Harnessing Fly Ash and Foundry Sand Waste Potentials for Sustainable Concrete Towards Building a Greener Future: A Case of South Africa

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Abstract

The effective reuse of waste resources across sectors has contributed to sustainable solid waste management, the development of new products, and advances in materials science. This study investigated the feasibility and effectiveness of incorporating industrial waste streams, specifically Type F Fly Ash (FA) and Foundry Sand Waste (FSW), into concrete mixes to promote sustainability in the African construction sector. The research assessed the effects of these secondary materials on the mechanical properties of concrete and evaluated their potential for practical use in infrastructure projects. A comprehensive characterization approach, including determination of the Fineness Modulus, Scanning Electron Microscopy (SEM), X-ray Diffraction (XRD), and X-ray Fluorescence (XRF) analyses, was employed to characterise the physical and chemical properties of FSW. Concrete samples were prepared with FSW replacement levels of 25% and 50%, while maintaining a constant 30% FA substitution, and were tested for compressive strength, split tensile strength, and water absorption at 7, 14, and 28 days of curing. The results showed that as more FSW was added, concrete strength decreased, but it remained within acceptable standards and was suitable for use on lightly trafficked roads and low-load-bearing structures.

Keywords: Circular Economy, Concrete, Fly Ash, Foundry Sand Waste, Sustainable Construction

1.0 Introduction

In recent years, due to the increasing volume of waste produced by industrial operations and the rising costs of its disposal, especially for foundry sand waste, there is a need to reconsider waste management strategies with environmental sustainability in mind. Many industrial by-products can harm land, water, and air quality. Consequently, researchers are exploring ways to reuse, repurpose, and recycle this waste for both economic and environmentally friendly applications. Among these wastes, which are generated in large quantities, are Fly Ash (FA), a byproduct of coal combustion in power plants during energy production, and Foundry Sand Waste (FSW), a byproduct of metal casting processes in foundries during the manufacture of ferrous and nonferrous metals. Fly ash results from burning pulverised coal, collected via electrostatic and mechanical separators in thermal power plants[1,2]. Also called “pulverised fuel ash,” it accounts for approximately 85% of the total ash produced during electricity generation[3]. Globally, it is estimated that over 900 million tonnes of FA are produced, but only a tiny fraction is utilized[4]. Due to the large volume of waste generated by Eskom plants, as shown in **Figure 1**, it is urgent to find a pathway for its utilization; therefore, one of the main sectors to utilize this resource is civil and road construction[5].

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Figure 1: Fly Ash generated from the Eskom coal-fired plant in South Africa

However, another type of ash produced by coal-fired thermal power stations is bottom ash, which is coarser-textured and typically collected from the bottoms of furnaces. Additionally, other coal ash by-products include boiler slag and flue gas desulfurization materials. Fly ash, a fine powder, is used as a secondary cementitious binder in Portland cement and as the main binder in alkali-activated systems. It consists of amorphous, spherical, glassy particles, which enhance its usability as a supplementary material in various applications. For decades, due to its high production volume, availability, and environmental benefits for product performance, FA has been regarded as a suitable mineral admixture or additive for partial replacement in the manufacture of Portland cement and concrete. The benefits of utilizing FA generally include conserving natural resources and materials, reducing greenhouse gas emissions, conserving energy in cement manufacturing, and decreasing the water and energy needed to produce concrete. Furthermore, FA has been successfully utilised for road embankments, soil and asphalt stabilisation, land reclamation, and flowable fill. In concrete technology, the use of FA is not unusual because it contains calcium oxide (CaO), the primary constituent of Portland cement. CaO imparts pozzolanic properties to cement, contributing to its widespread acceptance and application in the construction industry, particularly in concrete production and cement manufacturing, provided the loss of ignition (LOI) does not exceed 7%. Generally, FA is categorised into two types based on its sources and composition, viz: Class C and Class F. Class C fly ash originates from lignite coal combustion and is both pozzolanic and cementitious due to its CaO content, which is usually greater than 10%. Conversely, Class F ashes are derived from anthracite and are also pozzolanic but have a CaO content below 10%.

Similarly, foundry green sand is an essential part of the metal casting process because it can withstand the high melting temperatures of metals and alloys. It can accommodate any casting regardless of size, shape, or volume. Foundry sand waste (FSW), an industrial by-product of this manufacturing process, is produced in large quantities, as shown in **Figure 2**. After several cycles of use in the casting process, some of it is replaced with new sand to maintain its mechanical properties and prevent casting defects. FSW from foundries is practically unavoidable because the moulds and cores used for castings lose their physical and mechanical properties due to thermal stress and repeated cycles, which is why the “weak sand” must be replaced and discarded from the casting process.

Figure 2: Foundry sand waste from a ferrous foundry

Globally, millions of tonnes of this waste are produced annually by both ferrous and non-ferrous foundries. However, the composition of FSW varies depending on its origin, due to factors such as the type of castings produced, the types of sand used for moulds, the binder and additives, among others. A typical composition of green foundry sand is shown in **Table 1.**

Table 1: Typical Composition of Foundry Green Sand[6,7]

Constituents	**Silica Sand**	**Bentonite Clay**	**Additives**	**Trace elements**
% Composition	85 – 95%	4 – 10%	2 – 10%	< 1%

Foundry sand waste has become an important secondary material in recent years, especially in the construction industry, due to its wide use as a construction material. It has been used as a replacement for crusher sand or riverbank sand in making concrete, mortar, and grout in masonry construction; in the production of asphalt pavement to improve stability and skid resistance; and in the manufacture of bricks and ceramic tiles. Additionally, it serves as a flowable fill for backfilling excavations and as a road base and sub-base for laying foundations for roads, parking lots, and pedestrian walkways[8,9,10]. Furthermore, another significant area of high-volume consumption is in geotechnical applications. Over the years, FSW has been utilised for soil amendment, reinforcement, or stabilisation to improve soil engineering properties, especially in clay soils, by increasing shear strength and reducing plasticity[11,12]. Moreover, despite global efforts to prevent FSW from being disposed of in landfills, it still finds applications there, such as in landfill liners and cover materials, due to its physical and mechanical properties, including its granular shape and low permeability. Lastly, in the manufacture of cement, glass, and ceramics, FSW significantly reduces the use of fresh materials like sand. For example, FSW has been identified as a suitable source of silica sand for producing Portland cement clinker and as a raw material for glass and ceramic production because of its high silica (SiO_2) content[13,14,15,16].

Concrete with partial cement replacement by FA and sand replacement by FSW can match or surpass the strength of conventional concrete when FSW is kept at or below 25 – 34% and FA at around 20 – 30%[14,17,18]. Strength and durability improve primarily because FA's pozzolanic reaction and the fine particles of both materials refine the pore structure and make the interfacial transition zone denser, thereby reducing harmful pores, water sorptivity, and chloride permeability compared with plain cement concrete[14,19,20]. Despite known international work on FA and FSW[14,17,18], there is a lack of data on concretes produced with African FA and ferrous-foundry FSW, whose composition and fineness differ from those in other regions, limiting the ability to define safe replacement levels for local infrastructure.

Therefore, to harness the many advantages of using FSW, which is abundantly and locally available as a secondary material under various conditions, it is important to segregate and characterize the material before use, as it often contains contaminants and impurities due to its disposal location within the foundry premises. Specifically, in this study, we characterise the physical and chemical properties of foundry sand waste; evaluate compressive and split tensile strengths and water absorption at 7, 14, and 28 days; and identify replacement levels that meet minimum strength requirements for low-load African infrastructure. In conclusion, this research further emphasises the numerous benefits of adopting FSW and FA, including waste reduction, a lower construction carbon footprint, cost savings, job creation, circular-economy opportunities, and the sustainable production of concrete for local needs within the African continent.

2.0 Methodology

For this work, the primary materials used to produce concrete include coarse aggregate, ordinary Portland cement (PPC CEM I 52.5N), crusher sand, and water. Waste resources used as secondary materials incorporated into the concrete mix include Fly Ash class F (produced by AFRISAM) and foundry sand waste (from a ferrous foundry specialized in grey iron casting). These materials were further characterised using sieve analysis to determine the fineness modulus (FM) of the crusher sand and FSW. Additionally, X-ray diffractometry (XRD) and X-ray fluorescence (XRF) were employed to identify the mineralogical phase and chemical composition of the FSW, respectively, while Scanning Electron Microscopy (SEM) was used to examine the morphology of the FSW and FA. Furthermore, the FSW was subjected to a Toxicity Characteristic Leaching Procedure (TCLP) to assess the sand's potential to release metals under acidic conditions and to determine whether it meets the toxicity characteristic leaching procedure (TCLP) compliance requirement for construction sand.

For concrete production, a C25-grade mix design was prepared using a 1:2.07:3.11 (cement: sand: coarse aggregates) mix ratio to determine the optimal mix that yields concrete with good mechanical properties. The mix design is presented in **Table 2**. Samples were tested in triplicate to obtain the average value. The FA content was kept constant at 30% by weight, while the FSW content was varied. The following mix design was adopted to incorporate secondary materials, i.e., FA and FSW, as partial replacements for cement and crusher sand, respectively, with a nominal maximum size of 20mm for the coarse aggregate. The three-batch mix used includes: (i) control samples, i.e., concrete produced without the addition of FA and FSW; (ii) concrete produced with 30% FA, 70% OPC, 25% FSW, and 75% crusher sand; (iii) concrete produced with 30% FA, 70% OPC, 50% FSW, and 50% crusher sand. The concrete constituents were accurately weighed and mixed in a rotary concrete mixer to achieve a homogeneous mixture with an optimal water-to-cement ratio of 0.45, ensuring good compaction. Subsequently, each concrete batch was scooped into 100 x 100 x 100 mm plastic moulds and placed on a vibratory table for 1 minute to enhance durability. The concretes were covered with polythene overnight, then demoulded and placed in a curing tank to cure for 7, 14, and 28 days, with the water temperature maintained at 22 °C. After each curing period, three (3) samples from the same batch were tested in accordance with SANS 5863:2006 and SANS 6253:2006, which provide guidance for compressive and split tensile strength tests, respectively. This was done to determine the average strength of each design mix using a calibrated Toni Technik universal testing machine (model 1543) with a maximum load capacity of 300 kN.

Table 2: Concrete Mix Design

Component	Quantity (kg per m³ of concrete)	Ratio (by weight)
Cement (PPC CEM I 52.5N+FA)	347	1.00
Sand (FSW+ Crusher)	719	2.07
Coarse Aggregate (Stone)	1079	3.11
Water	197	0.45

3.0 Results and Discussion

This section presents and discusses the results obtained from the characterization of the foundry sand waste, Fly Ash and the mechanical strength properties of the concrete produced from the inclusion of FA and FSW into different batch mixes.

3.1 Fineness Modulus of Crusher Sand and FSW

The fineness modulus was determined for both FSW and crusher sand by pouring the dry mass of each sample into a vibratory sieve shaker to determine the fineness modulus, as the particle sizes of the materials used in concrete contribute to its mechanical strength and texture. The result obtained is presented in **Table 3**.

Table 3: Fineness Modulus for Crusher sand and Foundry sand waste

a) Crusher Sand, Dry Mass 957.6 g

Sieve size (mm)	Mass retained (g)	Percentage retained (%)	Cumulative percentage retained (%)	Percentage passed (%)
10	0.000	0.000	0.000	100.000
7.1	4.100	0.428	0.428	99.572
5	64.600	6.746	7.174	92.826
2	224.100	23.402	30.576	69.424
1	163.300	17.053	47.629	52.371
0.6	113.400	11.842	59.472	40.528
0.3	130.400	13.617	73.089	26.911
0.15	96.000	10.025	83.114	16.886
0.075	57.400	5.994	89.108	10.892
Pan	6.000	0.627	89.735	10.265
FM	**3.01**			

b) FSW, Dry Mass 768.1 g

Sieve size (mm)	**Mass retained (g)**	**Percentage retained (%)**	**Cumulative percentage retained (%)**	**Percentage passed (%)**
10	0.000	0.000	0.000	100.000
7.1	0.000	0.000	0.000	100.000
5	0.300	0.039	0.039	99.961
2	3.800	0.495	0.534	99.466
1	3.200	0.417	0.950	99.050
0.6	19.400	2.526	3.476	96.524
0.3	337.900	43.992	47.468	52.532
0.15	351.300	45.736	93.204	6.796
0.075	41.000	5.338	98.542	1.458
Pan	6.900	0.898	99.440	0.560
FM	**1.46**			

The fineness modulus analysis shows that crusher sand has a fineness modulus of 3.01, whereas FSW has a value of 1.46. This indicates that crusher sand is coarser than FSW. Given the process used to break down sand moulds after casting, and because FSW is recycled and reused multiple times in the casting process before it is finally discarded, the spent sand is expected to be finer than when it was initially used for mould making. Additionally, the additives and binders used in mould production contribute to the sand's finer texture. Nonetheless, blending these two types of sand, i.e., crusher sand and FSW, helps achieve better grading, thereby enhancing the mechanical strength properties of the resulting concrete.

3.2 Characterization of Fly Ash

3.2.1 Fly Ash Fineness Modulus

The fineness of the fly ash sample was determined by wet sieving in accordance with ASTM C311. This method is preferred over dry sieving for fine materials such as fly ash, as it disperses particles and prevents agglomeration, yielding a more accurate measurement of the mass retained on a 45-μm (No. 325) sieve. As shown in **Table 4**, only 12.4% of the sample is retained, well below the maximum allowable limit of 34% specified by ASTM C618 for Class F fly ash used in concrete.

Table 4: Fly Ash Fineness Modulus

Parameter	**Result**	**Unit**	**ASTM C618 Limit (Class F)**
Material retained on 45 μm (No. 325) sieve	12.4	% by mass	≤ 34%

In summary, the wet-sieving result of 12.4% retention on the 45-μm sieve confirms that the tested fly ash meets ASTM C618 fineness requirements. This fineness promotes effective pozzolanic reactivity while posing a low risk of impairing workability.

3.2.2 Fly Ash Particle Size Distribution

The laser diffraction results presented in **Table 5** indicate a median particle size (D50) of 14.6 µm, typical of moderately fine fly ash and within the typical range (12–20 µm) for Class F ash used in concrete. This median suggests that half the particles are finer than 14.6 µm, providing adequate specific surface area for pozzolanic reactions without unduly increasing water demand. Furthermore, the D90 value of 58.3 µm is significant because it indicates that only 10% of the particles by volume are larger than approximately 58 µm, confirming a limited amount of coarse material. A low proportion of coarse particles (>45 µm) is desirable, as coarse fractions tend to be less reactive and may act as inert fillers or even weaken the cementitious matrix. Together, the D50 and D90 values indicate a well-graded, predominantly fine ash that is likely to exhibit good reactivity, satisfactory workability, and consistent performance in blended cement systems.

Table 5: Fly Ash Particle Size Distribution

	Particle Size (µm)	**Typical Range for Class F**
D10 (10% finer)	**2.1**	1 – 4 µm
D50 (median)	**14.6**	12 – 20 µm
D90 (90% finer)	**58.3**	50 – 80 µm

3.2.3 Fly Ash Grain Size Distribution

The cumulative particle size distribution indicates a well-graded fly ash with a broad range of particle sizes, from submicron (0.5 µm) to 150 µm. At the fine end, 3.2% of particles are smaller than 0.5 µm, and 8.5% are below 1.0 µm. The presence of these ultrafine particles is beneficial for early pozzolanic reactivity, as they provide a large specific surface area for rapid reaction with calcium hydroxide. However, the proportion of such ultrafine particles is modest, which helps avoid excessive water demand. The fly ash grain size distribution is presented in **Table 6.** The distribution climbs steadily, with 28.4% passing 5 µm and 41.2% passing 10 µm, indicating that nearly half of the ash mass consists of particles finer than 10 µm, a fraction known to be highly reactive. The median particle size (D50) lies between 10 µm (41.2% passing) and 20 µm (62.8% passing); interpolation yields approximately 14 – 15 µm, consistent with typical moderately fine fly ash. This median value balances reactivity and workability: sufficient fineness to promote strength gain without causing an overly sticky mix.

Table 6: Fly Ash Grain Size Distribution

Particle Size (µm)	0.5	1.0	2.0	5.0	10.0	20.0	45.0	75.0	100.0	150.0
% Passing (Cumulative)	3.2	8.5	16.7	28.4	41.2	62.8	87.6	95.3	98.1	99.5

A key observation is the 87.6% passing at 45 µm. This indicates that only 12.4% of the ash is retained on a 45-µm sieve, well within the ASTM C618 maximum retention limit of 34%. Such a low coarse fraction strongly indicates good combustion efficiency and minimal unburned or inert coarse material. Furthermore, the data show 95.3% passing at 75 µm, 98.1% at 100 µm, and 99.5% at 150 µm, confirming that virtually the entire sample is finer than 150 µm. The near-absence of particles above 150 µm eliminates the risk of oversized, unreactive agglomerates that could impair the finish or durability. Overall, the distribution is continuous and well graded, without abrupt steps or bimodal features that might suggest poor grinding or incomplete combustion. The combination of a moderate D50, low 45-µm retention, and negligible material above 100 µm supports the classification of this fly ash as a high-quality pozzolan suitable for concrete, soil stabilization, and other cementitious applications where fineness and uniformity are critical for performance.

3.2.4 Fly Ash Microstructural Analysis

Scanning Electron Microscopy (SEM) was used to investigate the microstructural properties of the fly ash, and the micrograph reveals a heterogeneous morphology comprising spherical particles, irregular agglomerates, porous textures, and layered crystalline structures. These microstructural characteristics strongly influence the physical, chemical, and pozzolanic behaviour of fly ash when used in cementitious materials such as concrete, mortar, and geopolymer systems.

As shown in **Figure 3, Image A**, the shape of fly ash particles is irregular and angular, with partially fused structures and flaky, plate-like formations. Some particles appear rough and porous, indicating incomplete combustion of coal and the presence of unburnt carbon residues. The rough surface texture increases the specific surface area of the fly ash particles, which can enhance water demand during mixing. At the same time, these irregular particles contribute to mechanical interlocking within the cement matrix, improving bond characteristics. The layered and flaky morphology may also indicate the presence of aluminosilicate glass phases and crystalline minerals such as quartz or mullite. These phases are important because amorphous aluminosilicate content contributes significantly to pozzolanic reactivity.

Image B shows a highly porous, sponge-like microstructure with loosely packed agglomerates. The porosity suggests that the fly ash contains cenospheres or partially burned carbonaceous materials. Such porosity can enhance internal curing by retaining water within the matrix, thereby supporting long-term hydration in concrete systems. However, excessive porosity may also increase water absorption and reduce density. The fibrous, wrinkled texture around the particles indicates the formation of reaction products or thermally altered mineral phases. This morphology may enhance surface reactivity, as the irregular texture provides more active sites for chemical reactions with calcium hydroxide during hydration.

The SEM **Image C** shows smooth, spherical fly-ash particles (cenospheres) mixed with irregular ash fragments. These cenospheres vary in size, improving packing density and reducing voids in the hardened cement matrix. Their smooth, glassy surface provides a “ball-bearing effect,” lowering internal friction, reducing water demand, and improving workability, compaction, and rheological behaviour. The presence of both large and fine spheres indicates a wide particle-size distribution that further enhances packing and the microstructure.

The spherical particles also indicate the presence of amorphous, silica-rich phases that formed during the rapid cooling of molten material. This amorphous content is reactive and supports pozzolanic reactions, in which silica and alumina react with calcium hydroxide to form additional C–S–H gel, thereby improving strength, densifying the microstructure, and enhancing durability (e.g., resistance to sulphate attack and chloride penetration).

Additionally, fine particles agglomerate around larger ones, indicating ultrafine fractions that fill micro-voids, reduce pore connectivity, and refine the interfacial transition zone (ITZ), thereby generally lowering permeability and improving mechanical performance. Overall, the SEM results confirm that fly ash exhibits beneficial physical filler effects and chemical pozzolanic activity, resulting in a denser, more durable cementitious matrix suitable for use as a supplementary cementitious material.

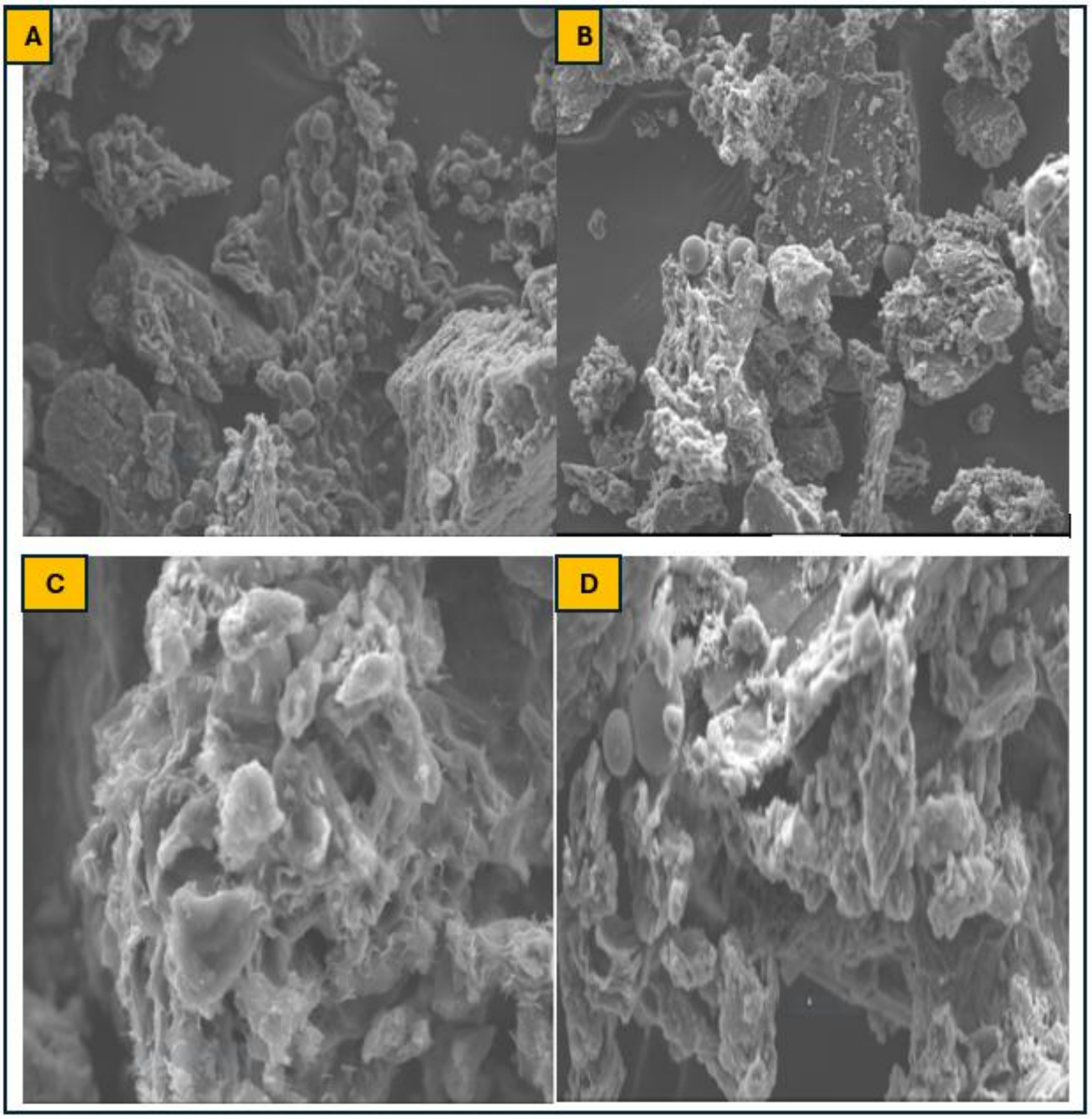

Figure 3: Fly Ash SEM Micrograph

3.3 FSW Toxicity Characteristics Leaching Procedure (TCLP)

To determine the TCLP of the FSW, 100g of the received sample was poured into a leaching solution prepared at a liquid-to-solid ratio of 20:1 and agitated for 18 hours in accordance with USEPA protocol. The leachate was then examined under Atomic Absorption Flame Spectrometry to determine its metallic composition. The result obtained is presented in **Table 7**.

The metals identified in the TCLP result from the casting process, as the raw sand is free of these elements. However, they are present in trace amounts, thereby complying with the **SANS 5832:2006** standard for determining organic impurities in fine aggregates used for concrete and mortar.

Table 7: TCLP for FSW

Cast Alloy (Grey Iron)		
Analysis	**FSW (mg/L)**	**Raw sand (mg/L)**
Al	7.12	0.60
Cr	0.00	0.04
Fe	2.71	0.55
Ni	0.10	0.00
Mn	0.00	0.00
Zn	0.00	0.00
Cu	0.00	0.00

3.4 FSW Chemical Composition – (X-ray Fluorescence)

To determine the chemical composition of the foundry sand waste used in concrete production, a sample of the material was analysed using an X-ray Fluorescence (XRF) machine, and the results are presented in **Table 8**.

Table 8: FSW Chemical Composition

Component	Result (%)
Na_2O	1.1355
MgO	1.2704
Al_2O_3	7.6099
SiO_2	83.5309
SO_3	0.9959
K_2O	1.1790
Fe_2O_3	2.9882
CaO	0.5219
Cr_2O_3	0.1069
NiO	0.1611
TiO_2	0.2531

From the XRF data, it can be deduced that the main component of FSW is quartz (SiO_2) at 83.5309%, while other minerals such as Fe_2O_3, Al_2O_3, MgO, Na_2O, and K_2O also constitute a significant portion of the material.

3.5 FSW mineral phase identification – (X-ray Diffraction)

X-ray Diffraction (XRD) helps identify crystalline phases and their relative proportions in the FSW, providing greater insight into the material's characteristics. The X-ray diffractogram obtained for the FSW used is shown in **Figure 4**.

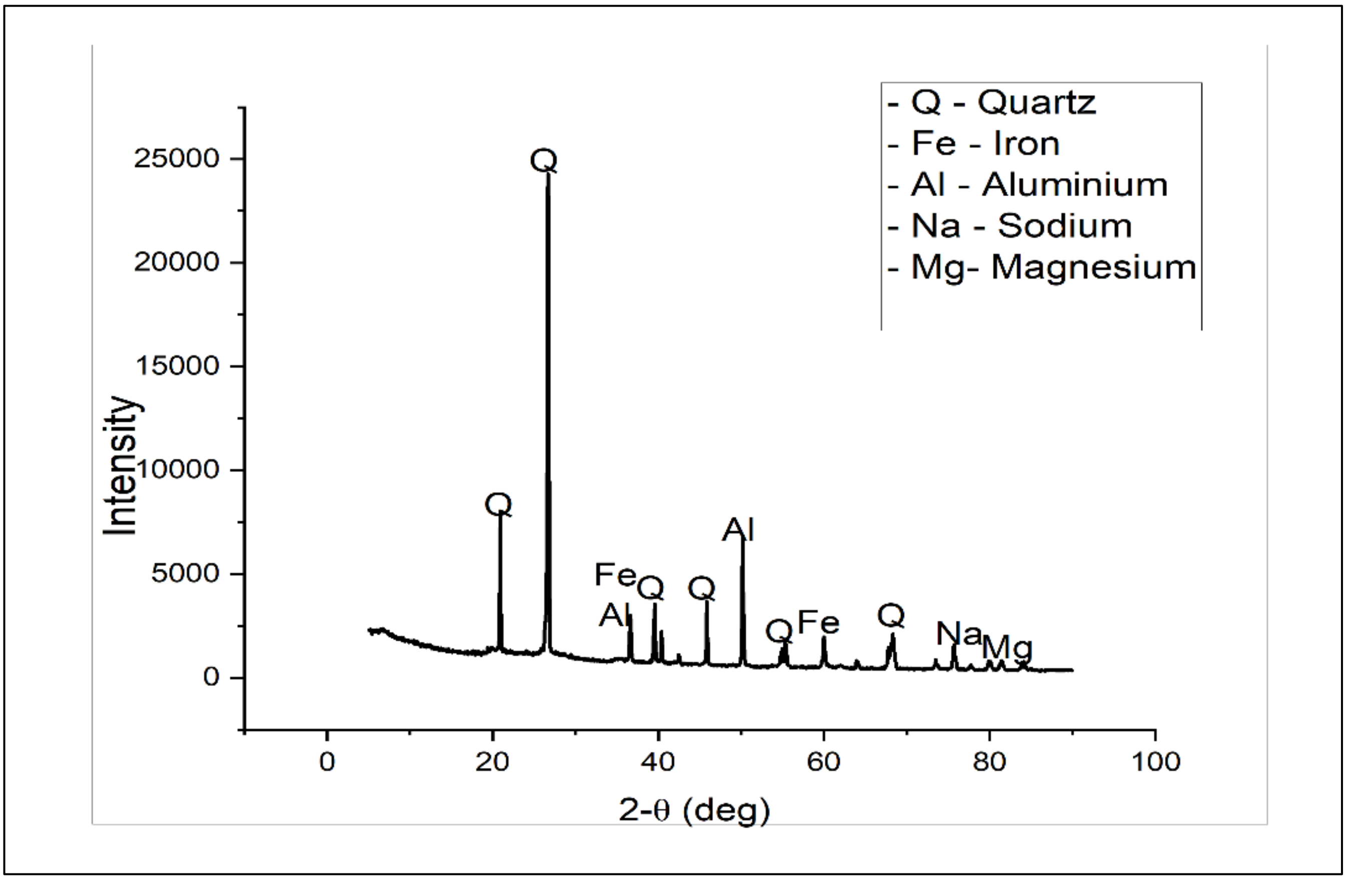

Figure 4: X-ray diffractogram of FSW

The X-ray diffractogram once again confirms that quartz (SiO_2) is the most dominant mineral in the FSW, consistent with the results of the chemical composition analysis shown in **Table 4**. A prominent quartz peak at 260 (2-Ө degrees), together with other minor peaks, indicates the relative proportions of quartz among other minerals and confirms the crystallinity and active state of the SiO_2 in the foundry sand waste.

3.6 Scanning Electron Microscopy with Energy-Dispersive X-ray Spectroscopy (SEM-EDS)

The FSW was examined using SEM-EDS to determine its elemental composition and analyse the microstructural features of the material, including crystal structure, surface morphology, particle sizes, grain boundaries, and other crystallographic characteristics. The SEM-EDS micrograph of the FSW is shown in **Figure 5.**

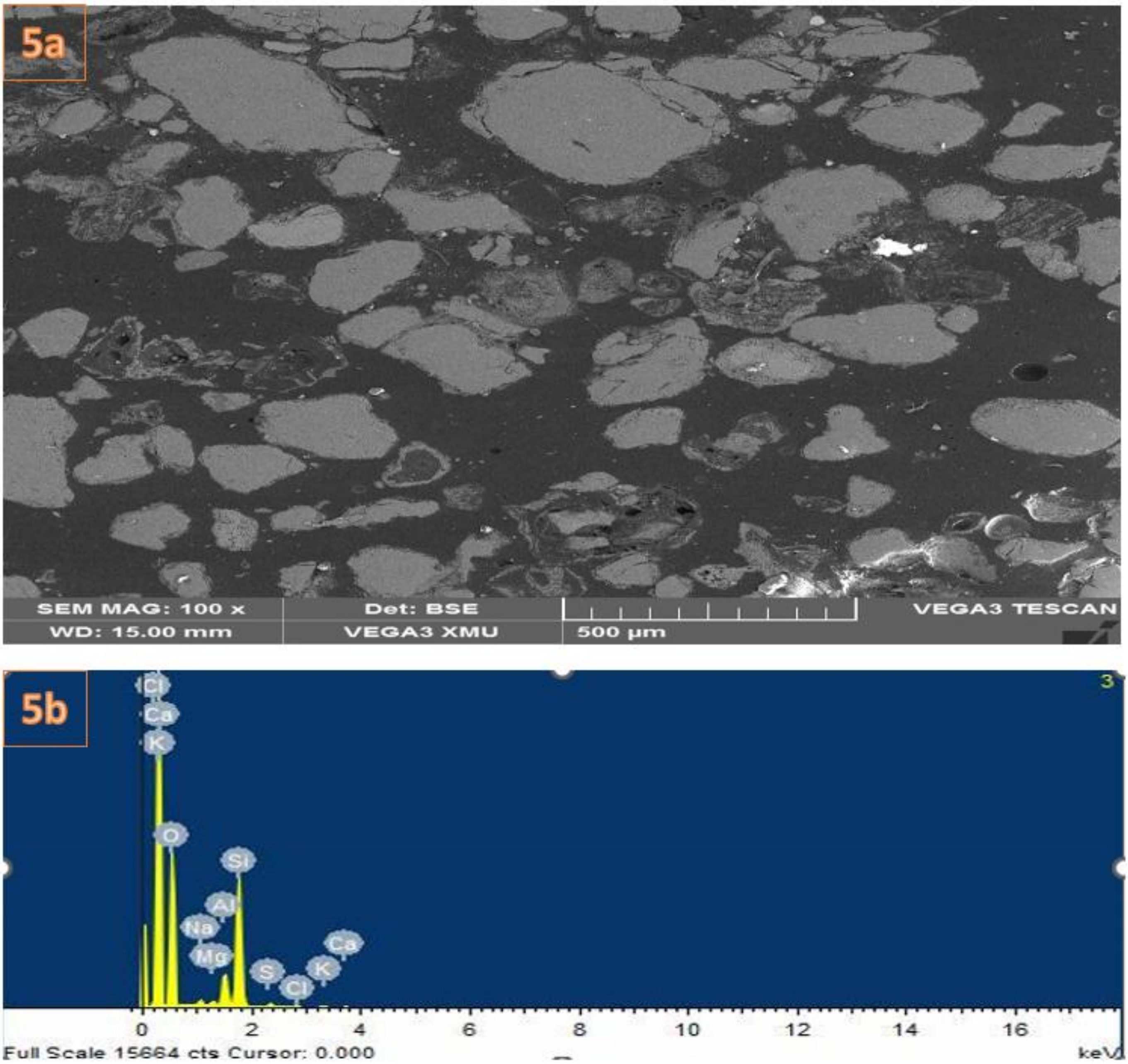

Figure 5: FSW micrograph showing surface morphology (SEM) and chemical composition (EDS)

Based on the SEM analysis presented, the interfacial phases, voids, and particle shapes of the FSW appear to exhibit a high specific surface area. The shape of the grains of the FSW could be said to be semi-round to angular, with many voids. Additionally, the presence of other materials, such as bentonite clay and coal dust, in the FSW accounts for the large interparticle spacing. Furthermore, the EDS provides a more detailed mineral composition of the material, consistent with XRD and XRF, and indicates a high presence of Chlorine (Cl), Calcium (Ca), and Potassium (K).

3.7 Concrete Compressive Strength

The concrete samples were tested under compression to determine the maximum axial load they could bear before deformation or failure at the end of each curing period. The result obtained is presented in **Figure 6.**

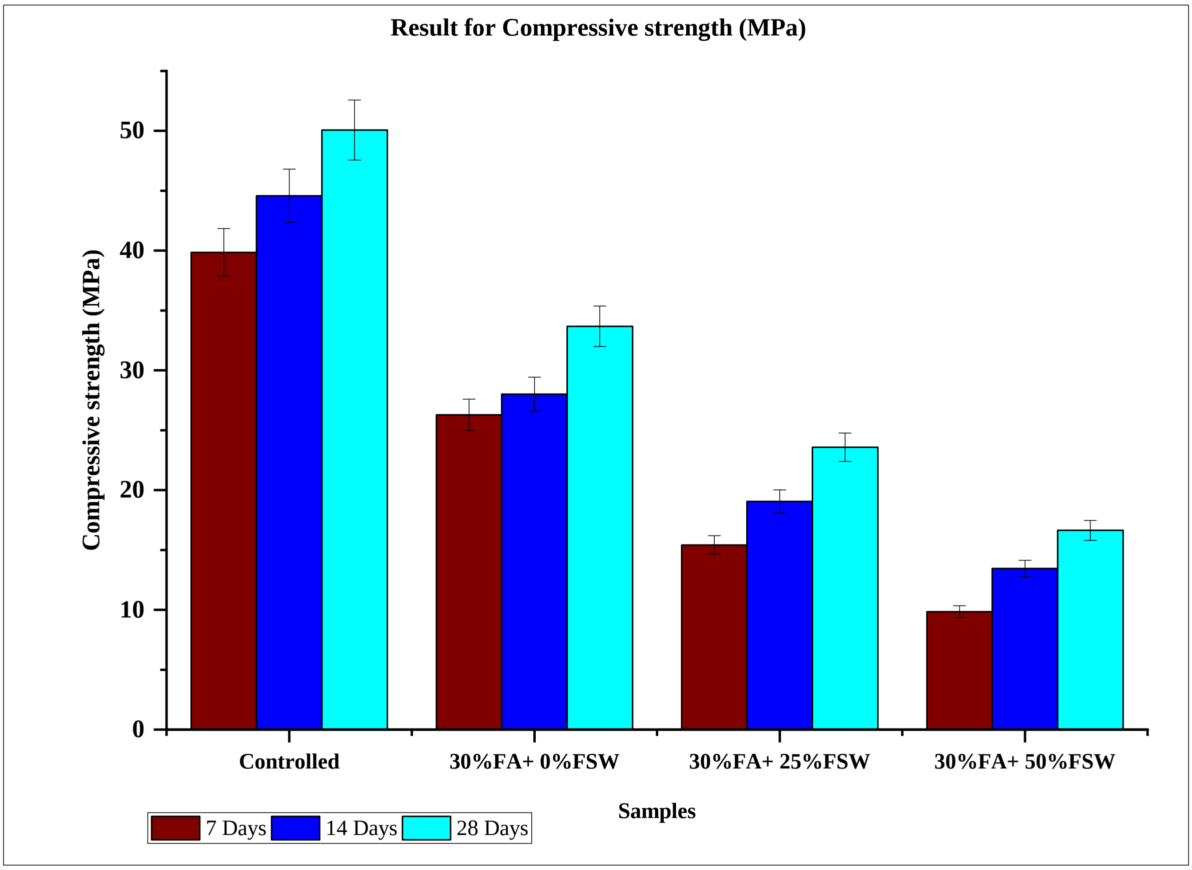

Figure 6: Compressive strength result after 7, 14 and 28 days of curing

From the compressive strength tests, it can be deduced that the compressive strength of each concrete increases over the curing period. Furthermore, the control mix demonstrated higher compressive strength than concretes containing FA and FSW. This is expected given the high content of non-replenishing materials used; however, these materials are not sustainable, and the higher consumption of cement in concrete production does not promote environmental sustainability and green construction because of the significant energy required, especially in heating cement kilns, and the levels of carbon dioxide (CO_2) emitted during the process. Nonetheless, concrete with only 30% FA still achieved good compressive strength (33.68 MPa) at 28 days of curing. Since the aim was to utilise both industrial waste by-products, it was observed that increasing the amount of FSW added to concrete reduced its mechanical properties and resistance to carbonation, which aligns with the findings of [7].

Therefore, the literature indicates that the partial replacement of natural or crusher sand with FSW in concrete should not exceed 20 – 30% by weight[19,21,22,23].

3.8 Split tensile strength test

For all concretes, a split tensile strength test was performed to assess tensile strength, providing insight into concrete durability and ensuring safety in concrete structures. The results obtained for each concrete tested under tension are shown in **Figure 7.**

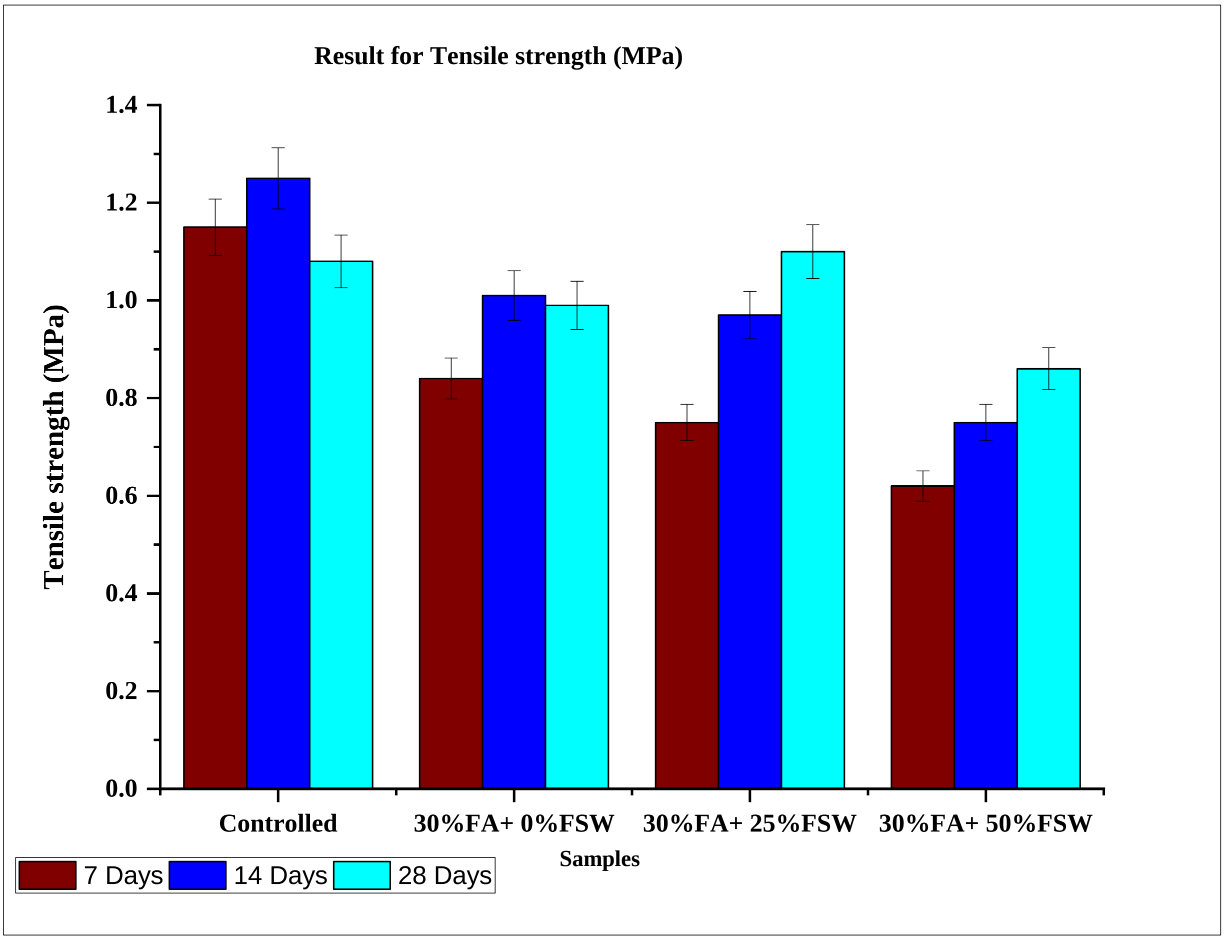

Figure 7: Split tensile result after 7, 14 and 28 days of curing

The trend observed in the split tensile tests closely mirrors that of compressive strength, indicating that the split tensile strength of the control sample exceeds that of concrete containing FA and FSW. Although concrete is generally weaker in tension than in compression, this test is important because it indirectly evaluates the bond strength between concrete components and assesses the concrete’s resistance to cracking. Split tensile strength increased across all mix designs as the curing period lengthened; however, adding ordinary steel fibre or polypropylene fibre, even at 0.5% or 1%, or supplementary cementitious materials such as slag, silica fume, and silica-based activators, can significantly enhance split tensile strength.

4.0 Conclusion

The use of industrial waste materials, such as fly ash and foundry sand waste, in Africa's construction sector is highly beneficial and encouraged because it helps reduce the consumption of depleting non-renewable resources. The TCLP of FSW indicates that the material is not toxic in accordance with **SANS 5832:2006** and complies with **SANS 1083**, which relates to the use of aggregates in concrete. Furthermore, chemical analysis of FSW showed that the combined content of SiO_2, $Al2O_3$, and Fe_2O_3 exceeds 90%, and, according to **ASTM C618**, these elements can be carefully classified as Class F pozzolan. Therefore, it is expected to exhibit high bond strength, and the FA should improve binder efficiency; however, due to the high content of non-reactive silica (SiO_2), this is not entirely the case. Nonetheless, this research demonstrates that incorporating only fly ash into a concrete mix design can yield a compressive strength of 33.68 MPa and a split tensile strength of 1 MPa after 28 days of curing. When FSW is incorporated, the compressive strength decreases to 23.58 MPa, but there is a slight increase in the split tensile strength after curing for 28 days. However, the inclusion of these two waste materials in concrete production still produces concrete with good mechanical properties, which are within the South African National Standards (SANS) acceptable standard of approximately 16 – 21 MPa, particularly suitable for infrastructure with low load-bearing requirements, while also addressing environmental issues caused by the large volume of waste generated. To further enhance the mechanical properties of concrete made with these waste materials, especially when used in large proportions, it is advisable to reinforce the concrete with steel or polypropylene fibres or other supplementary cementitious materials and to conduct additional testing to determine the durability index after an extended curing period.

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Využití potenciálu popílku a odpadního slévárenského písku pro výrobu udržitelného betonu pro environmentálně příznivou budoucnost: případová studie z Jihoafrické republiky

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Abstrakt

Efektivní opětovné využití odpadních zdrojů napříč odvětvími přispělo k udržitelnému nakládání s minerálními odpady, k vývoji nových produktů a pokroku v materiálovém inženýrství. Tato studie se věnovala posouzení proveditelnosti a účinnosti využití průmyslových odpadních toků, konkrétně úletového popílku typu F (FA) a odpadního slévárenského písku (FSW), do betonových směsí s cílem podpořit udržitelnost v africkém stavebnictví. Výzkum posoudil vliv těchto druhotných materiálů na mechanické vlastnosti betonu a vyhodnotil jejich potenciál pro praktické využití v infrastrukturních projektech. K charakterizaci fyzikálních a chemických vlastností FSW byl použit komplexní charakterizační přístup, zahrnující stanovení modulu jemnosti, analýzy pomocí skenovací elektronové mikroskopie (SEM), rentgenové difrakce (XRD) a rentgenové fluorescence (XRF). Byly připraveny vzorky betonu s 25% a 50% uplatněním FSW jako náhrady standardního písku a s uplatněním konstantní 30% náhrady cementu pomocí FA. Beton byl testován na pevnost v prostém tlaku, pevnost v tahu za ohybu a nasákavost po 7, 14 a 28 dnech zrání. Výsledky ukázaly, že s rostoucím podílem FSW pevnost betonu klesala, ale zůstávala v přijatelných mezích a beton byl vhodný pro použití v konstrukci vozovek s nízkým dopravním zatížením a v konstrukcích s nízkým zatížením.

Klíčová slova: oběhové hospodářství, beton, popílek, slévárenský písek, udržitelné stavebnictví