

The Improvement of Self-Compacting Concrete Strength with ESP-Glass Powder as a Substitute for Concrete Admixture

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Abstract

This study investigates the utilization of waste materials, namely glass powder and eggshell powder, as partial substitutes for fine aggregate and cement in Self-Compacting Concrete (SCC). The aim is to contribute to sustainable construction practices by reducing waste and enhancing concrete performance. Experimental analysis was conducted on SCC mixtures with varying percentages of eggshell powder (ESP) and glass powder. The results demonstrated that both materials can be effectively incorporated into SCC without compromising workability, as measured by slump flow and other tests. In terms of compressive strength, the addition of glass powder resulted in a significant increase, reaching a maximum of 56.6 MPa at a 20% substitution rate. ESP also positively influenced compressive strength, with the highest value of 48.7 MPa achieved at a 15% substitution rate. Furthermore, the study observed changes in the cracking pattern of SCC with increasing percentages of ESP and glass powder. These findings highlight the potential of waste materials to enhance the mechanical properties and sustainability of SCC, providing valuable insights for future applications in the construction industry.

Keywords: Compressive Strength, ESP, Glass Powder, Fine Aggregate, SCC

I. INTRODUCTION

In the manufacturing process, concrete material can be applied in many construction activities [1], [2], [3]. In recent years, concrete innovation has been developed, namely Self-Compacting Concrete (SCC). SCC is an innovative concept of concrete technology that is efficient and effective, with great fluidity so that it can flow and fill the spaces in the mold with little or no compaction process. So that it can reduce the compaction process time, for example, when using glass and eggshell waste [4], [5], [6]. Glass and eggshell waste come from different sources, but they have very different potential. Glass waste, with its strength and rigidity, is suitable for structural applications such as concrete. Meanwhile, eggshells, with their high calcium carbonate content, can be used as a source of calcium in building materials or even as a cement substitute, thus offering solutions to environmental and industrial problems. In addition, with a molecular structure rich in silica, glass waste has a much higher compressive strength than ordinary fine aggregates. This property, coupled with its high stiffness, makes glass very suitable for partial or complete replacement of aggregates in concrete production. The use of waste glass not only improves the performance of concrete but also provides an innovative solution to the problem of waste management [7], [8], [9], [10].

The eggshell is the outermost layer of the egg that serves to protect all parts of the egg from injury and damage. The composition of eggshells is 98.2% calcium carbonate, 0.9% magnesium, and 0.9% phosphorus [11]. The eggshell processing process includes washing, drying, and pulverizing using a blender before finally sieving with a No. 200 sieve. The resulting eggshell powder is then mixed with cement in making concrete [12], [13], [14]. In recent years, ESP has attracted increasing attention as a partial cement substitute in sustainable concrete. A study by Chong et al. (2024) tested ESP as an alternative to limestone in Portland cement; the results showed that although ESP reduced the compressive strength of concrete with substitution up to 15%, the hydration process was accelerated by the nucleation effect, but the strength still decreased gradually with increasing dosage (e.g., from 54.8 MPa in the control to 35.5 MPa at 15% ESP) [15], [16], [17]. Research on SCC that partially replaced the filler with glass powder (GP) up to 50% as a substitute for cement filler showed that the use of GP improved durability capabilities-including resistivity, capillary absorption, and chloride penetration, without reducing the compressive strength of the SCC [18]. In another study using RSM, SCC mixtures were tested with varying proportions of glass powder and marble powder. The analysis showed that the addition of GP required a high level of superplasticizer to avoid loss of workability, but the 28-day compressive strength increased significantly. Although the ESP approach is not available, it is useful for integrating waste filler materials [19]. Another study, addressing the use of environmentally friendly admixtures, demonstrated that ESP was mixed with fly ash (without SCC), where the ESP process involved similar washing, drying,

grinding, and 75 μ m screening. Geopolymer concrete, with 40% ESP, produced the highest compressive strength of ~32MPa, reinforcing the potential of ESP in environmentally friendly concrete applications [20].

In another study, it was reported that cement substitution of up to 10% ESP was able to increase compressive strength (~53.5MPa) and splitting tensile strength (~2.49MPa), as well as reduce the carbon footprint by approximately 10% due to reduced cement consumption [22]. Meanwhile, the optimal substitution rate is in the range of 8–10% for high-strength concrete without sacrificing structural strength. However, durability, particularly in aggressive environments (chlorides and sulfates), still requires further research due to potential weaknesses in certain chemical environments [23]. Although ESP substitution decreases the total hydration per weight of concrete, the nucleation effect on the ESP surface increases the hydration efficiency relative to cement. In addition, a monocarboaluminate phase is formed as detected by XRD/FTIR and TG, although the calcium hydroxide content decreases relatively with cement reduction [24]. Another study focusing on nano-modification of concrete showed 10% ESP as the optimal dosage to obtain an increase in compressive strength of up to ~11%, a decrease in deformation (~5–10%) and an increase in elastic modulus (4%) compared to the control, but high substitution (>25%) resulted in a drastic decrease in performance (-21% to -26%) [25]. More broadly, ESP has a limestone-like CaCO₃ content, providing a filler effect and accelerating the hydration process. This review highlights the optimal benefits of substitution at 10%, but also warns against resistance to water penetration, carbonation, and acidic/sulphate environments [26].

In previous studies described above, it was concluded that ESP was proven to be able to increase semen hydration and compressive strength when processed into a fine powder (<75 μ m). Furthermore, glass powder material as a filler substitute increases SCC durability and maintains compressive strength, but workability needs to be protected with a high-performance superplasticizer. Meanwhile, no SCC studies have been found that simultaneously and have not combine ESP and glass powder in one SCC mixture. This indicates a research gap that can be filled with waste composite experiments that utilize both materials. This research examines the effect of eggshell admixture on the compressive strength of self-compacting concrete. Secondly, along with the increasing awareness of environmental sustainability, this research will also investigate the effect of adding glass powder as a partial replacement of fine aggregate on improving the strength and durability of self-compacting concrete. Thus, this research is expected to contribute to the development of sustainable, environmentally friendly concrete.

II. METHOD

This study presents a laboratory investigation into the feasibility of utilizing waste materials—namely eggshell powder and glass powder (Figure 1) as alternative constituents in self-compacting concrete (SCC) mixtures. The data are derived from material property tests, conducted by varying the proportions of eggshell powder (0%, 7.5%, and 15%) as a partial replacement for cement, and glass powder (0%, 10%, and 20%) as a partial replacement for fine aggregate. These mixtures were then tested using a compressive strength machine to determine the compressive strength of the concrete mixture and to analyze the effect of this mixture substitution on the properties of the SCC material after 28 days of curing.



Figure 1 (a) Eggshell Powder and (b) Glass Powder

To further elaborate on the methodology, the experimental process began with the collection and preparation of raw materials, where eggshells were thoroughly cleaned, dried, and ground into fine powder, while glass waste was crushed and sieved to achieve a particle size comparable to that of fine aggregates. Each SCC mixture was designed according to standard mix design procedures to ensure uniformity in workability and consistency across all test samples. The batching process involved careful weighing of materials, followed by mechanical mixing to achieve a homogeneous blend. The fresh concrete mixtures were subjected to workability tests—including the slump flow, V-funnel, and J-ring tests—to assess their self-compacting properties before casting. Specimens were molded into standard cylindrical forms and cured in water for 28 days under controlled

temperature and humidity. After the curing period, compressive strength tests were conducted using a calibrated universal testing machine in accordance with ASTM C39/C39M standards. The data obtained were then statistically analyzed to compare the influence of different proportions of eggshell powder and glass powder on the mechanical performance of SCC.

III. RESULTS AND DISCUSSION

A. Concrete Mixing

The planning formula utilized in this study is based on two key standards: SNI 03-2834-2000, which outlines the procedures for developing mix designs for normal concrete in Indonesia, and EFNARC (The European Federation of National Associations Representing producers and applicators of specialist building products for Concrete) guidelines published in 2005, which provide comprehensive European recommendations specifically for designing self-compacting concrete (SCC). These references serve as foundational frameworks to ensure the proper proportioning, consistency, and performance characteristics of the concrete mix. As presented in Table 1, the concrete mix incorporates essential elements derived from both guidelines, facilitating the formulation of a balanced mix that meets both national and international standards for quality, workability, and durability in SCC applications.

Table 1 Ingredients of Self-Compacting Concrete

Material	Weight
Cement	4.83 kg
Water	4.10 kg
Fine aggregate	13.03 kg
Coarse aggregate	19.96 kg

Table 1 provides a detailed breakdown of the constituent materials used in the formulation of Self-Compacting Concrete (SCC), highlighting the precise weight of each component to ensure the desired performance characteristics of the mix. The total mix includes 4.83 kg of cement, which acts as the primary binding agent responsible for the strength and durability of the concrete. The water content, measured at 4.10 kg, plays a critical role in initiating the hydration process and contributing to the fluidity required for self-compaction. The fine aggregate, weighing 13.03 kg, consists of smaller particles that fill voids between larger aggregates and assist in achieving a smooth surface finish. Meanwhile, the coarse aggregate, totaling 19.96 kg, provides the necessary skeletal framework that contributes to the compressive strength and dimensional stability of the concrete. The careful proportioning of these materials is essential in producing SCC that is capable of flowing under its own weight, filling formwork completely, and encapsulating reinforcement without the need for mechanical vibration. This balance also ensures resistance to segregation and bleeding, which are vital for maintaining uniformity and quality in both fresh and hardened states of the concrete.

B. Slump flow and T_{500}

Table 2 Slump Flow and T_{500} Testing of Eggshell Powder

Cement Substitution	D1 (mm)	D2 (mm)	Average (mm)	T_{500} (sec)
0	650	560	605	5
7.5	650	540	595	3
15	650	560	605	4

Table 2 presents the results of the slump flow and T_{500} time tests conducted on Self-Compacting Concrete (SCC) incorporating varying levels of eggshell powder as a partial cement substitute. The slump flow test measures the horizontal spread diameter of the concrete, indicating its flowability, while the T_{500} test records the time required for the concrete to reach a 500 mm spread, reflecting its viscosity and flow rate. At 0% cement substitution (control sample), the slump flow diameters measured 650 mm and 560 mm, with an average of 605 mm and a T_{500} time of 5 seconds. When 7.5% of the cement was replaced with eggshell powder, the flow diameters were 650 mm and 540 mm, averaging 595 mm, and the T_{500} time improved to 3 seconds, suggesting increased flowability and reduced viscosity. At a higher substitution rate of 15%, the slump flow readings were again 650 mm and 560 mm, with an average of 605 mm and a T_{500} time of 4 seconds. These results indicate that the addition of eggshell powder at moderate levels can influence the fresh properties of SCC, with 7.5% substitution enhancing flow characteristics, while higher levels tend to maintain similar spread

but slightly reduce flow rate efficiency. The data suggest potential for sustainable cement replacement without significantly compromising workability.

Table 3 Slump Flow and T₅₀₀ Testing of Glass Powder

Fine aggregate Substitution (%)	D1 (mm)	D2 (mm)	Average (mm)	T500 (second)
0	650	560	605	4
10	550	550	550	4
20	580	620	600	3

Table 3 summarizes the results of slump flow and T500 time tests on Self-Compacting Concrete (SCC) incorporating glass powder as a partial substitute for fine aggregate at varying replacement levels. The slump flow test, represented by diameters D1 and D2, assesses the flowability of the concrete, while the T500 test measures the time required for the mix to spread to a 500 mm diameter, indicating its viscosity and flow rate. At 0% glass powder substitution (control mix), the flow diameters were 650 mm and 560 mm, with an average of 605 mm and a T500 time of 4 seconds. When 10% of fine aggregate was replaced with glass powder, both D1 and D2 recorded consistent values of 550 mm, yielding an average slump flow of 550 mm, while the T500 time remained unchanged at 4 seconds, suggesting a slight reduction in workability. At a 20% substitution level, the slump flow increased to 580 mm and 620 mm, with an average of 600 mm, and the T500 time decreased to 3 seconds, indicating improved flow characteristics and reduced viscosity. These findings suggest that while low-level substitution may slightly hinder flowability, higher percentages of glass powder can enhance the fresh properties of SCC, offering a viable approach to sustainable and efficient concrete production.

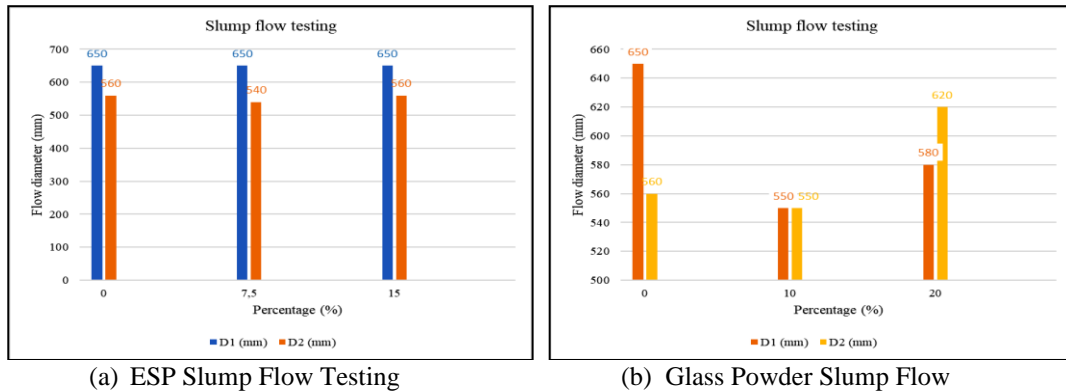


Figure 2 Slump Flow Test

Table 2 and 3, and Figure 4 show the results of the Slump flow test. The three variations are 0%, 7.5%, 10%, 15% and 20%. At 0% flow diameter (650 mm and 560 mm), 7.5% flow diameter (650 mm and 540 mm), 10% flow diameter (550 mm and 550 mm), 15% flow diameter (650 mm and 560 mm), and 20% flow diameter (580 mm and 620 mm).

C. J-ring Test

Table 4 J-ring Test of ESP

Cement Substitution (%)	J1 (mm)	J2 (mm)	J3 (mm)	Average (mm)
0	70	100	100	90
7,5	75	100	100	92
15	100	95	100	98,333

Table 4 presents the results of the J-ring test conducted on Self-Compacting Concrete (SCC) mixtures containing varying percentages of eggshell powder (ESP) as a partial replacement for cement. The J-ring test is used to evaluate the passing ability of SCC, particularly its capacity to flow through congested reinforcement without segregation or blockage. Measurements J1, J2, and J3 represent three replicate flow diameters taken around the J-ring, and their average provides an overall indication of the concrete's passing ability. At 0% ESP

substitution (control mix), the flow measurements were 70 mm, 100 mm, and 100 mm, resulting in an average of 90 mm. With 7.5% ESP replacement, the measurements slightly increased to 75 mm, 100 mm, and 100 mm, giving an average of 92 mm, suggesting a marginal improvement in passing ability. At 15% substitution, the values recorded were 100 mm, 95 mm, and 100 mm, leading to a higher average of approximately 98.33 mm. These results indicate that increasing the proportion of eggshell powder in the mix enhances the concrete's ability to pass through obstructions, possibly due to improved particle packing and mix cohesion. Therefore, ESP shows potential as a sustainable supplementary cementitious material that positively influences the flow characteristics of SCC, especially in reinforced structural applications.

Table 5 J-ring Test of Glass Powder

Fine Aggregate Substitution (%)	J1 (mm)	J2 (mm)	J3 (mm)	Average (mm)
0	70	100	100	90
10	70	100	95	88,33
20	100	94	100	98

Table 5 displays the J-ring test results for Self-Compacting Concrete (SCC) incorporating glass powder as a partial replacement for fine aggregate at varying substitution levels. The J-ring test assesses the passing ability of SCC by simulating flow through congested reinforcement, with measurements J1, J2, and J3 representing flow diameters in millimetres at three different points. At 0% glass powder substitution (control mix), the flow measurements were 70 mm, 100 mm, and 100 mm, yielding an average diameter of 90 mm. When 10% of the fine aggregate was replaced with glass powder, the corresponding measurements were 70 mm, 100 mm, and 95 mm, resulting in a slightly lower average of 88.33 mm, indicating a minor reduction in passing ability. However, at a 20% substitution level, the flow readings improved to 100 mm, 94 mm, and 100 mm, with an average of 98 mm, suggesting enhanced flowability through restricted spaces. These findings demonstrate that while a moderate replacement level may slightly hinder the mix's ability to pass through obstructions, a higher percentage of glass powder can enhance the passing ability, potentially due to improved particle distribution and reduced interparticle friction. Thus, glass powder shows promise as an eco-friendly alternative material in SCC mixtures, contributing positively to its fresh performance.

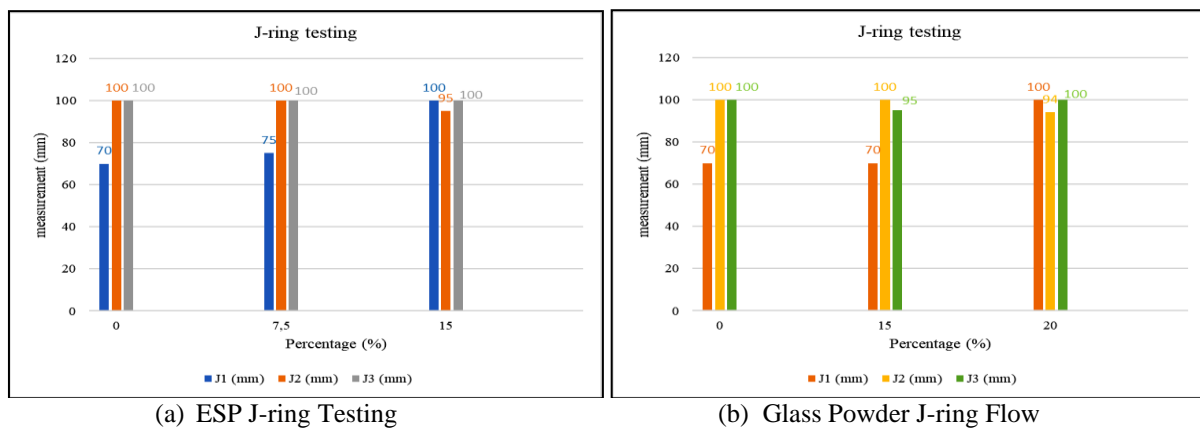


Figure 3 ESP and Glass powder J-ring Testing

Table 4, Table 5, and Figure 3 present the results of the J-ring test conducted to evaluate the passing ability and flow characteristics of self-compacting concrete (SCC) mixtures with varying percentages of material substitution. The test was performed across five variation levels: 0%, 7.5%, 10%, 15%, and 20%. At 0% substitution, the recorded flow diameters were 70 mm, 100 mm, and 100 mm. For the 7.5% variation, the values were slightly improved at 75 mm, 100 mm, and 100 mm. The 10% variation produced flow diameters of 70 mm, 100 mm, and 95 mm, while the 15% variation yielded results of 100 mm, 95 mm, and 100 mm. Finally, at 20% substitution, the test showed flow diameters of 100 mm, 94 mm, and 100 mm. These results indicate a general trend of increased flowability and consistency at higher substitution levels, suggesting improved passing ability of the concrete mix through reinforcing bars, which is a critical property for SCC performance.

D. Compressive Strength

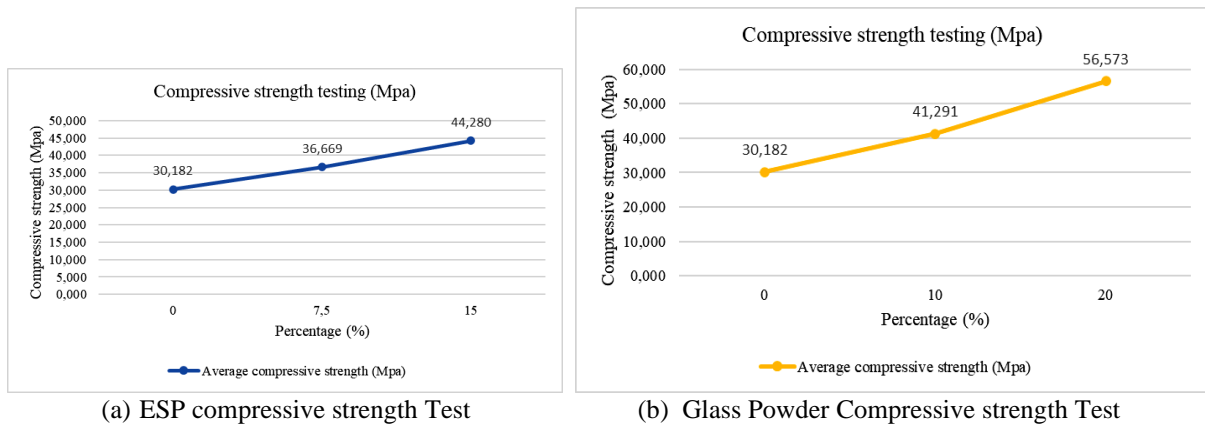


Figure 4 Compressive Strength Test of ESP

Figure 4 illustrates the compressive strength test results of self-compacting concrete (SCC) incorporating various proportions of eggshell powder and glass powder as partial substitutes in the mix. The data reveal a significant improvement in compressive strength as the percentage of these alternative materials increases. The highest compressive strength recorded for the eggshell powder variation was 44.28 MPa, which occurred at the 15% substitution level, indicating an optimal balance between workability and strength enhancement. Similarly, the glass powder variation achieved an even greater maximum compressive strength of 56.57 MPa, highlighting its superior pozzolanic properties and ability to enhance the concrete matrix. In contrast, the lowest compressive strength observed was 30.18 MPa in the control mixture with 0% substitution, demonstrating the beneficial impact of both eggshell and glass powders in improving the mechanical performance of SCC.

E. Crack Pattern

In the 0% variation, the crack patterns that occurred were conical and split crack patterns. The crack pattern generally starts from the center of the specimen and spreads towards the edges. One factor that may affect this crack pattern is the presence of segregation in the concrete mix. Segregation causes non-uniformity in aggregate distribution, which can become a weak point and trigger cracking. Figure 5a - 5e explains the stages of crack patterns that occur after the concrete is tested for compression.

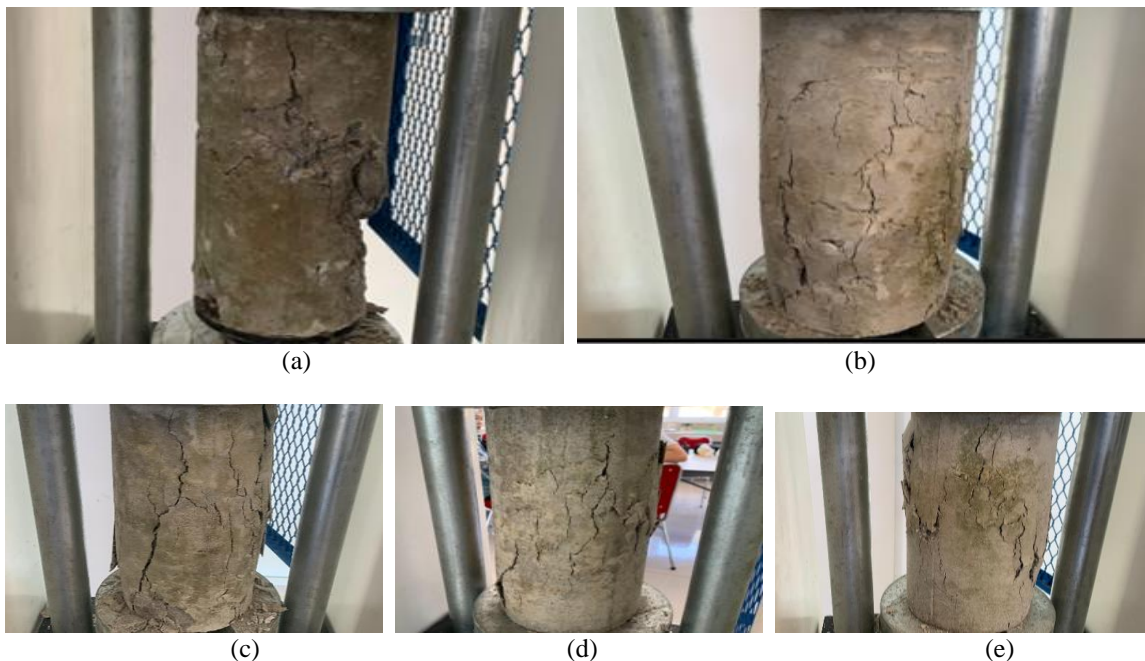


Figure 5 Crack Pattern level

At a 7.5% variation in Figure 5a, the crack pattern becomes more complex, namely conical, shear, and upright axis cracking patterns. The possibility of uneven stress distribution due to the addition of eggshell powder. The crack pattern produced at a 10% variation in Figure 5b is conical and split; this crack pattern is common in concrete. Most likely, the cracks that occur are caused by segregation in the concrete mixture. The non-uniformity of aggregate distribution due to segregation creates weak points that are prone to cracking. At 15% variation in Figure 5c, the crack patterns are cone and split crack patterns. The possibility is caused by the addition of a lot of eggshell powder, causing eggshell powder to clump. So that the distribution of eggshell powder is uneven. At a percentage variation of 20% in Figure 5d, the crack patterns that occur are cone and split crack patterns. The difference in size and weight between glass powder and coarse aggregate makes glass powder tend to rise to the top when the concrete mixture is transported or compacted. This causes the distribution of concrete constituent materials to be uneven.

IV. CONCLUSION

The study found that the self-compacting concrete mix design was based on the guidelines outlined in SNI 03-2834:2000. The materials required for 3 test pieces are cement content of 4.83 kg, water of 4.10 kg, fine aggregate of 13.03 kg, and coarse aggregate of 19.96 kg. The results of the slump flow and J-ring tests showed that neither the addition of fine aggregate substitution (0%, 10%, and 20%) nor the substitution of eggshell powder as cement (0%, 7.5%, and 15%) caused a significant decrease in the slump flow values, indicating that the addition of these materials did not interfere with the ability of the bet-on to flow independently and meet the workability requirements as per EFNARC 2005 standards. The compressive strength test results showed that both eggshell powder and glass powder can be good alternatives to increase the strength of Self-Compacting Concrete (SCC). The use of 15% eggshell powder resulted in an increase in compressive strength up to 44.280 MPa, while glass powder made a more significant contribution, with the maximum compressive strength reaching 56.573 MPa at 20% variation. The results obtained indicate that eggshell powder and glass powder have great potential to be developed as environmentally friendly concrete additives. The cracking pattern of concrete showed significant variation as the percentage of eggshell powder and glass powder substitution increased. At 0%, 10%, 15% and 20%, the crack patterns were generally conical and split. However, at the 7.5% variation, the crack pattern became more complex with shear cracking and parallel to the upright axis.

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