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Compressive Strength and Tensile Bond Strength of Rubber Tire Crumb Mortar Mixed with Fly Ash

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ABSTRACT

Currently, rubber tire crumbs have been utilized as an additive in the civil engineering field. The addition of rubber tire crumbs to the mortar can result in a decrease in the compressive strength of the mortar so its use is very limited due to its low compressive strength. One of the suggested applications is the use of RTC mortar as a mortar joint in masonry walls, but its effect on the bond strength of the mortar with the brick has not been studied. In the research, apart from the effect of compressive strength, the effect of using fly ash on the tensile bond strength between mortar and clay bricks was also observed. The tests were carried out in the laboratory following the ASTM C 109M-07 standards for compressive strength tests, and ASTM C 952-02 for tensile bond strength. The specimens were in the form of 50x50x50 mm^3 cube-mortar and cross-bricks totalling 48 each. Besides that, the influence of the age of testing was also observed, namely at the age of 14, 28, and 56 days. The test results show that the addition of fly ash can increase the compressive strength of rubber tire mortar, but decrease the tensile bond strength between mortar and clay bricks.

1. Introduction

Used rubber from car tires has been widely used as a mixture in civil engineering construction, such as in soil mixtures, flexible pavement layers, mortars, and concrete. Alfayez *et al.,* [1] state that the addition of used rubber tire crumbs (RTC) to the asphalt mixture can reduce the permanent deformation of flexible pavement and increase its resistance to rutting. Therefore, flexible pavement construction becomes more durable and has lower maintenance costs. The addition of RTC to the soil mixture also provides several benefits, including increasing the compaction properties and strength of weak soils [2- 4], improving the properties of gypseous soils [5], and increasing the bearing capacity of clay soils [2]. The addition of RTC to mortar or concrete also provides many benefits, such as increasing ductility and damping, as well as making the mortar/concrete lighter. However,

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weaknesses were also found, where the addition of RTC to the mortar mixture resulted in a decrease in the mechanical properties of the mortar, such as compressive strength, tensile strength, and flexural strength [6–8]. As a result of this decrease in strength, rubber tire mortar is not recommended for use as a structural material that must withstand large axial forces [9]. Some suggestions for using mortar with RTC include wall plaster [10], paving block [11], and mortar joints on masonry wall [12,13].

The next challenge is how to increase the compressive strength of the RTC mortar so that it has better performance. Meanwhile, several studies have stated that the addition of fly ash (FA) as a partial replacement for cement can increase the compressive strength of concrete. Setiawati [14] found that the compressive strength of concrete with a FA content of 12.5% replacing cement could increase by 60% compared to the compressive strength of normal concrete at 28 days of age. In another study, Zhang *et al.,* [15] used FA as a substitute for sand in mortar mixtures. From the compressive strength test, it is known that using 80% FA can obtain a maximum mortar compressive strength of 62.93 MPa or 23.56% higher than the compressive strength of ordinary mortar.

The results of these studies show the role of FA in increasing the compressive strength of mortar. Therefore, an idea emerged to add FA to the RTC mortar to increase its compressive strength. Yilmaz and Degirmenci [16] has conducted research to evaluate the possibility of using FA and RTC together as cement-based composite materials. The results showed that the compressive strength decreased with increasing RTC content but increased with increasing FA content for all curing periods. Faizah *et al.,* [17] have also conducted a study to investigate the possibility of using FA to increase the compressive strength of RTC mortar. The results of this study recommend the use of FA to increase the compressive strength of RTC mortar. The maximum content of FA is recommended to be 20% by weight of cement. The increase in the compressive strength of RTC mortar with FA mixture was significant when the mortar was aged between 28 – 56 days. Previous research only examined the effect of adding FA to RTC mortar on compressive strength, but not on bond strength. The bond strength characteristic between mortar to the brick is very important to study because RTC mortar is also recommended for use as a mortar joint in masonry walls. A significant weakness in brickwork is its weak bond and low bond strength. Many connected components relating to mortar and masonry units have an impact on this connection [18].

This research is a continuation of previous research which aims to determine the role of FA in rubber tire mortar mixtures, not only in compressive strength but also in the tensile bond strength produced by RTC mortar added with FA. The purpose of this study was to determine the possibility of using mortar with a mixture of RTC and FA together, especially for the application of mortar joints in masonry walls. This research is very necessary, because in previous research it was known that the addition of FA can increase the compressive strength of RTC mortar, but it has not been studied how it affects the bond strength of the mortar with the brick.

2. Methodology

This study conducted laboratory tests which included a mortar compressive strength test and a tensile bond strength test between the mortar and the clay bricks. The experiment was carried out at the Laboratory of Materials and Structures of Civil Engineering study program, Universitas Muhammadiyah Yogyakarta, Indonesia. The compressive strength test of mortar refers to ASTM C 109M-07 [19], while the tensile bond strength test follows ASTM C 952-02 [20].

2.1 Materials and Specimens

Materials used in this study included water, cement, sand, used rubber tire crumbs (RTC), fly ash (FA), and clay bricks. Sand is taken from the Progo River, which has a specific gravity of 2.54 and a unit weight of 1317.3 kg/m^3. Figure 1 shows the gradation curve of fine aggregate (sand). The RTC are made from used car tires that are taken from collectors in Central Java Indonesia, then shaved into granules that are shaped like fiber, and filtered using sieve no. 4 with an aperture of 4.75 mm. RTC has a specific gravity of 1.16 and a unit weight of 235.7 kg/m^3. The FA used is the residue from burning coal at PT. Tanjung Jati B Ltd in Jepara, Central Java. The FA is classified as type F with a specific gravity of 2.16, and has a chemical content as shown in Table 1. RTC and FA used in this study are shown in Figure 2. The bricks used are AT clay bricks from Magelang Regency, Central Java, with dimensions of about 220 mm in length, 110 mm in width, and 40 mm in height. The AT clay brick has a compressive strength of 1.42 MPa which was obtained from testing following the procedures for SNI 15-2094-2000 [21].

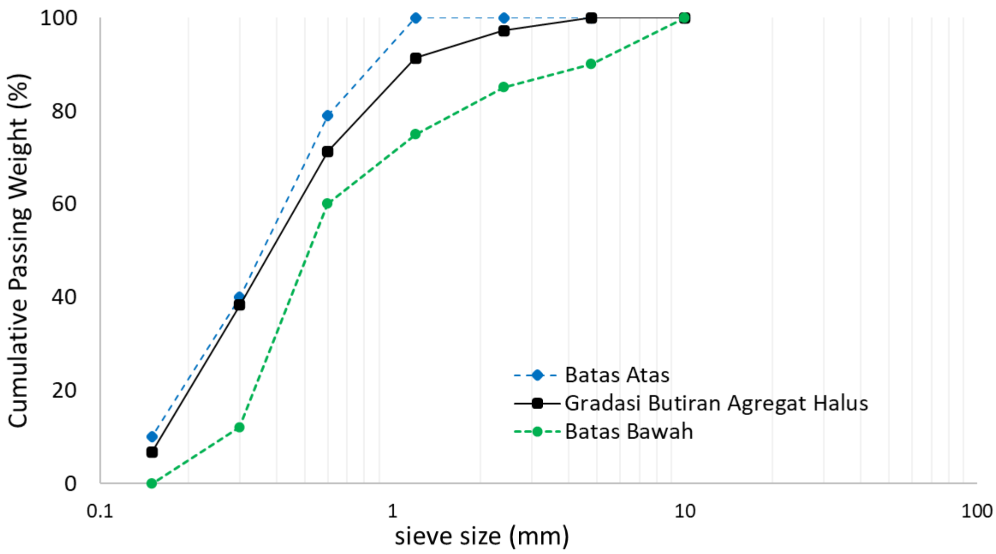
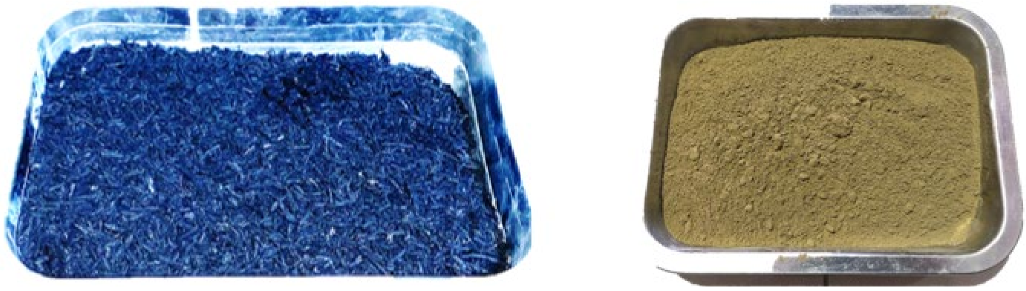


Fig. 1. Gradation curve of fine aggregate

Table 1
Chemical content of FA from PT. Tanjung Jati B Ltd

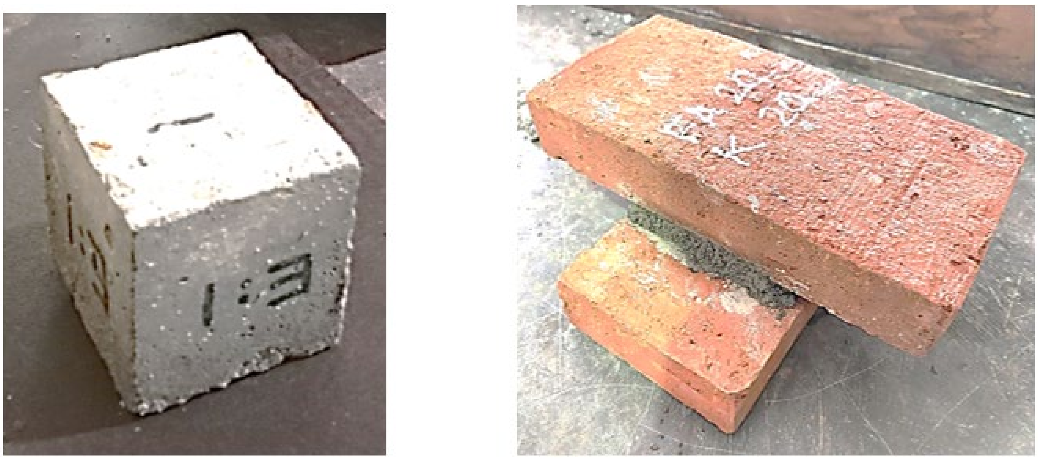
No.	Test Parameters	Result (%)
1	SiO_2	53,12
2	Al_2O_3	30,29
3	Fe_2O_3	0,05
4	CaO	4,32
5	MgO	0,26
6	SO_3	1,95
7	Na_2O	0,32
8	K_2O	0,08
9	*Loss of Ignition* (LOI)	1,79



(a) (b)

Fig. 2. RTC and FA used in this research (a) Used rubber tire crumbs (RTC) (b) Fly ash (FA)

The mortar compressive strength test used a cube-mortar specimen with a side length of 50 mm, while the tensile bond strength test used cross-brick specimen (Figure 3). A mortar joint between 2 clay bricks in a cross position has a thickness of between 15 – 20 mm. This mortar has the same variations with the cube-mortar specimens, which are influenced by the content of RTC and FA, as well as the age of the test. There are 16 variations, with the number of specimens being 3 per variation, so the total number of cube-mortar and cross-brick specimens respectively is 48. In general, specimens are divided into 3 groups (Group A, B, and C), with details shown in Table 2.



(a) (b)

Fig. 3. The specimens in the compressive strength and tensile bond strength tests (a) cube-mortar specimen (b) cross-brick specimen

Table 2
Variation and distribution specimens.

Specimens Group	No.	Specimens Code	RTC content	FA content	Test age (days)	Total
A	1	T0-F0	0%	0%	28	3
	2	T5-F0	5%			3
	3	T10-F0	10%			3
	4	T15-F0	15%			3
	5	T20-F0	20%			3
B	6	T20-F0	20%	0%	56	3
	7	T20-F5		5%		3
	8	T20-F10		10%		3
	9	T20-F15		15%		3
	10	T20-F20		20%		3
C	11	T20-F0-14	20%	0%	14	3
	12	T20-F0-28		0%	28	3
	13	T20-F0-56		0%	56	3
	14	T20-F20-14		20%	14	3
	15	T20-F20-28		20%	28	3
	16	T20-F20-56		20%	56	3
					Total	48

Group A specimens were used to determine the effect of adding RTC to mortar (without FA) on its compressive strength and tensile bond strength. Meanwhile, group B was used to see the effect of adding FA to RTC mortar (20% RTC content) on its compressive strength and tensile bond strength. Group A specimen testing was carried out at 28 days of age, while group B was at 56 days of age because the influence of FA was more significant at 56 days of age [17]. And then, to see the effect of age on the compressive strength and tensile bond strength between the mortar (with RTC and FA) and the clay bricks, group C specimens were prepared which were tested at the ages of 14, 28 and 56 days.

The mix design of mortar refers to the principle of absolute volume, which assumes that in a liquid state, there are no voids in the mixture [22]. The mix design results obtained the material requirements for making 1 m^3 of mortar as described in Table 3.

Table 3
Mix design for 1 m^3 mortar

	Content of		Weight of materials (kg)				
No.	RTC	FA	Cement	Water	Sand	RTC	FA
1	0%	0%	534.8	320.9	1292.7	0	0
2	5%	0%	534.8	320.9	1228.1	29.5	0
3	10%	0%	534.8	320.9	1163.5	59.1	0
4	15%	0%	534.8	320.9	1098.8	88.6	0
5	20%	0%	534.8	320.9	1034.2	118.2	0
6	20%	5%	508.1	320.9	1034.2	118.2	26.7
7	20%	10%	481.3	320.9	1034.2	118.2	53.5
8	20%	15%	454.6	320.9	1034.2	118.2	80.2
9	20%	20%	427.8	320.9	1034.2	118.2	107.0

2.2 Experimental Testing

After 24 hours from molding, the specimen is cured until just before testing, at the age of 14, 28, or 56 days. The curing process of cube mortar specimens uses the method of immersion in water, while cross brick specimens are covered with wet material which is kept moist. Curing is carried out in a room protected from sunlight, at a room temperature of around 25^o C.

Mortar compressive strength test with cube-mortar specimens using a Universal Testing Machine (UTM) with the position before the test shown in Figure 4. After the specimen is in the right position touching the upper and lower plates, the load is applied at a speed of 900 - 1500 N/s. The compressive strength of the cube-mortar (f'c in MPa) is calculated using the formula in Eq. (1), where F is the maximum force that can be resisted by the mortar (in N), and A is the compressive surface area (in mm^2), as illustrated in Figure 5. F and A values will be obtained from the UTM output after testing. UTM can also generate a relationship between P and A during testing which can be processed into a strength-stress relationship.

Fig. 4. The compressive strength test using UTM

$$f'c = \frac{F}{A} \quad (1)$$

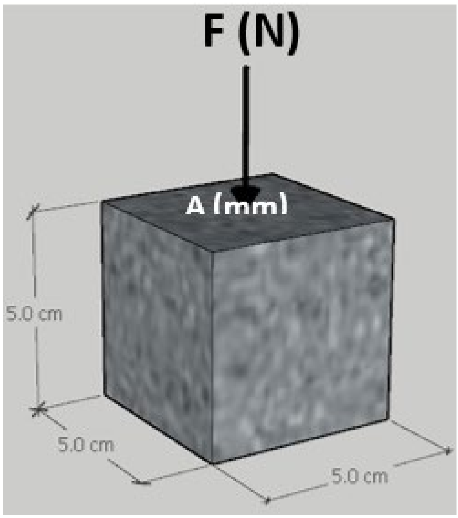
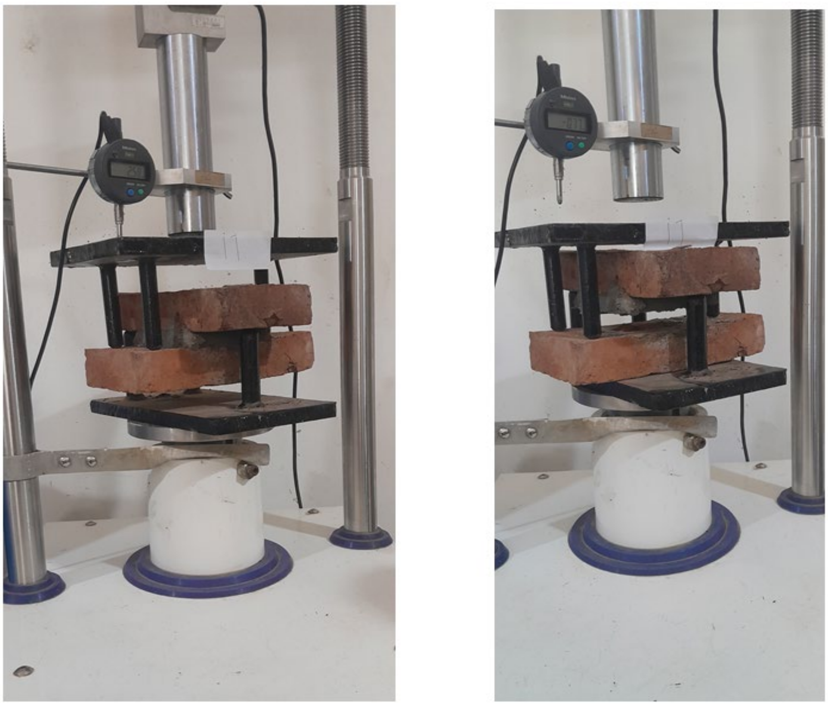


Fig. 5. Illustration for the force and area compression test

The tensile bond strength test between the mortar and the bricks was tested on the specimen as shown in Figure 3(b), using a digital compression strength test machine. The specimen is placed on the testing machine in the center position. The upper clay brick tip is held with an additional tool, while the lower clay brick tip is pressed through an additional tool intermediary, as shown in Figure 6. Once the specimen is ready to be tested, a load is applied at a speed of 2700 N/minute or at a speed that is estimated to cause failure in 1 - 2 minutes. The tensile strength test value between the mortar and the clay brick is obtained from the division between the maximum load (N) and the bond area (mm^2).



(a) (b)

Fig. 6. Tensile strength test between the mortar and the bricks(a) before testing (b) after testing

3. Result and Discussions

3.1 Compressive Strength Test Result

The results of the mortar compressive strength test for groups A and B are shown in Figure 7. RTC mortar that does not contain FA (group A) shows a decrease in compressive strength when the RTC content is greater (at 28 days old). At 20% RTC content, the compressive strength of the mortar is 1.699 MPa which is equivalent to 55% of the compressive strength of ordinary mortar. The decrease in the compressive strength of the mortar is caused by the weak bond between the RTC and the cement paste. The higher the RTC content, the more voids there are between the rubber and the cement paste, so that the compressive strength of the mortar decreases [6,23,24].

Furthermore, the addition of FA was carried out in RTC mortar (20% RTC), with variations in FA content up to 20% (group B). This test aims to determine whether the addition of FA can increase the low compressive strength of RTC mortar due to the addition of 20% RTC. From the study results shown in Figure 7, it can be stated that the addition of FA can increase the compressive strength of RTC mortar. The addition of 20% FA to a RTC mortar (20% RTC) can increase its compressive strength up to 1.3 times. This phenomenon indicates that FA can be recommended to be added to rubber tire mortar to increase its compressive strength. This is because FA has a high Silica content (see Table 1) so it is pozzolanic and can increase the bond interface between the rubber and the cement paste [25]. In addition, because FA is finer than cement, it can fill small voids in the mortar mix, and produce mortar that is denser and has higher compressive strength [26].

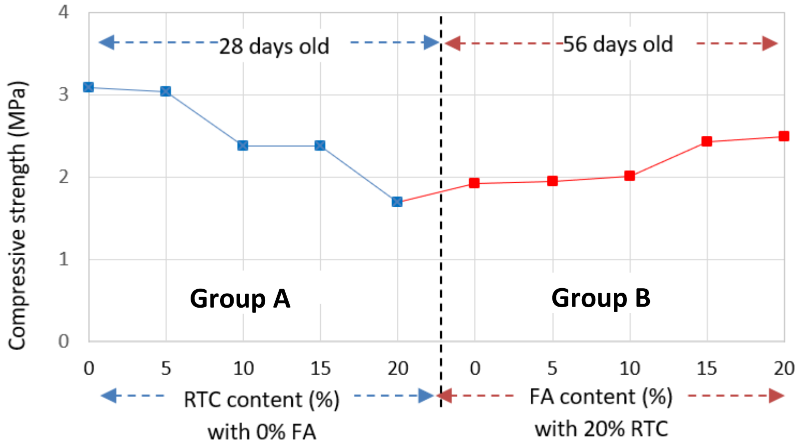


Fig. 7. The results of the compressive strength test of specimens in groups A and B.

3.2 Tensile Bond Strength Test Result

Mortar is widely used as a mortar joint in masonry walls which functions to bind clay brick units together so that a solid and strong wall is composed [27]. In building design, infill walls are not designed as structural elements that must withstand axial forces. However, infill walls have a role in increasing the stiffness of the structure, so that it is able to withstand horizontal forces such as earthquakes [12]. Therefore, it is necessary to study the role of fly ash in the bonding ability between the mortar joints and brick units. In this study, the tensile bond strength was also observed following the ASTM C-952-02 procedure. The results of the tensile bond strength test between mortar (Group A and B) and clay bricks are shown in Figure 8. The test results on specimen group A showed that the addition of RTC to the mortar reduced the tensile bond strength between the mortar and the clay bricks. At 20% RTC content, the tensile bond strength decreased by 45.5% compared to normal mortar. The addition of RTC to the mortar results in more voids arising due to the weak bond between the rubber and the cement paste [28], so that the bond area between the mortar and the brick also decreases. This causes the tensile bond strength to decrease.

The results of group B specimen testing in Figure 8 showed that FA additives in mortar containing 20% RTC could not improve the tensile bond strength between mortar and clay bricks, on the contrary it added a greater decrease. The analysis of this phenomenon can be explained that after adding FA, the mortar containing 20% RTC will be more solid so that it has greater adhesion bonds. This resulted in the bond between the mortar and the brick being weak. The bond test in this study used a tensile test, so the shear bond strength still needs to be investigated, because there is a possibility that the results will be different. The results of this study will be useful as a consideration in using FA as an additive in rubber tire mortar to increase its compressive strength. Especially if the mortar will be applied as a mortar joint on masonry walls using clay bricks.

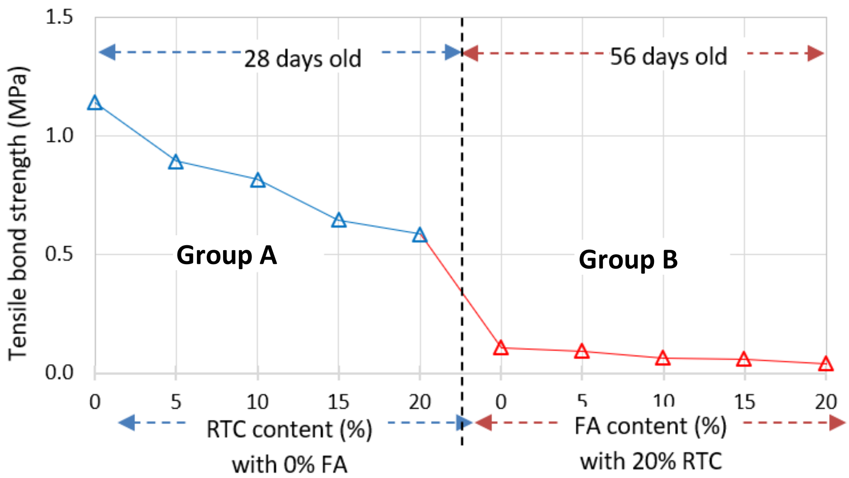


Fig. 8. The results of the tensile bond strength test of specimens in groups A and B.

3.3 Effect of Mortar Age

The results of the compressive strength and tensile bond strength tests at various ages (group C specimens) are shown in Figure 9. The addition of FA to RTC mortar (20% RTC) has been shown to increase the compressive strength at 28 and 56 days of age. A more significant increase occurred between the ages of 14 - 28 days, namely by 37%, while between the ages of 28 - 56 days it only increased by 9.5%. Meanwhile, the tensile bond strength test showed different result, where the older the specimen, the lower the tensile bond strength. The addition of FA to RTC mortar (20% RTC) resulted in a greater decrease in tensile bond strength, especially at the age of 28 – 56 days. From these studies it can be concluded that the addition of FA to RTC mortar (20% RTC) up to 56 days of age will result in further increasing its compressive strength but further decreasing its tensile bond strength compared to without FA. Therefore, the use of FA to increase the compressive strength of RTC mortar needs to be further considered, especially for its use as a mortar joint on clay masonry walls.

4. Conclusions

Compressive strength and tensile bond strength tests on RTC mortar with or without FA were carried out at 14, 28, and 56 days. From this study, it can be concluded that the addition of FA can increase the compressive strength of RTC mortar up to 1.3 times at the age of 28 days with an FA content of 20%. This increase is more significant at the age of 14 – 28 days. However, the higher FA content can result in a greater decrease in tensile bond strength between RTC mortar and clay bricks, especially at the age of 28 - 56 days. The use of RTC and FA mixed with mortar is useful in increasing the compressive strength value but reduces the tensile bond strength value of mortar with clay bricks. Looking at the results of the tensile bond strength test, it can be stated that the use of FA to increase the compressive strength of RTC mortar is not recommended for application as a mortar joint on clay brick masonry walls.

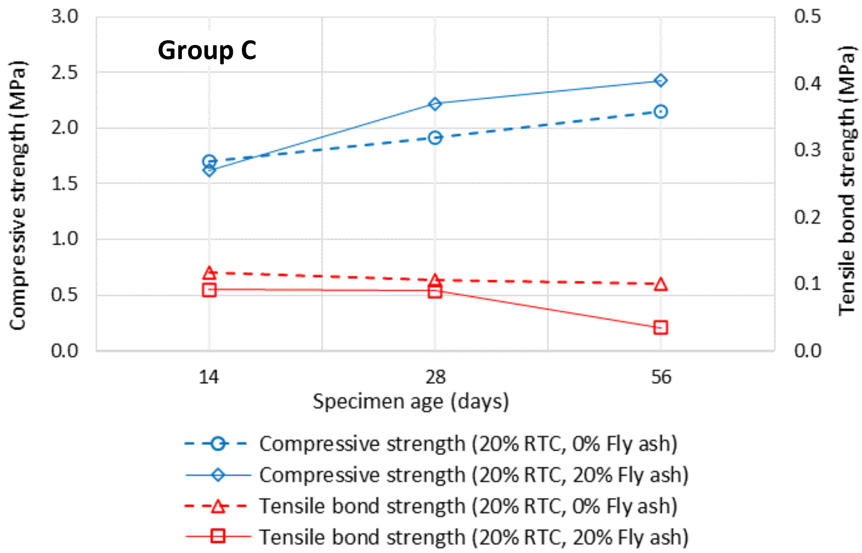


Fig. 9. Effect of Mortar age in Group C specimens testing

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