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Optimizing Piston Material Choice in Automotive Engines Using the Weighted Product Method

***Chandrasekar Raja, Anusuya Mohan, M. Ramachandran, Muniyammal Sakthivel**

REST Labs, Kaveripattinam, Krishnagiri, Tamil Nadu, India.

*Corresponding Author Email: chandrasekarsri@gmail.com

Abstract: *The meticulous selection of piston materials for automotive engines involves evaluating various properties and performance criteria. This study aims to assess the suitability of eight potential materials – Aluminum 2618-T6, Aluminum 4032-T6, Aluminum A360.0-F die casting alloy, Aluminum 6061-T6, Grey cast iron, AISI 8660 steel, AISI 4140 steel, and Ductile iron grade 65–45–12 – for piston applications using the Weighted Product Method (WPM), an approach in Multi-Criteria Decision Making (MCDM). The evaluation criteria include Knoop hardness, yield strength, modulus of elasticity, specific heat capacity, machinability, fatigue strength, density, and material cost. The WPM allows for a comprehensive assessment, incorporating normalized values and equal weighting across all criteria.*

The analysis identified AISI 4140 steel as the most suitable option, ranking first with the highest preference score. Following closely behind, AISI 8660 steel emerged as the second-best choice, with Aluminum 2618-T6 and Ductile iron grade 65–45–12 also ranking highly. In contrast, Aluminum 6061-T6, Aluminum 4032-T6, Grey cast iron, and Aluminum A360.0-F die casting alloy occupied lower ranks.

While the Weighted Product Method (WPM) provided a systematic framework for evaluating material alternatives across multiple criteria, practical applications may require adjustments to criterion weightage based on specific requirements. It is essential to consider these findings alongside other relevant factors, such as environmental impact and compatibility with manufacturing processes.

Keywords: *Piston materials, automotive engines, Weighted product method (WPM), Material selection, Performance optimization, Mechanical properties, Thermal properties, Cost-effectiveness and Automotive engineering.*

1. INTRODUCTION

In the automotive sector, piston serves as a vital element within the internal combustion engine, pivotal in converting the chemical energy derived from fuel into mechanical energy. Its fundamental role lies in transferring the force generated by the combustion of the air-fuel mixture to the crankshaft, thereby facilitating the engine's rotational movement. Given the demanding conditions within the engine cylinder, including high temperatures, pressures, and frictional forces, the choice of materials for pistons holds significant importance. Selecting appropriate materials for pistons entails navigating a complex process that hinges on achieving a delicate equilibrium among various properties and performance criteria. The optimal piston material should exhibit a distinct blend of mechanical strength, thermal conductivity, thermal expansion characteristics, wear resistance, and weight efficiency. Failing to meet these criteria can result in severe repercussions such as engine breakdowns, compromised performance, and heightened emissions [1]. One of the primary prerequisites for piston materials is the attainment of remarkable mechanical strength capable of withstanding the immense forces generated throughout the combustion process. The piston is subjected to cyclic loading and unloading, exposing it to substantial levels of stress and fatigue. It is imperative for the material to possess adequate tensile strength, yield strength, and fatigue resistance to forestall deformation, cracking, or failure under these rigorous conditions [2]. Aluminum alloys have conventionally emerged as the preferred material for pistons owing to their advantageous strength-to-weight ratio and commendable thermal conductivity. Among the commonly utilized aluminum alloys for pistons are Al-Si alloys, such as Al-Si-Cu or Al-Si-Mg alloys, renowned for their exceptional castability and mechanical properties. Furthermore, there has been a growing interest in aluminum matrix composites (AMCs) reinforced with ceramic particles or fibers due to their heightened strength and resistance to wear [3]. Maintaining optimal temperature control is vital in piston design, given the significant temperature variations pistons endure in engine operations. The material used for pistons should possess high thermal conductivity to ensure

effective heat transfer from the piston crown to the cooling system. This is essential for avoiding localized overheating and reducing thermal stresses [4]. Furthermore, the thermal expansion properties of the piston material are critical for maintaining the correct clearances between the piston and cylinder wall. Materials with a low coefficient of thermal expansion (CTE) are preferred to minimize the chances of seizure or excessive piston slap, both of which can result in wear and damage [5]. Aluminum alloys, especially those containing silicon as the main alloying element, demonstrate favorable thermal conductivity and relatively low coefficients of thermal expansion (CTEs) [6]. Researchers have also investigated the use of metal matrix composites (MMCs) reinforced with materials such as silicon carbide (SiC) or aluminum oxide (Al₂O₃) to improve thermal conductivity and decrease thermal expansion [7]. Pistons operate in an environment prone to abrasion, experiencing friction and wear from contact with cylinder walls and piston rings. Therefore, the piston material must possess exceptional wear resistance to ensure durability and sustain optimal engine performance over its lifespan. To enhance the wear resistance of piston materials, various surface treatments and coatings have been investigated. For example, plasma-sprayed coatings, including molybdenum (Mo) or chromium (Cr) based coatings, have been utilized to enhance wear resistance and minimize friction [8]. Diamond-like carbon (DLC) coatings have also become popular due to their exceptional hardness, low friction coefficient, and chemical inertness [9]. As the quest for improved fuel efficiency and reduced emissions continues, optimizing the weight of engine components has become crucial. Lighter pistons can contribute to lower reciprocating masses, leading to reduced inertial forces and improved engine dynamics [10]. Therefore, materials with high strength-to-weight ratios are preferred for piston applications. Aluminum alloys, especially those with lithium additions (Al-Li alloys), have been studied for their lightweight properties and high specific strength [11]. Additionally, the advancement of advanced composites, like carbon fiber-reinforced aluminum (Al/C) or titanium matrix composites (TMCs), has created new possibilities for reducing weight while maintaining exceptional mechanical properties [12, 13]. Beyond technical requirements, the manufacturing process and associated costs significantly influence the choice of piston materials. The selected material must be compatible with established manufacturing techniques, such as casting, forging, or powder metallurgy, to ensure cost-effective and large-scale production. Aluminum alloys have been widely adopted in the automotive industry due to their excellent castability and relatively low cost [14]. However, researchers have also explored alternative manufacturing methods, such as metal injection molding (MIM) and additive manufacturing (AM), to create complex piston designs and facilitate the use of advanced materials. Metal injection molding allows for the production of near-net-shape components with intricate designs, reducing material waste and the need for extensive post-processing [15]. Additive manufacturing techniques like selective laser melting (SLM) or direct metal laser sintering (DMLS) enable the creation of customized pistons with optimized geometries and tailored material properties [16]. The choice of piston materials is increasingly influenced by environmental sustainability and strict emissions standards. Materials that improve thermal efficiency, reduce friction, and lower weight can indirectly lead to reduced emissions and improved fuel economy. Recent advances in materials science have focused on incorporating reinforcements or coatings that enhance tribological properties, reducing friction and wear between the piston and cylinder walls [17]. Furthermore, lightweight materials and optimized designs can decrease reciprocating masses, reducing inertial forces and improving engine dynamics, thereby enhancing fuel efficiency. The automotive industry's relentless pursuit of greater efficiency, enhanced performance, and lower emissions will spur further advancements in piston material selection and design. Ongoing research is investigating advanced materials and manufacturing techniques to push the boundaries of piston performance. Emerging technologies like nanocomposites and hybrid materials show promise in improving mechanical strength, thermal conductivity, and wear resistance [18]. Moreover, the incorporation of smart materials or sensor technologies into pistons could enable real-time monitoring and adaptive control systems, optimizing engine performance and reducing emissions [19].

2. MATERIALS AND METHODS

The Weighted Product Method (WPM) is a well-established technique in Multi-Criteria Decision Making (MCDM) used to assist decision-makers in evaluating and ranking alternatives based on multiple criteria. In today's complex decision-making environments, where several factors must be considered simultaneously, MCDM methods are increasingly important. The WPM, in particular, is popular due to its ability to handle non-linear and incomparable criteria, making it applicable to various real-world scenarios [20, 21]. The theoretical basis of the WPM can be traced back to Bridgman's work on dimensionless numbers and their applications across different fields. Building on this concept, Miller and Starr introduced the Weighted Product Model, which later evolved into the WPM for MCDM problems. Since its inception, the WPM has been extensively studied, refined, and applied in diverse fields such as engineering design, supply chain management, environmental management, energy planning, and healthcare [22-24]. The Weighted Product Method (WPM) operates by multiplying the normalized performance ratings of alternatives for each criterion by their respective weights. This ensures that the relative importance of each criterion is appropriately considered in the overall evaluation process. The methodology involves creating a decision matrix, determining weight vectors, normalizing the decision matrix, calculating preference values for each alternative, and finally ranking the alternatives based on their preference values [25, 26]. One of the primary advantages of the WPM is its ability to

handle non-linear and incomparable criteria, making it valuable in complex decision-making situations. Furthermore, the WPM incorporates the relative importance of criteria through weight assignments, allowing decision-makers to prioritize specific factors based on their preferences or expertise. The method is also relatively straightforward to understand and apply, making it accessible to decision-makers from various backgrounds [27, 28]. The Weighted Product Method's versatility has made it applicable to a broad array of decision-making challenges in fields like engineering design, supply chain management, environmental management, energy planning, and healthcare. Moreover, the WPM enables sensitivity analysis, allowing decision-makers to assess how changes in criterion weights affect the ranking of alternatives [29, 30]. Despite its usefulness, the Weighted Product Method has limitations and areas for improvement. These include its compensatory nature, the subjective nature of weight assignment, and the potential for rank reversal. To address these shortcomings, researchers have explored extensions and modifications to the WPM, such as incorporating fuzzy logic, combining it with other MCDM methods, and developing hybrid approaches. When considering materials for pistons, eight potential alternatives emerge: Aluminum 2618-T61, Aluminum 4032-T6, Aluminum A360.0-F die casting alloy, Aluminum 6061-T6, Grey cast iron, AISI 8660 steel, AISI 4140 steel, and Ductile iron grade 65–45-12. Each of these materials offers unique properties that could impact piston performance and efficiency. To assess their suitability, several evaluation parameters have been identified: Knoop hardness in HK, Yield strength in MPa, Modulus of elasticity in GPa, Specific heat capacity in J/g-°C, Machinability, Fatigue strength in MPa, Density in g/cc, and Material cost in USD/kg. Firstly, Knoop hardness is crucial as it measures a material's resistance to indentation, which is essential for withstanding wear and deformation in high-pressure environments like engine cylinders. Aluminum 2618-T61 and AISI 4140 steel are known for their high hardness values, making them promising candidates. Secondly, yield strength indicates a material's ability to resist deformation under load, crucial for pistons enduring significant mechanical stress. Materials like AISI 4140 steel and ductile iron grade 65–45-12 offer impressive yield strength, suitable for high-performance applications. Thirdly, the modulus of elasticity measures a material's stiffness, influencing its ability to maintain shape under load. Aluminum 6061-T6 and AISI 4140 steel typically exhibit higher modulus values, desirable for applications demanding rigidity. Fourthly, specific heat capacity is vital for evaluating a material's thermal properties, crucial for pistons in high-temperature environments. Aluminum alloys like 2618-T61 and 6061-T6 generally possess favorable heat capacities. Fifthly, machinability is essential for assessing how easily a material can be shaped and formed during manufacturing. Aluminum alloys such as A360.0-F and 6061-T6 are known for their excellent machinability. Sixthly, fatigue strength measures a material's ability to withstand repeated loading cycles without failure, critical for pistons subjected to constant forces. AISI 8660 steel and Ductile iron grade 65–45-12 exhibit high fatigue strength, suitable for endurance applications. Seventhly, density is important for evaluating the weight-to-strength ratio of materials. Aluminum alloys like 2618-T61 and 6061-T6 typically have lower densities compared to steel or iron, favorable for lightweight pistons. Lastly, material cost is a practical consideration, especially for mass production applications. Aluminum alloys such as 4032-T6 and A360.0-F tend to be more economical compared to specialty steels or iron alloys. The selection of piston materials involves a comprehensive assessment of various factors, including mechanical properties, thermal characteristics, manufacturing considerations, and cost implications. By evaluating these eight candidate materials based on parameters such as hardness, yield strength, modulus of elasticity, specific heat capacity, machinability, fatigue strength, density, and material cost, engineers can make informed decisions to optimize piston performance and efficiency in diverse applications.

3. RESULT AND DISCUSSION

TABLE 1. Material Choice in Automotive Engines

Materials	MC1	MC2	MC3	MC4	MC5	MC6	MC7	MC8
M1	144	372	74.5	0.875	9	90	2.76	2.072
M2	150	317	78.6	0.85	7	110	2.68	2.128
M3	97	165	71	0.963	5	150	2.68	1.064
M4	120	276	68.9	0.896	9	95	2.7	1.904
M5	271	310	200	0.49	3	119	7.15	1.428
M6	220	1551	205	0.475	5	335	7.85	0.854
M7	369	1050	205	0.561	5	590	7.85	0.532
M8	195	310	168	0.49	5	193	7.15	1.54

Aluminum 2618-T61 (M1), Aluminum 4032-T6 (M2), Aluminum A360.0-F die casting alloy (M3), Aluminum 6061-T6 (M4), Grey cast iron (M5), AISI 8660 steel (M6), AISI 4140 steel (M7), and Ductile iron grade 65–45-12 (M8). Knoop hardness (MC1) in HK, Yield strength (MC2) in MPa, Modulus of elasticity (MC3) in GPa, Specific heat capacity (MC4) in J/g-°C, Machinability (MC5), Fatigue strength (MC6) in MPa, Density (MC7) in g/cc, and Material cost (MC8) in USD/kg. Table 1 presents a comparative examination of eight materials under consideration for piston applications, each assessed across various criteria. Knoop hardness, serving as an indicator of resistance to indentation, spans from 97 (for Aluminum A360.0-F die casting alloy) to 369 (for AISI 4140 steel), showcasing the wide range of hardness levels among the materials. Yield strength, crucial for enduring deformation, demonstrates significant diversity, ranging from 155 MPa (for AISI 8660 steel) to 1551 MPa (for AISI 4140 steel), highlighting the disparity in

mechanical properties across the materials. The modulus of elasticity, representing stiffness, varies from 68.9 GPA (for Aluminum 6061-T6) to 205 GPA (for Grey cast iron and both steel variants), indicating varied levels of material rigidity. Specific heat capacity, essential for managing thermal properties, varies from 0.475 J/g-°C (for AISI 8660 steel) to 0.963 J/g-°C (for Aluminum A360.0-F die casting alloy). Machinability, crucial for manufacturing efficiency, demonstrates discrepancies, with Aluminum A360.0-F die casting alloy scoring the lowest value (5) and Aluminum 2618-T61 and 6061-T6 scoring the highest (9). Fatigue strength, crucial for enduring cyclic loading, exhibits significant divergence, with AISI 4140 steel registering the highest value at 590 MPa and Aluminum A360.0-F die casting alloy at 150 MPa. Density, impacting weight-to-strength ratio, ranges from 2.68 g/cc (for Aluminum A360.0-F die casting alloy) to 7.85 g/cc (for both steel variants). Material cost per kilogram also varies notably, with Aluminum A360.0-F die casting alloy emerging as the most economical and AISI 4140 steel as the costliest option. These multifaceted attributes highlight the intricate process of material selection for optimizing piston performance.

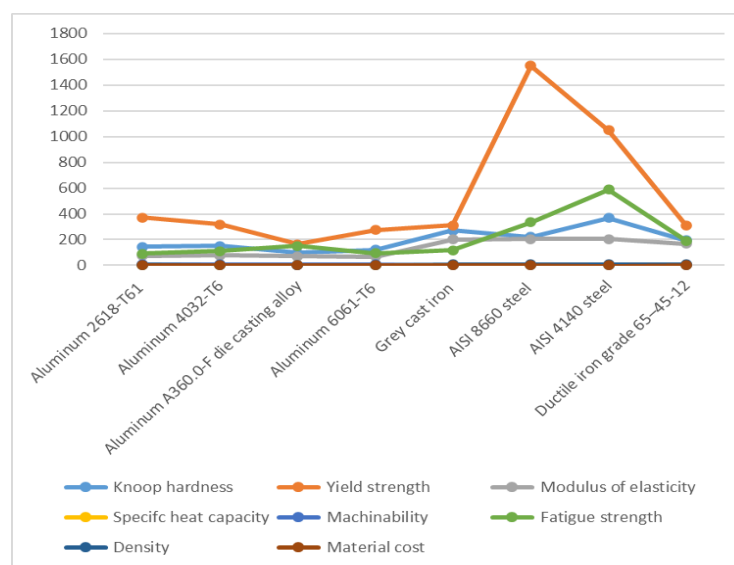


FIGURE 2. Material Choice in Automotive Engines

Figure 1 illustrates a comparative assessment of eight materials being considered for piston applications, each evaluated across various parameters. The Knoop hardness values range from 97 (Aluminum A360.0-F die casting alloy) to 369 (AISI 4140 steel), showcasing the diversity in hardness among the materials. Yield strength exhibits significant diversity, varying from 155 MPa (AISI 8660 steel) to 1551 MPa (AISI 4140 steel), highlighting the differences in mechanical properties across the materials. Modulus of elasticity ranges from 68.9 GPA (Aluminum 6061-T6) to 205 GPA (Grey cast iron and both steel variants), indicating varied levels of material stiffness. Specific heat capacity varies from 0.475 J/g-°C (AISI 8660 steel) to 0.963 J/g-°C (Aluminum A360.0-F die casting alloy). Machinability varies, with Aluminum A360.0-F die casting alloy scoring the lowest (5) and Aluminum 2618-T61 and 6061-T6 scoring the highest (9). Fatigue strength diverges significantly, with AISI 4140 steel leading at 590 MPa and Aluminum A360.0-F die casting alloy at 150 MPa. Density ranges from 2.68 g/cc (Aluminum A360.0-F die casting alloy) to 7.85 g/cc (both steel variants). Material cost per kilogram varies notably, with Aluminum A360.0-F die casting alloy being the most cost-effective and AISI 4140 steel being the priciest. These diverse attributes underscore the complexity of material selection for optimizing piston performance.

TABLE 2.

0.3902	1.0081	0.2019	0.0024	0	0.1525	0.971	0.2568
0.4065	0.8591	0.213	0.0023	0	0.1864	1	0.25
0.2629	0.4472	0.1924	0.0026	0	0.2542	1	0.5
0.3252	0.748	0.1867	0.0024	0	0.161	0.9926	0.2794
0.7344	0.8401	0.542	0.0013	0	0.2017	0.3748	0.3725
0.5962	4.2033	0.5556	0.0013	0	0.5678	0.3414	0.623
1	2.8455	0.5556	0.0015	0	1	0.3414	1
0.5285	0.8401	0.4553	0.0013	0	0.3271	0.3748	0.3455

Table 2 showcases normalized data utilizing the Weighted Product Method, facilitating a comprehensive comparison among the eight materials across multiple parameters. Each material's performance is adjusted relative to its counterparts, offering insights into their respective strengths. Aluminum 2618-T61, Aluminum 4032-T6, Aluminum A360.0-F die casting alloy, and Aluminum 6061-T6 are represented by normalized values reflecting their attributes in terms of hardness, yield strength, modulus of elasticity, specific heat capacity, machinability, fatigue strength, density, and material cost. Grey cast iron exhibits notably high normalized values for Knoop hardness, yield strength, and modulus of elasticity, underscoring its robustness and stiffness. Conversely, AISI 8660 steel and AISI 4140 steel are notable for their exceptionally high yield strengths, though this advantage comes with elevated material costs.

TABLE 3.

0.125	0.125	0.125	0.125	0.125	0.125	0.125	0.125
0.125	0.125	0.125	0.125	0.125	0.125	0.125	0.125
0.125	0.125	0.125	0.125	0.125	0.125	0.125	0.125
0.125	0.125	0.125	0.125	0.125	0.125	0.125	0.125
0.125	0.125	0.125	0.125	0.125	0.125	0.125	0.125
0.125	0.125	0.125	0.125	0.125	0.125	0.125	0.125
0.125	0.125	0.125	0.125	0.125	0.125	0.125	0.125
0.125	0.125	0.125	0.125	0.125	0.125	0.125	0.125

Table 3 demonstrates the even distribution of importance among the eight materials across various criteria. Each material is allotted an equal weight (12.5%) for Knoop hardness, yield strength, modulus of elasticity, specific heat capacity, machinability, fatigue strength, density, and material cost, ensuring a balanced assessment of all aspects. This uniform allocation implies an approach where no single factor is favored over others, aiming for a holistic evaluation of the materials. Whether it's the strong attributes of steel alloys like AISI 8660 and AISI 4140, the lightweight nature of aluminum alloys such as 2618-T61 and 6061-T6, or the durability of grey cast iron and ductile iron grade 65–45–12, each material is given equal consideration across the range of parameters.

TABLE 4.

0.889	1.001	0.8187	0.4698	1	0.7905	0.9963	0.8437
0.8936	0.9812	0.8242	0.4681	1	0.8106	1	0.8409
0.8462	0.9043	0.8138	0.4754	1	0.8427	1	0.917
0.869	0.9644	0.8108	0.4712	1	0.7959	0.9991	0.8527
0.9622	0.9785	0.9263	0.4369	1	0.8186	0.8846	0.8839
0.9374	1.1966	0.9292	0.4352	1	0.9317	0.8743	0.9426
1	1.1396	0.9292	0.4444	1	1	0.8743	1
0.9234	0.9785	0.9063	0.4369	1	0.8696	0.8846	0.8756

Table 4 showcases a weighted normalized matrix generated through the weighted product method, facilitating a thorough comparison of the eight materials across multiple parameters. Each material's performance is adjusted relative to its significance in Knoop hardness, yield strength, modulus of elasticity, specific heat capacity, machinability, fatigue strength, density, and material cost. The resulting weighted normalized values elucidate the materials' characteristics concerning the specified criteria. For example, Grey cast iron demonstrates notable excellence in Knoop hardness, yield strength, and modulus of elasticity, underscoring its durability and rigidity. Conversely, AISI 4140 steel displays outstanding performance in yield strength and fatigue strength, albeit with a higher associated material cost.

TABLE 5.

Materials	Preference score
Aluminum 2618-T61	0.14298
Aluminum 4032-T6	0.14046
Aluminum A360.0-F die casting alloy	0.13363
Aluminum 6061-T6	0.13644
Grey cast iron	0.13363
AISI 8660 steel	0.20342
AISI 4140 steel	0.2403
Ductile iron grade 65–45–12	0.14075

Table 5 presents preference scores derived from the weighted product method for the eight materials under consideration for piston applications, providing insights into their overall suitability. In the realm of aluminum alloys, Aluminum 2618-T61 and Aluminum 4032-T6 exhibit preference scores of 0.14298 and 0.14046, respectively, indicating their relatively high desirability. Aluminum 6061-T6 closely follows with a score of 0.13644. Similarly,

Grey cast iron and Aluminum A360.0-F die casting alloy share a preference score of 0.13363. AISI 8660 steel stands out with a notably higher preference score of 0.20342, suggesting its strong candidacy for piston materials. Meanwhile, AISI 4140 steel outperforms others with a preference score of 0.2403, highlighting its exceptional suitability despite a higher material cost. Ductile iron grade 65–45-12 demonstrates moderate desirability with a preference score of 0.14075 compared to other materials.

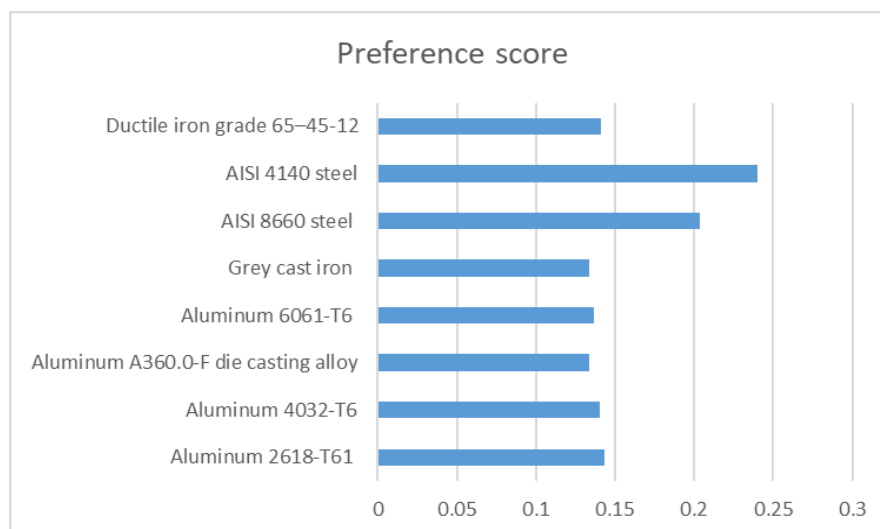


FIGURE 2.

Figure 2 illustrates preference scores derived from the weighted product method for the eight materials under assessment for piston applications, providing insights into their overall suitability. In the aluminum alloy category, Aluminum 2618-T61 and Aluminum 4032-T6 exhibit relatively high preference scores, closely followed by Aluminum 6061-T6. Similarly, Grey cast iron and Aluminum A360.0-F die casting alloy display comparable preference scores. AISI 8660 steel emerges with notably higher preference score, indicating its promising potential for piston materials. Conversely, AISI 4140 steel stands out with the highest preference score, highlighting its exceptional suitability despite a higher material cost. Ductile iron grade 65–45-12 demonstrates moderate desirability compared to other materials.

TABLE 6. Rank

Materials	Rank
Aluminum 2618-T61	3
Aluminum 4032-T6	5
Aluminum A360.0-F die casting alloy	8
Aluminum 6061-T6	6
Grey cast iron	7
AISI 8660 steel	2
AISI 4140 steel	1
Ductile iron grade 65–45-12	4

Table 6 illustrates the rankings assigned to the eight materials using the weighted product method, offering a clear insight into their comparative standings for piston applications. AISI 4140 steel claims the top spot with a rank of 1, indicating its superior suitability among the materials assessed. This ranking underscores the material's outstanding performance across various parameters, despite potentially higher costs. Following closely behind is AISI 8660 steel, securing the second rank. Although not surpassing AISI 4140 steel, AISI 8660 steel demonstrates significant potential for piston materials, earning a commendable position in the ranking. Aluminum 2618-T61, Ductile iron grade 65–45-12, and Aluminum 6061-T6 occupy ranks 3, 4, and 6, respectively. These materials exhibit diverse levels of suitability, with Aluminum 2618-T61 and Ductile iron grade 65–45-12 positioned in the mid-range of the ranking. Aluminum 4032-T6 and Ductile iron grade 65–45-12 attain ranks 5 and 8, respectively, indicating a lower level of suitability compared to higher-ranked materials. Meanwhile, Grey cast iron secures the seventh rank, placing it toward the lower end of the ranking. Aluminum A360.0-F die casting alloy holds the last position with a rank of 8, suggesting relatively limited suitability for piston applications compared to other materials in the assessment.

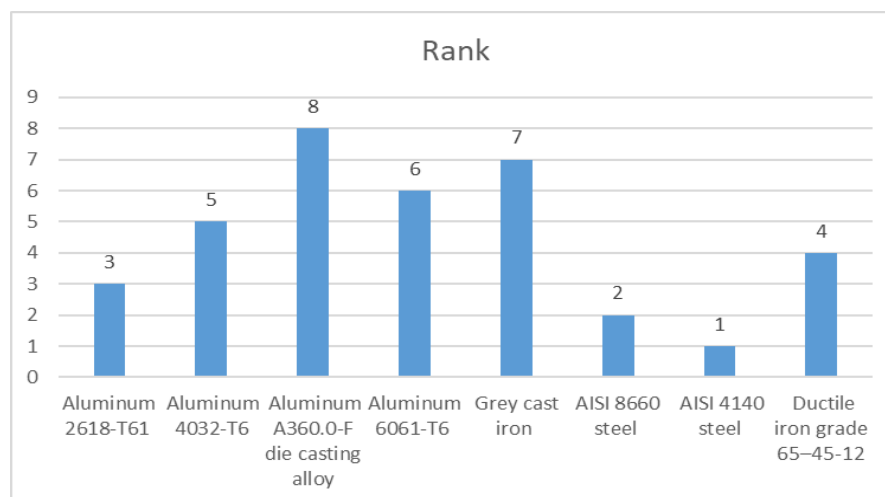


FIGURE 3. Rank

Figure 3 illustrates the hierarchical order assigned to the eight materials through the weighted product method, providing a comprehensive view of their relative standings for piston applications. AISI 4140 steel earns the highest position, ranking first among the materials evaluated. This rank highlights its exceptional suitability across various parameters, despite the possibility of higher associated costs. Close behind is AISI 8660 steel, securing the second rank. While not surpassing AISI 4140 steel, it demonstrates notable potential for piston materials, securing a commendable position in the ranking. Aluminum 2618-T61, Ductile iron grade 65–45-12, and Aluminum 6061-T6 claim the third, fourth, and sixth ranks, respectively. These materials showcase varying degrees of suitability, with Aluminum 2618-T61 and Ductile iron grade 65–45-12 positioned in the middle tier. Aluminum 4032-T6 and Ductile iron grade 65–45-12 rank fifth and eighth, respectively, indicating a lower level of suitability compared to higher-ranked materials. Meanwhile, Grey cast iron secures the seventh rank, positioning it toward the lower end of the hierarchy. Occupying the bottom spot is Aluminum A360.0-F die casting alloy, ranked eighth. This placement suggests its relatively limited suitability for piston applications compared to other materials in the evaluation. These rankings provide valuable direction in material selection, aiding in the identification of materials offering the most advantageous combination of properties for piston applications based on a comprehensive assessment of essential factors.

4. CONCLUSION

Selecting the right materials for automotive engine pistons is a crucial process that requires a thorough assessment of factors like mechanical strength, thermal properties, wear resistance, weight optimization, manufacturing considerations, and cost. The Weighted Product Method (WPM) is an effective tool for this, allowing a detailed evaluation of different materials based on various criteria. This study used the WPM to assess eight materials for piston use: Aluminum 2618-T61, Aluminum 4032-T6, Aluminum A360.0-F die casting alloy, Aluminum 6061-T6, Grey cast iron, AISI 8660 steel, AISI 4140 steel, and Ductile iron grade 65–45-12. The analysis found that AISI 4140 steel is the most suitable choice, performing exceptionally well across multiple parameters, despite potentially higher costs. AISI 8660 steel has shown promise, securing the second rank in the overall evaluation. The aluminum alloys, particularly Aluminum 2618-T61 and Aluminum 6061-T6, have demonstrated commendable suitability, holding mid-range positions in the ranking. Ductile iron grade 65–45-12 has also shown moderate desirability, while materials like Aluminum A360.0-F die casting alloy and Grey cast iron have been ranked lower in overall suitability. It's important to note that the WPM analysis has assigned equal weightage to all criteria, providing a balanced assessment of the materials. However, in practical applications, the relative importance of specific criteria may vary based on the specific requirements and constraints of the intended application. Therefore, decision-makers should carefully evaluate the weightage assigned to each criterion and conduct sensitivity analyses to ensure the robustness of the rankings. Additionally, it is important to consider the findings of this study alongside other pertinent factors, such as environmental impact, availability, and compatibility with existing manufacturing processes. Continuous research and development in materials science and engineering may introduce new advancements or alternative materials that could potentially surpass the options assessed in this study. The use of the Weighted Product Method has established a systematic and comprehensive framework for assessing the suitability of various materials for piston applications in automotive engines. The insights derived from this analysis can serve as a valuable foundation for further exploration, prototyping, and ultimately, informed decision-making to enhance piston performance and efficiency in the constantly evolving automotive sector.

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