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PENGARUH PENGGUNAAN BUBUK LIMBAH GENTENG KERAMIK SEBAGAI MATERIAL *CEMENTITIOUS* TERHADAP NILAI SLUMP FLOW MORTAR

INFLUENCE OF CERAMIC ROOF TILE WASTE POWDER AS CEMENTITIOUS MATERIAL ON MORTAR SLUMP FLOW.

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Abstrak

Kebutuhan yang terus meningkat terhadap material konstruksi berkelanjutan mendorong pemanfaatan limbah keramik sebagai bahan tambahan sebagai material c*ementitious*, mengingat potensinya dalam menekan dampak lingkungan dan meningkatkan efisiensi penggunaan sumber daya. Genteng keramik dibuat dari material lempung yang merupakan hasil penambangan yang memiliki efek perubahan topografi tanah asli. Estimasi genteng keramik produksi Kabupaten Kebumen pertahun adalah 174.424.333 buah dengan produk mencapai kualitas standar sebanyak ±95%, sehingga terdapat potensi limbah genteng keramik di Kabupaten Kebumen sebesar 8.721.216 buah. Berdasarkan hal tersebut penelitian ini bertujuan untuk mengetahui pengaruh bubuk limbah genteng keramik sebagai material substitusi pada sifat mortar terhadap sifat kelecakannya. Penelitian ini menyoroti pada tingkat kehalusan bubuk limbah genteng keramik yang lebih tinggi dibandingkan semen terhadap perilaku *slump flow* mortar. Penelitian ini meliputi pengujian ukuran bubuk limbah genteng dan pengujian *slump flow* mortar. Pengukuran kehalusan dilakukan menggunakan alat *Blaine*, sedangkan karakteristik alir mortar diuji dengan *flow table*. Lima variasi persentase penggunaan bubuk genteng keramik yaitu 0%, 10%, 20%, 30%, dan 50%. Hasil penelitian menunjukan bahwa semakin banyak material bubuk limbah genteng keramik dalam mortar dapat menurunkan nilai *slump flow,* yang berpengaruh terhadap tingkat berkurangnya tingkat kelecakan campuran mortar.

Kata kunci: bubuk limbah genteng keramik, mortar, substitusi semen, sifat kelecakan, tingkat kehalusan

Abstract

The increasing demand for sustainable construction materials is driving interest in the utilization of ceramic waste as a supplementary cementitious material due to its potential to reduce environmental impacts and improve resource efficiency. A ceramic roof is manufactured from clay extracted through mining activities, which can lead to significant alterations in natural land topography. The annual production of ceramic roof tile in Kebumen Regency is estimated at 174,424,333 units, with approximately 95% as standard quality requirements, resulting in an estimated waste generation of approximately 8,721,216 units per year. Therefore, this study aimed to investigate the effect of ceramic roof tile waste powder (CRTWP) as a cement substitution material on the workability of mortar. This study is the first to examine the influence of CRTWP, with fineness higher than that of cement, on the slump flow behavior of mortar. The experimental program included fineness testing using a Blaine apparatus and slump flow testing using a Flow Table. According to results, CRTWP was used in varying percentages, including 0%, 10%, 20% 30%, and 100%. The results showed that increasing the proportion of CRTWP in the mortar mixture leads to a reduction in slump flow, thereby decreasing the workability of mortar.

Keywords: ceramic roof waste powder, mortar, cement substitution, workability, fineness

I. INTRODUCTION

Infrastructure development is one of the fundamental pillars supporting economic growth and societal well-being. In recent years, government strategic priorities in the construction sector have increasingly emphasized environmental preservation through the implementation of sustainable construction practices. One promising approach involves the utilization of industrial and construction waste materials. The transformation of construction and landfill waste into cementitious material represents a sustainable approach that helps alleviate environmental degradation while simultaneously decreasing the reliance on natural raw materials in construction activities [1]. These wastes are utilized as substitutes for cement, replacements for coarse or fine aggregates, and as fibers in concrete. The incorporation of these waste materials not only contributes to waste reduction but also provides potential economic and environmental benefits. Consequently, the use of waste as a partial cement replacement has attracted significant attention. This is driven by the increasing demand for construction materials and the considerable environmental footprint of cement production. To minimize adverse environmental effects, concrete construction offers a viable approach for the effective utilization of industrial by-products as supplementary cementitious material [2].

In Indonesia, Central Java Province, Kebumen Regency is one of the regions that produces ceramic roof tiles derived from mining materials, such as clay. Most of the clay resources in Kebumen Regency are used as raw materials in roof tile and brick manufacturing industries, which are distributed across several areas, including Sruweng, Pejagoan, and Klirong Area [3].

Roof tile production in the region is estimated to reach approximately 174,424,333 units per year. At this level of production, tile manufacturers supported by experienced labor can produce about ±95% of tiles that meet quality standards, while approximately ±5% are classified as defective products. These defects include asymmetrical shapes, incomplete forms, partial cracking, breakage, and burning or overfiring during the kiln process [4].

Recent literature increasingly shows that various industrial by-products can be effectively used as partial replacements in cementitious material. This contributes to the reduction of environmental impacts in line with Sustainable Development Goals (SDGs). Investigations into waste-derived binders for wall plaster show that traditional manufacturing practices impose considerable environmental loads, while the adoption of environmentally friendly mortar formulations offers opportunities to lessen these impacts, enhance thermal properties, and lower overall energy demand. In general, existing studies reported that the integration of industrial waste materials into mortar compositions represents a promising approach to promote sustainability in the construction industry [5].

Numerous previous investigations have demonstrated the feasibility of utilizing ceramic roof tile waste as an alternative aggregate material in concrete production. For instance, some studies have used roof tile waste as a replacement for fine aggregate [6], while others have explored its use as a coarse aggregate in substantial proportions [7]. Additionally, studies have explored the use of traditional roof tile powder as a substitute for fly ash in self-compacting concrete (SCC) [8]. In 2022, a study was carried out to examine the utilization of waste clay bricks and lightweight concrete block residues as fine aggregates in mortar production [5]. The use of roof tile waste coarse aggregate as an internal curing agent significantly enhances the compressive strength of fly ash concrete while altering elastic behavior, highlighting the potential of roof tile waste as a sustainable alternative aggregate in concrete production [9]. Overall, these studies show that roof tile waste can effectively function as both fine and coarse aggregate, thereby enhancing the potential application in sustainable concrete technology.

Despite the extensive studies on the utilization of ceramic roof tile waste, existing investigations have predominantly focused on the application as fine or coarse aggregate in concrete and mortar. Limited attention has been given to the use of roof tile waste as cementitious material, particularly in powdered form. Moreover, studies that investigated ceramic roof tile waste powder (CRTWP) generally used materials with fineness lower than or comparable to that of cement, often reporting increased water demand and reduced workability. Consequently, the influence of CRTWP with fineness higher than cement on the fresh properties of mortar, especially slump flow behavior, remains insufficiently explored.

Therefore, this study aimed to investigate the effect of CRTWP as a partial cement substitution material on the workability of mortar. The novelty of this study is the examination of the influence of CRTWP with fineness higher than that of cement on mortar slump flow behavior. These results are expected to contribute to the development of sustainable cementitious material and provide meaningful information on the effective utilization of ceramic roof tile waste in mortar applications.

II. LITERATURE REVIEW

Earlier studies examined the application of various waste-derived materials as partial replacements in mortar and cement-based mixtures. The alternative materials explored in these studies consist of waste clay brick and waste lightweight concrete block, roof tile waste, eggshell powder, rice husk ash, recycled brick powder, and ceramic tile waste.

Although several studies have explored the potential of ceramic roof tile waste, limited investigations have addressed its utilization as a partial or complete substitute for cementitious binder. Recent studies have investigated the use of CRTWP with a fineness value of 2753 cm²/g, which is lower than that of cement, at substitution levels of 0%, 10%, 20%, 30%, and 50%. These studies primarily focused on the setting time behavior of mortar. The results showed that the incorporation of CRTWP into cement mixtures prolongs both the initial and final setting times. For the specimen with 0% substitution, the initial setting time was 151 minutes, while the final setting time was 236 minutes. In contrast, the specimen with 50% substitution showed an initial setting time of 208 minutes and a final setting time of 282 minutes [10].

Another study investigating the use of CRTWP passing the 45 µm sieve in mortar reported that mortar flowability decreased with increasing levels of cement substitution. At substitution levels of 0%, 10%, 20%, 30%, 40%, and 50%, the results are 180 mm, 175 mm, 165 mm, 160 mm, 155 mm, and 150 mm, respectively. These results showed that mortars containing CRTWP exhibit lower workability than the control mortar, mainly due to differences in material characteristics compared to cement [11].

In this study, the objective is to investigate the influence of CRTWP with a higher fineness than cement.

III. METHOD

This study was conducted using an experimental method in the laboratory. The experimental procedures consisted of several stages, including a literature review, equipment preparation, material preparation, material testing, specimen fabrication, experimental testing, and data analysis. Figure 1 shows the flowchart illustrating the stages.

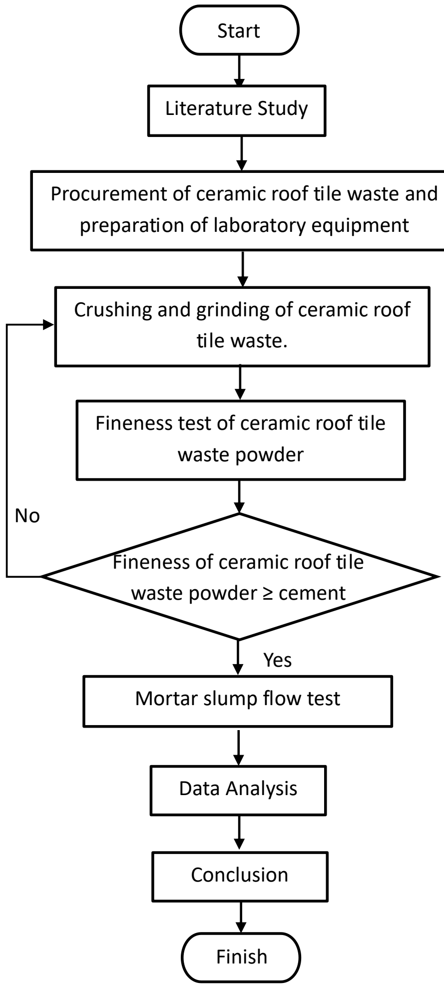

Figure 1. Study Flowchart

The equipment used included hammers, jaw crusher machines, an oven, finish mills, sieve set, Blaine apparatus, Flow Table, and mortar mixer. The materials used consisted of PPC cement, distilled water, silica sand, and ceramic tile waste powder. Five substitution levels of CRTWP for cement were prepared, namely 0%, 10%, 20%, 30%, and 50%. The testing program consisted of a fineness test for both cement and ceramic waste powder, as well as a mortar slump flow test.

A total of 15 roof tiles were prepared, obtained from a manufacturer as defective products. The preparation process started by converting the large-sized roof tile waste into fine powder. The crushing and grinding processes were performed using several types of equipment, including a hammer, a crusher machine, an oven, and a grinder.

Figure 2 shows the entire process. Figure 2(a) shows that the preparation process begins with natural drying for 2 days to reduce the moisture content. Tiles were manually crushed using a hammer into fragments measuring approximately 3–5 cm, as shown in Figure 2(b). Figure 2(c) shows that the sample was reduced into smaller pieces with jaw crusher machines. Figure 2(d) shows that the crushed material was oven-dried at 100°C for 24 hours to eliminate any remaining moisture in ceramic tile waste. Figure 2(e) shows that the dried material was then ground using a finish mill. The finish mill is a grinding device that uses steel balls with diameters ranging from 30 to 80 mm, occupying approximately 40% of the mill volume, to efficiently grind the material [12]. During the process, the steel balls collide with ceramic particles, breaking them down into finer powder. Figure 2(f) shows that the resulting powder was sieved through a No. 280 sieve to obtain a uniform particle size. Figure 2(g)-(h) CRTWP is ready to use.


(a) (b) (c) (d) (e) (f) (g) (h)

Figure 2. Preparation process of CRTWP: (a) natural drying; (b) manual crushing; (c) jaw crushing; (d) oven drying at 100°C; (e) grinding using a finish mill; (f) sieving through a No. 280 sieve; and (g–h) CRTWP ready for use

A. Fineness Test Procedure with Blaine Apparatus

The fineness test was conducted using a Blaine air permeability apparatus to measure the fineness of both cement and CRTWP. The test started by weighing the required amount of material. A filter paper with a diameter of 12.7 mm was placed inside the glass tube of the permeability cell. The sample was then added using a funnel, leveled at the surface, and covered with another filter paper on top. The sample was compacted using a plunger until it reached the specified level. The apparatus automatically calibrated the porosity to the standard value before the measurement was conducted.

The Blaine test is used to evaluate material fineness based on specific surface area per unit mass (cm^2/g or m^2/kg). Cement fineness significantly affects hydration and the fresh properties of cementitious mixtures. The increased fineness enlarges particle surface area, leading to higher water demand and greater internal friction, which reduces free water availability and consequently decreases workability of mortar or concrete. This relationship between cementitious material fineness and reduced workability has been widely reported in previous studies on cement fineness [13]. Figure 3 (a) and (b) show the automatic Blaine apparatus in preparation and measure fineness of cement and CRTWP.


(a) (b)

Figure 3 (a-b). Blaine test equipment

B. Mortar Slump Flow Test

To evaluate the workability of the mortar mixture during molding, a slump flow test was conducted [14]. This test uses the Flow Table apparatus to assess the flowability of mortar. It plays an essential role in determining the optimal water content required to achieve the desired consistency and ease of application. Under normal consistency conditions, the flow value of mortar typically ranges between 110% and 120%.

A flow table test was also conducted to determine the optimum water content required to maintain the workability of the mortar mixture during application.

The procedure begins with the preparation of mortar by mixing the designated materials [15]. After weighing 650 g of the materials, water was added to the bowl according to the volume specified in the standard. The mixture was then stirred mechanically for 30 seconds, paused for 15 seconds, and then stirred for 60 seconds. Once the mixture was ready, a slump flow test was performed using the Flow Table apparatus. The surface of the Flow Table was cleaned and dried before testing, and the flow mold was placed at the center of the table.

Approximately 25 mm of mortar mixture was poured into the flow mold and compacted 20 times using a tamping rod. The mold was then filled, and the surface was leveled with a straightedge. The mold was lifted vertically and slowly to allow mortar to flow freely. Subsequently, the Flow Table test was performed by rotating the table lever 25 times to apply impact. After the mortar had spread, the flow diameter was measured in four different directions, and the average value was recorded as the final slump flow diameter. Figure 4

(a) (b)

Figure 4 (a). Flow Table Mortar; **(b)** Slump flow test result with 50% CRTWP

IV. TEST RESULTS AND DISCUSSION

A. Fineness of Cement Material and Ceramic Roof Tile Powder

Fineness testing based on the Blaine air permeability method was carried out to determine the particle size of cement and CRTWP. The fundamental principle of this test is that finer particles have a higher surface area-to-volume ratio, which increases the surface available for reaction with water during the hydration process.

The first Blaine test was performed on Portland Composite Cement (PCC) used in this study, which has a fineness value of 4677 cm²/g. For ceramic roof tile waste material, the grinding process was initially carried out using a finish mill for 5 minutes, followed by sieving and the Blaine test. The resulting fineness value exceeded the minimum requirement specified in SNI 15-2049-2004, which is 2800 cm²/g [16]. The material was then reground, and fineness was still higher than SNI (Indonesian National Standard). Subsequently, the grinding duration of CRTWP was extended by 4 minutes, producing fineness greater than that of cement. Fineness value is 4871 cm²/g, and the result is shown in Table 1.

Table 1. Result: fineness value of Cement and CRTWP

Material	Standard requirement (cm²/g)	Blaine fineness (cm²/g)
PCC CEMENT	2800	4677
CRTWP	-	4871

These results show that CRTWP not only meets the minimum fineness requirement but also exhibits a finer particle size compared to the cement used. Minimizing mortar porosity and increasing the degree of cement hydration are essential for improving material performance. An effective strategy to overcome nonuniform particle gradation, functioning as both a binder and a filler, is the incorporation of cement particles with fineness exceeding that of conventional cement [17].

B. Slump Flow Mortar Results

The slump flow test aims to evaluate the workability of mortar during both the molding and application processes. This aspect of workability is important, as it directly influences the quality of the final product, particularly in terms of homogeneity and density. The required mortar flow value ranges between 110 ± 5% [15], which corresponds to 110–120% under normal mixture consistency conditions.

In the initial stage of specimen preparation, a control mixture was prepared, consisting of mortar without the substitution of CRTWP (0%), designated as BLANK. Slump flow test results were obtained with a water content of 241 ml. This value falls in the required mortar flow range, indicating that the control mixture satisfied the normal consistency condition. Subsequently, water volume was the reference variable for the preparation of subsequent specimens incorporating various percentages of CRTWP as partial cement substitution.

Slump flow test results for each replacement level of CRTWP showed significant differences, reflecting the effect of substitution on the workability of mortar. As the proportion of CRTWP in the mixture increased, the slump flow value showed a significant variation. This behavior is attributed to physical properties of tile waste powder, particularly particle size and specific surface area, which influence its interaction with the mixing water. The detailed results of the slump flow test are presented in Table 2, while the trend illustrating the relationship between the percentage of CRTWP substitution and the slump flow value is shown in Figure 6.

Table 2. Flow Table Test Results of Mortar with CRTWP Substitution

Specimen Code	Cement	CRTWP	Flow (%)
BLANK	100%	0%	110,5
BGS 1	90%	10%	100
BGS 2	80%	20%	90,5
BGS 3	70%	30%	81
BGS 5	50%	50%	55,5

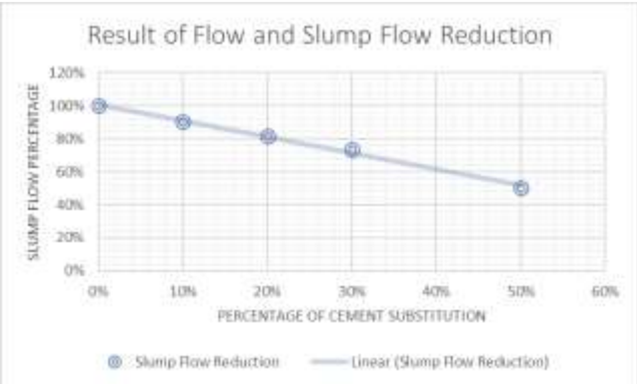

Figure 6. Comparison of mortar slump flow percentage and cement substitution percentage

Figure 6 shows the decreasing trend in slump flow with increasing CRTWP content. The control mixture containing 0% CRTWP exhibited a slump flow of 110.5%, which decreased to 100% and 90.5% at CRTWP substitution levels of 10% and 20%, respectively. A further reduction was observed at substitution levels of 30% and 50%, where slump flow values dropped to 81% and 55.5%. In general, slump flow decreased by approximately 49.8% from the control mixture to the mixture with 50% substitution. This progressive reduction in flowability can be attributed to the increased powder content and the greater fineness of CRTWP compared to cement, which increases the specific surface area and, consequently, the water demand. Consequently, the availability of free water in the mixture is reduced, leading to increased internal friction between particles and a decrease in workability of mortar.

C. Discussion

Fineness test results obtained using the Blaine apparatus showed that CRTWP exhibited a higher fineness value than PCC cement. Both values exceeded the minimum fineness requirement specified in SNI 15-2049-2004, which is 2800 cm²/g. In this study, the material was subjected to an extended grinding process, resulting in fineness greater than that of ordinary PCC. Previous studies have shown that the grinding procedure exerts a significant effect on the microstructural characteristics and pozzolanic activity of various types of ceramic waste when utilized as a partial cement replacement material [18].

Flow Table test results indicate a decrease in workability of mortar as the percentage of CRTWP substitution for cement increases. The control mixture containing 100% cement produced the highest flow value of 110.5%, which falls in the normal consistency range as specified in SNI 03-6825-2002. As the substitution levels of tile waste powder increased to 10%, 20%, 30%, and 50%, the flow values decreased consecutively to 100%, 90.5%, 81%, and 55.5%, respectively. This trend shows that mortar slump flow performance decreased from 100% to 50%, with the reduction in flow being approximately proportional to the level of cement replacement using CRTWP. This result is in line with previous studies indicating that a higher percentage of waste roof tile powder contributes to a significant reduction in mortar slump [19].

The reduction in flow is primarily attributed to the finer particle characteristics of CRTWP, which possess a larger specific surface area, resulting in higher water absorption and reduced particle lubrication in the mixture. Therefore, precise control of the water-to-cement ratio is essential to maintain optimal workability when using CRTWP as a partial cement replacement.

V. CONCLUSION

In conclusion, the following key findings can be drawn from this study:

a. The grinding duration using a finish mill significantly influences the fineness of CRTWP. A longer grinding time results in a higher fineness value.
b. The fineness level of CRTWP directly influences the workability of the mortar mixture.
c. Cement substitution with CRTWP leads to a progressive decrease in mortar slump flow, with an overall reduction of approximately 49.8% at 50% substitution compared to the control mixture. This shows that both substitution level and fineness play an important role at workability of mortar.

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