DINAMIKA REKAYASA
http://dinarek.unsoed.ac.id

Volume 22 Nomor 1 (2016) Hal. 86-93
e-ISSN 2527-6131
http://jurnaldinarek.id

PENGARUH KEHALUSAN BUBUK LIMBAH GENTENG KERAMIK TERHADAP NILAI *SLUMP LOSS* DAN KANDUNGAN AIR PADA BETON DENGAN SUBSTITUSI SEMEN

INFLUENCE OF CERAMIC ROOF TILE WASTE POWDER FINENESS ON SLUMP LOSS AND WATER CONTENT OF CONCRETE WITH CEMENT SUBSTITUTION

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Abstrak

Limbah genteng keramik cacat produksi pertahun sebesar ±15.262 ton saat ini belum dimanfaatkan maksimal. Penelitian sebelumnya menguji substitusi semen menggunakan bubuk limbah genteng keramik dengan kehalusan yang lebih rendah daripada semen. Hasil pengujian menyatakan bahwa substitusi semen dengan menggunakan bubuk limbah genteng tidak meningkatkan kuat tekan pada mortar. Pengaruh bubuk limbah genteng yang melebihi kehalusan semen terhadap kinerja beton segar belum cukup diteliti. Oleh karena itu, penelitian ini bertujuan menguji pengaruh bubuk limbah genteng keramik ultra-halus (CRTWP), sebagai pengganti sebagian semen terhadap perilaku kehilangan slump beton dan kebutuhan air. Limbah genteng digiling hingga mencapai kehalusan lebih tinggi daripada semen, yang ditentukan menggunakan metode permeabilitas udara Blaine.selama analisis, uji kehilangan slump dilakukdan menggunakan kerucut Abrams pada campuarn beton dengan lima tingkatan substitusi CRTWP: 0%, 2,5%, 5%, 7,5%, dan 10% berat semen. Nilai slump awal dipertahankan pada tingkat konstan untuk semua campuran. Hasil penelitian menunjukkan bahwa penambahan CTRWP dengan kehalusan melebihi kehalusan semen menghasilkan nilai kehilangan slump akhir yang relatif serupa, meskipun terdapat variasi dalam jumlah air pencampur yang dibutuhkan. Hasil ini menyiratkan bahwa CRTWP ultra-halus dapat digunakan sebagai pengganti sebagian semen tanpa mempengaruhi kemampuan kerja beton segar secara negatif, asalkan diterapkan penyesuaian air yang tepat.

Kata kunci: bubuk limbah genteng keramik, slump beton, substitusi semen

Abstract

The annual production of defective ceramic roof tile waste is estimated at around 15,262 tons yet remains underutilized. Previous studies reported that substituting cement with ceramic roof tile powder finer than cement does not significantly enhance mortar compressive strength. Furthermore, the effect of waste powder exceeding cement fineness on fresh concrete performance has not been sufficiently investigated. Therefore, this study examined the effect of ultra-fine ceramic roof tile waste powder (CRTWP) as a partial cement replacement on concrete slump loss behavior and water demand. The tile waste was ground to achieve fineness higher than cement using the Blaine air permeability method. Slump loss tests were conducted using an Abrams cone on concrete mixtures with CRTWP substitution levels of 0%, 2.5%, 5%, 7.5%, and 10% by weight of cement, with initial slump values maintained constant. The results revealed that incorporating ultra-fine CRTWP produced similar final slump loss values, despite differences in required mixing water. Higher water content signified better workability retention and slower early-stage stiffening. These results implied that ultra-fine CRTWP could be used as a partial cement substitute without adversely affecting fresh concrete workability, provided appropriate water adjustments are implemented.

Keywords: cement substitute, ceramic tile waste powder, concrete slump.

I. INTRODUCTION

Environmental sustainability is a central concern among stakeholders in the construction industry, driving the growing adoption of sustainable construction practices. This concern largely arises from the construction sector as a larger consumer of natural resources and energy. The extensive extraction of non-renewable materials, including natural stone and river sediments, has intensified in recent years, leading to significant environmental degradation. Moreover, construction activities constitute a major source of greenhouse gas emissions, contributing substantially to climate change.

Concrete, as a widely used construction material, depends extensively on non-renewable natural resources, including ordinary Portland cement, fine aggregates (sand), and coarse aggregates (crushed stone). In response to these challenges, numerous studies have investigated the incorporation of construction and industrial waste materials into concrete as supplementary cementitious materials. This method has been shown to effectively reduce the consumption of virgin natural resources, limit construction waste generation, and support the broader objectives related to sustainable construction and environmental protection. Various waste materials, including ferronickel slag [1], rice husk ash[2], coal combustion by-products such as fly ash [3], [4], ceramic waste (as raw substitution material[5], [6], as replacement for cement on concrete[7], [8], (as a partial cementitious of cement paste[9]), and in the green concrete industry[10]), and brick waste (as replacement for cement on concrete[8], of Cement Paste[11], [12]), have been successfully incorporated into concrete. These materials have been applied as partial replacements for cement [8], substitutes for coarse or fine aggregates. and in certain applications, as fiber reinforcement. The applications show the potential of waste-derived materials to reduce the amount of raw substance consumption in concrete production.

Another construction waste material with mineralogical properties comparable to those of bricks and conventional ceramics remains largely underexplored in cement-based material applications, namely, clay-based ceramic roof tile waste. A well-known roof tile product is Sokka, an unglazed ceramic tile from natural clay and widely manufactured in Kebumen Regency, Central Java Province, Indonesia. Studies on the Sokka roof tile manufacturing process show that approximately ±5% of total production is classified as defective [13], corresponding to an estimated annual waste generation of approximately 15,262 tons. This estimate is based on total roof tile production in Kebumen Regency in 2010, which reached 174,424,333 units, equivalent to approximately 305,242 tons [14]. When not properly managed, the substantial volume of ceramic waste may lead to significant environmental impacts and disposal challenges.

Previous studies showed the potential application of brick- and ceramic-based waste powders as supplementary cementitious or pozzolanic materials. [11] revealed the viability of brick waste powder as a pozzolanic additive in concrete, while [9] investigated utilizing Sokka roof tile waste as a partial cement replacement in mortar. Limited attention has been directed towards the influence of ceramic roof tile waste powder (CRTWP) on the fresh characteristics of concrete, particularly its workability and slump loss behavior.

This study is aimed at investigating the influence of finely ground CRTWP as a partial substitution of ordinary Portland cement on concrete workability, with a specific focus on slump loss characteristics following ACI and ASTM standards. The novelty of the analysis resides in the evaluation of CRTWP possessing fineness higher than OPC and its influence on time-dependent slump loss behavior. The results are expected to advance sustainable cement-based materials while providing technical understanding of the effective use of ceramic roof tile waste in structural concrete applications.

II. LITERATURE REVIEW

Partial replacement of concrete constituents has been extensively studied to improve sustainability, reduce costs, and increase concrete performance. The substitution of ordinary Portland cement with pozzolanic materials can improve compressive strength and durability through secondary hydration reactions. However, excessive replacement levels may reduce performance due to the slower reaction kinetics of pozzolanic materials compared to cement hydration.

A. Cement

Portland cement is a type of hydraulic cement obtained by grinding Portland cement clinker. The product primarily comprises hydraulically active calcium silicates, containing one or more types of calcium sulfate as a set-regulating agent, and may include other minor constituents [15].

Composite Portland cement is a hydraulic binder produced by the inter-grinding of Portland cement clinker and gypsum with one or more inorganic materials. The product can also be achieved by blending cement powder with supplementary inorganic constituents such as blast furnace slag, pozzolans, silicate compounds, and limestone. The total proportion of inorganic additions typically ranges from 6% to 35% by mass of composite Portland cement [16], following the relevant standards. Cement is required to satisfy both chemical and physical properties, among which fineness is a critical physical parameter. Based on Blaine air permeability test, the minimum required fineness is 280 m^2/kg (or 2,800 cm^2/g). Fineness plays a significant role in cement hydration and fresh concrete behavior. As particle size decreases, the specific surface area-to-volume ratio increases, providing a greater surface area for water–cement interaction per unit volume. This improved surface area influences hydration rate, water demand, and the rheological behavior of fresh concrete, which are directly related to workability as well as slump loss characteristics.

B. Cement Substitution

The percentage variation of CRTWP used in this study was set at 0%, 2.5%, 5%, 7.5%, and 10% by weight of cement. These replacement levels were selected based on the scope of the study conducted by [11], who investigated the influence of clay brick waste powder on the mechanical and physical characteristics of cement paste using four cement substitution levels, namely 2.5%, 5%, 7.5%, and 10%, which were assessed and compared with a control paste.

A partial replacement level of 5% was identified as optimal for specimens incorporating the waste powder after curing duration of 7 and 28 days, even though the addition of clay brick waste powder resulted in a decline in the compressive strength of cement paste. Analyses of mineralogical characteristics, chemical composition, and SEM (scanning electron microscopy) images showed that finely ground clay brick fragments signified pozzolanic behavior and could serve as a pozzolanic additive for concrete [11].

Hasan Baylavli and Eren Gödek (2024) investigated the utilization of ceramic waste as a substitute in composite cement production. The study assumed that all ceramic waste-based composite cements showed higher compressive and flexural strengths in comparison with ordinary Portland cement. The highest flexural strength was observed at a ceramic waste replacement ratio of 28% for all curing ages. Meanwhile, the highest compressive strength at 28 days was observed at a replacement ratio of 10%. The highest compressive strength across all curing ages was obtained at a replacement ratio of 28% after curing for 365 days. Composite cements containing up to 10% ceramic waste maintained acceptable setting times. However, increasing the substitution level to 15% or higher led to prolonged setting times.

According to another comprehensive review [7], ceramic waste powder showed significant pozzolanic activity at substitution levels of 5–10%, leading to increased calcium hydroxide consumption, improved generation of C–S–H (calcium silicate hydrate), and upgrades in density, durability, and strength. However, substitution levels exceeding 20–30% increased the proportion of inert silica, reduced material reactivity, improved porosity, leading to a decline in mechanical performance. Moderate incorporation of ceramic waste powder improved mechanical strength and reduced thermal conductivity. Excessive usage led to strength reduction, prolonged setting time, higher water absorption, as well as decreased thermal stability.

Studies on cement substitution using ceramic roof tile waste showed that the particle size was generally coarser compared to cement. This result implied that the length of grinding in the finish mill significantly influenced the fineness of ceramic waste powder. Prolonged grinding times led to greater fineness values, indicating improved particle refinement and increased potential reactivity [9].

C. Workability of Fresh Concrete

Fresh concrete can be defined as a composite material comprising ordinary Portland cement or other hydraulic binders, fine aggregates, coarse aggregates, and water in a plastic as well as workable state before the onset of hardening due to hydration. Well-designed fresh concrete should be capable of being mixed, transported, placed, and compacted without showing undesirable phenomena such as segregation or bleeding.

Workability of fresh concrete is influenced by several factors, including water content, cement content, aggregate grading, aggregate shape and surface texture, and compaction methods. The consistency or flowability of fresh concrete is commonly evaluated using the slump test, which serves as a practical indicator of workability following ASTM C143 and ACI guidelines.

Previous studies reported that partial substitution of cement with finely ground brick waste powder increased water absorption in the cementitious matrix, leading to lower slump values and altered mixture consistency [8]. This behavior is mainly due to the increased specific surface area of finer particles, resulting in higher water demand during mixing. Consequently, the presence of finely ground ceramic or brick waste powder significantly affects the rheological behavior of fresh concrete and may accelerate slump loss over time.

Existing study has predominantly focused on durability, long-term performance, and mechanical strength of cement-based composites, although numerous studies have investigated the utilization of brick and ceramic waste powders as supplementary cementitious components. Limited attention has been directed to the influence of CRTWP on the fresh characteristics of concrete, particularly its time-dependent workability and slump loss behavior.

As previous studies have reported pozzolanic potential of ceramic waste powders, the effect of particle fineness, specifically when fineness exceeds ordinary Portland cement, on slump loss mechanisms remains insufficiently understood. This lack of understanding is particularly critical for practical concrete applications, where workability retention is a major performance requirement.

This study hypothesizes that the partial substitution of ordinary Portland cement with finely ground CRTWP significantly affects the slump loss behavior of fresh concrete due to increased water absorption and altered particle packing characteristics. In addition, an optimum replacement level exists at which workability retention can be maintained without compromising fresh concrete performance. This study is aimed at addressing the observed gap by systematically assessing the relationship between CRTWP fineness, replacement level, and slump loss behavior in concrete.

III. METHODS

This study was performed to examine the behavior of concrete with CRTWP used as a partial cement replacement. All experimental procedures were performed under controlled laboratory conditions following Indonesian National Standards (SNI) and relevant testing regulations. The experimental program included the use of composite Portland cement, Blaine fineness testing, and concrete slump testing.

The study method consisted of several sequential stages, including a comprehensive literature review, material preparation, material characterization, specimen preparation, experimental testing, and data analysis. The materials used largely consisted of Portland Composite Cement (PPC), silica sand, Optima sand, crushed stone with a nominal maximum size ranging from 5 to 25 mm, and ceramic roof tile waste originating from Sokka roof tile production. The equipment applied during the process included hammers, a jaw crusher, a grinder (finish mill), an oven, sieves, a Blaine air permeability apparatus, a concrete mixer, and an Abrams cone.

CRTWP was used to partially substitute cement at five substitution levels: 0%, 2.5%, 5%, 7.5%, and 10% by weight of cement. The experimental program comprised fineness testing of the waste powder and slump loss testing of fresh concrete.

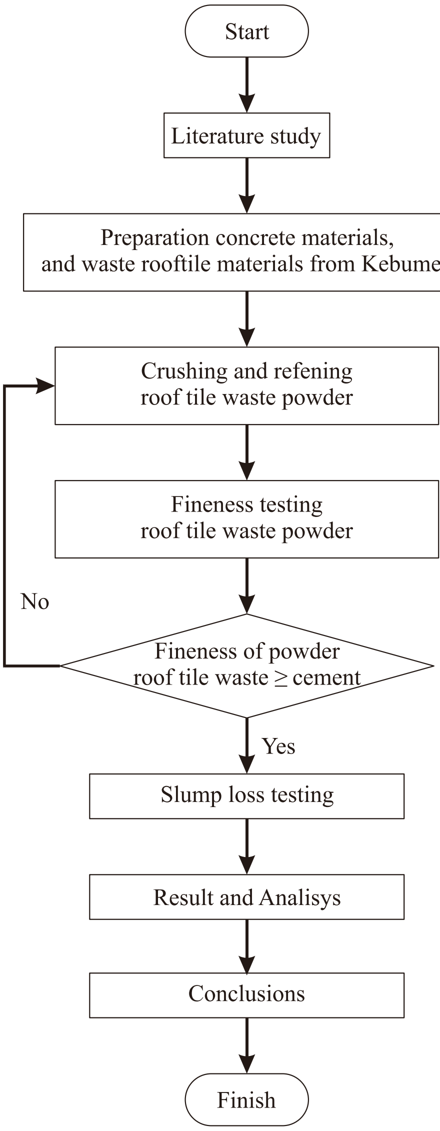

Figure 1. Study Flowchart

As many as 15 ceramic roof tiles that failed to meet quality control standards were collected from a roof tile manufacturer and used as raw material. The preparation process started with the reduction of water content by air-drying the tiles under sunlight for 2 days. Tiles were manually broken using a hammer into fragments measuring approximately 3–5 cm. These fragments were further reduced in size via a crusher before being dried in an oven for 24 hours at 100 °C to eliminate residual water. After drying, the material was weighed, amounting to a total mass of 11.99 kg.

The dried ceramic tile waste was subsequently ground using a finish mill until fineness comparable to or higher than cement was achieved. The finish mill operated via steel grinding balls with diameters ranging from 30 to 80 mm, occupying approximately 40% of the milling chamber, which facilitated effective particle size reduction through impact and abrasion [11]. The ground material was then sieved using a No. 280 sieve to obtain a uniformly fine powder suitable for use as a cement substitute. The overall preparation process of CRTWP was shown in Figure 2.


a). broken roof tile waste hammer b). crusher


c). oven d). grinding


e). 280 sieve f). roof tile waste powder

Figure 2. Crushing and refining the roof tile waste powder process

A. Fineness Test Procedure with Blaine Apparatus

Fineness test using the Blaine air permeability apparatus was conducted to determine the specific surface area of cement and CRTWP. The procedure followed the relevant standard methods for air permeability testing.

The test sample was initially weighed according to the required mass. A filter paper with a diameter of 12.7 mm was placed at the bottom of the permeability cell. The sample was then introduced into the cell using a funnel, after which the surface of the sample was carefully leveled. Another filter paper was placed on top of the sample, and the material was compacted via a plunger to achieve the specified porosity.

An air permeability test was performed by passing air through the compacted sample under controlled conditions. The apparatus measured the time required for a fixed volume of air to flow through the sample. Based on the measured flow time and the calibrated reference cement, the instrument automatically calculated Blaine specific surface area, expressed in cm²/g.

Figure 3 shows the use of the automatic Blaine apparatus for the fineness test of cement and CRTWP.

Figure 3. Automatic Blaine Tester

B. Concrete Slump Loss Testing

Slump loss testing was conducted to examine fresh concrete homogeneity and workability retention over time. The test was executed using a slump cone made of non-reactive metal following standard testing procedures. The mold was a truncated cone measuring 305 mm in height, 203 mm in base diameter, and 102 mm in top diameter. The top and bottom surfaces had an opening, which was parallel to each other and perpendicular to the cone axis.

Fresh concrete was placed into the mold in three layers of equal thickness, each representing about one-third of the mold volume. Each layer was densified with 25 evenly distributed strokes using a tamping rod. During the placement of the top layer, additional concrete was attached to ensure the mold was filled before compaction. The surface of the concrete was leveled by rolling the tamping rod across the top of the mold after compaction.

The mold was carefully lifted vertically to allow the concrete to subside freely. After the concrete was stabilized, the slump value was measured as the vertical difference between the height of the mold and the highest point at the center of the concrete surface. Slump value was recorded to the nearest 5 mm during the process.

Slump loss measurements were performed three times for each concrete mixture at intervals of 30 minutes. During the testing period, concrete samples were covered to minimize water loss due to evaporation.

a). slump loss 1 b). slump loss 2 (+30 minutes)

c). slump loss 3 (+60 minutes)

Figure 4. Slump loss testing stages

IV. TEST RESULTS AND DISCUSSION

A. Fineness of Cement Material and Ceramic Tile Powder

Fineness testing using the Blaine air permeability method was performed to determine the specific surface area of cement and CRTWP. The principle of this test was that finer particles possessed a higher surface area-to-volume ratio, which increased the potential contact area for hydration reactions with water.

The initial Blaine test conducted on PPC used in this study showed a fineness value of 4677 cm²/g. For ceramic roof tile waste, the material was first crushed using a jaw crusher and oven-dried for 24 hours before grinding. After grinding with a finish mill for 5 minutes and subsequent sieving, the Blaine fineness value obtained was lower than the minimum requirement specified in SNI 15-2049-2004, which was 2800 cm²/g [8].

Ceramic tile waste material was subjected to additional grinding for 2 minutes to achieve the desired fineness. This led to a fineness value exceeding the SNI requirement but still lower than that of cement. During the process, further grinding was conducted for an additional 2 minutes. Based on the final test results, CRTWP achieved a fineness value of 4871 cm²/g. The results showed that the waste powder satisfied the minimum fineness requirement and also signified a higher fineness level than the cement used in this study, justifying the classification as an ultra-fine cement substitute.

B. Slump Loss Results

Slump loss testing was conducted on five concrete mixture variants incorporating different percentages of CRTWP as a partial cement substitute, namely mixture A (0%), B (2.5%), C (5%), D (7.5%), and E (10%). All concrete mixtures were designed to achieve an initial slump value of 13 cm. Subsequent slump measurements were performed at intervals of 30 minutes up to 60 minutes.

The results of slump loss tests, along with the corresponding amounts of mixing water required for each concrete mixture, were shown in Table 1. The data represented the variation in slump loss behavior and water demand associated with different levels of cement substitution using CRTWP.

Table 1. Slump Loss Result

Cement substitution percentage (%)	**Water amount (ltr)**	**Slump loss (cm)**		
		0'	**30'**	**60'**
A = 0	12.9	13.00	8.50	6.00
B = 2.5	13.2	13.00	8.50	6.50
C = 5	13.1	13.00	8.50	6.00
D = 7.5	12.7	13.00	8.00	6.00
E = 10	12.8	13.00	7.50	6.00

C. Discussion

The results revealed that the partial cement replacement with CRTWP possessing Blaine fineness equal to or greater than cement led to relatively similar final slump loss values after 60 minutes. An average slump reduction of approximately 6 cm was observed across all concrete mixtures. This consistent final slump loss implied that cement substitution with CRTWP up to 10% did not significantly alter workability retention of fresh concrete. Despite this similarity in final slump loss, variations were observed in the amount of mixing water required to achieve the target initial slump value of 13 cm for each mixture.

When the water content of the control mixture (mixture A, 0% cement substitution) was obtained as the reference value (100%), the relative water requirements of the other concrete mixtures presented significant differences. These variations in water demand were shown graphically in Figure 5, presenting the effect of CRTWP fineness on the fresh concrete mixture behavior.

Figure 5. Graph of water content

Concrete mixtures with higher water content tended to show slower stiffening behavior, which was particularly evident in the results of the second slump measurement conducted after 30 minutes. This condition signified an improved workability retention during the early stages of hydration.

Mixtures with lower water content experienced a more rapid reduction in slump value at the same testing interval. This behavior was specifically pronounced in mixtures D (7.5% cement substitution) and E (10% cement substitution), indicating that reduced water availability accelerated early loss of workability in concrete containing higher proportions of CRTWP.

V. CONCLUSION

In conclusion, this study showed that grinding duration significantly influenced powder fineness, and CRTWP achieved Blaine fineness compared to the cement used. Concrete mixtures incorporating up to 10% CRTWP indicated relatively similar final slump loss values, with an average reduction of approximately 6 cm after 60 minutes. Although different water contents were required to achieve the target initial slump, mixtures with higher water content showed better workability retention during the early stages. These results signified that ultra-fine CRTWP could be used as a partial cement substitute without adversely affecting fresh concrete workability, provided appropriate water adjustments are applied.

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