



A Study Of Mcdm Technique To Determine The Best Quenching Temperature Of Q&P Steel

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ABSTRACT

One of the major problems faced in engineering is the selection of the material which is most suitable for the product in terms of durability, reliability, and cost. Selection of suitable material which gives maximum performance with minimum cost is often observed to be a multi-criterion decision making problem with different objectives. This paper presents an integrated approach to select the optimum quenching temperature for the quenching and partitioning steels which can give maximum performance with minimum cost. In the approach the criteria weights are computed using the entropy method and ranking of the alternatives is computed using the COPRAS and MOORA method. In this approach for selecting quenching temperature for the Q&P steel six number of alternatives and five criteria is used. The procedure is illustrated using a case study.

1. Introduction

High strength ferrous alloys containing significant fractions of retained austenite have been developed in recent years, and have important commercial applications. In sheet steels, for example, carbon-enriched metastable retained austenite is considered beneficial because of the TRIP (Transformation induced plasticity) phenomenon during deformation can contribute to formability and energy absorption. In gear and bearing surfaces, austenite is considered to provide damage tolerance in rolling/sliding contact fatigue applications. In thicker section structural applications, retained austenite may provide enhanced resistance to fracture. Similarly, austempered ductile cast iron materials develop favorable property combinations through a microstructure of fine ferrite plates in combination with carbon-rich retained austenite.

Steels with substantial amounts of carbon-enriched retained austenite are typically produced by transforming at low temperatures, leading to a microstructure containing “carbide-free bainite” that consists of bainitic ferrite laths with interlath retained austenite. Alloying additions such as Si or Al are made to suppress cementite precipitation that usually accompanies bainite formation. Recently, an alternative processing concept, “quenching and partitioning (or Q&P), has been developed for the production of austenite-containing steels, based on a new understanding of carbon partitioning hypothesized between martensite and retained austenite.

Selection of quenching temperature is very important for retaining adequate amount of retained austenite in the Q&P steel. Various methodologies are there for the selection of quenching temperature for example, KM equation. Different properties can vary drastically with varying quenching temperatures and thus selection of the best quenching temperature or the optimum quenching temperature is necessary. Multi criteria decision making or MCDM process provides ranking solution to find out the best quantitative solution from a set of. This paper applies the MCDM approach through which different quenching temperatures can be ranked and thus the best quenching temperature can be determined.

Various optimization techniques are used to the field of material selection in order to select the material most suitable for the design. Not selecting the proper material for the design may result in failure or reducing the efficiency and performance of the products, thereby, adversely affecting the productivity, profitability and reputation of organization. Based on several requirements material is selected for a particular product design. The goal of optimum product design is to select a material that gives maximum performance with minimum cost [Shanian & Savadogo, 2006]. Material selection is also an important factor for a product to strive in the competition in market because improper material selection may result in failure to fulfil customer and manufacturer requirements [Karande & Chakraborty, 2012]. In the last two decades most of the traditional materials are being replaced by new materials. The new materials are rapidly growing in type and numbers. With the different sets of available material, selection of material for particular product design has become a very difficult and tedious task. With increasing choice of materials and large number of manufacturing process available to the designers, the selection of an optimal material have become more complex and more challenging than before [Rao & Patel, 2010]. In order to solve such problems a large number of methods have been proposed by different authors in literature such as Ashby approach, analytic hierarchy process (AHP), Entropy, technique of order preference by similarity to ideal solution (TOPSIS), gray relational analysis (GRA), graph theory and matrix approach, ELECTRE [Elimination Et Choix Traduisant la REalite], VIKOR [Visekriterijumska optimizacija Kompromisno Resenje], and COPRAS [Complex Proportional Assessment]. In some situation exact data are in adequate to model the real-life situation. In order to deal such scenario fuzzy set theory is incorporated. In this paper material selection is made based on the Entropy MCDM method. Here the weight factors are calculated using the Entropy method and the ranking of the alternatives are done by COPRAS [Complex Proportional Assessment] and MOORA [Multi-Objective Ratio Analysis] method.

1.1 Background

1.1.1 Quenching and Partitioning

The current trends in the automotive industry have been mainly focused on increasing the crashworthiness properties of vehicles, while decreasing fuel consumption and gas emissions at the same time. For this purpose, the steel industry is continuously presenting innovative solutions to the automotive industry, since this material has the ability to adapt to the changing requirements. In particular, the past few decades have witnessed a significant research effort directed towards the development of Advanced High-Strength Steel (AHSS) grades, as they provide an opportunity

for the development of cost-effective and light-weight parts with improved safety and optimized environmental performance for automotive applications [Bhadeshia, 1999; De Moor et al., 2010; Caballero et al., 2013; Rodríguez et al., 2014]. These research strategies are based on the development of microstructures consisting of ultrafine microconstituents formed in non-equilibrium conditions, such as martensite or bainite, in combination with Retained Austenite (RA) [Santofimia et al., 2008; Caballero et al., 2009; Garcia-Mateo et al., 2012]. Harder microconstituents contribute to a simultaneous increase of strength and toughness whereas RA provides the improvement of strength and ductility through the Transformation Induced Plasticity (TRIP) effect [Speer et al., 2005; Santofimia et al., 2008]. The strain induced transformation to martensite provides an additional deformation and strain hardening mechanism, thereby suppressing strain localization and enhancing formability [Speer and Matlock, 2002; Gutiérrez et al., 2013]. Speer et al., proposed in 2003 a novel processing route, "Quenching and Partitioning" (Q&P) [Speer et al., 2003]. Q&P appears promising as a further improvement of mechanical properties can be attained via intelligent microstructural design [De Diego-Calderón et al., 2014; De Knijf et al., 2014a]. The Q&P process consists of a multi-step thermal processing route: first, after heating in order to obtain a fully austenitic or intercritical microstructure, the steel is quenched to a suitable pre-determined temperature (QT) below the martensite start (Ms) but above the martensite finish (Mf) temperatures to form a pre-defined amount of martensite; then, the steel is either held at this quenching temperature or brought to a higher Partitioning Temperature (PT), where the untransformed austenite is carbon enriched through carbon depletion of the supersaturated martensite [Edmonds et al., 2006; De Moor et al., 2011]. In this way, a complex microstructure formed by metastable RA and martensite is obtained after final quenching to room temperature. Although there are already works on characterization of the steel microstructure after Q&P [Santofimia et al., 2008; De Diego-Calderón et al., 2014; De Knijf et al., 2014a; Tan et al., 2014a; Tan et al., 2014b], there is still a lack of knowledge about the strain distribution between the microstructural constituents in Q&P structures during loading in the plastic range. Low carbon TRIP steel compositions have been used to successfully generate martensitic microstructures with substantial RA levels through Q&P processing [Speer et al., 2014]. Addition of elements, such as Si, retards the formation of carbides and gives rise to the carbon enrichment of austenite [Santofimia et al., 2008; Paravicini Bagliani et al., 2013]. Moreover, increased manganese levels have been shown to be effective at reporting significant austenite fractions with improved tensile

properties in Q&P steels [De Moor et al., 2011; Speer et al., 2014]. Mechanical property studies indicate that Q&P shows significant potential to generate novel property combinations that would otherwise be difficult in low alloy compositions [Speer et al., 2014].

New strategies for the creation of advanced high strength steels with improved mechanical properties of strength, toughness, and ductility are based on the development of microstructures consisting of ultrafine phases formed in nonequilibrium conditions such as martensite and bainite in combination with retained austenite. The refined and highly dislocated martensite and bainite contribute to a simultaneous increase of strength and toughness. Retained austenite contributes to the improvement of the strength/ductility combination via the transformation induced plasticity (TRIP) effect and to the improvement of the toughness if the retained-austenite grains have a filmlike morphology. One of the most innovative procedures to create microstructures consisting of martensite and retained austenite is the so-called quenching and partitioning (Q&P) process. This process starts with a total or partial austenitization, followed by a quench of the microstructure to a temperature (quenching temperature) below the martensite start (M_s) temperature but above the martensite finish (M_f) temperature to form a controlled fraction of martensite. This microstructure is then subjected to a treatment at the same or higher temperature (partitioning temperature) in order to accomplish the carbon diffusion from the carbon-supersaturated martensite to the neighboring austenite. Finally, the material is quenched to room temperature and the austenite that has been sufficiently carbon enriched remains metastable at room temperature, whereas the rest transforms into martensite. Investigations on the Q&P process were mainly focused on the application of this heat treatment to steels with chemistries very close to commercial TRIP steels, designed to promote bainite formation, whereas studies on steels specially designed to be subjected to the Q&P process are fewer. Depending on the steel composition and the particular heat treatments, formation of bainite, ferrite, and carbides during the Q&P process can overlap with carbon partitioning from martensite to austenite, reducing the effectiveness of this heat treatment leading to the desired microstructures. An adequate theoretical knowledge of the mechanisms occurring during the Q&P process would lead to a well control of these overlapping phenomena. In the present work, recent investigations on the microstructural changes during the application of the Q&P process in a variety of steel compositions are reviewed and discussed, leading to valuable information for the selection of alloying elements and heat treatment parameters in the design of Q&P steels.

1.1.2 Multi Criteria Decision Making

Decision making is a key factor to achieve success in any discipline, especially in a field which requires handling large amounts of information and knowledge as construction. Most construction processes and procedures are a compendium of many different tasks, processes and requirements, involving a great variety of factors and aspects to consider. In this manner, making decisions in such environments can often be an arduous and difficult operation to tackle. For these reasons, the need for a mechanism capable of assisting the characterization of such complex scenarios arises. Multi-criteria decision analysis (MCDA) emerged as a branch of operations research destined to facilitate the resolution of these issues. Since then, a great variety of multi-criteria decision making methods (MCDM) have been developed to tackle them under

different circumstances and fields of application [1–5]. Besides multi-criteria methods per se, some complements especially suitable for decision making problems, as e.g. fuzzy sets or numerical simulations, are also included in the review. Even lacking the basics and typical structure needed to perform a multi-criteria analysis, these tools have proved very useful to deal with aspects as uncertainty or risk, which are very common in decision making environments but unapproachable by traditional MCDM methods. No discriminatory filter was made when selecting the methods to be included in the review; indeed, the aim was to report the most relevant papers implementing multicriteria analysis in construction activities, attending to factors such as number of citations and variety in the field of application, regardless of their conceptual basis. On the other hand, the application cases assessed here are divided into single and hybrid approaches, depending on whether the paper under study uses a unique method or two or more in combination. Thus, single methods which count with at least two papers of application have their own subsection, whilst the rest are collected in “Others”. Meanwhile, hybrid approaches have been categorized according to the importance of their components. Therefore, those methods showing a notable preponderance on at least two different appearances are separated, whilst those cases whose hierarchy is not clear are grouped in “Others”. The observation period in which they all were gathered ranges from 1992 to 2013. Whilst the search was performed, an increase in the return of results was observed coinciding with the mid 90s, which led to set the lower limit of study around two decades before the last full calendar year, time long enough to arrive to consistent conclusions.

1.2 METHODOLOGY

1.2.1 Chemical composition of steel

TABLE 1.1. Chemical composition of current-generation Q&P steel grade

| Element | C | Mn | Al | Si | B | Cr | Mo | Ni | V | P | S | N | Fe |
|---------|------|------|-------|------|-------|------|------|------|-------|-------|-------|--------|------|
| wt % | 0.21 | 1.47 | 0.020 | 0.50 | 0.001 | 0.20 | 0.10 | 0.55 | 0.030 | 0.021 | 0.009 | 0.0048 | Bal. |

The chemical compositions of typical Q&P steels are listed in Table 1. The Q&P steels are hypoeutectoid iron–carbon alloys that typically contain 0.15–0.30% C by weight, similar to TRIP steels. The Q&P steels also contain alloying elements such as silicon that prevent the precipitation of the cementite phase (Fe_3C), which is present in typical steels at room temperature.

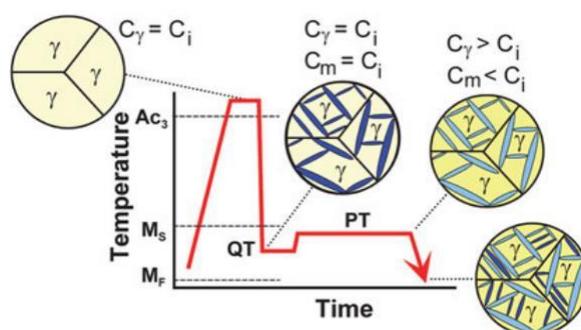


Fig.1.1- Schematic illustration of the thermal profile and phase transformation behavior of Q&P steels. QT quenching temperature, PT partitioning temperature.

This maintains the high carbon concentration in the austenite phase, which becomes stable at room temperature. Carbon content in current Q&P steels is limited to 0.15–0.30 wt% due to weldability concerns. As shown in Table 1, the manganese content in Q&P steels is relatively high, to enhance hardenability and austenite stability. Silicon is used to stabilize the austenite phase during continuous annealing and at room temperature, because silicon significantly increases the carbon activity in both ferrite and austenite and decreases carbon solubility in ferrite. As a result, silicon inhibits the formation of cementite during the partitioning stage. Because Q&P steels have already exhibited an excellent balance between ultrahigh strength and high ductility, other alloying elements have not been necessary, although opportunity is likely available to use microalloying and other concepts for additional enhancements.

1.3 Thermal Profile and Phase Transformation

The continuous annealing process and consequent phase transformation behaviors of Q&P steels are schematically shown in Fig. 1. To produce Q&P steel with ultrahigh strength and excellent ductility, a unique annealing process is conducted to obtain the appropriate phase distribution. First, the steel is heated to a temperature above A_{c3} (annealing temperature), where the material is composed of austenite. The material is then slowly cooled to a temperature below A_{r3} (slow cooling temperature, or SC), which is approximately 740 C (1360 F), to allow the formation of a certain amount of proeutectoid ferrite. The ferrite phase plays a significant role in the improvement of ductility. After slow cooling, the steel samples are then quenched to different temperatures

210°C, 225°C, 240°C, 250°C, 260°C, 280°C between M_s and M_f (quenching temperature) with a cooling rate higher than 50 C/s (90 F/s) wherein austenite transforms (partially) to martensite. The fractions of austenite and martensite can be controlled by this interrupted quenching process. After quenching, the steel is usually reheated to a higher temperature (partitioning temperature) and held for a couple of minutes. In a typical steel alloy, the supersaturated carbon in martensite would lead to cementite precipitation. However, the high content of silicon prevents the formation of cementite. Consequently, the excess carbon in the martensite phase partitions into the remaining austenite, because austenite with a face-centered cubic structure exhibits much higher carbon solubility than martensite with a body-centered cubic structure. Finally, the stable carbon-enriched austenite is retained when the steel is cooled to room temperature. After this unique heat treatment, the final microstructure composed of ferrite, martensite, and retained austenite is achieved. The key annealing considerations to produce Q&P steels are that fast cooling is needed, and, at the same time, the quench arrest temperature must be easily controlled below the M_s temperature.

1.4 Microstructure

The microstructure of commercial Q&P steels is composed primarily of martensite (50–80%) formed during quenching, and ferrite (20–40%) formed from the austenite phase during slow cooling, as well as dispersed retained austenite (5–10%) stabilized by carbon enrichment during partitioning. Reduced fractions of ferrite can be used in higher strength products. Example micrographs taken with a scanning electron microscope and a light optical microscope can be seen in Fig. 1.1. Small nodules of retained austenite are found, and films of austenite are also present in

the lath martensite. The fine Q&P microstructure is usually not well resolved by light optical microscopy.

Some additional aspects related to microstructure are also included in the following sections.

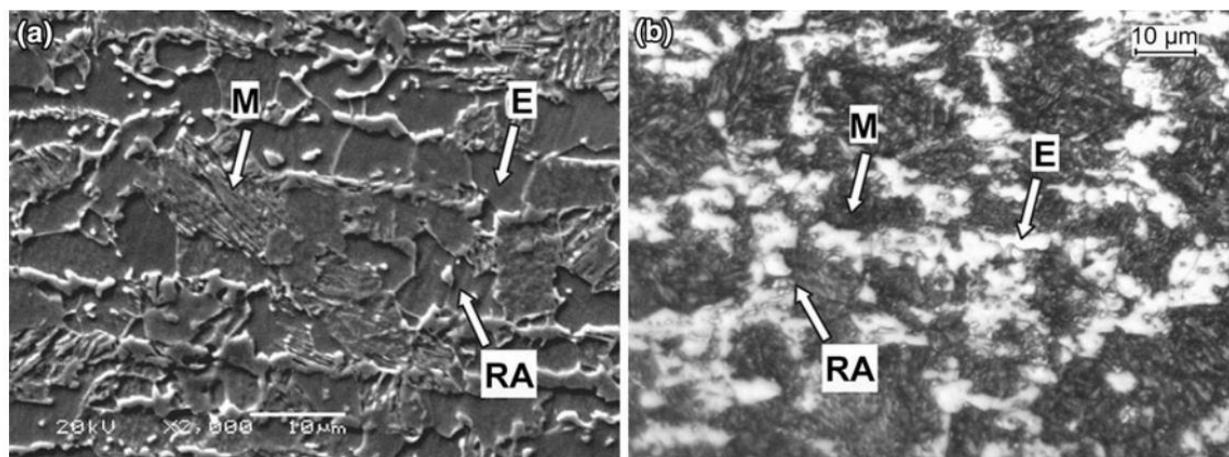


Fig.1.2- Microstructure of Q&P steel obtained using (a) scanning electron microscopy and (b) light optical microscopy. M martensite, F ferrite, RA retained austenite.

Carbon-enriched metastable retained austenite is considered beneficial because TRIP during deformation, that is, the TRIP phenomenon, can contribute to work hardening, formability, and fracture toughness. During deformation, the dispersed retained austenite progressively transforms to harder martensite, which creates a high work-hardening rate, even at higher strain level.

1.5 Mechanical Properties

The hardness measurement was done using EMCO Test Dura Scan Vickers hardness testing machine at 9.8 N load with a dwell time of 10 seconds. The reported hardness value is the average of at least five separate measurements.

Charpy impact specimens of dimensions 10 9 10 9 55 mm³ were prepared in accordance with EN 10045-1 standard and tested using a 300 J charpy impact tester. The tensile samples were prepared according to the ASTM E8M standard with a gage length of 32 mm and gage diameter of 6.25 mm. The tensile tests were carried out using the universal tensile machine of 100 kN capacity at a strain rate of 10³ s⁻¹. Dry sand rubber wheel (DSRW) abrasion experiments were carried out as per ASTM G 65-04 procedure B using dry abrasion test rig AR-50 machine [Make: DUCOM, Bangalore, India]. The abrasion-tested samples were cleaned with acetone in an ultrasonic cleaning

bath before and after the tests, and weight loss was measured. This was further converted to volume loss in order to nullify the density difference among different materials. The samples for mechanical testing were prepared such that principal direction of the forging was parallel to the length of charpy specimen, the gage length of tensile specimen, and the width of wear specimen. At least three tests on each condition were performed, and the average of these values have been calculated.

1.6 Application

The Q&P steels with ultrahigh strength and excellent ductility, or formability, are well suited to help reduce weight of car bodies, with the added advantage of enhanced occupant safety. The work-hardening rates of Q&P steels are substantially higher than for conventional high-strength steels (HSS), providing significant stretch forming capability. Compared to most other HSS with the same tensile strength, Q&P steels exhibit much higher formability; hence, they are particularly well suited for automotive structural and safety parts such as cross members, longitudinal beams, B-pillar reinforcements, sills, and bumper reinforcements, which cannot be cold formed using conventional HSS with similar strength levels.

2. MCDM

Multi criteria decision making (MCDM) process provides ranking solution to find out the best quantitative solution from a set of. In this research paper we applied entropy method because it is highly reliable for information measurement and provide high accuracy in determination of weight of the feature attribute of the product. A MCDM problem can be expressed in matrix format as:

$$M = \begin{matrix} & C_1 & C_2 & C_3 & \dots & C_n \\ \begin{matrix} A_1 \\ A_2 \\ A_3 \\ \vdots \\ A_m \end{matrix} & \begin{bmatrix} a_{11} & a_{12} & a_{13} & \dots & a_{1n} \\ a_{21} & a_{22} & a_{23} & \dots & a_{2n} \\ a_{31} & a_{32} & a_{33} & \dots & a_{3n} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ a_{m1} & a_{m2} & a_{m3} & \dots & a_{mn} \end{bmatrix} \end{matrix}$$

$$W = [w_1 \quad w_2 \quad w_3 \quad \dots \quad w_n]$$

Where $A_1, A_2, A_3, \dots, A_m$ are the available alternatives which are to be ranked by the decision maker $C_1, C_2, C_3, \dots, C_n$ are the criteria on which basis the available alternatives are to be ranked. a_{ij} is the performance of value of alternative A_i on the basis of criterion C_j and w_j is weight of the criterion C_j .

1.7 The Entropy Weight Method

The entropy weight method (EWM) is an important information weight model that has been extensively studied and practiced. Compared with various subjective weighting models, the biggest advantage of the EWM is the avoidance of the interference of human factors on the weight of indicators, thus enhancing the objectivity of the comprehensive evaluation results. Therefore, the EWM has been widely used in decision-making in recent years. For example, Wu et al. made a comprehensive assessment on lake water quality in Shahu Lake to provide valuable information about present lake water quality for decision-making [8]. Based on the EWM, Zhang and Wang [9] evaluated stress factors and the efficiency of water management measures in the Chongqing city of China [9]. Yu et al. [10] studied the water characteristics of Gucheng Lake, such as eutrophication, health, and spatial distribution by the EWM.

The EWM evaluates value by measuring the degree of differentiation. The higher the degree of dispersion of the measured value, the higher the degree of differentiation of the index, and more information can be derived. Moreover, higher weight should be given to the index, and vice versa. According to the traditional

literature, the results of the EWM are always reliable and effective. However, based on engineering practice, we have found that the weighted result of the EWM cannot always accurately reflect the information amount and importance of the index. Subsequently, the decision making result is distorted. In MCDM problems one of the toughest job is to assign weights accurately to criteria with respect to which the alternatives are to be ranked. For assigning weights to the criteria Entropy method is used. Steps to calculate the weights by Entropy method for the decision matrix M is as follows:

Step 1: Calculation of feature weight P_{ij} for the i th alternative and j th criterion

$$P_{ij} = \frac{a_{ij}}{\sum_{i=1}^m a_{ij}}, \quad (1 \leq i \leq m, 1 \leq j \leq n)$$

Step 2: The output entropy e_j of the j^{th} factor

$$e_j = -k \sum_{i=1}^m (P_{ij} \ln P_{ij}), \quad (1 \leq j \leq n)$$

$$k = 1 / (\ln m)$$

Step 3: Calculation of variation coefficient of j^{th} factor g_j

$$g_j = |1 - e_j|, \quad (1 \leq j \leq n)$$

Step 4: Calculation of weight of the entropy w_j

$$w_j = \frac{g_j}{\sum_{i=1}^m g_j} \quad (1 \leq j \leq n)$$

2.2 The Copras Method

In 1994, Zavadskas and Kaklauskas presented the COPRAS (Complex Proportional Assessment) method for ranking different alternatives [Zavadskas et al., 1994]. A large number of literatures is present describing the COPRAS method and its application [Zavadskas et al., 2001; Vilutiene & Zavadskas, 2003; Zavadskas et al., 2004; Kaklauskas et al., 2005; Kaklauskas et al., 2006; Zavadskas et al., 2008b]. Steps to rank alternatives by the COPRAS method is as follows: -

Step 1: Calculation of normalized decision matrix (x_{ij}):-

$$x_{ij} = \frac{a_{ij}}{\sum_{i=1}^m a_{ij}}$$

Where a_{ij} is the performance of value of alternative A_i on the basis of criterion C_j .

Step 2: Calculation of weighted normalize decision matrix (W_{ij}):-

$$W_{ij} = w_j * x_{ij}$$

Where w_j is the weight of the j^{th} criterion

Step 3: Calculation of S^+ and S^- :

S^+ and S^- are the sum of the weighted normalized value which are computed fro the benefit criteria and non benefit criteria.

Step 4: Calculation of relative weight of each alternative Q_i :

$$Q_i = (S_i^+) + \frac{\sum_{i=1}^m S_i^-}{S_i^- \sum_{i=1}^m \frac{1}{S_i^-}}$$

Step 5: Determining the priority order (Pri):

$$\text{Pri} = Q_i / \max Q_i$$

Maximum Value of Pri is given maximum priority and ranked 1, second largest value of Pri is given second priority and ranked 2 and so on.

2.3 The Moora Method

MOORA (Multi Objective Optimization on the Basis of Ratio Analysis) was first developed in the year 2004 by Brauers to solve various complex and conflicting decision matrix. The decision matrix of MOORA represents performance measures of alternatives w.r.t. various criteria. Steps involved to rank different alternatives by MOORA method is as follows:

Step 1:- Calculation of normalized decision matrix (x_{ij}):-

$$x_{ij} = \frac{a_{ij}}{\sqrt{\sum_{i=1}^m a_{ij}^2}}$$

Where a_{ij} is the performance of value of alternative A_i on the basis of criterion C_j .

Step 2: Calculation of weighted normalize decision matrix (W_{ij}):-

$$W_{ij} = w_j * x_{ij}$$

Where w_j is the weight of the j^{th} criterion

Step 3: Calculation of Priorities (Q_i):-

$$Q_i = \sum_{j=1}^n W_{ij}$$

Priorities is the difference between the sum of benefit criteria and non-benefit criteria.

Step 4: Ranking of alternatives:-

Maximum value of Q_i is given maximum priority and ranked 1, second largest value of Q_i is given second priority and ranked 2 and so on.

3. Case Study

For the validation of the proposed approach an example is considered for best quenching temperature selection from different quenching temperatures of a particular grade of quenching and partitioning (Q&P) steel using alternative criteria. Table I is the list of different alternatives present and table II represent the different criteria on which basis the alternatives are ranked.

TABLE-3.1-Q&P Temperature

| Serial No. | Q&P TEMPERATURE |
|------------|-----------------|
| 1. | 210 |
| 2. | 225 |
| 3. | 240 |
| 4. | 250 |
| 5. | 260 |
| 6. | 280 |

TABLE-3.2- Properties

| | |
|-------------------------------|---------|
| Charpy Impact Toughness at RT | J/cm2 |
| Abrasive Wear Volume loss | mm3 |
| Ultimate Tensile Strength | Mpa |
| Yield Strength | Mpa |
| Percent Total Elongation | No Unit |

TABLE-3.3: Mechanical properties of Q&P treated steels at different quenching temperatures

| Steel | Charpy Impact Toughness at RT(J/cm2) | Abrasive Wear Volume Less (mm3) | Ultimate Tensile Strength (Mpa) | Yield Strength (Mpa) | Percent Total Elongation |
|---------|--------------------------------------|---------------------------------|---------------------------------|----------------------|--------------------------|
| Q&P 210 | 89 | 350 | 1257 | 466 | 26.3 |
| Q&P 225 | 35 | 345 | 1280 | 458 | 25.8 |
| Q&P 240 | 41.2 | 356 | 1248 | 452 | 24.8 |
| Q&P 250 | 48 | 368 | 1248 | 445 | 27.9 |
| Q&P 260 | 86.8 | 354 | 1289 | 438 | 28.7 |
| Q&P 280 | 85 | 339 | 1268 | 427 | 28.5 |

3.1 RESULTS AND DISCUSSION

In this report the weight factors are determined by the entropy method and the ranking of different alternatives are done with the help of COPRAS and MOORA. Table IV represents the weight factor of different criteria from the entropy method.

TABLE-3.4: Weight factor of criteria by Entropy Method for COPRAS Method

| CIT | AWVL | UTS | YS | PTE |
|---------|--------|---------|---------|---------|
| 0.01003 | 0.0396 | 0.14996 | 0.06457 | 0.73584 |

TABLE-3.5: Normalize Decision Matrix for COPRAS Method

| S. No. | CIT | AWVL | UTS | YS | PTE |
|--------|-------------|-------------|-------------|-------------|-------------|
| 1. | 0.545454545 | 0.099431818 | 0.027667984 | 0.078183172 | 1.296296296 |
| 2. | 0.584415584 | 0.106534091 | 0.029644269 | 0.083767684 | 1.388888889 |
| 3. | 0.623376623 | 0.113636364 | 0.031620553 | 0.089352197 | 1.481481481 |
| 4. | 0.649350649 | 0.118371212 | 0.032938076 | 0.093075205 | 1.543209877 |
| 5. | 0.675324675 | 0.123106061 | 0.034255599 | 0.096798213 | 1.604938272 |
| 6. | 0.727272727 | 0.132575758 | 0.036890646 | 0.104244229 | 1.728395062 |

TABLE-3.6: Weighted Normalize Decision Matrix

| Serial No. | CIT | AWVL | UTS | YS | PTE |
|------------|----------|----------|----------|----------|----------|
| 1. | 0.005471 | 0.003937 | 0.004149 | 0.005048 | 0.953872 |
| 2. | 0.005861 | 0.004219 | 0.004445 | 0.005409 | 1.022006 |
| 3. | 0.006252 | 0.0045 | 0.004742 | 0.005769 | 1.09014 |
| 4. | 0.006513 | 0.004687 | 0.004939 | 0.00601 | 1.135562 |
| 5. | 0.006773 | 0.004875 | 0.005137 | 0.00625 | 1.180985 |
| 6. | 0.007294 | 0.00525 | 0.005532 | 0.006731 | 1.27183 |

TABLE-3.7: Calculation of S_i^+ & S_i^-

| S_i^+ | Value | S_i^- | Value |
|---------|-------------|---------|-------------|
| 1. | 0.968540137 | 1. | 0.003937404 |
| 2. | 1.037721576 | 2. | 0.004218647 |
| 3. | 1.106903014 | 3. | 0.00449989 |
| 4. | 1.153023973 | 4. | 0.004687385 |
| 5. | 1.199144932 | 5. | 0.004874881 |
| 6. | 1.29138685 | 6. | 0.005249871 |

TABLE-3.8. Calculation of Q_i & Rank

| SI. No. | Q_i | Rank |
|---------|----------|------|
| 1. | 1.203406 | 2 |
| 2. | 0.973816 | 6 |
| 3. | 1.042646 | 5 |
| 4. | 1.11532 | 4 |
| 5. | 1.29234 | 1 |
| 6. | 1.157456 | 3 |

TABLE-3.9: Weight factor of criteria by Entropy Method for MOORA Method

| CIT | AWVL | UTS | YS | PTE |
|----------|----------|----------|----------|----------|
| 0.138768 | 0.215587 | 0.215891 | 0.215494 | 0.214261 |

TABLE-3.10: Normalize Decision Matrix for MOORA Method

| Serial No. | CIT | AWVL | UTS | YS | PTE |
|------------|-------------|-------------|-------------|-------------|-------------|
| 1. | 0.532765287 | 0.405792806 | 0.405635812 | 0.424792601 | 0.397087112 |
| 2. | 0.209514439 | 0.399995766 | 0.413057947 | 0.417500024 | 0.389537927 |
| 3. | 0.246628425 | 0.412749254 | 0.402731499 | 0.412030591 | 0.374439558 |
| 4. | 0.287334088 | 0.42666215 | 0.402731499 | 0.405649587 | 0.421244502 |
| 5. | 0.519595808 | 0.410430438 | 0.415962261 | 0.399268582 | 0.433323198 |

| | | | | | |
|----|------------|-------------|-------------|-------------|-------------|
| 6. | 0.50882078 | 0.393039318 | 0.409185529 | 0.389241289 | 0.430303524 |
|----|------------|-------------|-------------|-------------|-------------|

TABLE-3.11: Weighted Normalize Decision Matrix

| Serial No. | CIT | AWVL | UTS | YS | PTE |
|------------|-------------|-------------|-------------|-------------|-------------|
| 1. | 0.073930548 | 0.087483496 | 0.087572983 | 0.091540381 | 0.085080226 |
| 2. | 0.029073811 | 0.086233732 | 0.089175352 | 0.089968872 | 0.083462732 |
| 3. | 0.034224029 | 0.088983213 | 0.086945969 | 0.088790241 | 0.080227742 |
| 4. | 0.039872655 | 0.091982647 | 0.086945969 | 0.087415171 | 0.09025621 |
| 5. | 0.072103051 | 0.088483307 | 0.089802367 | 0.086040101 | 0.092844201 |
| 6. | 0.070607826 | 0.084734015 | 0.088339333 | 0.083879276 | 0.092197203 |

TABLE-3.12: Calculation of Qi & Rank

| SI. No. | Qi | Rank |
|---------|-------------|------|
| 1. | 0.250640642 | 2 |
| 2. | 0.205447035 | 5 |
| 3. | 0.201204767 | 6 |
| 4. | 0.212507357 | 4 |
| 5. | 0.252306412 | 1 |
| 6. | 0.250289625 | 3 |

TABLE-3.13: Summary Table

| PROPERTIES | RANK BY COPRAS | RANK BY MOORA |
|---|----------------|---------------|
| Charpy Impact Toughness at RT(J/cm ²) | 2 | 2 |
| Abrasive Wear Volume Less (mm ³) | 6 | 5 |
| Ultimate Tensile Strength (Mpa) | 5 | 6 |
| Yield Strength (Mpa) | 4 | 4 |
| Percent Total Elongation | 1 | 1 |

4. CONCLUSION

According to COPRAS and MOORA method Percent Total Elongation is mostly preferred. If we consider COPRAS method then Abrasive Wear Volume less is least preferred and if we consider MOORA method then Ultimate Tensile Strength is less preferred. But rank of other properties are varying. Hence, we can conclude that on the basis of different criteria out of the six alternatives Percent Total Elongation is the most preferred property for best Quenching and partitioning temperature, Abrasive Wear Volume Less and Ultimate Tensile Strength is the least. The second, third, fourth and fifth rank alters in both the ranking method. Although COPRAS and MOORA both are used as MCDM techniques yet result obtained from the

both may vary.

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