Increasing performance of straight pattern of rubber tyre on asphalt track due to sulfur composition

P I Purboputro1*, A S Darmawan1*, M A Hendrawan1

1Department of Mechanical Engineering, Faculty of Engineering, Universitas Muhammadiyah Surakarta, Jl. Ahmad Yani, Tromol Pos 1 Pabelan, Surakarta 57162, Indonesia

*Corresponding author: Pramuko.Ilmu@ums.ac.id, pip272@ums.ac.id

Abstract. The motion of a ground vehicle is primarily determined by friction force transferred from road via tires. Therefore, the effect of the compound composition on the hardness and wear resistance is investigated. The grip coefficients on the track in wet and dry conditions are also investigated. In this research, the three combinations of black carbon and sulfur composition namely compound 1, compound 2 and compound 3 are provided. The hardness, wear resistance and grip coefficient are then tested. The results of the tests are also compared to the existing compound material which is already on the market. The shore A hardness of compound 1, compound 2 and compound 3 are 75, 75, and 77 respectively. The wear rate of compound 1, compound 2 and compound 3 in dry asphalt condition are 19.49 mm$^3$/sec, 18.64 mm$^3$/sec and 13.42 mm$^3$/sec respectively. The wear rate of compound 1, compound 2 and compound 3 in wet asphalt condition are 6.457 mm$^3$/sec, 5.933 mm$^3$/sec and 4.133 mm$^3$/sec respectively. The grip coefficient of compound 1, compound 2 and compound 3 in dry asphalt condition are 0.756, 0.751, and 0.725 respectively. The grip coefficient of compound 1, compound 2 and compound 3 in wet asphalt condition are 0.702, 0.693, and 0.685 respectively. The compound material already on the market has shore A hardness of 71, wear rate in dry asphalt condition of 11.40 mm$^3$/sec, wear rate in wet asphalt condition of 2.800 mm$^3$/sec, grip coefficient in dry asphalt condition of 0.773 and grip coefficient in wet asphalt condition of 0.727. The shore A hardness and wear rate of compound 1, compound 2 and compound 3 are higher than the shore A hardness and wear rate of the compound material already on the market. While the grip coefficient of compound 1, compound 2 and compound 3 are lower than the grip coefficient of the compound material already on the market.

1. Introduction

Globally, motor vehicles are the manufactured product of the highest value. They roll on rubber tires that transfer friction force and wear out over the vehicle’s lifetime. Vehicle tires are made of rubber because it is flexible and elastic. In addition, the rubber material does not quickly absorb heat. Tires are made of vulcanized rubber and various reinforcing materials. The most commonly used rubber matrix is the co-polymer styrene-butadiene (SBR) or a blend of natural rubber and SBR. In addition to the rubber compound, tires contain carbon black which is used to strengthen the rubber and aid abrasion resistance. Sulfur is also added in order to vulcanize the rubber compounds, transforming...
them into highly elastic material. Textile or steel fibers, usually in the form of a cord, used to provide the reinforcing strength or tensile component in tires [1-3].

Quality of product plays important role in manufacturing [4]. Tire is extensively developed in automotive industry nowadays. The development includes the creation of various types, physical understanding and modelling [5]. As the development of tires exist at many tire manufacturers, they are competing to produce quality tires both in terms of material mix, the tire models, performance and comfort during use. Factor composition is the most direct influence on the quality of tire to be produced.

Car tires release wear particles through mechanical abrasion. Wear and tear from tires significantly contributes to the flow of micro plastics pollution into the environment. The emissions from car tires are substantially higher than those of other sources of micro plastics, e.g., airplane tires, artificial turf, brake wear and road markings [6]. Pollution of the environment with plastics is recognized as a serious global threat because it can negatively affect human health, aquatic organisms, as well as the economy [7-9].

There are many factors that affect tire grip coefficient such as the vertical force of the tires against the asphalt, the coefficient of friction between the surfaces intersect, pattern, the air pressure in the tire and rubber types, road characteristics, the type of road surface, as well as tire temperature or the road temperature itself. Traction grip can be improved by improving the coefficient of friction between the tires with the road surface and increasing the vertical force. The road surface is a constant magnitude that no bias is changed, therefore the composition and coefficient of friction play the important role to improve the quality of the tire compound.

Coefficient of friction tire compound is a function of temperature. The best conditions are usually achieved compound tires at temperatures between 85 °C to 100 °C. Quality compound also depends on the type of rubber. The harder compound grip quality usually decreases, but resistance to the wear increases. Ideal conditions of course if the tire manufacturer can make a hard compound but having a good grip.

In this research natural rubber is mixed with other sup materials with some combination of the composition to make the outer layer of the tire. The objectives of this research is to study the effect of the compound composition on the hardness, wear rate and grip coefficient on the asphalt track in wet and dry conditions. The frictional behaviour of tires on any surface such as wet and dry condition is important for vehicle safety and control [10]. Hardness, one of mechanical property that important to consider, is a measure of a material’s resistance to localized plastic deformation. Hardness is an indicator of wear resistance [11, 12].

2. Materials and Methods
In this study, material used in this research were RSS (Rubber Smoke Sheet), SBR (Styrene Butadiene Rubber), black carbon, Sulfur, Paraffinic oil, Stearic acid, Paraffin wax, MBTS, Resin epoxy, and ZnO.

In the early stages of making the compound, the rubber was heated using a heater, after the rubber becomes softer, then do the mixing ingredients one by one and rolled.

The process was to mix the ingredients with different compositions, namely the composition of compound 1 made of 70 phr RSS, 3 phr Sulphur and 50 phr Black Carbon, composition 2 made of 70 phr RSS, 3.5 phr Sulphur and 55 phr Black Carbon, while composition 3 made of 70 phr RSS, 4 phr Sulphur and 60 phr Black Carbon.

The mixing of compositions 1, 2 and 3 was conducted by using roll machine. Then the vulcanization process was performed to determine the time and temperature of vulcanization.

The next process was Shore A hardness testing with SNI standard 0778-2009 point 6.22, and testing grip with ASTM D 2047-99.
The composition of composite can be seen in Table 1.

| No | Materials         | phr Compound 1 | phr Compound 2 | phr Compound 3 |
|----|------------------|----------------|----------------|----------------|
| 1  | RSS              | 70             | 70             | 70             |
| 2  | SBR              | 30             | 30             | 30             |
| 3  | Black Carbon     | 50             | 55             | 60             |
| 4  | Parafin Oil      | 6              | 6              | 6              |
| 5  | ZnO              | 4              | 4              | 4              |
| 6  | Stearic Acid     | 2              | 2              | 2              |
| 7  | Parafin Wax      | 0.5            | 0.5            | 0.5            |
| 8  | MBTS             | 1              | 1              | 1              |
| 9  | Epoxy            | 2              | 2              | 2              |
| 10 | Sulfur           | 3              | 3.5            | 4              |

2.1. Methods

This material used in this research were RSS (Rubber Smoke Sheet), SBR (Styrene Butadiene Rubber), black carbon, Sulfur, Paraffinic oil, Stearic acid, Paraffin wax, MBTS, Resin epoxy, and ZnO.

In the early stages of making the compound, the rubber was heated using a heater, after the rubber becomes softer, then do the mixing ingredients one by one and rolled.

The process was to mix the ingredients with different compositions, namely the composition of compound 1 made of 70 phr RSS, 3 phr Sulphur and 50 phr Black Carbon, composition 2 made of 70 phr RSS, 3.5 phr Sulphur and 55 phr Black Carbon, while composition 3 made of 70 phr RSS, 4 phr Sulphur and 60 phr Black Carbon.

The mixing of compositions 1, 2 and 3 was conducted by using roll machine. Then the vulcanization process was performed to determine the time and temperature of vulcanization.

The next process was Shore A hardness testing with SNI standard 0778-2009 point 6.22, and testing grip with ASTM D 2047-99

3. Results and Discussion

3.1 The result of hardness testing

![Figure 1. Histogram of the Relationship between Compound on Shore A hardness value](image)
After mixing processes, the composition of compounds can be seen in Table 1. Linings made from the composites are shown in figure 1. Figure 1 shows relationship between the types of compound on the Shore A hardness. The hardness of existing compound, compound 1, compound 2 and compound 3 were 71, 75, 75 and 77 respectively. The more sulphur the higher the hardness of compound. The compounds also have higher hardness than the existing compound. These aluminium powders are filtered with mesh 40, 50 and 60. The larger the mesh values the smaller the size of aluminum powder.

3.2 The result of wear testing on dry asphalt

As illustrated in Figure 2, in the wear on the dry track, the existing compound had the lowest wear value of 11.40 mm³/sec. In the same test, the highest wear value of 19.49 mm³/sec was occurred at compound 1. While compound 2 had wear value of 18.64 mm³/sec and compound 3 had a value of 13.42 mm³/sec at dry condition. The wear rate of compound 1, compound 2 and compound 3 higher than the existing compound.

3.3 The result of wear testing on wet asphalt

In the wear test on the wet track as can be seen in Figure 3, the existing compound had wear rate of 2,800 mm³/sec. While the compound 1 had high wear value of 6.467 mm³/sec. Furthermore, compound 2 and compound 3 had a wear value of 5.933 mm³/sec and 4.133 mm³/sec respectively.
The grip coefficient test results on the dry track were greater than the grip coefficient that occurs on the wet track conditions.

3.4 The result of wear testing on dry asphalt

In Figure 4 shows that the grip coefficient of the existing compound is higher than the grip coefficient of compound 1, compound 2, and compound 3. The figure also illustrate that the higher the composition of sulfur the lower the grip coefficient. The grip coefficient of the existing compound, compound 1, compound 2, and compound 3 were 0.773, 0.756, 0.751 and 0.725 respectively.

![Figure 4. Grip coefficient of straight pattern on dry asphalt](image)

3.5 The result of grip coefficient testing on wet asphalt

From Figure 5. The grip coefficient on wet asphalt track condition has 0.727 for existing compound. Compound 1, compound 2, and compound 3 had 0.702, 0.693, and 0.685, respectively. The The grip coefficient of compound 1, compound 2, and compound 3 are lower than the grip coefficient of existing compound. Compound 1,

![Figure 5. The grip coefficient on wet asphalt track](image)
4. Conclusion
In this study, the hardness of compound 1, compound 2 and compound 3 were higher than the existing compound. However, the wear rate was higher, and the grip coefficient was lower.

Acknowledgment
The authors gratefully acknowledge financial support from Education Ministry of Indonesia. The authors also would like to thank Mechanical Engineering Laboratory of Universitas Muhammadiyah Surakarta for all specimens’ preparation.

References
[1] Amari, T., Themelis, N. J., and Wemick, I. K.: ‘Resource recovery from used rubber tires’, Resources Policy, 1999, 25, (2), pp. 179-188.
[2] Okel, T. A., and Rueby, J. A.: ‘Silica morphology and functionality: Addressing winter tire performance’, Rubber World, 2016, 253, pp. 21-52.
[3] Sharifzadeh, M., Akbari, A., Timpone, F., and Daryani, R.: ‘Vehicle tyre/road interaction modeling and identification of its parameters using real-time trustregion methods’, IFAC-PapersOnLine, 2016, 49, (3), pp. 111-116.
[4] Darmawan, A. S., Anggono, A. D., and Hamid, A.: ‘Die design optimization on sheet metal forming with considering the phenomenon of springback to improve product quality, MATEC Web of Conferences, 2018, 154, 01105.
[5] Heinrich, G., and Klüppel, M.: ‘Rubber friction, tread deformation and tire traction’, Wear, 2008, 265, pp. 1052-1060.
[6] Kole, P. J., Löhr, A. J., Van Belleghem, F. G. A. J., and Ragas, A. M. J.: ‘Wear and Tear of Tyres: A Stealthy Source of Microplastics in the Environment’, Int. J. Environ. Res. Public Health, 2017, 14, (10), 1265.
[7] Wagner, M., Scherer, C., Alvarez-Muñoz, D., Brennholt, N., Bourrain, V., Buchinger, S., Fries, E., Grosbois, C., Klasmeier, J., Marti, T., Rodriguez-Mozaz, S., Urbatza, Vethaak, A. D., WintherNielsen, M., and Reifferscheid, G.: ‘Microplastics in freshwater ecosystems: What we know and what we need to know’, Environ. Sci. Eur., 2014, 26: 12.
[8] Chae, Y., and An, Y. J.: ‘Effects of micro- and nano plastics on aquatic ecosystems: Current research trends and perspectives’, Mar Pollut Bull., 2017, 124, (2), pp. 624-632.
[9] Nakki, P., Setala, O., and Lehtiniemi, M.: ‘Bioturbation transports secondary microplastics to deeper layers in soft marine sediments of the northern Baltic Sea’, Mar Pollut Bull., 2017, 119, pp. 255-261.
[10] Ella, S., Formagne, P. Y., Koutsos, V., and Blackford, J. R.: ‘Investigation of rubber friction on snow for tyres’, Tribology International, 2013, 59, pp. 292-301.
[11] Darmawan, A. S., Siswanto, W. A., and Sujitno, T.: ‘The Influence of Plasma Nitrocarburizing Process Temperature to Commercially Pure Titanium Surface Hardness’, Applied Mechanics and Materials, 2013, 315, pp. 700-704.
[12] Darmawan, A. S., Siswanto, W. A., and Sujitno, T.: ‘Comparison of Commercially Pure Titanium Surface Hardness Improvement by Plasma Nitrocarburizing and Ion Implantation’, Advanced Materials Research, 2013, 789, pp. 347-351.