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Silica/white rice husk ash hybrid filler for rubber composites for the manufacture of low speed castor wheel rubber treads

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Abstract

The possibility of replacing a part of the 60 pph of commonly used silica filler imported from Wellink Chemical Co., India used in rubber composite for the manufacture of low speed castor wheel rubber tread formulations was studied. The curing characteristics and mechanical properties such as specific gravity, hardness, tensile strength, rebound resilience and abrasion volume loss of the composites prepared with varying amounts of White Rice Husk Ash (WRHA) ranging from 15 to 60 pph were determined. Results obtained were compared with those properties of the control composite containing 60 pph of commercial silica alone. The composites were then modified into a hybrid filler system by incorporating 6% (w/w) silane coupling agent based on the load of silica it contains. Commercial silica loading in the composite were varied from 10, 15, 20 and25pph, keeping WRHA loading at 45 pph at which loading, composites showed the closest properties to the properties of the controlled composite among candidate WRHA composites. Physical and mechanical properties of the vulcanizates were determined. The results showed that WRHA/Silica: 45/20 hybrid containing rubber vulcanizates exhibited the properties comparable to those of the vulcnizates of the control.

An approximate cost estimation analysis revealed that around 50% of the imported filler material cost saving could be achieved using this recipe instead of using only imported silica filler in the formulation to produce economically competitive tire treads.

Key words: rubber composites, silane coupling agent, silica, tyre tread formulae, white rice husk ash

Introduction

During the manufacture of rubber products, incorporation of fillers to rubber matrices, in order to meet the end user service requirements and to gain economic advantages has been a common practice. Carbon black and silica are the most popular, widely accepted and technologically proven conventional reinforcing fillers used in the rubber product manufacturing applications irrespective of whether rubber is Natural Rubber (NR) or Synthetic Rubber (SR). In view of growing public concerns of the environment, increasing stringent regulations on disposal of waste and associated cost coupled with the increasing global competitiveness of rubber products in the market, interest has been growing among researchers to study the potential use of materials derived from agricultural and industrial waste to be used in the rubber product manufacturing sector. Materials derived from agricultural waste such as rice husk ash (RHA), palm kernel shell powder and industrial waste such as ground rubber tyre (GRT), buffing dust, fly ash, *etc.* are some of such waste materials that have been studied for their potential use in industrial applications (Maan *et al*., 2015; Tatangelo *et al*., 2019; Daud, *et al*., 2016; Withayalcool *et al*., 2017). Among the derived materials from agricultural waste, rice husk ash, obtained from rice husk using low cost processing technologies based on combustion process contains a considerable quantity of silica (Jembere and Fanta, 2017). WRHA has a firm guarantee of a reliable supply in significantly high quantities and therefore, could be considered a potential raw material for industrial applications. When referred the numerous studies that have been carried out, it is evident that the use of this material is very common in a wide spectrum of industrial sectors including rubber sector. Use of rice husk ash in other sectors such as ceramics, and cement industries has been reported in literature (Hossin, 2018; Zareei, 2017).

Basically two types of rice husk ash namely Black Rice Husk Ash (BRHA) and White Rice Husk Ash (WRHA) are derived from rice husk depending on the conditions in which the burning process of RHA is carried out. Among these two types, former is produced by partial combustion of rice husk under limited oxygen supply and contains substantial amounts of both silica and carbon. Carbon in BRHA is responsible for the black colour. On the other hand, WRHA is produced by complete combustion of the rice husk in the atmosphere at a higher temperature than that in BRHA. Both types have been widely studied for their vulcanization characteristics and mechanical properties in the rubber composites. These studies have shown that the effect of BRHA and WRHA on the processing and the vulcanizate properties of rubber composites are generally similar to the effects of semi reinforcing or non-reinforcing fillers when filled in natural rubber composites (Arayapranee, 2005; Da Costa, 2014a). It has been reported that rice husk as filler does not adversely affect the vulcanization characteristics or the aging properties of rubber compounds. A study carried out by De Costa *et al.*, 2001 observed that the rice husk ash responds to Si-69 silane coupling agent marginally improving the performance of filled natural rubber composites (Da Costa 2001b).

Most of the studies have been based on general recipe and to date, not much studies appear to have been reported on the use of these filler as partial filler in a hybrid filler system with commercial silica targeting a specific product. It has been reported that carbon black could be replaced partially from rice husk ash with satisfactory physical properties and improved in tyre tread compounds with reduced rolling resistance (Fernandez *et al.* 2017). A study carried out on partial replacement of silica by WRHA in natural rubber composite has shown the replacement of silica by WRHA improves cure rate and increase the resilience (Ismail and Chung 1999). In the work reported on WRHA/Silica filled systems, there is no much work carried out on the use of WRHA or its hybrid filler system in the rubber composites based on virgin rubber-reclaim rubber blends aiming to manufacture specified rubber products. Considering the above facts and the more or less similar colour of WRHA to that of commercial silica, attention was paid to study the possibility of the use of WRHA as filler in a specific rubber product formulation used in low speed castor wheel (up to 4 km/h) manufacturing sector where silica is used as component filler with other non-reinforcing fillers.

Present paper focuses on WRHA/silica filled composites based on NR and reclaim rubber blend, which meets a set of general specifications suitable for manufacture of a particular type of export market oriented low speed wheels at industrial scale.

Materials and Methods

Materials

Natural rubber (RSS Grade no. 3) and reclaim rubber (hydrocarbon content > 78%, Mooney viscosity ML (1+4) @100 and specific gravity 1.14) were supplied by C.W. Mackie PCL, Horana Sri Lanka and Raplast reclaim company Pvt. Ltd. India respectively. Commercial silica (purity 98%, Moisture content 6%, pH value 6.8, average particle size < 18 µm, and surface area 165 m^2/g) was supplied by Wellink chemical industrial company in India. The silane coupling agent, bis (3-triethoxysilylpropyl-tetrasulfane (Si-69) used was manufactured and supplied by Grand Central Intillc. (Pvt.) Ltd. China. China clay (Aluminum silicate 90%, Moisture content 5%) and Calcium Carbonate ($CaCO_3$ 90.8%, $MgCO_3$ 6.12%, moisture content 5.5%) were supplied by a local supplier, Lanka mineral clay (Pvt.) Ltd. Process oil was supplied by Raj petro specialties (Pvt.) Ltd. in India.

Preparation and characterization of WRHA

White rice husk ash was prepared by controlled burning of dried raw rice husk for four hours at controlled specific temperature of 600 ^oC in a Muffle furnace at University of Moratuwa for 4 hrs. Ash content of the rich husk ash generated was around 20% (w/w). The product was washed in clean water and dried to a constant weight. The dried product was then sieved through 80 mesh size to minimize the particle size variations. Particle size distribution in WRHA were analysed by using Beckman Coulter LS 13 320 particle size analyser.

Typical formulation

The formulation shown in Table 1, which is a recipe suitable for particular type of castor wheel tread, was used as the typical formulation in this study. Filler loading of this formulation was modified by replacing silica with different WRHA loading as shown in Table 2 and properties of the composites evaluated in the first phase of the study.

Rubber compound preparation

The rubber compound preparation was carried out using a 1.2 liter laboratory Banbury mixer (mixer type Farrell, Model BR Mixer, Item no 1529) and a 12-inch Farrell (1.5:1 friction ratio) laboratory type mill. Mixing sequence used is given in Table 3.

Table 1. *Typical formulation used for commercial products*

Material name	Amount (g)
Natural rubber (Ribbed Smoked Sheet 3)	77.00
Reclaim rubber [77% Rubber hydrocarbon (RHC)]	15.00
High styrene resin [HS 68 type; 32% (RHC)]	20.00
Precipitated silica	60.00
Mineral fillers	95.00
Coupling agent	3.50
Zinc oxide	5.00
Stearic acid	1.50
Antioxidant	2.00
Antiozonant	1.00
Sulphenamide accelerators	3.0
Guanidine accelerator	0.75
Sulphur master batch [S % 50 (w/w)]	10.00

Note: The recipe contains total rubber 100g contributed from RSS, reclaim rubber, high styrene resin and sulphur master batch.

Table 2. *Different filler types and loading used in the first phase*

Materials	Filler loading (phr)				
	Control	A	B	C	D
Silica filler	60	0	0	0	0
WRHA	0	15	30	45	60

Table 3. *Mixing sequence ingredients*

Time (min.)	Ingredients
0	Rubbers
1	Silica filler + Diethylene glycol + Coupling agent
2	China clay + Whiting + Crumb rubber + Oil + Styrene Resins
3	Zinc oxide + Stearic acid and other materials
3.5	Sulphur + Accelerators
4	Dump

Silica filler and Rice husk ash were dried before use at 100 ^{0}C and sieved through 80 mesh sieve to minimizes the particle size variations. During the first phase of the study, a series of WRHA filled composites with varying loadings from 15-60 phr at 15 intervals were prepared (Table 2). Silane coupling agent was added based on the WRHA loading maintaining the 6% (w/w) ratio. A commercial silica filled rubber composite of 60 phr based on the same formulation (a comparable commercial recipe) was also prepared as the control composite. Physical and mechanical properties of these composites were compared with the commercial silica based composite prepared following the commercial formulation of interest (Table 1). WRHA filled composite with closest properties to the properties of the typical composite was selected for the next phase of the study, *i.e*. study of silica/WRHA hybrid rubber composites.

Preparation of hybrid silica/WRHA filled rubber composites

WRHA based formulation which offered the closest properties to the typical composite was selected as the reference for further studies. This composite was modified to form a hybrid filler system of WRHA and silica by varying the Silica content of the composite (Table 4). Silane coupling agent equal to 6% (w/w) of the hybrid filler loading was also added in these formulations.

Determination of curing characteristics

Curing characteristics of the composites at 150 ^{o}C were studied using an Oscillating Disc Rheometer (ODR) according to ASTM D2084. The cure time (t_{90}), scorch time (t_{s2}) maximum torque (M_H), minimum torque (M_L), *etc.* were determined from the respective rheographs.

Physico-mechanical testing of the samples

Mixes were vulcanized for their respective t_{90}s in an electrically heated laboratory press (Press Model Schubert and press size 18 x 18 inches) at a pressure of 10.5 MPa. Vulcanizates were conditioned for 24 hours before testing. Physico-mechanical properties (Shore A hardness, tensile properties, rebound resilience and abrasion volume loss) were measured following the ISO 7619, ISO 37, ISO 4662 and ISO 4649, respectively. Tensile tests were carried out on an Instron Universal Testing machine, model 3365. All the mechanical tests were conducted at the ambient temperature at 28 ^{o}C ±2.

Table 4. *Formulations with progressive increment of silica in the selected WRHA filled rubber composite*

Materials	**Filler loading (Phr)**			
	E	**F**	**G**	**H**
Silica filler	10	15	20	25
WRHA*	X	X	X	X

* X: WRHA content in the selected formulation in the study carried out in the first phase

Results and Discussions

Particle sizes of the composites

Average particle size and the surface area of the WRHA used are presented in the Table 5 along with the corresponding information of commercial silica obtained from the technical data sheet provided by the supplier. It could be seen that average particle size of WRHA is larger than that of commercial silica used in the study. Commercial silica is a synthesized product made under control conditions while WRHA obtained here is a product obtained from agricultural waste using a simple and economical burning process without a strict control of the process.

Table 5. *Particle sizes of the filler*

Fillers type	**Average particle size (um)**	**Surface area (m^2/g)**
RHA (Rice Husk Ash)	45	75
Silica	18	165

Cure characteristics of filled composites

Table 6 shows the values of the scorch time (ts_2) and optimum cure time (t_{90}) of the composites. WRHA loading has only a slight retarding effect on both (ts_2) and t_{90}. WRHA is known to affect the curing rate differently depending on the levels and nature of the impurities, burning conditions, and the basicity of the fillers (Da Costa 20014a; Da Costa 2001b; Fernandez *et al.*, 2017; Ismail and Chung 1999; Siriwardena *et al*., 2001).

It could also be seen that control sample (60 phr silica loaded) has exhibited almost similar ts_2 and t_{90} values when compared with those exhibited by the corresponding WRHA filled sample (W60). Minimum torque (M_L) values presented in Table 6 shows that it is increased with increased WRHA loading. As WRHA forms aggregates and convoluted structures in NR phase, this trend is elucidated. The maximum value (M_H) which is an indicative of the stiffness of the vulcanizate also increased with the increasing loading probably due to the restrictions exerted by the possible agglomerates formed against the macromolecule movements with increasing filler loading. However, both control sample and WRHA filled NR composite at 60 phr loading exhibit almost similar properties irrespective of their source. Therefore, it could be concluded that filler type has no influence on the processability as far as the curing characteristics of both types of composites are concerned. Therefore, WRHA could be incorporated into wheel formulations under study without any processing problems.

Table 6. *Curing characteristics of the rubber composites studied*

Cure parameter	Control	A	B	C	D
t_{90}	1.43	1.29	1.47	1.55	1.62
t_{s2}	0.38	0.22	0.30	0.49	0.50
M_L	4.00	1.95	2.90	3.10	3.60
M_H	28.00	9.00	16.00	20.00	26.00

Physical properties

Specific gravity

Specific gravity of a composite is of great importance in rubber product manufacture as it directly determines the weight of the product. Generally, specific gravity and hardness of rubber composite increase with the increasing rigid filler loading in rubber composites (Osabohicn 2007). Figure 1 and 2 show that variation of those properties are in agreement with the trend mentioned above. Being inorganic fillers, both silica and WRHA have higher specific gravity than natural rubber and consequently, addition of filler increase the specific gravity of the composites. It could be noted that at the same filler loading (60 phr), WRHA filled composite exhibit a higher specific gravity than the commercial silica filled composites which probably may be due to the higher specific gravity of WRHA. However, specific gravity of all the samples closely falls within the acceptable levels as per the technical specifications recommended for the castor wheel in question given in Table 7 below.

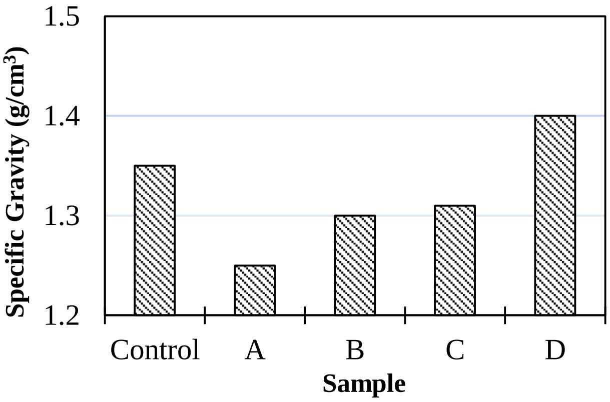

Fig. 1. Variation of specific gravity with filer loading

Hardness

Increasing WRHA loading from 15 to 60 phr has shown a gradual increase in the hardness value of the composites from 45 to 75 shore A (Fig. 2). Being a silica rich source, when percentage of rigid WRHA content is higher with simultaneous reduction of the percentage of softer elastomer content in the material, increase in the hardness is an expected trend. Similar trend could be seen for the numerous rubber composites studied with varying contents of similar filler types including WRHA filled rubber composites (Osabohicn *et al*., 2007, Daud *et al*., 2016b, Pongdhorn *et al*., 2002).

The hardness value of the control sample which has 60 phr silica has yielded the highest value among all the studied samples. At the same filler loading, WRHA filled composite shows a lower hardness value than that in silica filled counterpart suggesting the non-reinforcing character of the former. WRHA is renewable, but non-conventional filler derived from rice husk ash and consist of large size particles. Consequently, WRHA agglomerates yields a smaller surface area as reported earlier. Therefore, filler to matrix interaction become poorer in WRHA filled composites and lower hardness value is obtained for the composites in comparison to corresponding silica filled NR composites. However, it should be noted that the hardness of the composite D which has 60% WRHA loading is closer to the hardness value range set out (formulated) in the specifications given for the commercial composite (Table 7).

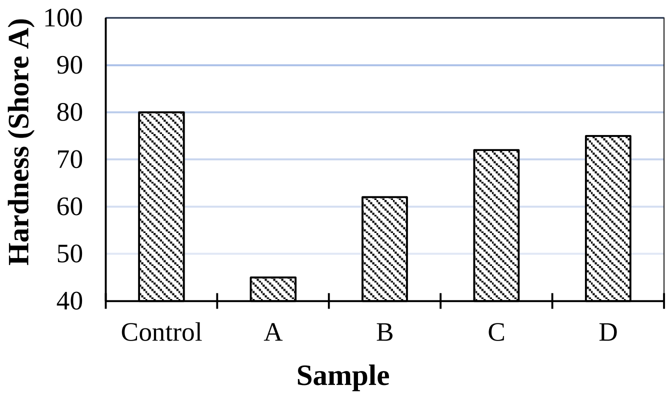

Fig. 2. Variation of harness with filer loading

Mechanical properties

Rebound resilience

Figure 3 shows the effect of filler type and WRHA loading on the rebound resilience of composites. As expected, rebound resilience has shown a gradual reduction in composites with increasing WRHA loading from 15 to 60 phr. Rebound resilience is related to the flexibility of molecular chains in the vulcanizate; the more flexible the molecular chains, the better the resilience is. However, when the filler loading is increased, it restricts the molecular movement which affects the flexibility with a simultaneous reduction of the flexible elastomer content in a unit volume of the composite. Therefore, with the addition of WRHA, composites exhibit poor flexibility and enhanced stiffness of matrix resulting in a gradual decrease in rebound resilience (Daud *et al.,* 2016b). At 60 phr filler loading, silica filled NR composites (control sample) has also showed lower resilience values than the first three WRHA filled composites. However, at the same filler loading, silica filled composites exhibits slightly higher resilience than 60% WRHA filled composite (W 60). This may be due to the better dispersion and reinforcement effect of silica in the rubber matrix. However, it is interesting to note that resilience values of Sample W45 and W60 (WRHA loading 45 and 60 phr) fall in the recommended range given in the specifications (Table 7).

Tensile strength

As it could be seen in Figure 4, WRHA filled composites have shown a slight reinforcing effect as evident from the increased tensile strength from sample W15 to W45. As the WRHA content exceeds 45 phr, it has shown a dramatic reduction in tensile strength. It has been reported in literature that WRHA has a tendency to agglomerate the particles (Siriwardena *et al.,* 2001). As the WRHA loading increases, they may form lager agglomerates reducing the surface area of filler particles that could be wetted by the rubber molecules. Consequently, the efficiency of stress transfer from the rubber matrix to the WRHA particles is reduced resulting in a drop of tensile strength with increasing filler loading. It is also shown that at the same higher filler loading (60 phr), WRHA filled composites have shown a drastic reduction in tensile strength compared to the corresponding silica filled counterpart. This observation clearly suggests poor reinforcing effect of WRHA than that in commercial silica used composites in this study. When the tensile properties required for the product which has given in the recommended specifications is considered, none of the WRHA filled composites has exceeded the minimum limits. Therefore, if WRHA is to be incorporated to NR to qualify the composite for particular application, it is necessary to modify the filler system to achieve the required level of tensile strength.

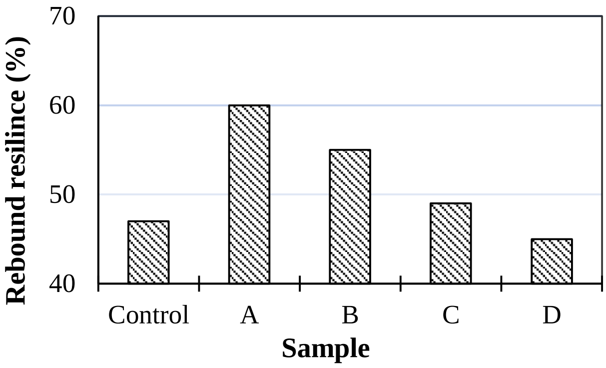

Fig. 3. Variation of rebound resilience with filer loading

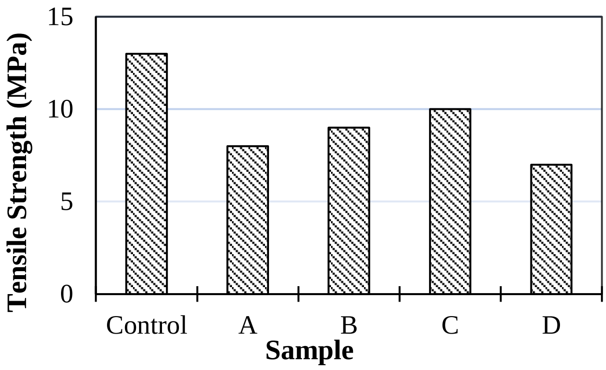

Fig. 4. Variation of tensile strength and modulus 100% elongation with t filler loading

Modulus @ 100% elongation

Modulus @ 100% elongation at different filler loading is presented shown in Figure 5. Increase in WRHA loading has only a slight increase in the modulus. This result is in agreement with the observations made with regard to WRHA filled natural rubber composites found in literature (Siriwardena *et al.*, 2001, Pongdhorn 2002). The highest modulus has been recorded by the WRHA filled composites with 60 phr filler loading. Comparison of modulus values of composites having 60 phr filler loading reveals that WRHA has a higher impact on the modulus of the composites which perhaps may be due to the presence of the larger WRHA agglomerates in the matrix. However, it has no any significance as the difference of the modulus values is only around 1 MPa. As far as the modulus values are concerned, all the composites qualify for the purpose as they all have met the required level of modulus given in the specifications for intended product (Slow speed castor wheel tread) given in Table 6.

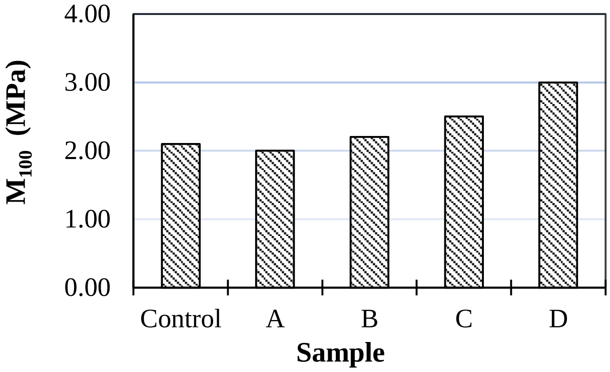

Fig. 5. Variation of Modulus @ 100% elongation with filer loading

Elongation @ break

Elongation at break of the WRHA filled composite series has shown a gradual reduction with increasing filler loading (Fig. 6). WRHA particles are not surface treated and therefore, rubber-WRHA interface is not strong enough to reinforce the matrix. Simultaneously, increase in WRHA loading, may tend to form larger WRHA agglomerates reducing the surface area of the filler particles as already reported in literature (Siriwardena *et al*., 2001). Strain induced crystallization of NR molecules is also restricted as fillers are added to the composites. As the filler loading increases, this effect becomes more prominent. These factors justify the decrease in elongation as the WRHA loading increases. However, when the elongation values of controlled sample (60 phr silica loaded sample) and the corresponding WRHA filled composite (60 phr WRHA loaded sample), former has recorded a higher elongation at break. At the same filler loading, silica may form agglomerates smaller than the WRHA fillers and wetted by the macromolecules more efficiently and therefore, higher elongation at break value could be expected due to the higher interactions (Van der Waals forces) between rubber matrix and filler particles. However, it is interesting to note that elongation at break of all the WRHA composites studied shows values more than 300%, thus the elongation at break of the composites could be obliterated as a determinant factor in the selection process of optimum WRHA loading.

Abrasion volume loss

Abrasion volume loss indicates the reinforcing effect of the filler and the heat development during the fiction of the material (Fig. 7). WRHA loading has resulted in increase of abrasion volume loss. This observation again suggests that WRHA is not a filler with reinforcing characteristics. Analysis of previous results observed for mechanical properties shows that, silica filled composites exhibit better reinforcing characteristics than that of corresponding WRHA filled composite (Controlled sample and W60). As discussed earlier, tendency towards filler agglomeration at high filler loading is also evident from these results, when one compares the abrasion volume loss trend of WRHA filled composites with that of increasing WRHA loading. However, as in the case of modulus and elongation, all the composites have abrasion volume loss below the limits of the recommended specifications for castor wheel given in Table 7.

A comparison of the recommended specifications and the mechanical properties achieved for the WRHA filled composites shows that sample W45 (WRHA loading 45 phr) exhibits the closest properties to the standard technical specifications presented in Table 7. Therefore, this composite was selected for preparation of hybrid fillers with silica in our further studies.

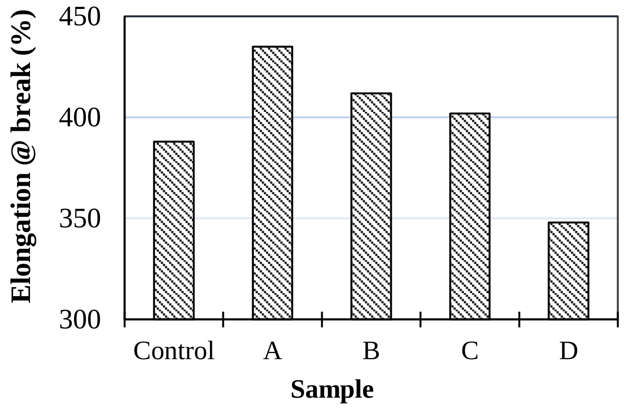

Fig. 6. Variation of elongation @ break with filler loading

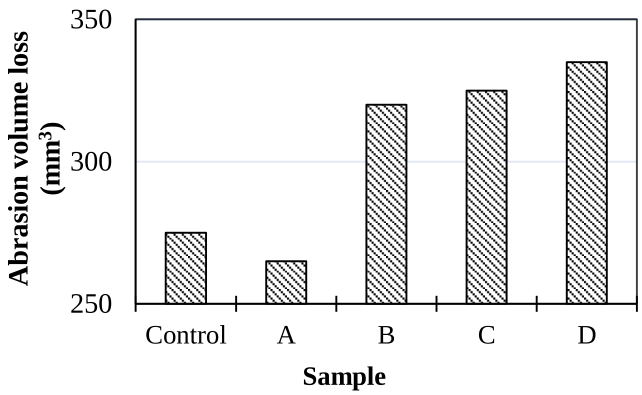

Fig. 7. Variation of abrasion volume loss with filler loading

Table 7. *Comparison of mechanical properties of different composites*

Physico-mechanical properties	C (WRHA loading 45 phr)	Control sample (Silca loading 60 phr)	Recommended specification
Specific gravity	1.31	1.35	1.34 ± 0.03
Hardness (Shore A)	72	80	79 - 82
Resilience (%)	49	48	45 ± 5
Tensile strength (MPa)	10	13	> 10
Modules 100 (MPa)	3.0	2.2	> 2
Elongation (%)	400	388	> 300
Abrasion volume loss (cm^3)	325	275	<350

Rubber composites with silica/WRHA filled systems

As the next step, composition of W45 which showed the closest performance to the required specifications was modified by using hybrid filler of WRHA and silica. As explained in the experimental section, silica content in the selected composite (W45) was progressively increased from 10 to 25 at 5 phr intervals. The resultant WRHA/silica hybrid filler system was treated with silane coupling agent as mentioned earlier. The physical and mechanical properties of these composites are tabulated in the Table 8.

Specific gravity of hybrid composites has shown a slight increasing trend with increasing silica loading. Specific gravity of the composites exceeds its value of control sample and reaches the level required in the specification as the silica content exceeds 15 phr loading. It could be seen that as the silica content increases the hardness values, rebound resilience, tensile strength and modulus @ 100% elongation of the composites also increase. This is attributed to the reinforcing effect of silica when used with a suitable coupling agent.

Both tensile strength and modulus @ 100% elongation of the hybrid composites increase with the silica loading. As the silica content exceeds 15 phr, composites have shown an increase in tensile strength. As the same WRHA content was used in each modified composite, it could be inferred that the contributing factor to these property changes is the silica incorporation. As the silica content reaches 20 phr, it could be seen an increase in tensile strength exceeding its value from the minimum required value given in specifications (10 MPa) presented in Table 7.

Table 8. *Mechanical and physical properties of hybrid composites*

Property	E	F	G	H	Control sample
Specific gravity	1.34	1.34	1.36	1.36	1.35
Hardness (Shore A)	75	77	78	80	80
Resilience (%)	51	51	51	53	48
Tensile strength (MPa)	10	10	12	14	13
Modulus @ 100% elongation (MPa)	4.0	4.0	5.5	5.5	2.2
Elongation %	370	380	388	400	388
Abrasion value (cm^3)	280	280	288	288	275

Increment seen in the modulus @ 100% elongation of the hybrid samples with silica shows improved filler to matrix attractions in the presence of a coupling agent. All the composites have registered higher modulus values than that required in the specifications for the intended product. It could be also observed that as the silica content of the hybrid composites increases, elongation at break has also increased. Similar property enhancements up to an optimum ratio of component fillers in hybrid carbon black and calcium carbonate fillers has been reported and the mechanical properties variations of the hybrid silica and WRHA filled composites reported in this study is in well agreement with the above observations (Reginald *et al*., 2019). This may be attributed to the contribution of the reinforcing filler on the property enhancement and the mutual restriction offered on each other by the component filler particles against the filler agglomeration.

Abrasion volume loss of the hybrid samples shows only a slight increase with the increase of the silica content of the hybrid composites as shown in Table 8. When the composite filled only with WRHA at 45 phr loading is compared with hybrid filler of Silica and WRHA treated with silane coupling agent, the latter has remarkably reduced the abrasion volume loss, *i.e.* improved abrasion resistance.

When physical and mechanical properties of the four WRHA/Silica hybrid composites studied are considered, there is no significant deviation in the properties from the minimum level of properties given in the recommended specifications. The work carried out by Chandrana *et al*. on a different combinations of silica containing hybrid filler incorporated NR composites has also shown that silica containing hybrid fillers could improve the mechanical properties of natural rubber composites (Candrana *et al*. 2018). Considering the economic aspects and the importance of having the allowance for the minimum specified limits in industrial applications, composite with Hybrid filler with 45% (w/w) WRHA and 20% (w/w) silica could be considered as the optimum hybrid filler combination for the application referred to.

Economic analysis

A summary of approximate estimation carried out on the cost of silica based filler materials (silica and WRHA) is given below (Table 9) using the rates in 2019 and certain assumptions. It could be seen that there is a potential for a considerable financial gain, if the hybrid filler is used to manufacture low speed wheel considered in this study achieving over 50% saving in the filler cost.

Table 9. *Approximate cost analysis*

Item	**Approximate cost (Rs/kg)**
Cost for Raw material (Cost for Husk in the local market)	5.00
Transport cost (assumption)	2.00
Cost for incineration based on an electrical box furnace (power requirement 3.33 kwh) used for incineration of rice husk (assumption)	11.37
Miscellaneous cost (10% of the total cost) (assumption)	1.18
Total cost of WRHA	20.21
Market price of silica	98.00
Total cost of selected hybrid filler (WRHA45:Silica 20)	44.13
Percentage of saving when silica filler is replaced with hybrid filler	54.96

Conclusions

Incorporation of WRHA in the composites studied has no remarkable influence on the curing characteristics of the composites. However, the physico-mechanical properties decreased with increase of WRHA loading. It has been shown that among the candidate WRHA filled composites, 45 phr WRHA filled composite exhibits physical and mechanical properties comparable to the properties of the control sample (commercial silica 60 phr filled composites) and also they are within the specifications given by the customers for the particular type of castor wheel under study except for abrasion resistance.

It was found that improvement of physico-mechanical properties could be achieved through hybrid filler systems of WRHA and silica composites treated with a silane coupling agent. This shows the potential for the use of hybrid filler systems in industrial applications replacing a considerable portion of commercial silica with WRHA filler. Therefore, this finding will certainly help to cut down quantities of commercial silica filler used in selected commercial white rubber compound recipes and to add value to the rice husk while mitigating the environmental problems associated with disposal of rice husk.

Considering overall properties of the hybrid composites studied, it was found that WRHA/silica: 45/20 filler system is qualified to be used to manufacture the low speed wheel of interest replacing 45 phr commercial silica in the formulation. It was also found that filler material cost saving would be approximately 50% per kg of silica filler used.

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