The Properties of Waste Rubber Tires in Increasing the Damping of Masonry Wall Structure

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Abstract. The accumulation of waste rubber tires causes environmental problems due to most of them cannot be recycled into new tires. Recently, this waste is gradually used as a material replacement in civil engineering such as in increasing damping properties. This study investigates the physical and mechanical properties of waste rubber tires including density (ρ), ultimate tensile strength (σ), elongation at break, hardness (Shore A), modulus of elasticity (E), and shear modulus (G). The specimens used were coded as A, B, C, and D to represent specified brand name. The testing method referred to ISO standards and was carried out in the laboratory of Center for Leather, Rubber, and Plastics (CLRP), and the structural laboratory of Department of Civil Engineering and Environmental, Gadjah Mada University, Yogyakarta, Indonesia. The result shows that the density of all brands is nearly the same which is around 1.1 gr/cm³. The A rubber tire is indicated as the best damping properties since it has the lowest value on tensile strength, hardness, modulus of elasticity and shear modulus. However, the elongation at break is the highest value, compared to the other specimens. B rubber tire shows hard rubber, while C and D are high strength rubber. Therefore, B, C, and D rubber tires are appropriate to be used as barrier supports which must be able to withstand large forces, while the damping is not a priority.

1. Introduction
Economic improvement of the Indonesian community generates an increase in the number of car ownership. This reality also improves the number of waste tire feared to be an environmental problem. A car tire consists of rubbers, fillers, reinforcing materials, plasticizers, and chemicals. The amount of rubber is around 40% of all components, so that the rubber material is the highest volume in the waste tires [1]. Therefore, expanding the utilization of rubber components from tires towards higher benefits is a good solution for environmental problems.

Currently, the utilization of waste rubber tires in Indonesia is very limited, including rubber formed into fenders, ropes, sandals, trash containers, and table-chairs sets. In Civil Engineering fields, waste rubber tires are also applied as a material mixture of soil [2], concrete [3], mortar and asphalt [4], in the form of rubber tire crumbs. The previous research shows the great benefit of the waste rubber tires as the replacement materials in civil engineering. Various studies indicate that the additions of waste rubber tire can reduce unit-weight and increase damping in concrete/mortar. The
additions of rubber tire crumbs in the mortar mixture can increase the damping ratio and decrease the unit-weight of mortar [5]. However, in concrete, it can increase the damping ratio [6], [7] and sound insulation, but decrease thermal conductivity [8]. Faizah, Priyosulistyo and Aminullah [5] also recommended the addition of rubber tire crumbs on mortar mixture to improve damping capacity of masonry walls.

Several studies [5] – [7] found that the addition of waste rubber tire in mortar/concrete mixture can increase the damping capacity of concrete/mortar. Meanwhile, mortar is very popular in Indonesian which is used in the masonry wall structures as a bed and head joints. Boen [9] also stated that the masonry wall infill is most widely used in the Indonesian house construction. Masonry wall damage under an earthquake often results in fatalities, so it is important to find a technique to increase the masonry wall resistance under earthquake. Using the high damping mortar as a bed joint or head joint on the masonry wall structure is a good idea to do.

The previous research took waste rubber tire crumbs from the waste collectors of mix tire brands. Each tire brand has specific properties that can indicate its damping properties. Therefore, properties investigation of each tire brand is critical to get the proper utilization. Using certain brands of rubber tire that have advantages in increasing damping, of course, will result in a more significant damping increase comparing by using mixed rubber tire brands.

There are many tire brands found in Indonesia, i.e., Bridgestone, Dunlop, Gajah Tunggal, Swallow, MRF, Goodyear, Achilles, Pirelli, Yokohama, Michelin, and others. Each of them has specific properties according to their service description and vehicle’s requirements explored in term of load index (LI) and speed index (SI). The maximum load capacity of a passenger car tire is indicated by its Load Index (LI), while the maximum permissible speed (at full load) of the tire is indicated by its Speed Index (SI) [1]. In this study, 4 tire brands among those mentioned above are examined, and is coded by A, B, C, and D.

The properties tested in this study are density (ρ), ultimate tensile strength (σ), elongation at break, hardness (Shore A), modulus of elasticity (E), and shear modulus (G). These properties can be used to indicate the characteristics of certain brands of rubber tire related to the consideration in selecting them for specific uses. Edeskarp [2] reported that the density of rubber tires was slightly higher than the density of water so that it will sink in the water. Besides, the compact density of rubber tires was higher than the bulk density, ranges from 1.08 – 1.27 gr/cm³ for its compact and 0.45 – 0.99 gr/cm³ for bulk. This result is in accordance with Bijarimi’s result which has a rubber compounds density value of 1.14 – 1.15 gr/cm³ [9].

Previous research also shows the results of rubber compound materials testing including tensile strength, elongation at break, and hardness. The rubber compound is a base material of rubber tire blended from natural rubber and chemical additive. Hendrawan and Purbpopotro [10] reported that the tensile strength of rubber compound was around 16.5 - 21.2 MPa, and the elongation at break was 289 - 576%. Besides, the hardness (Shore A) was around 61 – 71 [11] or 71 – 77 [10]. The hardness and elongation value indicates the elasticity of a material. The lower hardness or the higher elongation means the more elastic material. The elastic material has a good ability to return its shape to the original shape after loading. The rubber having high hardness is more resistant to abrasion and extrusion, while softer rubber will be easier to stretch and close on rough surfaces. The ratio of stress to strain in the elastic area represents a modulus of elasticity of the material. The material having a higher value of modulus of elasticity indicates a more rigid material [12].

2. Experimental Method

The experiment was carried out in the testing laboratory of Center for Leather, Rubber, and Plastics (CLRP), and the structural laboratory of Department of Civil Engineering and Environmental, Gadjah Mada University, Yogyakarta, Indonesia. The testing materials are waste rubber tires consisting of 4 brands coded by A, B, C, and D. All of them were from the car tires that is shown in Figure1. The physical and mechanical properties were given some tests including the density test (ρ), ultimate tensile strength test (σ), axial elongation test, hardness test (Shore A), modulus of elasticity test (E), and shear modulus test (G).
2.1. Density Test

The density test refers to ISO 2781: 2008 (Rubber, Vulcanized or Thermoplastic - Determination of Density) [13], using electronic densimeter having a precision of 0.01 presented in Figure 2. The beaker in the densimeter has a capacity of 250 cm$^3$. The specimen is a piece of the rubber tire having a mass of at least 2.5 gr. There are two methods for obtaining specimen densities, namely automatic and manual.

The specimen was placed on the lip of the beaker, and the digital monitor will show the mass in the air ($m_1$). Furthermore, this specimen was inserted in a beaker containing water to obtain the mass in the water ($m_2$). Density ($\rho$) of the specimens was known automatically from the digital monitor, but it can be calculated manually by Equation 1.

$$\rho = \frac{\rho_w m_1}{m_1 - m_2}$$  \hspace{1cm} (1)

where:
- $\rho$ = the density of rubber (gr/cm$^3$)
- $\rho_w$ = the density of water in the site (gr/cm$^3$)
- $m_1$ = the mass of rubber in the air (gr)
- $m_2$ = the mass of rubber in the water (gr)

2.2. Hardness Test

Hardness is a measure of the resistance to a reversible deformation of the rubber and shows the elasticity of a material. The lower hardness indicates the more elastic material. In this experiment, the hardness testing used the durometer (Shore A) method according to ISO 7619-1: 2010 (Rubber, Vulcanized or Thermoplastic Standard - determination of identification hardness - Durometer method/Shore Hardness) [14]. The automatic durometer hardness (Shore A) shown in Figure 3 has a solid spherical indenter by the dimensions is presented in Figure 4.

The pressure load of durometer (Shore A) is 1 ± 0.1 kg or 12.5 ± 0.5 N by a scale of penetration depth on 0 to 100 during 3 - 15 seconds. The specimens have a thickness of approximately 6 mm, and a surface area to get at least 3 test points. The distance between points must be more than 5 mm, and
the distance from the edge is more than 13 mm. The hardness value was obtained automatically from the digital monitor of the machine [12].

![Figure 3. The automatic durometer hardness (Shore A)](image)

Figure 3. The automatic durometer hardness (Shore A)

2.3. Tensile Strength Test

Tensile strength is the maximum tensile stress that can be achieved in stretching pieces of specimens expressed by force per unit area of the initial cross-section of original specimens. The experimental procedure according to ISO 37: 2011 (Rubber, vulcanized or thermoplastic - determination of tensile stress-strain properties) [15]. The specimens are waste rubber tires in the form of dumb-bells as shown in Figure 5. It has 20 ± 0.5 mm of measurement length, and a thickness in a narrow section is 2 ± 0.2 mm. The experimental set-up is presented in Figure 6. The testing machine runs on 500 mm/minute grip speed until the specimen breaks.

Tensile strength ($\sigma$) is the maximum stress when the specimen broken expressed by force per unit area of the original cross section as mentioned in Equation 2.

$$\sigma = \frac{F}{A_0}$$

$F$ is the nominal load applied to the specimen perpendicularly in units of Newton (N), and $A_0$ is a unit area of the original cross section before loading (m$^2$). The unit of tensile strength is MPa (SI) (where 1 MPa = 106 N/m$^2$).

In tensile strength test, there are three main parameters measured, namely tensile strength, elongation at break and modulus of elasticity of specimen. Elongation at break (%) is the maximum extension expressed as a percentage of extension at the break with original length before the sample is broken. Percent elongation at break is defined as Equation 3.

$$\text{Percent elongation} = 100 \times \frac{L_B - L_0}{L_0}$$

$L_0$ and $L_B$ denotation are the initial length of the tensile test specimen and its final length at rupture respectively [16]. Furthermore, the modulus of elasticity of specimen can be obtained by analyzing the strength-strain relationship curve resulted from the machine output automatically.
2.4. Shear Modulus Test

Shear modulus or modulus of rigidity (G) which relates the components of the shearing stress and shearing strain is the coefficient of elasticity for a shearing force expressed by the ratio of shear stress to the displacement per unit sample length (shear strain). Shear modulus can be experimentally determined from the slope of a stress-strain curve created during tensile tests conducted on a sample of the material. The constant of proportionality relating shear stress and shear strain is the shear modulus. It is represented by G, in a unit of Newton per square meter (N/m²) = Pascal (Pa) or pounds per square inch (psi) [16].

The specimen of the experiment is a waste rubber tire block with the length of a direction of withdrawal must be more than twice of the perpendicular direction. The set-up of the experiment is shown in Figure 7. The deformation of a rubber block if the forces (F) acting on the block is shown on the illustration in Figure 8, where F is the shearing load acting on the body, L is a height of the block, A is the area under shear and Δx is the deformation of the block. Furthermore, the shear stress induced in the body (τ), the shear strain (γ), and shear modulus (G) can be obtained using Equation 4.

\[
G = \frac{F}{A} = \frac{F}{\Delta x/L} = \frac{F}{A} \frac{L}{\Delta x}
\]

(4)

With G is a shear modulus, τ is shear stress, γ is a shear strain, F is acting forces, A is an area under shear, L is a height of the block, and Δx is the deformation of the block [16].
3. Result and Discussion

The physical and mechanical properties of waste rubber tires with a code of A, B, C, and D were investigated. The density test result shows that all specimens have a nearly same level of density, which is around 1.1 gr/cm³. This value is in accordance with the results of Edeskar's research [2]. The density of waste rubber tire is lesser than the density of some materials such as sand, cement, lime, and asphalt. Therefore, the waste rubber tire might be the waste as a replacement material of sands in the concrete mixture to get the lighter concretes. Batayneh, Marie and Asi [17] confirmed that content increasing of the rubber tire crumbs in the concrete mix could reduce the slump and the unit-weight of the mixes. Faizah, Priyosulistyo, and Aminullah [5] also reported that the addition of rubber tire crumbs in the mortar mixture could reduce the unit-weight of the hardened mortar. Unit-weight of mortar with 40% and 60% rubber tire crumbs contents decrease up to 22% and 32% respectively. Besides that, the unit-weights of the mortar cubes containing 40% and 60% rubber tire crumbs can classify as a lightweight mortar because the unit weight is less than 1850 kg/m³.

The specimen used in all of the experiment is prepared from a waste rubber car tire. Figure 9 shows a specimen of tensile strength test shaping a dumb-bells. The length of measurement is ± 20 mm, and a thickness in a narrow section is ± 2.0 mm. Some specimens break up in the middle, and some are slight to the edge under the tensile strength test, as shown in Figure 10.

The result of the tensile strength test given in Figure 11, shows that the value around of 10.64 – 14.358 MPa. B specimen has the highest value, but A specimen has the lowest value. These results exhibit that B specimen has the highest ability to withstand stress-loads which usually indicate a hard material, but A specimen is an opposite. The tensile strength result of this study is lesser than Bijarimis’s result that was found around 16.5 - 21.2 MPa. Bijarimi investigated the tensile strength of the rubber tire compound [11]. The other report shows that the tensile strength of rubber compounds is around of 13.46 – 16.69 MPa [10]. The variation on this tensile strength value might be caused by the difference of rubber quality, chemical additive contents, and age of tires.

Elongation at break and modulus of elasticity were also obtained in conjunction with the tensile strength test given in Figure 12 and 13 respectively. The specimen can stretch up to 238 - 296% of its original length when forced stress. The A specimen has the highest elongation at break but the lowest
on a modulus of elasticity. This result indicates that the A specimen is the softest and the most elastic one compared to other specimens. This finding is confirmed by the hardness of the test result given in Figure 14. The A specimen has the lowest value of hardness, while the B specimen has a highest, opposite to the tensile strength test result. The hardness test result is around 57.9 to 68.74, agrees with Sidabutar’s report showed in Figure 15, which describes various elastomer hardness. The rubber has 20 – 90 hardness value and around of 60 for rubber tire cars. The compounds having higher durometer values indicate harder compounds [12].

![Figure 11. The tensile strength test](image)

![Figure 12. The elongation of the specimens](image)

![Figure 13. Modulus of Elasticity (E)](image)

![Figure 14. Hardness (Shore A) of the specimens](image)

![Figure 15. Various of elastomer hardness](image)

The specimens were also examined by a shear modulus test, with an experimental set-up as represented in Figure 16. The specimen was attracted up to failure. The force was detected using a load-cell having a capacity of 1000 kg while a deformation was measured by a linear variable differential transformer (LVDT). After loading, the relationship curve between shear stress and shear strength can be described in Figure 17. From this figure, it can be obtained the shear modulus of all the specimens from the linear slope. The shear modulus of specimen is presented in Figure 18. The modulus of elasticity and shear modulus shows in-line results, where the highest to lowest values are owned by the C, D, B, A specimens respectively. The result of this study shows a good correlation between tensile strength, elongation at break, modulus of elasticity, hardness, and shear modulus of
specimens. All of the results are summarized in Table 1. The bold fonts show the minimum value, but the italic-underscore fonts show the maximum value.

![Figure 16. Experimental set-up of the shear modulus test](image)

Table 1. The summary of the experimental result

| No. | The experiment               | A    | B    | C    | D    |
|-----|------------------------------|------|------|------|------|
| 1   | Density (gr/m³)              | 1.112| 1.090| 1.120| 1.136|
| 2   | Tensile Strength (MPa)       | **10.640** | 14.358 | 11.896 | 11.792 |
| 3   | Hardness (Shore A)           | **57.90** | 68.74 | 66.98 | 67.60 |
| 4   | Elongation at break (%)      | **296** | 271  | **238** | 244 |
| 5   | Modulus of Elasticity, E (MPa) | **1.8522** | 2.0945 | **2.6131** | 2.4880 |
| 6   | Modulus of Rigidity, G (MPa) | **0.925** | 1.232 | **1.769** | 1.357 |

Table 1 shows that the A rubber tire has the lowest value on tensile strength, hardness, modulus of elasticity, and shear modulus compared to the other specimens. However, the elongation at break was found to be the highest one. It can be analysed that the A rubber tire has soft and elastic properties since its tensile strength is the lowest one. This statement was confirmed by its elongation having the highest value. The high elongation at break indicates that the rubber tire is easy to stretch under stress-force. This characteristic is in accordance with the low value on a modulus of elasticity and shear.
modulus, representing the less stiff and less brittle materials. As a result, it has high stretch-ability under the loading. The materials that have a low value on a modulus of elasticity and shear modulus seem to indicate a high damping material [18]. This observation offers the finding that A rubber seems appropriate to be chosen as an additive or replacement material, which can increase the damping ability of the material.

The B rubber tire has the highest value on tensile strength and hardness indicating that B rubber does not easily change in shape. This rubber tire can withstand great force due to its hard property. Therefore, B rubber is appropriate to be used as a material that must resist a high impact as resisting axial load and abrasion coating materials.

The C rubber tire has the lowest elongation at break but is highest in modulus of elasticity and shear modulus. This property shows the good ability to keep the original shape when loaded by strength or shear forces. The C rubber tire might be appropriate to be used as an additive that prioritizes stiffness.

As shown in Table 1, the D rubber has an intermediate value on all properties compared to the other specimens. This fact indicates that the D rubber tire is an ordinary rubber having a general property. It does not have any specific property compared to the other rubber tires. Nevertheless, the D rubber tire has a secondary property after the C rubber tire as an additive that prioritizes stiffness. It is initiated by its value on elongation at break, modulus of elasticity and shear modulus which are almost the same with the C rubber tire.

4. Conclusion

Various tests have been carried out in this study with the specimens from waste rubber tire having A, B, C and D brands code. The findings of this study can be summarized as follows.
1. All waste rubber tires have a density of around 1.1 gr/cm³.
2. The A rubber tire indicates the best damping properties since it has the lowest value on tensile strength, hardness, modulus of elasticity and modulus of rigidity, but having the highest elongation at break compared to the other specimens.
3. The B rubber tire shows a hard rubber material, while C and D shows a high strength rubbers materials. Therefore, the B, C, and D rubber tires are appropriate to be applied as a barrier supports materials, where the damping is not a priority.

Acknowledgment

The authors gratefully acknowledge the Research Directory of Gadjah Mada University which has given the Rekognisi Tugas Akhir (RTA) fund. The author also gave the highest appreciation to Universitas Muhammadiyah Yogyakarta as the main institution of the first author.

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