Journal of Solid and Fluid Mechanics (JSFM), 13(3): 1-3, 2023

Shahrood University of Technology

Journal of Solid and Fluid Mechanics (JSFM)

DOI: 10.22044/JSFM.2023.13057.3735

Manufacturing Engineering of Iran

Application of multi-criteria decision making method for selection of lightweight material in manufacturing of railway vehicles

Vahid Modanloo[1]

[1] Assist. Prof., Mechanical Engineering Department, Sirjan University of Technology, Sirjan, Iran

*Corresponding author: v.modanloo@sirjantech.ac.ir

Received: 05/02/2023 Revised: 05/28/2023 Accepted: 08/19/2023

Abstract

Selection of the proper material in manufacturing lightweight railway vehicles is a complex and essential challenge considering the available engineering materials. In this paper, the appropriate material has been selected for manufacturing railway wagons using a multi-criteria decision-making technique. Six engineering materials including DP600 steel, TRIP700 steel, TWIP steel, 6005-T6 aluminum, 60826-T6 aluminum and porous aluminum with closed cells were considered as engineering alternatives. Also, density, yield strength, ultimate tensile strength, the ratio of yield strength to maximum tensile strength, Young's modulus, cost and corrosion resistance were considered as selection criteria. To select the best material according to the mentioned criteria, the MOORA multi-criteria decision-making method was applied. By weighting the criteria and performing the analysis, it is found that the TWIP steel and 6082-T6 aluminum were chosen as the best candidates and aluminum foam and DP600 steel were selected as the worst candidates. Due to its maximum yield strength and ultimate tensile strength compared to other candidates, TWIP steel was chosen as the best material considering all criteria. Furthermore, the 6082-T6 material was chosen as the second-best material due to the high ratio of yield strength to ultimate tensile strength (0.88) and lower density and higher corrosion resistance than steel materials.

Keywords: Lightweight Material, Railway Structure, Multi-criteria Decision Making, Best Selection.

1. Introduction

The rail transportation industry is one of the most important factors in the growth and development of countries [1]. This industry has significant advantages such as low fuel consumption, reduction of air pollution, ease of moving goods, few accidents, and cost savings [2]. Wagon exhaustion and the lack of use of lightweight structures in their design and construction are among the important factors in the lack of development of this industry [3]. In recent years, lightweight materials have been widely developed in the aerospace and transportation industries [4]. Aluminum alloys, magnesium, titanium, high-strength steels, and reinforced composites are common lightweight materials in these industries [5]. Selection of the appropriate material for the manufacturing of wagon bodies based on the desired criteria is very important and complicated [6]. The body of these wagons should have high strength, low weight, and acceptable corrosion resistance. Also, the justifiable cost for selecting the proper material is also one of the key parameters in engineering design issues [7]. Advanced high-strength steel (AHSS) has been conventionally used in the construction of lightweight structures in the railway industry due to their extraordinary properties such as excellent mechanical strength and good ductility [8]. So far, much research has been performed to increase the strength and reduce the weight and cost of the AHSS steels used in the transportation industry and DP600, TRIP700, and TWIP steels are some of them [9]. In addition, the mentioned steels have good energy absorption and strength against impact compared to aluminum alloys, [10]. Aluminum alloys are also widely used in the transportation industry due to their unique properties such as low weight and high corrosion resistance, of which 6xxx series alloys are the most important type [11]. In recent years, porous aluminum foams have been proposed as a new material in the design of engineering structures in order to significantly reduce the weight of the structure [12]. These materials are widely used in the aerospace, automotive, and rail transportation industries due to their unique properties such as absorbing sound, energy and impact, electromagnetic shielding, and heat insulation [13]. With the development of the rail transportation industry and the significant costs of designing and manufacturing wagons, engineers have decided to select the best material for manufacturing such parts by providing intelligent methods. Since different criteria must be considered in selecting the desired material from among many available options, the multi-criteria decision-making (MCDM) method is proposed as a useful and effective tool [14

This research deals with the selection of the best material for the construction of rail industry wagon bodies. Six widely used engineering materials, including DP600 steel, TRIP700 steel, TWIP steel, 6005-T6 aluminum, 60826-T6 aluminum, and porous aluminum with closed cells are considered alternatives. Then, seven criteria namely density (ρ), yield strength (σ_y), ultimate strength (σ_u), ratio of yield strength to ultimate tensile strength (α), Young's modulus (E), cost (C), and corrosion resistance (R) are considered criteria. Finally, the best material will be selected for manufacturing the wagon bodies by using the MOORA method.

2. Methodology

Table 1 shows the engineering properties of the considered materials for manufacturing the wagon bodies used in the railways' industry. In this paper, both objective and subjective methods were examined to assign proper weights to criteria. Table 2 presents the Entropy weights calculated by Eqs. (1) to (4) [15].

Table 1. Properties of the considered materials [13]

	DP-600	TRIP-700	TWIP	6005-T6	6082-T6	Al-foam
ρ (kg/m^3)	8050	8050	8050	2700	2700	1000
σ_y (MPa)	410	520	750	240	250	20
σ_u (MPa)	700	800	1000	260	310	30
α	0.58	0.5	0.75	0.9	0.88	0.66
E (GPa)	200	200	200	69	70	12
C ($/kg)	0.55	0.55	1.5	1.9	1.9	46
R	1	1	1	3	3	3

Table 2. Criteria weights calculated by Entropy method

Criteria	Weight
ρ (kg/m^3)	0.001
σ_y (MPa)	0.038
σ_u (MPa)	0.058
α	0.173
E (GPa)	0.031
C ($/kg)	0.637
R	0.063

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}} \qquad i=1, 2, \dots, m; \quad j=1, 2, \dots, n \qquad (1)$$

$$e_j = -\frac{1}{\ln m}\sum_{i=1}^{m} n_{ij}\ln(n_{ij}) \qquad (2)$$

$$d_j = |1 - e_j| \qquad (3)$$

$$E_j = \frac{d_j}{\sum_{j=1}^{n} d_j} \qquad (4)$$

In the above equations, i and j denote the number of alternatives (6) and criteria (7), respectively. As can be deduced from Table 2, there is a big difference between the obtained weights. Hence, according to reference [13], the subjective method was used to weight the criteria, which is based on the experience and opinion of the decision-maker. Figure 1 depicts the used subjective weights. Afterward, the criteria selection was carried out using the MOORA method as given by Eq. (5) in which g is the number of criteria that should be maximized i.e. yield strength, ultimate strength, ratio of yield strength to ultimate tensile strength, Young's modulus and corrosion resistance. Also, $(n - g)$ is the number of criteria that should be minimized (cost and density). Each alternative that allocates the highest value of y_i^*, will be considered as the best selection [16].

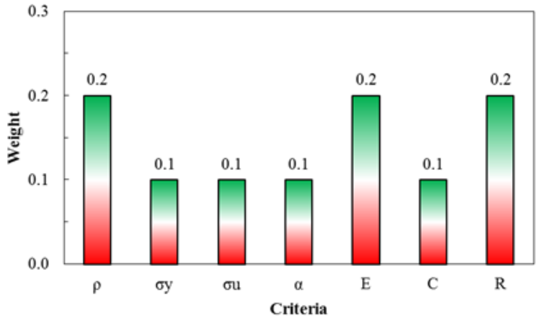

Figure 1. The used subjective weights

$$y_i^* = \sum_{j=1}^{g} E_j r_{ij} - \sum_{j=g+1}^{n} E r_{ij} \qquad (5)$$

3. Results and Discussion

Figure 2 illustrates the ranking results of criteria carried out by the MOORA method. As is shown, the TWIP steel has the best rating and, as a result, it will be selected as the best option for the manufacturing wagon body railway transport industry. On the other hand, aluminum foam was selected as the worst option due to its lowest rank.

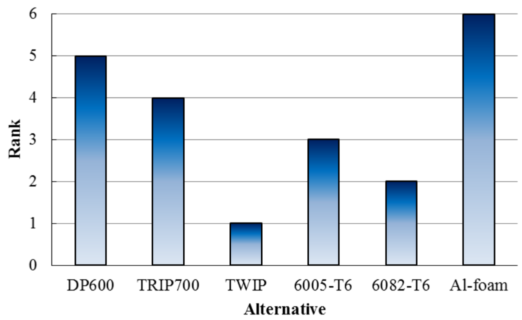

Figure 2. Ranking results of criteria

4. Conclusions

In this paper, the multi-criteria decision-making (MCDM) method was used to select the best material for manufacturing wagon bodies used in the railway transport industry. Six materials including DP600 steel, TRIP700 steel, TWIP steel, aluminum 6005-T6, aluminum 6082-T6, and closed-cell porous aluminum were considered as Alternatives. Moreover, their properties including density, yield strength, ultimate tensile strength, the ratio of yield strength to ultimate tensile strength, Young's modulus, cost, and corrosion resistance were considered as criteria. After assigning subjective weights to criteria, the best candidate was selected using the MOORA method. The results showed that TWIP steel and AA6082-T6 are the best options, respectively. On the other hand, aluminum foam and DP600 steel were selected as the worst options.

5. References

[1] Fakhari M, Salehi M (2021) Health Condition Monitoring of railway wheels through vibration analysis using the moving RMS. *Journal of Solid and Fluid Mechanics* 11(4):85-92.

[2] Ezoji R, Talaee MR (2019) Aerodynamic analysis and modeling of effect of nose shape parameters on overturn of high speed train under crosswind. *Journal of Solid and Fluid Mechanics* 9(3):155-176.

[3] Sarafrazi V, Talaee M (2016) Analysis and modeling of aerodynamic pressure wave due to high-speed trains passage. *Journal of Solid and Fluid Mechanics* 6(3):65-78.

[4] Sun Y, Anwar M, Hassan NM, Spiryagin M, Cole C (2021) A review of hydrogen technologies and engineering solutions for railway vehicle design and operations. Rail Eng Sci 29:212-232.

[5] Raza SA, Shah N, Sharif A (2019) Time frequency relationship between energy consumption, economic growth and environmental degradation in the United States: Evidence from transportation sector. Energy 173:706-720.

[6] Zhang D, Tang YY, Peng QY (2023) A novel approach for decreasing driving energy consumption during coasting and cruise for the railway vehicle. Energy 263:125615.

[7] Jagadeesh P, Puttegowda M, Oladijo OP, Lai CW, Gorbatyuk S, Matykiewicz D, Rangappa SM, Siengchin S (2022) A comprehensive review on polymer composites in railway applications. Poly Comp 43(3):1238-1251.

[8] Ulianov C, Önder A, Peng Q (2018) Analysis and selection of materials for the design of lightweight railway vehicles. IOP Confe Series: Mat Sci Eng 292(1): 012072.

[9] Im JM, Shin KB (2019) Technology of Light Weight Railway Vehicle using Composite Materials. Int J Rail 12(2):23-27.

[10] Sivamaran V, Azaruddin S (2021) A Short Review on Applications of Aluminium Composites: Automotive, Aerospace and aircraft, Rail transport, and Marine transport industry. J Prod Ind Eng 2(2):36-42.

[11] Sivamaran V, Azaruddin S (2021) A Short Review on Applications of Aluminium Composites: Automotive, Aerospace and aircraft, Rail transport, and Marine transport industry. J Pro Ind Eng 2(2):36-42.

[12] Shi T, Wang C, Mi G, Yan F (2019) A study of microstructure and mechanical properties of aluminum alloy using laser cleaning. J Manuf Proc :42:60-66.

[13] Sharma V, Zivic F, Adamovic D, Ljusic P, Kotorcevic N, Slavkovic V, Grujovic N (2022) Multi-Criteria Decision Making Methods for Selection of Lightweight Material for Railway Vehicles. Mater 16(1):368.

[14] Moradian M, Modanloo V, Aghaiee S (2019) Comparative analysis of multi criteria decision making techniques for material selection of brake booster valve body. J Traff Transp Eng (English Edition) 6(5):526-534.

[15] Modanloo V, Doniavi A, Hasanzadeh R (2016) Application of multi criteria decision making methods to select sheet hydroforming process parameters. Dec Sci Let 5(3):349-360.

[16] Modanloo V, Alimirzaloo V, Elyasi M (2019) Multi-objective optimization of the stamping of titanium bipolar plates for fuel cell. ADMT J 12(4):1-8.