Utilization of Kaolin as a Filling Material for Rubber Solid Tire Compounds for Two-wheeled Electric Scooters

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Abstract. Kaolin is a mining material widely used as a filler in the manufacture of various types of finished goods made from natural rubber. Kaolin in this study was used as a special filler for solid tires for two-wheeled electric scooters commonly used by children. The purpose of this study was to determine the effect of the kaolin loading on the curing properties of the rubber compound, the mechanical properties of the vulcanizate, and the thermal properties of the rubber vulcanizate. Kaolin loading was varied from 22 to 42 per hundred rubber. The compounds were mixed on a two-roll mill. The vulcanization process took place at 140 °C for 17 minutes. The test results showed that kaolin loading had a strong effect on the maximum torque, scorch time, optimum vulcanization time, and mechanical properties of the vulcanizate. Thermo gravimetric analysis showed that the thermal stability of the vulcanizate was influenced by kaolin loading.

1. Introduction

Natural rubber (NR) is a polymer widely used for various purposes including tires. It is a non-polar polymer with double crosslinks, which has high flexibility but not resistant to non-polar solvents, ozone and oil [1-2]. The mechanical properties of NR can be improved by adding synthetic rubbers and additives. The advantages of synthetic rubber are oil, ozone, and acid resistance, but not elasticity. The combination of NR with synthetic rubber at a certain loading can improve the mechanical properties by producing a better product.

Solid tires are a product that has been developed for a long time. The solid tires for special purposes such as forklifts are generally made of NR which is composite with synthetic rubber. On the other hands the solid tires for children's bicycles, patient wheelchairs, two-wheeled electric scooters for children's, conveyances, are generally made of synthetic rubber such as styrene-butadiene rubber (SBR), butadiene nitrile rubber (NBR), polyurethane. The weakness of solid tires from synthetic rubber is stiff, and it is easy to suffer physical damage. This is because synthetic rubber is not elastic like NR, when it crosses the road the friction will result in a vibration. By looking at the mechanical properties of NR, this study used NR combined with SBR, by using fillers consisted of kaolin, CaCO₃ and silica.

The development of solid tires using NR with various types of fillers has been carried out. Nasruddin and Aprillena [3] have researched to make solid tire vulcanizates for forklifts from NR materials with SBR, butadiene rubber (BR), chloroprene rubber (CR), and ethylene propylene diene monomer (EPDM). Nasruddin [4] has made solid tires for wheelchairs using NR without synthetic rubber with...
fillers of silica, fly ash and kaolin. Rukkur et al [5] developed a heat-resistant solid tire from NR with carbon-N-330 and silica (VN3) fillers.

NR as the material for two-wheeled solid tires for electric scooters used by children in this study was combined with styrene-butadiene (SBR) rubber. The combination of NR with SBR can improve the mechanical properties of solid tires. Several studies revealed that SBR can improve abrasion, heat, oil, and crack resistance due to ozone attack [6]. In the case of amorphous elastomer, it does not undergo strain-induced crystallization, increases processability, and improves product mechanical properties [7].

The filler material is one of the ingredients that determine the mechanical properties and cost of the finished rubber product. The loading of Kaolin as the object of research for the two-wheeled motorcycle was varied. While for CaCO₃, silica and other additives, the loading is conditioned. Determination of the loading of kaolin intended to obtain better elasticity, abrasion resistance and mechanical properties.

Kaolin is a clay mineral that contains kaolinite which consists of hydrated aluminosilicates. According to Hassan and Abdu [8] kaolin is white, soft, crystalline mineral with porous cell structure, irregular shape, containing SiO₂, muscovite, quartz, feldspar, and anaphase. Yahaya et al [9] reported that the particle size of kaolin was between 25-35 µm, and 0.4–0.75 µm. Widodo et al [10] stated that kaolin consisted of 65.78% SiO₂, 19.55% Al₂O₃, 0.90% Fe₂O₃, and 8.29% loss of ignition (LOI).

Kaolin with the formula Al₂O₃:SiO₂ or Al₂Si₂O₅(OH)₄ [11-12] can be used as a functional filler [13]. The use of kaolin for paint mixtures, ceramic materials has been widely used [14]. Kaolin in the manufacture of rubber finished goods is used as a non-reinforcing filler which does not crystallize [15]. Fillers are used to reducing rubber content, reduce costs, strengthen or lighten compounds, increase the number of chains, modify the physical properties of rubber, and to improve the mechanical properties of rubber [16-17].

The use of kaolin as a filler for rubber compounds has been widely used by previous researchers. Nasruddin and Susanto [18] used kaolin as a filler in NR, NBR and EPDM composites. According to Surya et al, [19] the addition of 5 per hundred rubber (phr) kaolin with alkanolamide can increase the cross-link density of NR compounds. Wu and Tian [20] reported that kaolin with a plate-like structure can reduce rubber heat, as a substitute for silica for certain rubber products.

Several researchers reported the effect of kaolin on the mechanical properties of rubber vulcanizates. It can be used as a reinforcing filler in NR and SBR composites [21-24]. Jincheng et al [25] reported kaolin has better tensile strength than carbon black. According to Peter et al [26] kaolin and silica modified with prepolymer phosphorylated cashew shell aqueous solutions improved the tensile properties and thermal stability of natural rubber.

Kaolin and CaCO₃ are used as volume-enhancing fillers and silica as reinforcing fillers. CaCO₃ as a filler is widely used for the manufacture of rubber compounds. It can increase the modulus of elasticity, compressive strength, high tensile strength and polyethylene density [27]. CaCO₃, type of polar filler, is easier to spread in polar rubber than non-polar rubber [28]. The addition of filler in the elastomeric matrix to improve physical properties and simplify the production process.

Silica as an inorganic reinforcing filler has been widely used [29-35]. The combination of reinforcing fillers with fillers that increase volume, in addition to reducing production costs, can simultaneously improve the mechanical properties of the vulcanizate. To increase filler activity with the NR-SBR matrix, silane-89 was added as a linking agent [30-31, 36-37]. The coupling agent can enhance polymer-polymer and polymer-filler interactions. Carbon black together with titanium dioxide at predetermined loading forms the grey color of solid tires [4].

By looking at the molecular structure, shape and mechanical properties of kaolin, CaCO₃, silica as a filler, NR, and SBR as described above, rubber vulcanizate can be used for solid tires for two-wheeled electric scooters for children. Thus, the objectives of this study were to determine the effect of the kaolin loading on the curing properties of the rubber compound, the mechanical properties of the vulcanizate, and mass degradation.
2. Material and methods

2.1. Material

The material used in this research is natural rubber (NR) according to the Indonesian Rubber Standard (SIR-20) from one of the crumb rubber factories in Palembang City. Styrene-butadiene rubber (SBR-1500) with mechanical properties of viscosity Mooney ML (1 + 4) 100 between 47-56, elongation at break, 550-750%, reflection elasticity 39% min, tensile strength 27.9 Mpa min. Titanium dioxide (TiO₂ - R105), density 4.10 g/cm³, content 95%, the average particle size is 0.3 μm. Black carbon (CB-N330) ash content 0.56%, sulfur content 0.88%. Titanium dioxide (TiO₂ - R105), density 4.10 g/cm³, content 95%, the average particle size is 0.3 μm. Black carbon (CB-N330) ash content 0.56%, sulfur content 0.88%. Zinc oxide (ZnO) molecular weight 81.408 g/mol, density 5.606 g/cm³, water-solubility 0.16 mg/100 ml (30 °C). Stearic acid (C₁₈H₃₆O₂) einecs no: 166-828-5, cas no: 57-11-4, molecular formula (Mf): C₁₈H₃₆O₂, purity 99%, freezing point 53–59 °C. Kaolin 400 mesh size from Tanjung Pandan Belitung Indonesia. Calcium carbonate (CaCO₃) cas no. 471-34-1, purity 99%, humidity 0.33%. Silicon dioxide (SiO₂) einecs No. 215-683-2, purity 99.8%. Silane-89. Coumarone resin (CR) cas no. 63393-89-5, purity 99%. Paraffinic oil-60. Paraffin wax melting point 136-140 °F, oil content 2%. Butylated hydroxytoluene (BHT) mf: C₁₅H₂₄O, purity 99%.

2.2. Methods

2.2.1. Rubber compounding. Five formulation of NR-SBR composites with various kaolin loadings (22, 27, 32, 37, and 42 phr) were prepared (Table 1).

Table 1. Compound formulations of solid tire.

| Material                  | Amount, phr |
|---------------------------|-------------|
|                           | L-01*       | L-02*       | L-03*       | L-04*       | L-05*       |
| NR                        | 92.75       | 92.75       | 92.75       | 92.75       | 92.75       |
| SBR                       | 7.25        | 7.25        | 7.25        | 7.25        | 7.25        |
| TiO₂                      | 5.25        | 5.25        | 5.25        | 5.25        | 5.25        |
| CB                        | 0.15        | 0.15        | 0.15        | 0.15        | 0.15        |
| ZnO                       | 4.75        | 4.75        | 4.75        | 4.75        | 4.75        |
| Stearic acid              | 2.25        | 2.25        | 2.25        | 2.25        | 2.25        |
| Kaolin                    | 22          | 27          | 32          | 37          | 42          |
| CaCO₃                     | 25          | 25          | 25          | 25          | 25          |
| Silica                    | 47          | 47          | 47          | 47          | 47          |
| Silane-89                 | 3.25        | 3.25        | 3.25        | 3.25        | 3.25        |
| Coumarone resin           | 7           | 7           | 7           | 7           | 7           |
| Paraffinic oil            | 8           | 8           | 8           | 8           | 8           |
| Paraffin wax              | 2.5         | 2.5         | 2.5         | 2.5         | 2.5         |
| BHT                       | 1.75        | 1.75        | 1.75        | 1.75        | 1.75        |
| MBTS                      | 1.25        | 1.25        | 1.25        | 1.25        | 1.25        |
| TMTD                      | 0.75        | 0.75        | 0.75        | 0.75        | 0.75        |
| PVI                       | 0.25        | 0.25        | 0.25        | 0.25        | 0.25        |
| Sulphur                   | 2.85        | 2.85        | 2.85        | 2.85        | 2.85        |

Note: *Ratio of material in per hundred rubber (phr)

Firstly, NR was milled using an open mill until soft, then the SBR was added until homogeneous. TiO₂ was added until the color became white, then the CB was added until the color became grey. Next, ZnO and stearic acid were incorporated until homogeneous. Finally, kaolin, CaCO₃, silica, silane-89,
coumarone resin, paraffin oil, paraffin wax, BHT, PVI, MBTS, TMTD and sulphur were added subsequently.

2.2.2. Test method. The resulting rubber compounds were tested by a moving die rheometer (UR-2010, U-CAN Dynatex Inc, Taiwan) at 150 °C. In order to prepare the vulcanized rubber sheets, the rubber compound of the five treatments were compression molded using a hydraulic hot-press.

Testing of mechanical properties of rubber vulcanization includes: specific gravity (ASTM D.297-15), hardness testing before ageing (ASTM D.2240-15), hardness after ageing ASTM D. 573-04 (2015), compression set, defl 25%, 70 °C, 22 hours (ASTM D.395-16e1), tensile strength before and after ageing (ASTM D.412-16). Mass degradation testing using thermogravimetric analyzer (TGA).

3. Results and discussion

3.1. Cure Characteristics

The results of the rubber compound curing characteristics shown in Table 2 provide information on the maturation profile of the compound described by delta torque $\Delta_s$ (Max – Min), curing time (t90), and scorch time (ts2). The test results of rubber compounds at 22 phr kaolin loading (L-01) shows the highest $\Delta_s$ (Table 2). The increase in kaolin loading from 27 phr (L-02) to 42 phr (L-05) cause $\Delta_s$ to decreased from 12.57 kg-cm (L-02) to 10.76 kg-cm (L-05). The $\Delta_s$ illustrates the crosslinks density formed during vulcanization. The fillers dispersed in the polymer matrix affect the interaction between polymer and filler [38], thus affect the compound cure characteristic (Table 2).

| Curing Characteristic | L-01 | L-02 | L-03 | L-04 | L-05 |
|-----------------------|------|------|------|------|------|
| S* Max – Min, kg-cm ($\Delta_s$) | 12.79 | 12.57 | 10.08 | 11.60 | 10.76 |
| S* Maximum, kg-cm | 13.38 | 13.27 | 12.28 | 13.01 | 13.07 |
| S* Minimum, kg-cm | 0.59 | 0.70 | 2.20 | 1.41 | 2.31 |
| Opt cure time (t90), min: sec | 8:10 | 8:48 | 0:56 | 1:29 | 1:03 |
| Scorch time (ts2), min: sec | 0:40 | 0:52 | 0:24 | 0:40 | 0:20 |

The cure time (t90) illustrates the compound maturation time. The shorter the maturation time of the compound, the cheaper the vulcanization costs. The cure time is the time to form crosslinks during vulcanization [39]. The difference in curing time in Table 2 is influenced by the kaolin loading in the NR-SBR matrix. The curing time is found to be the longest at 27 phr kaolin loading (L-02).

The formation of crosslinking is caused by the reaction of sulphurs with the polymer matrix which is accelerated by activators, co-activators and accelerators. Kaolin, CaCO3, and silica with the help of silane-89 during vulcanization inserted between the NR and SBR molecules contribute to improving the mechanical properties of the vulcanizate. Crosslinking affects hardness, density, compression and other mechanical properties.

The test results of the scorch time (ts2) for formula L-01 (kaolin 22 phr) was 0:40 sec. This value is the same as the formula L-04 (37 phr). At a kaolin loading of 32 phr (L-03) a scorch time (ts2) 0:24 sec is the shortest time among treatments. Considering the kaolin loading (Table 1) and the results of testing the cure characteristic compounds (Table 2), one can conclude that the increase in the loading of kaolin in the NR-SBR compound matrix did not reflect a linear increase or decrease in scorch time (ts2). The effect of filler distribution and crosslinking reaction speed in each treatment affects the difference in scorch time (ts2). The distribution of the filler into the NR-SBR compound was influenced by the rate at which silane-89 softened the polymer matrix. In addition, stearic acid as a coactivator added to the rubber matrix acts as a plasticizer to distribute the filler into the NR-SBR polymer chain.
3.2. Mechanical properties of a rubber vulcanizate

The test results on the mechanical properties of solid tire vulcanization from five formula have been investigated as shown in Figures 1 to 4. The effect of kaolin loading combined with CaCO₃ and silica on the NR and SBR matrices gave different results. Kaolin as a filler in the NR and SBR matrices affects the vulcanization process, compound maturation, curing time, and scorch time (Table 2).

In the vulcanization process, kaolin affects the formation of crosslink density which is illustrated by the results of the specific gravity test. An increase in the kaolin loading (Table 1) in NR and SBR vulcanizate affected the curing time and scorch time (Table 2), followed by an increase in specific gravity (Figure 1).

NR and SBR matrices with kaolin filler with a loading of 22 phr (L-01) had a lower specific gravity value (1.313 g/cm³) than other formulas. Increasing the loading of kaolin to 27 phr (L-02), and 32 phr (L-03) had the same specific gravity (1.323 g/cm³). At 37 phr (L-04) kaolin loading there was an increase in density (1.334 g/cm³), an increase in the loading of 42 phr (L-05) kaolin in NR and SBR compounds also an increase in density up to 1.343 g/cm³.

The distribution of fillers in rubber composites affects the mechanical properties of rubber vulcanizates [40-41]. This is related to the density of the material linked to the NR and SBR vulcanizates. The higher the specific gravity value, the increase in material density. The change in the value of specific gravity is theoretically followed by a change in the value of hardness which affects the change in the value of the compression set.

The hardness test results for kaolin loading of 22 phr (L-01) before ageing 55 Shore A, after ageing increased (57 Shore A). Increasing the kaolin loading of 27 phr (L-02), increasing the hardness before ageing (58 Shore A), and after ageing (59 Shore A). At the loading of kaolin 32 phr (L-03), 42 phr (L-05) hardness before ageing is the same as hardness L-02, likewise with hardness after ageing L-03 and L-05 the value is 59 shore A equal to hardness before ageing L-02.

For the kaolin loading of 37 phr, the hardness before ageing 56 shore A was lower than the hardness of L-02, L-03 and L-05. In contrary, the hardness after ageing for the loading kaolin of 37 phr was 60 shore A, higher than L-01, L-02, L-03 and L-05. The increase in hardness after ageing in all formulas was due to the shrinkage of the rubber vulcanizate volume during heating. The vulcanization was heated in an oven at a temperature of 72 °C for 72 hours. At this temperature and time, the low boiling point evaporates easily, at the same time there is a narrowing of the rubber vulcanizate volume which causes an increase in hardness. When viewed from the test result data, the facts show that an increase in the loading of kaolin is not necessarily followed by an increase in hardness values (Figure 2). This is probably due to the distribution of the filler, the softener material used, and the imperfect cross-linking

![Figure 1. Effect of kaolin loading on the specific gravity of solid tires.](image1.png)

![Figure 2. Effect of kaolin loading on hardness before and after ageing in solid tires.](image2.png)
reaction. The high hardness value of the two-wheeled electric scooter solid tire for children affects the user's comfort. The solid tires that are too hard will cause shocks when used on uneven roads.

Changes in the value of specific gravity and hardness affect the compression set. If the specific gravity and hardness values are high, the solid tire does not return to its original state when compressed. Theoretically, the filler added to the rubber matrix in a certain loading can fill the space between the rubber molecules. Compression set test data for the loading of kaolin 22 phr (L-01) to 27 phr (L-02) showed an increase from 23.42% to 27.11% following the increase in specific gravity (Figure 1 and Figure 2). At a kaolin loading of 27 phr (L-02) to 32 phr (L-03) followed by an increase in the compression set value of 30.82%. At the loading of kaolin 37 phr (L-04) up to 42 phr (L-05) the increase in the compression set value was not significant from 31.01% to be 31.14%. The value of the compression set cannot be separated from the influence of the distribution of fillers (kaolin, CaCO₃ and silica) into the NR-SBR rubber vulcanizate. The distribution of fillers in the NR-SBR matrix in this study was accelerated by paraffin oil as a softener, stearic acid, coumarone resin, paraffin wax, and xilane-89 as a coupling agent.

The abrasion resistance is an important parameter for determining the service life of a solid tire, where when a solid tire is susceptible to abrasion its service life is shorter. The bond strength among the solid tire molecules determines the abrasion resistance. Abrasion cannot be separated from the influence of the bonds among molecules that form the rubber vulcanizate structure. In addition, the specific gravity and hardness values describe the density and hardness of the rubber vulcanized structure which affects the abrasion resistance. The higher the specific gravity value, theoretically, the amount of material in space is denser/denser and the level of hardness is high. The high density of a material in space describes the stronger the bonds among the molecules of the material which have an impact on hardness and abrasion resistance.

The results of the abrasion resistance test for each formula (Table 1) increased (Figure 4) along with the increase in the kaolin loading. At the loading of kaolin 22 phr (L-01) there was an abrasion of 201.4 mm³, at the loading of kaolin 27 phr (L-02) there was an increase in the abrasion of 211.5 mm³. Increasing the loading of kaolin to 32 phr (L-03), the abrasion increased to 225.8 mm³, the abrasion increased to 239.6 mm³ at the loading of kaolin to 37 phr (L-04), and the loading of kaolin to 42 phr (L-05) there was an abrasion of 236.5 mm³.

The increase in abrasion can be caused by weak bonds between the material molecules, and there is excess space between the rubber composite molecules and the filler. Therefore, friction with other objects to experience abrasion quickly. Facts showed the addition of fillers (Table 1) to the rubber matrix must be balanced with the strength of the bonds between molecules (adhesion and cohesion) that form

![Figure 3](image-url)  Effect of kaolin loading on solid tire compression set.  

![Figure 4](image-url)  Effect of kaolin loading on the abrasion resistance of solid tires.
it. One of the ways to increase the bond strength among the material molecules in the polymer matrix can be done by increasing the cross-link reaction with the addition of additives to strengthen the solid structure of the tire.

Determination of tensile strength and tear strength in the rubber vulcanizate is to see the ability of solid tires when experiencing pull and tear from other objects. The tensile strength, tear strength, and abrasion strength are related to the strength of the bonds between molecules, cohesion, and adhesion that form them. Where if there is friction or pulling, it can survive until it breaks and tears. The bond among the molecules of the material is influenced by the homogeneity of the material which is evenly distributed into the rubber matrix and the vulcanization process which forms cross-links.

Tensile strength and tear strength test data as in Figure 5 and Figure 6, are not linear with the increase in the kaolin loading. The results of the tensile strength test for the loading of kaolin 22 phr (L-01) were higher (9.1 MPa) compared to the loading of kaolin 27 phr (L-02) 6.9 MPa, 32 phr (L-03) 7.5 MPa, and 42 phr (L-05) 6.5 MPa. The addition of kaolin with a loading of 37 phr (L-04) was the highest (10.4 MPa) than all formulas (Figure 5).

The changes that occur are caused by changes in the crosslink structure, and cutting the main chain [42]. In addition, the changes in tensile strength are caused by chain scission and an increase in cross-link density [43]. Increasing the loading of kaolin in a mixture of CaCO$_3$ and silica in the NR-SBR matrix causes sideloading which affects the cross-link reaction and the bonds among the molecules of the material which ultimately affect the tensile strength.

As well as the tensile strength test result, the tear strength test results are not linear with the increase in the loading of kaolin (Table 1 and Figure 6). Solid tires vulcanizate with kaolin loading of 22 phr (L-01), tear strength value of 26.1 N/mm$^2$ is higher than that of vulcanizate with a kaolin loading of 27 phr (L-02) and a kaolin loading of 32 phr (L-03), however, it is lower than the kaolin loading of 37 phr (L-04) and 42 phr (L-05) (Figure 6).

Kaolin with the formula 2H$_2$O. Al$_2$O$_3$.2SiO$_2$ with the SiO-Si composition at different loadings in the rubber matrix affects the space for the polymer and the bonds between molecules. The difference in space is caused by differences in the loading of kaolin that occupies the available space. The more the kaolin loading reduces the space for the polymer and affects the value of the tear strength.

Based on the data from the tensile strength and tear strength test results as described above, the kaolin distributed in the NR-SBR matrix may not be evenly distributed when compounding at the open mill. The spread of kaolin and additives into the NR-SBR matrix during compounding in an open mill affects the tensile strength and tear strength values.

3.3. Mass degradation analysis
Mass degradation can be caused by breaking bonds between molecules, induced by other particles causing molecules to spontaneously polar. The polarity of a compound is due to the difference in electronegativity between the atom and the shape of the molecule. Solid tires consist of fillers and additives in the NR-SBR matrix (Table 1). When the bonds among molecules are weak, the mass will naturally be degraded by environmental conditions. The mass of solid tires can be reduced due to abrasion when there is friction with other objects and the influence of heat that damages the surface, slowly towards the center point. The results of the TGA analysis are shown in Figures 7(a)-(d).

![TGA Analysis](image)

**Figure 7.** Material mass reduction thermogram with (a) 22 phr, (b) 27 phr, (c) 32 phr, and (d) 37 phr of kaolin filler on solid tire vulcanizate.

To determine the mass loss, it was analyzed using the thermo gravimetric method (TGA). The TGA method is used to determine the thermal stability of the volatile component fractions by calculating the change in mass with temperature changes. The measurement of mass degradation using thermogravimetric analysis has been widely used [44-46]. The mass reduction analysis of four solid tire vulcanization formula used the thermo gravimetric method. The test data for the four samples are based on the temperature differences that occur in two stages. Each degradation stage was caused by a different loading of kaolin added to the composite matrix. Theoretically, of all the materials used to make rubber compounds into solid tire vulcanizate, NR-SBR and additives are conditioned except for kaolin. The difference in each stage is influenced by the amount of kaolin that is distributed in the mixture of ingredients.

The results of TGA analysis for sample L-01 (Figure 7(a)) showed that the mass reduction in the first stage occurred in the temperature range of 298.7 °C to 443.6 °C. In this temperature range, there was a massive decrease in mass, namely 39.95%. The mass loss in the first stage comes from volatile elements...
with a low boiling point below 443.6 °C. The second stage of degradation occurred at a temperature range of 449.2 °C to 537.3 °C with a mass decrease of 6.22%. The mass that is degraded in the second stage is the mass which has a high boiling point, possibly from zinc and titanium.

The decrease in the mass of the L-02 sample (Figure 7(b)) in the first stage occurred at the temperature range of 172.1 to 429.4 °C with a mass decrease of 45.07%. The second stage of degradation occurred at a temperature range of 433.9 °C to 523.7 °C with a mass decrease of 7.49%. The decrease in sample mass with code L-03 (Figure 7(c)) in the first stage occurred at the temperature range of 108.4 °C to 424.9 °C with a mass decrease of 46.5%, while the second degradation occurred at a temperature of 428.3 °C to 522.1 °C with a decrease in mass of 6.75%. The degradation of the sample with the L-04 code in the first stage occurred at a temperature of 110 °C to 396 °C with a mass reduction of 40.97%, while the second stage degradation at a temperature of 399.4 °C to 523.7 °C with a mass decrease of 10.6%.

Based on the mass of degradation of each stage, for the first stage, the four samples were derived from volatile elements such as Silane, paraffin oil, NR, SBR, stearic acid, paraffin wax, coumarone resin. The second stage of the mass reduction comes from the titanium element’s, Zn, silica, kaolin, CaCO₃, and other additives such as MBTS, TMTD, PVI. Loss of mass due to the decomposition process is characterized by breaking chemical bonds, evaporation, increasing temperature, reducing the interaction between substances with reducing agents and desorption. The TGA curve occurs based on the degradation stage which is limited by the temperature range. Changes in temperature are converted into changes in energy and mass during heating and then plotted against temperature and time.

Conclusion
The mechanical properties of solid tires are influenced by the constituent materials such as natural rubber, synthetic rubber, additives, fillers and material loadings. Kaolin as a volume increasing filler at different loadings affected the mechanical properties of solid tires. The hardness, compression set, elasticity and abrasion were important parameters to assess the safety and comfort of using solid tires. Test results of curing characteristic for a compound with 27 phr kaolin loading were as follows: delta torque of 12.57 kg-cm, cure time of 8:48 seconds, and scorch time of 0.52 second. The results of mechanical properties testing were as follows: hardness before and after ageing of 58 and 59 Shore A, respectively, compression set test of 25%, and abrasion resistance of 211.5 mm³. The mass degradation for each sample occurs in two stages, each of which is differentiated based on temperature. The difference in the loading of kaolin affects the degradation temperature and mass degradation.

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