E-ISSN: 2528-388X
P-ISSN: 0213-762X

INERSIA
Vol.19, No.1, May 2023

Modification of Used Rubber Tire Mortar with Fly Ash Addition

Restu Faizah[a,*], Putra Andhika Dwi Pratama[a], Prio Arif Wibowo[a], Nugroho Budi Prasetyo[a], Muhammad Harris Darmawan[a], Aryansyah Aditiya Prasetya[a], Retnowati Setioningsih[b]

[a]Department of Civil Engineering, Faculty of Engineering, Universitas Muhammadiyah Yogyakarta, Bantul DIY 55183, Indonesia
[b]Department of Civil Engineering, Faculty of Engineering and Planning, Institut Teknologi Nasional Yogyakarta, Sleman, DIY 55281, Indonesia

Keywords:
Used rubber tire mortar
Fly ash
Mortar compressive strength

ABSTRACT

Used tire rubber mortar has been studied for its physical, mechanical, and dynamic properties. Adding used tire rubbers to the mortar is considered effective in improving the brittle properties of the mortar, as well as increasing the mortar's elasticity and damping ability. However, the higher the tire rubber content, the lower the strength of the mortar. Therefore, the use of tire rubber mortar has some limitations. This study investigates the possibility of fly ash as an admixture in tire rubber mortar to enhance its compressive strength. The compressive strength test follows the provisions of ASTM C-109, with a cube-shaped test object measuring 5x5x5 cm3. The specimen type consists of normal mortar, 30%, and 40% tire rubber mortar. Variations in fly ash content are 0%, 5%, 10%, 15%, 20%, 25%, and 30%, respectively. Compressive strength tests were conducted when the mortar was 14, 28, and 56 days. With five specimens for each variation, 245 specimens were tested. The test results show that adding fly ash can be recommended to increase the compressive strength of tire rubber mortar, with a maximum content of 20% by weight of cement. The tire rubber mortar with fly ash mixture experienced a significant strength in 28 – 56 days due to the escalation of fly ash adhesion between the rubber paste and cement.

1. Introduction

The waste from used tire rubber is so massive in Indonesia that it has accumulated in several places. It is feared that the number will continue to rise and could result in environmental issues if not swiftly addressed. The idea of converting used tire trash into various products, such as flowerpots, fender straps, table chairs, kids' toys, and carpets, has started to be done. However, more needs to be done to counteract the rise in rubber tire waste. It is necessary to make a breakthrough to utilize used tire rubber in various fields. Utilising used tire rubber in different areas becomes a concern of environmental sanitation programs, namely the waste management movement with the 3R principles, reduce, reuse, and recycle [1]. Rubber waste is a particular kind of garbage that is hard to degrade and cannot disintegrate in the soil; therefore, recycling the waste into more valuable products is a better processing strategy. [2].

The prospect of employing used rubber tires has started to be investigated in civil engineering as a mixture of structural materials in powder, such as asphalt, soil, mortar, and concrete [3]–[6]. According to the findings of various earlier research, adding used rubber tire powder to asphalt can enhance its adhesive qualities, increase its resilience to rutting and traffic loads, and lessen its sensitivity to temperature fluctuations. Moreover, adding used rubber tire powder to the asphalt mixture is thought to conserve energy and lower the cost of maintaining asphalt roads [4]. Researchers have examined the advantages of adding used rubber tire powder to soil and concrete in reducing the maximum dry density and ideal moisture content. [7]. Used rubber tire reduces concrete's compressive, flexural, and tensile strengths. In the form of powder, it can boost concrete's resistance to water absorption and carbonation. Although it reduces the material's strength [8], another study demonstrated that adding used tire rubber powder to concrete could improve its ductility and dampening properties. [5], [9].

*Corresponding author.
E-mail: restu.faizah@umy.ac.id

http://dx.doi.org/10.21831/inersia.v19i1.57722
Received January 15th, 2023; Revised May 28th, 2023; Accepted May 28th, 2023
Available online May 31st, 2023

1.1. Used Rubber Tire

Natural rubber, synthetic rubber, different chemicals, carbon black, and sulfur are all used to make a rubber tire. Rubber tires' hardness and tensile strength can be increased by adding more carbon black and sulfur, but the rate at which tire rubber wears out on wet and dry cement tracks can be decreased [10]. The uniqueness of tire rubber is its elasticity and resistance to friction.

Rubber tire waste has been thoroughly investigated for its qualities in civil engineering. It is used as a mixture of concrete, asphalt, and soil in powder as a partial alternative for aggregate [11]. [12] tests the rubber properties of used tires for several brands, including density, tensile strength, hardness, elongation at break, modulus of elasticity, and rigidity, as displayed in Table 1. Based on the findings, compared to other structural materials like cement or sand, used rubber has a relatively low density of only 1.1 gr/cm3. The used tire rubber demonstrates special qualities, such as being elastic and having a nearly 3-fold stretch capacity. Researchers are interested in employing rubber tire waste as an additive component to replace some of the sand in concrete.

Table 1. Properties of used rubber tires [12]

No.	Properties	Specimen codes			
		A	B	C	D
1	Density (gr/cm^3)	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

1.2. Used Rubber Tire Mortar

Adding used rubber tire mortar provides several benefits, such as enhancing the brittleness and ductility of the mortar and making the mortar lighter [13]. In addition, mortar with a mixture of used rubber tire powder also showed a better ability to dampen vibrations [14]. However, the addition to the mortar also has a weakness, which decreases the mechanical strength of the mortar. The decreased mechanical strength of the used rubber tire mortar was due to the weak bond between the used tire rubber and the cement paste [5]. It influences the chemical components of recycled tire rubber, including stearic acid, zinc oxide, extender oils, and carbon black, which are challenging to combine with cement paste [15]. Mortar made from a rubber tire combination is not recommended for structural parts due to its typically low strength. [9].

This phenomenon is deplorable because using used tire rubber as a mixture in mortar can increase the elasticity and damp mortar. Still, due to limitations in compressive strength, its application is minimal. Furthermore, the assumption appears, i.e., if the strength of used rubber tire mortar can be increased, then its effect in increasing ductility and damping and reducing mortar weight can be further utilized. [13].

Several studies have been carried out using rubber tire mortar as a structural material, including for making concrete brick units [3], and mortar joint on masonry walls [16]. Due to the comparatively low strength requirements—at least 3 MPa—used rubber tire mortar is seen to be a viable option for concrete brick and mortar joints in masonry wall systems. In contrast, mortar with a less than 40% composition often has a compressive strength of more than 3 MPa [5], [16]. Using used rubber tire mortar in a mortar joint on a masonry wall is thought to boost the wall's ductility and dampening capabilities, according to the findings of laboratory experiments. Due to the same loading, masonry walls that use mortar joints with a used rubber tire mixture have a lesser drift ratio and deviation than normal walls. Furthermore, walls made of mortar are more resilient to resonance events [17].

1.3. Fly Ash on Mortar

Fly ash is a blackish-gray residual material from coal combustion and forms very soft grains (less than 0.1 mm) and pozzolanic properties. Fly ash has a density of about 2.23 gr/cm3, a moisture content of 4%, a specific gravity between 2.15 – 2.6, and a surface area of 1.2 m2/gr. Coal fly ash provides chemical components, such as silica (SiO2), alumina (AleO3), iron oxide (Fe2O3), calcium (CaO), as well as magnesium, potassium, sodium, titanium and sulfur in small amounts [18].

Currently, fly ash has been widely used as a soil stabilizing factors for highways [19], embankments and retaining walls [20], waste cover material [21], and geopolymer materials [22]. Fly ash can also be used as a substitute for cement in concrete mixes to enhance the compressive strength of concrete.

This study substituted fly ash for some cement to boost mortar's compressive strength. This theory is based on the findings of prior research, which showed that adding fly ash to mortar could boost the mortar's strength. [18], [23]. The addition of fly ash to the mortar has the potential to improve its workability and increase compressive strength. This demonstrates that fly ash offers excellent pozzolanic characteristics. [24]. [18] showed that concrete's optimum fly ash content was 12.5% against cement. At this level, the concrete can have a maximum compressive strength value [18].

Fly ash particles can speed up the cement's hydration process and surface absorption impact, which improves mortar strength. The chemical composition of fly ash contains Al2O3 and SiO2, which are readily soluble and produce a pozzolanic reaction. Fly ash is resistant to sulfate attack and can be utilized as a cement alternative [25]. Several investigations have shown fly ash to contribute to the workability of geopolymer concrete compositions [22].

2. Method

2.1. Setting and Materials

This research was conducted at the Materials and Structures Laboratory, Civil Engineering Study Program, Faculty of Engineering, Universitas Muhammadiyah Yogyakarta (UMY). The materials included sand, cement, water, used tire rubber powder, and fly ash. The sand was from the Progo River with a BJ of 2.54 and a unit weight of 1516 kg/m3. Used tire rubber as shavings/powder, was taken from a collector in the Cilacap area, with a BJ of 1.16, and a unit weight of 235.7 kg/m3 (Figure 1). The fly ash was in F type from Tanjung Jati B Ltd, Jepara (Figure 2) with the chemical content shown in Table 2.

Figure 1. Used rubber tire powder from Cilacap

Figure 2. *Fly ash* of Tanjung Jati B Ltd, Jepara.

Table 2. Chemical content of fly ash (Tanjung Jati B Ltd, Jepara)

No.	Parameter Test	results (%)
1	SiO_2	53,12
2	Al_2O_3	30,29
3	Fe_2O_3	0,05
4	CaO	4,32
5	MgO	0,26
6	SO_3	1,95
7	Na_2O	0,32
8	K_2O	0,08
9	*Loss of Ignition* (LOI)	1,79

2.2 Object test and curing

The tests carried out in this study were a mortar compressive strength test, referring to ASTM C-109 [26]. The test object was a cube mortar with a size of 5x5x5 cm3, totaling 245 pieces. Five samples were used for each variation, as shown in Table 3. The cube mortar test object was a mixture of water, cement, sand, used tire rubber, and fly ash, with a water-cement factor (fas) of 0.9 and a cement ratio of: sand is 1:4.

In this study, three variations of used tire rubber content were taken, namely 0%, 30%, and 40% to the volume of sand, to compare the effect of adding fly ash to used rubber tire mortar with different used rubber tire levels. In addition, seven variations of fly ash content were taken, namely 0%, 5%, 10%, 15%, 20%, 25%, and 30%, respectively, by weight of cement. With several variations of these fly ash levels, it is expected to obtain a trend of increasing or decreasing the compressive strength of mortar due to several different levels of fly ash.

In addition to variations in used rubber tire and fly ash content, the compressive strength of the mortar was also observed at several test periods, 14, 28, and 56 days. With several variations taken in this study, it is hoped that the pattern of increasing the compressive strength of mortar with fly ash mixture at several ages can be predicted.

The mortar mix design uses the absolute volume method, assuming no air voids are in the mixture. Based on the properties of the mortar constituent materials, the amount of material needed to make 1 m3 of the mixture can be calculated, as shown in Table 4 to Table 6.

The stage of making the test object includes weighing the materials according to the results of the mix design, followed by mixing/stirring, printing, and curing; after rearranging all the ingredients, then printed using a 5x5x5 cm3 cube mold. After 24 hours, the specimen is released from the mold, and curing is continued by immersing the specimen in a bath filled with water (Figure 3). The curing time varies according to the age of the test, 14, 28, and 56 days, respectively.

Table 3. Number and variation of tested objects

Content of fly ash (%)	Used Rubber Tire (%)			Testing period
	0	30	40	
0	5	5		14 days
5	5	5		
10	5	5		
15	5	5		
20	5	5		
25	5	5		
30	5	5		
0	5	5	5	28 days
5	5	5	5	
10	5	5	5	
15	5	5	5	
20	5	5	5	
25	5	5	5	
30	5	5	5	
0	5	5		56 days
5	5	5		
10	5	5		
15	5	5		
20	5	5		
25	5	5		
30	5	5		

Table 4. Mix design 1 m^3 mortar without (0%) rubber used tire powder (in kg)

Materials	Content of fly ash (%)						
	0	5	10	15	20	25	30
Fly ash	0	19	39	58	77	97	116
Cement	386	367	348	328	309	290	270
Water	386	386	386	386	386	386	386
Sand	1247	1247	1247	1247	1247	1247	1247
Used tire rubber powder	0	0	0	0	0	0	0
Numbers	2020	2020	2020	2020	2020	2020	2020

Table 5. Mix design 1 m^3 mortar with 30% rubber used tire powder (in kg)

Materials	Content of fly ash (%)						
	0	5	10	15	20	25	30
Fly ash	0	19	39	58	77	97	116
Cement	386	367	348	328	309	290	271
Water	386	386	386	386	386	386	386
Sand	873	873	873	873	873	873	873
Used tire rubber powder	171	171	171	171	171	171	171
Number	1816	1816	1816	1816	1816	1816	1816

Table 6. Mix design 1 m^3 mortar with 40% rubber used tire powder (in kg)

Materials	Content of fly ash (%)						
	0	5	10	15	20	25	30
Fly ash	0	20	40	60	80	100	121
Cement	402	382	362	362	362	301	281
Water	362	362	362	362	362	362	362
Sand	778	778	778	778	778	778	778
Used tire rubber powder	237	237	237	237	237	237	237
Number	1779	1779	1779	1779	1779	1779	1779

Figure 3. Curing cube test object of 5x5x5 cm^3

Figure 4. Universal Testing Machine (UTM) the Materials and Structures Laboratory, Civil Engineering Study Program UMY

2.3. Compressive Strength Test

Mortar compressive strength tests were conducted at the Materials and Structural Laboratory of the Civil Engineering Study Program, UMY for 14, 28, and 56 days. The compressive strength test follows the procedures for SNI 03-6825-2002 [27] using *Universal Testing Machine* (UTM) (Figure 4).

Before the compression test, the test object is weighed, and its dimensions are measured. From this weight and volume data, the density of the test object will be obtained using the formula in Equation 1.

$$Density = \frac{weight}{volume} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

When the mortar has reached the required age, it is placed on the testing apparatus, compressed until it breaks, and the compressive strength value is assessed. The results of this test will be shown graphically as a relationship between load and displacement or stress and strain (Figure 5). The mortar's compressive strength and elastic modulus can be calculated from the relationship graph between strength - strain, load - displacement.

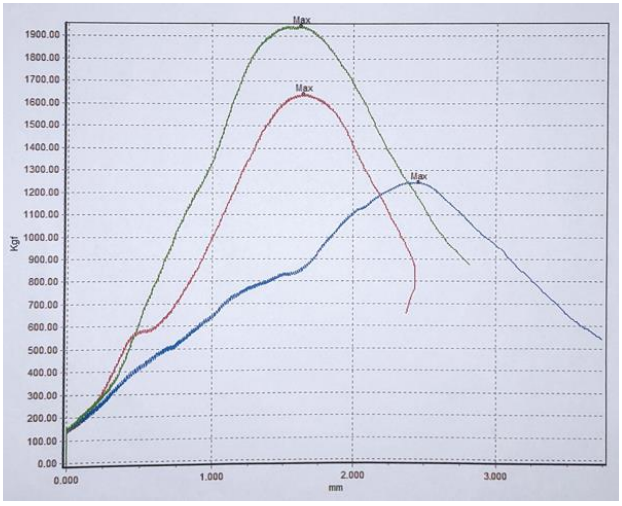

Figure 5. Graph of relationship between load – displacement (output from UTM)

The compressive strength of cubic mortar is expressed as the ratio between the maximum load (P max) and the compressive cross-sectional area (A), as illustrated in Figure 6, with the formula in Equation 2 [27]. The unit for compressive strength is N/mm2 or MPa. The modulus of elasticity can be determined from the slope of the stress-strain or load-displacement curve when elastic.

$$\text{compressive strength} = \frac{P\ maks}{A} \quad (2)$$

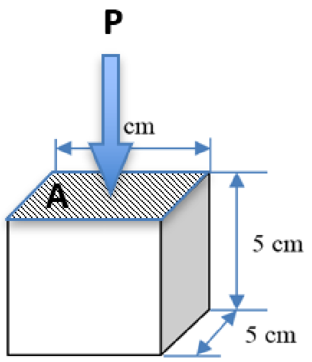

Figure 6. Illustration of compressive strength test of cube mortar

3. Results and Discussion

After the compressive tests were carried out on all the test objects, the compressive strength values of the mortar were obtained from 245 pieces. In this test, five compressive strength values were obtained for each variation, shortening was carried out, and three median values were taken. Furthermore, the compressive strength value of each variation is determined by the average of the three intermediate values. Figure 7 shows an object of the specimen after the pressure test was completed using the Universal Testing Machine (UTM).

To simplify the analysis, the results of the compressive strength test of all specimens were grouped into three, namely (i) the compressive strength of the mortar without used rubber tire with variations in the test period, (ii) the compressive strength of the 30% used rubber tire mortar with the variation in the age of the test, and (iii) compressive strength of used rubber tire powder mortar 0%, 30%, and 40%, respectively, at 28 days. The compressive strength test results for the three groups are presented in Figures 8 to 10.

Figure 7. The test object after being compressed with UTM

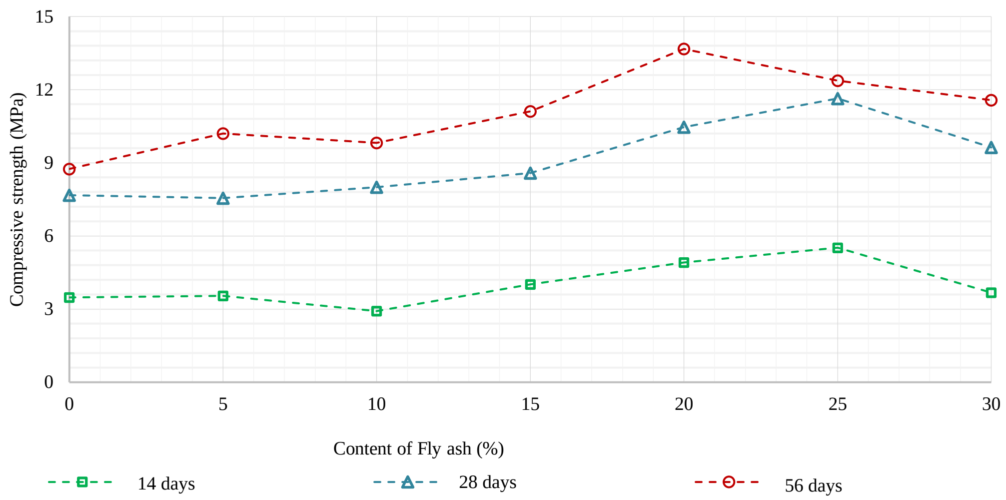

Figure 8. Compressive strength mortar without rubber used tire powder (0%) in 14, 28, and 56 days

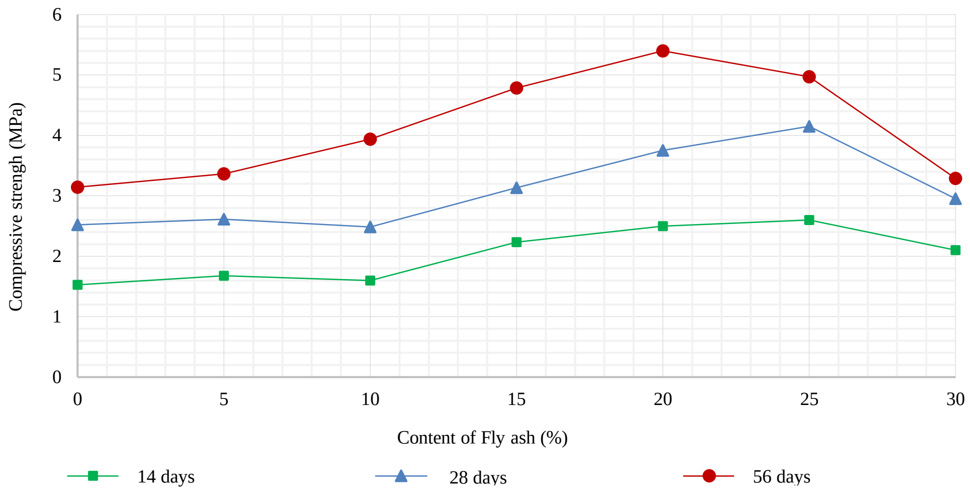

Figure 9. Compressive strength mortar with 30% rubber used tire powder (0%) in 14, 28, and 56 days

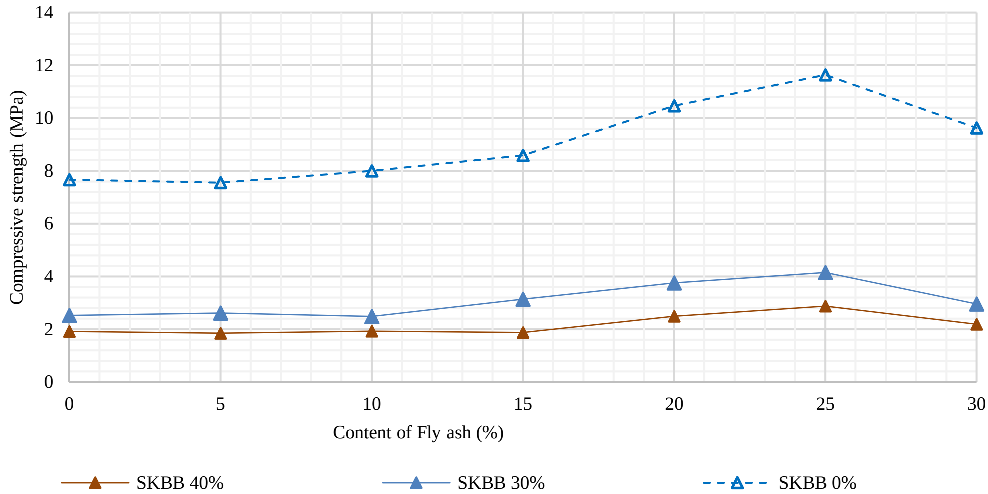

Figure 10. Compressive strength mortar with 0%, 30%, and 40% in 28days

From the test results, it can be concluded that the higher the fly ash content, the bigger the compressive strength of the mortar. This is under the initial prediction; namely fly ash can increase the compressive strength of mortar. Figure 8 shows that adding fly ash tends to increase the compressive strength of used rubber tire mortar at all periods. The increase in maximum compressive strength from the results of the mortar compression test was 55%, 52%, and 59%, respectively, at the test ages of 14, 28, and 56 days. The compressive strength of the mortar within 14 and 28 days decreases at a fly ash content of more than 20%.

Meanwhile, at 56 days, it decreased to more than 25% fly ash content. It is estimated that the optimum fly ash content is at 20%, replacing the weight of cement. In other words, the use of fly ash in mortar should not exceed 20% to replace the significance of cement.

Similar results also occurred in the mortar with a 30% mixture (Figure 9). The increase and decrease in compressive strength pattern due to fly ash in normal mortar and 30% mixture of mortar look almost the same. Still, the maximum compressive strength of 30% mortar is only about 40% of the compressive strength of normal mortar. From this phenomenon, adding fly ash can increase the compressive strength of normal mortar and combined mortar with a similar pattern. In other words, the role of fly ash in increasing the compressive strength of mortar is not disturbed by the presence in the mixture. Thus, the addition of fly ash to increase the compressive strength of the mortar is quite effective. However, paying attention to the recommended fly ash levels is also necessary. From the results of this study, the fly ash content should not be more than 20% to replace the weight of cement.

Compared to the results in Figure 8 and Figure 9, the reality is that the strength of used rubber tire mortar is much lower than normal mortar. The higher the used rubber tire powder level, the smaller the strength will be gained. These results agree with previous studies, which said that the powder addition to the mortar can reduce the strength of the mortar, due to the nature of rubber which has a weak bond with cement paste [5], [13], [28], [29]. The increase in mortar compressive strength due to the addition of fly ash in 30% mortar looks higher than the escalation in normal mortar. In 30% used rubber tire powder level of Mortar (Figure 9), the maximum increase in the compressive strength of the mortar at the age of 14, 28, and 56 days was 70%, 65%, and 72%, respectively, while in normal mortar it was 59%, 52%, and 56%. From these results it can be predicted that the presence of fly ash can increase the bond between the rubber and the cement for the compressive strength of the mortar.

The period is also very influential on the strength of the mortar. In a normal mortar, the increase in compressive strength between ages 28 to 56 was insignificant (Figure 8). In 30% used rubber tire powder level in mortar, it was seen to be more significant (Figure 9). It indicates that fly ash's role in enhancing the compressive strength is more optimal in a mortar with used rubber tire powder mixture than normal mortar. In other words, the mortar is more sensitive to the effects of fly ash than normal mortar. Based on the obtained results, it is predicted that the bond between fly ash and rubber will be better at a period of more than 28 days. This was evidenced by an increasingly significant increase in compressive strength over 28 days.

In addition, from Figure 10, it can also be seen that the increase in the compressive strength of the mortar at 28 days of age has a similar pattern between normal mortar, 30%, and 40% mortar. The difference lies in the compressive strength of the mortar, which indicates that the addition resulted in a sharp decrease in the mortar's compressive strength. The results of this analysis can strengthen the previous statement, which states that adding fly ash to the used rubber tire powder mortar is recommended because it can increase the compressive strength of the mortar and has a fairly stable pattern. The addition of fly ash to several types of mixture mortars that use different phases and cement can be further investigated, such as sand ratios, different levels of used rubber tire powder, and fly ash content.

Based on density observations, mortar with used rubber tire powder mixture offers a lower density, as shown in Figure 11. The density of 30% and 40% used rubber tire powder mortar, respectively, is 86% and 80% compared to the thickness of normal mortar. From Figure 11, it can also be seen that the addition of age does not result in a significant change in mortar density. Likewise, adding fly ash levels did not significantly affect changes in mortar density.

In this study, 30% and 40% used rubber tire powder mortar with a density of less than 1.8 gr/cm3, classified as a lightweight material [30]. It is crucial for building construction because lightweight materials can lower the structure's weight, affecting the building's modest base shear force to face an earthquake.

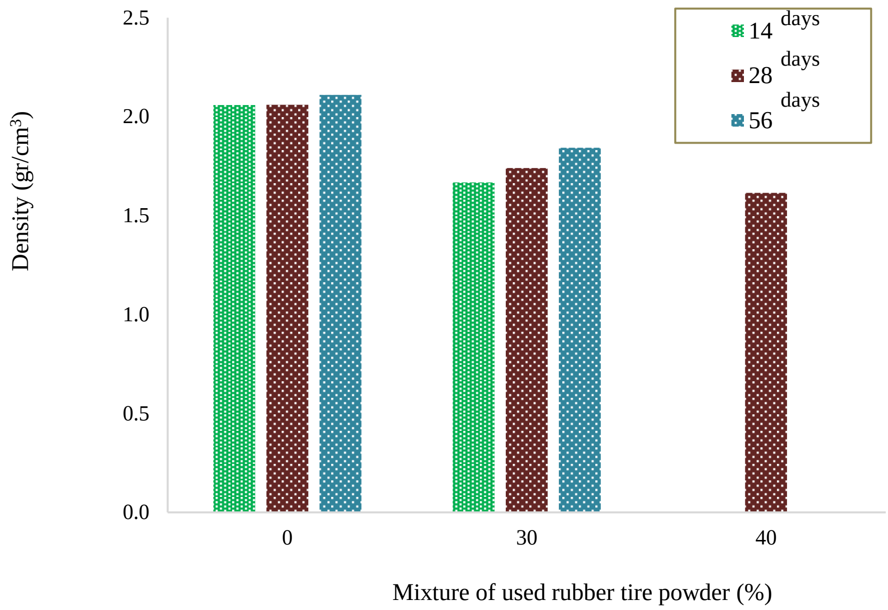

Figure 11. Densities of standard mortar dan mixture of used rubber tire powder mortar

4. Conclusions

Based on the test results, several conclusions can be drawn as follows:

1. The addition of fly ash to the used rubber tire powder mortar can increase the compressive strength of the mortar by 52 – 59% of the compressive strength of the mortar without fly ash.
2. The recommended fly ash content is less than 20% replacing the weight of cement.
3. The mixture of used rubber tire powder in mortar with fly ash between 28 – 56 days experienced a significant increase in strength.
4. The density of mortar with 30% and 40% used rubber tire powder is classified as light material

Acknowledgment

The author would like to thank Universitas Muhammadiyah Yogyakarta for funding this research through the Institute of Research and Innovation.

References

[1] P. RI, *PP No. 27 Tahun 2020 tentang Pengelolaan Sampah Spesifik*, no. PP No.7 th.2020. 2020.

[2] M. L. Rochman and M. Setiyo, “Mini Review: Potensi Limbah Ban Menjadi Bahan dan Produk yang Berguna,” *Jurnal Teknik Mesin Institut Teknologi Padang*, vol. 9, no. 1, p. 7, 2019.

[3] D. M. Sadek and M. M. El-Attar, "Structural behavior of rubberized masonry walls," *Journal of Cleaner Production*, vol. 89, pp. 174–186, Feb. 2015, doi: 10.1016/j.jclepro.2014.10.098.

[4] S. A. Alfayez, A. R. Suleiman, and M. L. Nehdi, "Recycling Tire Rubber in Asphalt Pavements: State of the Art," *Sustainability*, vol. 12, no. 21, p. 9076, Oct. 2020, doi: 10.3390/su12219076.

[5] R. Faizah, H. Priyosulistyo, and A. Aminullah, “Sifat Fisik dan Mekanik Mortar dengan Campuran Serutan Karet Ban Bekas Berbagai Merk,” *Jurnal Teknik Sipil*, vol. 27, no. 2, pp. 117-126–126, Aug. 2020, doi: 10.5614/jts.2020.27.2.2.

[6] B. Ajmera, B. Tiwari, and J. Koirala, "Geotechnical Properties of Clays Modified with Recycled Crumb Rubber," in *Geotechnical and Structural Engineering Congress 2016*, Phoenix, Arizona, Feb. 2016, pp. 1404–1413. doi: 10.1061/9780784479742.117.

[7] L. N. Snodi and I. S. Hussein, "Tire Rubber Waste for Improving Gypseous Soil," *Materials Science and Engineering*, p. 7, 2019.

[8] B. S. Thomas and R. C. Gupta, "A comprehensive review on the applications of waste tire rubber in cement concrete," *Renewable and Sustainable Energy Reviews*, vol. 54, pp. 1323–1333, Feb. 2016, doi: 10.1016/j.rser.2015.10.092.

[9] A. A. Aliabdo, A. E. M. Abd Elmoaty, and M. M. AbdElbaset, "Utilization of waste rubber in non-structural applications," *Construction and Building Materials*, vol. 91, pp. 195–207, Aug. 2015, doi: 10.1016/j.conbuildmat.2015.05.080.

[10] M. A. Hendrawan and P. I. Purboputro, “Studi Karakteristik Sifat Mekanik Kompon Karet dengan Variasi Komposisi Sulfur dan Carbon Black sebagai Bahan Dasar Ban Luar,” in *Simposium Nasional Teknologi Terapan (SNTT) 3*, 2015, p. 8.

[11] S. Yang, R. A. Lohnes, and B. H. Kjartanson, "Mechanical Properties of Shredded Tires," *Geotechnical Testing Journal, GTJODJ*, vol. 25, no. 1, pp. 44–52, Mar. 2002.

[12] R. Faizah, H. Priyosulistyo, and A. Aminullah, "The Properties of Waste Rubber Tires in Increasing the Damping of Masonry Wall Structure," in *IOP Conference Series: Materials Science and Engineering*, Universitas Tarumanegara Jakarta, Oct. 2019, vol. 650, p. 012041. doi: 10.1088/1757-899X/650/1/012041.

[13] R. Faizah, H. Priyosulistyo, and A. Aminullah, "An Investigation on Mechanical Properties and Damping Behaviour of Hardened Mortar with Rubber Tire Crumbs (RTC)," *MATEC Web Conf.*, vol. 258, p. 05002, 2019, doi: 10.1051/matecconf/201925805002.

[14] B. Liu, S. Yang, W. Li, and M. Zhang, "Damping dissipation properties of rubberized concrete and its application in anti-collision of bridge piers," *Construction and Building Materials*, vol. 236, p. 117286, Mar. 2020, doi: 10.1016/j.conbuildmat.2019.117286.

[15] M. Bekhiti, H. Trouzine, and A. Asroun, "Properties of Waste Tire Rubber Powder," vol. 4, no. 4, p. 4, 2014.

[16] R. Faizah, “Perilaku Dinamik Dinding Pasangan Bata In-plane Menggunakan Spesi Mortar Serutan Karet Ban Bekas,” Dissertation, Universitas Gadjah Mada, Yogyakarta, Indonesia, 2021.

[17] R. Faizah, “Perilaku Dinamik Dinding Pasangan Bata In-plane Menggunakan Spesi Mortar Serutan Karet Ban Bekas,” Dissertation, Universitas Gadjah Mada, Yogyakarta, Indonesia, 2021.

[18] M. Setiawati, “Fly Ash Sebagai Bahan Pengganti Semen Pada Beton,” in *Seminar Nasional Sains dan Teknologi 2018*, Jakarta, 2018, p. 8. [Online]. Available: jurnal.umj.ac.id/index.php/semnastek

[19] T. Takada *et al.*, "Utilization of coal ash from fluidized-bed combustion boilers as road base material," *Resources, Conservation and Recycling*, vol. 14, no. 2, pp. 69–77, Aug. 1995, doi: 10.1016/S0921-3449(95)80001-8.

[20] S. Wang and H. Wu, "Environmental-benign utilisation of fly ash as low-cost adsorbents," *Journal of Hazardous Materials*, vol. 136, no. 3, pp. 482–501, Aug. 2006, doi: 10.1016/j.jhazmat.2006.01.067.

[21] E. Cokca and Z. Yilmaz, "Use of rubber and bentonite added fly ash as a liner material," *Waste Management*, vol. 24, no. 2, pp. 153–164, Jan. 2004, doi: 10.1016/j.wasman.2003.10.004.

[22] P. Chindaprasirt, T. Chareerat, and V. Sirivivatnanon, "Workability and strength of coarse high calcium fly ash geopolymer," *Cement and Concrete Composites*, vol. 29, no. 3, pp. 224–229, Mar. 2007, doi: 10.1016/j.cemconcomp.2006.11.002.

[23] A. Yilmaz and N. Degirmenci, "Possibility of using waste tire rubber and fly ash with Portland cement as construction materials," *Waste Management*, vol. 29, no. 5, pp. 1541–1546, May 2009, doi: 10.1016/j.wasman.2008.11.002.

[24] R. Yanita and A. Sagab, "Pemanfaatan Bahan Limbah untuk Campuran Bahan Plesteran," vol. 1, p. 10.

[25] T. Qi, G. Feng, Y. Zhang, J. Guo, and Y. Guo, "Effects of Fly Ash Content on Properties of Cement Paste Backfilling," *JRST*, vol. 12, no. 3, pp. 133–141, 2015, doi: 10.12783/issn.1544-8053/12/3/3.

[26] ASTM, *Standard Test Method for Compressive Strength of Hydraulic Cement Mortars (Using 2-in or (50-mm) Cube Specimens)*. 2007, p. 9.

[27] BSN, *Metode Pengujian Kekuatan Tekan Mortar Semen Portland untuk Pekerjaan Sipil*. 2002.

[28] M. A. Mutar, T. S. Hussein, and S. H. Malik, "Effect of Crumb Rubber Aggregates on the Characteristics of Cement Concrete as Partial Replacement," *International Journal of Mechanical and Production Engineering Research and Development (IJMPERD)*, vol. 8, no. 1, p. 11, 2018.

[29] O. Youssf, M. A. ElGawady, J. E. Mills, and X. Ma, "PREDICTION OF CRUMB RUBBER CONCRETE STRENGTH," p. 7, 2014.

[30] BSN, *Tata cara Rencana Pembuatan campuran Beton Ringan dengan Agregat Ringan*, vol. SNI 03-3449-2002.