Avrupa Bilim ve Teknoloji Dergisi
Sayı 56, S. 1-8, Aralık 2025

Araştırma Makalesi

www.ejosat.com ISSN:2148-2683

European Journal of Science and Technology
No. 56, pp. 1-8, December 2025

Research Article

Mechanical Performance of Recycled Composites for Marine Auxiliary Machinery

Ömer Şengül[1*], Hasan Yılmaz[2]

[1*] Kocaeli University, Maritime Faculty, Ship Machinery Operating Engineering, Kocaeli, Turkey, (ORCID: 0000-0002-2293-5064), omer.sengul@kocaeli.edu.tr
[2] Giresun Municipality, Giresun, Turkey, (ORCID: 0000-0002-6942-734X), hayilmaz28@gmail.com

(İlk Geliş Tarihi 03.11.2025 ve Kabul Tarihi 09.12.2025)

(**DOI:** 10.5281/zenodo.18045000)

ATIF/REFERENCE: Şengül, Ö. & Yılmaz, H. (2025) Mechanical Performance of Recycled Composites for Marine Auxiliary Machinery. *European Journal of Science and Technology*, (56), 1-8.

Abstract

This study explores the development and characterization of sustainable polymer composites reinforced with coconut shell powder (CSP), an agricultural by-product, incorporated into a recycled polypropylene (rPP) matrix. The composites were fabricated via homogeneous blending using a twin-screw extruder followed by injection molding, with CSP loadings of 2%, 5%, 8%, 10%, 12.5%, 15%, 18%, and 20% by weight. The mechanical and physical properties, including tensile strength, Izod impact strength, hardness, and density, were systematically evaluated to determine the reinforcing effect of CSP as a natural filler within the recycled matrix. The results revealed a significant improvement in mechanical performance up to 15 wt.% CSP, where the tensile strength reached 25.60 MPa, yield strength increased to 20.99 MPa, and the elastic modulus nearly doubled to 1213.72 MPa compared to neat rPP. The impact strength improved to 5.98 kJ/m², Shore-D hardness increased from 68 to 71, and density rose from 0.890 g/cm³ to 0.930 g/cm³. Beyond this threshold, excessive filler loading led to particle agglomeration and reduced matrix cohesion. These findings indicate that CSP–rPP composites offer a promising balance between strength, stiffness, and weight, making them suitable for non-structural and semi-structural applications in marine auxiliary machinery systems, such as pump housings, valve components, insulation covers, and pipe supports, where corrosion resistance and low density are critical. Furthermore, the utilization of recycled and bio-based constituents contributes to sustainable shipbuilding practices, aligning with green ship design principles and international maritime environmental standards. This work highlights the potential of agricultural waste valorization in producing eco-efficient materials tailored for marine engineering applications.

Keywords: Marine machinery, sustainable maritime, coconut shell powder, composite materials, mechanical properties, polypropylene, recycling, sustainable production, green materials.

Deniz Yardımcı Makineleri için Geri Dönüştürülmüş Kompozitlerin Mekanik Performansı

Öz

Bu çalışma, tarımsal bir yan ürün olan hindistan cevizi kabuğu tozu (CSP) ile takviye edilmiş geri dönüştürülmüş polipropilen (rPP) esaslı sürdürülebilir polimer kompozitlerin geliştirilmesi ve karakterizasyonunu incelemektedir. Kompozit malzemeler, iki vidalı ekstrüder kullanılarak homojen karıştırma işlemi sonrasında enjeksiyonla kalıplama yöntemiyle üretilmiş olup, ağırlıkça %2, %5, %8, %10, %12,5, %15, %18 ve %20 oranlarında CSP ilavesi gerçekleştirilmiştir. Çekme dayanımı, Izod darbe dayanımı, sertlik ve yoğunluk dahil olmak üzere mekanik ve fiziksel özellikler sistematik olarak değerlendirilerek, doğal bir dolgu malzemesi olarak CSP'nin geri dönüştürülmüş matris üzerindeki takviye etkisi araştırılmıştır. Bulgular, %15 ağırlık oranına kadar CSP katkısının mekanik performansta belirgin iyileşme sağladığını göstermiştir. Bu oranda, çekme dayanımı 25,60 MPa'a, akma dayanımı 20,99 MPa'a yükselmiş, elastik

[*] Corresponding Author: omer.sengul@kocaeli.edu.tr

modül ise saf rPP'ye kıyasla neredeyse iki katına çıkarak 1213,72 MPa değerine ulaşmıştır. Darbe dayanımı 5,98 kJ/m²'ye yükselmiş, Shore-D sertliği 68'den 71'e, yoğunluk ise 0,890 g/cm³'ten 0,930 g/cm³'e artmıştır. Bu eşik değerin üzerinde ise aşırı dolgu miktarı partikül yığılmasına ve matris bütünlüğünün zayıflamasına neden olmuştur. Elde edilen sonuçlar, CSP–rPP kompozitlerinin dayanım, rijitlik ve ağırlık arasında dengeli performans sunduğunu ve düşük yoğunluk ile korozyon direncinin kritik olduğu pompa gövdeleri, vana bileşenleri, izolasyon kapakları ve boru destekleri gibi deniz yardımcı makine sistemlerinde yapısal olmayan veya yarı-yapısal uygulamalar için uygun olduğunu ortaya koymaktadır. Ayrıca, geri dönüştürülmüş ve biyolojik kökenli bileşenlerin kullanımı, sürdürülebilir gemi inşasına katkı sağlayarak yeşil gemi tasarımı prensipleri ve uluslararası denizcilik çevre standartları ile uyum göstermektedir. Bu çalışma, tarımsal atıkların değer kazanımı yoluyla deniz mühendisliği uygulamalarına yönelik çevre dostu ve verimli malzemelerin üretiminde önemli bir potansiyel sunduğunu vurgulamaktadır.

Anahtar Kelimeler: Denizcilik makineleri, sürdürülebilir denizcilik, hindistan cevizi kabuğu tozu, kompozit malzemeler, mekanik özellikler, polipropilen, geri dönüşüm, sürdürülebilir üretim, çevreci malzemeler.

1. Introduction

Global plastic production increased rapidly following the end of the Second World War, with continuous growth particularly evident after the 1950s. As of 2022, the total annual production of plastics exceeds 400 million tons (OECD 2022). The continuous rise in plastic consumption has brought significant drawbacks, surpassing waste management capacities and resulting in severe environmental issues. According to the 2022 OECD report, approximately 353 million tons of plastic waste were generated in 2019 alone (Geyer et al., 2017; Lebreton et al., 2018). Of this amount, only 9% was recycled, 19% was incinerated for energy recovery, and nearly 50% was disposed of in landfills (Geyer et al., 2017; Vilaplana & Karlsson, 2020). Similarly, studies by Geyer et al. (2017) and Lebreton et al. (2018) have demonstrated the rapid accumulation and dispersion of plastics in natural environments, including the massive concentration observed in the world's oceans (Geyer et al., 2017). These findings underscore the strategic importance of advanced recycling technologies in achieving circular economy objectives. Furthermore, plastics can persist in nature for centuries without degradation, while microplastics pose additional threats. Their impact on ecosystems and human health make this issue highly significant within the context of sustainability research. Among recycling methods, mechanical recycling remains the most widely applied technique. This process involves the collection, sorting, cleaning, and reprocessing of waste plastics, and is considered cost-effective. Figure 1 illustrates the recycling cycle of plastics.

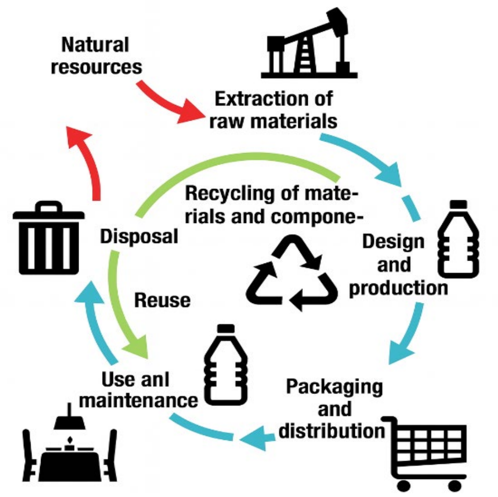

Figure 1. Schematic representation of the recycling cycle of plastic materials.

Polyolefins, particularly polypropylene (PP), are widely preferred due to their versatility. However, during multiple processing cycles, various structural degradations may occur. Chain scission, oxidative degradation, additive depletion, and recrystallization phenomena alter the mechanical properties of PP, leading to losses in its critical mechanical and thermal performance (Al-Salem et al., 2009; Ragaert et al., 2017; Vitaplana & Karlsson, 2020). Despite these drawbacks, the low density, processability, chemical resistance, and cost-effectiveness of PP make it an ideal material for automotive applications. In addition, recycled polypropylene (rPP) is frequently utilized in packaging and construction sectors. Nevertheless, when compared with virgin PP, the environmental implications of rPP use must be carefully considered. rPP typically exhibits notable reductions in mechanical performance, which restricts its direct applications. This performance deterioration has prompted strategies such as the incorporation of natural fillers, polymer blending, and the use of compatibilizers to enhance the overall properties (Horne et al., 2020; OECD 2022).

Marine auxiliary machinery systems comprise essential units such as pumps, compressors, heat exchangers, separators, valves, and piping networks, which ensure the efficient and safe operation of main propulsion systems. The materials used in these components must exhibit a well-balanced combination of mechanical strength, corrosion resistance, thermal stability, and low density to withstand harsh marine environments. Although metal-based materials have traditionally been preferred due to their high strength, they often suffer from corrosion, excessive weight, and high maintenance costs when exposed to seawater and humid conditions.

Coconut shell powder (CSP)–reinforced recycled polypropylene (rPP) composites emerge as lightweight, corrosion-resistant, cost-effective, and energy-efficient alternatives for use in marine environments. Their potential integration aligns with the concept of green ship design and supports the environmental sustainability goals set forth by the International Maritime Organization (IMO), particularly those outlined under MARPOL Annex VI, which emphasize the reduction of emissions and the use of eco-friendly materials (Beygisangchin et al., 2021; Horne et al., 2020).

Therefore, this study systematically investigates the mechanical and physical properties of CSP–rPP composites to assess their suitability for use in marine auxiliary machinery systems. The influence of varying CSP contents on tensile strength, impact strength, elastic modulus, and hardness was examined in detail. The findings aim to establish a scientific foundation for the development of sustainable engineering materials tailored to meet the lightweight, durable, and environmentally compliant requirements of the modern maritime industry (Horne et al., 2020; Ragaert et al., 2017).

In recent years, the use of natural fillers and fibers has gained remarkable importance in sustainable materials research. Agricultural and forestry by-products are considered low-cost, renewable, and biodegradable resources. Examples include wood flour, rice husk, walnut shell, hemp, and jute fibres, which have been successfully incorporated into PP and other thermoplastics to form composites, as reported in various academic studies (Beygisangchin et al., 2021; Khalaj & Nazari, 2021). Figure 2 presents an extended comparison of plastic recycling methods.

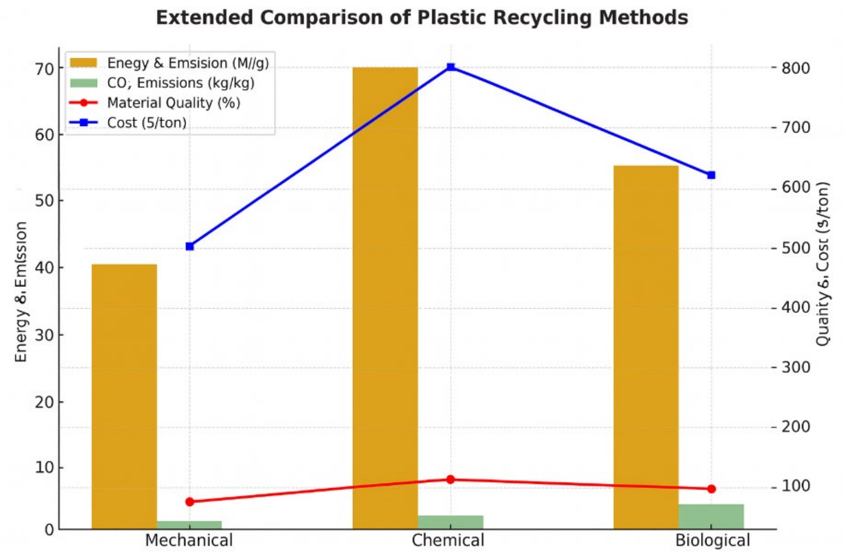

Figure 2. Extended comparison of the recycling methods of plastic materials (Geyer et al., 2017; Al-Salem et al., 2009)

CSP has recently emerged as one of the most extensively studied natural fillers. Coconut shells, primarily considered agricultural waste, are abundantly produced in Asian and Pacific countries. They are characterized by a high cellulose content (30–35%) and a substantial lignin fraction (40–45%) (Beygisangchin et al., 2021). When incorporated into polymer matrices, CSP contributes to stiffness and hardness, while the presence of mineral phases enhances the thermal resistance of the composites. However, when the CSP particle content exceeds 15 wt.%, particle agglomeration and void formation tend to occur, leading to weakened matrix–filler interactions. Consequently, several studies have reported reductions in mechanical performance under these conditions (Arjmand et.al., 2014; Khalaj, & Nazari, 2021; Prachayawarakorn et al., 2020; Reddy & Reddy, 2014). Due to the inherently low polarity of PP, its compatibility with natural fillers is limited, restricting its potential in composite formation. This incompatibility often results in weak interfacial adhesion between the polymer matrix and the filler. To overcome this issue, compatibilizers such as maleic anhydride-grafted polypropylene (PP-g-MAH) are commonly employed. Their use enhances the wettability of the interface, thereby improving tensile and impact strength (Arjmand et al., 2014; Beßling, & Orlowsky, 2022; Prachayawarakorn, & Poomkaew, 2020). Caramitu et al. reported significant improvements in mechanical properties of PP-based hybrid composites through the incorporation of bio-based reinforcements (Yung et al., 2009). Similarly, Ramesh et al. demonstrated that combining beeswax with CSP enhanced the engineering performance of bio-based composites (Andezai et al., 2020). In the present study, rPP/CSP composites were fabricated via injection moulding using filler loadings ranging from 2% to 20% by weight. The effects of CSP addition on tensile strength, yield strength, elastic modulus, impact resistance, hardness, and density were systematically investigated to evaluate the mechanical performance of these composites. The objective was to identify the optimum CSP filler content and provide insights for guiding future research in this field.

2. Material and Methods

2.1. Preparation of the filling material

In this study, rPP was used as the matrix material. The reinforcing material, CSP, was obtained from food industry waste. The coconut shells were thoroughly washed to remove surface impurities and subsequently oven-dried at 60 °C for 48 hours. After drying, the shells were ground using a knife mill and sieved through a 150 µm mesh to achieve a particle size range of 75–150 µm. The prepared CSP powder was stored in vacuum-sealed packages to prevent moisture absorption. Figure 3 illustrates the processing sequence of coconut shell powder preparation.

Figure 3. Processing steps involved in the preparation of coconut shell powder.

2.2. Preparation of Composite Granules

The prepared CSP powder was mixed with rPP at predetermined ratios and processed in a twin-screw extruder. The extrusion process was carried out using temperature profiles suitable for polypropylene processing and an appropriate screw speed. The extruded strands were subsequently pelletized into granules. Figure 4 presents the twin-screw extruder setup, while Figure 5 shows the plastic composite granules.

Figure 4. Twin screw extruder machine

Figure 5. Plastic composite granular mixed material

2.3. Production of Test Specimens

The obtained composite granules were converted into standard test specimens using the injection moulding method. The injection moulding process was carried out under temperature, pressure, and mold parameters appropriate for the characteristics of the rPP/CSP composite material. Figure 6 shows the injection moulding machine used in the study.

Figure 6. Injection moulding machine

2.4. Mechanical Tests and Characterization

Tensile testing was performed in accordance with the ASTM D3039 standard using a Shimadzu universal testing machine at a crosshead speed of 2 mm/min. The average values obtained from five specimens were taken as reference for evaluation. Figure 7 shows the tensile test specimens, while Figure 8 presents the universal testing machine used in the tests.

Figure 7. Tensile test specimen

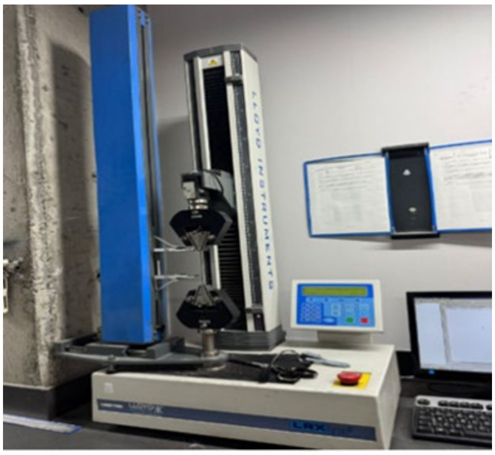

Figure 8. Tensile test equipment

Figure 9. The Izod impact testing. (Instron 9050)

Figure 10. Standard Izod test specimens used in the test.

The impact test was conducted in accordance with the ISO 180/1A standard using an Instron CEAST 9050 apparatus. Five distinct specimens were tested, and the mean values were calculated. Figure 9 presents the Izod impact testing device, whereas Figure 10 illustrates the Izod test specimens. The density measurements were carried out based on the Archimedes principle. The device used for density determination is presented in Figure 11. The Shore D hardness tests were performed using a ZWICK brand hardness tester, as shown in Figure 12.

Figure 11. Density measurement device.

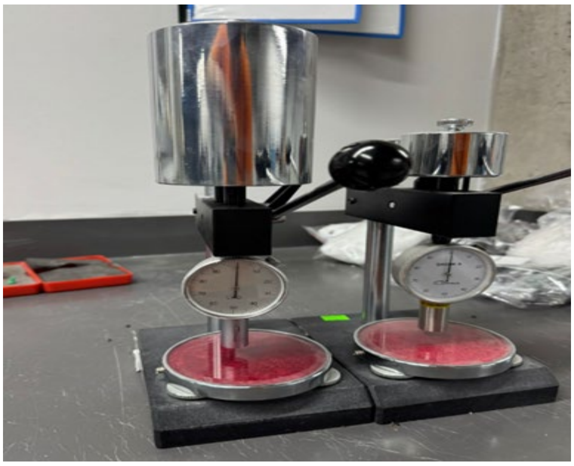

Figure 12. Shore D hardness testing apparatus.

3. Results and Discussion

In this study, the mechanical and physical properties of rPP/CSP composites produced by the injection moulding method were investigated. The results revealed that the CSP filler content had a pronounced influence on the overall composite performance. For the tensile properties, the tensile strength of neat rPP was measured as 22.10 MPa, and its elastic modulus was 590.15 MPa. With increasing CSP content, the tensile strength gradually improved, reaching the highest value of 25.60 MPa at 15 wt.% CSP, which represents the optimum composition. The elastic modulus exhibited a similar trend, increasing up to 1213.72 MPa, approximately doubling compared to neat rPP. This enhancement was attributed to the rigid nature of the CSP particles, which restricted the matrix deformation and facilitated more effective stress transfer across the filler–matrix interface. However, at 20 wt.% CSP, significant reductions were observed in both tensile strength and modulus. This decline was associated with particle agglomeration, formation of micro-voids, and weak interfacial adhesion between the filler and the matrix at high filler loadings. Regarding yield strength and elongation, the addition of CSP led to an increase in yield strength, while the elongation at break exhibited a continuous decreasing trend. Neat rPP, due to its high ductility, could undergo large deformations during tensile loading, whereas the rigidity of CSP restricted this behaviour. Above 15 wt.% CSP, the fracture elongation sharply decreased, indicating that the material became more brittle. This finding demonstrates that, while CSP enhances the stiffness of the rPP matrix, it simultaneously deteriorates its flexibility. For the impact properties, the impact resistance of neat rPP was determined as 4.20 kJ/m². With increasing CSP content, the impact strength gradually increased up to 5.98 kJ/m² at 15 wt.% CSP, indicating improved energy absorption. This improvement was attributed to the filler particles acting as crack deflectors and energy dissipators, hindering crack propagation. However, at 18–20 wt.% CSP, the impact strength decreased again to around 4.10 kJ/m², approaching that of neat rPP. This reduction was associated with filler agglomeration, interfacial weaknesses, and void formation at high filler ratios, which promoted premature crack initiation. In terms of hardness and density, both parameters exhibited a consistent increase with increasing CSP content. The Shore D hardness of neat rPP was measured as 65, and it increased steadily, reaching 72 Shore D at 20 wt.% CSP. This enhancement was attributed to the high lignin and mineral content of the CSP, contributing to a stiffer surface structure. Similarly, the density of neat rPP (0.90 g/cm³) increased to 1.01 g/cm³ at 20 wt.% CSP, a moderate rise that does not significantly compromise the lightweight advantage of rPP, thus maintaining its application potential in engineering components. Overall, the results indicate that the optimum mechanical performance of rPP/CSP composites was achieved at 15 wt.% CSP content. The detailed mechanical properties are summarized in Table 1, and the corresponding graphical representations are presented in Figure 13.

Table1. Mechanical Properties of Recycled Polypropylene/Walnut Shell Composites

Composition	Tensile Strength (MPa)	Strength Yield (MPa)	Elongation Yield (%)	Elastic Modulus (MPa)	Izod Impact (kJ/m²)	Hardness (Shore-D)	Density (g/cm³)
Recycled PP	22.1	18.16	3.42	590.15	4.86	68	0.89
2% CSP+ PP	22.63	18.29	3.53	1046.17	4.96	69	0.92
5% CSP + PP	23.41	18.98	3.75	1152.28	5.18	69	0.92
8% CSP + PP	23.95	19.32	3.82	1196.53	5.82	69	0.92
10% CSP + PP	24.31	19.96	3.99	1202.72	5.6	70	0.92
12.5% CSP+ PP	24.75	20.37	4.12	1218.75	5.61	70	0.93
15% CSP + PP	25.6	20.99	4.07	1213.72	5.98	71	0.93
18% CSP + PP	22.2	18.01	3.1	540.63	4.14	72	0.98
20% CSP + PP	20.36	17.45	2.09	430.26	3.1	72	1.01

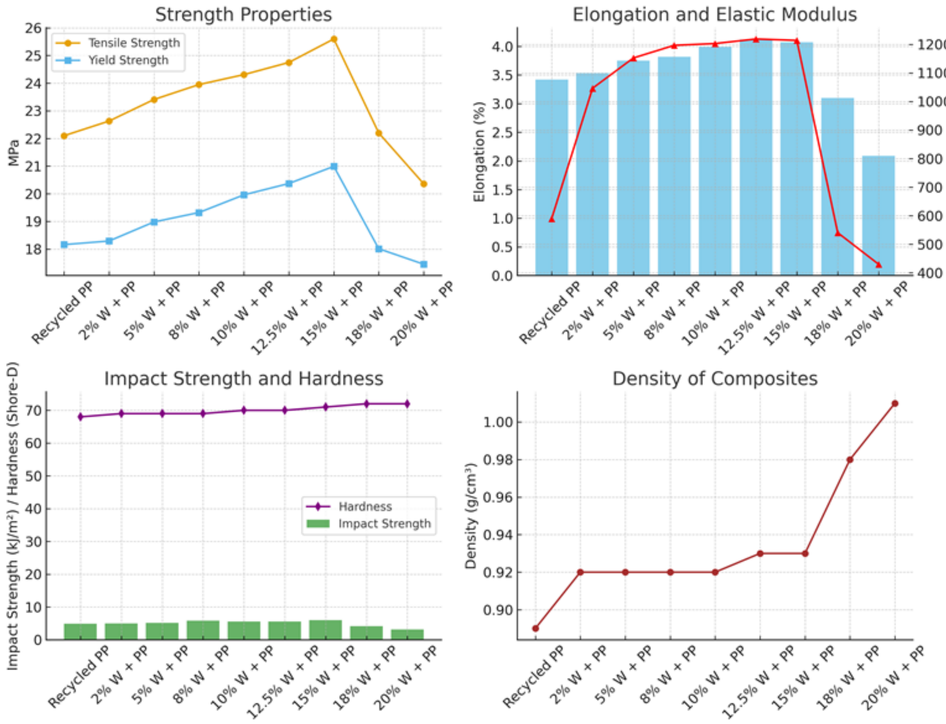

Figure 13. Graphical representation of the mechanical properties of rPP/CSP composites.

Within this range, both tensile and impact properties increased, the elastic modulus reached its maximum value, and the hardness and density values rose in a controlled manner. At higher filler contents, however, decreases in mechanical properties were observed due to morphological irregularities and interfacial incompatibility between the matrix and the filler. These results confirm that the incorporation of CSP provides a limited yet effective reinforcement contribution to rPP-based composites.

4. Conclusion

The obtained findings demonstrate that the incorporation of CSP significantly affects the mechanical and physical performance of the rPP matrix. In particular, the increase in tensile strength and elastic modulus observed at 15 wt.% filler content indicates that the lignocellulosic particles effectively contribute to load transfer, forming a rigid and continuous network structure among the polymer chains. However, the reduction in mechanical properties at 20 wt.% CSP is attributed to particle agglomeration, microvoid formation, and weak interfacial bonding between the matrix and filler phases. These trends are consistent with previous studies reported in literature. Andezai et al. (2020) determined the optimum filler ratio for rice husk–reinforced PP composites to be between 10–15 wt.%, while Khalaj & Nazari (2021) reported increased porosity and brittleness at higher filler loadings. In terms of impact resistance, a typical "bell-shaped" trend was observed — the impact strength increased gradually up to 15 wt.% CSP and then decreased at higher concentrations. This behavior can be explained by the ability of the filler particles at lower loadings to hinder crack propagation and absorb impact energy, whereas at higher loadings, interfacial weaknesses and uneven particle distribution lead to premature failure. Similarly, Khalaj & Nazari (2021) observed a noticeable reduction in impact strength beyond the optimum filler ratio in natural fiber–reinforced PP composites. The continuous increase in hardness and density is directly associated with the lignin and mineral content of CSP (Andezai et al., 2020; Pracella et al., 2010; Reddy & Reddy 2014). The Shore D hardness increased from 65 to 72, while the density rose slightly from 0.90 to 1.01 g/cm³ — a marginal increase that does not compromise the lightweight nature of the composite. This enhancement suggests that the developed composites possess the potential to meet the requirements for surface durability and stiffness in automotive and construction applications. Overall, these results confirm that CSP functions as a limited yet highly effective reinforcement for rPP matrices, contributing to the development of sustainable engineering materials suitable for industrial-scale implementation. From an application perspective, the developed CSP–rPP composites exhibit a well-balanced combination of strength, stiffness, hardness, and corrosion resistance. These characteristics make them highly suitable for marine auxiliary machinery components, including pump casings, valve housings, pipe supports, insulation covers, and separator shells. Since these components operate under harsh marine conditions—such as high salinity, humidity, temperature fluctuations, and mechanical vibration—the low density, dimensional stability, and corrosion resistance of CSP–rPP composites offer significant advantages. Compared to metallic materials, their lightweight nature and reduced maintenance requirements contribute to improved energy efficiency and service life in marine systems. The main engine, together with the auxiliary machinery that supports its operation, forms a complex system known as the engine room (Yorulmaz, & Avcı, 2024). The movement, navigation, and manoeuvring ability of ships are achieved through the propulsive power generated by the main engine installed on board. Moreover, the use of recycled polymers and agricultural waste–based fillers aligns with the principles of sustainable shipbuilding and green ship design. This approach supports the environmental sustainability targets set forth by the International Maritime Organization (IMO) under MARPOL Annex VI, promoting emission reduction, material recyclability, and eco-friendly production. Consequently, CSP–rPP composites can be regarded as lightweight, durable, corrosion-resistant, and cost-effective materials with strong potential for implementation in marine auxiliary machinery systems, contributing to the development of sustainable maritime engineering materials for the next generation of ships.

References

Al-Salem, S. M., Lettieri, P., & Baeyens, J. (2009). Recycling and recovery routes of plastic solid waste (PSW): A review. *Waste Management*, 29(10), 2625-2643.

Andezai, A. M., Maringa, M., & Masu, L. M. (2020). Investigating the mechanical properties of reinforced coconut shell powder/epoxy resin composites. *International J. of Engineering*, 13(10), 2742-2751.

Arjmand, M., Mahmoodi, M., Park, S., & Sundararaj, U. (2014). Impact of foaming on the broadband dielectric properties of multi-walled carbon nanotube/polystyrene composites. *Journal of Cellular Plastics*, 50(6), 551-562.

Beßling, M., & Orlowsky, J. (2022). Quantification of the Influence of Concrete Width per Fiber Strand on the Splitting Crack Failure of Textile Reinforced Concrete (TRC). *Polymers*, 14(3), 489.

Beygisangchin, M., Abdul Rashid, S., Shafie, S., Sadrolhosseini, A. R., & Lim, H. N. (2021). Preparations, properties, and applications of polyaniline and polyaniline thin films—A review. *Polymers*, 13(12), 2003.

Geyer,R., Jambeck, J. R. & Law, K. L. (2017). Production, use, and fate of all plastics ever made. *Science Advances*, 3(7),700782.

Horne, F. J., Liggat, J. J., MacDonald, W. A., & Sankey, S. W. (2020). Photo‐oxidation of poly (ethylene terephthalate) films intended for photovoltaic backsheet. *Journal of Applied Polymer Science*, 137(17), 48623.

Khalaj, G., & Nazari, A. (2021). Retraction notice to "Modeling split tensile strength of high strength self compacting concrete incorporating randomly oriented steel fibers and SiO2 nanoparticles. [Compos. Part B 43 (2012) 1887–1892]. *Composites Part B: Engineering*, 222, 109110.

Lebreton, L., Slat, B., Ferrari, F., et al., (2018). Evidence that the Great Pacific Garbage Patch is rapidly accumulating plastic. *Scientific Reports*, 8, 4666.

OECD. (2022). Global Plastics Outlook: Policy Scenarios to 2060. Paris, France: OECD Publishing, [Online]. Available: https://www.ocnamibia.org/globalplasticcrisis?gad_source=1&gad_campaignid=23013725228&gbraid=0AAAAA9UZ0YTmE_t66dvDMtOnk0nI3Lh1H&gclid=Cj0KCQjwvJHIBhCgARIsAEQnWlBmZUQXJ9ssKxC5fWJJJ4_cJtck9feNovN9M_34E0vY-7psVVx1nhEaAtGMEALw_wcB

Pracella, M., Haque, M. M. U., & Alvarez, V. (2010). Functionalization, compatibilization and properties of polyolefin composites with natural fibers. *Polymers*, 2(4), 554-574.

Prachayawarakorn, J., & Poomkaew, S. (2020). Property improvement of biodegradable high-methoxy pectin film by different contents of dialdehyde starch. *Journal of Polymers and the Environment*, 28(8), 2227-2235.

Ragaert, K., Delva, L., & Van Geem, K. (2017). Mechanical and chemical recycling of solid plastic waste. *Waste Management*, 69, 24–58.

Reddy, M. I., & Reddy, V. S. (2014). Dynamic mechanical analysis of hemp fiber reinforced polymer matrix composites. *Int. J. Eng. Res. Technology*, 3(09).

Vilaplana F., & Karlsson S. (2020). Quality concepts for the improved use of recycled polymeric materials. *Macromolecular Materials and Engineering*, 305(1), 1900737.

Yorulmaz, M., & Avcı, S. (2024). Gemi makine dairesi için Fine Kinney ve AHP yöntemleri ile risk analizi ve yönetimi. *Balkan Sosyal Bilimler Dergisi*, 13(25), 17-28.

Yung, K. C., Zhu, B. L., Yue, T. M., & Xie, C. S. (2009). Preparation and properties of hollow glass microsphere-filled epoxy-matrix composites. *Composites Science and Technology*, 69(2), 260-264.