Materials Research Proceedings 63 (2026) 72-84 https://doi.org/10.21741/9781644904053-9

A Comparative Analysis of the Influence of Fly Ash on the Mechanical Behavior of Self-Compacting Concrete

Dawit BEZA[2*], Muluken GETACHEW[1], Opeoluwa Rotimi DADA[2], Aschalew ZERIHUN[1] and Bolanle Deborah IKOTUN[2]

[1]Department of Construction Technology and Management, College of Engineering, and Technology, Mizan Tepi University. Tepi, Ethiopia

[2]Department of Civil and Environmental Engineering and Building Science, College of Science, Engineering and Technology, University of South Africa

23955090@mylife.unisa.ac.za

Keywords: Fly Ash, Self-Compacting Concrete, Mechanical Properties, Ordinary Portland, Cement

Abstract. Concrete is a widely used construction material composed of cement, fine and coarse aggregates, and water, mixed in specific proportions. Its strength and durability are critical for the performance of civil engineering structures, particularly in building construction. However, these properties are significantly influenced by factors such as mixed design, workmanship, and compaction methods. Therefore, research is essential to optimise and mitigate the effects of these variables, thereby enhancing the performance of concrete. This study aimed to evaluate the fresh and hardened properties of self-compacting concrete (SCC) incorporating fly ash as a partial replacement for cement. Four mix groups were prepared: a control mix with 0% fly ash, and SCC mixes with 5%, 10%, and 15% fly ash replacement. Materials were sourced locally from the Tepi and Jimma areas, apart from Class F fly ash, and chemical admixtures were acquired from Addis Ababa. The mix ratio used was 1:1.735:1.728 (cementitious material: fine aggregate: coarse aggregate), with varying cement and fly ash contents. Fresh properties were assessed using slump flow, flow table, segregation resistance, T500 mm time, and J-ring tests. Compressive strength was measured at 7, 14, and 28 days. The results demonstrated that all SCC mixes met ASTM standards for fresh properties. The compressive strength of all mixes with fly ash outperformed that of C-25 grade concrete, with the 10% replacement achieving the highest strength of 50.2 MPa. Moreover, all replacement levels up to 15% demonstrated superior performance compared to the control mix. Although the optimum replacement percentage was not definitively identified, SCC with fly ash showed improved properties across all parameters. In conclusion, the incorporation of fly ash in SCC enhances both performance and economic viability, rendering it a sustainable alternative to conventional SCC that solely uses ordinary Portland cement (OPC).

1. Introduction

Concrete is one of the most important and widely used construction materials globally (Ye et al., 2020). It is primarily composed of fine aggregate (sand), coarse aggregates (crushed stone), cement, and water, which are mixed in specified proportions to form a hard, stone-like mass after hydration. The versatility, availability, durability, relatively low cost of concrete and ability to conform to any structural shape have made it the generally preferred material for various civil works such as buildings, bridges, dams, roads, and tunnels (Letsosa et al., 2024) (Wlodarczyk & Jedrzejewski, 2016).

Over the decades, concrete has become synonymous with strength, durability, and permanence. As highlighted by (Zhang et al., 2018). Concrete has established itself as the backbone of modern infrastructure due to various factors such as the availability of raw materials, ease of fabrication

Content from this work may be used under the terms of the Creative Commons Attribution 3.0 license. Any further distribution of this work must maintain attribution to the author(s) and the title of the work, journal citation and DOI. Published under license by Materials Research Forum LLC.

on-site, and its ability to be moulded into various shapes. However, despite its strengths, the performance of conventional concrete can be significantly affected by several construction-related factors (Ye et al., 2020). These factors include improper water-to-cement ratio, poor mixing, inadequate vibration, and a lack of skilled labour during placement and finishing, which can lead to defects such as honeycombing, voids, and segregation. These defects ultimately compromise concrete strength, durability, and long-term serviceability (Alyamaç & Ince, 2009; Bhat, 2020; Campos et al., 2020). One major method to ensure the integrity of conventional concrete is to eliminate air voids and achieve maximum compaction through mechanical methods vibration. However, this process is not only labour-intensive but also dependent on the expertise of construction workers and the availability of appropriate equipment. In cases where skilled workers are unavailable, the risk of improper compaction increases. Therefore, in response to this challenge, a novel type of concrete known as Self-Compacting Concrete (SCC) was developed in the late 1980s in Japan (Kaish et al., 2018; Roig-Flores et al., 2016).

Self-Compacting Concrete (also referred to as Self-Consolidating Concrete or Self-Levelling Concrete) is a highly flowable, non-segregating concrete that spreads into place under its weight and fills the formwork even in the presence of dense reinforcement without the need for mechanical vibration. It maintains homogeneity during placement and offers a practical solution to challenges associated with compaction, especially in structures with complex geometries or congested steel arrangements. The development of SCC marked a breakthrough in concrete technology as SCC not only addresses the limitations of conventional concrete in terms of compaction but also enhances the quality and speed of construction. Self-Compacting Concrete has increasingly gained attention in both research and practice due to its benefits in terms of labour reduction, improved surface finishes, reduced construction noise (by eliminating vibrators), and better structural integrity in reinforced sections (Gesoğlu et al., 2012; Jagadesh et al., 2023; Roig-Flores et al., 2016).

Despite these advantages, SCC has not been widely adopted in some regions, largely due to limited awareness, lack of technical knowledge, and the relatively higher initial cost of materials such as chemical admixtures and supplementary cementitious materials. However, with increasing demand for faster, safer, and higher-quality construction, SCC is gradually gaining acceptance worldwide (Gesoğlu et al., 2012; Jagadesh et al., 2023; Jalal et al., 2015).

The production of SCC requires a precise mix design approach that balances flowability, segregation resistance, and strength. Unlike conventional concrete, SCC often incorporates a higher content of fine materials or fillers such as fly ash, limestone powder, silica fume, or slag. These materials enhance the fresh properties of SCC, such as flowability and viscosity, and assist in maintaining uniformity throughout placement. The selection of appropriate materials and mix proportions is essential to prevent problems like bleeding, segregation, or reduced strength (Hassan et al., 2015; Uysal & Yilmaz, 2011).

Fly ash, a commonly used mineral admixture in SCC, is a by-product of coal combustion in power plants. There are two main classes of fly ash, namely: Class C, which originates from lignite burning of coal, and Class F originates from anthracite materials and possesses pozzolana properties, which enhance the long-term strength and durability of concrete. Nevertheless, there is another type of fly ash known as Class N, which contains various materials such as volcanic ashes or pumicites, shales and clays. However, before it can be pozzolanic or cementitious, it must be calcinated. Generally, the spherical particle shape and fine texture of fly ash help to improve the workability and flow of SCC, making it an ideal material for enhancing fresh properties. Furthermore, the use of fly ash contributes to sustainability by reducing the consumption of Portland cement and utilizing industrial waste (Abd Elaty & Ghazy, 2018; Habibur Rahman Sobuz et al., 2023). In recent years, the application of SCC in the construction sector has increased,

especially in complex and densely reinforced structures, precast elements, high-rise buildings, and repair works worldwide (Alhorani et al., 2022; Bhagwat et al., 2023).

This research, therefore, evaluates and compares the properties of self-compacting concrete with supplementary materials such as fly ash and without fly ash.

2. Fly Ash and Self-Compacting Concrete

2.1 Fly Ash

Fly ash, known as pulverized fuel ash, is the residue ash from the combustion of powdered coal, transported by the flue gases and precipitated electrostatically or mechanically from thermal or coal-fired power stations (Behl et al., 2021; Rivera et al., 2015). It is the most used artificial pozzolana material (Shetty, 2005). According to (ASTMC618, 2010), this material does not include ashes produced from the direct injection of lime into the boiler for sulfur removal or the burning of industrial or municipal garbage, which is also known as "incinerator ash". Fly ash mineral composition could vary from one coal-fired plant to another; however, the major chemical constituents in fly ash are silica, alumina and oxides of calcium and iron (Loeb, 2008). A typical fly ash composition is presented in Table 1. Fly ash produced from coal-fired power plants is naturally a variable material due to a range of influencing factors. One of the primary reasons for this variability is the mineralogical composition of the coal itself, which can differ significantly depending on its source and geological formation. Additionally, the degree to which the coal is pulverized before combustion affects the surface area exposed to burning, thereby influencing the characteristics of the resulting fly ash (Reta & Mahto, 2019).

The type of furnace used during the combustion process also plays a crucial role, as different furnace designs operate under varying thermal conditions and combustion dynamics. Furthermore, the oxidation conditions within the furnace, particularly the air-to-fuel ratio, significantly affect the chemical and physical properties of the fly ash. An excess or deficiency of oxygen can lead to incomplete combustion or the formation of unwanted phases in the ash. Finally, the method of collection, handling and storage before its intended usage can contribute to its variability. For example, the improper handling or exposure to moisture and contaminants during storage can alter its physical and chemical characteristics, reducing its consistency and reliability for use in industrial applications such as cement and concrete production.

Table 1: Typical chemical composition of fly ash ((Mulugeta, 2017).

Contents	CaO	SiO_2	Al2O3	Fe_2O_3	MgO	Na_2O	K_2O	TiO_2	LOI	MnO	P_2O_5	H_2O
%	0.01	42.28	26.72	3.04	0.88	2.00	0.48	0.54	16.53	0.08	0.18	5.60

2.1.1 Classification of Fly Ash

Fly ash is broadly classified into two main categories according to (ASTMC618, 2010) namely: Class C and Class F, depending on the type of coal, combustion temperature, collection method and percentage of Calcium oxide. Class C fly ash originates from sub-bituminous coal and lignite and contains higher calcium content (CaO > 20%), while Class F fly ash is typically derived from anthracite and bituminous coal and contains low calcium content (CaO < 10%). Class F fly ash is particularly suitable for use in concrete requiring long-term durability and sulfate resistance. When used as a partial replacement for cement in concrete, fly ash contributes to the strength

development, improves workability, and enhances durability. Its effectiveness in concrete largely depends on its chemical and physical properties, particularly the presence of reactive silica and alumina, which react with calcium hydroxide during cement hydration to form additional calcium silicate hydrate (C–S–H), and the primary binder in concrete.

2.2 Self-Compacting Concrete

Self-compacting concrete (SCC), also known as super workable concrete or self-compactable concrete, is a high-performance concrete which can flow through and fill the gaps of reinforcement and the corners of the moulds without the need for external vibration (Prasad, 2016). It can be placed without vibration equally well in lightly or heavily reinforced sections. It has excellent deformability and segregation resistance, which result in the quality of the hardened concrete being independent of the workmanship during placing (Plank & Meyer, 2015). Originally developed to offset a growing shortage of skilled labour (EFNARC, 2002). In its plastic state, it flows silently under its weight and maintains homogeneity while completely filling the formwork of any shape, even around congested reinforcement. One of its advantages is that it does not require compaction as it self-compacts by its movement properties (Kapoor, 2012). Due to its high fluidity and resistance to segregation, it can be pumped over longer distances (Prasad, 2016)" and when transported in ready mixed concrete trucks, it minimizes transit mixtures and the turnaround time (Ghosh, 2017). Some key parameters to consider before classifying some concrete to be self-hardening include:

I. Filling Ability: SCC should be able to fill the formwork completely by going into every corner on its own.
II. Passing Ability: SCC should have the capability to pass the congested reinforcement without the need for external compaction, such as a vibrator.
III. Segregation resistance: SCC, like other concrete, is made up of several constituent materials having different specific gravities, so it is possible that at the time of placing materials having heavy mass tend to settle, causing segregation. The mix should be made such that it is able to resist segregation and maintain its homogeneity.

The properties of SCC based on performance are graphically illustrated in Figure 1.

The use of Self-compacting concrete (SCC) in the construction sector offers many benefits, such as improved productivity, reduced labour costs, enhanced aesthetics, and a safer work environment (The Engineering Community, 2011). However, it also presents challenges, including the need for precise materials monitoring, more trial batches, high sensitivity to mix variations, careful handling during transport and on-site placement, and increased formwork pressure that may cause leaching (concept concrete, 2019; The Engineering Community, 2011). Compared with conventional concrete of similar mechanical properties, the material cost of SCC is higher due to the relatively high demand of Cementation materials and chemical admixtures, including high-range water-reducing admixtures (HRWRA) and viscosity-enhancing admixtures (VEA) (Rajasekaran, 2017)

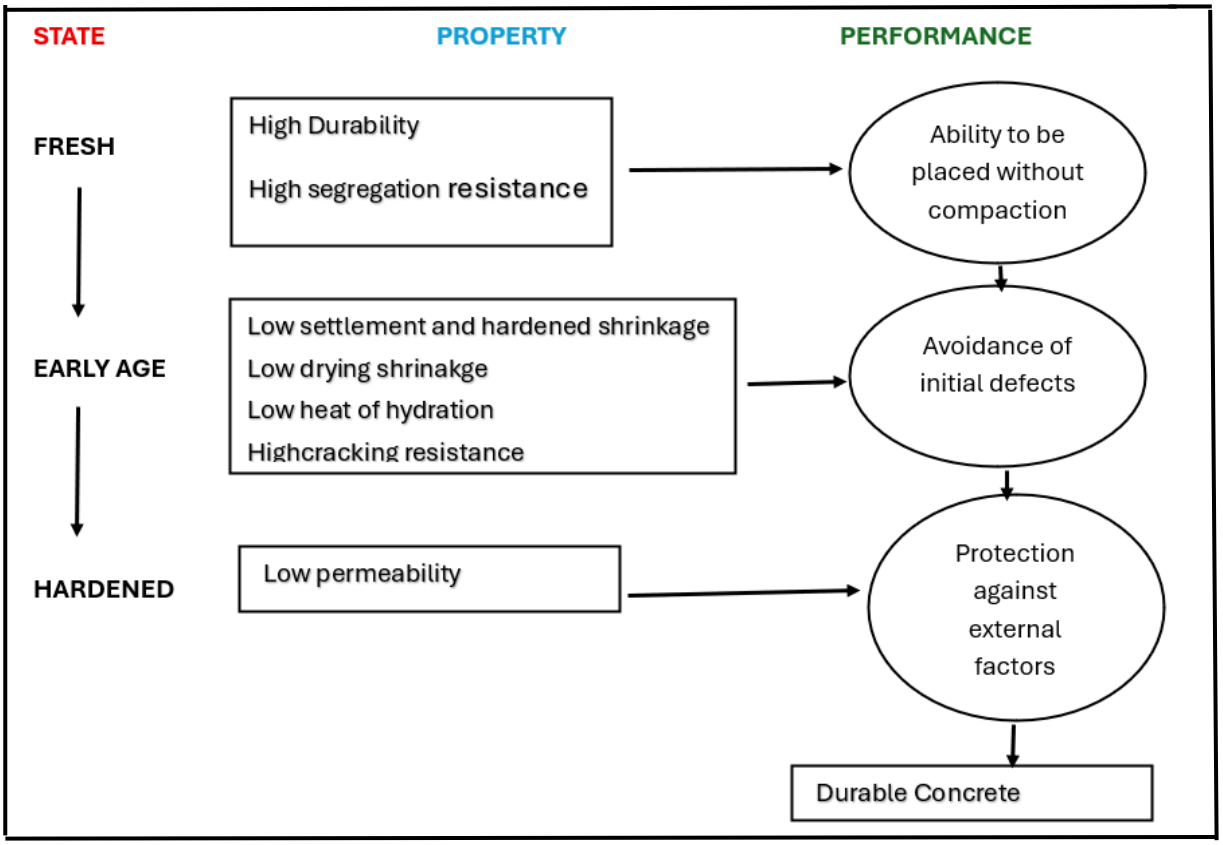


Figure 1: Graphical definition of Self-Compacting Concrete (Okamura, 2003)

Overall, the benefits of SCC, such as noise reduction, improved durability, thinner concrete sections and faster construction, outweigh those of conventional concrete, although the cost of production has been its major limitation due to larger quantities of Portland cement or supplementary cementitious materials used in SCC. Furthermore, more cementitious materials may be required to increase the fines content, to achieve stability, while admixtures such as HRWR and possibly a Viscosity Modified Admixture (VMA) will also increase the cost of SCC.

3. Materials and Methodology

3.1 Materials

The materials used for this research include ordinary Portland cement (OPC) grade 42.5N CEM, fine aggregate, water, admixture (polycarboxylic ether (PCE)), viscosity-modifying agent and fly ash.

3.2 Methodology

The methodology for this experimental research on determining the properties of self-compacting concrete with and without the inclusion of fly ash is outlined as follows: firstly, all materials used for producing concrete were carefully selected, measured, and mixed in a concrete mixer to ensure homogeneity; then, they were poured into cubic moulds measuring 15cm x 15cm x 15cm. The mix ratio used was 1:1.735:1.728 (cementitious material: fine aggregate: coarse aggregate), with varying cement and fly ash contents. When the concrete samples were demoulded, they were placed in a water-curing tank and left to cure for 7, 14, and 28 days. A total of 27 self-compacting samples were produced with 5%, 10%, and 15% fly ash inclusion, while the quantities of superplasticizer and super viscosity modifying agent used were kept constant at 1.2% and 0.4%, respectively. The Polycarboxylic ether (PCE) based superplasticizer conforms to ASTM C 494-92

in aqueous form to enhance workability and water retention, while the VMA ensures that the stability of the concrete is maintained to avoid segregation of the ingredients. Additionally, nine (9) control samples of normal concrete were made without fly ash, PCE, and VMA. These samples were cured for 7, 14, and 28 days and tested for mechanical properties, and then compared to the values obtained for self-compacting concrete. The measurement of each concrete constituent is presented in Table 2. Various tests were conducted to determine the fresh property parameters of each mix design based on fly ash addition, including the slump test, T500mm flow test, segregation resistance test, V-funnel test, L-box test, and J-ring tests. For the mechanical property test, only the compressive strength test was conducted on the concrete samples to determine the strength of the concrete under compression, especially with the inclusion of FA at different percentages. This test was done in triplicate after each curing period, and the average value recorded is presented in Figure 7.

4. Results and Discussion

Measurement of concrete constituents per mix design and the results obtained from each conducted test is presented and discussed in this section.

Concrete Constituents

The concrete composition by weight for each design mix is shown in Table 2. The cement demand decreases as fly ash content increases; however, it is maintained at a reasonable level so that the concrete's strength is not affected, while the admixture and VMA content stay constant.

Table 2: Concrete composition measurement

Concrete Composition	SCC with 5%	SCC with 10%	SCC with 15%	SCC with 0%	Normal Concrete
Cement	434.15 Kg/m^3	411.3 Kg/m^3	388.45 Kg/m^3	457Kg/m^3	370 Kg/m^3
Sand	792.92 Kg/m^3	792.92 Kg/m^3	792.92 Kg/m^3	792.92 Kg/m^3	763 Kg/m^3
Coarse Aggregate	789.96 Kg/m^3	789.96 Kg/m^3	789.96 Kg/m^3	789.96 Kg/m^3	1043.47 Kg/m^3
Fly Ash	22.85 Kg/m^3	45.7 Kg/m^3	68.55 Kg/m^3	0	-
HRWR	5.484 Kg/m^3	5.484 Kg/m^3	5.484 Kg/m^3	5.484 Kg/m^3	-
VMA	1.828 Kg/m^3	1.828 Kg/m^3	1.828 Kg/m^3	1.828 Kg/m^3	-
Water	174.07 Kg/m^3	174.07 Kg/m^3	174.07 Kg/m^3	174.07 Kg/m^3	178.6 Kg/m^3

Slump and Slump Flow Test

The slump test for normal concrete, which is used to determine the workability of concrete, was conducted by removing the slump cone from the moulded sample, and the gap between the tip of the inverted slump cone and the top of the collapsed concrete was recorded as the slump value. This is according to the ASTM C143M standard, and for normal concrete, the value was 11.3mm.

Although the ASTM C1611M standard for Slump Flow Test procedure is similar, it measures the spread diameter of SCC to determine the flowability and ability of SCC to pass through an obstruction or formwork. For this research, the Slump Flow Test result obtained for each design mix is presented in Figure 2.

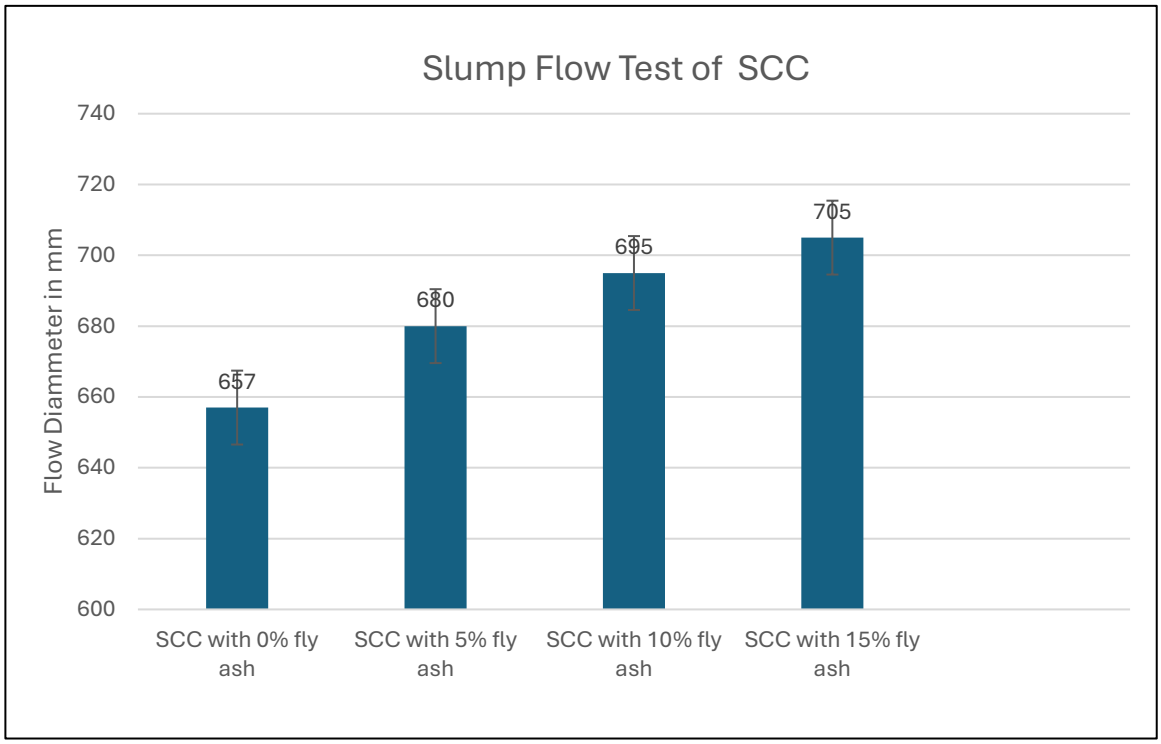


Figure 2: SCC Slump Flow Test Result

Based on ASTM C1611M standard for Slump Flow Test, a good SCC slump flow diameter ranges from 650mm to 800mm and from Figure 2, it can be seen that the more addition of fly ash to the concrete mix made the concrete the more flowable it becomes with SCC containing 15% FA exhibiting the highest flow table diameter of 705mm depicting that it has a better flowability and filling - ability properties as compared to other mix design as a result it can fill formworks faster with its weight. When compared with the control sample (SCC with 0% FA), it is evident that FA reduces the water absorption capacity of concrete, thereby contributing to the flowability properties of fresh concrete.

T_{500mm} Flow Test

The T_{500mm} flow test is a measure of the time required for SCC to flow and reach a diameter of 500mm (20 inches) during a slump flow test. This test indicates the viscosity of SCC, and it is essential to consider this factor when working with SCC, especially when the time to project completion is key. The result for the SCC design mix containing fly ash as compared to the control sample is presented in Figure 3.

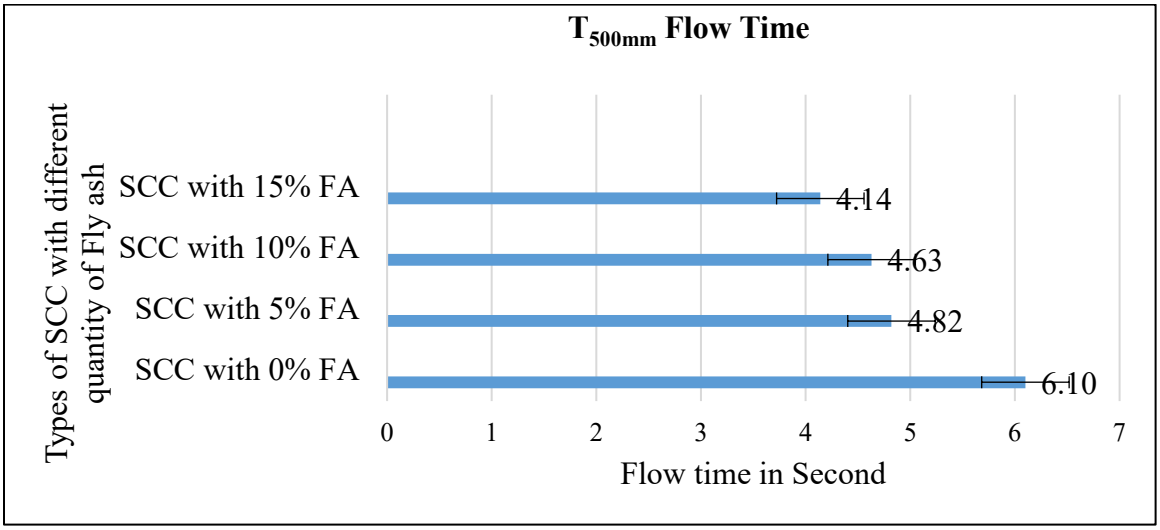


Figure 3: SCC T_{500mm} Flow Time Result

According to ASTM C1611, a good flow time for SCC is between 3-5 seconds, and from Figure 3, it can be inferred that adding FA to the concrete mix is essential for achieving this time because it increases SCC viscosity. Without FA, the time to reach a 500mm diameter is 6.10 seconds, but adding more FA to the mix increases flow speed and decreases the time needed for the concrete to flow and reach a 500mm diameter. From this research, a 15% addition of FA results in a time of 4.14 seconds to achieve a 500mm flow diameter. This test offers information on the time needed to fill a cubic metre of formwork under real-life site conditions.

Segregation Resistance of Self-Compacting Concrete

This test was conducted by pouring SCC slurry with FA on a horizontal concrete flow table to examine the free flow and stability of the concrete ingredients. As presented in Figure 4, the ingredients of the SCC mix containing fly ash are seen at all corners of the flow table. On the other hand, to achieve this in ordinary concrete, workability can only be improved by increasing the water content of the mix, which results in a reduction in the strength of hardened concrete and affects the stability of fresh concrete. However, for SCC, water is thickened by a viscosity-modifying admixture and stability is enhanced while segregation is controlled. Hence, SCC is better in segregation resistance as compared to ordinary concrete.



Figure 4: Showing Segregation Resistance of SCC

The J-Ring Test

The J-ring test is a quality control test for determining the passing ability of fresh SCC. The concrete passing ability of SCC slurry is obtained by measuring and calculating the difference in slump flow of the concrete with and without the J-ring apparatus, as illustrated in Figure 5. However, this property is vital in construction technology because it provides valuable information such as passing ability, concrete stability and identification of obstruction. In return, the information helps to optimize mix design and minimize structural risk.



Figure 5: Showing J-Ring Apparatus for the passing ability test of SCC

For this research, the J-Ring test was conducted according to ASTM C1621 and the values obtained for each mix design, that is, SCC with 0% FA, 5% FA, 10% FA and 15% FA are presented in Figure 6.

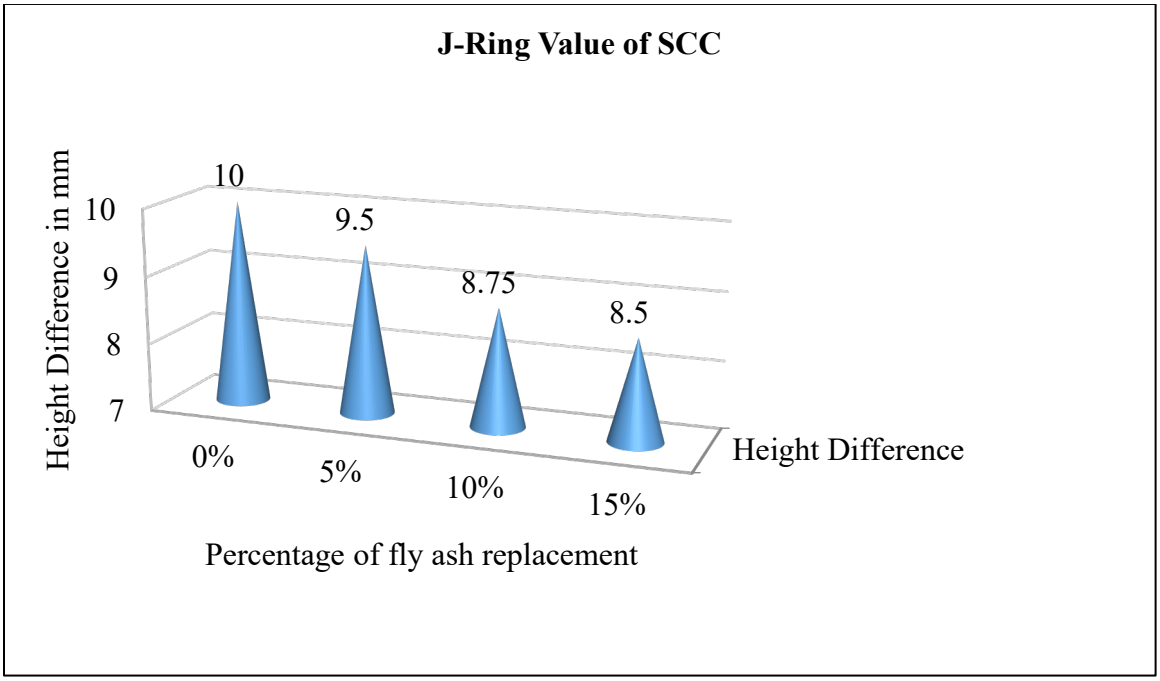


Figure 6: Result of J-Ring Test of SCC

The result of the J-ring test highlights the importance of adding fly ash to SCC, as it allows the concrete to pass more easily through obstructions or formwork compared to SCC with 0% FA. A

lower J-ring value indicates a better passing ability of the SCC. Therefore, it can be concluded that SCC with 15% FA, exhibits a superior passing ability compared to SCC with 5% and 10% FA.

Compressive Strength Test

The compressive strength test was conducted on the ordinary concrete (OC) samples after curing for 7, 14 and 28 days. Similarly, the test was also conducted on SCC samples after the same curing period for concrete with 0%, 5%, 10% and 15% fly ash content to determine the strength of the concrete under compression, and to examine the effect of fly ash on the strength of SCC. The result obtained is presented in Figure 7.

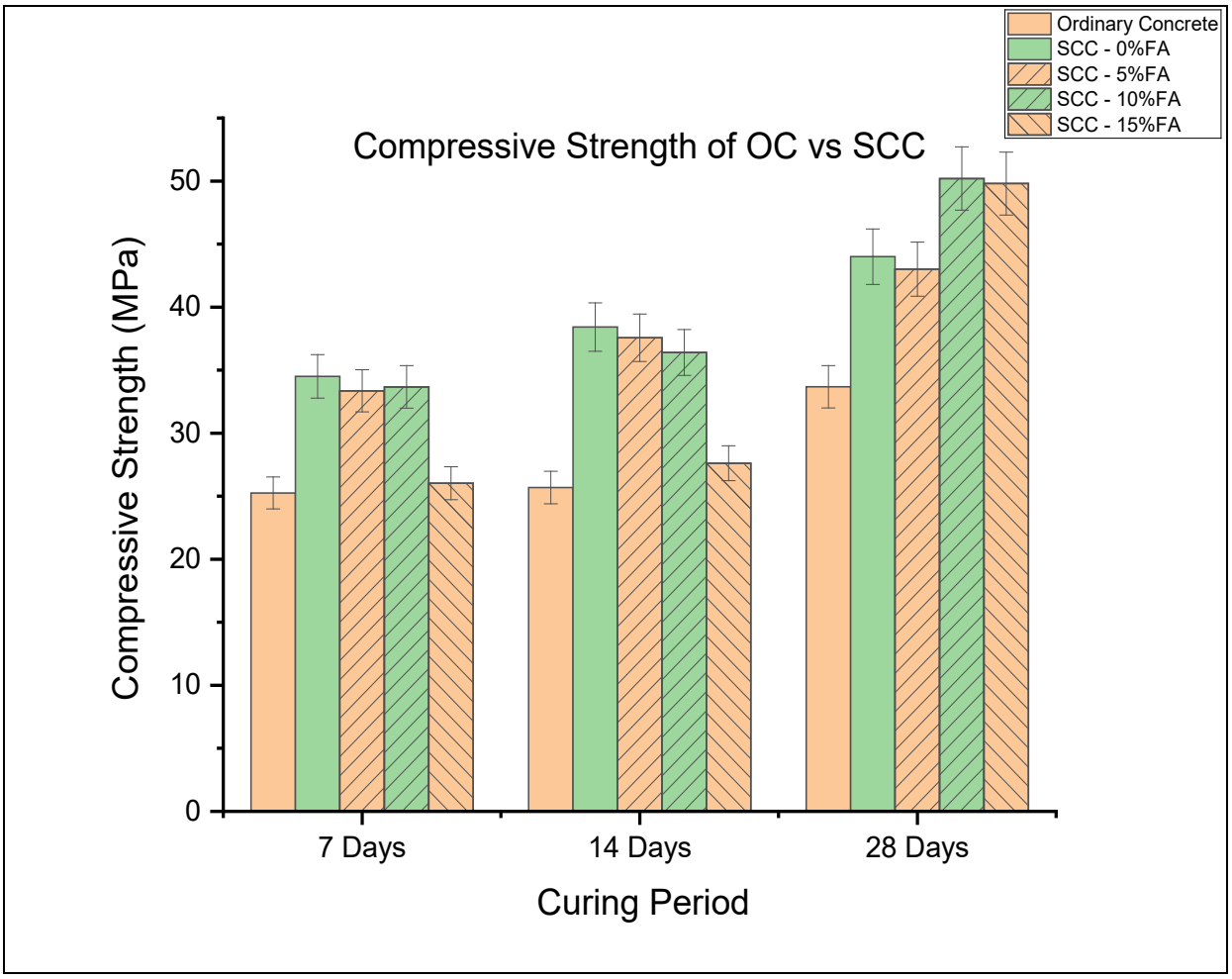


Figure 7: Compressive Strength Test of OC vs SCC

Figure 7 presents the result of the compressive strength test conducted on both ordinary concrete and self-compacted concrete. Firstly, it is observed that strength increases as the curing age progresses. Furthermore, it can be deduced that during the entire curing period, the SCC samples gained more strength than ordinary concrete, and similarly, SCC with 0% FA gained early strength between 7 and 14 days compared to SCC with the inclusion of fly ash. However, at 28 days of curing, SCC with FA content gained better strength than the one without FA, except for SCC with 5%FA. In addition, the overall strength gained by SCC was very impressive and meets the minimum strength required for many civil works; however, SCC with 10%FA presents the best compressive strength of 50.2 MPa at 28 days, followed by the design mix with 15%FA that has the strength of 49.8 MPa. Lastly, considering the results obtained from the fresh properties of SCC

and the mechanical property (compressive strength), it can be inferred that the addition of fly ash is beneficial to SCC especially when inclusion percentage is optimized, and it reduces the overall cost of material purchase, as fly ash is a waste material and mostly collected from other industries at little to no cost.

Conclusion

The findings of this research have proven that the inclusion of fly ash in the design mix of self-compacting concrete has several advantages such as enhancement of flowability, filling ability, segregation resistance, and passing ability around congested reinforcement. This research also confirms that fly ash addition to SCC further enhances the concrete mechanical strength based on the compressive test result, as the highest strength of 50.2 MPa was obtained from SCC containing 10% FA, which greatly exceeds the values 33.68 MPa and 44 MPa obtained for normal concrete and concrete slurry without the addition of fly ash, respectively. Furthermore, the cost of producing SCC with fly ash is relatively lower as compared to ordinary concrete and SCC without fly ash because in most cases fly ash is a by-product of other sectors and readily available for disposal without a cost and when added to concrete mix, the amount of cement usage is reduced thereby reducing cost while promoting green construction. Finally, the adaptation of SCC in construction works helps to eliminate the need for concrete vibration or compaction, especially in tight areas, thereby reducing the time of project completion and associated cost. The scope of this research focused on the impact of fly ash on the flowability and strength of SCC; however, to determine the cost savings per cubic meter, it is recommended that a cost comparison analysis be conducted.

References

[1] Abd Elaty, M. A. A., & Ghazy, M. F. (2018). Fluidity evaluation of fiber reinforced-self compacting concrete based on buoyancy law. *HBRC Journal*, *14*(3), 368–378. https://doi.org/10.1016/j.hbrcj.2017.04.003

[2] Alhorani, R. A. M., Asaad, S. A., & Abendeh, R. M. (2022). Effect of white cement bypass dust on the degradation of roller compacted concrete subjected to sulphate attack. *International Journal of Pavement Engineering*, *23*(10), 3662–3676. https://doi.org/10.1080/10298436.2021.1913592

[3] Alyamaç, K. E., & Ince, R. (2009). A preliminary concrete mix design for SCC with marble powders. *Construction and Building Materials*, *23*(3), 1201–1210. https://doi.org/10.1016/j.conbuildmat.2008.08.012

[4] Behl, V., Singh, V., Dahiya, V., & Kumar, A. (2021). Characterization of physico-chemical and functional properties of fly ash concrete mix. *Materials Today: Proceedings*, *50*, 941–945. https://doi.org/10.1016/j.matpr.2021.06.353

[5] Bhagwat, Y., Nayak, G., Pandit, P., & Lakshmi, A. (2023). Effect of polypropylene fibres on strength and durability performance of M-sand self compacting concrete. *Cogent Engineering*, *10*(1). https://doi.org/10.1080/23311916.2023.2233783

[6] Bhat, J. A. (2020). Mechanical behaviour of self compacting concrete: Effect of wood ash and coal ash as partial cement replacement. *Materials Today: Proceedings*, *42*, 1470–1476. https://doi.org/10.1016/j.matpr.2021.01.311

[7] Campos, H. F., Klein, N. S., & Marques Filho, J. (2020). Proposed mix design method for sustainable high-strength concrete using particle packing optimization. *Journal of Cleaner Production*, *265*, 121907. https://doi.org/10.1016/j.jclepro.2020.121907

[8] concept concrete. (2019, May 25). *Current advancement and the pros and cons of self compacting concrete*. https://www.conceptconcretewa.com.au/pros-and-cons-of-self-compacting-concrete/

[9] Gesoğlu, M., Güneyisi, E., Kocabağ, M. E., Bayram, V., & Mermerdaş, K. (2012). Fresh and hardened characteristics of self compacting concretes made with combined use of marble powder, limestone filler, and fly ash. *Construction and Building Materials*, *37*, 160–170. https://doi.org/10.1016/j.conbuildmat.2012.07.092

[10] Habibur Rahman Sobuz, M., Saha, A., Akid, A. S. M., Vincent, T., Tam, V. W. Y., Yalçınkaya, Ç., Mujahid, R., & Sutan, N. M. (2023). Performance of self-compacting concrete incorporating waste glass as coarse aggregate. *Journal of Sustainable Cement-Based Materials*, *12*(5), 527–541. https://doi.org/10.1080/21650373.2022.2086936

[11] Hassan, A. A. A., Ismail, M. K., & Mayo, J. (2015). Mechanical properties of self-consolidating concrete containing lightweight recycled aggregate in different mixture compositions. *Journal of Building Engineering*, *4*, 113–126. https://doi.org/10.1016/j.jobe.2015.09.005

[12] Jagadesh, P., de Prado-Gil, J., Silva-Monteiro, N., & Martínez-García, R. (2023). Assessing the compressive strength of self-compacting concrete with recycled aggregates from mix ratio using machine learning approach. *Journal of Materials Research and Technology*, *24*, 1483–1498. https://doi.org/10.1016/j.jmrt.2023.03.037

[13] Jalal, M., Pouladkhan, A., Harandi, O. F., & Jafari, D. (2015). Comparative study on effects of Class F fly ash, nano silica and silica fume on properties of high performance self compacting concrete. *Construction and Building Materials*, *94*, 90–104. https://doi.org/10.1016/j.conbuildmat.2015.07.001

[14] Kaish, A. B. M. A., Breesem, K. M., & Abood, M. M. (2018). Influence of pre-treated alum sludge on properties of high-strength self-compacting concrete. *Journal of Cleaner Production*, *202*, 1085–1096. https://doi.org/10.1016/j.jclepro.2018.08.156

[15] Letsosa, C. M., Dada, O. R., & Ikotun, B. D. (2024). The effects of different curing conditions on the polypropylene fibre reinforcement concrete. *Journal of Physics: Conference Series*, *2888*(1). https://doi.org/10.1088/1742-6596/2888/1/012022

[16] Plank, J., & Meyer, L. (2015). New insights into physicochemical interactions occurring between polycarboxylate superplasticizers and a stabilizer in self-compacting concrete. *Journal of Sustainable Cement-Based Materials*, *4*(3), 164–175. https://doi.org/10.1080/21650373.2015.1024296

[17] Reta, Y., & Mahto, S. (2019). Experimental Investigation on Coffee Husk Ash as a Partial Replacement of Cement for C-25 concrete. *Cikitusi Journal for Multidisciplinary Research*, *6*(0975–6876), 152–158.

[18] Rivera, F., Martínez, P., Castro, J., & López, M. (2015). Massive volume fly-ash concrete: A more sustainable material with fly ash replacing cement and aggregates. *Cement and Concrete Composites*, *63*, 104–112. https://doi.org/10.1016/j.cemconcomp.2015.08.001

[19] Roig-Flores, M., Pirritano, F., Serna, P., & Ferrara, L. (2016). Effect of crystalline admixtures on the self-healing capability of early-age concrete studied by means of permeability and crack closing tests. *Construction and Building Materials*, *114*, 447–457. https://doi.org/10.1016/j.conbuildmat.2016.03.196

[20] The Engineering Community. (2011, June 11). *Self-compacting concrete (SCC) - Advantages, Disadvantages and Applications*. Engineering Articles. https://www.theengineeringcommunity.org/self-compacting-concrete-scc-advantages-disadvantages-and-applications/

[21] Uysal, M., & Yilmaz, K. (2011). Effect of mineral admixtures on properties of self-compacting concrete. *Cement and Concrete Composites*, *33*(7), 771–776. https://doi.org/10.1016/j.cemconcomp.2011.04.005

[22] Wlodarczyk, M., & Jedrzejewski, I. (2016). Concrete Slabs Strengthened with Basalt Fibres - Experimental Tests Results. *Procedia Engineering*, *153*, 866–873. https://doi.org/10.1016/j.proeng.2016.08.200

[23] Ye, Y., Liu, J., Zhang, Z., Wang, Z., & Peng, Q. (2020). Experimental Study of High-Strength Steel Fiber Lightweight Aggregate Concrete on Mechanical Properties and Toughness Index. *Advances in Materials Science and Engineering*, *2020*. https://doi.org/10.1155/2020/5915034

[24] Zhang, P., Han, S., Ng, S., & Wang, X. H. (2018). Fiber-Reinforced Concrete with Application in Civil Engineering. *Advances in Civil Engineering*, *2018*. https://doi.org/10.1155/2018/1698905