Knowledge-based Engineering and Sciences (2022), **3**, (3), 83–92
doi:10.51526/kbes.2022.3.3.83-92

RESEARCH PAPER

The Physico-Mechanical Properties of Natural Rubber Latex Foam when Loaded by Different Sizes of Rice Husk Powder

Shamala Ramasamy,[1] Aissa Bouaissi,[*,2,3] Messaoud Saidani,[4] and Khadija Mbarki[5]

[1]School of Materials Engineering, Universiti Malaysia Perlis, Perlis 01000, Malaysia
[2]School of Engineering, University of Plymouth, Plymouth PL4 8AA, UK
[3]UNA Developments Ltd, Airport Business Centre, Plymouth Devon PL6 7PP, UK
[4]School of Energy, Construction and Environment, Coventry University, UK
[5]Laboratory of Environmental Engineering and EcoTechnology (LGEET), National School of Engineering of Sfax (ENIS), Sfax University, Route de la Soukra km 4, 3038 Sfax, Tunisia
[*]Corresponding author. Email: aissabouaissi@yahoo.fr

(Received 22 November 2022; revised 17 December 2022; accepted 23 December 2022; first published online 31 December 2022)

Abstract

This study investigates a novel idea of adding rice husk powder (RHP) into natural rubber latex foam (NRLF) as a way of creating an end product with improved characteristics, marketability, and disposal opportunities. Many sectors have attempted the recycling of RHP, but never with NRLF. This study intends to examine how the mechanical and physical characteristics of RHP-filled NRLF are impacted by RHP size. RHP-filled NRLFs (various sizes) were subjected to numerous mechanical tests, including a tensile and compression study, and the results were matched with that of a controlled NRLF. The results showed that the RHP size, the higher the compression set and the lower the recovery percentage. It was also observed that the lower the RHP filler size, the higher the stress as observed in the stress-strain graph. Better interaction between finer RHP and NRLF was also demonstrated by the decrease in (Qf/Qg) and increase in hardness values of 63 microns RHP-filled NRLFs.

Keywords: Natural rubber latex; Rice husk powder; Stress-strain analysis

1. Introduction

Natural fibers are considered a synthetic fiber alternative because of their unique benefits, such as being non-toxic, not irritating to the skin, eyes, or respiratory system, and having non-corrosive qualities [1]. In addition to the environmental advantages, technological considerations also spur interest in natural fibers as an alternative to or addition to conventional fillers, including glass fibers in polymer composites [2–5]. Natural fibers are preferred over synthetic fibers in many applications because they are more cost-effective, lighter, less likely to damage processing equipment, improve the surface finish of molded composite parts, have better relative mechanical properties, are simpler to modify mechanically and chemically, have a lower density, and are easily sourced renewable materials [6–8]. Researchers from all over the world are interested in natural fibers because they have superior qualities to glass fiber, particularly lignocellulose-based natural fibers [9]. A well-known natural fiber, rice husk, makes up 20–25% of the weight of a rice grain and has a hard, fibrous, woody, protective shell [10].

The dentate rectangular components that makeup rice husk's (RH) exterior are primarily silica-coated, have a thick cuticle and have surface hairs. The amount of silica in the mid-region and inner epidermis is often lower [11]. RH's inner surface, which surrounds the rice grain, is smoother than its outside, which has a high silica content [12,13]. The external silicon cellulose membrane of RHs acts as a natural barrier against termites and other microorganisms that could harm the crop. This element is assumed to be the cause of the weak bonding between the different matrix binders and the accessible functional groups on RH surfaces. To improve the adhesion of RH to the binders and subsequently the characteristics of the resulting composite, it is important to ensure the removal of silica and other surface contaminants should be removed [14–17]. The smooth and wax-containing inner surface of RH contains natural wax and lipids that serve as a protective barrier to the grain [18]. The incorporation of RH into numerous polymer matrices, including low-density polyethylene, high-density polyethylene, polypropylene, styrene-butadiene rubber, and polyurethane has been reported in various studies. The studies have determined that RH increases flame retardancy in addition to tensile & flexural modulus [19].

Latex is mainly composed of polyisoprene, water, and a trace quantity of carbohydrates, proteins, and contaminants. Before becoming "dry rubber," collected latex goes through a number of processing steps that include preservation, concentration, coagulation, dewatering, drying, cleaning, and blending [18]. The phenomenon known as "strain-induced crystallization" is a special property of natural rubber (NR), which implies the ability of NR to crystallize when stretched; the homogeneous microstructure of NR accounts for this property [20]. Heavy machinery and high power input are needed for NR processing. To be handled easily in liquids, fluids, and solids, the rubber must be available in a physical form [21]. The distinctive mechanical qualities of NR made it one of the most significant elastomers that are widely employed in industrial, engineering, and technological domains; it is an essential and indispensable material in several applications, such as gaskets, seals, tires, and mountings [22].

Natural rubber latex is cellular rubber produced from liquid latex. The Dunlop process is most suited for the creation of thick-section molded latex foam rubber items such as foam, cushions, mattresses, and pillows [23]. It has long been established that latex foam exhibits higher resilience, support factor, and dynamic and static fatigue resistance. Furthermore, the excellent pressure relief that latex foam offers, particularly in bedding, is frequently emphasized. Previous works have reported the integration of fibers into natural rubber latex (NRL) [24]; latex foam has also been reinforced with mineral fillers such as kaolinite clay and calcium carbonate [5,25–27].

Dananjaya et al [28] Using the Dunlop technique, processed mica waste (PMW) loading ranging from 0 to 10 phr at 2% intervals was added to natural rubber centrifuged latex and transformed into (NRLF) composites. The composites' stated physico-mechanical characteristics. The improved tensile characteristics and tear strength show that PMW strengthens the foam rubber. Additionally, when PMW is added, it has been demonstrated that the compression set, cross-link density, shrinkage, and bulk density all significantly rise while the recovery %, elongation at break, swelling index, and gelling time of the foams gradually decrease. According to studies using a scanning electron microscope (SEM), the inclusion of filler increased cell diameters. The employment of PWM to create filled NRLFs with better characteristics could be inferred, adding value to both mica and natural rubber at the same time.

By combining five kinds of commercially available mineral fillers at five different loading amounts, Krunarathna et al. [29] created various natural rubber latex foam. Fillers have the ability to strengthen the foam's rubber phase. Consequently, by adding filler, same load-bearing properties may be produced at greater expansion [30]. By doing so, material costs may be reduced. Methodology China clay, talc, dolomite, calcite, and a 50:50 mixture of the two as filler materials were used to create the specimens. Every one of these fillers was added to NR latex foam at loading levels of 5, 10, 15, 20, and 25 phr. Batch processing was used to create the latex foam. A Hobart style planetary mixer was used to prepare the foam. All of them were duplicated three times and put in complete random design to create 25 separate foams. The reference specimen, which was created without the use of fillers, served as a comparison for the test specimens' density, tensile strength, compression set, and indentation hardness index characteristics. Results and analysis Up to 20 phr of calcium carbonate filler loading, the compound's hardness rises; beyond that point, it starts to decline. Fillers acting as hardening agents in rubber compounds and consistent filler distribution in the rubber phase might be to blame for the increase in hardness. The reduction in hardness for filler loadings over 20 phr is most likely due to calcium carbonate agglomeration.

However, there have been no attempts to use RHP as a filler in NRL foam. Hence, this study investigates the impact of different sizes of RH content on the physical and mechanical properties of NRLF; this is aimed at offering an alternative way of managing RH waste to reduce landfill pollution and open fires caused by agricultural waste. The study investigated the tensile and compressive properties of the NRLF-RHP composite, as well as its foam density behavior.

2. Experimental

2.1 Materials and Formulation

Table 1 displays the formula used to investigate the impact of RHP size (125 & 63 m) on NRLF. This study used NRL (Low Ammonia (LATZ) type) and latex chemicals (Sulphur, ZDEC, ZMBT, Zinc Oxide, Antioxidant, Potassium Oleate, DPG, and SSF) from Zarm Scientific & Supplies Sdn. Bhd, Malaysia. Before use, rice husk from Kilang Padi Nazra Sdn. Bhd. Malaysia was gathered, crushed, and sieved. The range of RHP loading was 0 to 10.0 pphr.

Table 1: *Formulation used to study the effect of RHP size (125 and 63 μm) on rice husk powder filled natural rubber latex foam.*

Ingredients	Total Solid Content (%)	Formulation(pphr)
LA Latex	60	100
Sulphur	50	2
Antioxidant	50	1
Potassium Oleate	20	4
ZDEC	50	1
ZMBT	50	1
Zinc Oxide	50	3
DPG	40	0.3
SSF	20	1.2
Rice Husk Powder (125 or 63μm)	25	0, 2.5, 5.0, 7.5, 10

2.2 Sample Preparation

First, LATZ type NRL was sieved, weighed, and mixed for roughly 30 min using a mechanical stirrer. Sulfur, an anti-oxidant, and potassium oleate soap were then added, and the mixture was agitated at 10 rpm [31]. Accelerators (ZMBT and ZDEC) were gradually added to the mixture after two hours. After that, the NRLF compound underwent continuous stirring at a speed of 10 rpm for 8 hours at room temperature [32]. The NRLF compound was vigorously beaten and foamed with a stand mixer (KENWOOD, kMix) after 8 hours of maturation, increasing the volume to up to 3 times that of the initial volume (beaten for about 5 min) [33]. After reaching the necessary volume, the foaming speed was slowed down to produce a fine, even foam.

The foam was then mixed evenly for a further 90 seconds before DPG and zinc oxide (ZnO), the main gelling agent, were added [34]. The secondary gelling ingredient, sodium silico-fluoride (SSF), was then added right away, and the foam was further beaten for 90 sec. The un-gelled foam was then swiftly poured into the required aluminum mold and allowed for 3 min at room temperature to gel. After 3 min, the gelled foam was dried for two hours at 100 ^{o}C.

After the foam had dried, it was de-molded and extensively cleaned with de-ionized water to get rid of the excess non-reacted materials and potassium oleate soap. Following washing, the cured NRLF was dried for 8 h at 80 ^{o}C. The color of the final product (well-dried foam) was observed to be off-white. The control NRLF sample with no RHP content was made using the same method. However, an additional step was introduced before the maturation process during the preparation of the NRLF sample with RHP filler loading. The necessary amount of RHP was introduced into the compound after adding the primary (ZDEC) and secondary (ZMBT) accelerators. The compound was then allowed to develop for 8 h with slow stirring (10 rpm). The subsequent procedures were the same as those used to prepare the NRLF control sample with no RHP content. Table 1 presents the pphr of the chemicals used in the preparation step.

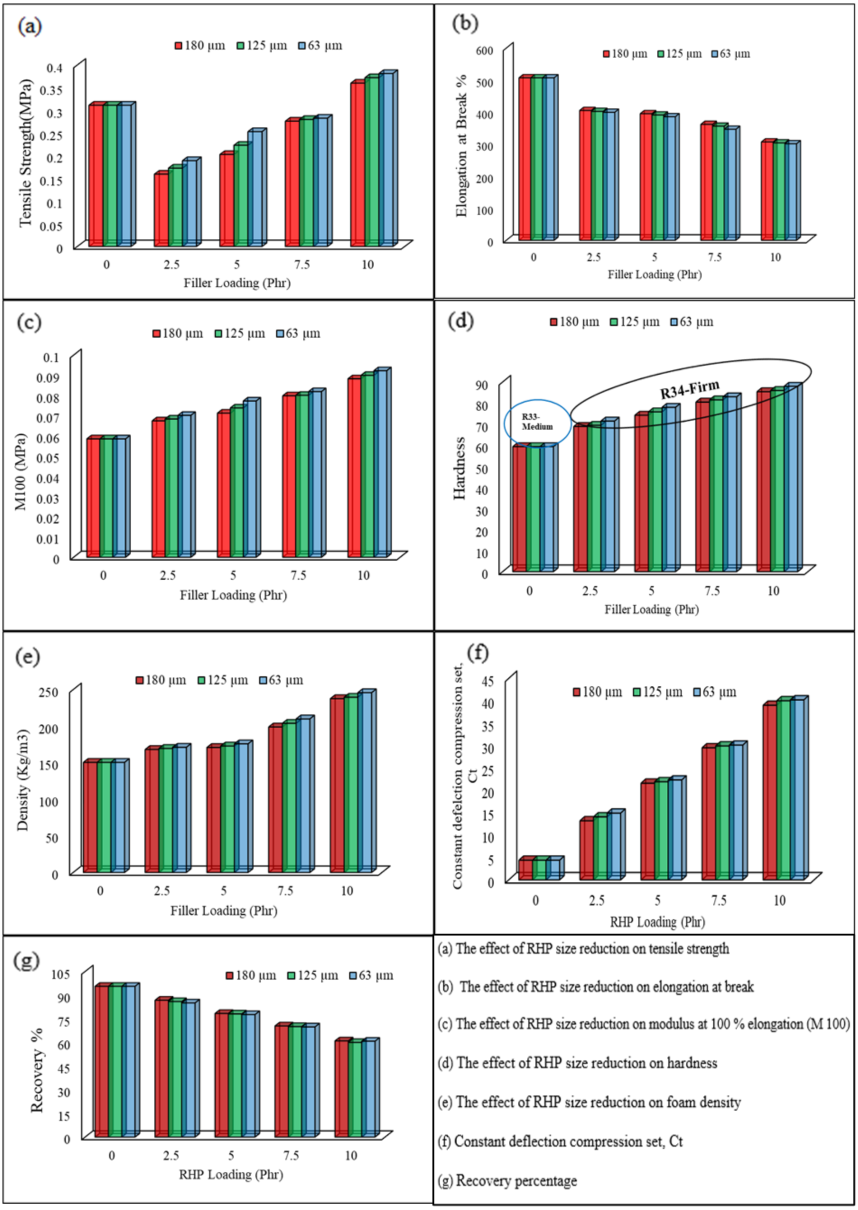
3. Results and Discussion

3.1 Tensile Properties

The tensile strength (TS) of controlled, different-sized RHP-filled NRLFs is shown in Figure 1(a) It was found that the TS decreases for all 3 different sized RHP at 2.5 pphr RHP content. However, the loss in TS reduces with declines in the RHP size possibly because, even at lesser concentrations, the smaller RHP filler particles are evenly distributed throughout the NRL complex [35]. When foreign components are included in the NRL compound, the TS of the NRL compound often decreases [36]. However, the reduction can be bettered by reducing the RHP particle size. It was also noted that reduced agglomeration in NRLF due to smaller RHP particles reduces the number of stress concentration points. Additionally, Figure 1(a) demonstrates that the TS increases with decreasing RHP size at higher RHP content. The improved filler-matrix interaction also improves the TS as the size of the RHP particle is reduced. There is the availability of more surface area for interaction with NRL chemicals when the size of the RHP particle is smaller. In natural rubber latex, the typical size of the rubber particle is 5 m [37]. Improved interaction and adhesion of RHP-filled NRLF was observed as the size of the RHP was decreased from 180 m to 125 m & 63 m. As a result, the increased TS may be attributable to the smaller RHP particles' improved compatibility with the NRL compound. The elongation at break and modulus at 100% elongation (M100) for the controlled NRLF and different-sized RHP-filled NRLFs are shown in Figure 1(b & c). The result showed decreases in the elongation at break as the RHP size reduces, while the M100 exhibited an upward trend. The smaller RHP particles served as more contact points for improved interaction with the flexible rubber chains, leading to the formation of aggregates and cross-linkages, thereby affecting the elasticity of the RHP-filled NRLF as it becomes more rigid. The foam nature of the RHP-filled NRLF conferred it with a microporous structure. Further reduction of the RHP size resulted in a finer cell structure of the RHP-filled NRLF. The spaces in the NRLF foam structure may potentially be filled in with smaller RHP particles. This is also the reason for the improved stiffness of the RHP-filled NRLF.

3.2 Compression Properties

The pattern of the compressive stress-strain relationships of the controlled and different-sized RHP-filled NRLFs are shown in Figure 2. The figure showed that for 10, 20, 30, 40, and 50% strain, the stress value increases as the RHP size is reduced. This demonstrates that the required level of stress for efficient compression of the RHP-filled NRLF increases with declines in the RHP particle size. The optimum stress value was noted for 50% compression of 10 pphr of 63 m-sized RHP-filled NRLF. A



(a) The effect of RHP size reduction on tensile strength

(b) The effect of RHP size reduction on elongation at break

(c) The effect of RHP size reduction on modulus at 100 % elongation (M 100)

(d) The effect of RHP size reduction on hardness

(e) The effect of RHP size reduction on foam density

(f) Constant deflection compression set, Ct

(g) Recovery percentage

Figure 1: *The effect of RHP size reduction on different properties of various sized RHP filled NRLF samples.*

higher level of compatibility was also observed between the RHP and the rubber particles in the NRL compound following a reduction in RHP size, leading to improved reinforcement. This may be due to the increasing level of the even stiffness of the RHP-loaded NRLF following the adherence and dispersion of the smaller RHP particles within the foam structure [38].

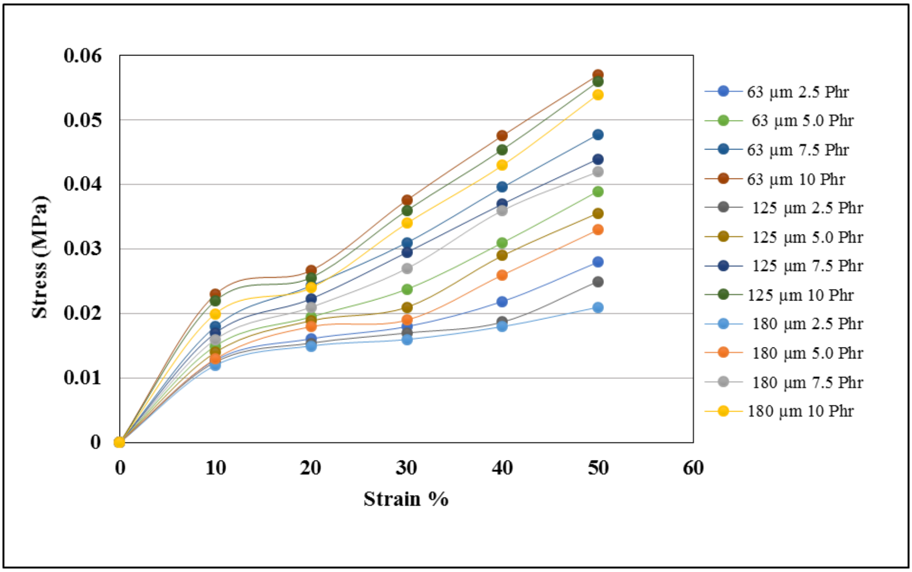


Figure 2: *Compressive stress-strain relationships of controlled and various sized RHP filled NRLFs.*

3.3 Hardness

The correlation between hardness and decreases in RHP size is shown in Figure 1(d). It is amply demonstrated that as RHP size is decreased, NRLF-filled RHP becomes harder. Generally, RHP can influence the hardness of NRLF and this is improved as the microporous voids of NRLF are occupied by smaller RHP particles. The reduction of the RHP size increases the interaction between RHP and the matrix because of the increased available surface area and the interaction with the NRLF compound when the size of the RHP particles is reduced. Consequently, the hardness of RHP-filled NRLF increased as the RHP size approached the size of the rubber particle.

3.4 Foam Density (FD)

Figure 1 displays changes in FD as a result of RHP size reduction Figure 1(e). The reduction of the RHP particle size caused only a slight increase in FD. For instance, at 10 pphr, the density of a 63-m-long RHP-filled NRLF is 245.9047 kg/m3, whereas the density for a 125-m length is 239.6124 kg/m3 & that of and 180-m length is 237.70 kg/m3. This could be due to the higher compactness of smaller RHP particles compared to the larger ones. Smaller RHP particles improved the FD of RHP-filled NRLF following the introduction of the NRL compound.

3.5 Rubber Filler Interaction

Figure 3 highlights the relationship between RHP size reduction and rubber filler interaction in RHP-filled NRLF. As the RHP size is decreased, the Qf/Qg value decreases. It is understood that the degree of interaction between the filler and matrix increases with decreasing Qf/Qg values [39]. According to Figure 3, the rubber filler interaction gets stronger as the RHP size gets smaller. The fraction of surface area available for interaction with the NRL chemical increases when RHP size is decreased, thereby increasing the compatibility between RHP and the rubber particles in the NRL compounds. This minimizes the filler-filler & matrix-matrix interaction while encouraging filler-matrix interaction, which results in more crosslink formation.

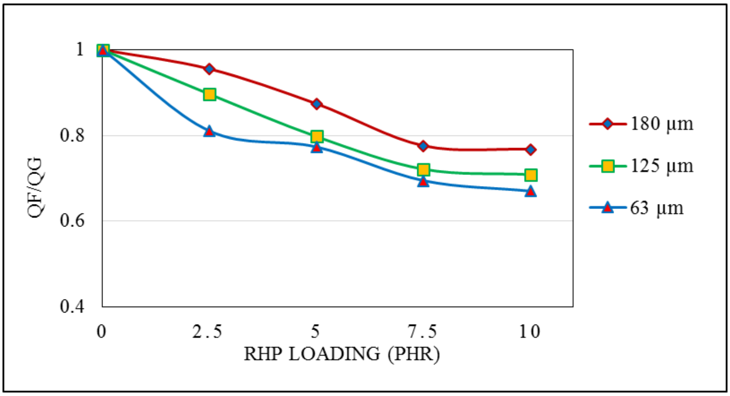


Figure 3: *The rubber-filler interaction of various sized RHP filled NRLFs.*

3.6 Compression Set Properties

The constant deflection compression set, Ct of controlled and different-sized RHP-filled NRLFs, is shown in Figure 1(f). The compression test is better way of understanding the behavior of RHP-filled NRLF when heated and compressed. A material's high elastic behavior is indicated by low compression sets [40]. Figure 1(f) illustrates the pattern of increase in the compression set as the size of the RHP decreases. The recovery percentage was observed to decrease as the RHP size decreased, as seen in Figure 1(g). The lighter the particles interact better with the NRLF compound when the size of the RHP particles is reduced, bringing about a better distribution of the RHP particles within the NRLF. The compressed RHP-filled NRLFs were heated at 70 ^{o}C for a while during the compression set test. The smaller, more evenly distributed RHP particles underwent deformation and hardening, which improved the stiffness of the NRLF-filled RHP. When compared to NRLFs with larger RHP particle sizes, these RHP-filled NRLFs appeared to exhibit a lower recovery percentage.

4. Conclusion

This study demonstrated that smaller RHP particles increase the interfacial adhesion of RHP and NRLF, making RHP a more suitable reinforcing filler for improving the tensile characteristics, hardness, compression behavior, and foam density of NRLFs. The strong RHP particles-NRLFs interaction, which affects the properties of NRLFs, is also explained by the rubber filler interaction and the Qf/Qg value which decreases with the RHP size. The reduction of the RHP particle size caused only a slight increase in foam density. The optimum stress value was noted for 50% compression of 10 pphr of 63 m-sized RHP-filled NRLF. A higher level of compatibility was also observed between the RHP and the rubber particles in the NRL compound following a reduction in RHP size, leading to improved reinforcement.

Acknowledgements

The authors would like to gratefully acknowledge Universiti Sains Malaysia, CeGeoGTech, Universiti Malaysia Perlis for all their support.

Conflicts of Interest: **The authors have no conflict of interest to any part.**

Abbreviations

Symbols	Description
RHP	Rice Husk Powder
NRLF	Natural Rubber Latex Foam
ZDEC	Zinc diethyldithiocarbamate
ZMBT	Zinc 2-mercaptobenzhiozolate
DPG	Diphenylguanidine
SSF	Sodium silicofluoride
RH	Rice Husk
NR	Natural Rubber
NRL	Natural Rubber Latex
PMW	Processed Mica Waste

References

[1] Li Y, Ding X, Guo Y, Rong C, Wang L, Qu Y, et al. A new method of comprehensive utilization of rice husk. J Hazard Mater 2011;186:2151–6.

[2] Rozman HD, Kumar RN, Khalil HPSA, Abusamah A, Lim PP, Ismail H. Preparation and properties of oil palm frond composite based on methacrylic silane and glycidyl methacrylate. Eur Polym J 1997;33:225–30.

[3] Al-khafaji ZS, Radhi NS, Mohson SA. Preparation and modelling of composite materials (polyester-alumina) as implant in human body. Int J Mech Eng Technol 2018;9.

[4] Mussa MH, Abdulhadi AM, Abbood IS, Mutalib AA, Yaseen ZM. Late age dynamic strength of high-volume fly ash concrete with nano-silica and polypropylene fibres. Crystals 2020;10:243.

[5] Li J, Salim RD, Aldlemy MS, Abdullah JM, Yaseen ZM. Fiberglass-reinforced polyester composites fatigue prediction using novel data-intelligence model. Arab J Sci Eng 2019;44:3343–56.

[6] Johar N, Ahmad I, Dufresne A. Extraction, preparation and characterization of cellulose fibres and nanocrystals from rice husk. Ind Crops Prod 2012;37:93–9.

[7] Premalal HGB, Ismail H, Baharin A. Comparison of the mechanical properties of rice husk powder filled polypropylene composites with talc filled polypropylene composites. Polym Test 2002;21:833–9.

[8] Cao XV, Ismail H, Rashid AA, Takeichi T, Vo-Huu T. Maleated natural rubber as a coupling agent for recycled high density polyethylene/natural rubber/kenaf powder biocomposites. Polym Plast Technol Eng 2012;51:904–10.

[9] Khalf AI, Ward AA. Use of rice husks as potential filler in styrene butadiene rubber/linear low density polyethylene blends in the presence of maleic anhydride. Mater Des 2010;31:2414–21.

[10] Al-Khafaji ZS, Majdi A, Shubbar AA, Nasr MS, Al-Mamoori SF, Alkhayyat A, et al. Influence of High Volume RHA on Properties of Cement Mortar. IOP Conf Ser Mater Sci Eng, vol. 1090, IOP Publishing; 2021, p. 12028.

[11] Al-Baghdadi HM, Shubbar AAF, Al-Khafaji ZS. The Impact of Rice Husks Ash on Some Mechanical Features of Reactive Powder Concrete with High Sulfate Content in Fine Aggregate. Int Rev Civ Eng 2021;12:248–54.

[12] SHUBBAR ALI, Al-khafaji Z, Nasr M, Falah M. Using non-destructive tests for evaluating flyover footbridge: case study. Knowledge-Based Eng Sci 2020;1:23–39.

[13] Hanoon DS, Sallal AK, Shubbar AA, Al-Khafaji ZS, Nasr MS, Al-Mamoori SF, et al. Early age assessment of cement mortar incorporated high volume fly ash. IOP Conf Ser Mater Sci Eng 2021;1090:012019. https://doi.org/10.1088/1757-899x/1090/1/012019.

[14] Ghayyib RJ, Salman AJ, Jawad ZF, Al-Khafaji ZS. Effect of Silica-Based Wastes on Wear Rate and Hardness Properties of Epoxy Composites as a Construction Material. Key Eng Mater, vol. 895, Trans Tech Publ; 2021, p. 31–40.
[15] Shubbar A, Nasr M, Falah M, Al-Khafaji Z. Towards net zero carbon economy: Improving the sustainability of existing industrial infrastructures in the UK. Energies 2021;14:5896.
[16] Hamad MA, Nasr M, Shubbar A, Al-Khafaji Z, Al Masoodi Z, Al-Hashimi O, et al. Production of Ultra-High-Performance Concrete with Low Energy Consumption and Carbon Footprint Using Supplementary Cementitious Materials Instead of Silica Fume: A Review. Energies 2021;14:8291.
[17] Al-Mamoori SF, Shubbar AA, Al-Khafaji ZS, Nasr MS, Alkhayyat A, Al-Rifaie A, et al. Production of Ternary Blend Binder as an Alternative to Portland Cement. IOP Conf Ser Mater Sci Eng, vol. 1090, IOP Publishing; 2021, p. 12069.
[18] Yalcin N, Sevinc V. Studies on silica obtained from rice husk. Ceram Int 2001;27:219–24.
[19] Ciannamea EM, Stefani PM, Ruseckaite RA. Medium-density particleboards from modified rice husks and soybean protein concentrate-based adhesives. Bioresour Technol 2010;101:818–25.
[20] Chand N, Sharma P, Fahim M. Tribology of maleic anhydride modified rice-husk filled polyvinylchloride. Wear 2010;269:847–53.
[21] Zhao Q, Zhang B, Quan H, Yam RCM, Yuen RKK, Li RKY. Flame retardancy of rice husk-filled high-density polyethylene ecocomposites. Compos Sci Technol 2009;69:2675–81.
[22] Yang H-S, Kim H-J, Son J, Park H-J, Lee B-J, Hwang T-S. Rice-husk flour filled polypropylene composites; mechanical and morphological study. Compos Struct 2004;63:305–12.
[23] Kim H-S, Kim S, Kim H-J, Yang H-S. Thermal properties of bio-flour-filled polyolefin composites with different compatibilizing agent type and content. Thermochim Acta 2006;451:181–8.
[24] Hossain KMZ, Chowdhury AMS, Haque ME, Dafader NC, Akhtar F. Effect of natural antioxidant (Diospyros peregrina) on the aging properties of radiation vulcanized (γ-radiation) natural rubber latex film. Polym Plast Technol Eng 2010;49:136–40.
[25] Barlow C, Jayasuriya S, Tan CS. The world rubber industry. Routledge; 2014.
[26] Alkhabet MM, Yaseen ZM, Eldirderi MMA, Khedher KM, Jawad AH, Girei SH, et al. Palladium/Graphene Oxide Nanocomposite for Hydrogen Gas Sensing Applications Based on Tapered Optical Fiber. Materials (Basel) 2022;15:8167.
[27] Keshtegar B, Bagheri M, Yaseen ZM. Shear strength of steel fiber-unconfined reinforced concrete beam simulation: Application of novel intelligent model. Compos Struct 2019;212:230–42.
[28] Dananjaya SA V, Somarathna YR, Karunanayake L, Siriwardena S. Waste mica as filler for natural rubber latex foam composites. J Polym Res 2022;29:1–16.
[29] Krunarathna GT, Withanage NS, Edirisinghe DG. Effect of different types of fillers on properties of natural rubber latex foam 2015.
[30] Blackley DC. Polymer Lattices Science and Technology. Vol. 3. Maclaren & Sons London 1966.
[31] Joseph R. Practical guide to latex technology. Smithers Rapra; 2013.
[32] Kajon S, Suwanna P. Development of Natural Rubber Latex Foam with Reduced Allergenic Potential for Hand Exercising Application 2020.
[33] Rathnayake W, Ismail H, Baharin A, Darsanasiri A, Rajapakse S. Synthesis and characterization of nano silver based natural rubber latex foam for imparting antibacterial and anti-fungal properties. Polym Test 2012;31:586–92.
[34] Kanagaraj L, Bao CA, Ying CS, Ing K. Mechanical properties and thermal stability of methyl methacrylate grafted latex and natural rubber latex foam blends. J Eng Sci Technol 2019;14:3616–27.
[35] Hussain AJ, Al-Khafaji ZS. Experimental investigation on applying waste iron filings in the engineering fields for protection the environment from contamination. Mater Today Proc 2021.

[36] Roberts AD. Natural rubber science and technology. Oxford University Press; 1988.
[37] Hamza ZP, Dilfi KFA, Muralidharan MN, Kurian T. Microwave oven for the rapid determination of total solids content of natural rubber latex. Int J Polym Mater 2008;57:918–23.
[38] Rahman MW, Haque ME, Rahman MM, Abedin MZ. Improvement of physico-mechanical properties of radiation-vulcanised natural rubber latex films by adding urea. Polym Plast Technol Eng 2009;48:696–700.
[39] Varghese S, Karger-Kocsis J. Natural rubber-based nanocomposites by latex compounding with layered silicates. Polymer (Guildf) 2003;44:4921–7.
[40] Nawamawat K, Sakdapipanich JT, Ho CC, Ma Y, Song J, Vancso JG. Surface nanostructure of Hevea brasiliensis natural rubber latex particles. Colloids Surfaces A Physicochem Eng Asp 2011;390:157–66.