Experimental analysis on the technical behavior of carbon black filled rubber blends' rollers for rice husk removal application

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Abstract: In rice husk removal processes, the rubber rollers are used to produce white rice kernels. Paddies are fed between two rubber rollers and the removal of husk takes place due to high friction generated between the paddy layer and outer surface of rubber rollers. Husk removal application involves rubber compounds with promising physico-mechanical properties. Small scale rice mills in Tamil Nadu, India face problems in periodic replacement of rubber rollers due to poor service life. Based on the survey, it was found that the rubber compounds with high hardness lead to efficient husk removal and at the same time cause breakage of rice. Employing soft rubber eliminates the breakage of rice, but on the other hand the sharp corners of paddy damage the rubber. This research work focuses on the development of rubber compounds for effective rice husk removal application. Carbon black filled, pure and blends of natural rubber (NR), acrylonitrile butadiene rubber (NBR), and epoxidized natural rubber (ENR) are developed. Mechanical properties and lab scale rice husk separation studies are conducted for the developed rubber compounds. The ENR-NBR blends prove to be suitable materials for husk removal application.

Keywords: husking, rubber, carbon black, physico-mechanical properties.

Analiza zachowania się rolek z mieszanek kauczukowych napełnionych sadzą w procesie usuwania łuski ryżowej metodą walcowania

Streszczenie: Usunięcie łusek z ziaren ryżu metodą walcowania pomiędzy rolkami wykonanymi z kauczuku napełnionego sadzą następuje w wyniku tarcia wytwarzanego między warstwą nasion ryżu a powierzchnią rolek. Do tego typu zastosowań potrzebne są mieszanki kauczukowe o specjalnych właściwościach fizyko-mechanicznych. Ze względu na niewielką trwałość dotychczas stosowanych materiałów gumowych, małe młyny ryżu w Tamil Nadu w Indiach borykają się z koniecznością okresowej ich wymiany. Na podstawie przeprowadzonych badań stwierdzono, że rolki wykonane z mieszanek kauczukowych o dużej twardości skutecznie usuwają łuski, ale niestety powodują jednocześnie pękanie ziaren ryżu. Z kolei zastosowanie mieszanek kauczukowych o mniejszej twardości ogranicza zjawisko pękania, ale ostre łuski uszkadzają rolki. Zbadano właściwości mechaniczne i efektywność w procesie separacji łuski ryżowej napełnionych sadzą wulkanizatów kauczuku naturalnego (NR), butadienowo-akrylonitrylowego (NBR), epoksydowanego kauczuku naturalnego (ENR) lub ich mieszanin. Wulkanizaty mieszaniny ENR-NBR okazały się najbardziej odpowiednimi materiałami na rolki do zastosowań w procesie usuwania łuski ryżowej.

Słowa kluczowe: łuska ryżowa, kauczuk, sadza, właściwości fizyko-mechaniczne.

Primary stage of rice milling is the husk removal operation. In ancient days, the husk was removed from paddy with the help of impeller type huller. To avoid rice breakage, the modern rice milling industries are using rubber rollers for paddy de-husking [1]. Rubber roller type hulling machine consists of two rubber rollers of the same diameter placed close to each other rotating with different speeds (normally, 950 rpm and 1300 rpm) [2]. Controlled amount of paddy will

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be passed in-between these rollers. Removal of husk takes place due to high friction generated between the paddy layer and rubber surface. Based on the survey conducted from small scale rice mills in Tamil Nadu, it was found evident that the rubber compounds with high hardness lead to efficient husk removal and at the same time cause breakage of rice. On the other hand, rubber compounds with low hardness can efficiently eliminate the breakage of rice. However, the sharp corners of the paddy will damage the rubber [3–7]. This indeed leads to periodic replacement of rubber rollers due to poor service life. The latter stated problem creates interest to focus on the development of rubber compounds with promising mechanical properties for rice husk removal applications and enhanced service life. Few resplendent works had been reported on rubber nanocomposites comprising nanoparticles (nanoclay, nanosilica, fly ash) reinforced NR-NBR blend system and ENR-NBR blend system [natural rubber (NR), acrylonitrile butadiene rubber (NBR) and epoxidized natural rubber (ENR)] [8–11]. However, the research work on applying these blend system for husk removal application remains unexplored. The research work utilize NR-NBR blends and ENR-NBR blends in presence of carbon black for husk removal application. Carbon black filled pure and blends of NR, NBR and ENR are prepared. Mechanical properties like hardness, wear and rice husk separation studies are conducted for the developed rubber compounds. On observation, ENR-NBR blends proven as suitable materials for husk removal application compared to NR-NBR blends. Upon blending, the unique properties of individual materials (*i.e.*, ENR and NBR) contribute for effective rice husk removal process due to compatibility between blend components.

EXPERIMENTAL PART

Materials

– Acrylonitrile butadiene rubber (Nancar 1052) containing 33 % acrylonitrile was supplied by Taiwan Nancar Co. Ltd., Taiwan.

– Epoxidized natural rubber containing 50 mol % epoxidic units was supplied from Malaysian Rubber Board, Malaysia.

– Natural rubber was supplied by the Rubber Board--Kottayam, Kerala.

– The compounding ingredients such as sulfur, zinc oxide, stearic acid, *N*-cyclohexyl-2-benzothiazyl sulphenamide (CBS), *N*-isopropyl-*N*-phenyl-*p*-phenylenediamine (IPPD) were purchased from Bayer Co. (Malaysia) Sdn Bhd.

– Carbon black (ISAF N231) was supplied by Birla Carbon.

– Standard rubber grade process oil (Elasto 710) was purchased from the local market.

– Indian paddy variety namely BPT 5204 were purchased from local market.

Preparation of raw rubber

The compounding formulations are prepared as shown in Table 1. Rubber compounding was carried out in two roll mill at friction ratio of 1 : 2. Initially rubbers are masticated followed by addition of carbon black and other ingredients like process oil, sulfur, stearic acid, CBS, zinc oxide, and IPPD.

Experimental setup

Experimental setup was fabricated to husk rice grains (paddy) individually in a controlled manner. Samples of rice were pressed between two small blocks of rubber which slides with the help of motor and worm drive arrangement. Desired load (10–40 N) was applied for contact using the loading arm, and the imbalance of the arm was balanced using a counter weight. Speed of sliding is controlled using speed controller to set the desired speed for tests. Due to relatively small rubber samples the speed of the sliding base should be lower than the speed of roller in practice (50 mm/min is the velocity of sliding base, in reality it is around 270 m/min) [2]. Grains were husked

T a b l e 1. Formulation of the rubber compounds

Component	Sample code										
	NR	ENR	NBR	R1	R2	R3	R4	R5	R6	R7	R8
	Content of component in rubber compounds, phr										
NR	100	–	–	80	–	60	–	40	–	20	–
ENR	–	100	–	–	80	–	60	–	40	–	20
NBR	–	–	100	20	20	40	40	60	60	80	80
ISAF N231	40	40	40	40	40	40	40	40	40	40	40
Stearic acid	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
IPPD	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
CBS	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28
ZnO	2	2	2	2	2	2	2	2	2	2	2
Elasto 710	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
Sulfur	1	1	1	1	1	1	1	1	1	1	1

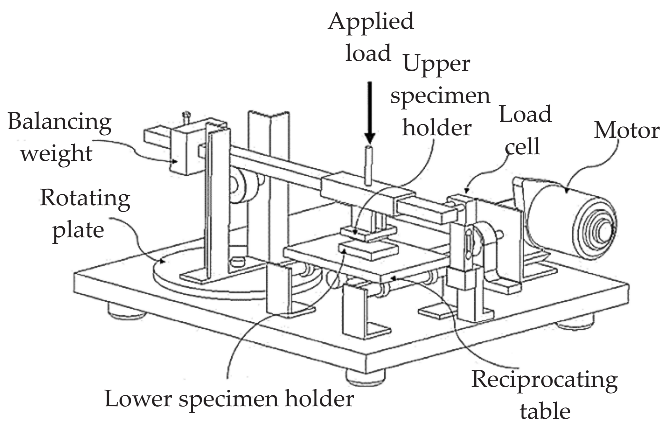

Fig. 1. Schematic diagram of experimental setup for rubber wear measurement

at different loads and the magnitude of husking and rice breakage is measured by counting the husked grains manually. Experimental setup for rubber wear measurement is shown in Fig. 1.

Methods of testing

– Hardness of the samples of vulcanized rubber compound was measured using Shore A hardness tester by following ASTM D2240-05 standard.

– Abrasion resistance of vulcanized rubber compound was tested by DIN abrasion tester by following the ASTM D5963-96 standard.

– Scanning electron microscope (model: VEGA3, producer: TESCAN) was used to examine the surface morphology of vulcanized rubber compound. To prevent electrostatic charge while examining, a thin gold layer is coated on the samples under vacuum condition.

RESULTS AND DISCUSSION

Hardness of vulcanized rubber compounds

The hardness of vulcanized pure and blended rubber compounds are shown in Fig. 2. In neat rubber batches, the NBR has higher hardness value compared to NR and ENR. NR and ENR almost have similar hardness value. Among blend systems, R7 has higher hardness value (18.96 %) followed by R8 (17.24 %), R5 (12.06 %), R6 (10.34 %), R3 (6.89 %), R1 (3.44 %), R4 (3.44 %) compared to R2. The blend system R2 shows minimum hardness value which is more optimum for rice husking operation. If hardness is high, the rice breakage is more in husking operation. Compared to neat NR and ENR rubber, the blend system R2 has higher hardness. If hardness is too low, the sharp edges of the paddy will damage the rubber.

DIN abrader test results

Figure 3 shows the wear loss of vulcanized pure and blended rubber compounds. Carbon black filled NBR

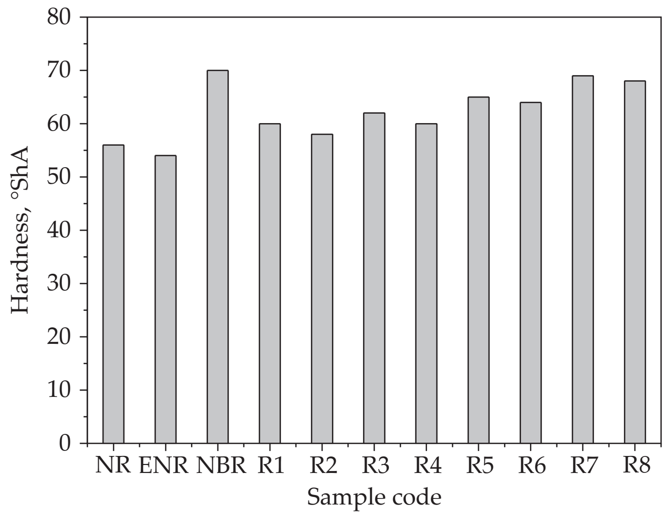

Fig. 2. Hardness of vulcanized pure and blended rubber compounds

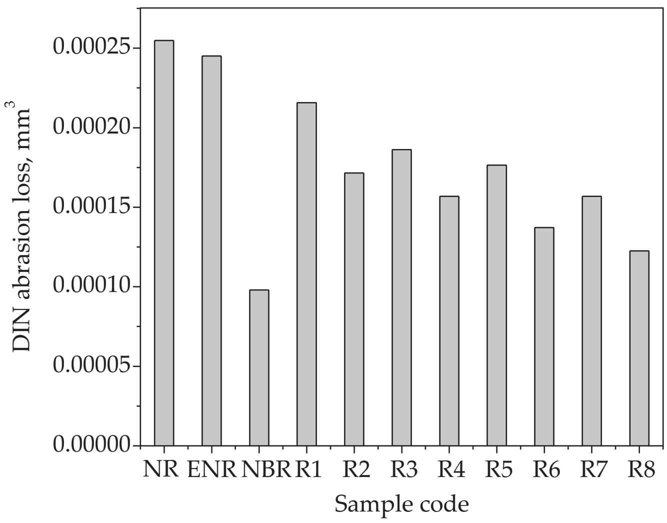

Fig. 3. Wear loss of vulcanized pure and blended rubber compounds

shows higher resistance to wear compared to carbon black filled NR and ENR system. In blend systems, ENR-NBR blends portrayed higher resistance to wear compared to NR-NBR blends. In ENR-NBR blend system, the wear resistance pronounce based on the content of NBR. Rubber compounds R8, R6, R4, R2 show 43.05 %, 36.57 %, 27.31 %, 20.37 % higher wear resistance compared to R1.

Husking and breakage percent of rice

The percentage husking of rice in the developed experimental setup is shown in Fig. 4. The husking percentage of neat rubber batch NBR has higher value followed by NR and ENR at various applied loads. Among blend systems, R8 and R6 have higher husking percentage followed by R2, R3, R4, R7, R1 and R5 for four different loads.

The breakage percent of rice in the developed experimental setup are shown in Figure 5. In neat rubber batches, the breakage percent is higher for NBR followed by NR and ENR. Among blend systems, the breakage per-

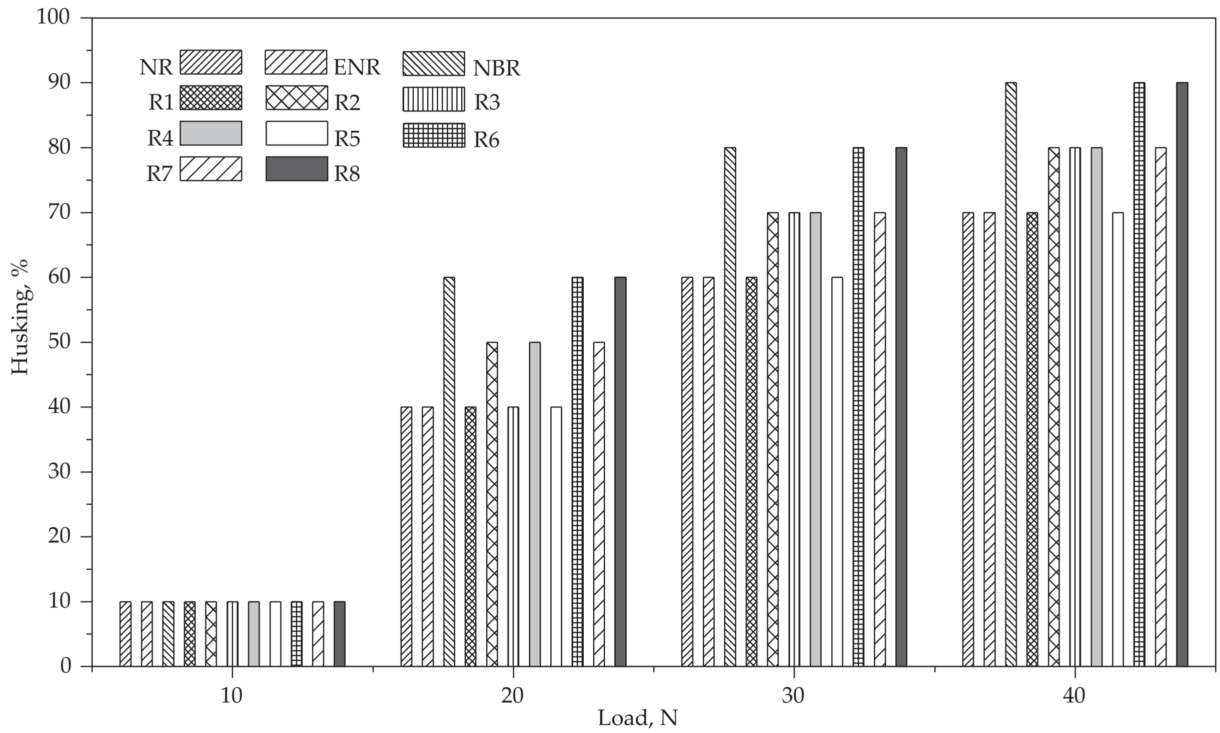

Fig. 4. Percentage husking of rice in the developed experimental setup

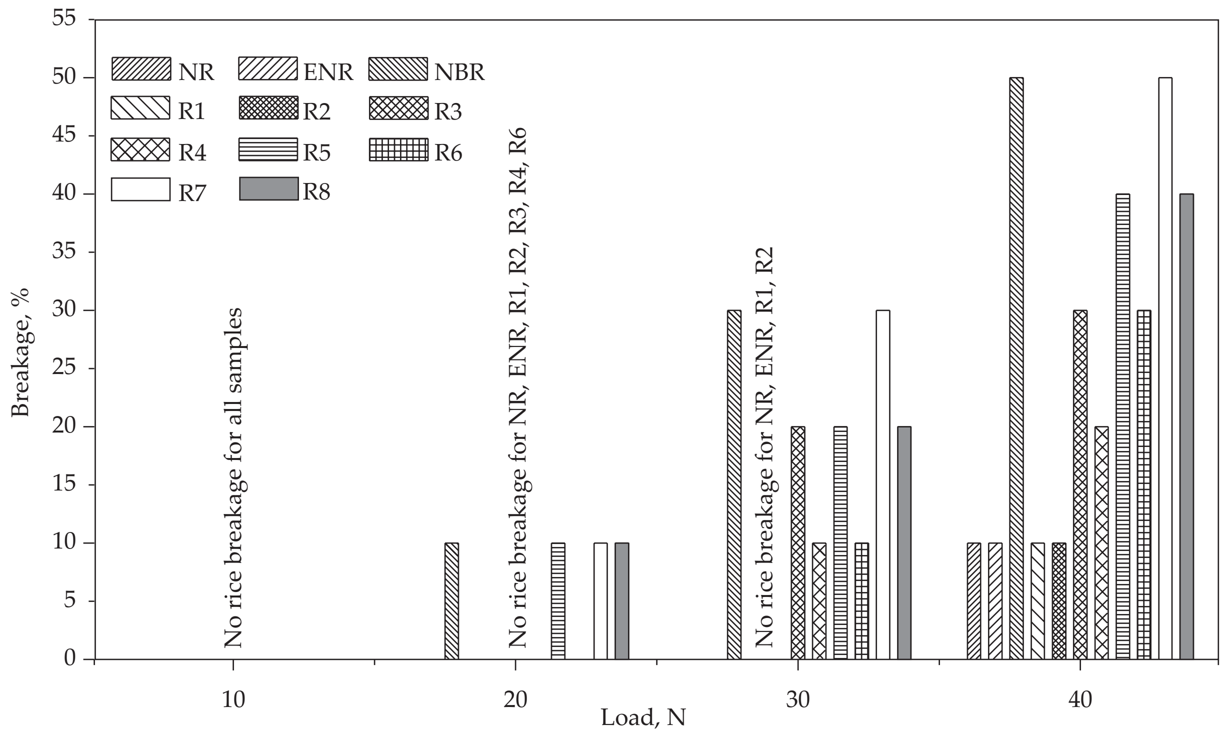

Fig. 5. Percentage breakage of rice in the developed experimental setup

cent of rice is higher in the following orders R7, R5, R8, R3, R6, R4, R1 and R2.

Mass loss of rubber after rice husking

The mass loss of pure and blended rubber compounds after rice husking with applied load are shown in Fig. 6. The mass loss for applied load of 40 N is considered for analysis, since mass loss for 10 N, 20 N and 30 N have very negligible value. Carbon black filled NBR shows higher resistance to wear compared to carbon black filled NR and ENR system. The blend system R8 shows minimum weight loss followed by R6, R4, R2, R5, R7, R3 and R1.

Scanning electron microscopy

The SEM images of carbon black filled NR-NBR blend (R1) and ENR-NBR blend (R2) are shown in Fig. 7.

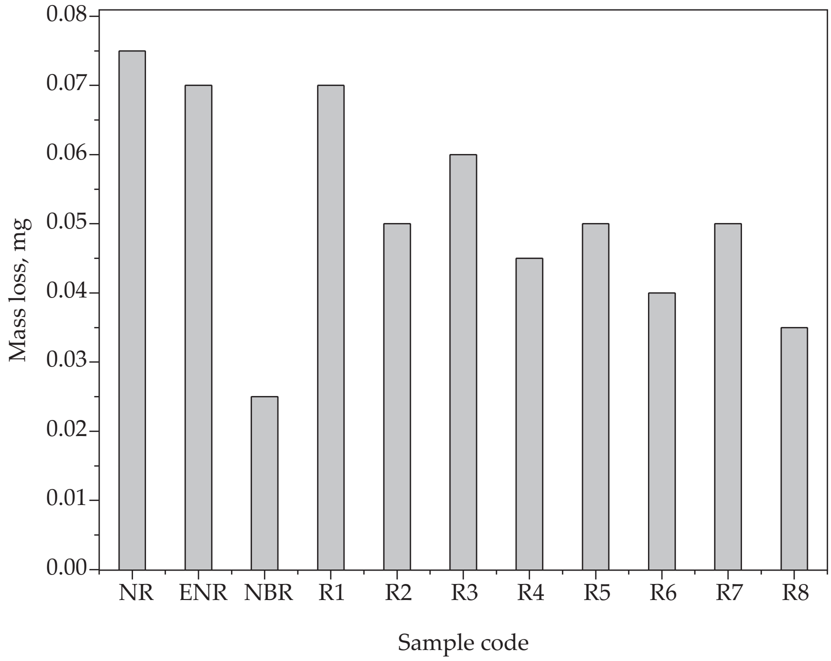

Fig. 6. Mass loss of vulcanized pure and blended rubber compounds after rice husking

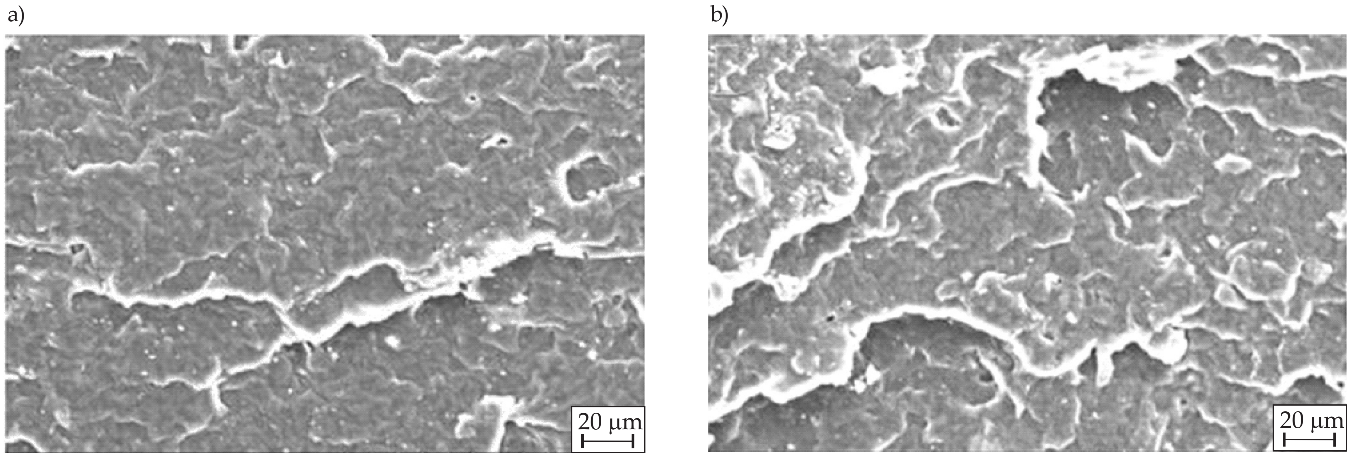

Fig. 7. Morphology of tensile fractured surface of vulcanized: a) NR-NBR blend (R1), b) ENR-NBR blend (R2)

Both the images show rough surface morphology due to presence of carbon black which alters the crack propagation path depending on their orientation in rubber blends [12–16]. However, high tortuous crack path has been observed for R2 compared to R1. Compatibility match between NBR and ENR creates strong physical and chemical interaction between the two. Hence, compatibility and presence of carbon black form strong restriction to crack propagation.

Reason behind the obtained mechanical properties by rubber compounds

Carbon black filled NBR compounds portrayed high hardness, wear resistance, husking capacity compared to carbon black filled ENR and NR systems. This can be attributed to the presence of acrylonitrile content (33 wt %) in NBR. Glass transition temperature gradually increases with acrylonitrile content, which eventually drops the elastic properties at room temperature. Hence, carbon black filled NBR compounds portray high hardness, which resulted improvement in resistance to wear [12]. Carbon black added NR, ENR and NBR compounds cannot be directly employed for rice husking applications. Wear loss of NR and ENR is comparatively higher than NBR, whereas rice breakage is eventually higher for NBR compared to NR and ENR.

The stated drawback has been made to overcome through blends. Enhanced mechanical properties are observed for ENR-NBR blends compared to NR-NBR blends. This may be due to compatibility between ENR and NBR due to polar-polar interaction between the two [13], whereas NR and NBR are incompatible as there exist a polarity mismatch between the blend partners [15, 17, 18]. In ENR-NBR blend system, R2 portrays balance of mechanical properties with special reference to effective husking capacity with minimal rice breakage and less wear rate.

CONCLUSIONS

Mechanical properties and rice-husk separation studies are conducted for the developed pure and blended rubber compounds. Carbon black added NR, ENR and NBR compounds cannot be directly employed for rice husking applications. Overview of advantages and limitations observed through testing are highlighted. NBR portrayed higher resistance to wear compared to NR and ENR.

On the other hand, NR and ENR depicted minimal rice breakage during husking operation compared to NBR. The stated limitation of individual rubber compounds are minimized through blending of ENR-NBR and NR-NBR. Enhanced mechanical properties are observed for ENR-NBR blends compared to NR-NBR blends. This may be due to compatibility (polarity match) between the former blends and incompatibility (polarity mismatch) between the latter blends. Under ENR-NBR blend system, R2 portrays balance of mechanical properties with special reference to effective husking capacity with minimal rice breakage and less wear rate. Hence, ENR-NBR blends containing 80–20 phr composition have proven as suitable materials for rice husk removal application.

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