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Evaluation of Automotive Brake Disc Material Selection Using Weighted Sum Method (WSM)

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Abstract. *Selecting suitable materials for automotive brake discs is an important process in the construction and assembly of braking systems. Brake discs or rotors are important components that convert kinetic energy into thermal energy to enable efficient braking and ensure vehicle and occupant safety. The choice of brake disc material is important to ensure optimum performance, reliability and durability under various operating conditions. Several important properties such as efficient heat dissipation, high mechanical strength, wear resistance and constant friction properties should be considered when choosing a suitable material for brake discs. Historically, Gray cast iron (GCI) continues to be the number one choice for brake discs due to its excellent heat transfer capabilities, effective vibration damping, and cost effectiveness. GCI effectively withstands the high temperatures and mechanical stresses encountered during braking, providing reliable and consistent performance. However, advances in materials science and engineering are researching alternative materials for brake disc applications Titanium alloys such as Ti-6Al-4V offer exceptional favour such as lightweight design, high-calibre strength, and corrosion resistance. These properties make titanium alloys suitable for certain applications that require reduced weight and increased performance. TMC combines a titanium matrix with ceramic reinforcements to improve performance compared to conventional materials. There are various factors to consider when choosing the brake disc material, such as: B. Vehicle type, weight, intended use (racing, daily driving, etc.), operating temperature, and cost considerations. Thorough testing and evaluation are performed to ensure that selected materials meet required performance criteria such as braking efficiency, durability, wear resistance and heat aging resistance. As the automotive industry continues to advance, there is more R&D exploring advanced materials such as carbon-ceramic composites for high-performance and luxury vehicles. These materials provide excellent braking performance, weight savings and long life. Research Significance: The study of material selection for automotive brake discs will show results in the performance, reliability, and safety of braking systems. The aim is to identify suitable materials that improve braking efficiency, durability and thermal stability. Efforts in this area have led to improved braking performance through the development of materials with optimal friction properties. These materials result in shorter braking distances, increased responsiveness, and improved overall braking efficiency. Additionally, research is focused on identifying lightweight materials that maintain structural integrity and heat dissipation capabilities. This weight savings contributes to improved fuel efficiency, lower emissions, and improved vehicle handling and performance. Durability and longevity are important aspects studied in research. Materials with high mechanical strength and wear resistance are selected to ensure long-term durability and long service life. Effective heat dissipation is also an important factor. The aim of the research is to find materials with good thermal conductivity and stability. This prevents brake slippage and ensures smooth, reliable braking performance even under the most demanding conditions. Cost-effectiveness is also a consideration, as researchers strive to find materials that balance performance, durability, and cost. Identifying cost-effective materials without compromising safety and performance is critical for widespread adoption in the automotive industry. Methodology: Weighted Sum Method: It method is the mathematical approach by combines many factors or criteria by assigning weights to each of them. A weighted sum is calculated by the means of multiplying the weight of each one element by the corresponding value and summing it up. This method allows comprehensive evaluation and ranking of alternatives based on their weighted scores. It provides a simple and effective way to consider multiple factors at once and make decisions. Alternate Parameters: GRAY CAST IRON (GCI), TMC, AMC 1 & AMC 2, TI-ALLOY (TI-6AL-4V). Evaluation Parameters: Friction coefficient tμ), Wear rate (x10^{-6} mm^{3}/N/m), Specific gravity (Mg/m^{3}), Compressive Strength (MPa), Specific heat (Cp (KJ/Kg. K)). Result: From the result it is seen that Gray cast iron (GCI)*

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got the first rank where as is the Ti-Alloy (Ti-6Al-4V) having the lowest rank. Conclusion: The first ranking material gray cast (GCI) is obtained with the best and suitable material for automotive brake disc

Keywords: *Brake Disc Material, Material properties, weighted sum method.*

1. INTRODUCTION

The core component of any vehicle's foundation brake is the "friction pair," consisting of the frictional materials themselves, typically comprising a stationary component (pad or slipper) and a rotating brake disc or drum. This study takes into consideration both the effects of frictional contact interactions on the brake's performance and the material modelling characteristics of these components. The friction material is a complex combination of various constituents, often held together by a phenolic binder matrix [1]. The braking process plays a crucial role in a vehicle's ability to stop or in modify the vehicle's kinetic energy to heat energy. This construct links between the brake disc and its lining. Proper dissipation of this heat to surrounding structures and efficient airflow around the braking system are crucial. However, the thermodynamic resistance between brake pads and brake discs can lead to excessive temperatures during the braking stage. [2]. Automotive brake friction materials (BFMs) are composed of a sophisticated mixture of over 20 different components. Copper is commonly incorporated into BFMs due to its advantageous physical properties, including high thermal conductivity. Previous research has indicated that copper helps in achieving a uniform frictional surface within the contact, promoting friction stability and reducing sensitivity to changes in speed and pressure. Furthermore, the inclusion of copper fibres in BFMs acts as reinforcement, minimizing pad wear and facilitating the formation of contact plateaus [3]. The braking system is an essential component for automobile assurance. Its central purpose is to decelerate the vehicle through the friction created between the brake pads and the rotor facial, modify the kinetic energy toward heat energy. This friction-based mechanism allows the vehicle to completely slow down or come to a complete block [4]. There are two essential categories of friction materials used in braking systems. Disc brake pads and drum brake pads. Disc brake pads are passed down in a broad collection circling automotive and industrial applications. These pads consist of a steel backing course with friction material attached to the surface that contacts the brake disc. Drum brakes, on the other hand, utilize the friction assembled by a set of shoes that push outward on a rotating cylindric component termed the brake drum. The purpose of this application was to review the raw materials used in brake pads and analyze current trends in the industry [5]. Hard braking is a situation in that the vehicle's speed rapidly drops to zero in a very short course of time, commonly during an accident. It changes kinetic energy into mechanical energy that is a fruitful frictional heat. Most of this heat (approximately 90%) is absorbed by the brake system at the link credit in between the disc and the brake lining [6].

2. VIKOR METHOD

It is an easy approach which is often used to deal with one-dimensional problems. In a scenario with m terms and n criteria, the finest terms are determined by satisfying

A* wsm =Max∑_j^i a_ij w_j

where i ranges from 1 to m. here*

wsm represents the weighted sum method of the finest option, n is the number of decision-making criteria, ai j corresponds to the real value of the i-th term for the j-th criterion, and wj is the weight comparable to the importance of the jth criterion is assigned to the criterion. The total values for each one excellent choice are found by summing the products. However, applying this method to complex decision-making problems presents challenges. Difficulties will arise when combining n number of dimensions, especially. n no. of units, as the assumption of further services is omitted. [7]. The Weighted Gray gas sum approach, early introduced by Hottel and Sarofim (1967) as part of the zonal method, can be applied to any calculation with other absorption coefficients. This work demonstrates the versatility of this approach in transmission direction equations, favouring its use in any sending equation solving method just as: B. Exact Method, P-N Approximation or Discrete Ordinate Method [8]. In early years, it shows an increased focus on upgrading the efficiency of complex systems, including aircraft, leading to the emergence of multidisciplinary design optimization (MDO) as a significant discipline in engineering [9]. MDO aims to develop new strategies for constructing and enhancing complex systems, with a specific emphasis on reducing the time and costs associated with interdisciplinary collaboration. The proposed approach in this context involves a simplified normalization procedure that relies on three or more measures in evaluating the effectiveness of changes, simplifying the ranking process [10]. The conclusion drawn is that in easy and simple weighted sum-product method is easier in work with for providing more reliable decision-making. Hence, the proposal suggests the adoption of a streamlined normalization approach utilizing four utility measures for assessing total utility and simplifying the ranking process. Furthermore, this work announces a new method to accurately determine the geometric aerosol surface concentration (GSA) with an amazing temporal resolution of seconds. This method involves modifying a commercially available nanoparticle surface area monitor and using a weighted sum to combine the instrument's response under different conditions. These combined responses establish a interconnection with aerosol GSA concentrations [11]. Regarding the selection context of automation, the proposed approach uses a weighted summation model that considers expert panel ratings on various factors. The purpose of this model is to cut down the influence of individual decision makers who may have different opinions, thereby rushing the decision-making process. By excluding the highest and lowest weights and subjective factors assigned by experts, a comprehensive technique for robot selection is developed [12].

3. EVALUATION PARAMETERS

Compressive Strength (Mpa): Compressive strength is a basic mechanical property that shows the ability of a material to withstand compressive forces without deforming or breaking. It measures the highest compressive stress a material will withstand before it breaking or crushing. Compressive strength is expressed in units of megapascals (MPa) and is determined by standardized test methods. To assess the compressive strength of a material, specimens are prepared, usually in the structure of cubes or cylinders, according to specific dimensions and shapes. The specimen is subjected to increasing loads or forces in a controlled manner until it fails in compression. The maximum force at the point of failure is recorded within the compressive strength that are measured by dividing the force by the area of the specimen. Compressive strength is affected by several factors such as material composition, microstructure, and porosity. Dense materials with regular and well-bonded structures usually exhibit higher compressive strength. Conversely, materials with a high proportion of voids, defects, or weak intergranular bonds tend to have low compressive strength. Compressive strength is an important parameter in many industries and applications. It is very important in civil engineering to assess the load-bearing capacity of components such as concrete, masonry and rock formations. These materials determine the weight-bearing capacity of buildings, bridges, dams, and other infrastructure. It helps ensure the durability and reliability of manufactured products such as automotive parts, aerospace parts, and industrial machinery. Understanding the compressive strength of materials allows engineers and designers to make informed decisions about material selection, structural design and safety considerations. Choosing materials with sufficient compressive strength for a particular application can ensure the structural integrity and longevity of the product designed or manufactured. It is very important to mention that certain materials will have many ranges of typical compressive strength. In summary, compressive strength is an important mechanical property that measures a material's ability to withstand compressive forces. It is determined by standardized test methods and is expressed in MPa. Compressive strength plays an important role in various industries, especially construction and manufacturing, and influences material selection, structural design, and product reliability considerations.

Friction Co-Efficient (μ): The coefficient of friction, also referred to as the friction coefficient, is a dimensionless value that quantifies the extent of friction between two surfaces that are in contact. It represents the ratio between the force needed to overcome the resistance caused by friction between the surfaces and the normal force exerted on the surfaces, pushing them together. This coefficient plays a vital role in characterizing and predicting the behaviour of frictional interactions in various applications and industries. It serves as a fundamental parameter in disciplines such as engineering, physics, and materials science. The coefficient of friction can be shows into two main types: static and dynamic. The static coefficient of friction (μ s) describes the resistance to movement between two surfaces that are relatively stationary. It indicates the maximum frictional force that must be overcome to set an object in motion. On the other hand, the dynamic coefficient of friction (μ k) refers to the resistance to maintaining motion between surfaces that are already in relative motion. Different materials have distinct frictional behaviour, with rough and textured surfaces generally having higher coefficients of friction than smooth surfaces. Laboratory tests using standard friction measurement techniques are used to determine the coefficient of friction. Common methods include the slope test, which measures the angle at which an object begins to slide and relates the frictional force to applied normal force and tilt angle. It aids design along with engineering by definitive the forces and torques required to move objects and components, designing efficient braking systems, and permissive part evasion.

Wear Rate (Mm^3/S): Wear rate,also knwn as wear rate or wear loss, refers to a amount of material loss or degradation that occurs over time due to mechanical interactions between two relatively moving surfaces. Quantify the amount of material detached or removed from a surface per unit time under specified operating conditions. Wear rate is an important parameter in many fields such as engineering, tribology, materials science and manufacturing. This provides valuable insight into the durability, reliability and performance of materials, components and systems subjected to sliding, rolling or frictional contact. The wear rate is affected by several factors such as the type of material in contact, surface roughness, applied load or pressure, sliding or rotational speed, temperature, lubrication, and the presence of contaminants or abrasive particles. Various wear mechanisms can matter material loss, these consist of adhesive wear, abrasive wear, erosive wear, fretting deterioration and fatigue wear. Wear rate is typically quantified by measuring the weight or volume loss of the material or evaluating the dimensional difference of the component all along the wear test. Wear rate is calculated by dividing the amount of material loss by the product of the applied load or pressure and the sliding or rolling distance.

Specific heat (cp (kj/kg. K)): It is thermodynamic property that characterize the total amount of heat energy required to raise the temperature of a unit mass of element by 1 degree Celsius (or 1 Kelvin) under constant pressure setting. It is a fundamental property used to characterize the thermal behaviour of materials and substances. Specific heat is an intrinsic property of a substance and depends on its chemical composition, molecular structure, and phase (solid, liquid, or gas). Different goods have many specific heat values because to different atomic or molecular interactions. Specific heat is commonly conveyed in units of Joules/Kilograms/Celsius (J/kg °C) or Joules/Kilograms/Kelvin (J/kg °K). The specific heat of a substance is determined experimentally through calorimetry or other heat transfer measurement techniques. In calorimetry, a known mass of the substance is subjected to a controlled temperature change, and the heat energy exchanged is measured. The specific heat is calculated by dividing the measured heat energy by the mass of the substance and the change in temperature.

Specific Gravity (Mg/M^ {3}): Specific gravity is a unitless measure that compares the density of a substance to the density of water. It is a fundamental property used to characterize the relative heaviness or lightness of a material or substance. Specific gravity does not have any units and is determined by dividing the substance's density by the density of water. Specific gravity values aid in substance identification, purity assessment, and predicting behavior in various industries and applications. Specific gravity is widely used in various industries and applications. It helps in characterizing and identifying substances, assessing their purity, and predicting their behavior in different environments. Specific gravity values are used in fields such as chemistry, materials science, geology, and engineering. Specific gravity measurements can be performed using various methods, including buoyancy techniques, pycnometers, and hydrometers. It is important to note that specific gravity is influenced by temperature and pressure. Therefore, specific gravity values are often reported at standard conditions, such as room temperature and atmospheric pressure, to ensure consistency and comparability.

4. ALTERNATIVE PARAMETERS

Gray Cast Iron (Gci): They are commonly used material for brake disc operation in the automotive business. GCI has good mechanical and thermal properties, making it suitable for withstanding the high temperatures and frictional forces that appear during braking. Excellent wear resistance, thermal conductivity and damping properties ensure durability, efficient heat dissipation and reduced vibration. In addition, GCI is inexpensive and easy to cast, allowing mass production and complex designs. Its combination of properties makes GCI an ideal choice for brake discs, ensuring reliable and efficient braking performance in vehicles. However, constant advances in materials and braking system technology continue to explore alternative materials for further advancement.

Ti-Alloy (Ti-6al-4v): Ti-6Al-4V which is commonly considered as an alternative material for automotive brake discs and it is also a titanium alloy. Compared to traditional gray cast iron, Ti-6Al-4V offers several advantages such as lightweight construction, superior strength, corrosion resistance, and heat resistance. These properties can contribute to improved vehicle performance, durability, and longevity of the brake discs. However, the higher cost, manufacturing challenges, and potential differences in friction performance compared to gray cast iron need to be carefully evaluated. Further research and development are necessary to fully assess the feasibility and benefits of incorporating Ti-6Al-4V into automotive brake disc materials.

TMC: TMC (Titanium Metal Matrix Composite) is a potential material for automotive brake discs due to its advantageous properties. TMCs offer advantages such as lightweight construction, high strength, thermal stability, wear resistance, and efficient heat dissipation. These properties can contribute to improved vehicle performance, durability, and braking efficiency. However, considerations such as cost, manufacturing complexity, and the need for thorough friction performance evaluation need to be taken into account. Further research and development are necessary to fully understand the feasibility and benefits of utilizing TMCs in automotive brake disc materials.

AMC 1 & AMC 2: Material selection for automotive brake discs is a complex process considering various factors such as thermal conductivity, wear resistance, and thermal expansion. A variety of materials are available and the choice depends on the specific application and performance requirements. Several articles describe in detail how to select a brake disc material, with flow charts showing each step of the selection process. One study also investigated the tribological behavior of various AMC surfaces compared to brake lining materials

5. RESULT AND DISCUSSION

TABLE 1. Automotive brake disc material selection

AUTOMOTIVE BRAKE DISC MATERIAL SELECTION					
Properties Material	Compressive Strength (MPa)	Friction coefficient(µ)	Wear rate (x10^ {-6}mm^ {3} /N/m)	Specific heat, Cp (KJ/Kg. K)	Specific gravity (Mg/m^ {3})
Gray cast iron (GCI)	1293	0.41	2.36	0.46	7.2
Ti-alloy (Ti-6Al-4V)	1070	0.34	246.3	0.58	4.42
TMC	1300	0.31	8.19	0.51	4.68
AMC 1	406	0.35	3.25	0.98	2.7
AMC 2	761	0.44	2.91	0.92	2.8

Table 1 presents the material selection for automotive brake discs using the Analysis method in WSM Alternative. The parameters considered include Compressive Strength (MPa), Friction coefficient (µ), Wear rate (x10^ {-6} mm^ {3} /N/m), Specific heat (Cp (KJ/Kg. K)), and Specific gravity (Mg/m^ {3}). The materials listed in the table include Gray cast iron (GCI), Ti-alloy (Ti-6Al-4V), TMC, AMC 1, and AMC 2.

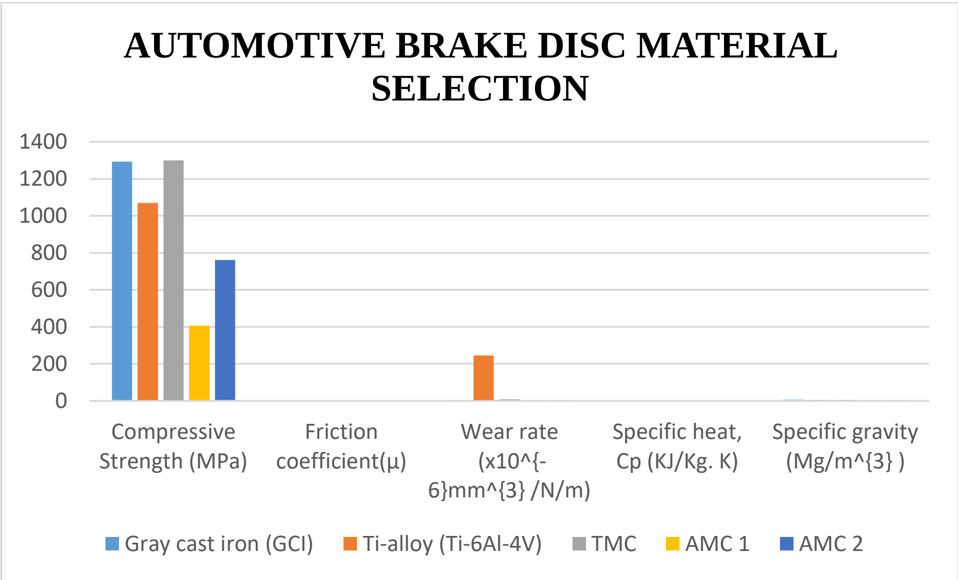

FIGURE 1. Automotive brake disc material selection

Figure 1 Shows that the Gray cast iron is slightest has lesser comparative strength than the TMC. And the lowest of all the material is AMC 1 in comparative strength. And the only disadvantage material for the automotive brake disc is Ti-alloy (Ti-6Al-4V) because of its wear rate is high. And there is no significant change those Friction coefficient, specific heat and specific gravity.

Table 2. Normalized data of Automotive brake disc material selection

NORMALIZED DATA				
0.9946	0.9318	1	0.4693	1
0.8230	0.7727	0.0095	0.5918	0.6138
1	0.7045	0.2881	0.5204	0.6500
0.3123	0.7954	0.7261	1	0.3750
0.5853	1	0.8109	0.9387	0.3888

Table 2 displays the normalized data for the WSM Alternative, representing Compressive Strength (MPa), Friction coefficient (µ), Wear rate (x10^ {-6} mm^ {3} /N/m), Specific heat (Cp (KJ/Kg. K)), and Specific gravity (Mg/m^ {3}). The materials listed in the table include Gray cast iron (GCI), Ti-alloy (Ti-6Al-4V), TMC, AMC 1, and AMC 2.

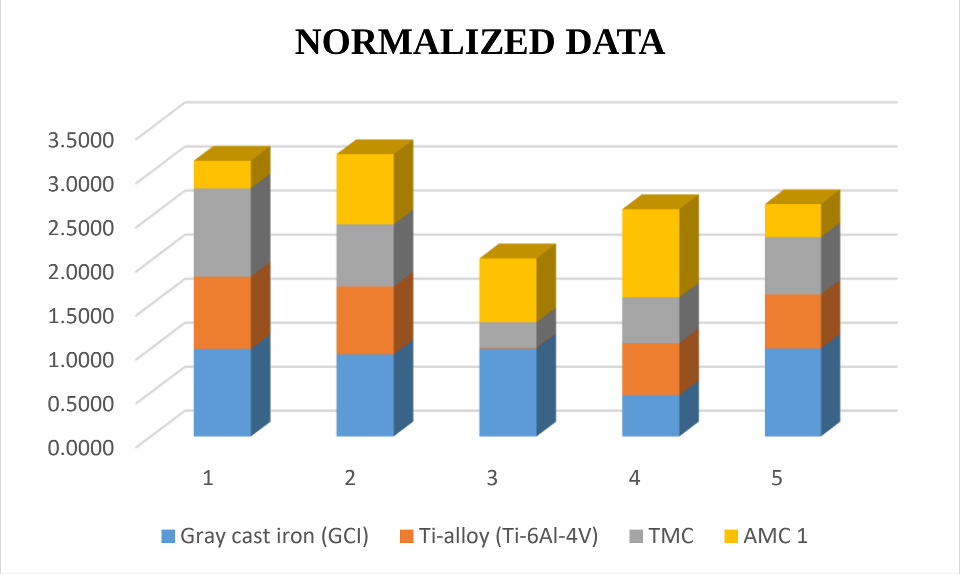

FIGURE 2. Normalized data for Automotive brake disc material selection

Figure 2 shows the Normalized data for WSM Alternative: Compressive Strength (MPa), Friction coefficient (µ), Wear rate (x10^ {-6} mm^ {3} /N/m), Specific heat (Cp (KJ/Kg. K)), Specific gravity (Mg/m^ {3}); Gray cast iron (GCI), Ti-alloy (Ti-6Al-4V), TMC, AMC 1, AMC 2. The Gray Cast Iron is the highest in the material selection.

TABLE 3. Weightages of the materials

WEIGHT				
0.20	0.20	0.20	0.20	0.20
0.20	0.20	0.20	0.20	0.20
0.20	0.20	0.20	0.20	0.20
0.20	0.20	0.20	0.20	0.20
0.20	0.20	0.20	0.20	0.20

Table 3 provides the weights utilized for the analysis, where equal weights are assigned to all parameters.

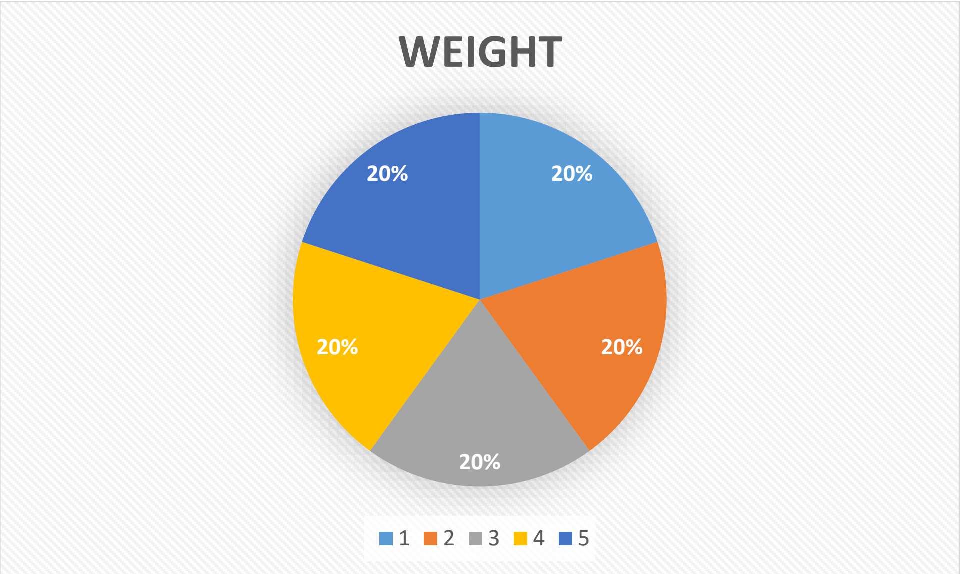

FIGURE 3. Weight data for Automotive brake disc material selection

Figure 3 shows the Weight data for WSM Alternative: Compressive Strength (MPa), Friction coefficient (µ), Wear rate (x10^ {-6} mm^ {3} /N/m), Specific heat (Cp (KJ/Kg. K)), Specific gravity (Mg/m^ {3}); Gray cast iron (GCI), Ti-alloy (Ti-6Al-4V), TMC, AMC 1, AMC 2. The weight is allotted to each of them is same.

TABLE 4. Weighted normalized decision matrix

WEIGHTED NORMALIZED DECISION MATRIX				
0.198923	0.186364	0.2	0.093878	0.2
0.164615	0.154545	0.001916	0.118367	0.122778
0.2	0.140909	0.057631	0.104082	0.13
0.062462	0.159091	0.145231	0.2	0.075
0.117077	0.2	0.162199	0.187755	0.077778

Table 4 illustrates the decision matrix for the alternative, where the normalized values are weighted accordingly. The parameters considered in the matrix include Compressive Strength (MPa), Friction coefficient (μ), Wear rate (x10^ {-6} mm^ {3} /N/m), Specific heat (Cp (KJ/Kg. K)), and Specific gravity (Mg/m^ {3}). The materials listed in the table are Gray cast iron (GCI), Ti-alloy (Ti-6Al-4V), TMC, AMC 1, and AMC 2.

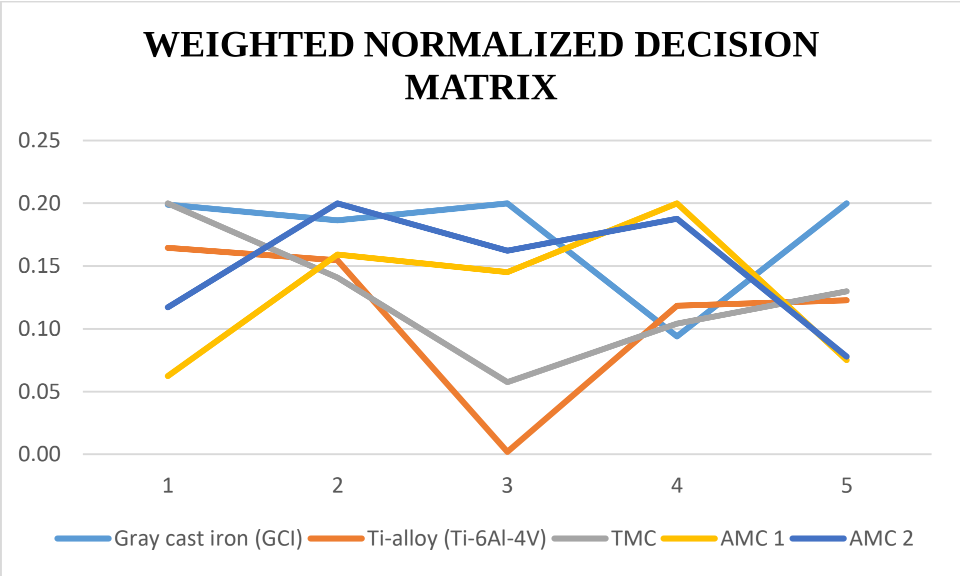

FIGURE 4. Weighted Normalized Decision Matrix for Automotive brake disc material selection

Figure 4 presents the multiple value representation of the Weighted Normalized Decision for the WSM Alternative, considering parameters such as Compressive Strength (MPa), Friction coefficient (μ), Wear rate (x10^ {-6} mm^ {3} /N/m), Specific heat (Cp (KJ/Kg. K)), and Specific gravity (Mg/m^ {3}). The materials included in the figure are Gray cast iron (GCI), Ti-alloy (Ti-6Al-4V), TMC, AMC 1, and AMC 2.

TABLE 5. Preference score & Rank

	PREFERENCE SCORE	**RANK**
Gray cast iron (GCI)	0.879164	1
Ti-alloy (Ti-6Al-4V)	0.562222	5
TMC	0.632622	4
AMC 1	0.641783	3
AMC 2	0.744809	2

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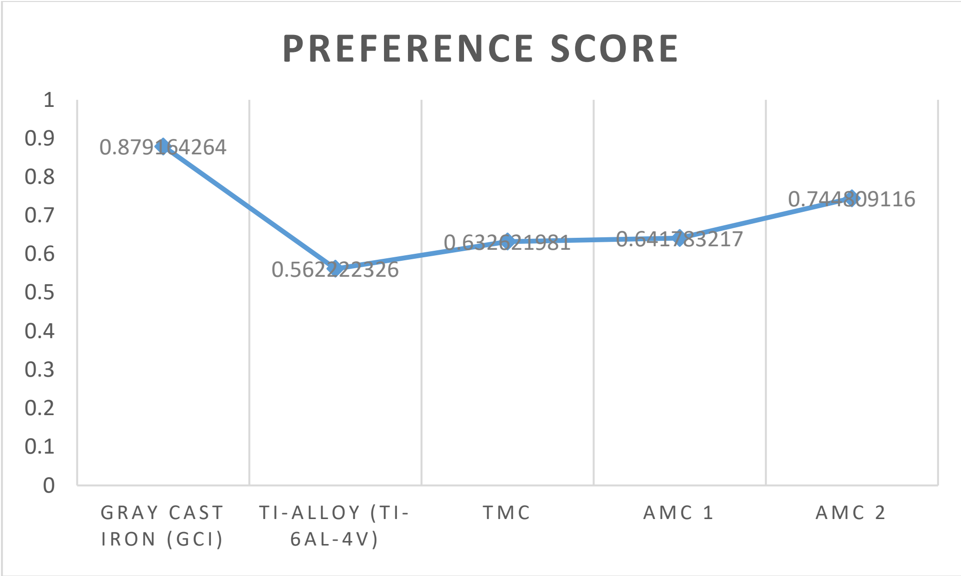

FIGURE 5. Preference Score for Automotive brake disc material selection

Figure 5 illustrates the Preference score for the WSM Alternative, considering parameters such as Compressive Strength (MPa), Friction coefficient (µ), Wear rate (x10^ {-6} mm^ {3} /N/m), Specific heat (Cp (KJ/Kg. K)), and Specific gravity (Mg/m^ {3}). Among the materials listed, Gray Cast Iron emerges as the top-ranked choice, surpassing the others.

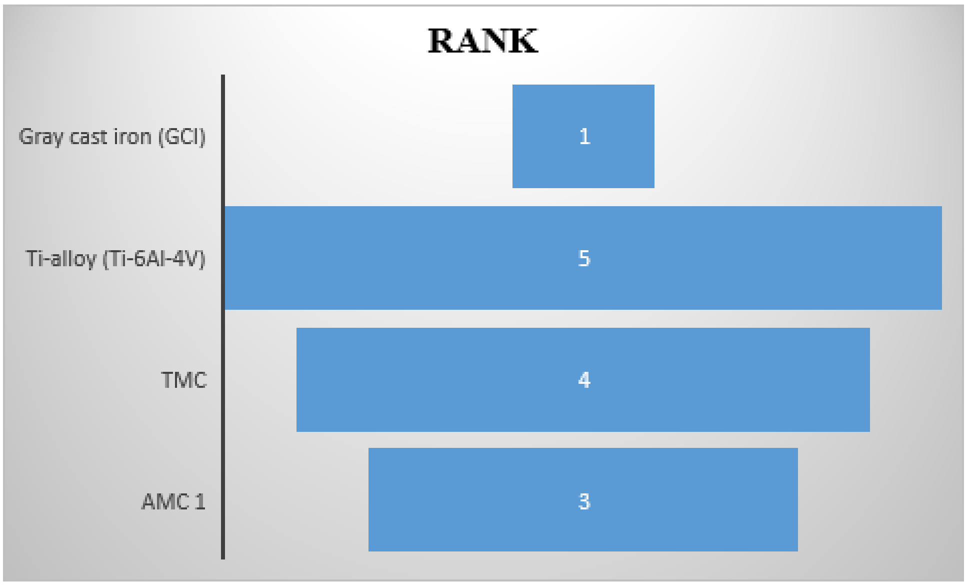

FIGURE 6. Rank for Automotive brake disc material selection

Figure 6 displays the ranking of materials for the Automotive Brake Disc Material Selection in the WSM Alternative based on parameters such as Compressive Strength (MPa), Friction coefficient (µ), Wear rate (x10^ {-6} mm^ {3} /N/m), Specific heat (Cp (KJ/Kg. K)), and Specific gravity (Mg/m^ {3}). Gray Cast Iron occupies the top position, surpassing the other materials in terms of performance and suitability

6. CONCLUSION

Selecting suitable materials for automotive brake discs is an important process in the construction and assembly of braking systems. Brake discs or rotors are important components that convert kinetic energy into thermal energy to enable efficient braking and ensure vehicle and occupant safety. The choice of brake disc material is important to ensure optimum performance, reliability, and durability under various operating conditions. Several important properties such as efficient heat dissipation, high mechanical strength, wear resistance and constant friction properties should be considered when choosing a suitable material for brake discs. The study of material selection for automotive brake discs will show results in the performance, reliability, and safety of braking systems. The aim is to identify suitable materials that improve braking efficiency, durability and thermal stability. Efforts in this area have led to improved braking performance through the development of materials with optimal friction properties**.** Regarding the selection context of automation, the proposed approach uses a weighted summation model that considers expert panel ratings on various factors. The purpose of this model is to cut down the influence of individual decision makers who may have different opinions, thereby rushing the decision-making process. By excluding the highest and lowest weights and subjective factors assigned by experts, a comprehensive technique for robot selection is developed. At Last, the result is obtained.

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