1.22223, 1.22223}

TOPSIS strategy was used to calculating the weight of criterion for the estimation of each input parameters. At that point values of Table 9 is normalized in the range of 0 to 1 scale to construct DM appropriate by utilizing Eq. (5) later than count of NDM a WNDM is resolved for each criterion by multiplying every section of the NDM d_{hl} along with related criterion weight w_{hl} comparable to that segment as using Eqn. (6).

Table 7: Pair–wise comparison matrix used for trial.

	PDC (T-1)	PDC (T-2)	PDC (T-3)
PDC (T-1)	1	1.5	2
PDC (T-2)	0.66666	1	1.5
PDC (T-3)	0.5	0.66666	1

Table 8: Relative weights acquired from the comparison matrix.

PDCs	**Weight (w_i)**	**σ_{max}, CI, RI**	**CR**
PDC (T-1)	2.0879	σ_{max} = 3.001534	0.001323
PDC (T-2)	2.0188	CI = 0 .000767	
PDC (T-3)	2.0189	RI = 0.58	

Closeness index of option with respect to distinct criterion: Lastly, Eqn. (8) and (9) is used to calculate Euclidian distance as well as closeness index value on behalf of each alternative. Later than entire calculation, to obtain ideal arrangement of parameters data are ranked. Alternative along with greatest $\emptyset_h$ data is chosen as ideal alternative. The determined data are shown in Table 10. It is concluded that alternate A -14 have CI of 0.80183 which is pursued by alternative A -10 having data 0.794221. Alternative A-5 demonstrates the least execution of chosen data of 0.176017. The optimization results shows that alternative A -15 having parameters set of WB = 2.275 kg, TB = 1190 ℃, TF = 12 sec, TD = 250℃.

Table 9: Normalized and weighted normalized matrix.

Alternative	**NM**			**WNM**		
	PDC (T-1)	**PDC(T-2)**	**PDC(T-3)**	**PDC (T-1)**	**PDC(T-2)**	**PDC(T-3)**
A-1	0.131797	0.312647	0.202272	0.043	0.098447	0.07271
A-2	0.299536	0.225105	0.280935	0.098	0.070881	0.100987
A-3	0.251611	0.312647	0.202272	0.082	0.098447	0.07271
A-4	0.215665	0.137565	0.280935	0.07	0.043317	0.100987
A-5	0.347461	0.312647	0.280935	0.113	0.098447	0.100987
A-6	0.299536	0.137565	0.325884	0.098	0.043317	0.117145
A-7	0.215665	0.36267	0.123612	0.07	0.114198	0.044435
A-8	0.347461	0.225105	0.202272	0.113	0.070881	0.07271
A-9	0.143778	0.312647	0.280935	0.047	0.098447	0.100987
A-10	0.131797	0.137565	0.202272	0.043	0.043317	0.07271
A-11	0.299536	0.225105	0.325884	0.098	0.070881	0.117145
A-12	0.131797	0.312647	0.202272	0.043	0.098447	0.07271
A-13	0.347461	0.225105	0.280935	0.113	0.070881	0.100987
A-14	0.215665	0.137565	0.123612	0.07	0.043317	0.044435
A-15	0.215665	0.225105	0.280935	0.07	0.070881	0.100987
A-16	0.215665	0.225105	0.280935	0.07	0.070881	0.100987

Table 10: Euclidian distances, closeness index and alternatives ranking.

Alternatives	β_h^+	β_h^-	$\emptyset_h$	Ranking
A-1	0.061958	0.084462	0.576846	3
A-2	0.083265	0.048747	0.369264	14
A-3	0.073177	0.056457	0.435512	11
A-4	0.062767	0.084347	0.573344	5
A-5	0.105634	0.022565	0.176017	16
A-6	0.090894	0.072547	0.443871	10
A-7	0.075932	0.084356	0.526278	6
A-8	0.080501	0.062055	0.435301	12
A-9	0.07907	0.06992	0.469293	9
A-10	0.028276	0.109132	0.794221	2
A-11	0.094982	0.045992	0.326242	15
A-12	0.061958	0.084462	0.576846	4
A-13	0.094229	0.046232	0.329146	13
A-14	0.027231	0.110182	0.80183	1
A-15	0.068553	0.062981	0.478819	7
A-16	0.068553	0.062981	0.478819	8

Depends on analysis the alternatives ranking in decreasing order are A-14 > A-10 > A-1 > A-12 > A-4 > A-7 > A-15 > A-16 > A-9 > A-6 > A-3 > A-8 > A-13 > A-2 > A-11 > A-5 as shown in Table 10.

IV. CONCLUSION

The considerable outcomes of experimental trial and optimization have been used to investigate the best parameters to minimize underfill defect in gear forging. The response is offered in terms average of PDC (T-1), PDC (T-2), and PDC (T-3) respectively. The superlative parameters were establish by doing trial on various input parameter such as weight of billet, temperature of billet, time of forging and temperature of die. AHP-TOPSIS technique has been used for optimization simultaneously these performance criterion. Here, AHP determines the weights of the whole performance assessment standards towards entire performance, and another hand the TOPSIS strategy provide the closeness index of every alternatives by offer best outcomes which are very near the real and far from the worst. The response accomplished from this investigation will be useful in various fields of forging industries for performance analysis and optimization along with essential condition for outstanding performance. The considerable outcomes received from this research on underfill defect in gear forging are given below.

1. AHP-TOPSIS technique has been adjusted to the combination of input parameters which is built up by means of Taguchi design of investigations technique for the entire performance criteria. From the examination it has been discovered that underfill defect criterion has a considerable consistency ratio value of 0.001323 which is under 0.1. The equal weights of the criterion are PDC-1 = 2.0879, PDC-2 = 2.0188 and PDC-3 = 2.0189 respectively. This proposes that the criterion has governed huge effect on entire execution of trial doing with input parameters to minimize underfill defect in forging industries.
2. The finest input parameter arrangement which creates the ideal weight of billet, temperature of billet, time of forging and temperature of die depends upon AHP-TOPSIS method among the minimum rejection criteria simultaneously is A-14 alternative. The closeness index positioning of every input parameter combinations has sequence of order: A-14 > A-10 > A-1 > A-12 > A-4 > A-7 > A-15 > A-16 > A-9 > A-6 > A-3 > A-8 > A-13 > A-2 > A-11 > A-5 respectively.
3. The above examination shows that A-14 alternative has a best input parameter used to minimize underfill defect in forging industries. In current examination it has been discovered that by applying A-14 input parameter the percentage rejection of underfill defect in gear forging will be minimize from 2.73% to 1.48%.

Hence, optimization depends upon AHP-TOPSIS approach as well as MCDM standard to discover the best possible alternative amongst concurrent discussion of all criterions.

V. FUTURE SCOPE

Outcomes given by current research work has been explained above, still there is lot of scope for future work in order to study the selection of other process parameters like friction and number of parts for obtaining zero defect forging.

Conflict of interest. The authors(s) declare that they have no conflict of interests.

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