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Sustainable and Recycled Materials Additives for Tire Rubber Manufacturing: A Review

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Abstract:

Material scientists and researchers aim to create durable, manufacturable, affordable, and lightweight materials. Nanomaterials have attracted significant attention due to their distinct physical and chemical properties, which are most commonly employed in automobile tires. Tires are manufactured by blending several materials, including rubber, steel threads, and reinforced fillers. Rubber mixes play a crucial role in tire attributes. It determines road-contact tire cover performance. A good tire has minimal rolling friction and a strong grip. The physical and chemical reactions between the rubber and the filler determine tire quality. Previous studies investigated adding materials, such as carbon black, nano-silica, nano-alumina, titanium oxide, and clay nano-grains. Also, this article summarizes the research status of the green materials that can meet the requirements of environmental friendliness and sustainability, replace traditional materials, and sustainable materials that are additives for natural and synthetic rubber of tires come from natural sources, such as rice ash, coconut, or recycled waste tire, to improve the tire properties, such as tensile strength, hardness, wear resistance, fatigue and rolling resistance, thermal conductivity, abrasion resistance, rebound resilience and wet grip. This brief provides insight into the sustainable and unsustainable additives and discusses their application in tire manufacturing.

Keywords:

Carbon black; Nanomaterial; Nano additives; Rice husk silica; Sustainable materials; Tire rubber.

Highlights:

- Promoting tire rubber's thermal conductivity by employing tread tire rubber nano reinforcement fills.
- Using a different amount of rice husk silica as a sustainable filler during tire manufacturing to maximize tire life.
- Enhancing the mechanical properties of tire rubber using various fillers, such as clay, carbon black, and silica, among others.

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1.INTRODUCTION

The most important rubber products in terms of volume and significance are automobile tires. They are the vehicle's most significant design and spring component. The tire industry accounts for more than half of the global rubber consumption, both natural and synthetic [1]. A tire must also exhibit limited wear, strong durability, and provide adequate driving comfort. To maximize mileage, abrasion resistance should be as high as feasible. The rolling resistance must be as low as possible to reduce the environmental impact and driving cost, and to reduce fuel consumption [2]. The so-called "magic triangle" of tire qualities comprises the three most significant attributes: rolling resistance, tread wear, and wet grip. It is necessary to strike a balance between them. These standards are incompatible since it is not feasible to improve all three qualities simultaneously. In every case, a compromise between these qualities ought to be reached [3]. The tradeoff between strong wet grip, low rolling resistance, and high wear resistance has historically been a significant issue for tire designers. The amount of energy absorbed during rotation and deflection is known as rolling resistance. Less gasoline is needed to move the car ahead due to the lower rolling resistance. However, reducing rolling resistance often impairs wet grip, which is obviously undesirable [4,5]. The tire tread compound can be significantly improved by substituting silica for (all or part of) carbon black. This substitution has enabled manufacturers to create tires that offer greater winter performance, improved wet grip, and lower rolling resistance [4,5]. The curing behavior and physio-mechanical properties of an SBR rubber-based tire tread compound with N234 carbon black are studied in NR and BR rubber blends with N330 carbon black. The effects of sulphur and accelerator contents on the characteristics of rubber compounds are examined using numerous curing agents [6]. Demonstrated how the failure and strength characteristics of a bias tread NR/BR-based compound were affected by the partial replacement of natural rubber with synthetic rubbers, styrene butadiene, and cis butadiene, using effective and conventional Sulphur curing systems and mixtures of various carbon black grades [7]. Carbon black is a popular filler in rubber tire compounds; however, it is being replaced by silica due to "green tires" improved rolling resistance, durability, and wet grip. [8,9]. Approximately 22% of Rice husk generated during milling is a significant agricultural residue used as biomass, a promising energy carrier with potential for environmentally friendly energy utilization [10]. Nanosilica powder, known for its high porosity and surface area, is used for various applications, including improving the properties of industrial tires through its thermal degradation capabilities [11]. Lignin-silica hybrids can be produced from biomass through alkaline fractionation, pH adjustment, and pyrolysis under inert gas conditions, yielding carbon-silica materials with diverse applications. [12]. Figure 1 summarizes recent advancements in structured silica materials, nano-silica gel, and hybrid silica-based composites from various alternative sources [13].

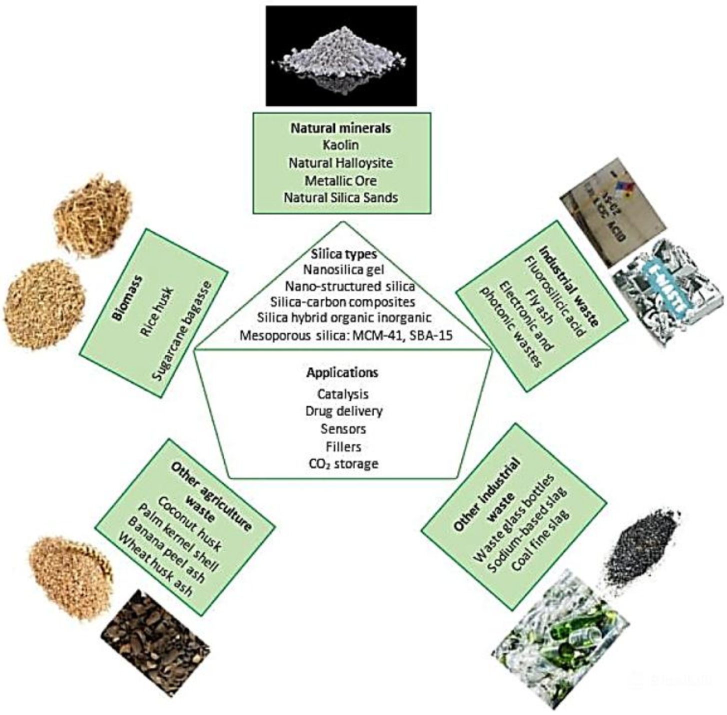

Fig. 1 The Diagram Depicts Various Types of Silica from Various Natural and Industrial Wastes and their Various Applications [13].

A benign chemical process is used to extract amorphous silica nanoparticles from rice husk ash, with an average diameter of 35nm, without releasing harmful CO or other pollutants. [14]. The development of green rubber, cords, and additives in tire fabrication focuses on sustainability, derived from bio-renewable resources or waste materials. It will significantly contribute to the tire manufacturing industry, as shown in Fig. 2 [15].

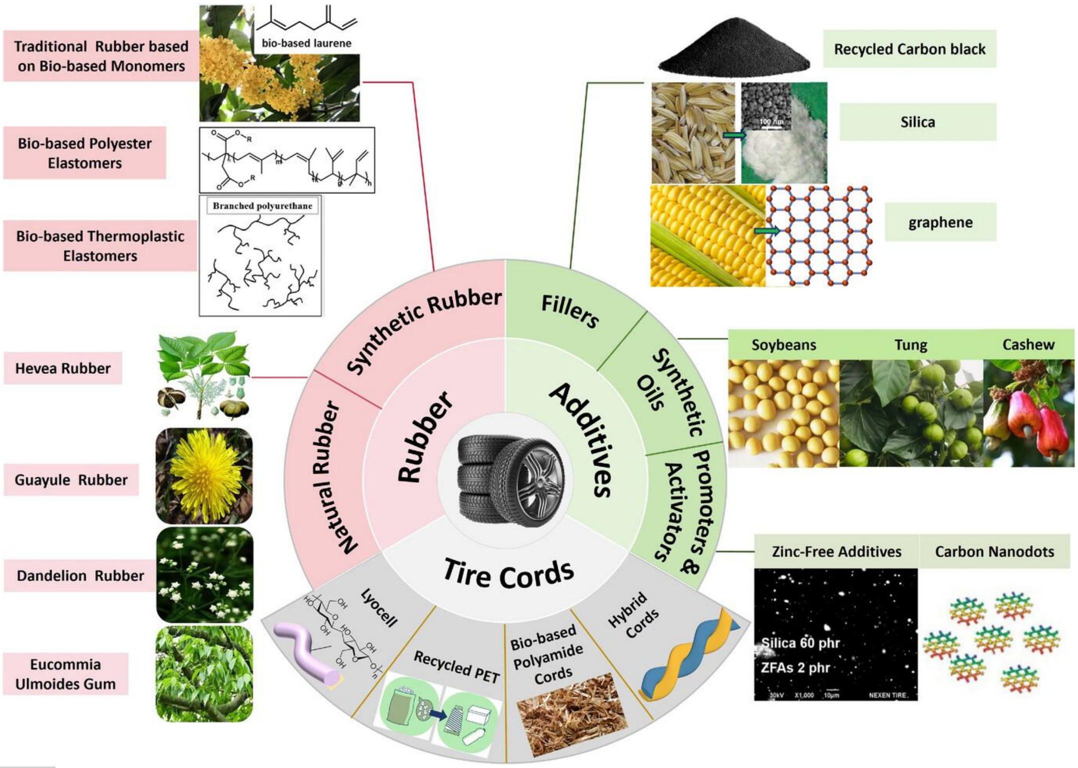

Fig. 2 A Comprehensive Overview of the Sustainable Materials Currently Utilized in Tires [15].

The purpose of this study is to improve the dynamic and mechanical properties of rubber tires through the use of materials that have been previously published and discussed by researchers. These materials can be developed from sustainable materials derived from natural sources, thereby increasing tire life and wear resistance.

2.AUTOMOBILE NANOTECHNOLOGY APPLICATIONS

Advancements in nanotechnology are expected to impact the automotive sector. The small size of nanoparticles allows modification of their chemical and physical properties to enhance the overall performance of conventional materials, and an increase in the surface area of metal nanoparticles leads to a significantly higher level of reactivity in a converter that removes pollutants, thereby reducing emissions [52].Because humans rely on cars more frequently than either air or water transportation, the automotive industry is where much nanotechnology-based research and development is concentrated. Nanotechnology is influencing automotive interiors, electronics and electrics, drive trains, engines, chassis, tires, and emissions. Figure 3 shows the significant car components that have been altered by nanotechnology [16].

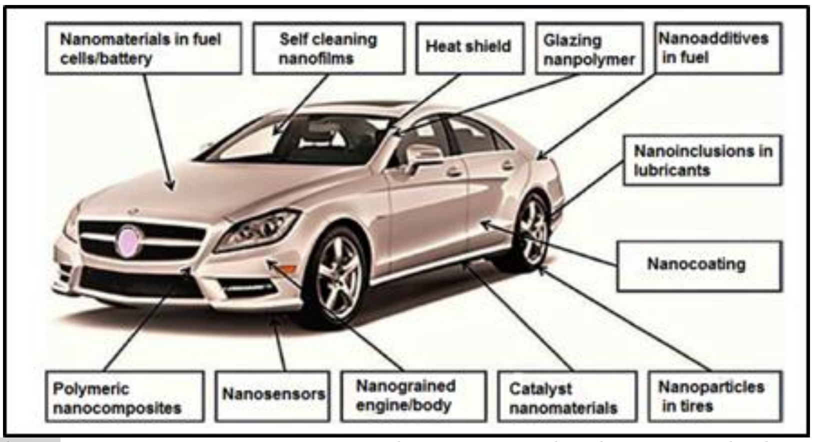

Fig. 3 Various Car Components Where Nanotechnology is Applied [17].

3.FUNCTIONS AND PERFORMANCE OF TIRES

The foundation of the automotive mechanism is made up entirely of tires [18]. The tires serve several purposes and are an important part of the car. The whole weight of the vehicle is first carried by the tires. Second, friction between the tire and the road in the longitudinal direction produces the traction force and the braking force. Third, the tires generate steering forces and provide lateral directional stability through friction between the tire and the road. Last but not least, the vertical flexibility of the tires cushions the car over road imperfections and absorbs road impact [18].

4.MATERIALS USED IN A TIRE

The car tire is composed of several layers and components, as seen in Fig. 4 [18]. It is primarily comprised of rubbers, including natural rubber (NR), polybutadiene rubber (PB), styrene-butadiene rubber (SBR), and polyisoprene rubber (IR). Other ingredients include fillers, antioxidants, vulcanization agents, and accelerators. [19-20]. Car tires typically contain about 75% SBR, 10%-25% PB, and 0-15% NR. Heavy goods vehicle (HGV) tires typically contain 10% SBR, 10% PB, and approximately 80% NR [21]. The variance in composition results from the various operating conditions to which truck tires are subjected, including higher loads, varying lateral forces, and longer service lives [22-23]. As vulcanization agents, sulfur, selenium, and tellurium make up about 1% to 2% of the mass of automobile and HGV tires [24]. In elastomers, these compounds are added in a ratio of 3–4 parts per 100 parts of rubber [21]. As vulcanization accelerators, Pb, Mg, Zn, certain sulfur compounds, and calcium oxides are added [25].

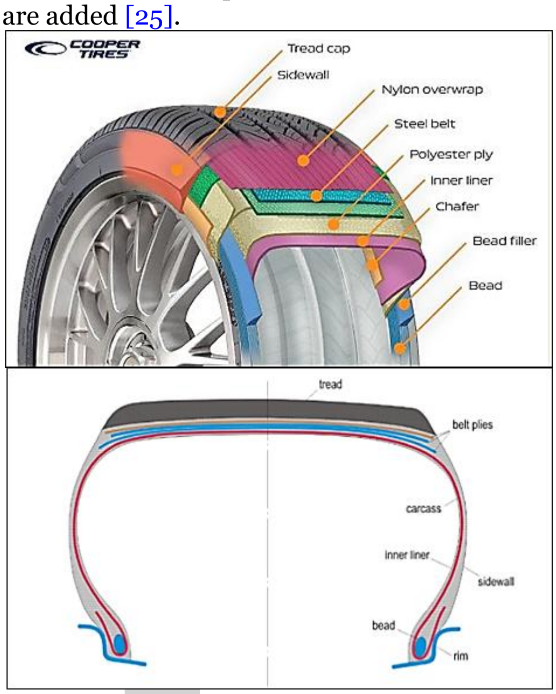

Fig. 4 Parts of a Tire [10].

5.USE NANOMATERIALS IN TIRES

Nanotechnology plays a crucial role in developing innovative materials and processes in the automotive industry. For example, silica and nanoscale soot particles provide current tires with their excellent mileage, durability, and traction. Materials with layers or nanoparticles at the nanoscale have positive effects on both exterior and interior surfaces. Smaller fractions of nanomaterials enhance the matrix's properties, resulting in lightweight composites with reduced cost and easier processing. Due to their increased surface area, nanocomposites transfer load more efficiently from the matrix to the reinforcements. Assuming excellent adhesion at the interface, nanomaterials can be reduced in size, thereby decreasing the crack-propagation length at the interface and improving strength and toughness [26]. Carbon black (CB) is produced in 15 million metric tons per year, of which 93% (automobile tires, 73%), 20% rubber products other than tires, and 7% going into paints, inks, coatings, and plastics compounding [27]. About 30% of the rubber mixture used to make tires consists of fillers. The use of fillers enhances the tire's strength and performance. The interactions between the rubber and the reinforcing fillers determine how well tires operate. Nano fillers have been used to enhance tire performance due to their surface properties. Common fillers include silica, soot, and carbon black [16].

6.ADDITIVES, NANOPARTICLES, OR NANO FILLERS FOR RUBBER TIRE

Regarding its vast improvement in the last decades, the tire industry has always taken first place due to the volume of studies done on improving the properties of rubber, such as rheological properties, tensile properties, tear resistance, and bonding strength, through the use of many different materials as fillers for rubber tires. Alkhazraji [28] employed 60phr carbon black with aluminum oxide nanoparticles (50 nm) at 2.5%, resulting in an 800% reduction in wear and slip rate, an increase in hardness, and a 22% increase in cornering stiffness. Yang [29] employed a combination of polyvinyl chloride (PVC) and silicone rubber, incorporating nano calcium carbonate ($CaCO_3$), to enhance the mechanical properties of the material. Ying [30] showed the effects of incorporating nano-SiO_2 materials on the mechanical and electrical properties of rubber-based composites for specific applications. Ali Samadi [31] improved uniaxial tension tests by incorporating nanoclay montmorillonite into butyl-based rubber vulcanized with a phenolic resin for use in bladder formulation. Bhushan [32] investigated the addition of nanoclay particles to three carbon black grades at 20 phr: N330, N550, and N660. The findings revealed that N550 carbon black had the best nanoscale effect, improving tensile strength by roughly 53%. Zafarmehrabian [33] found that adding precipitated silica ratios of 5, 10, and 20 to tread tire rubber (NR, BR) improved fatigue resistance, rolling resistance, and heat accumulation. Silica in the rubber compound composition decreased tire tread tensile strength, modulus, and wet grip. The size and surface of carbon black particles significantly impacted tire characteristics. In the tire industry, replacing carbon black with precipitated, shapeless silica is a common reinforcing additive, especially for passenger and truck tread compounds. Silica's surface differs from that of carbon black, resulting in distinct dynamic properties when reacting with elastomers. However, using silica alone significantly increases compound viscosity, making it difficult to prepare and cure rubber compounds. Therefore, silica filler and fluidity factors have been beneficial for improving process ability and reinforcing properties [34-35]. Silica-filled compounds are commonly employed in the tire industry to achieve an optimal balance among rolling resistance, wet grip, and abrasion resistance [36]. Meng-jiao Wang [37] examined the effects of adding silica particle weight ratios to S-SBR, BR, and IR rubber. The rubber composites offer superior wear resistance. Ahmad Zarei [38] mixed nanocomposites based on organo clay [OC]/butadiene rubber [BR]/natural rubber [NR] with three sulfur/accelerator ratios: S/Acc 1.5/2, 1.5/1.5, and 2.5/1. Lower S/Acc ratios increased OC intercalation and impacted crosslink density and polysulfide bond percentage, thereby decreasing sample tensile performance and abrasion loss. Mohd Bijarimi [39] demonstrated that carbon black structures and carbon black grades N375 and N339 had an insignificant effect on the physical properties of NR/SBR composites, including hardness, rebound resilience, tensile strength, and tear strength. Bandyopadhyaya [40] tested sinusoidal tensile loading on vulcanised NR sheets with a thickness of 2mm and four carbon black loadings: 0, 20, 40, and 60 phr. The results showed that the damping properties of filled rubber decreased with increasing carbon black content. Wisojodharmo [41] mixed Natural Rubber (NR) and Butadiene Rubber (BR) at 100:0, 95:5, and 85:15 with N220 and N234 carbon black. Adding BR to NR enhanced abrasion resistance, rebound resilience, and hardness. However, the rubber compounds reinforced with N220 or N234 appeared to have equivalent mechanical and thermal qualities. Gaob [42] used nanocarbon-coated silica as a reinforcing agent in tire tread rubber at three ratios: 0, 22.5, and 45 Phr. The results showed that the dynamic mechanical properties and thermal conductivity were significantly improved at a 45 Phr ratio. Oleiwi [43] showed Al_2O_3 and SiO_2 were added to SBR at 0, 5, 10, 15, 20, and 25 phr. Increasing the Al_2O_3 and SiO_2 reinforcing filler loading resulted in the greatest performance. SiO_2 improved tensile, hardness, and abrasion resistance more than Al_2O_3. Whereas Al_2O_3 outperforms SiO_2 in thermal conductivity and resilience. Robertson ٤٤]] found that the heat treatment of CB at around 1000°C eliminated surface functional groups without changing surface area, reducing bound rubber and mechanical reinforcement. Sethulekshmi [45] reviewed the reinforcing ability of different nanofillers, such as clay, graphene, carbon nanotube CNT, TiO_2, chitin, cellulose, and BaTiO, in the NR matrix. Sajjayanukul [46] used the Mooney viscometer and the Rubber Process Analyzer to study natural rubber (NR) compounds with varying carbon black loadings and types. Carbon black significantly affects rubber viscoelasticity, and the uncured NR damping factor decreases with increasing black loading. According to Soares [47], using metal oxides, such as titanium dioxide nanoparticles, as solid fillers in tiers can provide unique properties, including UV blocking, antifouling, antibacterial, and increased modulus and tensile strength. Titanium dioxide nanoparticles are utilized as tire wall pigment and in filler modification with a silane to enhance rubber mixture interaction. Akinlabi [48] found that titanium dioxide nanoparticles in tire filler minimize dynamic hysteresis loss. The research indicated that reducing dynamic hysteresis loss by 10% can result in a 2% decrease in fuel usage. Chueangchayaphan [49] found that adding TiO_2 from 0 to 110 phr to Acrylonitrile butadiene rubber NBR rubber enhanced the composites' dielectric constant from 102 to 105 Hz. The TiO_2-filled NBR composite offers enormous potential for dielectric elastomer actuators. Vaikuntam [50] examined the effects of in-situ silica and precipitated silica on the friction, abrasion, and cracking of solution styrene-butadiene rubber (SSBR) polymers. In-situ silica systems reduced friction coefficients, aiding low rolling resistance. Giftson [51] concluded that Natural rubber or styrene-butadiene rubber (SBR) with 3% multiwall carbon nanotubes and 10% silicon dioxide (Nanosilica) improved tensile strength, tear strength, and hardness by 600%, 250%, and 70%, respectively. Additionally, it was demonstrated that 3% montmorillonite clay and 10% silicon dioxide were added to natural rubber (SBR), improving stiffness, thermoplastic stability, and decay resistance. Tomar [52] found that adding nanoscale soot increased fuel economy and durability, due to the coarser surfaces it provided compared to regular tires. Due to their high surface energy, soot nanoparticles interact strongly with natural rubber in tires, improving rolling resistance and reducing inner friction. Jinu [53] added 10% nanosilica to natural rubber or SBR to boost wear resistance and grip. The hardness and tensile strength of natural rubber or SBR can be increased by adding 3%. Multiwall carbon nanotube MWCNT. Xu [54] modified soybean oil (MSO); it was synthesized from soybean oil and Sulphur. The double bond number decreased from 4.6 to 1.7 per molecule as the sulphur weight percentage increased from 0 to 9 wt %. Tread rubber-modified soybean oil TR-MSO-25phr was compared to tire tread rubber-aromatic hydrocarbon plasticizer (TR-AO) to assess MSO's tire tread rubber application. The ageing and wear resistance of MSO-6% plasticized rubber was superior to that of AO-plasticized rubber. Liu [55] prepared epoxidized solution-polymerized styrene-butadiene rubbers (ESSBR) with varying epoxy degrees as macromolecular coupling agents to eliminate VOCs.Silica/ESSBR/SSBR/BR nanocomposites excelled Bis-(ɤ-triethoxysilylpropyl)-disulfide (TESPD) modified silica/rubber nanocomposites in dynamic and static mechanical tests, without volatile organic compounds VOC emissions. Cardona [56] studied Pyrolytic carbon black (CBp). It includes the original CB (80-90 %) introduced in the tires manufacturing process, as well as Sulphur (1-3 weight %) and a proportionate amount of inorganics, such as SiO_2, ZnO, K_2O, and Fe_2O_3 (10-15 wt.%). The presence of inorganics in CBp impairs the critical attributes of rubber composites, such as tensile strength, tear strength, and hardness. According to Van Hoek's study [57], the greatest tensile strength of a revulcanization formulation based on carbon black was 5 MPa. It could be enhanced to 6.5 MPa using 2.8 phr of 1,3-DiPhenylGuanidine (DPG) in the formulation. After adding a silanization step during the revulcanization process by adding 3.2 phr bis[3-(triethoxysilyl)Propyl]Tetrasulfide (TESPT), tensile strength improved to 8 MPa [58-60]. The seven most common elements in tire components are shown in Table 1, along with their origins and purposes [61-65].

Table 1 The Elements Found in Tire Components.

Element	Source/Function
Zinc	Vulcanization activator/accelerator that promotes the production of rubber crosslinks [61].
Iron	Component of steel belts in tire structure [62].
Aluminum	Tires can be made with aluminum hydroxide added to improve traction in wet or snowy conditions; however, this addition has lowered tire life due to decreased abrasion resistance [63]. Aluminum powder has also been used to shorten the vulcanization time of thick rubber composites [61].
Magnesium	Magnesium oxide is used as a vulcanization accelerator in tires. It has been used in rubber since the 1840s. It is now more widely employed as a curing agent and acid neutralizer in polychloroprene and other elastomers; it is also a filler that imparts the rubber with fire, corrosion, and wear resistance [62].
Copper	Steel cords used in tire manufacturing are coated with brass to promote rubber-metal adhesion [63].
Titanium	Titanium (together with cobalt, nickel, and chromium) is employed as a catalyst in the conversion of 1,3-butadiene to polybutadiene rubber [64].
Barium	Barium is used as a filler in various rubber products and for its acid resistance [64]. Barium compounds, such as barite and Blanc Fixe (BaSO4), are marketed as enhancing tire "aging resistance and weatherability" [65].

Esmaeili [66] revealed that Multi-Walled Carbon Nanotubes (MWCNT) increased energy dissipation by 1040 % at 10 phr MWCNTs compared to the control at a strain size of 200 %. Rathi [67] examined the dispersion of Treated Distillate Aromatic Extracts (TDAE) oil in an SBR/BR mix, i.e., the most common tire industry blend for the Passenger Car Tire (PCT) tread. The goal is to discover a technique for an SBR/BR blend compound compatible with TDAE oil that improves tread performance. Ferrer [68] studied the economic usefulness of heat generation in cement kilns and power plants, culminating in tire remanufacturing. Also, Ferrer [68] proposed a simple choice criterion for tire retreaded frequency. Indriasari [69] blended NR and BR with CB and TDAE oil at 70 °C and a rotor speed of 50 rpm. An improvement in Mooney viscosity and 300% elongation modulus was found by increasing filler mixing time and high rotor speed. Zhu [70] found that high-performance silica/rubber composites could be produced using serial continuous mixing rather than two-stage mixing. SSBR and BR were the matrix rubber. 45 phr silica and 25 phr carbon black-reinforced formulations showed better filler mixing and increased filler dispersion, as well as improved physical, mechanical, and dynamic mechanical characteristics. Grunert [71] precipitated silica and bifunctional organosilanes nearly completely replace carbon black fillers in modern passenger car tire tread compounds to increase wet traction (safety) and rolling resistance (fuel economy). Bijarimi [39] discovered that an NR compound containing high-structural carbon black N550 improved torque and achieved faster cure times. NR/SBR mixtures did not impact this behavior. Carbon black grades did not affect NR/SBR mixes' hardness, rebound resilience, tensile, or rip strength. The effect of the vulcanization additive (VA) was investigated in silica-filled epoxidized natural rubber ENR tire treads. Kunakorn Chumnum [72] demonstrated composites made from bromobutyl rubber (BIIR) and natural rubber (NR) mixes with CNTs and carbon black. BIIR was altered using ionic liquid (IL) and butylimidazole (IM) and combined with NR at 70:30 and 80:20 ratios to optimize self-healing propagation. Compared to pure BIIR/NR blends, BIIR/NR-CNTCB with IL and IM improved curing and tensile characteristics. Ravi [73] proposed popular natural fillers, including jute, sisal, hemp, bamboo, grass, and bagasse. Various definitions exist for natural and synthetic fibers in polymer science and engineering. The definitions focus on climate change compliance and are customized to specific composites applications. The use of synthetic fibers as reinforcing agents offers many benefits; however, environmental concerns, such as high manufacturing costs, non-biodegradability, and limited reuse, drive the search for eco-friendly, biodegradable alternatives in natural fiber composites [74-78]. Mirabedini [79] found that TiO_2 increased the modulus of silicone elastomer coatings (SEC) rapidly in tensile testing. Further increase in TiO_2 led to a drop in modulus. The pull-off test indicated that TiO_2 increased adhesion strength up to 10 wt.%. Bhattacharya [80] studied how nanofillers, i.e., montmorillonite, hectorite, laponite, sepiolite, silica, carbon black, expanded graphite, and carbon nanofibers, affect NR nanocomposites. Carbon black (CB), carbon nanotubes (CNTs), and graphene (GE) all showed the optimal dispersion in temperature-vulcanized (RTV)-SR composites. Song [81] concluded that Pure SR weakened mechanical properties, including a tensile strength of 0.40 MPa and a fracture strain of 115.07%. The fracture strain increased to 211.15%, and the tensile strength reached 4.5 MPa with the addition of a hybrid filler at 10 phr. The mechanical characteristics of the SR/conductive carbon black–polymerized - carbon nanotube (CCB-P-CNT) composite were significantly improved over the SR filled with 10 phr CNTs because conductive carbon black enhanced by polymerization of 3-trimethoxysilyl propyl methacrylate monomer (PMPS) enhances CNT dispersibility in the SR matrix [82]. Adding a graphene nanoribbon (GNR) to the SR matrix improved the composite's mechanical properties [83]. By adding 2 wt% GNR to the SR matrix, the tensile strength increased to 0.40 MPa, the fracture strain fell to 78%, and Young's modulus improved to 0.85 MPa [84]. Sarath [85] found that adding expanded graphite (EG) to the SR matrix improved mechanical properties by increasing the fracture strain to 221% and the tensile strength to 6.8 MPa. With 7 phr EG, the Young's modulus at 100% strain increased to 3.86 MPa, the rip strength rose to 30.2 N/mm², and the hardness increased to 65 [86]. Zhao [87] compared the thermal conductivities of GF and GF-CB hybrid composites in an SR matrix. When GF was introduced to the SR matrix, thermal conductivity improved significantly. Adding CB as a hybrid filler resulted in nearly constant thermal conductivity up to 4 wt% of the CB-GR hybrid in the SR matrix. The thermal diffusivity of SR composites based on GF and CNTs was also measured by Hu [88]. The author found that the Pure SR has a thermal diffusivity of 0.105 m²/s, whereas GF and CNTs improved this value.

7.Sustainable Material Additives of Tire Rubber from Natural Materials and Waste Tire

Pabasara [89] produced carbon black from rice husk waste. The tire inner liner compound was selected based on the particle size of ball-milled Paddy Husk Carbon Black PHCB powder. The compound formula was created for seven PHCB-to-industrial carbon black ratios (N330). A 40% PHCB and 60%N330 carbon black sample had the best characteristics. Fernando [90] investigated the use of rice straw ash with 62%–82% silica as a rubber compounding filler. The rice straw ash improved the tensile properties of rubber vulcanizates; however, it decreased their hardness, tear strength, and compression set. De Silva [91] compared rice husk carbon black (RHCB) with N330 carbon black in terms of rheological and curing characteristics, elongation and strength, resilience, and hardness. The RHCB did not increase strength; however, it positively impacted elasticity or resilience. Choophun [92] revealed the impact of silica loading (10–50 phr) from rice husk waste chemically treated and calcinated at 600 °C on NR. The best mechanical properties were for tensile strength 21 MPa with silica 20phr, hardness shore type A(45) with silica 50phr, and abrasion loss 0.24% with 50 phr composite mechanical characteristics. Chundawat [93] studied Rice husk silica compounds and found they were comparable to conventional silica at the same phr loads (15, 30, and 50). In tread tire tests, higher RHS doses increased rebound resilience and heat buildup and reduced abrasion loss. Fernandes [94] demonstrated how silica could replace carbon black as a filler in tire tread. RHA at (22.5, 45, and 67.5 Phr), which includes more than 70%, the tire uses between 3% and 4% less fuel than one with a tread made of carbon black materials. Also, a 20% decrease in rolling resistance, thereby reducing greenhouse gas emissions. Ullal [95] found that a 30 phr concentration of composite silica+RHA resulted in superior mechanical properties compared to commercial silica filler alone. Le [96] synthesized stable nanosilica from rice husk using the sol-gel technique, achieving a high specific surface of 340 m²/g and an average size of 3 nm. Alnaid [97] examined the effects of Rice Straw (RS) at five

RS loadings: 10, 20, 30, 40, and 50 phr, based on reinforced Standard Malaysian Rubber (SMRL), on modulus, hardness, crosslink density, and tensile strength. The author found that increasing RS content improved properties; however, it reduced tensile strength and elongation. Xue [98] demonstrated that Pyrolytic rice husk (PRH), combining charcoal and silica, functioned as a hybrid filler. The effects of rotating speed and milling media on the physicochemical properties and reinforcing performance of PRH were studied. The highest reinforcement was observed in a ball-milled product made in an ethanol medium at 400 rpm (EM-400). Compared to unmilled/NR vulcanizates, EM-400/NR vulcanizates showed a 44%, 18%, and 9% higher tensile strength, 300% modulus, and rip strength. Jong's [99] natural rubber, filled with 10-40% hydrolyzed corn flour, significantly increased in tensile strength, Young's modulus, and toughness; however, it decreased elongation and 300% modulus compared to unhydrolyzed corn flour composites. Ubi [100] found that rice husk-derived Silica-filled natural rubber composites exhibited favorable mechanical properties and could be used to replace standard fillers in tires. The properties of the RHS at 50 phr to 90 phr filler loading levels were investigated to establish its viability as a replacement for unsustainable carbon black (N772) fillers used in the rubber industry. The RHS composites produced a maximum tensile strength of 13.20 MPa and a rip strength of 119 MPa at 90 phr. They shore the material has a hardness of 69 at 90 phr, a compressive set of 6.72% at 80 and 90 phr, an elongation at break of 453.60% at 80 phr, a bound rubber content of 92.14% at 50 phr, and a crosslink density of 3.87×10^{-2} mol/cm^3 at 70 phr. The tear strength was 63.97%, and the shore strengths were 89.16% and 97.40%, respectively. Gautam [101] prepared spherical nanosilica particles via a sol-gel process using TEOS, ethanol, and liquid ammonia. As the stirring speed increased, the diameters of the particles decreased. At 400 and 600 rpm stirring speeds, the particles had average sizes of 674 nm and 418 nm, respectively. The primary constituents of scrap tire rubber powder were natural and synthetic rubber, with iron (Fe) present, consistent with the steel belt used in tire production. Hasri [102] synthesized Rice husk nanosilica using hydrothermal techniques at various temperatures and durations and investigated its properties. The reaction temperatures employed were 120°C, 150°C, and 180°C, with reaction times of 2, 4, and 6 hours, followed by titration with sulfuric acid to pH 7-8. The XRF examination findings indicated that rice husk ash included 98.31% silica (SiO2). Synthesized nanosilica had the greatest particle size of 27.44 nm at 180°C for 6 hours. The smallest size was 15.40 nm at 120 °C and 6 hours of reaction time. Jembere [103] replaced commercial silica in the natural rubber industry with silica extracted from RHA using alkaline extraction. RHA silica had lower Rheological properties, such as scorch time, and better mechanical properties, including hardness, Young's modulus, and abrasion resistance, compared to commercial silica-filled rubber composites. Jong [104] utilized a flexible carboxylated styrene-butadiene CSB with 25% styrene and 75% butadiene content to interact with the filler network of Soy particles dried powder, which included 90% protein, 5% ash, and 5% fat, with 93% of SP particles generated having a number-averaged size of 210 nm. The composites were formed by mixing natural rubber latex, CSB nanoparticles, and soy protein nanoparticles. These modified natural rubber composites were analyzed to determine the optimal CSB concentration and their static and dynamic mechanical characteristics. Sasidhar [105] extracted the Mesoporous Silica Nanoparticles (MNS) from amorphous RHA using the sol-gel process with a few modifications. The particle size was less than 100 nm. The production of mesoporous nanosilica MNS has intriguing uses in agriculture. Wiebeck [106] combined rice husk ashes and waste tire rubber powder (natural rubber and SBR). Tensile strength, modulus of elasticity, and break strength of test specimens of natural rubber GB1 filled with rice husk ash were 10 phr (RHA) 18.0 MPa, 702%, and 2.56 MPa, respectively. The best Hardness Shore A result was obtained with rice husk ash at 40 phr. Cheng [107] used the alkali-treatment-time approach to produce white carbon black from RH. The purity of white carbon black products reached a maximum at 2 hours, exceeding 99%. Vargas [108] demonstrated recent methods for preparing silica and nanosilica from rice husk, as shown in Fig. 5.

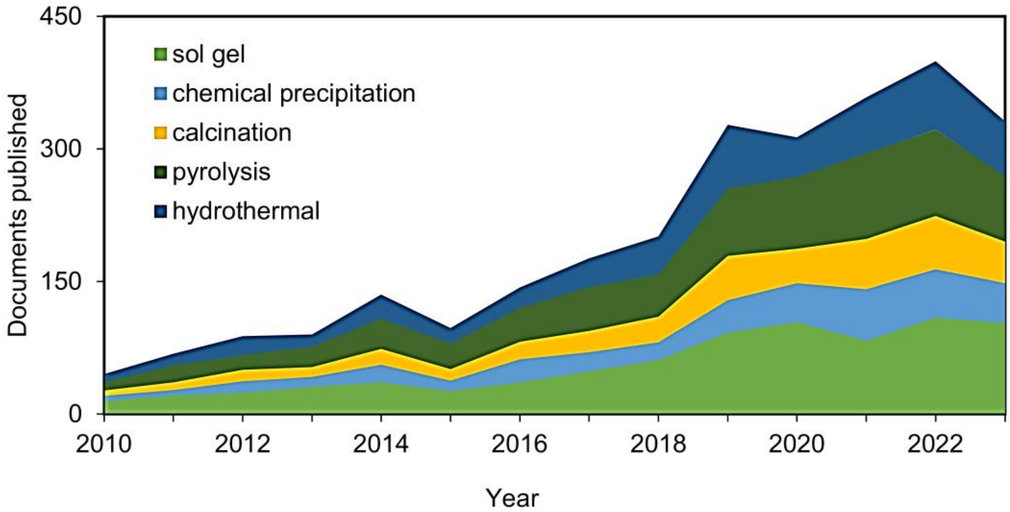

Fig. 5 Evolution and Distribution of Published Publications on Silica Extraction Techniques using Rice Husk During the Previous Decade (Scopus) [108].

Ismail [109] found that the use of white rice husk ash (WRHA) as a filler for natural rubber compounds achieved maximum physical properties at 10 phr. Multifunctional additive (MFA) improved curing characteristics and filler dispersion. Öner [110] showed that adding carbon black from waste tires to epoxy composites improved their mechanical and thermal properties, resulting in a 11.6% increase in flexural strength and a 34.6% increase in crystallization. According to Moulin [111], the specific surface area and oil absorption number of the Recovered Carbon Black (RCB) produced by Steam Water Thrombolysis (SWT) were quite comparable to N330 values of 78 m^2/g and 102 mL/g. Currently, RCB has an ash content of over 20%, whereas typical carbon black has an ash content of less than 1%. It is likely that the high ash content reduces the reinforcing properties. Paleri [112] examined the impact of using carbon black (N762) and biocarbon made from dried distiller's grains with solubles (DDGS) heated to 900 °C. Composites were created and described using 30 phr of filler. The overall mechanical characteristics of the NR matrix showed a decrease in crosslink density due to the increased biocarbon particle size. It has a stronger wet skid resistance and a lower rolling resistance than carbon black vulcanizate, which may be advantageous for tire applications. Hernandez [113] demonstrated the recovery of carbon black CB nanoparticles from waste tires by employing the hydrocarbon pyrolysis process. The CB nanoparticle yield (~22 nm) was recovered. The nanomaterial exhibited strong heat conductivity and stability. Lai [114] represented the weight ratios of pyrolysis carbon black (PCB) from waste tires and N660 carbon black using the sample codes SBR-1, SBR-2, SBR-3, SBR-4, SBR-5, and SBR-6, with values of 0/100, 20/80, 40/60, 60/40, 80/20, and 0/100, respectively. The results showed that PCB black could replace 20% of N660 without significantly affecting SBR compounds in terms of tensile strength and tear strength. However, the Abrasion Resistance Index (ARI) gradually dropped as the amount of PCB black increased. González-González [115] recovered pyrolytic carbon black with various properties by chemically activating waste tire powder with acid (H_2SO_4) and/or alkali (KOH). KOH increased the carbon black's oxygen content, enhancing its stability in water suspension, while H_2SO_4 more effectively removes surface contaminants, increasing its surface area. Verma [116] reported modified epoxy resin composites containing nanocarbon black from waste tire pyrolysis with varying carbon filler contents (0, 5, 10, and 15 wt%). It was found that 5% carbon black in the epoxy resin showed the best mechanical properties. Ojha [117] studied carbon black from agricultural wastes (wood apple peels), using pyrolysis at different temperatures (400, 600, and 800 °C). The author found that it improved tensile strength, tensile modulus, flexural strength, and flexural modulus. Chauhan [118] showed tensile, bending, and impact tests were performed on carbon black-added carbon fiber-reinforced epoxy composite samples at different weight ratios, i.e., 0, 5, 10, and 15% by weight. The hybrid composite (10% by weight) showed significant improvements in tensile strength, flexural strength, and impact strength, with values of 65.78, 32.07, and 36.11%, respectively. Table 2 summarizes the most important rubber additives used in the manufacture of automobile tires.

Table 2 A Summary of the Most Important Rubber Additives Used in the Manufacture of Automobile Tires.

No.	Additives	Results	No.	Additives	Results
1	Employed carbon black 60 phr with aluminum nano oxide (50 nm) at a rate of 2.5%, the natural rubber used SMR20 [28]	increasing in hardness by about 52% due to the addition of 60 phr carbon black, while 44%due to mixing 2.5% of nano Al_2O_3.	14	Precipitated silica replaces carbon black fillers in modern passenger car tire tread [71]	increase wet traction (safety) and rolling resistance (fuel economy)
2	Employed a combination of polyvinyl chloride (PVC) and silicone rubber, together with the incorporation of nano calcium carbonate ($CaCO_3$) [29]	Enhance rubber–plastics-toughening mechanism	15	Adding expanded graphite (EG) to the SR matrix [85]	mechanical characteristics by increasing fracture strain to 221% and tensile strength to 6.8 MPa. With 7 phr EG, the Young's modulus at 100% strain increased to 3.86 MPa, the rip strength rose to 30.2 N/mm^2, and the hardness rose to 65.
3	Additives nano-SiO_2 to rubber [30]	Improving the mechanical and electrical properties of rubber	16	Thermal diffusivity of SR composites based on GF and CNTs [88]	Pure SR was reported to have a thermal diffusivity of 0.105 m^2/s, whereas GF and CNTs improved this value.
4	Incorporating nanoclay montmorillonite into butyl-based rubber [31]	Improved uniaxial tension tests	17	Comparison between the thermal conductivities of GF and GF-CB hybrid composites in SR matrix.[87]	GF was introduced to the SR matrix, and thermal conductivity improved significantly. Adding CB as a hybrid filler resulted in nearly constant thermal conductivity up to 4 wt.% of the CB-GR hybrid in the SR matrix.
5	Adding some nanoclay particles to three different classes of carbon black (N330, N550, and N660) at 20 phr [32]	N550 carbon black has the best nanoscale effect, improving tensile strength by roughly 53%.	18	Adding nanoscale soot with natural rubber in tires [52]	increases fuel economy and durability
6	Precipitated silica ratio (5,10,20) to tread tires rubber (NR, BR) [33]	improves fatigue resistance, rolling resistance, and heat accumulation.	19	Replacing carbon black (22.5, 45, and 67.5 Phr) with RHA silica in a basic tread tire [94] [97]	20% reduction in rolling resistance and, consequently, lower greenhouse gas emissions.
7	Adding silica particle weight ratios to S-SBR, BR, and IR rubber [37]	superior wear resistance	20	Silica nanoparticles from rice husk ash	surface of the sample was about 340 m^2/g, average size of 3 nm
8	Sulfur/accelerator ratios (S/Acc 1.5/2, 1.5/1.5, and 2.5/1) to Nanocomposites based on organo clay [OC]/butadiene rubber [BR]/natural rubber [NR] [38]	Lower S/Acc ratios increased OC intercalation, decreased sample tensile performance, and abrasion loss	21	Surface of the sample was about 340 m^2/g, average size of 3 nm [96]	Higher RS loading resulted in shorter scorch and cure times in SMRL. The fine size of RS gave better properties than the coarser size at the same loading.
9	Carbon black N375 and N339, adding NR/SBR composites [39]	Improvement in hardness, rebound resilience, tensile strength, and tear strength	22	Pyrolytic rice husk (PRH) containing biochar and silica acted as a hybrid filler [98]	The influence of ball milling on the physicochemical properties of PRH was investigated.
10	Mixed Natural Rubber (NR) and Butadiene Rubber (BR) at 100:0, 95:5, and 85:15 with N220 and N234 carbon black [41]	Adding BR to NR enhances abrasion resistance, rebound resilience, and hardness.	23	Spherical nanosilica particles at different stirring speeds (400 rpm and 600 rpm) [117]	The average particle size of nanosilica was 674 nm and 418 nm at stirring rates of 400 rpm and 600 rpm, respectively.
11	Nano carbon-coated silica as reinforcing tire tread rubber (0, 22.5, and 45 Phr) [42]	The dynamic mechanical properties were improved greatly, and thermal conductivity at the value of 45Phr	24	Titanium dioxide nanoparticles as solid fillers in tires [48],[49]	provide unique qualities including UV blocking, antifouling, antibacterial, and increased modulus and tensile strength
12	Al_2O_3 and SiO_2 were added to SBR at 0, 5, 10, 15, 20, and 25 phr [43]	SiO_2 improves tensile, hardness, and abrasion resistance more than Al_2O_3.	25	Add 10% nanosilica to NR natural rubber or SBR [51]	boost wear resistance and grip
13	Aluminum hydroxide added to rubber tire [45],[47].	improve traction in wet or snowy conditions			

8.CONCLUSIONS

This paper reviewed many studies and ideas on the materials used in car tires and their manufacture. The focus is on the most important additives added to tire components to extend their operational life and the results they achieve.

- It was found that adding carbon black alone to the rubber used to make the tire, whether rubber or synthetic, improves hardness and reduces wear. Adding it to rubber with nano-alumina will enhance hardness and stiffness by around 2 times compared to adding each separately. Among the additives that increase the hardness, resilience, and thermal conductivity of the rubber used in tire manufacturing are commercial SIO_2 or sustainable Silica from rice husk waste, silicon dioxide (nanosilica) to NR, and SRB.
- The wear resistance, wet grip, rolling resistance, and abrasion resistance of natural or synthetic rubber were improved by adding rice husk ash-derived nanoalumina or nanosilica particles to BR, IR, SBR, and NR.
- Adding silica to tire tread rubber (NR, BR) and adding nanoscale soot to natural rubber in the tire improves rolling resistance, increasing efficiency and reducing fuel costs.
- Improving the modulus of elasticity of car tire rubber by adding graphene nanoribbon to the SR matrix or using titanium dioxide nanoparticles with natural or synthetic rubber.
- Prior research has demonstrated that nanocarbon black can be extracted from used tires or from natural sources like rice hulls using a variety of techniques, such as sol-gel and perspiration. It can then be recycled as an additive to tire rubber to enhance its performance and also protect the environment through natural and industrial waste disposal.
- Hybrid fillers for tire rubber, such as nanosilica with carbon black, silica with biochar, and carbon black with TiO_2, enhance rheological and mechanical properties of tires.
- Damaged tires can be recycled, and the resulting materials can be used as additives to rubber to improve its properties, such as at the tire factory (governmental and private) in Diwaniyah, Iraq.

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NOMENCLATURE

BR	*Butadiene rubber*
CB	*Carbon black*
CNT	*Carbon nanotube*
DPG	*DiPhenylGuanidine*
GE	*Graphene*
HGV	*Heavy goods vehicle*
IR	*Polyisoprene rubber*
MWCNT	*Multiwall carbon nanotube*
MSO	*Modified soybean oil*
NBR	*Acrylonitrile butadiene rubber*
NR	*Natural rubber*
PB	*Polybutadiene rubber*
PVC	*Polyvinyl chloride*
PHCB	*Paddy Husk Carbon Black*
RHCB	*Rice husk carbon black*
SSBR	*Styrene butadiene rubber polymers*
SBR	*Styrene-butadiene rubber*
SEC	*Silicone elastomer coatings*
TR-MSO	*Tread rubber-modified soybean oil*

REFERENCES

[1] Ciesielsk A. **An Introduction to Rubber Technology.** Rapra Technology Limited; 1999; 1st ed.

[2] Grosch KA. **The Rolling Resistance, Wear and Traction Properties of Tread Compounds.** *Rubber Chemistry and Technology* 1996; **69**(3): 495–568.

[3] Donnet JB. **Carbon Black: Science and Technology.** New York: Basel; 1993; 2nd ed.

[4] Erman B, Mark JE, Roland CM. **The Science and Technology of Rubber.** Academic Press (Elsevier); 2013; 4th ed.

[5] Ten Brinke A. **Silica Reinforced Tyre Rubbers.** M.Sc. Thesis, Univ. of Twente; 2002.

[6] Shiva M, Atashi H. **Failure Optimization and Curing Properties of a Passenger Tire Tread Compound.** *Iranian Journal of Polymer Science & Technology* 2010; **23**(3): 187-201.

[7] Shiva M, Atashi H. **Improvement in Tear Resistance and Crack Growth of Tire Tread Compound with Effective Cure Systems and Use of Semi-Reinforcement Fillers.** *Iranian Journal of Polymer Science & Technology* 2008; **21**(4): 285–295.

[8] Li Y, Han B, Liu L, Zhang F, Zhang L, Wen S, Lu Y, Yang H, Shen J. **Surface Modification of Silica by Two-Step Method and Properties of Solution Styrene Rubber (SSBR) Nanocomposites Filled with Modified Silica.** *Composites Science and Technology* 2013; **88**: 69-73.

[9] Fernandes M, Santos N. **SBR in Solution for High-Performance Tires.** *17th Latin American Rubber Technology Conference*; 2015.

[10] Shen Z, Wang F, Wang Z, Li J. **A Critical Review of Plant Based Insulating Fluids for Transformer: 30-Year Development.** *Renewable and Sustainable Energy Reviews* 2021; **141**: 110787.

[11] Farhan RZ, Ebrahim SE. **Preparing Nanosilica Particles from Rice**

Husk Using Precipitation Method. *Baghdad Science Journal* 2021; **18**(3): 494-500.

[12] Pham CD, Dang MDT, Ly TB, Tran KD, Vo NT, Do HNN, Mai PT, Le PK. **A Review of the Extraction Methods and Advanced Applications of Lignin-Silica Hybrids Derived from Natural Sources.** *International Journal of Biological Macromolecules* 2023; **230**: 123175.

[13] Bazzi L, Hesemann P, Laassiri S, El Hankari S. **Alternative Approaches for the Synthesis of Nano Silica Particles and Their Hybrid Composites: Synthesis, Properties, and Applications.** HAL Id: hal-04090016; 2023.

[14] Kumar SP, Yassin MM, Marimuthu S, Kalarani MK, Thiyageshwari S, Meenakshi G. **Eco-friendly Synthesis and Characterization of Amorphous Silica from Rice Husk.** *Agricultural Science Digest* 2023; **43**(6): 790-795.

[15] Gautam KD. **Effect of Stirring Speed on the Morphology of Nanosilica by Sol-Gel Method.** *Materials Today: Proceedings* 2023; **74**(4): 713-717.

[16] Mathew J, Joy J, George SC. **Potential Applications of Nanotechnology in Transportation: A Review.** *Journal of King Saud University – Science* 2019; **31**(4): 586-594.

[17] Asmatulu R, Nguyen P, Asmatulu E. **Nanotechnology Safety in the Automotive Industry.** Elsevier; 2013; 1st ed.

[18] Wang T. **Analysis on Tyre Wear.** Ph.D. Thesis, KTH Royal Institute of Technology; 2017.

[19] Sommer F, Dietze V, Baum A, Sauer J, Gilge S, Maschowski C, Gieré R. **Tire Abrasion as a Major Source of Microplastics in the Environment.** *Aerosol and Air Quality Research* 2018; **18**(8): 2014–2028.

[20] Williams PT, Besler S. **Pyrolysis-Thermogravimetric Analysis of Tyres and Tyre Components.** *Fuel* 1995; **74**(9): 1277-1283.

[21] Camatini M, Crosta GF, Dolukhanyan T, Sung C, Giuliani G, Corbetta GM, Cencetti S, Regazzoni C. **Microcharacterization and Identification of Tire Debris in Heterogeneous Laboratory and Environmental Specimens.** *Materials Characterization* 2011; **46**(4): 271-283.

[22] Barbin WW. **Tire Compound Development, in Rubber Products Manufacturing Technology.** New York; 2017.

[23] Lepine J, Na X, Cebon D. **An Empirical Tire-Wear Model for Heavy-Goods Vehicles.** *Tire Science and Technology* 2022; **50**(3): 211-229.

[24] Harrison RM, Jones AM, Gietl J, Yin J, Green DC. **Estimation of the Contributions of Brake Dust, Tire Wear, and Resuspension to Non-exhaust Traffic Particles Derived from Atmospheric Measurements.** *Environmental Science & Technology* 2012; **46**(12): 6523–6529.

[25] Rackaitis M, Graves D. **Rubber, in Handbook of Industrial Chemistry and Biotechnology.** Springer Gewerbestrasse, Switzerland; 2017: 1463-1491.

[26] Ghoreishy MHR, Soltani S, Etemadi AH. **Finite Element Analysis and Footprint Determination of a Bias Truck Tire under Vertical Static Load Using Global/Local Method.** *Iranian Journal of Polymer Science and Technology* 2010; **23**(3): 247-254.

[27] Medalia AI. **Effect of Carbon Black on Dynamic Properties of Rubber Vulcanizates.** *Rubber Chemistry and Technology* 1978; **51**(3): 437-523.

[28] Alkhazraji AN. **Enhancement of Mechanical Properties and Handling Characteristic of Tire Rubber Using Different Percentage of Nano Aluminum Oxide and Carbon Black.** *International Journal of Nanoelectronics and Materials* 2018; **11**(3): 263-270.

[29] Yang L, Hu Y, Guo H, Song L, Chen Z, Fan W. **Toughening and Reinforcement of Rigid PVC with Silicone Rubber/Nano-CaCO3 Shell-Core Structured Fillers.** *Journal of Applied Polymer Science* 2006; **102**(3): 2560-2567.

[30] Ying H, Xiulan F, Min W, Panfeng H, Yunjian G. **Research on Nano-SiO2/Carbon Black Composite for Flexible Tactile Sensing.** *International Conference on Information and Automation (ICIA)*; 2007: 541–545.

[31] Samadi A, Kashani MR. **Effects of Organo-Clay Modifier on Physical–Mechanical Properties of Butyl-Based Rubber Nano-Composites.** *Journal of Applied Polymer Science* 2010; **116**(4): 2101-2109.

[32] Grum J. **Modern Tribology Handbook, Volume One: Principles of Tribology and Volume Two: Materials, Coatings, and Industrial Applications.** *International Journal of Microstructure and Materials Properties* 2009; **4**(3): 412–413.

[33] Zafarmehrabian R, Gangali ST, Ghoreishy MHR, Davallu M. **The Effects of Silica/Carbon Black Ratio on the Dynamic Properties of the Tread Compounds in Truck Tires.** *E-Journal of Chemistry* 2012; **9**(3): 1102-1112.

[34] Wang MJ, Wolff S, Donnet JB. **Filler-Elastomer Interactions. Part I: Silica Surface Energies and Interactions with Model Compounds.** *Rubber Chemistry and Technology* 1991; **64**(4): 559–576.

[35] Wolff S, Wang MJ. **Filler—Elastomer Interactions. Part IV. The Effect of the Surface Energies of Fillers on Elastomer Reinforcement.** *Rubber Chemistry and Technology* 1994; **65**(2): 329–342.

[36] Rattanasom N, Saowapark T, Deeprasertkul C. **Reinforcement of Natural Rubber with Silica/Carbon Black Hybrid Filler.** *Polymer Testing* 2007; **26**(3): 369-377.

[37] Wang MJ. **Silica Rubber Masterbatch Produced with Continuous Liquid Phase Mixing- A Review of the History and Future of the Mixing.** *IOP Conference Series: Materials Science and Engineering* 2016; **137**: 012015.

[38] Zarei A, Jalali-Arani A. **The Relationship of Vulcanization and Structural Characteristics-Dispersion of Organoclay-Mechanical Properties in (Butadiene Rubber/Natural Rubber) Based Nanocomposite.** *Advanced Polymer Technology* 2018; **37**(5): 1469-1477.

[39] Bijarimi M, Zulkafli H, Beg MDH. **Mechanical Properties of Industrial Tyre Rubber Compounds.** *Journal of Applied Sciences* 2010; **10**(13): 1345-1348.

[40] Bandyopadhyaya S, Kitey R, Upadhyay CS. **The Effect of Carbon Black Content on Viscoelastic Properties of Vulcanized Natural Rubber.** *Physical Science Forum* 2022; **4**(1): 9.

[41] Wisojodharmo LA, Fidyaningsih R, Fitriani DA, Arti DK, Indriasari, Susanto H. **The Influence of Natural Rubber – Butadiene Rubber and Carbon Black Type on the Mechanical Properties of Tread Compound.** *IOP Conference Series: Materials Science and Engineering* 2017; **223**: 012023.

[42] Gao X, Yang W, Wang C, Tian X. **Study on Properties of Carbon-Coated Silica Prepared by Polymer Pyrolysis Reinforced Rubber Composites.** *Polymer Testing* 2022; **110**: 107563.

[43] Oleiwi JK, Hamza MS, Abed MS. **Improving the Properties of the Tire Tread by Adding SiO2 and Al2O3 to SBR Rubber.** *International Journal of Applied Engineering Research* 2010; **5**(9): 1637–1652.

[44] Robertson CG, Hardman NJ. **Nature of Carbon Black Reinforcement of Rubber: Perspective on the Original Polymer Nanocomposite.** *Polymers* 2021; **13**(17): 2909.

[45] De Silva C, Weragoda VSC, Wathsala T, Alahapperuma KG. **Synthesis and Utilization of Paddy Husk Carbon Black (PHCB) for Rubber Compounding.** *Conference Series: Moratuwa Engineering Research Conference*; 2022.

[46] Sajjayanukul T, Saeoui P, Sirisinha C. **Experimental Analysis of Viscoelastic Properties in Carbon Black-Filled Natural Rubber Compounds.** *Journal of Applied Polymer Science* 2005; **97**(6): 2197–2203.

[47] Soares BG. **Rubber Nanocomposites with Metal Oxides as Nanofillers, in Progress in Rubber Nanocomposites.** Composites Science and Engineering; 2017: 285-318.

[48] Akinlabi SA, Ogbonna OS, Mashinini PM, Adeniran AA, Fatoba OS, Akinlabi ET. **Titanium and Epoxy for Automobile Application: A Review.** *Proc. of the Eighth International Conference on Advances in Civil*; 2019.

[49] Chueangchayaphan W, Luangchuang P, Chueangchayaphan N. **High Performance of Titanium Dioxide Reinforced Acrylonitrile Butadiene Rubber Composites.** *Polymers* 2022; **14**(23): 5192.

[50] Vaikuntam SR, Bhagavatheswaran ES, Xiang F, Wießner S, Heinrich G, Das A, Stöckelhuber KW. **Friction, Abrasion and Crack Growth Behavior of In-Situ and Ex-Situ Silica Filled Rubber Composites.** *Materials* 2020; **13**(2): 442.

[51] Felix DG, SivaKumar G. **Nano Particles in Automobile Tires.** *Journal of Mechanical and Civil Engineering* 2014; **11**(4): 07-11.

[52] Tomar S. **Innovative Nanotechnology Applications in Automobiles.** *International Journal of Engineering Research & Technology* 2012; **1**(10): 1-5.

[53] Mathew J, Joy J, George SC. **Potential Applications of Nanotechnology in Transportation: A Review.** *Journal of King Saud University – Science* 2019; **31**(4): 586-594.

[54] Xu H, Fan T, Ye N, Wu W, Huang D, Wang D, Wang Z, Zhang L. **Plasticization Effect of Bio-Based Plasticizers from Soybean Oil for Tire Tread Rubber.** *Polymers* 2020; **12**(3): 623.

[55] Liu C, Guo M, Zhai X, Ye X, Zhang L. **Using Epoxidized Solution Polymerized Styrene-Butadiene Rubbers (ESSBRs) as Coupling Agents to Modify Silica without Volatile Organic Compounds.** *Polymers* 2020; **12**(6): 1348.

[56] Cardona N, Campuzano F, Betancur M, Jaramillo L, Martínez JD. **Possibilities of Carbon Black Recovery from Waste Tyre Pyrolysis to be Used as Additive in Rubber Goods - A Review.** *IOP Conference Series: Materials Science and Engineering* 2018; **299**: 012019.

[57] Kim IJ, Kim D, Ahn B, Lee HJ, Kim HJ, Kim W. **Vulcanizate Structures of SBR Compounds with Silica and Carbon Black Binary Filler Systems at Different Curing Temperatures.** *Polymers* 2020; **12**(10): 2291.

[58] Van Hoek JW, Heideman G, Noordermeer JWM, Dierkes WK, Blume A. **Implications of the Use of Silica as Active Filler in Passenger Car Tire Compounds on Their Recycling Options.** *Materials* 2019; **12**(5): 834.

[59] O'Loughlin DP, Haugen MJ, Day J, Brown AS, Braysher EC, Molden N, Willisb AE, MacFarlane M, Boies AM. **Multi-element Analysis of Tyre Rubber for Metal Tracers.** *Environment International* 2023; **178**: 108112.

[60] Grigoratos T, Martini G. **Non-exhaust Traffic Related Emissions. Brake and Tyre Wear PM.** European Commission; 2014.

[61] Kikuchi N, Ota T, Uchida M, Nippa S. **Aluminium Hydroxide and Tyre Tread Rubber Composition and Pneumatic Tyre Employing the Aluminum Hydroxide.** European Patent, EP1112961 A1; 2001.

[62] Miyazaki T. **Winter Tire.** European Patent, EP3064543 B1; 2019.

[63] Vinod VS, Varghese S, Alex R, Kuriakose B. **Effect of Aluminum Powder on Filled Natural Rubber Composites.** *Rubber Chemistry and Technology* 2001; **74**(2): 236–248.

[64] Hebei CN. **Magnesium Oxide in Tires.** Available from: https://www.magnesiumking.com/about-us.html; 2020.

[65] Barbin WW. **Tire Compound Development, in Rubber Products Manufacturing Technology.** New York, Routledge; 2017.

[66] Esmaeili A, Masters I, Hossain M. **A Novel Carbon Nanotubes Doped Natural Rubber Nanocomposite with Balanced Dynamic Shear Properties and Energy Dissipation for Wave Energy Applications.** *Results in Materials* 2023; **17**: 100356.

[67] Rathi A. **Process-Design for Tire Tread Compounds with Good Compatibility to Mineral-based Safe Process Oils.** M.Sc. Thesis, University of Twente; 2016.

[68] Ferrer G. **The Economics of Tire Remanufacturing.** Ph.D. Dissertation, France; 1997.

[69] Indriasari, Kaewsakul W, Dierkes WK, Blume A. **Defining Key Factors in Carbon Black-Filled NR/BR Compounds for Balancing Aircraft Tire Tread Properties.** *Journal of Composites Science* 2019; **3**(2): 32.

[70] Zhu L, Pan Y, Tian X, Liu H, Bian H, Wang C. **Continuous Preparation and Properties of Silica/Rubber Composite Using Serial Modular Mixing.** *Materials* 2019; **12**(19): 3171.

[71] Grunert F, Wehmeier A, Blume A. **New Insights into the Morphology of Silica and Carbon Black Based on Their Different Dispersion Behavior.** *Polymers* 2020; **12**(3): 655.

[72] Chumnum K, Kalkornsurapranee E, Johns J, Sengloyluan K, Nakaramontri Y. **Combination of Self-Healing Butyl Rubber and Natural Rubber Composites for Improving the Stability.** *Polymers* 2021; **13**(3): 446.

[73] Ravi M, Dubey RR, Shome A, Guha S, Kumar CA. **Effect of Surface Treatment on Natural Fibers Composite.** *IOP Conference Series: Materials Science and Engineering* 2018; **376**: 012089.

[74] Kuan HTN, Tan MY, Shen Y, Yahya MY. **Mechanical Properties of Particulate Organic Natural Filler-reinforced Polymer Composite: A Review.** *Composites and Advanced Materials* 2021; **30**: 2633366X2110058.

[75] Gunatillake PA, Adhikari R. **Biodegradable Synthetic Polymers for Tissue Engineering.** *European Cells & Materials Journal* 2003; **5**: 1-16.

[76] Begum K, Islam MA. **Natural Fiber as a Substitute to Synthetic Fiber in Polymer Composites: A Review.** *Research Journal of Engineering Sciences* 2013; **2**(3): 46-53.

[77] Zaaba NF, Ismail H. **Thermoplastic/Natural Filler Composites: A Short Review.**

Journal of Physical Science 2019; **30**(1): 81–99.

[78] Gowda TGY, Sanjay MR, Bhat KS, Madhu P, Senthamaraikannan P, Yogesha B. **Polymer Matrix-natural Fiber Composites: An Overview.** *Cogent Engineering* 2018; **5**(1): 1446667.

[79] Mirabedini SM, Mohseni M, PazokiFard S, Esfandeh M. **Effect of TiO2 on the Mechanical and Adhesion Properties of RTV Silicone Elastomer Coatings.** *Physicochemical and Engineering Aspects* 2008; **317**(3): 80-86.

[80] Bhattacharya M, Maiti M, Bhowmick AK. **Influence of Different Nanofillers and Their Dispersion Methods on the Properties of Natural Rubber Nanocomposites.** *Rubber Chemistry and Technology* 2008; **81**(5): 782-808.

[81] Song P, Song J, Zhang Y. **Stretchable Conductor Based on Carbon Nanotube/Carbon Black Silicone Rubber Nanocomposites with Highly Mechanical, Electrical Properties and Strain Sensitivity.** *Composites Part B: Engineering* 2020; **191**: 107979.

[82] Gan L, Shang S, Yuen CWM, Jiang SX, Luo NM. **Facile Preparation of Graphene Nanoribbon Filled Silicone Rubber Nanocomposite with Improved Thermal and Mechanical Properties.** *Composites Part B: Engineering* 2015; **69**: 237-242.

[83] Puech P, Kandara M, Paredes G, Moulin L, Weiss-Hortala E, Kundu A, Ratel-Ramond N, Plewa JM, Pellenq R, Monthioux M. **Analyzing the Raman Spectra of Graphenic Carbon Materials from Kerogens to Nanotubes: What Type of Information can be Extracted from Defect Bands?.** *C — Journal of Carbon Research* 2019; **5**(4): 69.

[84] Schuepfer DB, Badaczewski F, Guerra-Castro JM, Hofmann DM, Heiliger C, Smarsly B, Klar PJ. **Assessing the Structural Properties of Graphitic and Non-graphitic Carbons by Raman Spectroscopy.** *Carbon* 2020; **161**: 359-372.

[85] Sarath PS, Samson SV, Reghunath R, Pandey MK, Haponiuk JT, Thomas S, George SC. **Fabrication of Exfoliated Graphite Reinforced Silicone Rubber Composites-Mechanical, Tribological and Dielectric Properties.** *Polymer Testing* 2020; **89**: 106601.

[86] Zhao S, Bai L, Zheng J. **Facile Preparation of Carbon Nanotubes–Graphene Hybrids and the Effect of Aspect Ratio of Carbon Nanotubes on Electrical and Thermal Properties of Silicone Rubber Based Composites.** *Materials Research Express* 2018; **5**(1): 015603.

[87] Zhao YH, Zhang YF, Wu ZK, Bai SL. **Synergic Enhancement of Thermal Properties of Polymer Composites by Graphene Foam and Carbon Black.** *Composites Part B: Engineering* 2016; **84**: 52-58.

[88] Hu H, Zhao L, Liu J, Liu Y, Cheng J, Luo J, Liang Y, Tao Y, Wang X, Zhao J. **Enhanced Dispersion of Carbon Nanotube in Silicone Rubber Assisted by Graphene.** *Polymer* 2012; **53**(15): 3378–3385.

[89] Pabasara WGA, Saputhanthree A, Weragoda VSC. **Utilization of Paddy Husk Carbon Black as an Alternative Filler Material in Rubber Industry.** *IOP Conference Series: Materials Science and Engineering* 2022; **1258**: 012011.

[90] Fernando ANA, Pabasara WGA, Gayashini KY, Liyanage DN. **Investigation of Mechanical Properties of Rice Straw Ash-filled Natural Rubber Compounds.** *IOP Conference Series: Materials Science and Engineering* 2021; **1149**: 012005.

[91] De Silva C, Weragoda VSC, Wathsala T, Alahapperuma KG. **Synthesis and Utilization of Paddy Husk Carbon Black (PHCB) for Rubber Compounding.** *IOP Conference Series: Materials Science and Engineering* 2022; **1258**: 012010.

[92] Choophun N, Chaiammart N, Sukthavon K, Veranitisagul C, Laobuthee A, Watthanaphanit A, Panomsuwan G. **Natural Rubber Composites Reinforced with Green Silica from Rice Husk: Effect of Filler Loading on Mechanical Properties.** *Journal of Composites Science* 2022; **6**(12): 374.

[93] Chundawat NS, Parmar BS, Deuri AS, Vaidya D, Jadoun S, Zarrintaj P, Barani M, Chauhan NPS. **Rice Husk Silica as a Sustainable Filler in the Tire Industry.** *Arabian Journal of Chemistry* 2022; **15**(9): 104051.

[94] Fernandes MRS, De Sousa AMF, Furtado CRG. **Rice Husk Ash as Filler in Tread Compounds to Improve Rolling Resistance.** *Polímeros* 2017; **27**(1): 55-61.

[95] Ullal VN, Shivaramu HT, Aveen KP. **Rice Husk Ash Utilization, Composition and Properties: A Brief Review.** *Journal of Metals, Materials and Minerals* 2022; **32**(4): 37-46.

[96] Le VH, Ha Thuc CN, Ha Thuc H. **Synthesis of Silica Nanoparticles from Vietnamese Rice Husk by Sol–**

Gel Method. *Nanoscale Research Letters* 2013; **8**: 58.
[97] Alnaid A, Noriman NZ, Dahham OS, Hamzah R, Adam T, Al-Samarrai MN, Mohammed M, Azlan UAA. **Curing Characteristics Tensile and Physical Properties of Rice Straw Filled Standard Malaysian Rubber.** *IOP Conference Series: Materials Science and Engineering* 2018; **319**: 012003.
[98] Xue B, Wang X, Sui J, Xu D, Zhu Y, Liu X. **A Facile Ball Milling Method to Produce Sustainable Pyrolytic Rice Husk Bio-filler for Reinforcement of Rubber Mechanical Property.** *Industrial Crops and Products* 2019; **141**: 111750.
[99] Jong L. **Particle Size and Particle–Particle Interactions on Tensile Properties and Reinforcement of Corn Flour Particles in Natural Rubber.** *European Polymer Journal* 2016; **74**: 136-147.
[100] Ubi PA, Ademoh NA, Abdulrahman AS, Hassan AB, Dashe JD, Oyeyemi SW, Ngolemasango F. **Mechanical Characteristics and Regression Models of Rice Husk Silica Reinforced Natural Rubber Composites.** *Nigerian Journal of Technological Development* 2023; **20**(3): 146–154.
[101] Gautam KD, Ullas AV. **Effect of Stirring Speed on the Morphology of Nanosilica by Sol-Gel Method.** *Materials Today: Proceedings* 2023; **74**(4): 713-717.
[102] Hasri, Putri SE, Anwar M, Askar M. **Synthesis of Rice Husk Nanosilica Using the Hydrothermal Method.** *IOP Conference Series: Earth and Environmental Science* 2023; **1240**: 012011.
[103] Jembere AL, Fanta SW. **Studies on the Synthesis of Silica Powder from Rice Husk Ash as Reinforcement Filler in Rubber Tire Tread Part: Replacement of Commercial Precipitated Silica.** *International Journal of Materials Science and Applications* 2017; **6**(1): 37-44.
[104] Jong L. **Improved Natural Rubber Composites Reinforced with a Complex Filler Network of Biobased Nano Particles and Ionomer.** *Materials Chemistry and Physics* 2018; **203**: 156-165.
[105] Sasidhar B, Malathi P, Rahale CS, Gnanachitra M, Sharmila DJS. **Synthesis and Characterization of Mesoporous Nanosilica Derived from Rice Husk Ash.** *International Journal of Environment and Climate Change* 2023; **13**(10): 3526-3532.
[106] Wiebeck H, Valenzuela FR, Esper FJ, Martn-Cort GR, Hennies WT, Costa MVV. **Tire Rubber Powder/ Rice Husk Ash Polymer Compound.** *Materials Science Forum* 2012; **727-728**: 1547-1551.
[107] Cheng Q, Xu C, Huang W, Ma C, Fan G, Yan J, Jian Z, Zhang Y, Song G. **Preparing High Purity White Carbon Black from Rice Husk.** *Food Science & Nutrition* 2020; **8**(1): 575–583.
[108] Vargas V, Galarneau A, Castillo J, Christensen JH. **Sustainable Harnessing of SiO2 Nanoparticles from Rice Husks: A Review of the Best Synthesis and Applications.** *Processes* 2023; **11**(5): 1319.
[109] Ismail H, Nasaruddin MN, Ishiaku US. **White Rice Husk Ash Filled Natural Rubber Compounds: the Effect of Multifunctional Additive and Silane Coupling Agents.** *Polymer Testing* 1999; **18**(4): 287-298.
[110] Öner GA. **Flexural Strength and Thermal Properties of Carbon Black Nanoparticle Reinforced Epoxy Composites Obtained from Waste Tires.** *Open Chemistry* 2022; **20**(1): 863–872.
[111] Moulin L, Da Silva S, Bounaceur A, Herblot M, Soudais Y. **Assessment of Recovered Carbon Black Obtained by Waste Tires Steam Water Thermolysis: An Industrial Application.** *Journal of Cleaner Production* 2018; **188**: 1-9.
[112] Paleri DM, Rodriguez-Uribe A, Misra M, Mohanty AK. **Preparation and Characterization of Eco-friendly Hybrid Biocomposites from Natural Rubber, Biocarbon, and Carbon Black.** *Express Polymer Letters* 2021; **15**(3): 236–249.
[113] Gómez-Hernández R, Panecatl-Bernal Y, Méndez-Rojas MA. **High Yield and Simple One-step Production of Carbon Black Nanoparticles from Waste Tires.** *Heliyon* 2019; **5**(7): e02139.
[114] Lai SM, Chu YL, Chiu YT, Chang MC, Hsieh TY, Hsieh MH. **Effect of Pyrolysis Carbon Black from Waste Tires on the Properties of Styrene–Butadiene Rubber Compounds.** *Polymers and Polymer Composites* 2021; **29**(2): 75–86.
[115] González-González RB, González LT, Iglesias-González S, González-González E, Martinez-Chapa SO, Madou M, Alvarez MM, Mendoza A. **Characterization of Chemically**

Activated Pyrolytic Carbon Black Derived from Waste Tires as a Candidate for Nanomaterial Precursor. *Nanomaterials* 2020; **10**(11): 2253.

[116] Verma A, Baurai K, Sanjay MR, Siengchin S. **Mechanical, Microstructural, and Thermal Characterization Insights of Pyrolyzed Carbon Black from Waste Tires Reinforced Epoxy Nanocomposites for Coating Application.** *Polymer Composites* 2020; **41**(1): 338–349.

[117] Ojha S, Acharya SK, Raghavendra G. **Mechanical Properties of Natural Carbon Black Reinforced Polymer Composites.** *Journal of Applied Polymer Science* 2015; **132**(1): 41211.

[118] Chauhan S, Bhushan RK. **Improvement in Mechanical Performance Due to Hybridization of Carbon Fiber/Epoxy Composite with Carbon Black.** *Advanced Composites and Hybrid Materials* 2018; **1**(3): 602–611.