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Correlation Of Barely Straw Content and Performance Properties of Polystyrene Butadiene Rubber Composites

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ABSTRACT

In this study, the main aim was to correlate the barely straw (BS) content with mechanical (e.g. impact strength and Shore hardness) and physical (e.g. water absorption (WA)) properties of BS/polystyrene butadiene rubber (SBR) composites. BS/SBR composites were prepared with 10, 20, 30, and 40% BS content. All composites showed to have improved mechanical properties in comparison to neat SBR. The impact strength slightly increased with increasing BS content up to 30% and then decreased. Shore hardness also showed a slight increase with increasing the content of BS. As expected, increasing BS content resulted in an increase in WA. Most importantly, a robustand positive correlation was found between BS content and impact strength, Shore hardness, and WA properties. The correlation indices between BS content and impact strength, Shore hardness and WA were r^2 = 0.711, r^2 = 0.966 and r^2 = 0.943, respectively. Therefore, straw could to used as alternative raw materials for conventional wood in reinforcement of polymer composites.

العلاقة بين نسبة الألياف المقواة من قش الشعير على خصائص بوليمر مركب من مطاط الستايرين بيوتادايين

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الكلمات المفتاحية:
كومبزت
قش الشعير
مطاط الستايرين بيوتادايين
مقاومة الصدم
الصلادة

الملخص

الهدف الرئيسي من هذه الدراسة هو تحديد العلاقة بين محتوي الألياف المقواة وخواص بوليمر مركب (كومبزت) مكون من الستايرين بيوتادايين (المادة الحاضنة) وقش الشعير (الحشوة).حيث تم في هذه الدراسة الربط بين محتوى القش والخواص الميكانيكية (مثل مقاومة الصدم والصلادة) والخواص الفيزيائية (مثل امتصاص الماء). تم تحضير بوليمرات مركبة تحتوى على نسب 0، 10، 20، 30، و 40% من قش الشعير. أظهرت النتائج تحسن الخواص الميكانيكية مقارنة بالوليمر الأصلي. حيث زادت خاصية الصدم بمقدار طفيف بزيادة نسبة القش حتى 30% وبعد ذلك تناقصت. صلادة شور زادت هي أيضا بزيادة نسبة القش. من جهة أخرى، زادت خاصية امتصاص الماء بزيادة نسبة القش. النتائج أوضحت وجود علاقة قوية بين محتوى القش وهذه الخواص. معاملات الارتباط بين محتوى القش ومقاومة الصدم وصلادة شور وامتصاص الماء كانت r^2 = 0.771، r^2 = 0.966 و r^2 = 0.943، على التوالي. وبذلك، يمكن استخدام قش الشعير كمادة بديلة عن الخشب في تقوية وتعزيز خواص البوليمرات.

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1. Introduction

Natural fiber (NF) reinforced polymer composites (NFRPCs) have enormous attention in recent years [1]. They possess several advantages over synthetic-fiber-reinforced composites, including renewability, biodegradability, low weight, low cost, and noncorrosive [2-3]. Moreover, NFRPCs could be burn up with no or less residue, energy produced during burning might be recovered with good rate [4]. NFRPCs are used in many applications such as transportation, construction, furniture, electronics and packaging [1, 5]. NFRPCs are a type of biocomposites prepared using NFs derived from plants, minerals, and animals. Plant fibers are the most popular of the NFs, used as reinforcement in NFRPCs [6]. Plant fibers can be subdivided into nonwood fibers and wood fibers. Fibers from plant consist of cellulose, hemicelluloses, and lignin.

Nonwood fibers are one of the important alternative resources for fibrous from conventional wood in order to develop eco-friendly composites. [7]. Nonwood materials such as barely (BS),and wheat straw (WS) are used to fabricate NFRPCs [8-9]. It was reported that BS has been utilized successfully as a filler for many types of plastics [10-12]. According to Masłowski et al. [10], using straw in the field of NFRPCs could reduce the costs of their production. In addition, straw may modify natural rubber, resulting in composites with high performance in certain enhanced applications. Other results found by Zhang et al. [11] showed that straw could be used to produce straw/linear low-density polyethylene composites with good performance. Parareda et al. [12] investigated the feasibility of incorporating BS as reinforcement in a biobased polyethylene in order to develop a fully biobased and recyclable material. They claimed that the BS was effective filler to produce biobased composites for semi-structural and engineering purposes.BS was used also to reinforce other polymers such as polypropylene [13], high density polyethylene (HDPE) [14], recycled HDPE [15], and thermoplastic starch [16]. However, BS is mostly used as concrete or elastomeric fillers [17-18].In this present study, the feasibility of using BS particles as reinforcement in a polystyrene butadiene rubber (SBR) matrix to develop a fully recyclable biocomposites were evaluated. The evaluated properties were mechanical (e.g. impact strength and Shore hardness) and physical (e.g. water absorption (WA)) properties. It is important to declare that properties of SBR and other types of rubber are known to be weak which limit their uses. As a result, reinforcing fillers could be used to enhance their properties [19]. Generally, the literature about using BS to reinforce SBR is scarce [12] in comparison to other nonwood materials like WS.

2. Experimental work

Materials

BS was used as fillers in this study. BS was collected from local farms in Zliten city in Libya (It is located 160 km to the east of Tripoli). SBR from Parc Scientific(UK) was used as a matrix.

Methods

Preparation of Straw

BS was washed and dried at room temperature for 48 h. Afterwards, BS were ground and sieved to get a particle size of 212 µm.

Preparation of Composites

BS were dried in an oven for 4 h at 60 °C, with SBR. Mixing was carried out using a twin screw extruder (Brabender, Germany) (L/D ratio of 48) with a screw speed of 70 r.p.m. at 180 ºC. Composites with BS contents of 10, 20, 30, and 40% wt. were prepared. Information about composites prepared in this study are presented in Table 1.

Table 1: Composites prepared in this study.

Sample	SBR, %	BS, %
SBR	100	0
SBRB1	90	10
SBRB2	80	20
SBRB3	70	30
SBRB4	60	40

Characterization

Mechanical properties

Charpy impact examination was accomplished using (CEAST Resil Impactor tester) with impact energy of 15 J at room temperature. Five samples from each composite were measured according to ASTM (D256-10).

Shore hardness A measurements were performed by a Durometer, Shore A scale according to ASTM (D2240). 10 hardness measurements per composite were performed.

Water absorption test

The WA investigation was done in agreement with ASTM D570. It was carried out by soaking the samples in distilled water for 10 days (240 h) at room temperature. Before that, composites were placed in an oven at 60 °C for 24 h, to eliminate the moisture. Then the composites were weighed. Composites were soaked in water and weighed by time. Three samples of each composite were used in this investigation. WA was calculated as follows:

$$WA (\%) = M_1 - M_0 / M_0 \times 100$$

where M_1 is the mass of the sample after immersion (g) and M_0 is the mass of the sample before immersion (g).

3. Results and discussion

Mechanical properties

The impact strength and Shore hardness properties of SBR and BS/SBR composites are presented in Table 2. Standard deviations values in parentheses in Table 2. Overall, the impact strength and Shore hardness of all composites were slightly higher than that of neat SBR.

Table 2: Mechanical properties of SBR and BS/SBR composites.

Sample	Impact strength, KJ/m^2	Shore hardness A
SBR	2.63 (0.02)	95.20 (0.2)
SBRB1	3.50 (0.04)	95.70 (0.5)
SBRB2	4.45 (0.02)	95.90 (0.4)
SBRB3	4.46 (0.02)	96.10 (0.5)
SBRB4	4.41 (0.06)	96.60 (0.3)

As shown in Fig. 1, impact properties were slightly increased with increasing BS content. After 30% BS loading the impact strength started to decrease. Similar observation was reported by Hyvärinen and Kärki [9]. They found that the use of BS slightly improved the impact strength of BS/polypropylene composites. Similarly, it is in line with many studies [20-21], which they reported that the impact properties of NFRPCs could be increasing the filler content. Guo et al. [22] studied the impact properties of polypropylene/carbonate composites and declared that the these properties may increases at low filler loading, and decreases with more filler addition. In fact, the impact resistance of NFRPCs us depended on many factors such as rigidity of filler, interfacial properties and filler size and dimensions [23-24]. As stated by Rasib et al. [24] the higher impact strength possibly due to the proper shape and small size of the filler, which results excellent filler dispersion. In fact, reinforcements can occur with small filler size even if the interface among the filler and rubber polymer is weak [25]. This effect of filler content is not always true. For example, several studies [26-28] reported that the increase in filler content decreases the toughness, the capability of polymer to absorb energy and, finally the impact strength.

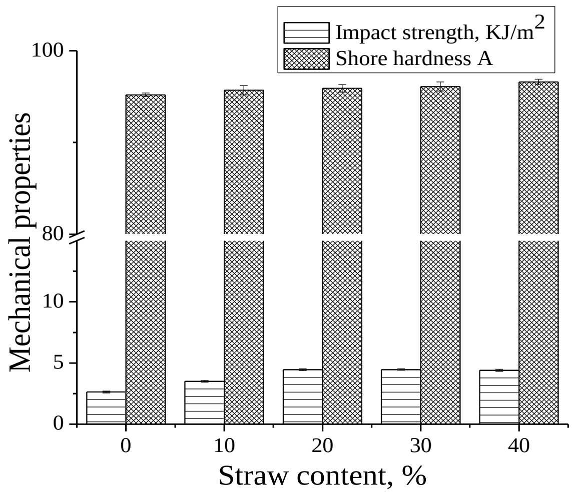

Fig. 1: Impact strength and Shore hardness A of SBR and SBR/BS composites

Filler content appears to have insignificant effects on the Shore hardness of SBR/BS composites. This is because increasing BS content resulted in a slight increase in the Shore hardness, as can be seen in Fig.1. For rubbery materials, the strength and hardness can be improved via adding of reinforcements [29]. Masłowsk et al. [10] declared that using straw as a filler could lead to improve wide range of rubber properties such as: mechanical (including the hardness), and barrier properties. They also found that the hardness properties of NFRPCs increased with increasing straw loading. Practically, hardness properties are based on the resistance of substances to penetration. In point of fact, fillers normally results an increase in the hardness properties associated with more resistance to plastic deformation. Generally, the hardness value increases with increasing the filler content. This would be clear in the case of small filler size and homogeneous distribution of filler. Many factors affect the NFRPCs hardness such as polymer type, and filler type and shape. Hardness in NFRPCs is surface properties directly connected to the filler loading [30].

Correlation of straw content and mechanical properties

As shown in Figs. 2 and 3, the impact strength and Shore hardness results of SBR/BS composites were highly correlated with the straw content.

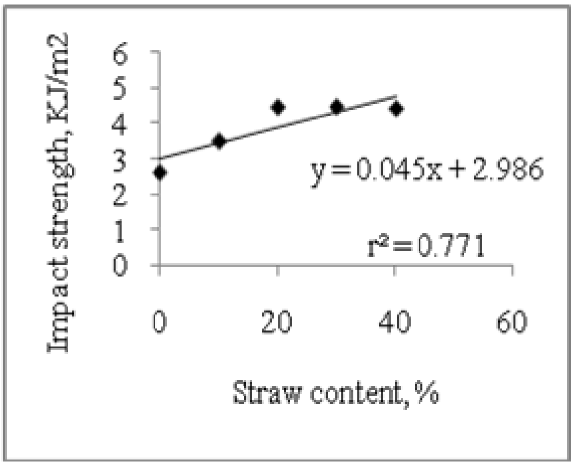

Fig. 2: Effect of straw content on impact strength of SBR/BS composites

These results indicate very strong positive relationships, which means a strong positive correlation between straw content and these properties. The coefficient of determination in the case of straw content and impact strength was (r^2= 0.711): indicating a strong correlation and very strong positive relationship.

Similarly, the coefficient of determination in the case of straw content and Shore hardness depicts a very strong positive association (r^2=0.966). Thesevery strong positive relationships, allow essentially all the measured points to be on the same line, so the graphs were linear, as shown in Figs. 2 and 3. This means that these properties increased almost linearly with increasing straw content. This may indicate that the straw content can be considerable parameter that correlates with these properties of BS/SBR composites. Indeed, the correlation between them is still unclear. This is because the literature about barley straw-reinforced SBR is scarce.

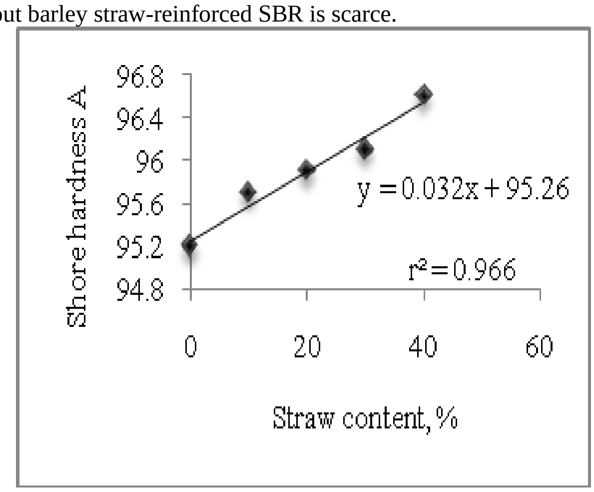

Fig 3: Effect of BS on Shore hardness of composites prepared in this study

Water absorption

The obtained WA values of SBR and SBR/BS composites are revealed in Fig. 4. Fig. 4 illustrates the percentage of WA of SBR and SBR/BS composites at room temperatures for period of 240 h (10 days). As expected, WA in the SBR and all SBR/BS composites increased with soaking time and thereafter it became almost constant. SBR showed an insignificant trend of WA. The neat SBR absorbed less than 0.40 % water after 10 days of immersion in water. WA of SBR/BS composites were higher than that of SBR.

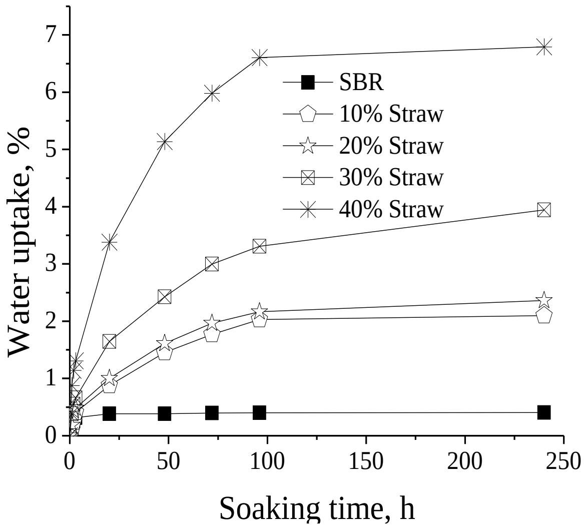

Fig. 4: WA of SBR/BS composites

Correlation of straw content and WA properties

The WA results of the 240 h water immersion test were highly correlated with the straw content. As is evident from Fig. 5, WA results showed a very strong correlation with straw content (r^2= 0.943).It increased progressively and almost linearly more from the less filled composites (10%) to the more filled composites (40%). Nonetheless, the percentage of WA of these composites seem to be not too high. As in woody materials, the composition and properties of BS as non-woody materials plays an important role in reinforcing polymers. Wood and nonwood materials are mainly composed of cellulose, hemicellulose, lignin, and other materials.

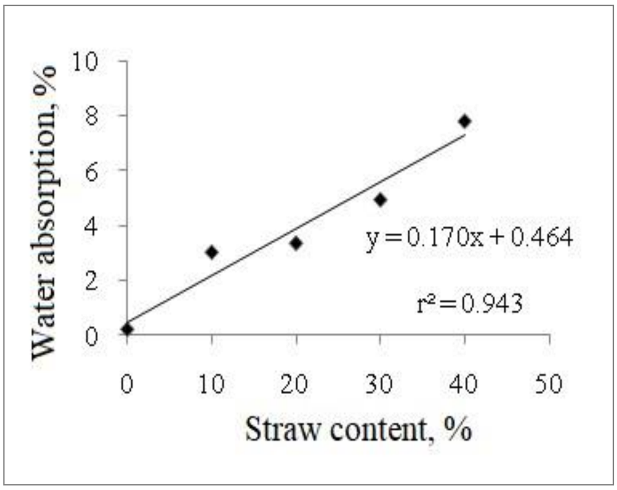

Fig. 5: Effect of straw content on WA of SBR/BS composites

It is important to declare that all non-wood materials if compared against wood materials, consist of lower cellulose [9] and lignin content [30]. Chemical composition of NF (e.g. cellulose content) is an important factor concerns their properties [8, 32]. Higher cellulose and lignin, better filler dispersion and strong adhesion normally provide better strength to the NFRPCs[33-34]. On the other hand, lignin may perform as a matrix to hold cellulose fibers together. Diffusion of lignin into the fiber walls increases stiffness and allows stress transfer between the matrix and the cellulose fibers. Accordingly, the low cellulose and lignin content of straw can be the reason for the slight improvements on the mechanical properties in comparison to woody materials as known in the literature. Moreover, the skin of the straw appears to be smoother , which may affect the pull-out resistance of fibers adversely [18]. Furthermore, the existence of non-poplar materials (e.g. cutin or wax) in the BS surfaces may reduce its application in bio-composite field [33]. According to all of these differences non-woody reinforced polymers were found to provide less improvement in the mechanical properties than wood fiber-reinforced ones, as pointed out by Hyvärinen and Kärki [9]. Basically, the superior properties of the NFRPCs can be based on its microstructure, void content, stress transfer efficiency, and filler chemical composition [35-36]. On the hand, non-woody like: BS, suppose to provide a vast low-cost potential alternative to wood fibers in producing NFRPCs[8]. On the whole, the obtained results in this study confirmed that BS could to be used as substitute of wood material to reinforce polymers where mechanical properties should not be crucial, and they would not be exposed to a high moisture environment.

4. Conclusions

The conclusions from this present study can be as a following:

- BS could to be proposed as a potential alternative for wood as a raw material source for reinforcing polymers.
- Composites showed to have improved mechanical properties in comparison to neat SBR. For example. the impact properties were slightly increased with increasing filler content up to 30% and, then decreased. In a similar way, hardness properties increased with increasing the amount of BS.
- The use of BS as a reinforcing materials in SBR matrix caused an increase in the WA. As expected, the increase in WA was increased with increasing the BS content. Nonetheless, the percentage of WA of these composites seem to be not too high.
- Very strong positive correlation was demonstrated between BS content and mechanical (impact strength and hardness) and physical (WA) properties. This may indicate that the straw content can be considerable parameter which correlates with these properties of NFRPCs. Since the literature about BS reinforced SBR is scarce, additional research should be carried out to confirm this effect.
- Ecological and economic benefits, solving typical agriculture problems and reducing the pressure on forest resources can be reached with straw utilization in the field of polymer composites.
- Comparison with wood fibers, non-wood materials such BS appears to provide less reinforcement effect for polymer matrices.

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6. **References**

[1]- Khalid, M. Y., Al Rashid, A., Arif, Z. U., Waqas, A., Hassan, A., (2021), Natural Fiber Reinforced Composites: Sustainable Materials for Emerging Applications., Results Eng., 11, 1-12. https://doi.org/10.1016/j.rineng.2021.100263

[2]- Liu, W., Mohanty, A. K., Drzal, L. T., Askel, P., Misra, M., (2004), Effects of Alkali Treatment on the Structure, Morphology and Thermal Properties of Native Grass Fibers as Reinforcements for Polymer Matrix Composites., J. Mater. Sci., 39, 1051-1054. DOI:10.1023/B:JMSC.0000012942.83614.75

[3]- Binoj, J. S., Raj, R. E., Hassan, S. A., Mariatti, M., Suchart, S., Sanjay, M. R., (2020), Characterization of Discarded Fruit Waste as Substitute for Harmful Synthetic Fiber-Reinforced Polymer Composites., J. Mater. Sci. 55, 8513-8525. https://doi.org/10.1007/s10853-020-04620-8

[4]- Patel, H. K., Balasubramanian, V., Peijs, T., (2017), The Fracture Toughness of Natural Fibre- and Glass Fibre-Reinforced SMC.,Plast. rubber. compo., 46, 1-10. https://doi.org/10.1080/14658011.2017.1357868

[5]- Pervaiz, M., Sain, M. M., (2003), Carbon Storage Potential in Natural FiberComposites.,Resour. Conserv. Recycl., 39, 325-340. https://doi.org/10.1016/S0921-3449(02)00173-8

[6]- Ravi, B., Siva,A., Ramakrishna, B., (2017), Plant Fiber Reinforced Polymer Matrix Composites: A Review., Int. J. Adv. Eng. Res. Sci., 6, 999-1008. ISSN: 2319-8354

[7]- Ashori, A., (2006), Nonwood Fibres - A Potential Source of Raw Material in Papermaking.,Polym.Plast. Technol. Eng., 45, 1133-1136. DOI:10.1080/03602550600728976

[8]- Panthapulakkal, S., Zereshkian, A., Sain, M. (2006), Preparation and Characterization of Wheat Straw Fibers for Reinforcing Application in Injection Molded Thermoplastic Composites.,Bioresour. Technol., 97, 265-272. https://doi.org/10.1016/j.biortech.2005.02.043

[9]- Hyvärinen, T. M., (2015), The Effects of the Substitution of Wood Fiber with Agro-Based Fiber (Barley Straw) on the Properties of Natural Fiber/Polypropylene Composites., MATEC Web of Conferences, 30, 1-5. DOI:10.1051/matecconf/20153001014

[10]- Masłowski, M., Miedzianowska, J., Strakowska, A., Krzysztof, S., Małgorzata, I. S., (2018), The Use of Rye, Oat and Triticale Straw as Fillers of Natural Rubber Composites.,Polym. Bull., 75, 4607-4626. https://doi.org/10.1007/s00289-018-2289-y

[11]- Zhang, L., Xu, H., Wang, W., (2020), Performance of Straw/Linear Low Density Polyethylene Composite Prepared with Film-Roll Hot Pressing., Polym., 12, 1-17. https://doi.org/10.3390/polym12040860

[12]- Parareda, F. S., Fernando, J., Eduardo, E., Alejandro, R., Francesc, X. E., Fabiola, V., (2020),Feasibility of Barley Straw Fibers as Reinforcement in Fully Biobased Polyethylene Composites; Macro and Micro Mechanics of the Flexural Strength., Molecules,25, 1-16. https://doi.org/10.3390/molecules25092242

[13]- Pugliaa, D., Luzi, F., Lilli, M., Sbardella, F., Pauselli, M., Torre, L., Benincas, P., (2020), Straw Fibres from Barley Hybrid Lines and their Reinforcement Effect in Polypropylene Based Composites., Ind. Crop. Prod., 154, 1-8. https://doi.org/10.1016/j.indcrop.2020.112736

[14]- Zabihzadeh, M., Dastoorian, F., Ebrahimi, G., (2010), Effect of MAPE on Mechanical and Morphological Properties of Wheat Straw/HDPE Injection MoldedComposites., J.Reinf.Plast.Compos., 29, 123-131. https://doi.org/10.1177/0731684408096426

[15]- Rojas-León, A., Guzmán-Ortiz, F. A., Bolarín-Miró, A. M., Otazo-Sánchez, E.M., Prieto-García, F., Fuentes-Talavera, F. J., Román-Gutiérrez, A. D., (2019), Eco-Innovation of Barley and HDPE Wastes: A Proposal of Sustainable Particleboards., Rev. Mex.Ing.Quím. 18, 57-68. DOI:10.24275/uam/izt/dcbi/revmexingquim/2019v18n1/Rojas

[16]- Lopez-Gil, A. M., Miguel, R., De Saja, J. A., Bellucci, F. S., Ardanuy, M., (2014), Strategies to Improve the Mechanical Properties of Starch-Based Materials: Plasticization and Natural Fibers Reinforcement.,Polímeros., 24, 36-42. http://dx.doi.org/10.4322/polimeros.2014.054

[17]- Masłowski, M., Miedzianowska, J., Strzelec, K., (2017), Natural Rubber Biocomposites Containing Corn, Barley and Wheat Straw., Polym. Test., 63, 84-91. https://doi.org/10.1016/j.polymertesting.2017.08.003

[18]- Bouasker, M., Belayachi, N., Hoxha, D., Al-Mukhtar, M., (2014), Physical Characterization of Natural Straw Fibers as Aggregates for Construction Materials Applications., Materials., 7, 3034-3048. https://doi.org/10.3390/ma7043034

[19]- Zhenghua, Q., Zonglin, P., (2019), Reinforcing Styrene-Butadiene Rubber Composites by Constructing Multiple Interaction Between Rubber and Silica.,Polym. Comp.,40, 1740-1747. https://doi.org/10.1002/pc.24928

[20]- Manickam, R., Lakshmi, N. R., Nagarajan, S., Damodaran, V. K., Devarajan, B., (2022), Influence of Filler Material on Properties of Fiber-Reinforced Polymer Composites: A Review., e-Polymers., 22, 898-916. https://doi.org/10.1515/epoly-2022-0080

[21]- Hakim, A., Sabbah, A. S., Metwally, A., Begawy, S. E., Elshafie, E. S., (2012), Mechanical Properties and Morphology Studies of Nanocomposites Based on RSF/Nanoclay Modified/HDPE Nanocomposites., Life. Sci. J., 9, 134-142. https://api.semanticscholar.org/CorpusID:21689741

[22]- Guo, T., Wang, L., Zhang, A., Cai, T., (2005), Effects of Nano Calcium Carbonate Modified by a Lanthanum Compound on the Properties of Polypropylene., J. Appl. Polym. Sci., 97, 1154-1160. https://doi.org/10.1002/app.21804

[23]- Kenan, B., Halil, D., (2020), Examining the Mechanical and Thermomechanical Properties of Polymethylmethacrylate Composites Reinforced with Nettle Fibres.,Arab. J. Sci. Eng. 45, 665-674. https://doi.org/10.1007/s13369-019-04136-7

[24]- Rasib, S. M., Mariatti, M., Atay, H., (2021), Effect of Waste Fillers Addition on Properties of High-Density Polyethylene Composites: Mechanical Properties, Burning Rate, and Water Absorption., Polym. Bull., 78, 6777-6795. https://doi.org/10.1007/s00289-020-03454-3

[25]- David, M. H., (2019), Reinforcement of Latex Systems by the Use of Fillers, Chapter 5 in book "Latex Dipping: Science and Technology, Berlin, Boston: De Gruyter.

[26]- Sreekanth, M. S., Bambole, V. A., Mhaske, S. T., Mahanwa, P. A., (2009), Effect of Particle Size and Concentration of Flyash on Properties of Polyester Thermoplastic Elastomer Composites. JMMCE., 8, 237-248. https://www.scirp.org/pdf/JMMCE20090300007_96038507.pdf

[27]- Mengeloglu, F., Karakuş, K., (2012), Mechanical Properties of Injection-Molded Foamed Wheat Straw Filled HDPE Biocomposites: the Effects of Filler Loading and Coupling Agent Contents.,BioRes., 7, 3293-3305.

[28]- Zanaib, Y. S., (2012), Mechanical and Physical Properties of High Density Polyethylene Filled with Carbon Black and TitaniumDioxide., DJES., 5, 147-159.DOI:10.24237/djes.2012.05112

[29]- Muhammad, S., Rochmadi, R., Hary, S., Budhijanto, B., Shinta, V., (2022), Nanostructured Silica from Bagasse Ash: the Importance of Mixing Parameters on its Reinforcing Role in Natural Rubber Composite., Arab. J. Sci. Eng., 47, 5735-5746. https://doi.org/10.1007/s13369-021-05647-y

[30]- Ivana. P, Barbarić-Mikočević, Z., Alan, A., (2016), Chemical Composition of Straw as an Alternative Material to Wood Raw Material in Fibre Isolation., Drv. Ind., 67, 119-125. DOI:10.5552/drind.2016.1446

[31]- Beg, M., Pickering, K., (2008), Reprocessing of Wood Fibre Reinforced Polypropylene Composites. Part II: Hygrothermal Ageing and its Effects., Compos.: Part A., 39, 1565-1571. https://doi.org/10.1016/j.compositesa.2008.04.013

[32]- Aparna, K. B., Sreejith, M. P., Shaniba, V., Jinitha, T. V., Subair, N., Purushothaman, E., (2017), Coconut Shell Powder Reinforced Thermoplastic Polyurethane/natural Rubber Blend-Composites: Effect of Silane Coupling Agents on the Mechanical and Thermal Properties of the Composites., J. Mater. Sci., 52, 6712-6725. https://doi.org/10.1007/s10853-017-0907-y

[33]- Bledzki, A., Gassan, J., Theis, S., (1998), The Effect of Poly-Ethylene-Co-Glycidyl Methacrylate Efficiency and Clay Platelets on Thermal and Rheological Properties of Wood Polyethylene Composites., Mech. Compos. Mater., 34, 563-568. ISSN Online: 2160-0406 ISSN Print: 2160-0392

[34]- Chen, W., Xu, Y., Shi, S., Cao, Y., Chen, M., Zhou, X., (2018), Fast Modification on Wheat Straw Outer Surface by Water Vapor Plasma and its Application on Composite Material., Sci. Rep., 8, 1-8. https://doi.org/10.1038/s41598-018-20285-5

[35]- Chang, H., Yeh, H., Yang, T., Wu, T., Xu, J., Wu, J., (2017), Characterization of Wood-Plastic Composites Made with Different Lignocellulosic Materials that Vary in their Morphology: Chemical Composition and Thermal Stability.,Polym., 9, 1-11. https://doi.org/10.3390/polym9120726

[36]- Shebani, A. N., Van Reenen, A. J., Meincken, M., (2009), The Effect of Wood Species on the Mechanical and Thermal Properties of Wood-LLDPE Composites., J. Compos. Mater.,43, 1305-1318. https://doi.org/10.1177/0021998308104548