Journal on Materials and its Characterization
Vol: 3(3), September 2024
REST Publisher; ISSN No: 2583-6412
Website: https://restpublisher.com/journals/jmc/
DOI: https://doi.org/10.46632/jmc/3/3/4

Advancements and Applications of Plastics: A Comprehensive Review

***A. Prasanna, T. Selvaraju, P. Harish**

Jamal Mohamed College (Autonomous), Tiruchirappalli, Tamil Nadu, India.

*Corresponding Author Email: ap@jmc.edu

Abstract: *A family of thermoplastic materials known as plastics has remarkable mechanical, thermal, electrical, and chemical qualities that make them ideal for a variety of industrial uses. Plastics, as opposed to commodity plastics, are made to be more resilient to environmental elements including moisture, chemicals, and UV light. They also have more strength and stiffness. A few common examples include acrylonitrile butadiene styrene (ABS), polyethylene terephthalate (PET), polyamide (nylon), polycarbonate (PC), polyethylene (PE), and polypropylene (PP). The automotive, aerospace, electrical and electronic, construction and consumer goods sectors all make substantial use of these materials because of their adaptability, durability, and capacity for precision engineering to suit certain performance needs. Technological developments in plastics have transformed a number of sectors by providing improved functionality, robustness, and adaptability. Recent years have seen major advancements in these materials, opening up new possibilities in a variety of industries. The creation of innovative polymer blends, nanocomposites, and additive manufacturing techniques which enable customized characteristics to fulfill particular application requirements are important breakthroughs. Because of their high strength-to-weight ratio, corrosion resistance, and lightweight nature, plastics are gradually taking the place of conventional materials like metals in the automotive and aerospace sectors. Furthermore, developments in thermoplastic composites provide enhanced thermal stability and impact resistance, which makes them perfect for interior parts and structural components Because of their superior electrical insulating qualities, flame retardancy, and tolerance to high temperatures, engineering polymers like polycarbonate and polyphenylene sulfide (PPS) are frequently used in electronics and electrical engineering. These materials maintain safety and dependability while helping to reduce the size and improve the performance of electrical equipment. Furthermore, because of their chemical resistance, sterilizability, and biocompatibility; plastics are used in the medical industry to make surgical tools, implants, and housings for medical devices. Plastics are essential for constructing complicated shapes with great accuracy and strength in additive manufacturing (3D printing). The spectrum of printable polymers has increased due to developments in material compositions and printing technology, allowing for quick prototyping and customized manufacture of end-use parts.*

Keywords: *Engineering plastics, Polymer materials, Thermal stability, Mechanical strength, Grey Relational Analysis, Sustainable polymers.*

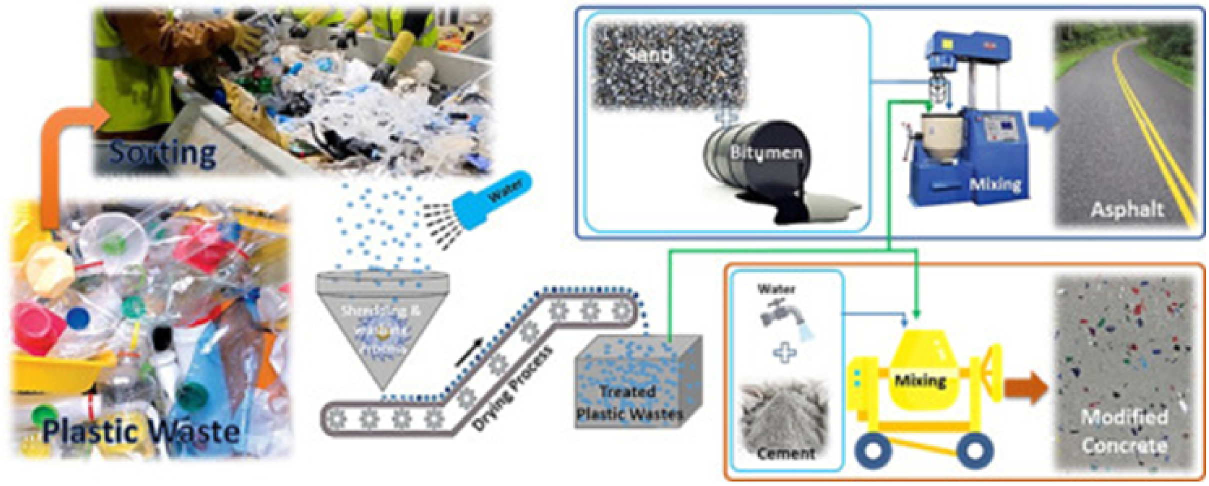
1. INTRODUCTION

A class of solid, nonmetallic materials known as plastics is made up of materials “with physical characteristics that allow them to function for extended periods of time in structural applications, over a wide temperature range, under mechanical stress, and in challenging chemical and physical environments.” Plastics are widely used in many different types of products. Engineering polymers (EPs) include poly (ethylene terephthalate) (PET), polycarbonate (PC), polyamide (PA), and poly (phenylene oxide) (PPO). These polymers are used extensively in a variety of industries, including communications, electronics, automotive, precision instruments, and electronics. Every resin has unique uses and exceptional qualities of its ownPlastic-made machine components are frequently employed in systems that lack strong compulsions and high powers because of the aforementioned drawbacks. Currently, plastic materials are used in the manufacturing of gears, journal bearings, rolling bearing cages, machine tool slide coatings, and related machine parts.

Plastics are used in the production of certain machine parts. The much increased solubility in organic solvents suggests that the network polymer-typical gel structure is absent. Oxyalkylation did not appear to result in any molecular disintegration. The derivatives have dispersity factors ranging from 2.5 to 25 and molecular weights (Mu) between 2000 and 50,000. It appears that the derivatives are helpful prepolymers for thermosetting engineering polymers. These two polymers are particularly intriguing for combining with the more costly high performance

plastics due to their comparatively cheap cost. Both substances are available alone or together in a variety of commercial mixes that are utilized in electrical and electronic devices.The network design of thermosetting polymers determine their characteristics. Comprehending the links between structure and property is crucial for designing practical macromolecular materials. The distributions of molecular orientation and anisotropy in articles injection-molded from various plastics have been reported. “The grafting of thermoplastic chains onto rubbery particles in rubber-modified elastomers is an example of structural modifications for the purpose of improving polymer performance, and this has proven effective for imparting energy-dissipative properties thereby reducing brittleness.” Takeshima and Funakoshi have investigated the polycarbonate orientation distributions, whereas C. Hsiung et al. have looked at orientation distributions in articles made of injection-molded poly (ether ether ketone). Technological developments in material science, polymer chemistry, and production have propelled recent advances in plastics. The creation of novel polymer blends and composites, which provide better mechanical qualities, increased thermal stability, and increased resistance to environmental influences, is one of the major advancements. Furthermore, the production of nanocomposites with customized qualities, such improved strength, stiffness, and barrier qualities, has been made possible by the advent of nanotechnology. In addition, the production of plastics has been completely transformed by additive manufacturing processes like 3D printing, which enable the quick prototyping and customisation of components with intricate geometries. These additive manufacturing techniques shorten new product launch times and provide more design freedom. Plastics have become widely used in many sectors due to their performance and adaptability. Because of their lightweight nature, fuel economy, and flexibility in design, plastics are gradually taking the place of conventional materials like metals in the car industry. They are utilized in a number of automobile parts, such as under-the-hood applications, external body panels, and interior trim. Plastics are essential to the aerospace industry because they let airplanes fly lighter and more fuel-efficiently. These materials have great strength-to-weight ratios and tolerance to extreme climatic conditions, which make them useful for structural components, cabin interiors, and engine components. Furthermore, plastics are widely used in electrical and electronic engineering to produce parts such electronic device housings, insulators, and connections. They are essential in this industry because of their superior flame retardancy, tolerance to high temperatures, and electrical insulation qualities. Because plastics are biocompatible, sterilisable, and resistant to chemicals, they are utilized in the medical industry to make implants, equipment housings, and medical devices. They provide dependability and safety while facilitating the creation of cutting-edge medical technology. For the creation of molded microstructures, the prediction of the dimensional resolution, which is dependent on viscosity, shrinkage, and crystallization of plastics, is crucial. Because of their inadequate stability, conventional test structures like as “flow spirals” cannot be employed in microscale molding. Polycarbonate (PC) is an amorphous material that is transparent. Benzene and oxygen are added to a polymer’s lengthy carbon chain. This material cannot be used to prevent wear. Compact discs (CDs) and car door knobs are common places to find PC.

Low-Tg polymers were the subject of the majority of foaming experiments and applications involving supercritical CO2. Engineers frequently attempt to alter high-Tg polymers by mixing them with other polymers in an attempt to reduce the Tg. PC and PET are highly crystalline polymers with high Tg, hence they are seldom foamed by the pressure-induced process due to the glass transition or unavoidable crystallization that occurs during the foaming process. These plastics are particularly useful in a variety of automotive, electronics, and packaging applications because of their relatively high glass transition temperature (Tg) and high melting temperature (Tm), which enable them to maintain their strength and form at high temperatures. The main qualities of structural plastics that have contributed to their success in the plastics industry are their excellent impact performance and high stiffness throughout a broad temperature range. Supporting the above assumptions and adding to our understanding of POM and PEEK roll behavior under contact load are the goals of this investigation. The component tests were performed again with identical conditions on the rolls from previous studies in order to achieve this goal. Additionally, throughout the testing, more pictures of the rolls’ front faces were obtained.. Lignin has demonstrated great potential when included into thermosetting resin compositions. Star-like molecular structures may be created by reacting with flexible polymeric segments. These structures can then be functionalized and crosslinked to produce materials with a variety of mechanical and viscoelastic characteristics. Plastic recycling is one of the



most talked-about issues in the world today due to the massive build-up of plastic garbage and the depletion of non-renewable resources. Around 400 million tons of plastic are produced worldwide currently, and more are anticipated in the coming years. New flame retardants are being developed for more ecologically friendly applications as an additional upgrade to meet market demand. To meet the strict flame retardancy regulations, these flame retardants are typically loaded into plastic compositions at a rate of lo-20 . These polymers are sometimes categorized as plastics because of their high glass transition temperatures, which exceed 100°C. The researched polymers' varying viscoelastic characteristics are revealed by the separation of the R and G components using the modified SOR.

2. MATERIALS AND METHOD

2.1 Parameters:

Polyamide, additionally referred to as nylon, is a kind of plastic that is distinguished by its exceptional mechanical strength and mild heat stability. The versatility of it could be used to a wide range of products, including as consumer items, insulators for electricity, and automotive components. Another popular material that stands out is polycarbonate (PC), which has a moderate mechanical strength and good heat stability. This makes it the material of choice for applications which includes safety equipment, electronics housings, and automobile glazing that call for both thermal resistance and durability Despite having comparatively lower mechanical strength and thermal stability, polyethylene (PE) is widely used in insulation, pipe systems, and packaging because of its flexibility and inexpensive cost. In the meanwhile, Polypropylene (PP) is appropriate for a variety of applications, including packaging, automotive components, and medical equipment, as it finds a balance between mechanical strength and cost-effectiveness. Lastly, Acrylonitrile Butadiene Styrene (ABS) is a popular material for home appliances, automobile interiors, and consumer electronics due to its exceptional mechanical strength and mild temperature stability. These plastics all have different qualities and benefits that enable them to meet a variety of commercial and industrial demands. A number of important considerations are involved in the evaluation of plastics: cost and environmental effect are non-benefit criteria; benefit criteria include mechanical strength and thermal stability. A material's mechanical strength is a crucial factor in determining its structural integrity and load-bearing capability, which in turn affects how suitable the material is for a given application. Similar to this, thermal stability is essential for maintaining the material's performance and dimensional stability over time, especially in areas with high temperatures or variable thermal conditions. On the other hand, cost and environmental effect are non-benefit factors that need to be carefully taken into account. Cost influences whether a material is economically feasible to use, but environmental effect includes things like emissions during manufacture and disposal, biodegradability, and recycling potential. To choose the best plastics for a particular application and ensure peak performance while lowering costs and environmental impact, it is crucial to strike a balance between these criteria.

2.2 Gray Relational Analysis (GRA):

A strong mathematical technique for determining the degree of linkage or correlation between several data sets is gray relational analysis, or GRA. GRA was created in the 1980s by Deng Julong and was based on the Gray System Theory, which addresses systems with imperfect and ambiguous information. Since then, GRA has been widely used in a number of disciplines, including environmental science, engineering, management, and economics.Fundamentally, GRA measures the degree of similarity or closeness between several variables or factors in order to quantify the links between them. Because GRA functions on a relative scale as opposed to standard statistical approaches, which rely on precise numerical values, it is especially helpful when working with data that may be confusing, inaccurate, or susceptible to uncertainties.

1. Gray Relational Coefficient: This coefficient measures how closely two sets of data are correlated or comparable.

A dimensionless measure of similarity is obtained by normalizing the disparities between matching data points, which form the basis of the calculation.

2. The Gray Relational Grade is an all-inclusive index that shows how closely related various collections of data are to one another overall. It offers a way to rank or prioritize various aspects according to their relative effect or relevance and is developed from the Gray Relational Coefficients.

3. Data are usually arranged in GRA into reference series, which indicate ideal or intended values, and comparison series, which represent actual or observed values. GRA allows for the evaluation of system performance or optimization by detecting deviations or inconsistencies between the comparison and reference series.

Gray Relational Analysis has diverse applications across various disciplines

1. Engineering: GRA is used in engineering design, optimization, and decision-making processes. It helps identify critical factors affecting system performance, optimize process parameters, and analyze the relationships between design variables and performance metrics.

2. Management: In management systems, GRA supports decision-making, resource allocation, and performance evaluation. It helps managers to rank activities for improving overall effectiveness and efficiency, pinpoint areas for improvement, and evaluate the relative performance of various departments or initiatives.

3. Economics: Economic data, trends, and policy initiatives may all be analyzed and assessed using GRA. It facilitates economists' comprehension of the intricate relationships between economic variables and their evaluation of the effects of many factors on economic development and stability.

4. Environmental Science: Resource management, ecological modeling, and environmental impact assessment all use GRA. It makes it easier to analyze environmental data, pinpoint the key variables affecting the health of ecosystems, and create long-term plans for conservation and restoration.

A flexible and reliable framework for studying complex systems and interactions is provided by gray relational analysis, especially in cases when the data may be ambiguous or lacking. GRA offers useful insights for decision-making, optimization, and problem-solving in a variety of domains by measuring the degree of association between various variables. It is anticipated that as GRA research develops further, so will its applications, advancing science, engineering, and management.

3. ANALYSIS AND DISCUSSION

TABLE 1. Advancements and Applications of Plastics

Alternative	Mechanical Strength	Thermal Stability	Cost	Environmental Impact
Polyamide (Nylon)	8	7	5	9
Polycarbonate (PC)	7	8	9	6
Polyethylene (PE)	5	4	3	4
Polypropylene (PP)	6	6	2	7
Acrylonitrile Butadiene Styrene (ABS)	9	5	8	8

Based on the primary evaluation criteria of mechanical strength, thermal stability, cost, and environmental effect, Table 1 provides a thorough analysis of many plastics. Polyamide, or nylon, outperforms the competition in these benefit categories thanks to its impressive mechanical strength and respectable thermal stability. Its substantial environmental effect and expensive cost, however, present difficulties in several applications. Closely behind with strong mechanical strength and high thermal stability, polycarbonate (PC) is a good choice for situations needing resistance to high temperatures. Still, its comparatively hefty price is worth taking into account. Overall, Polyethylene (PE) and Polypropylene (PP) perform quite well; however, PE prioritizes cost-effectiveness whereas PP tends to have a more balanced profile. Last but not least, Acrylonitrile Butadiene Styrene (ABS) shows itself as a formidable opponent with remarkable mechanical strength, which makes it perfect for demanding applications. ABS is still the material of choice in many sectors despite its comparatively high cost and negative environmental effects. Through a multi-criteria evaluation of various options, stakeholder's may balance sustainability, cost, and performance factors to make well-informed decisions unique to their needs.

A thorough analysis of several plastics is shown in Figure 1 using the following important evaluation criteria: cost, environmental effect, mechanical strength, and thermal stability. With respect to these benefit criteria, Polyamide (Nylon) comes out on top due to its remarkable mechanical strength and good thermal stability. In other applications, nevertheless, their high cost and substantial environmental effects present difficulties. Following closely, polycarbonate (PC) has good mechanical strength and strong thermal stability, making it a good choice for applications requiring resistance to high temperatures. However, given its comparatively high cost, it merits examination. Both polypropylene (PP) and polyethylene (PE) perform quite well overall, with PP tending to have a more balanced profile and PE favoring cost-effectiveness. Last but not least, Acrylonitrile Butadiene Styrene (ABS) shows itself as a formidable opponent with remarkable mechanical strength, which makes it perfect for

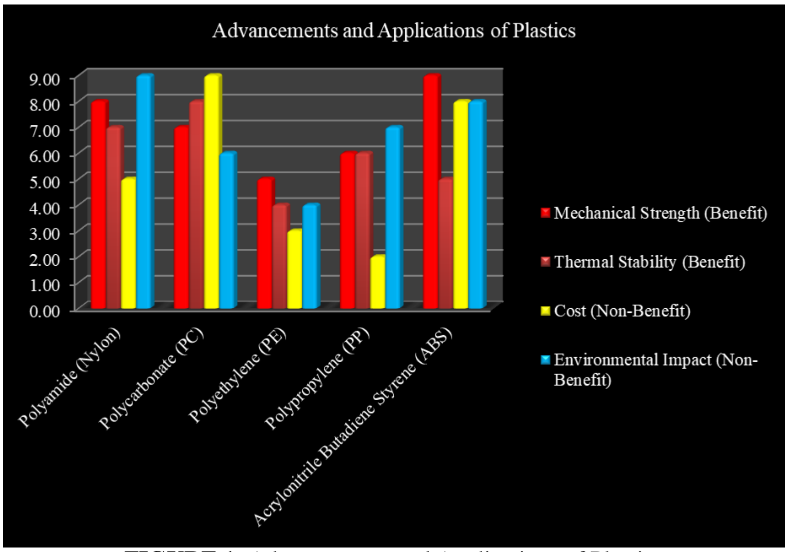


FIGURE 1. Advancements and Applications of Plastics

demanding applications. ABS is still the material of choice in many sectors despite its comparatively high cost and negative environmental effects. Through a multi-criteria evaluation of various options, stakeholders may balance sustainability, cost, and performance factors to make well-informed decisions unique to their needs.

TABLE 2. Normalized Data

Mechanical Strength	Thermal Stability	Cost	Environmental Impact
0.7500	0.7500	0.5714	0.0000
0.5000	1.0000	0.0000	0.6000
0.0000	0.0000	0.8571	1.0000
0.2500	0.5000	1.0000	0.4000
1.0000	0.2500	0.1429	0.2000

The normalized data obtained from Table 1 are shown in Table 2, which offers a standardized depiction of the assessment parameters for every plastics options. By ensuring that all characteristics are scaled to the same range, normalization makes it easier to compare various criteria fairly. Higher values indicate greater performance in comparison to the other choices within each criterion. The values in this normalized dataset range from 0 to 1. Notably, polyamide (Nylon) and polycarbonate (PC) score highly in both mechanical strength and thermal stability categories because to their constant performance. Their normalized ratings, however, vary in terms of cost and environmental effect, which reflects differences in their sustainability and economic viability.. The profiles of polyethylene (PE) and polypropylene (PP) are different; while PE is more cost-effective than PP, it is not as strong mechanically or thermally stable. In terms of mechanical strength, Acrylonitrile Butadiene Styrene (ABS) excels, even though it receives lower marks in other categories. Decision-makers may more properly evaluate the relative advantages and disadvantages of each plastics option by standardizing the data in this way, which helps with well-informed decision-making for a variety of applications.

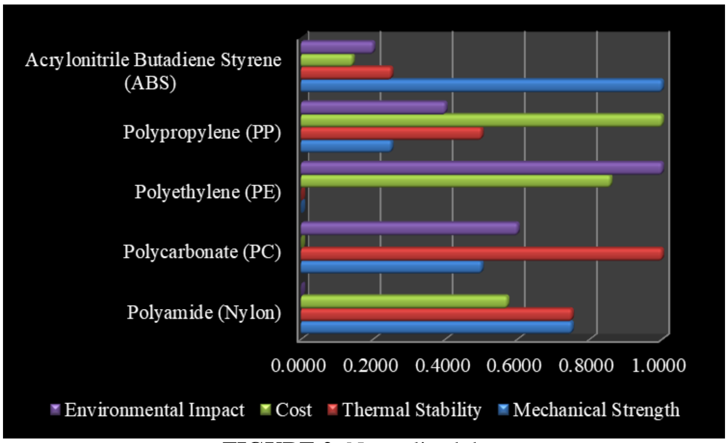


FIGURE 2. Normalized data

With the help of the normalized data obtained from Table 1, Figure 2 presents a uniform depiction of the assessment criteria for every plastics substitute. By ensuring that all characteristics are scaled to the same range, normalization makes it easier to compare various criteria fairly. Higher values indicate greater performance in comparison to the other choices within each criterion. The values in this normalized dataset range from 0 to 1. Notably, polyamide (Nylon) and polycarbonate (PC) score highly in both mechanical strength and thermal stability categories because to their constant performance. Their normalized ratings, however, vary in terms of cost and environmental effect, which reflects differences in their sustainability and economic viability. The profiles of polyethylene (PE) and polypropylene (PP) are different; while PE is more cost-effective than PP, it is not as strong mechanically or thermally stable. In terms of mechanical strength, Acrylonitrile Butadiene Styrene (ABS) excels, even though it receives lower marks in other categories. Decision-makers may more properly evaluate the relative advantages and disadvantages of each plastics option by standardizing the data in this way, which helps with well-informed decision-making for a variety of applications.

TABLE 3. Deviation Sequence of Alternatives Across Decision Criteria

Alternative	Mechanical Strength	Thermal Stability	Cost	Environmental Impact
Polyamide (Nylon)	0.2500	0.2500	0.4286	1.0000
Polycarbonate (PC)	0.5000	0.0000	1.0000	0.4000
Polyethylene (PE)	1.0000	1.0000	0.1429	0.0000
Polypropylene (PP)	0.7500	0.5000	0.0000	0.6000
Acrylonitrile Butadiene Styrene (ABS)	0.0000	0.7500	0.8571	0.8000

Table 3 displays the order of deviation for every plastics substitute, emphasizing the extent of departure from the optimal performance for every assessment criterion. Deviation sequences shed light on how well alternatives perform in relation to ideal or optimal values for each criterion. In this dataset, more dispersion is shown by larger deviation values, whereas lower values imply closer approach to the greatest performance. In terms of mechanical strength and thermal stability, polyamide (Nylon) and polycarbonate (PC) show very little variation, demonstrating their competitiveness in these domains. Their difference does, however, become more noticeable when considering cost and environmental effect, indicating possible disadvantages in these domains. When compared to the best-performing alternatives, polyethylene (PE) and polypropylene (PP) exhibit larger variances across a variety of parameters, indicating their relative inferiority. Thermal stability and affordability are two areas where Acrylonitrile Butadiene Styrene (ABS) excels and is positioned attractively. However, its variance in mechanical strength and environmental effect should be taken into account. Decision-makers may more accurately determine the advantages and disadvantages of each option by examining deviation sequences, which makes it easier to make well-informed decisions for a variety of plastics applications.

TABLE 4. Result of final GRG Rank

Alternative	GRG	Rank
Polyamide (Nylon)	0.5513	4
Polycarbonate (PC)	0.5972	2
Polyethylene (PE)	0.6111	1
Polypropylene (PP)	0.5886	3
Acrylonitrile Butadiene Styrene (ABS)	0.5383	5

The final Grey Relational Grade (GRG) rankings for each plastics alternative are shown in Table 4. Taking into account all assessment criteria and their corresponding Grey Relation Coefficients, the GRG shows the total performance of each choice. Greater alignment with the intended or ideal performance is reflected in a greater GRG, which denotes a stronger overall correlation with the reference sequence. With a GRG of 0.6111, Polyethylene (PE) is the option that ranks highest in this ranking, demonstrating its superior overall performance across all analyzed categories. Polycarbonate (PC), which comes in second place with a GRG of 0.5972, is not far behind. With GRGs of 0.5886 and 0.5513, respectively, Polypropylene (PP) and Polyamide (Nylon) hold the third and fourth spots. With a GRG of 0.5383, Acrylonitrile Butadiene Styrene (ABS) comes in fifth place, suggesting a comparatively lower overall performance when compared to the other options. Decision-makers may efficiently prioritize and choose the best plastics substitute for their particular applications by taking the GRG rating into account. This will guarantee optimal performance and the intended results.

Figure 3 For every plastics alternative, the Grey Relational Grade (GRG) values offer a thorough analysis of their overall performance based on several evaluation criteria. With a GRG of 0.6111, polyethylene (PE) is the best option overall, showing excellent correlation with the reference sequence as well as best performance in terms of cost, environmental effect, mechanical strength, and thermal stability. Polycarbonate (PC), which comes in second place with a GRG of 0.5972, is not far behind With GRGs of 0.5886 and 0.5513, respectively, Polypropylene (PP) and Polyamide (Nylon) hold the third and fourth places. With a GRG of 0.5383, Acrylonitrile Butadiene Styrene (ABS) comes in fifth place, suggesting a comparatively lower overall performance when compared to the other

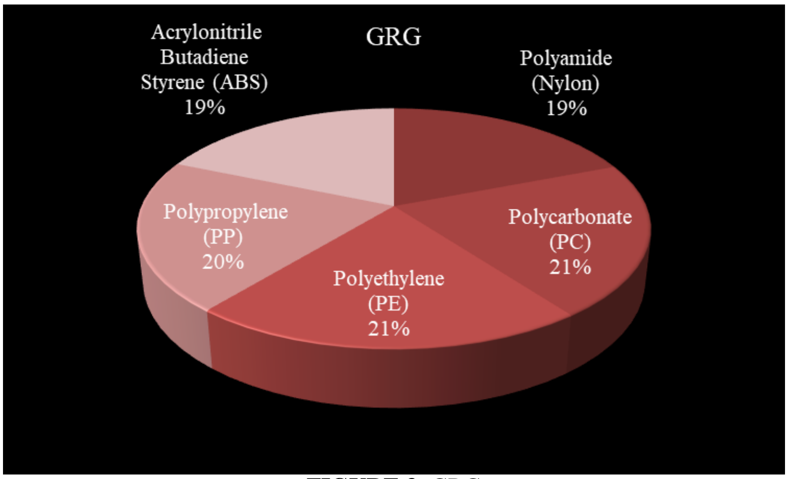


FIGURE 3. GRG

options. Decision-makers may use these GRG values to gain important insights that help them rank and choose the best plastics substitute based on how well it performs overall and how well it matches the specified criteria.

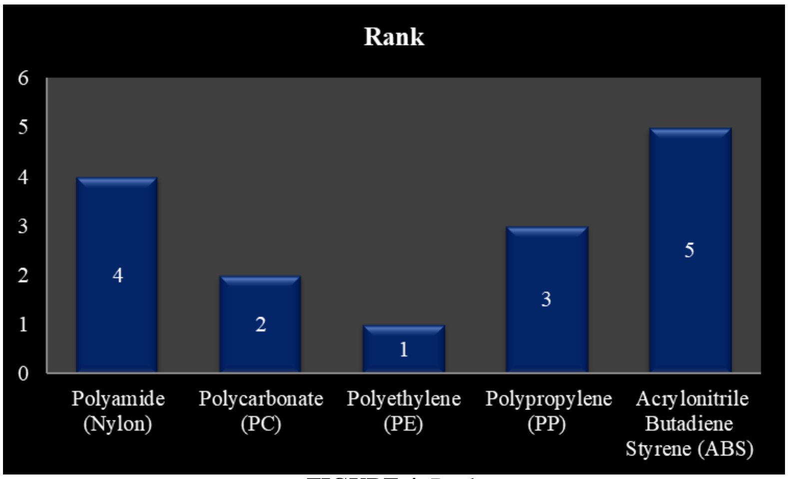


FIGURE 4. Rank

Figure 4 According to its performance, each plastics substitute is ranked in the supplied list, with Polyethylene (PE) holding the top place at rank 1. This rating indicates that Polyethylene is a good competitor for a variety of applications since it demonstrates the most beneficial features among the alternatives analyzed. Polycarbonate (PC), at number 2, is ranked closely behind because to its excellent performance and fit for certain needs. Third place goes to Polypropylene (PP), demonstrating PP’s competitiveness over the other options. Nylon, or polyamide, comes in at number four, showing off its advantages and future uses even if it was barely surpassed by alternatives with higher rankings. Finally, Acrylonitrile Butadiene Styrene (ABS) comes in at position five, indicating that it performs comparatively worse than the other options that were assessed. Based on certain requirements and performance standards, decision-makers may choose the best plastics substitute with the help of this rating.

4. CONCLUSION

This thorough analysis emphasizes the noteworthy developments and wide range of uses of plastics in several sectors. Technological advancements in material science, polymer chemistry, and manufacturing have propelled the development of plastics. These developments have produced materials that are essential in a variety of applications due to their improved mechanical strength, thermal stability, and other desired qualities. Because of their high strength-to-weight ratio, corrosion resistance, and lightweight nature, plastics are gradually taking the place of conventional materials like metals in the automotive and aerospace sectors. Furthermore, plastics are widely used in the domains of electronics, electrical engineering, and medicine, where their special qualities aid in the creation of cutting-edge tools and technology. The evaluation also stresses how crucial it is to take into account elements like environmental impact and cost-effectiveness when choosing engineering polymers for certain uses. Even if these materials have many advantages, in order to guarantee the best results, it is crucial to evaluate their entire performance and sustainability. All things considered, the development and uses of plastics have fueled innovation and growth in a variety of sectors, providing answers to challenging engineering problems and opening the door for the creation of high-performance, sustainable goods in the future.

REFERENCES

[1]. Wu, Leo C-F., and Wolfgang G. Glasser. "Plastics from lignin. I. Synthesis of hydroxypropyl lignin." Journal of Applied Polymer Science 29, no. 4 (1984): 1111-1123.
[2]. Leu, T. S., & Wang, C. S. (2004). Synergistic effect of a phosphorus–nitrogen flame retardant on plastics. Journal of applied polymer science, 92(1), 410-417.
[3]. Feyzullahoglu, Erol, and Zehra Saffak. "The tribological behaviour of different plastics under dry friction conditions." Materials & Design 29, no. 1 (2008): 205-211.
[4]. Glasser, Wolfgang G., Charlotte A. Barnett, Timothy G. Rials, and Vasudev P. Saraf. "Plastics from lignin II. Characterization of hydroxyalkyl lignin derivatives." Journal of Applied Polymer Science 29, no. 5 (1984): 1815-1830.
[5]. Tarantili, P. A., A. N. Mitsakaki, and M. A. Petoussi. "Processing and properties of plastics recycled from waste electrical and electronic equipment (WEEE)." Polymer degradation and stability 95, no. 3 (2010): 405-410.
[6]. Wagner, A. H., Yu, J. S., & Kalyon, D. M. (1989). Injection molding of plastics. Advances in Polymer Technology: Journal of the Polymer Processing Institute, 9(1), 17-32.
[7]. Izamshah, R., M. A. Azam, M. Hadzley, MA Md Ali, M. S. Kasim, and MS Abdul Aziz. "Study of surface roughness on milling unfilled-polyetheretherketones plastics." Procedia Engineering 68 (2013): 654-660.
[8]. Muller, P. C., Kelley, S. S., & Glasser, W. G. (1984). Plastics from lignin. IX. Phenolic resin synthesis and characterization. The Journal of Adhesion, 17(3), 185-206.
[9]. Gijsman, Pieter, and Marjolein Diepens. "Photolysis and photooxidation in plastics." 2009.
[10]. Kemmann, O., Schaumburg, C., & Weber, L. (1999, March). Micromolding behavior of plastics. In Design, Test, and Microfabrication of MEMS and MOEMS (Vol. 3680, pp. 464-471). SPIE.
[11]. Endo, Hiroki, and Etsuo Marui. "Fundamental studies on friction and wear of plastics." Industrial Lubrication and Tribology 56, no. 5 (2004): 283-287.
[12]. Liang, Ming-Tsai, and Chang-Ming Wang. "Production of plastics foams by supercritical CO2." Industrial & engineering chemistry research 39, no. 12 (2000): 4622-4626.
[13]. Kelley, Stephen S., Wolfgang G. Glasser, and Thomas C. Ward. "Plastics from lignin XIV. Characterization of chain-extended hydroxypropyl lignins." Journal of Wood Chemistry and Technology 8, no. 3 (1988): 341-359.
[14]. Wu, J., Eduard, P., Thiyagarajan, S., Noordover, B. A., van Es, D. S., & Koning, C. E. (2015). Semi-Aromatic Polyesters Based on a Carbohydrate-Derived Rigid Diol for Plastics. ChemSusChem, 8(1), 67-72.
[15]. Galli, P., J. C. Haylock, and A. DeNicola. "High performance polyolefins: The new way towards plastics applications." In Macromolecular Symposia, vol. 100, no. 1, pp. 95-100. Basel: Hüthig & Wepf Verlag, 1995.
[16]. Berer, M., and Zoltan Major. "Characterisation of the local deformation behaviour of plastics rolls." Strain 48, no. 3 (2012): 225-234.
[17]. Hofmann, Klaus, and Wolfgang Glasser. "Plastics from lignin, 23. Network formation of lignin-based epoxy resins." Macromolecular Chemistry and Physics 195, no. 1 (1994): 65-80.
[18]. Gausepohl, H., S. Oepen, K. Knoll, M. Schneider, G. McKee, and W. Loth. "Super-polystyrene: a new class of plastics with versatile properties." Designed Monomers and Polymers 3, no. 3 (2000): 299-315.
[19]. Jaidev, K., Biswal, M., Mohanty, S., & Nayak, S. K. (2021). Sustainable waste management of plastics generated from E-waste: a critical evaluation of mechanical, thermal and morphological properties. Journal of Polymers and the Environment, 29, 1763-1776.
[20]. Smith, R., Georlette, P., Finberg, I., & Reznick, G. (1996). Development of environmentally friendly multifunctional flame retardants for commodity and plastics. Polymer degradation and stability, 54(2-3), 167-173.
[21]. Smith, R., P. Georlette, I. Finberg, and G. Reznick. "Development of environmentally friendly multifunctional flame retardants for commodity and plastics." Polymer degradation and stability 54, no. 2-3 (1996): 167-173.
[22]. Hwang, Eui Jeong, Tadashi Inoue, and Kunihiro Osaki. "Viscoelasticity of some plastics analyzed with the modified stress-optical rule." Polymer Engineering & Science 34, no. 2 (1994): 135-140.
[23]. Rials, T. G., & Glasser, W. G. (1984). Plastics from lignin. X. Enthalpy relaxation of prepolymers. Journal of wood chemistry and technology, 4(3), 331-345.
[24]. Luo, Lai-Ma, Ze-Long Lu, Xin-Min Huang, Xiao-Yue Tan, Xiao-Yu Ding, Ji-Gui Cheng, Liu Zhu, and Yu-Cheng Wu. "Electroless copper plating on PC plasticswith a novel palladium-free surface activation process." Surface and Coatings Technology 251 (2014): 69-73.
[25]. Chang, K-C., and M-F. Yeh. "Grey relational analysis based approach for data clustering." IEE Proceedings-Vision, Image and Signal Processing 152, no. 2 (2005): 165-172.
[26]. Hamzaçebi, C. and Pekkaya, M., 2011. Determining of stock investments with grey relational analysis. Expert Systems with Applications, 38(8), pp.9186-9195.

[27]. Sallehuddin, Roselina, Siti Mariyam Hj Shamsuddin, and Siti Zaiton Mohd Hashim. “Application of grey relational analysis for multivariate time series.” In 2008 Eighth International Conference on Intelligent Systems Design and Applications, vol. 2, pp. 432-437. IEEE, 2008.

[28]. Wu, H. H. (2002). A comparative study of using grey relational analysis in multiple attribute decision making problems. Quality Engineering, 15(2), 209-217.

[29]. Song, Q., & Shepperd, M. (2011). Predicting software project effort: A grey relational analysis based method. Expert Systems with Applications, 38(6), 7302-7316.

[30]. Morán, J., Granada, E., Míguez, J. L., & Porteiro, J. (2006). Use of grey relational analysis to assess and optimize small biomass boilers. Fuel processing technology, 87(2), 123-127.

