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Original Research Article

An application for the selection of steel sheet materials used in automotive construction with the MOORA method

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ABSTRACT

The new generation of steel grades that can be used in automotive construction is increasing day by day and the material selection becomes very important both in the design and manufacturing processes due to the development in the materials. In this study, data on tensile strength, formability, load that weld joints can bear, fatigue stress, corrosion resistance and price criteria of high strength low alloy (HSLA), dual phase (DP), three phase (TRIP) and complex phase (CP) steel sheet materials used in the automotive industry were determined and a study was conducted for the material selection using the MOORA (Multi Objective Optimization on the Basis of Ratio Analysis) ratio approach. It was concluded that the selection of DP grade steel sheet material according to the MOORA ratio approach among the materials used in the study would be the optimum choice.

Keywords: Automotive construction, automotive sheet materials, steel sheet grades, material selection, MOORA method.

1. Introduction

Significant progress has been made in the automotive industry in terms of safety, fuel economy, crash resistance and comfort, and in this direction, various steel sheet materials are used in vehicles. In order to achieve the stated targets, steel sheet manufacturers are introducing new generation steel grades every day and contributing to the development of the automotive industry [1]. The new generation steel grades used in the automotive industry, which show the tensile strength-elongation relationship of these steel grades and the usage areas of sheet materials in automobiles, are shown in Figure 1. Figure 1a shows the elongation-tensile strength relationship of these steels and Figure 1b shows the regions of these steels used in automobiles.

Material selection plays a very important role in product design and development. Again, the selection of the right material is of great importance in the success of the manufacturers and it is necessary to choose the optimum material that achieves maximum performance and minimum cost in development [5-7]. Recently, effective solutions in material selection have been obtained by using multi-criteria decision making (MCDM) approach [8]. In the MCDM approach, there are various approaches according to the type of decision making. In the material selection made in these approaches, after the problem is defined, criteria are determined and evaluated and the best one is selected among the alternatives. Hambali et al., with AHP (Analytical Hierarchy Process) analysis, concluded that the most suitable material for automobile bumper is glass fiber reinforced epoxy material [9].

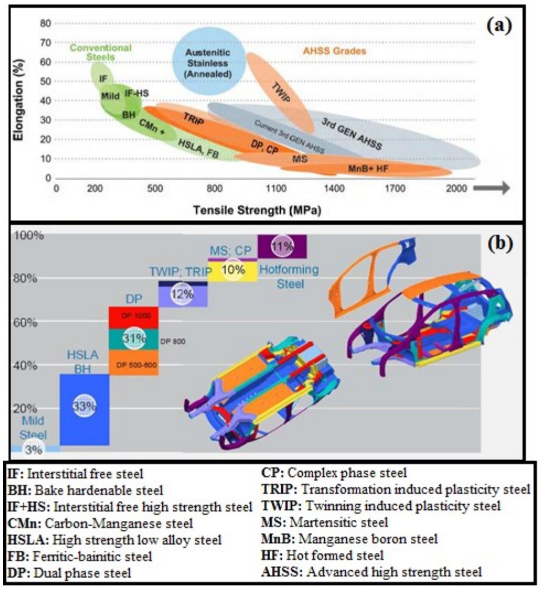

Figure 1: a) Elongation-tensile strength relationship, b) the regions of steel grades used in the automotive industry [2-4].

Mayyas et al. performed material selection among ten different materials used in automotive panels using QFD (Quality Function Distribution) and AHP methods [10]. Girubha and Vinodh made the material selection of an automobile part using the VIKOR (Vlse Kriterijumska Optimizacija Kompromisno Resenje) method [11]. Hasanzadeh et al., using AHP, TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) and MOORA methods for the automotive bumpers, stated that the composite material containing 0.5% nano alumina among six different alternative composite materials would be the most appropriate choice [12]. Mondal et al., on the other hand, selected materials among magnesium alloys in automobile wheels in accordance with the MOORA method. They found that among eight different magnesium alloys, the AZ91 grade was the most suitable for this selection [13]. Banerjee et al., among four different materials (carbon fiber/epoxy composites, steel, aluminum and titanium alloys) used in automobile parts (piston, wheel, brake disc, bumper, etc.) using the CODAS (Combinative Distance-Based Assessment) method, stated that the most suitable material is titanium alloy [14]. Steel sheet materials are used extensively in automotive construction (chassis, body, etc.). Furthermore, since different types of sheet materials can be used in these regions, material selection comes to the fore. It has been observed that there are almost no applications in which material selection is made for new generation steel sheet materials used in automotive construction and there is a gap in the literature.

In this study, data on tensile strength, formability, load that weld joints can bear, fatigue stress, corrosion resistance and price criteria of high strength low alloy (HSLA), dual phase (DP), three phase (TRIP) and complex phase (CP) steel sheet materials used in the automotive industry were determined and a study was conducted for the material selection using the MOORA ratio approach.

2. Material Selection Method

2.1. Alternative materials and properties

In this study, the properties of sheet materials were determined by using the technical information of the automotive steel sheet manufacturing company [15]. In this selection process, an orientation towards materials with high tensile strength and alternatives to each other from the new generation steel generations was generally achieved. In this context, four different materials were determined. HSLA (high strength low alloy) steels are produced by adding small amounts of titanium, niobium and vanadium to C-Mn steels, making the grain structure micro and thus gaining strength [16]. The properties of CR460LA grade sheet material were taken from these steels. DP (Dual Phase) steels are low carbon steels consisting of soft ferrite and hard martensite structure [17]. The properties of DP600 grade sheet material were taken from these steels. In TRIP (Transformation Induced Plasticity) steels, three phases containing bainite and residual austenite are present in certain proportions in a soft ferrite matrix in the microstructure [18]. The properties of TRIP700 grade sheet material were taken from these steels. CP (Complex Phase) steels are a type of steel with ferrite and martensite, as well as bainite and in some cases residual austenite [17]. The properties of CP600 grade sheet material were taken from these steels.

Table 1: Materials and criteria used for material selection and material properties.

Material	Price (USD/ton)	Corrosion resistance	Tensile strength (MPa)	Formability	Weldability (pure tensile load) kN	Weldability (tensile-shear load) kN	Fatigue stress (MPa)
CR460LA	900	4	520	18.31	11.00	18.09	458
DP600	1000	2	590	26.27	13.10	22.30	503
CP600	1100	3	600	22.98	15.10	21.20	493
TRIP700	1200	3	690	42.65	6.70	13.00	560

Table 2: Values of the normalized decision matrix.

Material	Price (USD/ton)	Corrosion resistance	Tensile strength (MPa)	Formability	Weldability (pure tensile load) kN	Weldability (tensile-shear load) kN	Fatigue stress (MPa)
CR460LA	0.426	0.649	0.431	0.315	0.463	0.476	0.454
DP600	0.474	0.325	0.489	0.452	0.551	0.587	0.498
CP600	0.521	0.487	0.498	0.396	0.609	0.558	0.488
TRIP700	0.568	0.487	0.572	0.735	0.282	0.342	0.555

Multi-criteria properties of CR460LA, DP600, TRIP700 and CP600 steel materials were obtained. In the tensile strength criterion of the materials used in this study, the minimum tensile strength value was used for all materials from the catalog. In the formability criterion, major strain amounts corresponding to "0" minor strain amount in the forming limit curve were used. In the weldability criterion, the load values which the welded joint can carry under pure tensile load and tensile-shear load were used. In the fatigue stress criterion, the maximum stress values obtained in 2×10^6 cycles under repeated tensile loading (R=0.1) were selected. In the price criterion, price information obtained from the internet is used [19]. The corrosion resistance criterion was determined by evaluating the alloy element amount and experience from a scale of 1-5 (1: very good, 2: good, 3: moderate, 4: bad and 5: very bad). In Table 1, the materials and criteria used for material selection and material properties are given.

2.2. MOORA method

The MOORA method is a multi-criteria decision-making method developed by Brauers and Zavadskas [20] and used frequently recently. In this method, the interactions between the criteria are considered as a whole and material selection is made with weighted values. Although there are many methods in the MOORA method, the most used one is the MOORA ratio approach. The steps of this approach are as follows.

Stage 1: The decision matrix (K) is created. This matrix is obtained from the criteria determined at the beginning.

$$K = \begin{pmatrix} k_{11} & k_{12} & \cdots & k_{1m} \\ k_{21} & k_{22} & \vdots & k_{2m} \\ \vdots & \vdots & \ddots & \vdots \\ k_{n1} & k_{n2} & \cdots & k_{nm} \end{pmatrix} \quad (1)$$

Stage 2: The decision matrix (K) is normalized. The normalized decision matrix (N) is created with the help of the equation 2 given below and the maximum or minimum objective in the selected criteria is not examined.

$$k_{ij}^{\ *} = \frac{k_{ij}}{\sqrt{\sum_{i=1}^{n} k_{ij}^{\ 2}}} \ , i = 1,2,\dots,n, j = 1,2,\dots,m \quad (2)$$

Stage 3: Performance of decision criteria (X); It is determined with the help of the equation 3 given below by subtracting the sum of performance values for minimization from the sum of performance values for maximization purposes.

$$X = \sum_{j=1}^{t} k_{ij}^{\ *} - \sum_{j=t+1}^{n} k_{ij}^{\ *} \ , i = 1,2,\dots,n \quad (3)$$

Stage 4: The resulting X values are sorted. As a result of the ranking, the material with the highest value is selected in the first place.

3. Results and Discussion

The decision matrix (K) considered in the MOORA ratio approach for material selection is indicated in Table 1. These values are converted to their normalized values using the equation given in Stage 2. The values of the normalized decision matrix are given in Table 2.

While evaluating the performance of the decision criteria, it is desired that the tensile strength, formability, weldability and fatigue strength criteria be maximum. Similarly, it is desirable that the price and corrosion resistance criteria should be minimal. When substituting for each material in the equation 3 given in Stage 3, the performance values of the decision criteria (X) are obtained. The performance values of the decision criteria given in Stage 4 are listed and the ranking of the material selection is obtained. In Table 3, the material selection order obtained with the MOORA ratio approach is given.

Table 3: Material selection ranking obtained with the MOORA ratio approach.

	X	Ranking
CR460LA	1.064	4
DP600	1.778	1
CP600	1.541	2
TRIP700	1.431	3

The MOORA ratio approach reveals very effective results in material selection among four materials that exhibit different microstructure properties but are close to each other in terms of tensile strength. The reason for choosing the MOORA approach in the study is the advantages such as using different, easy and understandable mathematical processes compared to other methods (AHP, QFD, TOPSIS, VIKOR, CODAS etc.) by considering all the criteria. In such a study, it is suggested that steels with martensite phase or DP grade should be generally preferred by using QFD and AHP material selection methods in automotive panels (eg A, B columns, doors, hood, etc.) [10]. Therefore, from the results obtained from this study, it is possible to say that it would be more optimum to prefer dual phase (DP) steel sheet materials. Mild steel, which is frequently used in automotive, has been shown to perform well in a new and unique MCDM method made by using different metal combinations in automotive inner and outer panels [21]. DP steel sheet material selected in this study exhibits superior mechanical properties compared to mild steel sheet materials used extensively in automobiles. Also, like mild steels, its forming and weldability is quite good. Thanks to these features, it can be very reliable for use in the automotive industry.

4. Conclusion

In this study, data on tensile strength, formability, load that weld joints can bear, fatigue stress, corrosion resistance and price criteria of high strength low alloy (HSLA), dual phase (DP), three phase (TRIP) and complex phase (CP) steel sheet materials used in the automotive industry were determined and a study was conducted for the material selection using the MOORA (Multi Objective Optimization on the Basis of Ratio Analysis) ratio approach. In the study, it was tried to select as many criteria as possible in the multi-criteria selection methods within the scope of this study, and when evaluated with the criteria of tensile strength, forming ability, welding ability, fatigue strength, price and corrosion resistance, it is possible to summarize the order in material selection among the four materials determined at the beginning of the study as follows. It is recommended to use DP grade steel sheet material first. This material is followed by CP grade steel sheet material and TRIP grade steel sheet material comes in third place. It was concluded that the last preferred material is HSLA grade sheet material.

CRediT authorship contribution statement

Batuhan Özakın: Problem definition, Conceptualization, Investigation, Methodology, Writing - original draft, Writing - review & editing.

Declaration of conflicting interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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