Effect of Used Tire Rubber Powder Addition as Eco-concrete Innovation Through Job Mix Formula on Compressive Strength and Modulus Elasticity of Concrete

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ABSTRACT
This article discusses the effect of adding used tire rubber powder as an admixture of fine aggregate using the design method of job mix formula K-250 according to SNI 03-2834-2000. The variation of adding used tire rubber powder is 0%, 2.5%, 5%, 7.5%, and 10% against the acceptable aggregate content weight ratio. The Fas used was 0.58 with 210 l/m³ water. The test methods used are inspection of concrete constituent materials, vicat test, slump test, compressive strength, and modulus of elasticity of concrete. From testing the slump test, compressive strength, and elastic modulus of 28-day-old concrete, the more the level of addition of used tire rubber powder, the value of slump, compressive strength, and modulus of elasticity of concrete decreases. Seen at an average compressive strength of 21.06 MPa has an elastic modulus value of 21564.02 MPa, while at an average compressive strength of 15.13 MPa, the average elastic modulus value is 18268.14 MPa. Both data show that regular concrete is plastic and concrete with an admixture of used tire rubber powder is elastic. The compressive strength value decreased proportionally to the used tire rubber powder addition level, with a percentage decrease of 28% from standard concrete. The theoretical modulus of elasticity decreased by 15% from regular concrete, and the experimental modulus of elasticity increased by 3%. From the stress-strain relationship graph, concrete with used tire rubber powder experienced an increase in strain value of 171% of regular concrete when subjected to a load of 140 kN. The strain value illustrates the elasticity of concrete, where the more significant the strain value in concrete, the more elastic the concrete. It is concluded that concrete with used tire rubber powder is elastic, and regular concrete is plastic. The elasticity of concrete affects the resistance of deformation when damage occurs, so concrete with used tire rubber powder can minimize structural damage because it is more elastic.

Keywords: *Eco-concrete, Job Mix Formula, Used Tire Rubber Powder, Compressive Strength, Modulus of Elasticity*

1. INTRODUCTION

The era of globalization has had a rapid impact on the development of technology and science, the economy, ecosystem change, climate, development, and the environment. These issues encourage state authorities to realize sustainable development to preserve the environment. In PP No. 59 of 2017, the idea of sustainable development strives for world balance; if the world's population increases, it will increase infrastructure and housing development activities. There is a 4% increase (135 EJ) in fossil fuel use due to development and industrial opening, which causes an increase in world CO_2 gas emissions by 5% (10 $GtCO_2$) from 2020 [1]. Innovating environmentally friendly construction materials is indispensable in achieving sustainable development goals.

In 2019, it was reported that 44,162,778 m³ of lime, 240,148,221 m³ of sand, and 122,740,205 m³ of stone were used to make concrete [2]. This exploitation of natural resources causes environmental damage. Concrete is a material often used to construct infrastructure, buildings, and housing with a higher level of durability than other materials. In addition, the community prefers concrete because of its workability,

but in practice, it does not pay attention to the SNI rules for making concrete and its designation. This causes the concrete produced to be easily damaged, and structural failure occurs within a few years after the construction is carried out.

The transportation sector harms the environment, as evidenced by the number of motorized vehicles in Indonesia, which reached 111,571,239 units in 2018 [3]. In 2019, motor vehicle production increased by 2% and continues to grow yearly [4], causing rubber tire waste in the surrounding environment. Waste rubber tires are non-biodegradable and persistent [5]. Reduction of waste rubber tires by burning can cause lung cancer due to dioxin particles in the smoke from combustion. The American Academy of Pediatrics Committee on Environmental Health noted that more liver cancer deaths and hospitalizations occur due to fine particles from burning waste tires [6]. Based on this phenomenon, the idea is to use tire rubber as an added material in eco-concrete manufacturing.

Innovation in using used tire rubber as an alternative material for environmentally friendly concrete because it has stability and a high level of flexibility [7]. They are making eco-concrete innovation products more potent and flexible to minimize damage due to high vibrations (reducing deformation of building structures). The addition of rubber into concrete can significantly contribute to environmental protection by solving the problem of waste tire disposal [8]. In addition, environmentally friendly concrete products can become construction materials to maintain ecological stability and sustainability.

In manufacturing environmentally friendly concrete with used tire rubber additives, it is necessary to innovate the mix design formula to produce substitute concrete with stable quality. This is because the addition of rubber powder significantly results in a decrease in concrete quality. Modification of the optimal and balanced job mix formula produces good quality concrete paste in minimizing damage. The solution in this activity is to get the optimal mixing innovation of used tire rubber substitution for sand.

2. THEORETICAL BASIS

2.1. Eco-friendly Concrete

Concrete constituents consist of materials that do not damage the environment or use aggregate substitutes with materials that do not damage the environment. These are called green concrete (Eco-concrete). Efforts to prevent environmental damage due to the exploitation of natural materials that make up concrete can be made with substitutes or admixtures in the form of waste as an innovation in creating environmentally friendly concrete [9].

2.2. Used Tire Rubber

Scrap tires consist of non-organic materials that do not dissolve in soil or groundwater and have a dense texture with springy properties, high bending, tensile strength, elastic modulus, and good shear modulus [10].

Used tires are synthetic rubber, natural rubber, silica, resin, carbon black, sulfur, and certain oils [7]. These constituent components make used tire rubber have good elasticity and flexural properties, plastic, and not easy to heat [11]. The properties that influence used tire rubber to interact in the concrete manufacturing process are particle size. This means that using tire rubber particle size as a composite additive in concrete depends on its needs and use. In this study, used tire rubber in powder form was used as a fine aggregate admixture.

2.3. Properties of Rubber Concrete

Concrete with rubber powder has good resistance characteristics, such as chloride penetration, corrosion, cold and heat resistance, abrasion resistance, impact and crack strength, and electrical resistivity [8]. The addition of waste tire rubber powder can affect concrete's compressive and flexural strength performance due to the chemical components that make up waste tire rubber [12]. Used tire rubber was selected as an admixture for fine aggregates by considering environmentally friendly materials. It is temporarily assumed that used tire rubber can increase the absorption capacity, making the concrete ideal for use as a construction structure.

2.3. Job Mix Formula

Determining the concrete mix ratio can be done using manual comparisons according to the provisions for making concrete (3 sand, two split stones, one cement) or using a mix design [13]. The increase in mechanical properties of concrete with rubber mixtures can increase if the level of addition is optimal (not excessive) [8].

This research will use the mixing method with the job mix formula through the Excel program. The job mix formula was chosen because this method has the advantage of determining various gradations of fine and coarse aggregates. In addition, the job mix formula is used to control the ratio of the mixture of used tire rubber additives to produce an optimal mixture.

3. METHOD

K-250 concrete design was used with a targeted compressive strength (f'c) of 20 MPa according to SNI 03-2834-2000 on procedures for making regular concrete. The test objects comprised 15 pieces of concrete cylinders with a 15 cm x 30 cm high diameter. The research location is in the Structures and Materials Laboratory of the Civil Engineering Department, Semarang State University.

The fine aggregate used is sand type, for example. Muntilan, coarse aggregate type local crushed stone, cement type 1 PCC brand Dynamix versatile. The concrete ingredients used have passed the laboratory inspection test. Various concrete mixer options are available, such as free and paid samples.

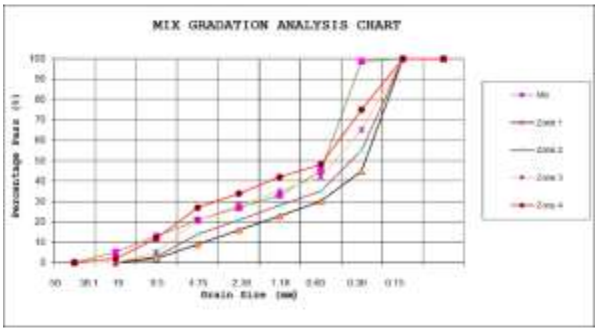

Figure 1 Mix gradation analysis chart

In determining the cement water factor, the trial and error job mix formula and initial compressive strength testing were carried out to prove that the formula used could produce concrete with the specified specifications (K-250). This study used a cement water factor 0.58 with a water content per cubic 210 liters.

The following table presents the mix design plan for manufacturing each of 3 concrete cylinders with variations in the addition of used tire rubber powder 0%, 2.5%, 5%, 7.5%, and 10%. The level of addition of used tire rubber powder refers to the ratio between the content weight of sand and the content weight of rubber powder.

Table 1. Proportion of test piece material requirements

Concrete Making Plan (3 Samples + 12,5% Residues)					
Variations	**Fine aggregate (kg)**	**Rubber (kg)**	**Coarse aggregate (kg)**	**Cement (kg)**	**Water (kg)**
0%	12.968	0.000	19.453	6.475	3.755
2.5%	12.644	0.083	19.453	6.475	3.755
5%	12.320	0.166	19.453	6.475	3.755
7.5%	11.996	0.250	19.453	6.475	3.755
10%	11.672	0.333	19.453	6.475	3.755

The process of mixing the concrete constituent materials using a mixing machine. The slump test was conducted on fresh concrete and manufacturing concrete cylinders with molds.

After making the test specimens, the test specimens were treated by soaking in water for 27 days and stored at room temperature for testing. Testing the compressive strength and modulus of elasticity of concrete is done when the concrete is 28 days old with a CTM (Compression Testing Machine), compressor meter, and dial gauge.

4. RESULTS AND DISCUSSION

4.1. Vicat Test

The addition of used tire rubber powder to the concrete mix does not affect the binding time of the cement directly, nor does it affect the compressive strength results during testing. This is because tire rubber powder is not used as an additive in cement but as a substitute for fine aggregate. The results of the Vicat test on Dynamix red PCC cement show a graph as shown in the following figure:

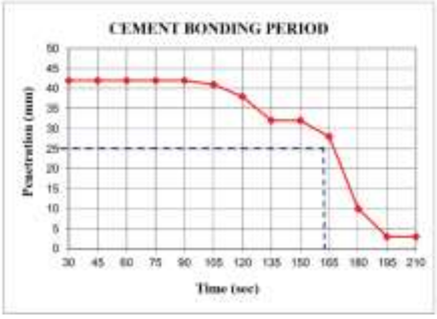

Figure 2 Mix gradation analysis chart

Based on Figure 2, concerning the interpolation theory that uses 25 mm penetration as the initial bonding time, Red Dynamix PCC cement takes 162.5 minutes as the initial bonding time and the final bonding time with 3 mm penetration at 210 minutes (3.5 hours). The research results on cement bonding time using Red Dynamix PCC cement samples (general purpose) show that the material can be used as a binder material in making research samples. From the research data, different types of cement for the same added material are needed to compare the research results of the treatment given.

4.2. Slump Test

When testing in the laboratory, the data obtained from the slump test results in the manufacture of fresh concrete with the added material of used tire rubber powder, as shown below:

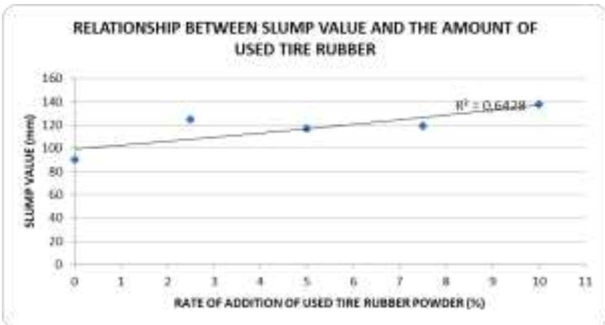

Figure 3 Graph of fresh concrete slump test

Figure 3. Graph of fresh concrete slump test obtained data of fresh concrete with variations in the addition of used tire rubber powder 0%, 2.5%, 5%, 7.5%, and 10% consecutive average slump test values of 90 mm, 125 mm, 117 mm, 119 mm, and 138 mm. The addition of used tire rubber powder to the concrete mixture can influence the slump test results, where the more the rubber powder addition, the lower the concrete slump value will be. This condition is caused by the fact that rubber powder cannot absorb water, while sand has good absorption of water, which can affect the increase in slump value. The slump test results show the most optimal workability of concrete, namely the addition of used tire rubber powder by 10% with a slump value of 138 mm. The slump test value in this study ranged from

90 mm to 138 mm, and the slump test value, according to SNI 03-2834-2000, was 75 mm to 150 mm.

In the research results, irregularities, namely in adding 2.5% of used tire rubber powder, resulted in a slump value of 125 mm. This value is lower than the slump value in the variation of the addition of 5% and 7.5% used tire rubber powder, which has a slump value of 117 mm and 119 mm. This can be caused by the influence of several factors, among others:

a. Sand temperature and room temperature: The hotter the sand/room temperature is, the higher the water absorption is, which can cause an increase in slump value. To overcome the slump value that does not fit the limit, it is necessary to add cement water. SK SNI 03-2834-2000 p. 10, regarding air temperature correction and applies when the sand temperature is high or hot.
b. It is essential to note that the concrete batching plant is not only a concrete batching plant but also a concrete batching plant used to produce concrete. The concrete batching plant, or a concrete mixing plant, is a device that homogeneously combines various ingredients to form concrete. This is a great way to get the most out of your concrete, but it's also a great way to get the most out of your concrete.

The treatment of fresh concrete, namely the addition of cement water to the concrete of each variation, can cause results outside the plan. These results can affect the results of the concrete compressive strength test. The addition of cement water can backfire because the test results cannot be predicted. In the test object, adding cement water can increase the compressive strength or vice versa.

4.3. Compressive Strength

Concrete mixtures with used tire rubber powder additives can reduce the compressive strength of concrete. The more the level of addition of used tire rubber powder, the more the compressive strength value will decrease linearly.

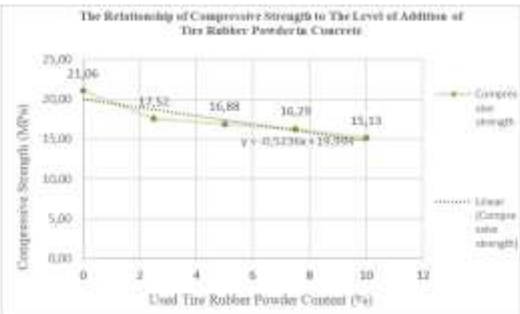

Figure 4 Graph of compressive strength values of 28-day-old concrete

From the data analysis of the concrete compressive strength test results as shown in Figure 4, the average compressive strength value of the three test specimens in each variation of the addition of used tire rubber powder 0%, 2.5%, 5%, 7.5%, and 10% respectively is 21.06 MPa, 17.51 MPa, 16.88 MPa, 16.29 MPa, and 15.13 MPa. The average compressive strength value indicates that the concrete produced is a standard type with a range of concrete compressive strength values of 15 MPa-30 MPa [14].

This study used three samples of 28-day-old specimens for compressive strength testing in each variation to prevent errors in the research results. In Figure 4.7 for each specimen, the distribution of the decrease in compressive strength value is not the same, even though the average compressive strength value decreases linearly. For example, the data shows that the resulting data is too ambiguous or unstable at a 5% addition of used tire rubber powder. This can be influenced by the distribution factor of used tire rubber additives in each different test specimen so that there are test specimens that produce high compressive strength with a significant increase from other test specimens and in test specimens with the same level of rubber powder addition can cause a substantial decrease in compressive strength value as well. This condition can occur because taking fresh concrete in each cylinder mold when making test specimens cannot be ascertained to have the same distribution of added material levels.

The above description concludes that the distribution of added materials in each test specimen affects the decrease in the compressive strength value produced. That is, this situation makes it clear that adding used tire rubber powder can reduce the compressive strength value of concrete.

4.4. Modulus of Elasticity

A comparison of the results of the calculation of elastic modulus using ASTM and SNI formulas is presented in the form of a graph as shown below:

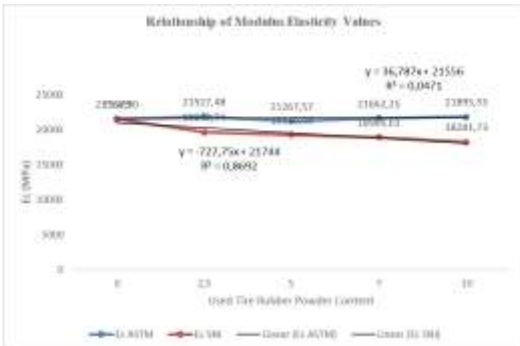

Figure 5 Relationship graph of ASTM and SNI elastic modulus values

From Figure 5. graph of the relationship between the elastic modulus value of concrete with ASTM and SNI references, the average elastic modulus value of each variation is obtained as follows:

a. According to the ASTM equation for the percentage variation of the addition of used tire rubber powder of 0%, 2.5%, 5%, 7.5%, and 10%, respectively, of

21579 MPa, 21927.48 MPa, 21267.57 MPa, 21662.25 MPa, and 21895.55 MPa.

b. For the elastic modulus value of the SNI equation with variations in the addition of used tire rubber powder of 0%, 2.5%, 5%, 7.5%, and 10%, respectively of 21568.9 MPa, 19672.74 MPa, 19310.08 MPa, 18969.61 MPa, and 18281.73 MPa.

The test results found that the best elastic modulus value with the ASTM equation was concrete with a mixture of 2.5% used tire rubber powder of 21927.48 MPa. This shows an increase of 0.15% from standard concrete. According to SNI, the best elastic modulus value is in standard concrete samples of 21568.9 MPa. This result follows the theory that the greater the compressive strength value, the greater the elastic modulus value. For the optimal elastic modulus with the addition of rubber powder, 2.5% is 19672.74 MPa. This result shows a decrease in the regular concrete's elastic modulus of 8.8%.

The conclusion obtained from the two comparisons is that the accuracy of the data according to SNI is higher than according to ASTM.

4.5. The Effect of Adding Used Tire Rubber Powder on Compressive Strength and Modulus Of Elasticity Of Concrete.

Concrete mixtures with used tire rubber powder additives can reduce the compressive strength of concrete. The more the used tire rubber powder is added, the linearly compressive strength value will decrease. This study's optimal compressive strength value is found in standard concrete specimens, 21.06 MPa. In concrete, with the addition of used tire rubber powder, the optimal solution is to add 2.5% rubber powder at 17.52 MPa. These results show a 3.54 MPa decrease in compressive strength of regular concrete.

The elastic modulus can be realized in linear regression in analyzing the stress-strain relationship. The magnitude of the elastic modulus value is proportional to the magnitude of the compressive strength value; the more significant the compressive strength value, the greater the elastic modulus value. The elastic modulus value shows the magnitude of the change in the length of concrete at a particular stress, where the more significant the elastic modulus value in concrete, the smaller the change in the length of concrete.

In theory, the modulus elastics value of SNI calculation results show that the more used tire rubber powder is added, the longer the strain occurs in concrete. This can be seen from the decrease in the modulus of elasticity value at each addition of used tire rubber powder content in concrete. At an average compressive strength of 21.06 MPa, the elastic modulus value is 21568.9 MPa, while at an average compressive strength of 15.13 MPa, the average elastic modulus value is 18281.73 MPa. Both data have shown that regular concrete without adding used tire rubber powder has plastic properties, and concrete with the addition of used tire rubber powder tends to have elastic properties.

To determine whether concrete is elastic or plastic experimentally as a validation of theory. The longer the strain that occurs in concrete when under the same stress, the more elastic the concrete. This can be seen when the concrete receives the same pressure of 140 kN; the more the level of addition of used tire rubber powder, the more strain increases. The strain value increases by 57% - 171% of the strain in standard concrete. This means concrete with additional tire rubber powder is more elastic than regular concrete.

From the two analyses of the above results, it can be concluded that concrete with the addition of used tire rubber powder is elastic, and standard concrete is plastic. The elastic properties of concrete can affect the strain value during fracture. Elastic concrete will experience destruction in a longer time than plastic concrete due to the length of strain caused when receiving pressure that can return to its original position without changing shape. Elastic concrete is expected to help prevent building structures' collapse due to natural disasters such as earthquakes and minimize the cracking of concrete structures.

4.6. Effective Job Mix Formula with The Addition of Used Tire Rubber Powder

Referring to the research results, it can be concluded that the most optimal job mix formula for rubber concrete approaching the K-250 concrete specification is the variation of adding used tire rubber powder of 2.5%. At the time of validation of the test results, concrete with a variation of 2.5% achieved the compressive strength of the K-250 concrete plan and a good elastic modulus value. The average compressive strength value is 17.52 MPa, the average elastic modulus value according to SNI is 19665.37 MPa, and the average modulus value according to ASTM is 21927.48 MPa.

5. CONCLUSION

Concerning the results and discussion of the research, the following conclusions can be drawn:

1. adding used tire rubber powder as eco-concrete affects the compressive strength value; the greater the percentage of the addition of used tire rubber powder, the lower the compressive strength value. The percentage decrease in compressive strength is 28% of the compressive strength of regular concrete.
2. There is an effect of the addition of used tire rubber powder as eco-concrete on the modulus elasticity value of concrete. The modulus elasticity value decreased by 15% in theory and increased by 3% from the experimental results to the modulus elasticity value of standard concrete. Concrete with waste tire rubber powder is elastic, with strain values rising by 57% - 171% of regular concrete.

3. Concrete with a variation of 2.5% addition of used tire rubber powder as eco-concrete is the optimal mix design of K-250 grade concrete. It falls into quality class II as a structural material. Compressive strength results during testing. This is because if the type of cement used has a longer initial and final bond time, it is likely to affect the compressive strength value of the concrete. In this study, type I PCC cement with the brand Dynamix Red was used. With interpolated reference, the initial penetration occurred at minute 162 with a settlement value of 25 mm, and the final bond time was at minute 210 (3.5 hours). These results indicate that the cement is suitable for use because the final bond time is < 8 hours.

6. SUGGESTIONS

From the conclusions and data processing of the research results to follow up on this research, here are some suggestions for the future as an effort to improve and ideas for new research ideas:

1. Research is needed on the addition of rubber powder with the same variation with different types of binders or cement, such as using PPC or PCC cement with other brands, to review the comparison of the results of cement bonding time and slump values produced from different types and brands of cement.
2. In manufacturing fresh concrete mixtures, temperature stability is required, both room and material temperature, mainly sand, so the water absorption or fas plan remains stable. This is necessary so that there is no additional treatment, such as the addition of cement water factor, which can affect the results of concrete compressive strength.
3. In the process of stirring fresh concrete mixtures, accuracy is needed so that the concrete mix is more homogeneous to avoid unstable compressive strength results in each test object.
4. To obtain more accurate elastic modulus results, it is necessary to test the chemical properties of used tire rubber powder, and it is recommended that a type of fibrous tire rubber be used to stabilize the compressive strength. In addition, high accuracy is required in testing the elastic modulus of concrete to read the dial gauge.
5. In making the job mix formula, more attention must be paid to the design regulations according to SNI to obtain accurate and accountable research results. If possible, research can be conducted by comparing the job mix formula according to SNI and a simple mix design with a mixture reference of 1: 2: 3 to determine the difference in the compressive strength value produced. In addition, research can be carried out with more significant variations to obtain differences in compressive strength and modulus of elasticity values with a high difference.

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