Characteristics of Mortar Composed of Crushed Solid Waste of Roof Tiles as Partial Replacement of Fine Aggregate

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Abstract. Due to the growing quantity of solid waste resulting from building damage, it is suggested that roof tile waste could be used in mortar in place of sand. This study aims to determine the physical and mechanical properties of mortar produced with waste roof tile as one of the ingredients. In this investigation, 15%, 25%, 35%, and 50% of the roof tile weight was substituted for sand. The specimen is a cube measuring 5 x 5 x 5 cm, with a testing age of 28 days. Consideration was given to four forms of testing: compressive strength, tensile strength, water absorption, and mortar density tests. The results demonstrated that the unit weight of sand in both its loose and compacted states is greater than that of roof tiles. While roof tiles have a higher water absorption rate than sand (26.8% vs. 6.0%), the compressive strength of all roof tile mortar variations was greater than the 13.07 MPa of the control mortar. When more roof tiles are used in place of sand, mortar's tensile strength typically decreases. The ratio of tensile strength to compressive strength ranges from 1.61 percent to 2.49 percent, which is less than the 3.9 percent ratio of the control mortar. The average quantity of water absorbed by mortar with roof tiles is 8.3%, and the greatest amount of water is absorbed when 50% of the mortar is replaced with sand. Roof tiles with a 35% composition and a 7.7% water absorption rate are recommended as an alternative to sand. This form of roof tile mortar is nearly identical to Type M mortar, which can be used to create structural concrete. Roof tile waste has the potential to be used as a substitute for sand in mortar mixtures, it can be concluded.

Keywords: Mortar, Roof Tile Waste, Strength, Water Absorption

1 Introduction

Every day, thousands of loads of recyclable construction and demolition materials are sent to landfills. Directive 2008/98/EC of the European Union mandates that 70% of these waste streams be recovered by 2020, but current treatment facilities have limited capacity for sorting construction waste [1].

Aggregates are utilized extensively in civil construction projects, including the production of Portland cement concrete, asphalt concrete, and granular subbase for road construction [2]. The intensity of mineral raw material production in European Union

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nations is highly dynamic, as it is dependent on the execution of approved investment projects for a specific time period. In Europe, natural sand and gravel resources are dwindling, and there is a shift toward the use of recycled pulverized and manufactured aggregates as well as recycled materials. Conflicts resulting from extractive land use are prevalent throughout Europe, and the need for long-term planning is a pressing social, economic, and political issue.

Standard recommendations from Norway, the Netherlands, Belgium, Germany, Austria, the United Kingdom, and Denmark permit the use of recycled masonry and roof tiles in new concrete. As part of the European standard HRN EN 12620:2013, the use of recycled aggregates is also contemplated [3].

The roof tile manufacturing industry in Croatia generates approximately 90 million pieces annually. Approximately 6–10% of the total quantity of tiles produced are damaged during production and transport, resulting in approximately 21,600 tons of waste. Similarly, the brick-making industry in Croatia produces approximately 900 million pieces per year, with waste from the production of clay bricks accounting for between 2 and 5 percent of the total quantity produced, or 3,150,000 tons of material. Damaged masonry and roof tiles cannot be sold, and the majority of these materials end up in landfills. However, one possible application for these materials is in the production of concrete, either as aggregate or as a partial cement replacement [4].

To accomplish the desired properties of recycled aggregate concrete, it is necessary to improve the recycling process in terms of aggregate grading and to investigate the optimal mixtures of natural and recycled aggregate for specific applications. To optimize concrete mixtures, it is necessary to determine the fundamental properties of concrete mixtures produced with varying proportions of concrete components that are believed to be significant for mixture optimization.

The goal of the work described here was to get the best possible result with the fewest number of experiments. Montgomery et al. [5] used the largest amount of information possible to build a model of the experimental process. Mortar with various compositions of other materials has been developed, for example, the optimum replacement of cement by silica fume on the compressive strength and physical properties of mortar using the design of the Taguchi Method [6]. This paper also shows how concrete could be used in load-bearing structures if crushed bricks and roof tiles were used in place of some of the natural aggregate.

The objectives of this research are to determine the compressive strength, density, water absorption, and tensile strengths of concrete if the aggregate is replaced with 15%, 25%, 35%, and 50% of crushed roof tiles. Water cement ratio (w/c) used is 0.60. Mortar was tested at the age of 28 days with 60 specimens, each test to be carried out are testing for compressive strength, tensile strength, density and water absorption (porosity) of concrete mortar. The shape of the samples is a cube test object with dimensions of 5 cm x 5 cm x 5 cm.

2 Method

The research was carried out experimentally at the Structure and Materials Laboratory, Faculty of Engineering, University of Mataram. The composition of roof tiles and other material composition can be seen in Table 1.

Table 1. Percentage of roof tiles composition

Roof tiles Composition (%)	Cement (gr)	Water (gr)	Roof tiles (gr)	Fine Aggregate (gr)
0%	300	285	0	1200
15%	300	285	180	1020
25%	300	285	300	900
35%	300	285	420	780
50%	300	285	600	600

Table 1 shows 5 different mixture compositions were used as research variables. The composition of the mixture is distinguished based on the composition of the cement and crushed roof tiles content. For the control variable the composition is 1: 4 and partial replacement of sand with roof tiles is carried out at 0 %, 15 %,25 %, 35 %, and 50 % of the sand weight. The results were analysed using statistical methods refer to ACI 214R-11 [7].

Compressive strength can be obtained using Equation (1). This equation is used for determining concrete strength also applies to mortar compressive strength.

$$f_c' = \frac{P}{A} \tag{1}$$

The tensile strength of concrete, ft, can be approached using split tensile test as Equation (2).

$$f_t = \frac{2P}{\pi dL} \tag{2}$$

Excessive water absorption in the mortar reduces its quality. The mortar absorption test was conducted using SNI 03-2113-2000 as a guide [8]. The Equation (3) can be used to calculate the percentage of water absorption.

$$WA = \frac{m_{SSD} - m_D}{m_D} \times 100\% \tag{3}$$

3 Result and Discussion

3.1 Properties of materials

The properties of each material used in this research was observed according to Indonesian standard (SNI). The brief properties of fine aggregate, including value of the density and the absorption of fine aggregate and crushed roof tiles can be seen in Table 2.

Table 2. The properties of fine aggregate and crushed roof tile

Type of the Test	Fine aggregate	Roof tiles
Unit weight of loose	1.144 gr/cm3	1.036 gr/cm3
Unit weight of solid	1.299 gr/cm3	1.163 gr/cm3
Bulk dry specific gravity	2.297	1.710
Sutured surface dry	2.167	1.349
Absorption	6 %	26.8%
Mud Content	0.112%	.695%
Gradation	Area II	Area II
Size (% pass sieve)	No. 4: 5,600 %	No. 4: 100%
Fineness Modulus	3,722	3,676

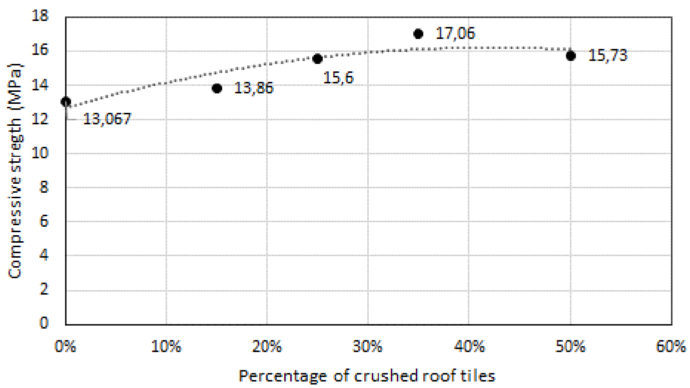

Fig. 1. Compressive strength of mortar

3.2 Compressive Strength

Referring to Fig. 1, it can be seen that the compressive strength of mortar increases with the increase in the percentage of sand replacement by crushed roof tiles. All variations of the addition of roof tiles resulted in a mortar compressive strength greater than the control mortar (0%) of 13.067 MPa. The maximum compressive strength obtained is 17.06 MPa with the substitution of 35% roof tile. When associated with SNI 03-6825-2002 [9] regarding the classification of types of mortar, the mortar that can be produced with the substitution of 35% crushed roof tiles almost falls into the category of Type M mortar (minimum of 17.2 MPa). This type of mortar can be used for structural concrete purposes.

From the results obtained, it can be said that in terms of compressive strength of mortar, crushed roof tiles have a significant effect on replacing sand by up to 50%, this will have an impact on the environment because it successfully utilizes solid waste produced, especially from this roof tiles.

3.3 Tensile Strength

The calculation of the tensile strength of mortar is carried out by adopting the procedures for the tensile strength of concrete, considering that mortar has the same properties as concrete. Therefore, Equation (2) is used in producing mortar tensile strength data. The result obtained is presented in Fig. 2.

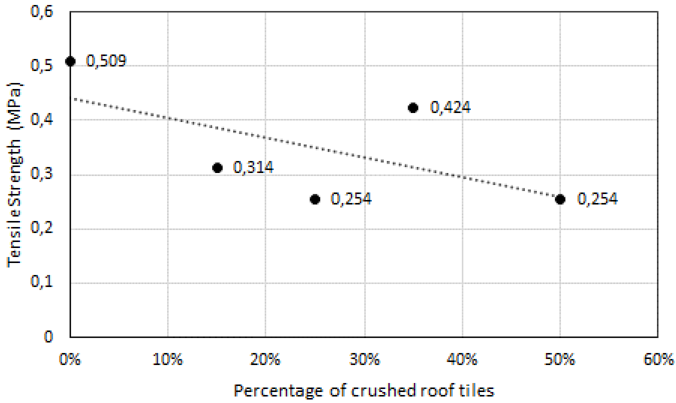

Fig. 2. Tensile strength of mortar

Table 3. The ratio of the tensile strength to the compressive strength of the mortar

Roof tile content (%)	f'c (MPa)	ft (MPa)	Ratio (%)	Ratio normalized
0	13.06	0.509	3.90	1.00
15	13.86	0.314	2.27	0.58
25	15.6	0.254	1.63	0.42
35	17.06	0.424	2.49	0.64
50	15.73	0.254	1.61	0.41
			Average	0.51

In general, the tensile strength of mortar decreases as more roof tiles are used to replace sand. Table 3 displays the ratio of the tensile strength to the compressive strength of the mortar. From the data, it can be seen that the ratio of tensile strength to compressive strength (1.61-2.49%) is lower in all mortars with roof tile additions than in control mortar (3.9%). This tensile strength value is not proportional to the control mortar's tensile strength. If the ratio is idealized relative to the standard mortar, the mean value is 0.51.

3.4 Water Absorption

As stated previously, water absorption is the volume of water absorbed by a material and is calculated by dividing the weight of the absorbed water by the weight of the desiccated material. As demonstrated in Figure 3, the water absorption of mortar treated with the addition of roof tile to the mixture composition is marginally higher than that of the control mortar (7.1%). 8.3% is the average water absorption rate of roof tile mortar. At a sand replacement level of 50%, the maximum water absorption rate reaches 9.4%.

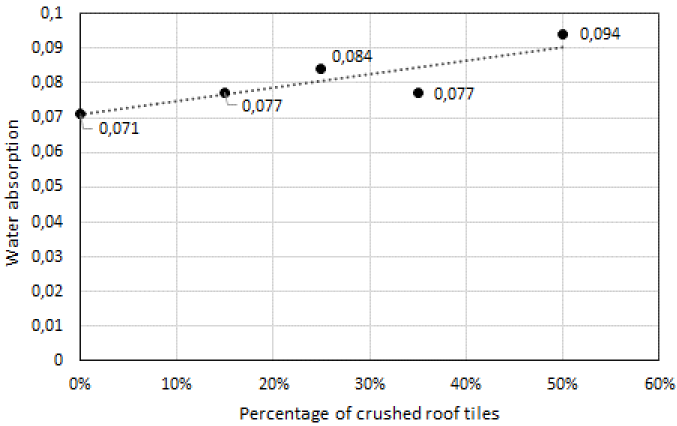

Fig. 3. Water absorption of mortar

When examining the water absorption test results for sand and roof tile separately, their absorption rates are 6% and 26.8%, respectively (see Fig. 3). Thus, there is a significant decrease in the mortar's average water absorption after it has been formed as a new material, which is 8%. This can be interpreted as signifying that the mortar created by mixing sand, roof tile, cement, and water worked perfectly to fill the spaces between the roof tiles. These results suggest using a 35% roof tile composition with a 7.7% water absorption rate as a substitute for sand.

3.5 Density

As was previously mentioned, roof tile has a lower unit weight and density than sediment under the same conditions, but a significantly higher water absorption. Theoretically, therefore, mortar with roof tiles should have a lower density than control mortar.

Fig. 4 displays the results of this study's density test. The value of mortar density with the addition of roof tile is almost identical to that of the control mortar, as shown in the figure. This is likely due to the roof tile being precisely mixed with sand and cement paste, so that the voids in the mortar are filled by roof tile. The average density of the roof tile mortar was 1.30, which was nearly identical to the density of the control mortar (1.31). This result is expected considering the unit weight of loose roof tiles is lower than that of loose sand.

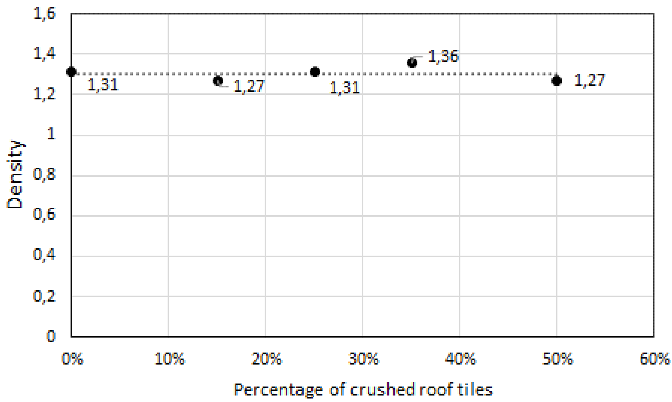

Fig. 4. Density of mortar

Fig. 4 demonstrates that the mortar density investigated in this study is relatively constant between 1.27 and 1.36. Because the dimension of the roof tile and fine aggregate were nearly identical, the gradation has an excellent fineness modulus. It indicates that a 35% decrease in mortar density is effective. Therefore, it will be applicable when a low density of structures is required, such as on energy-absorbing structures with a high energy-absorption capacity per unit weight.

4 Conclusion

On the basis of the test results and discussion in this study, it can be concluded that roof tile waste has the potential to replace sand in mortar mixtures. The unit weight of loose and solid sand is greater than that of the roof tile. It caused the roof tile's water absorption to be 26.8% greater than sand's (6%). All mortar variations for roof tiles have a higher compressive strength than the standard mortar (0%), which is 13.067 MPa. The mortar containing 35% roof tile nearly qualifies as Type M mortar (with a minimum of 17.2 MPa), and it can be used for structural concrete applications. In general, the tensile strength of mortar decreases as a greater proportion of roof tiles replaced sand. The utmost water absorption for mortar with roof tiles is 9.4% when 50% sand replacement is used. The average water absorption of roof tile mortar is 8.3%. The average mortar density of roof tile was 1.30, which was nearly identical to that of the control mortar (1.31). As an alternative to sand, a composition of 35% is recommended for roof tiles.

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