

Study on the Friction Contact Model between a Rigid Ball and Rubber Surface with Various Rubber Materials: A Numerical Investigation

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Abstract - A type of rubber material will have a different response when receiving external frictional loads. In this simulation, the friction contact phenomenon is modeled as friction contact between a rigid ball and the surface of a rubber material for several variations of rubber material, namely, Styrene Butadiene Rubber reinforced with carbon black (SBR-25), soft type tire rubber (type-S) and hard type tire rubber (type-H) where the two contact surfaces are still smooth and have not been abraded at all. Analysis of the friction indentation test using the finite element method with the help of ANSYS Workbench software, which is one of the finite element method software that is popularly used. In the simulation, there are variations in indentation depth, namely 0.1 mm, 0.4 mm and 0.7 mm with a constant speed of 15 mm/s at each depth. The rubber test material is assumed to be a hyperelastic material in contact with a perfectly rigid spherical material. This main research aims to determine the magnitude of the deformation and stress of the rubber material and the coefficient of friction from frictional contact with variations in the rubber material.

Keywords: hyperelastic, SBR-25, coefficient of friction.

I. INTRODUCTION

Each material has characteristics and properties that are different from other materials. So when a material receives external loads in the form of pressure, strain or force, the results can show a different response from one material to another.

The properties of the material against the external load it receives can be various, it can be elastic, elastic-plastic, plastic, hyperelastic, viscoelastic, or viscoplastic. To determine the properties of the material, the material must pass a test. Tests that can be carried out are in the form of indentation tests. One of the properties of the material to be tested is hyperelastic, to determine the response that will occur

with the material. In this test, the test material is softer than the indenter or scratching material.

During the contact process between materials, the softer material will experience deformation and wear traces are formed. The properties of materials like this are what you need to know. One of the benefits is in the industrial world which produces components from hyperelastic materials. For example: tires, conveyor belts, elastomers bearing pads, seals, circular bearing pads, shoe soles, rubber pads used on overpasses or suspension bridges and disks in pin on disk devices.

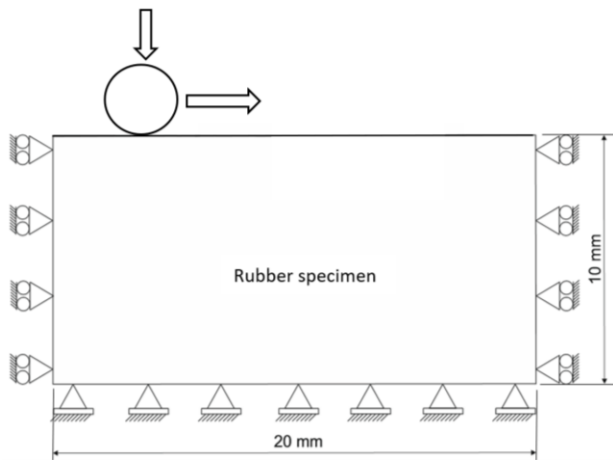
In this simulation, rubber materials are often used in everyday life, such as between tires and the road when braking. The braking capacity during frictional contact is proportional to the friction coefficient between the tire and the road. One simple model to describe the friction contact simulation is contact between a spherical shape and a flat surface. In this simulation, the case of contact between the surface of an elastomeric material, namely Styrene Butadiene Rubber reinforced with carbon black (SBR-25), soft type tire rubber (S-type) and hard type tire rubber (H-type), is taken against the rigid ball indenter. SBR-25 is a rubber material in the form of Styrene Butadiene Rubber which is reinforced with 25% carbon black content. Meanwhile, type-H and type-S materials are hard and soft types of vulcanized rubber that are obtained from tire market, with a process of forming chemical cross-links from independent molecular chains which can increase elasticity and reduce plasticity.

In this simulation, the case of the contact model is taken, namely frictional contact between a flat surface in the form of hyperplastic material and a rigid ball indenter. The hyperelastic material constant value is determined based on previous experimental results. Friction contact simulation analysis uses the finite element method with the help of ANSYS Workbench software which provides non-linear analysis facilities for contact mechanics. The simulation was carried out by varying the depth with a constant speed of

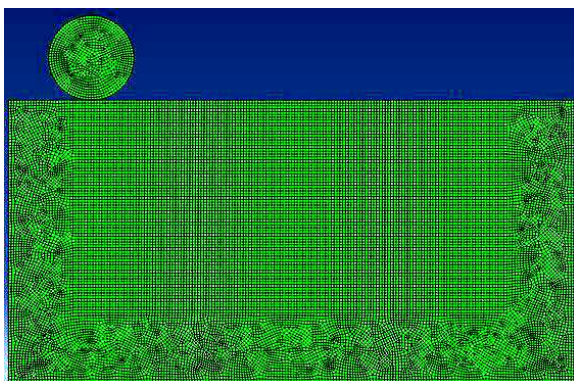
indentation. The desired result is the amount of stress on the rubber surface and the coefficient of friction that occurs.

II. MATERIAL AND METHODS

In this simulation, the model image from this research is modeled in 2 (two) dimensions (2D) with the geometry explained in Figure 1. Figure 1(a) is a schematic model of friction contact while figure 1(b) is a model obtained from FEM software. In this case, the elastomer is a hyperplastic material while the ball indenter is rigid. The right and left sides of the elastomer are supported in the horizontal direction and can move freely in the vertical direction, while the bottom of the elastomer is fixed supported. The indenter is pressed on the rubber surface. The solution to this case was carried out using the finite element method. The indentation or displacement in the vertical direction of the indenter has a depth variation of 0.1 mm, 0.4 mm and 0.7 mm which is applied to 3 material variations, namely SBR-25, Type-S (Soft rubber), and Type-H (Hard rubber), then provides displacement indenter in the horizontal direction with a constant sliding speed of 15 mm/s. The results obtained are reaction force, maximum stress and friction coefficient.



(a)



(b)

Figure 1: (a) Indentation and friction contact modeling scheme and (b) modeling with FEM

The next step is to provide material properties. The material properties are input into the FEM software using constant values that have been calculated in other research from the results of material tensile tests. For SBR-25 material, the material constants use the Yeoh version, while for type S and type H materials use the Mooney-Rivlin version. Constant values are shown in table 1 and table 2 below.

Table 1: Material Constants of Hyperelastic Model of Yeoh

Material	C_1 MPa	C_2 MPa	C_3 MPa	$D_{com/}$ (MPa) ⁻¹	$\rho/10^3$ kgm ⁻³
SBR-25	0,337	-0,0053	0,0005	0,062	1.12

Table 2: Material Constants of Hyperelastic model of Mooney-Rivlin

Material	C_1 MPa	C_2 MPa	D_{com} (MPa) ⁻¹	$\rho/10^3$ kgm ⁻³
Type-S	0.81	1.24	0.062	1.12
Type-H	0.38	1.48	0.062	1.12

After giving the properties to the two parts, the next step is to provide a sliding step to input the position of the indenter displacement and the indent distance. In this modeling, a simulation is carried out with detailed modeling data carried out in the simulation in table 3 below.

Table 3: Input for simulation modelling

Material	Input data
1. SBR-25	The rigid ball is in frictional contact with a rubber surface with an indentation depth of 0.1 mm, 0.4 mm, 0.7 mm with a friction coefficient of adhesion (roughness) of 0.5 and a speed of 15 mm/s.
2. Type-S	
3. Type-H	

III. RESULTS AND DISCUSSION

3.1 Deformation and stress contour of each material

After carrying out the simulation, you can see the surface contour or deformation and stress for the type of rubber material at a certain indentation depth. Figure 2 is for an indent of 0.1 mm, figure 3 is for an indent of 0.4 mm and figure 4 is for an indent of 0.7 mm.

Friction indentation is done by sliding the rigid ball from left to right. From the picture you can see the qualitative distribution of stress in the rubber material, the deeper the indentation, the greater the stress that occurs.

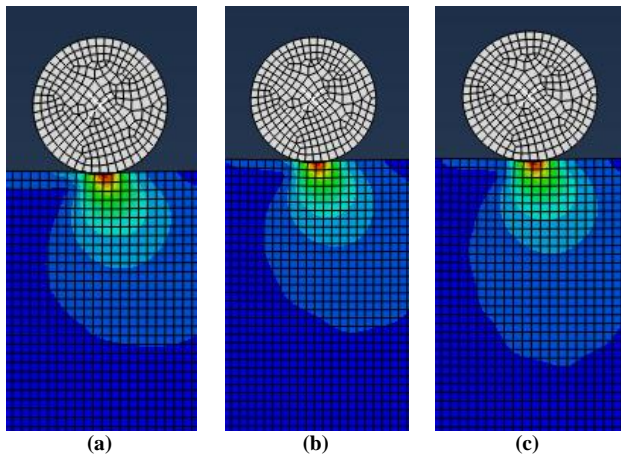


Figure 2: Contour for indentation depth of 0,1 mm (Material a. SBR-25, b. type S dan c. type H)

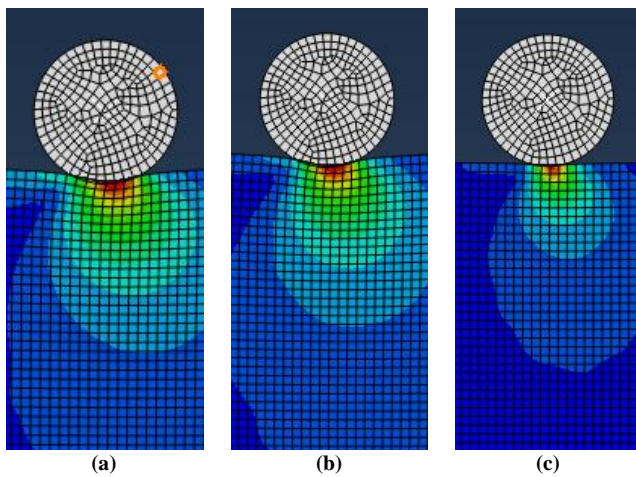


Figure 3: Contour for indentation depth of 0,1 mm (Material a. SBR-25, b. type S dan c. type H)

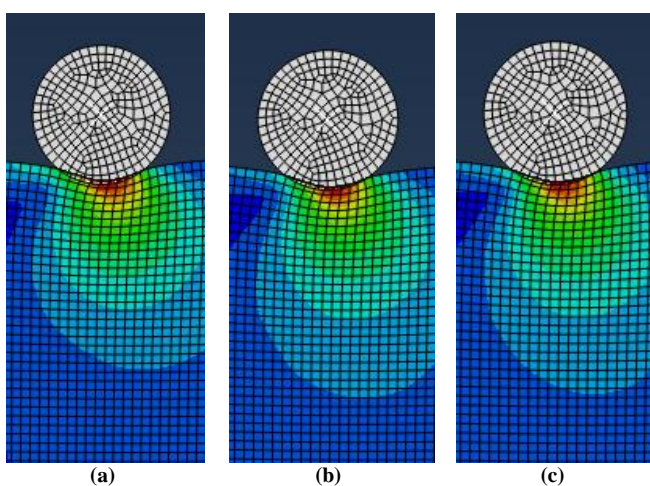


Figure 4: Contour for indentation depth of 0,1 mm (Material a. SBR-25, b. type S dan c. type H)

3.2 The maximum stress on friction contact

The maximum stress during frictional contact with respect to the indenter displacement distance is given in Figure 5 to Figure 7 below. It can be seen that the voltage that occurs is fluctuating.

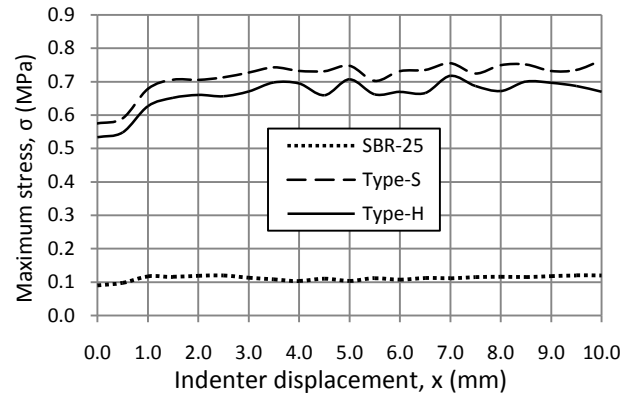


Figure 5: The maximum stress with respect to the indenter displacement for depth of indentation of 0.1 mm

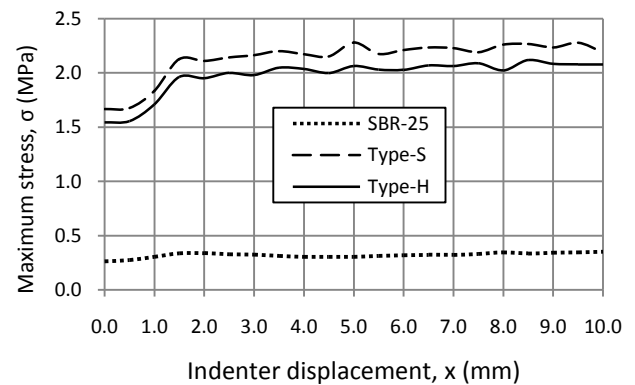


Figure 6: The maximum stress with respect to the indenter displacement for depth of indentation of 0.4 mm

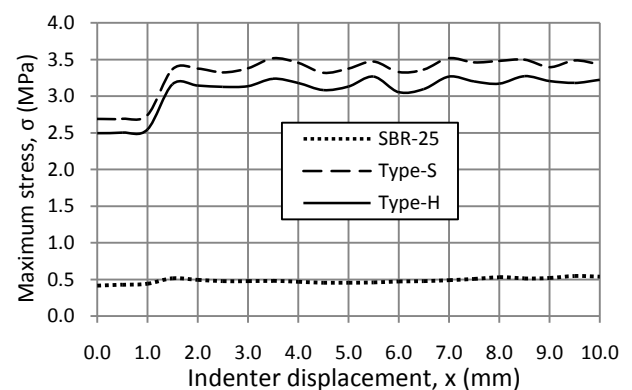


Figure 7: The maximum stress with respect to the indenter displacement for depth of indentation of 0.7 mm

At an indentation depth of 0.1 mm, when the indenter is shifted to the middle position, there is an increase in the stress value which tends to stabilize along with the indentation depth. The stress in Type-S material tends to be the highest compared to other materials, namely 0.7635 MPa, while SBR-25 tends to have the lowest stress.

At an indentation depth of 0.4 mm, when the indenter is shifted to the middle position, there is an increase in the stress value which tends to stabilize along with the indentation depth. The stress in Type-S material tends to be the highest compared to other materials, namely 2.278 MPa, while SBR-25 tends to have the lowest stress.

At an indentation depth of 0.7 mm, when the indenter is shifted to the middle position, there is an increase in the stress value which tends to stabilize along with the indentation depth. Meanwhile, when indenting from the middle position to the end, the stress in the Type-S material tends to be the highest compared to other materials, namely 3.517 MPa, while SBR-25 tends to have the lowest stress.

At an indentation depth of 0.1 mm, the displacement from the initial to the final position of the stress experiences fairly stable up and down fluctuations. The stress on Type-S material also tends to be the highest compared to other materials, while SBR-25 tends to have the lowest stress.

At an indentation depth of 0.4 mm, the displacement from the start to the end of the stress fluctuates up and down. The stress in Type-H material also tends to be the highest compared to other materials, while SBR-25 tends to have the lowest stress.

At an indentation depth of 0.7 mm, the displacement from the start to the end of the stress fluctuates up and down. The stress on Type-H material also tends to be the highest compared to other materials, while SBR-25 tends to have the lowest stress..

3.3 Friction forces with respect to indenter displacement

Graphs showing the relationship between friction force and indenter displacement are given in Figure 8, Figure 9 and Figure 10 below.

At an indentation depth of 0.1 mm when the indenter was in the initial position up to the 2.5 mm position there was a fairly high increase in the three materials. After that the indenter experienced a slight decrease to a distance of 5-7 mm and increased again at the final position. The horizontal force on Type-S material tends to be the highest compared to other materials, namely 0.386 N, while SBR-25 tends to have the lowest horizontal force.

At an indentation depth of 0.4 mm when the indenter was in the initial position up to the 2 mm position there was a fairly high increase in the three materials. After that, the indenter decreased to a distance of 8.5 mm and increased again to the final position. The horizontal force on Type-S material tends to be the highest compared to other materials, namely 1.143 N, while SBR-25 tends to have the lowest horizontal force.

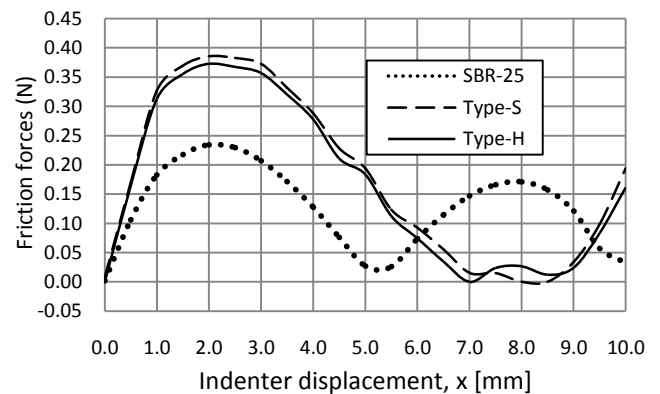


Figure 8: The relationship between friction forces and indenter displacement for indentation depth of 0.1 mm

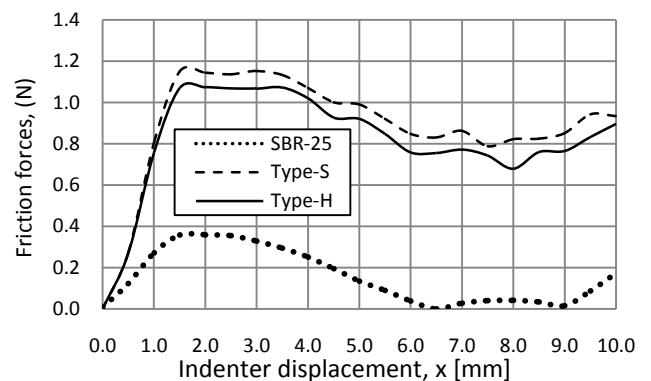


Figure 9: The relationship between friction forces and indenter displacement for indentation depth of 0.4 mm

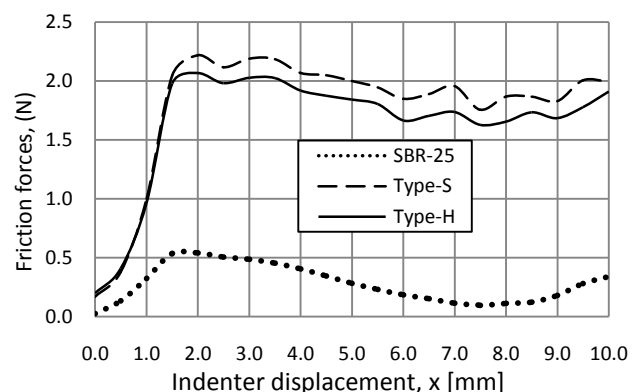


Figure 10: The relationship between friction forces and indenter displacement for indentation depth of 0.7 mm

At an indentation depth of 0.7 mm when the indenter was in the initial position up to the 2 mm position there was a fairly high increase in the three materials. After that, the indenter decreased to a distance of 8.5 mm and increased again to the final position. The horizontal force on Type-S material tends to be the highest compared to other materials, namely 2.219 N, while SBR-25 tends to have the lowest horizontal force.

At an indentation depth of 0.1 mm, the horizontal force experiences fluctuations along the indenter displacement, along the indenter displacement the value of the horizontal force tends to increase and decrease. Type-H material has a relatively higher horizontal force than the others, namely 2.825 N, while Type-H material tends to have a smaller horizontal force than the others.

At an indentation depth of 0.4 mm when the indenter was in the initial position up to the 2.5 mm position there was a fairly high increase in the three materials. After that, the indenter decreased to a distance of 7 mm and increased again to the final position. The horizontal force on Type-S material tends to be the highest compared to other materials, namely 7.761 N, while SBR-25 tends to have the lowest horizontal force.

At an indentation depth of 0.7 mm, the horizontal force experiences fluctuations along the indenter displacement, along the indenter displacement the value of the horizontal force tends to increase and decrease. The SBR-25 material has a relatively higher horizontal force than the others, namely 9.276 N, while the Type-H material tends to have a smaller horizontal force than the others.

3.4 Coefficient of friction along friction contact

Graphs that state the relationship between friction force and indenter displacement are given in Figure 11, Figure 12 and Figure 13 below.

At an indentation depth of 0.1 mm on Type-H and Type-S materials, the total coefficient of friction value on the graph increases at the beginning and tends to be stable until the final position, on the SBR-25 material it increases at the beginning then decreases in the middle position, and increases again in final position. The SBR-25 material has a relatively higher total friction coefficient value than the others, namely 3.570, while the Type-S and Type-H materials tend to have a lower total friction coefficient value.

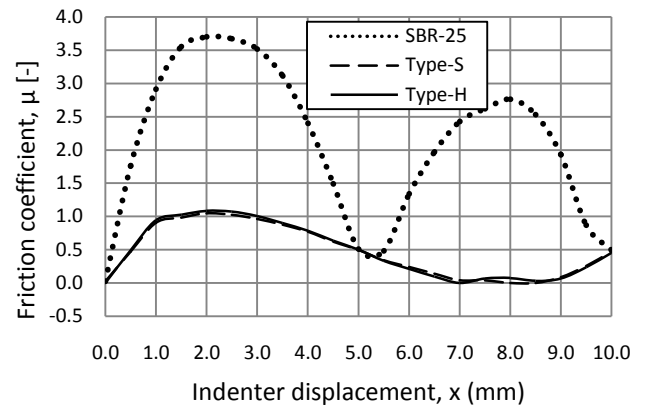


Figure 11: The relationship between coefficient of friction and indenter displacement for indentation depth of 0.1 mm

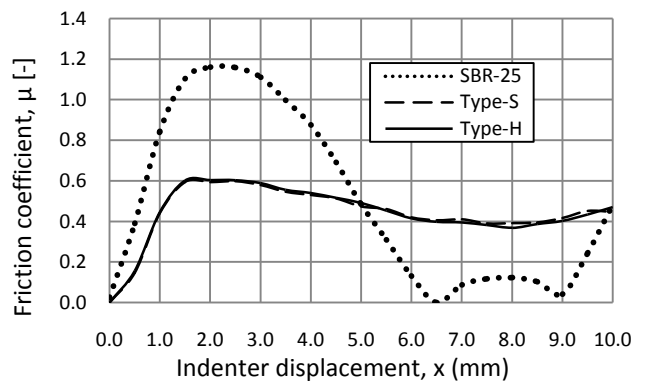


Figure 12: The relationship between coefficient of friction and indenter displacement for indentation depth of 0.4 mm

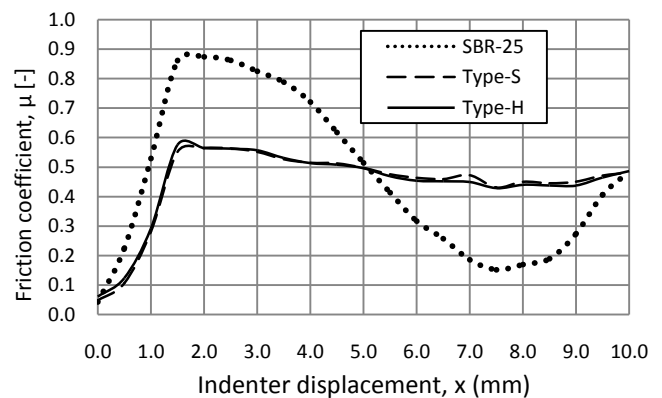


Figure 13: The relationship between coefficient of friction and indenter displacement for indentation depth of 0.7 mm

At an indentation depth of 0.4 mm on Type-H and Type-S materials, the total coefficient of friction value on the graph increases at the beginning and tends to be stable until the final position, on the SBR-25 material it increases at the beginning then decreases in the middle position, and increases again in final position. The SBR-25 material has a relatively higher total coefficient of friction than the others, namely 1.159.

At an indentation depth of 0.7 mm on Type-H and Type-S materials, the total coefficient of friction value on the graph increases at the beginning and tends to be stable until the final position, on the SBR-25 material it increases at the beginning then decreases in the middle position, and increases again in final position. The SBR-25 material has a relatively higher total friction coefficient value than the others, namely 0.874.

3.5 Total Coefficient of friction

Total coefficient of friction consists of friction coefficient due to deformation and friction coefficient due to roughness (adhesion). Coefficients of friction due to deformation are given at Figure 11, Figure 12 and Figure 13 above. Meanwhile, coefficient of friction due to adhesion is 0.5 that is given in Table 3.

At an indentation depth of 0.1 mm, the three materials experience fluctuations along the indenter displacement, along the indenter displacement the value of the total friction coefficient tends to increase and decrease. The SBR-25 material has a relatively higher total friction coefficient value than the others, namely 4.070, while the Type-S and Type-H materials tend to have a low total friction coefficient value.

At an indentation depth of 0.4 mm on Type-H and Type-S materials, the total friction coefficient value on the graph increases at the beginning and tends to be stable until the final position, on the SBR-25 material it increases at the beginning then decreases in the middle position, then fluctuates until final position. The SBR-25 material has a relatively higher total friction coefficient value than the others, namely 1.659 while the Type-H material tends to have a lower total friction coefficient value than the others.

At an indentation depth of 0.7 mm on Type-H and Type-S materials, the total friction coefficient value on the graph tends to be stable until the final position, on SBR-25 material there is a fairly high increase in the middle position. The SBR-25 material has a relatively higher total coefficient of friction than the others, namely 1.374.

IV. CONCLUSION

The results of simulations and calculations carried out on rubber materials (with a hyperelastic model) were obtained by simulating 3 different types of materials, namely, SBR-25, Type-S, and Type-H. Variations in indentation depth with a constant speed were carried out with a rigid ball indenter with a rubber surface. From results above, several conclusions were obtained, namely:

1. The characteristics of the SBR-25 material are very different from those of type S and type H. Meanwhile,

the characteristics of type S and type H materials when subjected to frictional contact are very similar.

2. Along sliding, the initial position to the maximum depth of the friction indentation, the surface contour tends to be wavy, while from the maximum indentation position towards the end of the friction indentation, the surface contour of the material tends to be wavy. This can be seen from the surface contour at the final position of the indentation.
3. By giving the depth variations during sliding indentation, the maximum stress and friction force values of the rubber material fluctuate greatly.
4. The friction force and friction coefficient values tend to increase when the sliding indentation reaches to the middle position of the rubber surface.

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