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Published by the Faculty of Engineering, Khon Kaen University, Thailand

Effect of bonding agent ratio on mechanical and physical properties of natural rubber compounds for rubber to textile adhesion applications

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Received 27 September 2022
Revised 13 February 2023
Accepted 21 February 2023

Abstract

This study aims to modify natural rubber (*Hevea brasiliensis*) into a compound for rubber-to-textile adhesion application using bonding agents, namely resorcinol (R) and hexamethylenetetramine (H). The composition variations of R and H were designed to be 0:0, 1:1, 1:2, and 1:3 for sample FRC-0, FRC-1, FRC-2, and FRC-3, respectively. The physical and mechanical properties, namely curing time, tensile strength, tear strength, elongation, shore A hardness, rebound resilience, density, abrasion resistance, and adhesion test based on ASTM D1876 were determined. The results of the adhesiveness test showed that the FRC-1 formulation with 1:1 ratio of R:H has a maximum load of 195.25 N with graphical observation indicated no displacement or debonding area. In case of FRC-2, it has a lower maximum load of 105.26 N with a displacement or debonding area indicated by graphical observation. The characterization results suggested that FRC-1 sample with 1:1 ratio of R:H, showed the optimum formulation for rubber-to-textile adhesion. It forms largest adhesive product and has outstanding physical and mechanical qualities, particularly in the peel test, which measures the effectiveness of rubber-textile bonding.

Keywords: Adhesive compound, Rubber-Textile adhesion, Bonding agent, Natural rubber

1. Introduction

Adhesion is the bonding of two dissimilar materials by close interfacial contact, allowing mechanical force or work to pass through the interface. The interfacial forces that hold the two phases together may be influenced by the van der Waals force, chemical bonding, or electrostatic attraction. Interfacial forces, as well as the mechanical properties of the interfacial zone and two bulk phases, determine the system's mechanical strength [1]. An adhesive is a substance capable of forming bonds to each of the two parts when the final object consists of two sections that are bonded together [2].

In rubber engineering products, such as tires and belts, bonded rubber-textile could form a heavy mechanical strength that allows the product to be used as its function [3]. A previous study has revealed that latex alone cannot be a suitable binder of rubber-to-rubber or rubber-to-textile adhesion because of the lack of active groups in latex and therefore, its weak tensile properties [4]. Surface roughness is one factor that impacts this bonding strength [5]. The rubber industry, especially the retread tire sector, considers using the same compounding as the rubber compound as adhesive [6]. It could lead to tread peeling during tire usage because of insufficient adhesive strength on it [7]. Wisojodharmo et al. has revealed the importance of adhesive on rubber-to-rubber compounding in application of retread tire. The surface of the tire retread needs to be attached to a new tread layer using an adhesive compounding consisting of natural rubber and bonding agent additives [7]. The bonding between rubber and fabrics material (textile such as nylon, canvas, rayon, etc.) as reinforcing for articles is necessary to be done. Rubber to textile bonding depends on the adhesive component [8]. The adhesive part, which binds the surface of the textile and rubber together without considerably stiffening or tenderising the textile and without changing the rubber's vulcanisation characteristics, bears a significant duty in rubber textile bonding [9]. Similar to rubber to rubber bonding, adhesion of rubber-to-textile can be achieved by several resins and the addition of bonding agents to the rubber compound. It is expected to improve the adhesive strength of rubber to textile thus, the textile could optimise its roles as reinforcing the rubber product [10, 11].

Charch, et al. invented Phenol formaldehyde as an adhesive for cellulosic material and rubber. While, urea formaldehyde was patented by Maney et al. in 1940 for fabric and rubber. Aniline formaldehyde and ketone formaldehyde were used by Herahberger et al. in 1940 for untreated rayon cord with rubber [12-14].

Resorcinol is a chemical additive used in formaldehyde binding solutions for rubber dispersion and natural compound binders. In the binding component system, Resorcinol is coupled with a formaldehyde donor, such as hexamethylenetetramine [15]. Resorcinol acts as an adhesive between the rubber and the reinforcing material that forms during the curing process. This technique works well for bonding rubber to reinforcing materials, including glass fibre, steel, and other metals. Some works have evaluated the use of resorcinol and formaldehyde donor for rubber-fiber adhesion [16], rubber-metal [17], and rubber to other reinforcing materials [18].

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doi: 10.14456/easr.2023.10

Resorcinol has two hydroxyl groups (OH) and is included in the benzene compound. The (OH) group in resorcinol is located in the meta position so this compound is also called 1,3 benzenediol. In most applications, especially in the rubber industry, resorcinol is a phenolic resin that acts as a reinforcing agent in the compounding of rubber products. Resorcinol as a methylene acceptor requires a methylene donor [19].

The methylene donor compound used is hexamethylenetetramine (HMTA). The advantage of using HMTA compounds is that besides being cheap, they can also be polymerized directly because they act as curing agents, form crosslinker structures and act as methylene donors for resorcinol. The presence of acceptors and donors in this system makes it easy for resorcinol molecules to connect with other resorcinol to form a connection, which is in the form of a methylene bridge bond. As shown in Figure 1, after being polymerized automatically in the rubber mixture, a compound called Resorcinol Formaldehyde Novolak Resin is formed. Then, it is expected that this resin can provide improvements in physical and mechanical properties as mentioned above, as well as increase adhesive resistance and improve thermal properties of rubber products which can later be applied to adhesive compounds for rubber to textile applications. This is brought on by the rubber's enhanced polarity, which results from the capacity of resin for hydrogen bonding [20].

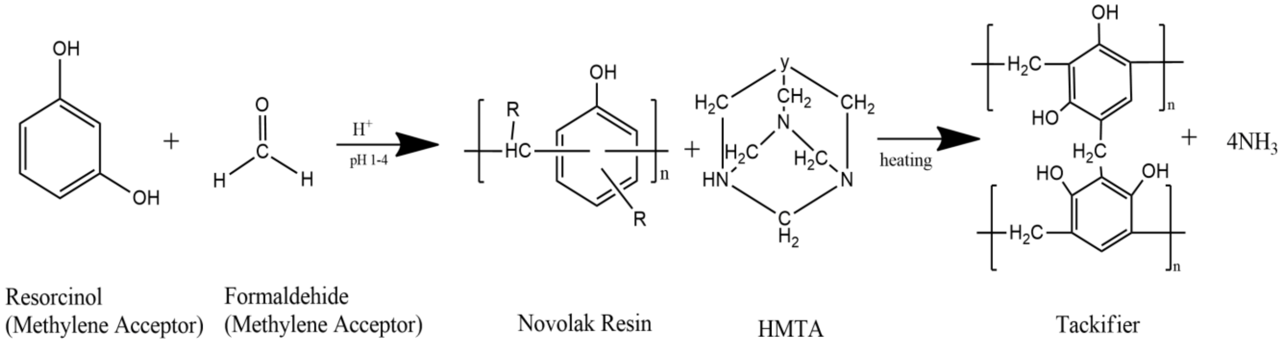

Figure 1 Reaction between resorcinol and formaldehyde hexamethylenetetramine

Current study reports the preparation of rubber-to-textile adhesive compounding from rubber smoked sheet using bonding agent resorcinol and hexamethylenetetramine. The amount of effective bonding agent is essential to achieve better properties of the adhesive compound. However, many manufacturers do not provide the information of composition suggestion of both bonding agents, resorcinol and hexamethylenetetramine. Hence, the effect of the bonding agent ratio on the mechanical properties of rubber-to-textile adhesive was evaluated. The corresponding physical characterization such as peel test was also determined.

2. Experimental and method

2.1 Materials

All of the mixing ingredients were used as they were obtained. A local source in Indonesia provided natural rubber, Ribbed Smoked Sheet (RSS#1), with a density of 0.95 g/cm^3. Cabot (China) supplied the carbon black N 220 with maximum ash 0.5%. Ultrasil 7000 GR Silica with specific surface area (CATB) of 160 m^2/g was purchased from PT Evonik (Indonesia), while the Bis(triethoxysilylpropyl)tetrasulfide (TESPT) with relative density 1.095 g/cm^3 was obtained by Merck (Singapore). Resorcinol with 80% purity and1.2 g/cm^3 density and hexamethylenetetramine with 80% purity and 1.25 g/cm^3 density were acquired from Rhein Chemie (Germany). Paraffinic oil 60 as processing oil with viscosity kinematic 6.9 at 210 F was provided by PT Pertamina (Indonesia). Other additives, 2,2,4-trimethyl-1,2-dihydroquinoline with 1.08 g/cm^3 density as antioxidant, Zinc oxide with 5.61 g/cm^3 density and stearic acid with 0.94 g/cm^3 density as activator, and N-Cyclohexyl-2 benzothiazolesulfenamide with 1.3 g/cm^3 density as accelerator, from PT Multi Citra Chemindo Nusa (Indonesia), were used. Curative material as sulfur (Midas SP 325) was produced by Miwon Co (Japan). Nylon 66 with density of 1.14 g/cm^3, melting point 260 ^{0}C, and tensile strength 850 MPa was obtained from PT Samudra Luas Paramacitra (Indonesia).

2.2 Preparation of rubber-textile adhesive compounding

To prepare the adhesive rubber compounds, a laboratory kneader (Moriyama DS3-10MWB-E, Japan) was employed. There were two steps to the mixing. In the first step, the mixing temperature was set to 100°C, and the speed was set at 32 rpm. After combining a predetermined amount of natural rubber RSS1 and the fillers for about 10 minutes, resorcinol and hexamethylenetetramine as formulated in Table 1 with other additives, were added directly into the kneader for about 5 minutes at 100°C. The compound was run through the two-roll mill six times at 70°C. After storing the masterbatch for a night to allow the rubber compound to rest, the batch was processed to be mixed with curatives by using two-roll mill (LMS-09T, China) six times at 60^{o}C. For roughly 2 minutes, the temperature was set to 70°C, and the speed was set to 32 rpm. After mixing, the batch was run through the two-roll mill again, cooled, and held for another 24 hours in room temperature before being used for sample preparation and further analysis.

The formulation in Table 1 was according to the previous research of Ismujanto et al. [21]. In this research, author vary the ratio of resorcinol and hexamethylenetetramine as suggested from the manufacturers [22].

Table 1 Formulation of rubber-textile adhesive compounding [21, 22]

Material	Formula (phr)			
	FRC-0 (R:H=0:0)	**FRC-1 (R:H=1:1)**	**FRC-2 (R:H=1:2)**	**FRC-3 (R:H=1:3)**
RSS-1	100	100	100	100
Carbon Black N220	45	45	45	45
Silica	2.5	2.5	2.5	2.5
Silane (TESPT)	0.50	0.50	0.50	0.50
Resorcinol	0	2.40	1.60	1.20
Hexamethylenetetramine	0	2.40	3.20	3.60
Processing oil	5	5	5	5
Additives	10.9	10.9	10.9	10.9
Curatives	3.2	3.2	3.2	3.2

Table 2 Reaction of R and H to produce adhesive

Formulation		**Resorcinol** (MW= 110.11 g/mol)	**Hexamethylene tetraamine** (MW= 140.19 g/mol)	**Adhesive product** (MW= 268.22 g/mol)
FRC-1	Initial	0.33 mol	0.25 mol	-
(R:H = 1:1)	Reaction	0.25 mol	0.25 mol	0.25 mol
	Balance	0.08 mol	-	**0.25 mol**
	mass			**67.99 gram**
FRC-2	Initial	0.22 mol	0.34 mol	-
(R:H = 1:2)	Reaction	0.22 mol	0.22 mol	0.22 mol
	Balance	-	0.12 mol	**0.22 mol**
	mass			**57.72 gram**
FRC-3	Initial	0.16 mol	0.38 mol	-
(R:H = 1:3)	Reaction	0.16 mol	0.16 mol	0.16 mol
	Balance	-	0.22 mol	**0.16 gram**
	mass			**43.29 gram**

2.1 Stoichiometric calculation of adhesive

Due to the polymerization between resorcinol and hexamethylenetetramine in Figure 1, the stoichiometric calculation was employed to assume the adhesive agent product on each formulation as shown in Table 2.

Using the chemical stoichiometric reaction principle [23], the number of adhesive products was calculated from the three formulations for rubber to textile formulation (FRC). It was ignored for FRC-0 (R: H=0:0) because it did not include the bonding agent. FRC-1 (R: H=1:1) had the highest adhesive products in the product mixture, with 67.99 grams, followed by FRC-2 (R: H=1:2) with 57.72 grams, and FRC-3 (R: H=1:3) with 43.29 grams. The FRC-1 (1:1) formulation had the most adhesive products out of the three. Thus, it was predicted to substantially impact the mechanical and physical properties of finished rubber adhesives.

2.2 Testing of rubber compounding

Compound from 2.2 was prepared to be testing specimen by using hotpress machine. Firstly, curing time of compound was determined by using Moving Die Rheometer (MDR Professional MonTech, Germany) at 140°C. Then, vulcanization was done according the rheometer testing result, following the needs of each characterization standards. Several testing were measured according to a certain standard to characterize the mechanical properties of adhesive compounding. The sample was measured under normal conditions and after the ageing process at 70°C for 72 hours.

The hardness Shore A was measured by Durometer hardness tester (Mitutoyo, Japan) as mentioned by ASTM D2240. Each sample was taken with five measurements with different positions with a distance of at least 6 mm. Rebound Check Resilience Tester (Gibitre Instruments, Italy) was employed to measure rebound resilience with an encoder setting of 90°. Measurement was carried out three times for conditioning and followed by three times repeating measurement. The compression set test was measured by compression set device (MonTech, Germany) followed by ASTM D395 at 70°C for 22 hours and kept at room temperature for 30 minutes before three times measurements. The sample density was measured by analytical balance (AND GR-200, Japan) according to ASTM D297-15. Tensile strength and tear strength were determined using Universal Testing Machine (Go Tech AI-7000-S, Taiwan) according to ASTM D412 and ASTM D624, respectively.

2.3 Preparation and testing of the peel test sample

The pieces of rubber compound according to Arti et al. was bonded with nylon 66 using four types of adhesive formulation [24]. Preparation of layering peel test sample was described in Figure 2 (Detail A), they were made and cured at 140°C at 30 min according to cure profile of rubber compounding. Testing of peel strength was done using Universal Testing Machine (Go Tech AI-7000-S, Taiwan) according to ASTM D1876 as Figure 2 (Test specimen) with head speed of 254 mm/min.

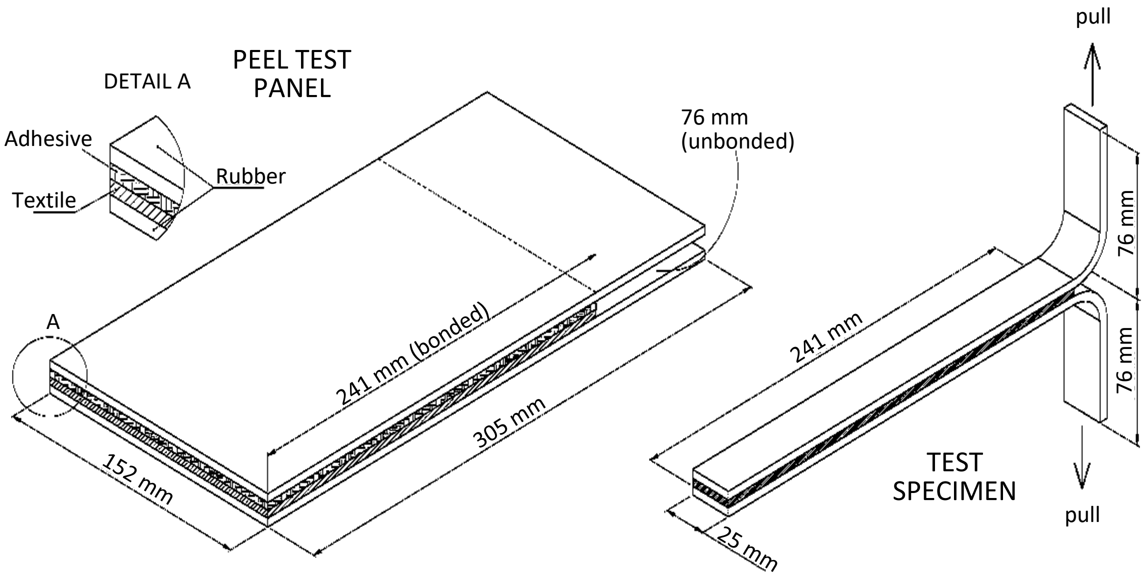

Figure 2 Configuration of peel test panel and peel test specimen (re-draw based on ASTM D 1876 with necessary adjustment)

3. Results and discussion

3.1 Fourier Transform Infra-Red (FTIR)

The phenomenon of two substrates being glued together with a bonding agent is an interesting phenomenon because from that process, various bonding mechanisms can be studied between the three types of materials. Rubber to textile bonding is a complex phenomenon. Chemically and mechanically, the fiber and the elastomer are diametrically opposed. The fibers' polarity and high modulus contrast with the non polarity of rubber and elasticity [25].

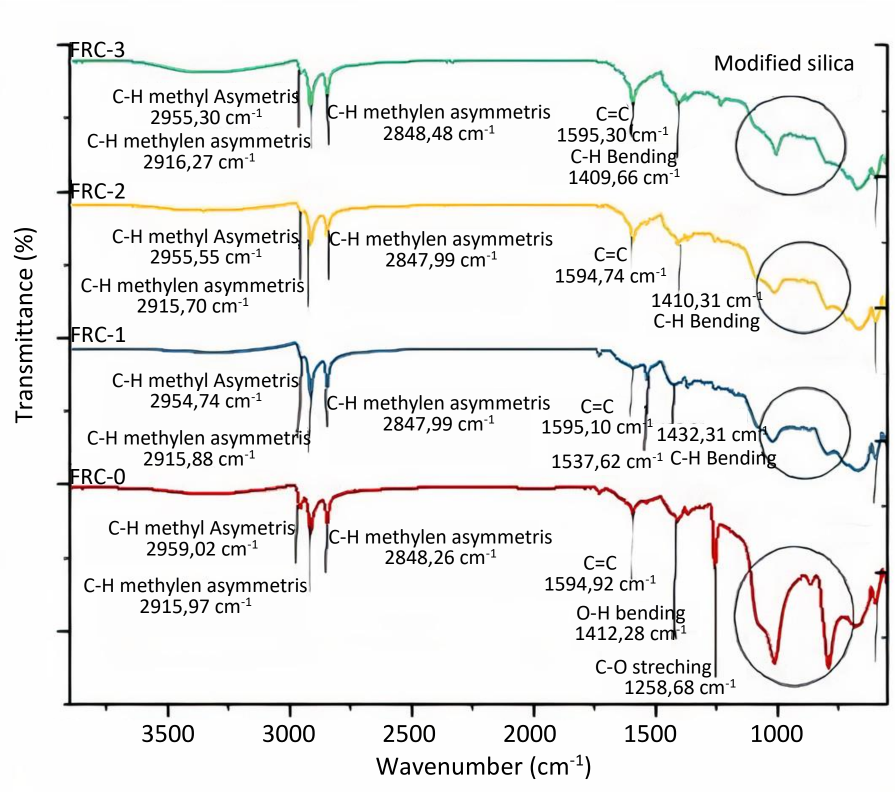

Figure 3 Spectra of FRC-0, FRC-1, FRC-2, and FRC-3

Figure 3 shows the FTIR spectra of the FRC-0, FRC-1, FRC-2, and FRC-3. C-H in ortho and para positions were left unsubstituted, resulting in IR spectra. The reaction of resorcinol and hexamethylenetetramine formed a crosslink, as seen in IR spectra on Figure 3, where the C-H group at ortho and para positions was missing, resulting in the formation of a new chemical bond, the methylene bridge, as a result of the curing effect. The appearance of the (OH-) bonding group at 3358 cm^{-1}, Phenyl ring and C-H methylene bridge

(1428cm^{-1}) is a group of resorcinol formaldehyde novolak resin (tackifier agent) [26]. The appearance of the (OH-) group also indicates the interaction of hydrogen bonds between the tackifier and nylon. The presence of C-H methyl and methylene, C=C, is the main indication of the existence of rubber as the main ingredient in manufacturing this adhesive rubber compound. The presence of C=O (carbonyl) bonds in the 1730cm^{-1} region shows the presence of nylon bonded to the tackifier [27]. In general, the adhesive properties (adhesive promoters) are carried by resorcinol in the form of RF resin [28].

It was discovered that increasing the number of hexamethylenetetramine on the ratio reduces the peak intensity of the methylene bridge formed in the range of 1500 - 1400 cm^{-1}. The spectral area depicts a phenolic ring substituted on para and ortho positions. The intensity decreases as the number of mono substituted phenolic rings decreases and crosslinking occurs [29].

The result shows an interesting presence of siloxane bridges between 1100–600cm^{-1}. The existence of this siloxane bridge indicates that the adhesive rubber compound forms a bridge siloxane bond (silane group) which can cover the nylon surface from contact with external conditions such as water, moist air, etc. Siloxane bridge indicates that nylon interacts strongly with rubber and makes nylon a reinforcing textile in the manufacture of rubber products.

The appearance of modified silica in the FT-IR spectra in the area of 1100-800 cm^{-1}, as well as the appearance of C-S-S-C bonds between rubber and modified silica, are also solid reasons for the high hardness values [30].

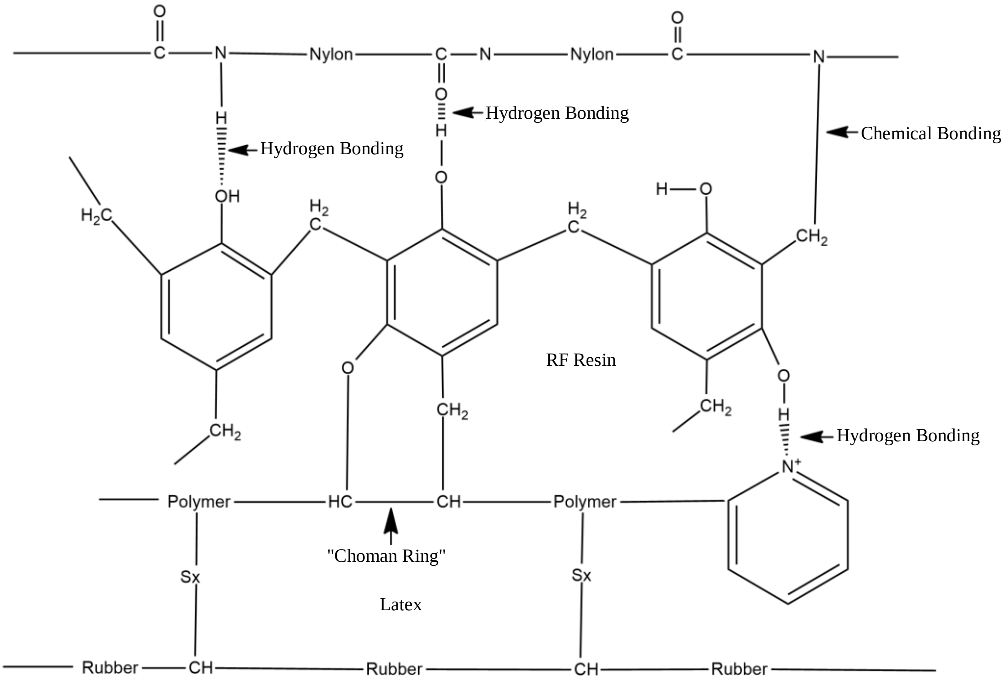

Figure 4 Possible reaction during the adhesive process between rubber-Resorcinol Formaldehide Novolak Resin (adhesive product)-Nylon [23]

From the Figure 4, the possible bonds formed are hydrogen bonds, certain chemical bonds (e.g. C-N), methylene bridge, chroman ring bonds and crosslinking (rubber to textile). The presence of some of these chemical bonds can be detected using FT-IR. In addition to the mechanism of chemical bonding (molecular bonding), there are also several models or binding systems that may occur in the adhesion of polymer systems, including mechanical interlocking, mechanical entanglement, electrostatic, interdiffusion and so on. For the case of bonding rubber to a rubber or nylon substrate and the cord (iron/metal) itself, several models of chemical bonds can occur, such as bonds or dipole moment interactions, van der Waals forces (ionic, covalent, or metallic bonds) [31].

3.2 Curing time

The curing curve may be utilized to define the microstructural features of cured rubber compounds [32]. It was possible to extract a number of crucial data, most importantly was curing time. In the study, curing time was examined [33]. Curing time was depicted as the amount of time needed to obtain 90% of the maximum torque [34]. This criteria was taken into consideration as the primary requirements for applying adhesive during the production of rubber-textile product. Curing time will be followed by quick molding and high production effectiveness, which can help cut back on energy use [35, 36].

Parajito [37] found that curing characteristic of rubber compound was a function of ingredient loading. With the bonding agent, the curing time was reduced, as shown in the Figure 5. The curing time was 16.45 minutes without a bonding agent. When a tackifier was added to the FRC-1(1:1) curing period, the curing time increased about 29% to 21.23 minutes. As observed in stoichiometric calculations, the presence of the highest tackifier content bound to the rubber caused the increase in curing time. The addition effects the rubber compound to be more resistant and stable to external disturbances although increase the curing time [38].

On contrary, the number of adhesive products generated stoichiometrically for FRC-2 and FRC-3 was smaller than FRC-1 (1:1). Furthermore, the excess of hexamethylenetetramine in FRC-2 and FRC-3 (see Table 2) resulted in a reduction in curing time. In this case, hexamethylenetetramine compounds operated as curing agents, hastening the production of crosslinker structures [39].

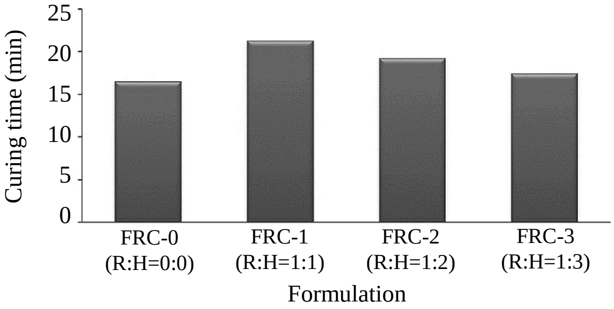

Figure 5 Curing characteristic of adhesive compound

3.3 Hardness shore A

In general, the ratio of filler to additives and the density of molecular bonds in the material affect the hardness value of rubber vulcanizates. Hardness value of rubber is interfered by the strength of the bond between molecules in a material when subjected to external pressure [40]. In accordance with the theory that previously proposed by Wennekes [41], the addition of adhesive products will increase the value of hardness shore A. In this experiment, the value of the hardness increases slowly from the comparison of the tackifier FRC-1 (1:1) and FRC-2 (1:2), then rises sharply after the FRC-3 ratio (1:3), as shown in Figure 6. The smallest hardness test value is FRC-0 (0:0) of 66.03 Shore A. The largest hardness value is FRC-3 (1:3) of 67.70 Shore A. Increase in hardness can be due to the presence of bonding agent that improved adhesion of natural rubber and filler, compared to that without bonding agent. However, after the ageing process, hardness change sharply increased. It is a proof that adhesive products can act as antiaging agents in compounding [41].

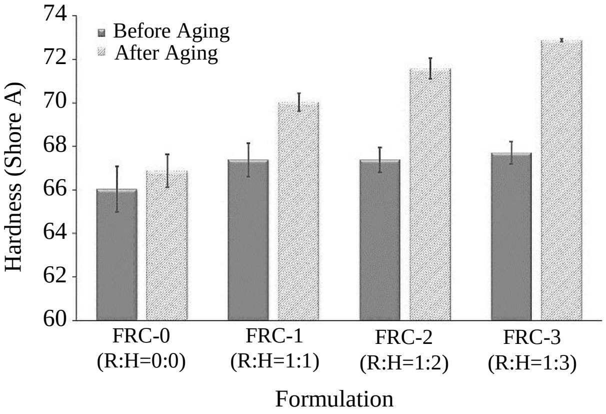

Figure 6 Hardness test result of adhesive compound

3.4 Tensile strength

Figure 7 shows the physical parameter values for tensile strength with bonding agent variations. The addition of a bonding agent in each formulation increased the tensile strength compared to FRC-0. Adhesive resin could be functioned as a processing aid in the rubber industry by reducing compound viscosity. Commonly, a decrease in rubber viscosity was followed by a rise in chain mobility, which led to an increasing in the tensile strength of natural rubber vulcanizate. Since the rubber molecules were widely apart as a result of the rubber particle's enlarged state, easier natural rubber molecular chain mobility suggested that the molecular contact between natural rubber chains had lessened [42]. This was evidence that resorcinol-formaldehyde Novolak Resin increased the interaction between natural rubber and filler and improved the tensile strength.

The formulation without the addition of bonding agent FRC-0 (0:0) resulted in a tensile value of 24.7 MPa. Meanwhile, with the addition of bonding agent on FRC-1(1:1), the tensile value was 28.41 MPa. Then with the addition of hexamethylenetetramine the tensile values were 25.56 MPa at FRC-2 (1:2) and 25.01 MPa at FRC-3 (1:3). These results were with conformity with the hardness shore A value, i.e. when the hardness increases, the tensile decreases [43].

The value of the tensile strength changed before and after aging. In FRC-0 (0:0) there was a significant decrease/change of 12%, while in FRC-1 (1:1) it was 0.03%, FRC-2 (1:2) was 0.07%, and FRC-3 (1:3) and 5%. The more adhesive product formed, the smaller the change in the tensile strength value before and after ageing because the adhesive product itself can also act as an aging resistance resin [44]. The tensile value increases as the ratio of hexamethylenetetramine increases.

3.5 Tear strength

Tear strength properties in the modification of natural rubber material as the adhesive product is necessary needed so that the rubber material can play an optimum role, especially during the application process as rubber to textile adhesive. The smaller value of the tear strength, the poorer quality of adhesive material because it can be ripped easily [45].

Tear strength of the adhesive product for rubber to textile formulation (FRC) as in FRC-1 (1:1) would rise with the inclusion of a bonding agent. The addition of a bonding agent increased the tear strength of the rubber to textile formulation (FRC) as in FRC-1 (1:1), that seen from Figure 8. This demonstrated the effectiveness of Resinol-Formaldehyde Novolak. Resin is polymerized and acts as a resin reinforcer on tear strength mechanical properties [46]. However, in FRC-2 and FRC-3, the tear strength value did not significantly different with FRC-0 due to the excess hexamethylenetetramine.

This was related to the bonding agent that increased the interaction between rubber and filler.

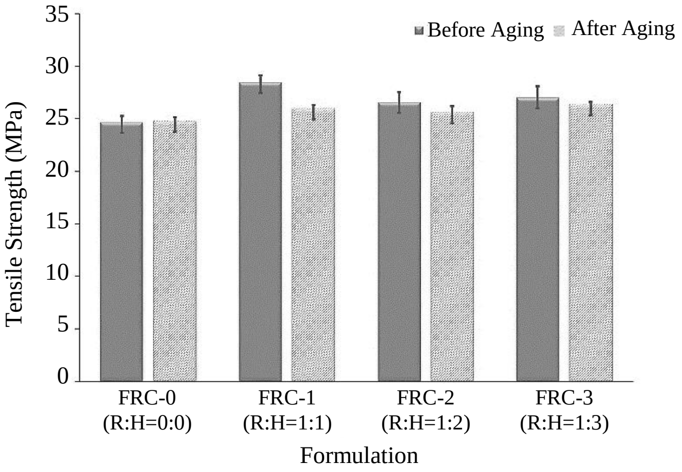

Figure 7 Tensile strength test result of adhesive compound

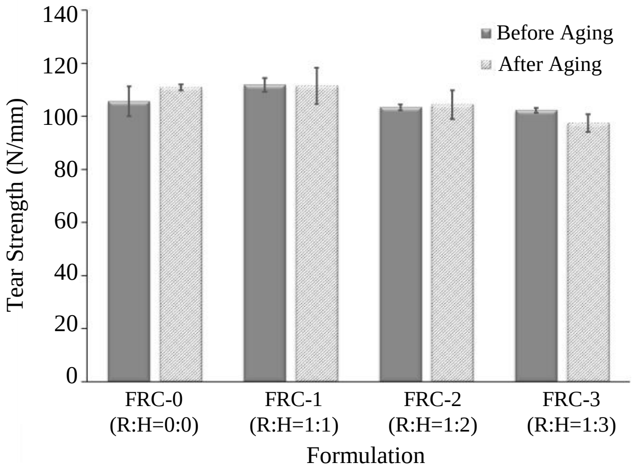

Figure 8 Tear strength test result of adhesive compound

3.6 Rebound resilience

Resilience was measured to investigate the effect of rubber ratio on the elasticity and flexibility of vulcanizates. When the plunger is released from a certain height and collides with the sample, the sample deforms and absorbs energy that cannot be recovered when returning to its original height.

The addition of a tackifier raised the rebound resilience value from FRC-0 (0:0) to 61.20% at FRC-1, according to the results of the rebound test measurement (1:1). Furthermore, it reduced by 58.29% in FRC-2 (1:2) and increased somewhat in FRC-3 (1:3), which was 59.07%. Figure 9 also showed that the tackifier product created in each formulation contributes to the variation in rebound values in each formulation.

Increment in the adhesive product in FRC-1 increases rubber resilience as its directly proportional to the degree of elasticity. FRC-1 (1:1) of 61.20% is the most optimum rebound value. For some materials, such as rubber, the value of rebound resilience is necessary for dynamic mechanical applications [47].

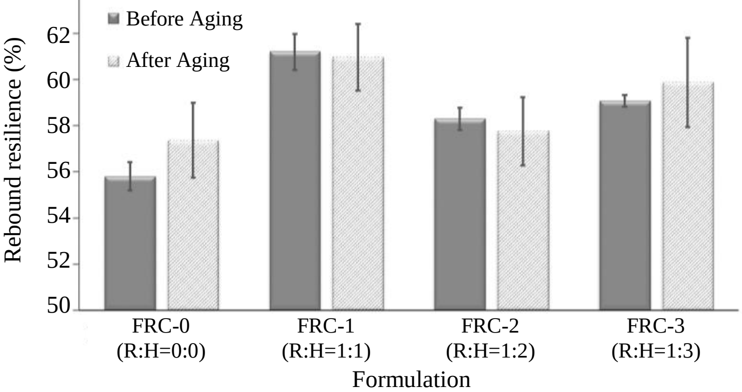

Figure 9 Rebound resilience test result of adhesive compound

3.7 Compression set

Compression set was the amount of persistent deformation that occurs over time and at a specific temperature when a material is compressed to a specific deformation. It was a measurement of the compound's flow resistance when compressed [48]. Rubber materials deflected when put under stress, thus it was crucial to assess how well the specimen returns to its former shape. A crucial quality was compression set, especially for products with long life cycles. Compression set was related to the returning of rubber to its original shape. The smaller the compression value, the better the performance of the compound.

Hence this process was related to flow resistance and could not be separated from the role of the bonding agent (Resorcinol Formaldehyde Novolak Resin) as a resin reinforcer in adhesive products that effect better rubber-filler adhesion and higher crosslink density [49].

There was a decrease in the value of the compression test from FRC-0 (0:0), namely 30.63% to 20.42% at FRC-1 (1:1). It increased again on FRC-2 (1:2) by 27.98% and experienced a decrease again on FRC-3 (1:3) which was 25.11%. The decrease as seen on Figure 10 was expected since adhesive product improve rubber filler adhesion and increasing flow resistance of compounding, thus the compound easily returned to original shape [50].

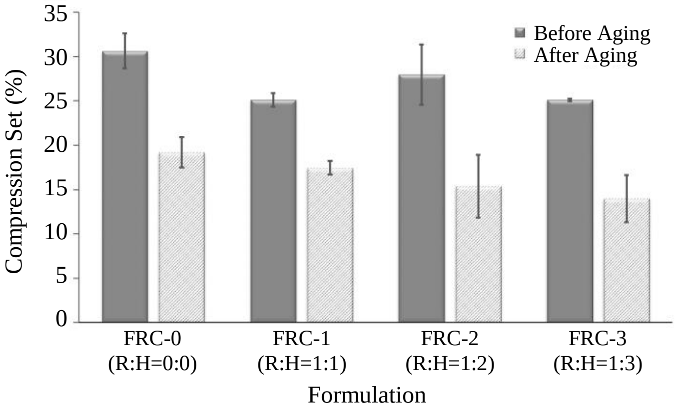

Figure 10 Compression set test result of adhesive compound

3.8 Density

There was a very insignificant decreasing in the density value along with the addition of the tackifier, where the largest value was found in FRC-0 (0:0) which was 1.11 g/cm^3 and the smallest value in FRC-3 (1:3) was 1.10 g/cm^3.

3.9 Peel test

The peel test aims to determine how strong the adhesive strength of the bonding agent between two similar substrates such as rubber with rubber or rubber with other substrates such as nylon/fiber or with cord/metal.

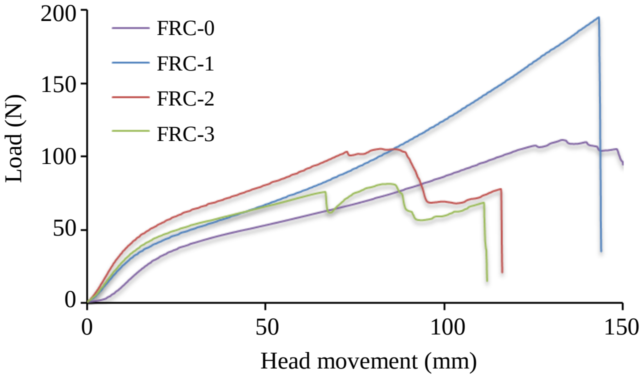

Figure 11 Peel test result

There was relationship between the failure/ debonding and the peel. It was observed that the peel failure mode changes from cohesive within the adhesive to adhesive with increase in peeling rate [51].

From the test of FRC-1 (1:1) shown by Figure 11, a trend was found that there was no displacement area/unbounding on both rubber and textile substrates. In this test, the maximum load ranges was 192.25 N. This fact was correlated with the stoichiometric results in the previous explanation that most products formed at FRC-1 (1:1). In contrast to the trend in FRC-1, FRC-2 and FRC-3, the debonding/displacement area was started after sample has been loaded 100 N and 60 N, respectively. This observation was attributed to the increasing adhesive product, resulting in mechanical interlocking and anchorage of the adhesive in rubber and textile surface [52]. However, the incorporation of adhesive in the rubber formulations always brings about significant increase in energy dissipation behavior of the vulcanizates [53]. In addition, its role as a resin tackifier was proven in this peel strength test. This characteristic is expected in the manufacturing of rubber products in its later application. The existence of debonding area is probably because the number of tackifier factors formed in the stoichiometric calculation of FRC-2 (1:2) and FRC-3 (1:3) is less than that of FRC-1 (1:1).

4. Conclusion

We have modified natural rubber for rubber-to-textile adhesion application using resorcinol and hexamethylenetetramine as bonding agents. The effect of different ratio of bonding agents, resorcinol and hexamethylenetetramine, were investigated to determine the best condition. From the results of mechanical and physical testing, it can be concluded that the optimum formulation is FRC-1 with a bonding agent ratio of resorcinol and hexamethylenetetramine is 1:1, as predicted in theoretical stoichiometry, which forms a higher molar of adhesive product. Peel test result illustrated the bonding strength and FRC-1 showed no displacement area during testing. Other bonding agent ration (1:2 and 1:3) produced excess hexamethylenetetramine and less adhesive product, that increased the possibility of debonding area during peel test. Hence, it was weak the adhesive strength. Based on chemical testing using FT-IR, it can be suggested that there was a polymerization reaction of resorcinol formaldehyde Novalak Resin, as evidenced by the presence of OH and CH methylene bridge groups.

5. Acknowledgement

The authors would like to acknowledge the Agency for Assessment and Application of Technology (BPPT) Indonesia for the financial support by DIPA Project entitled Nanomaterial Engineering of Natural Polymers for Aircraft Tires (3501.011.001) to conduct this research. We also would like to thank PT Samudra Luas Paramacitra for providing nylon textile samples.

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