Chapter 9
Urban Mining and Circular Economy in South Africa: Waste as a Resource for New Generation of Hybrid Materials

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9.1 Introduction

Driven by a philosophy of exponential consumerism, excess of availability, and rapid manufacturing of new products, highly unsustainable levels of waste generation have arisen in the South African context. It converges to the crucial need to adapt the way waste is managed (Rootes 2009; Arora et al. 2017; Silva et al. 2017).

Conventional waste management solutions partake in the surge of rejected materials that end up either dumped in non-engineered landfill or incinerated to become ashes. This leads to reconsidering conventional methods and brainstorming for more sustainable system that could require the use of further materials that could be found through extraction and mining of discarded and rejected materials. Traditional and accepted conventional waste management methods are currently colluded towards unsustainability and the inevitable need for redesign to achieve satisfactory environmental outcomes for sustainable development and waste minimisation.

The South African waste sector, public and private, is an underutilised resource of materials and energy. The focus on waste has intrinsic economic value, and the formal and informal recycling systems are fundamental to the South-African waste management system (Karani and Jewasikiewitz 2007; Arora et al. 2017).

The movement of reforms of traditionalist waste management bases has already started in some developing countries, while some countries considered to be part of the "first world" are fundamentally reconceptualising and reframing their waste management systems (Lauridsen and Jørgensen 2010; Cramer 2013; Silva et al. 2017).

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Waste and society, consumption behaviours, and circular economy concepts reinforce the drive for renewed adapted standards in governance structures, waste policies, and contextualized waste scenarios. Circular economy concepts provide greater social and environmental benefits when juxtaposed to the South African context and its formal and informal ecosystems (Cossu 2013; Cossu and Williams 2015; Ghisellini et al. 2016).

In most developed countries, urban mining concepts are being applied on a large and global scale to recuperate resources from anthropogenic mines. In countries from the global south like South Africa, secondary resource can be perceived as both a challenge and an opportunity for material recovery towards resource benefits, environmental savings, and economic benefits as well.

South African sustainable cities should not differentiate between waste and resources. They need to consider innovative philosophies that include secondary resource utilisation. Urban mining could be specifically relevant to the four high priority waste streams identified by the South African RDI waste roadmap: municipal solid waste, waste plastic, organic waste, and waste tyres.

This contribution is a compendium of preliminary experimental studies conducted in the KwaZulu-Natal province. The research compiles investigations conducted in the KwaZulu-Natal province, on the municipal solid waste (glass) streams, the waste tyres waste stream, paper mill sludge (PMS) waste, and food waste. Urban Mining

"Closing Loop" has become a trendy subject of conversation in the waste management expert's community; it is becoming a subject of conversation even outside the sphere of the waste management sector. Recycling, recovery of resource, landfill diversion, and waste minimisation are terms used in debates and conversations between politicians, national governance systems, businesses, and industries. This diverse groups are now evolving the conversation to material recovery, zero waste, and circular economy while drifting to more concepts such as urban mining and landfill mining. Due to social media and easier way of communication, waste management or waste awareness exists and has become a viral topic. Societies are more aware of waste resource management, and they acknowledge the importance of the resources still present in what is considered as waste. In the context of South Africa, many reasons can explain this momentum; as a developing country, South Africa has seen an increase in consumerism as well as a shortage of raw materials for example, and many landfilled are starting encountering a lack of space availability for waste disposal. Moreover, GHG emissions mitigation has become a priority in South Africa, as a consequence the need for control of environmental contaminations, such as the use of proper engineering landfill systems, and the need of proper waste treatment have become priorities.

The circular economy model rejects the linear "take-make-waste" approach (Cossu 2013; Cossu and Williams 2015). This model strives to maintain products' usage for a longer time via reusing waste and reducing waste generation. It also consists in utilising as much as secondary raw materials as possible while in production cycles to promote economic growth and to create new job opportunities.

The concept of Materials Recycling fits within an idea of transformation of selected wastes into new generation of materials that become usable in the manufacture of other products. This recovered materials are reintroduced in production cycles.

All activities relating to the extraction and processing of wastes previously stocked, in particular, kinds of deposits (e.g. municipal landfills) is called landfill mining. As the natural continuation of this concept, urban mining is the extension of landfill mining. It expands the process of reclaiming compounds and elements from any kind of anthropogenic stocks, including buildings, infrastructure, industries, products (in and out of use), and environmental media receiving anthropogenic emissions (Cossu 2013; Cossu and Williams 2015).

As defined by R.Cossu and I.Williams, from an etymological point of view, urban mining should refer to the exploitation of anthropogenic stocks; however, today the term is widely used for describing almost any sort of material recycling (Cossu 2013; Cossu and Williams 2015).

9.2 The Case of South Africa

Several factors have contributed to the rise of consumerism in South Africa: population growth, extensive urbanisation, economic and industrial growth, and shift of income bracket via rising incomes. Consumption of materials in South Africa and in countries of the global south is still low compared to developed countries (Arora et al. 2017).

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9.3 Municipal Solid Waste (Glass)

This study considers the feasibility of utilising waste glass as a partial replacement of natural aggregates in concrete. As the chemical and physical properties of cullet are similar to fine aggregate, cullet used in concrete can reduce the amount of waste glass that ends up in landfills (Umapathy et al. 2014; Senthil Kumar and Baskar 2015a, b), including colored glass which is typically not recycled. However, currently there are very few applications of waste glass in concrete due to lack of knowledge and long-term data on the behaviour of concrete containing glass aggregate (Senthil Kumar and Baskar 2015a, b). The Glass Recycling Company (TGRC) was established in South Africa in 2006 as a glass industry association body with the overall objective of reducing the total volume of glass being sent to landfills. There are however numerous challenges faced by TGRC. The logistics involved in transportation of waste glass poses a great challenge due to its weight and shape. Although recycling of waste is a top priority in the waste hierarchy, the cost of producing glass has decreased substantially over the past few years; hence, recycling is becoming as expensive or even more expensive than producing new glass from virgin resources. This has led to a decrease in price paid for glass and an increased focus on potential alternative applications for this waste stream. Since the main component of glass is sand, the properties and specifications are very similar, and concrete containing glass aggregate meets the requirements of conventional concrete (The Clean Washington Centre, 1996). A potential problem recognised by Stanton (1940) is the effect of the alkali-silica reaction (ASR) which may occur between the cement which is alkaline and reactive silica, theoretically creating "silica gel" which is prone to microscopic cracking in the presence of moisture. However, the presence of ASR gel may not necessarily result in destruction of the concrete; it is however considered as a possible risk and should be mitigated effectively (Swamy 1992). Positive effects of glass introduction were reported, whereby particles smaller than 1.18 mm showed lower expansion than natural fine aggregates and particles smaller than 75 μm in size showed an increase strength development, which could possibly attribute to the cementitious properties of glass powder (Liang et al. 2007, 2021). In South Africa, this unconventional way of producing concrete may receive scepticism because it is perceived that waste materials are inferior to virgin materials, and for this reason, more extensive testing is important to demonstrate the benefits and provide technical confidence.

9.4 Waste Tyres

The rapid expansion of the automobile industry throughout the globe has led to an increase in demand for natural and synthetic materials. The large number of vehicles present today has led to the accumulation of waste tyres worldwide. Rubber tyres are one of the most widely used materials in the transport industry; however, the disposal of used tyres is difficult due to their characteristics and properties (Torretta et al. 2015). There are approximately one and a half billion tyres manufactured annually throughout the globe (Pilusa et al. 2014). In South Africa, there are fourteen million tyres sold annually (Department of Environmental Affairs 2018). Due to the non-biodegradable properties of the tyres, the disposal of the used tyres in a sustainable way becomes challenging (Bisht and Ramana 2017). It is estimated that there are approximately 30 million to 60 million tyres in stockpiles throughout South Africa (Department of Environmental Affairs 2018). The latest waste tyre statistics show that approximately 27.01% of waste tyres collected in South Africa were recycled for the first 6 months in 2019.

Incineration of these tyres releases toxic chemicals such as carbon monoxide, sulphur, and nitrogen oxides into the atmosphere, which are detrimental to the health of organisms and the environment (Ziadat and Sood 2014; Bisht and Ramana 2017). Disposal of tyres at landfills and stockpiles pose many hazards as they promote the breeding of pest and bacteria (Eldin and Senouci 1994). Due to the chemical composition of tyres, they are highly combustible. Therefore, the accumulation of tyres is regarded as a fire hazard as they are difficult to extinguish if set alight (Ziadat and Sood 2014). The ambient grinding process is one of the material recovery methods used to convert waste tyres into crumb rubber. The rubber component of the tyre is shredded into coarse-sized particles which are used in a variety of applications. The steel found in the tyre is removed and recycled. However, polymer fibres that are used as tyre reinforcement are disposed at landfill sites.

The concept of using fibres for concrete reinforcement is not a new one. Previous studies investigated the effects of incorporating fibres in concrete, for example, using fibre derived from recycled PET drink bottles. Generally, addition of fibres to concrete would act as crack inhibitors and substantially increase the tensile strength, cracking resistance, impact strength, wear and tear, fatigue resistance, and ductility of concrete (Kandasamy and Murugesan 2011; Koo et al. 2014; Al-Hadithi and Alani 2015).

Shi Yin et al. describe this a sewing effect, increasing the ductility; it is also at times defined as a “bridging” effect (Yin et al. 2015). Furthermore, they noted when testing beams that plain concrete beams failed almost instantaneously with the occurrence of the first crack, but the fibre beams (polypropylene fibre) failed over a period of additional bending as the bending force was transmitted to the fibres once the first cracks occurred; this was a result of the matrix action that is attributed due to the concrete mixed with the fibres (Pešić et al. 2016).

Trois et al. explored a possible solution for the reuse of tyre fibres by adding them as a performance enhancement material in low strength concrete. Experiments were conducted using different masses of contaminated and partially cleaned tyre fibres as a replacement for fine aggregates in the concrete (Naicker et al. 2015).

The tyre fibres were substituted by percentage mass for fine aggregates in the concrete mixes, while all other components remained constant. The following concrete mixes were designed for the investigation:

1. 0% Tyre fibre mix (control)
2. 2% Partially clean fibre mix
3. 5% Partially clean fibre mix
4. 2% Contaminated fibre mix (contaminated with crumb rubber from the tyres)
5. 5% Contaminated fibre mix (contaminated with crumb rubber from the tyres)

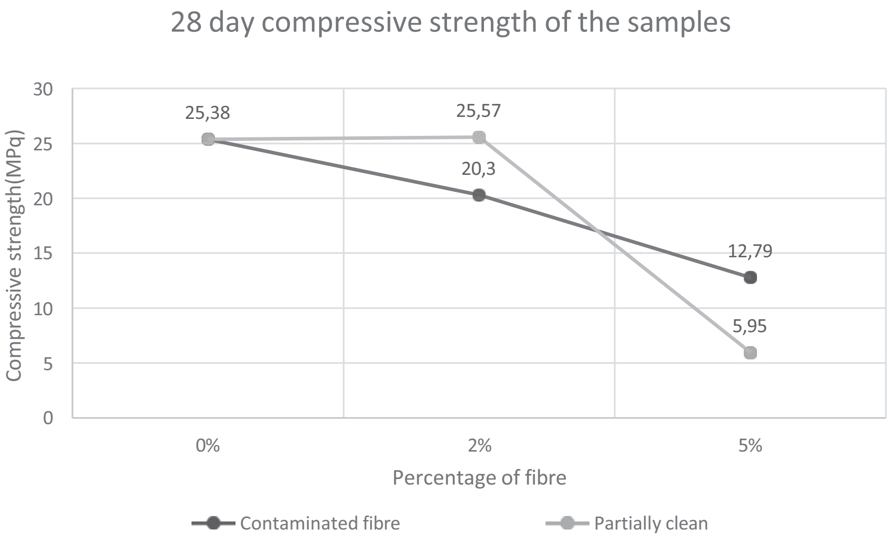

Fig. 9.1 28-day results for compression strength for the different concrete mixes. (Naicker et al. 2015)

9.4.1 Compression Strength Test

The results obtained from the compression strength test are presented in Fig. 9.1. Three cubes were cast for each concrete mix, and an average value was used as the final strength of the mix.

From Fig. 9.1, it can be noted that the target strength of 25 MPa was achieved for the control mix. The concrete mix containing 2% partially cleaned fibres displayed an increased compressive strength of 0.19 MPa when compared to the control mix. A large transition was recorded between concrete mixes containing 2% and 5% partially cleaned fibres. The concrete mix containing 5% partially cleaned fibres was relatively dry when compared to the other mixes. One of the reasons for the phenomena is the absorption of the water by the partially cleaned fibres. A gradual decline in the compressive strength of concrete mixes containing contaminated fibres was experienced. This trend was also experienced in experiments conducted on concrete incorporated with contaminated tyre fibres (Pešić et al. 2016; Baričević et al. 2018). The high volume of crumb rubber may influence the strength of the concrete. Past literature mentions that as the volume of crumb rubber increases, the compressive strength of the concrete decreases (Al-Tayeb et al. 2013; Dong et al. 2013; Hunag et al. 2016; Bisht and Ramana 2017).

As it is exhibited in Fig. 9.1, for the 5% partially cleaned fibre concrete mix, the compressive strength for the third cube does not lie within 15% of the average; therefore, the results for the mix is not valid. This would suggest that more samples will be required to evaluate the compressive strength of the concrete mix and improve the validity of the results.

9.4.2 Splitting Tensile Test

The results from the splitting tensile test are presented in Fig. 9.2. Three cylinders were casted, and an average splitting tensile strength was calculated for each concrete mix.

As observed in Fig. 9.2, there is an increase of 0.15 MPa in the tensile strength for the concrete mix containing 2% partially cleaned fibres, when compared to the control mix. A sharp decline is noted in the tensile strength between 2% and 5% partially cleaned concrete mixes. The concrete mixes containing contaminated fibres experienced a gradual decline in the tensile strength of the concrete as the percentage of fibre added increased. During the tests, it was noted that the samples did not split completely into two separate pieces. A crack could be noted; however, the fibres held the samples together.

9.4.3 Flexural Test

The results obtained from the flexural test of the concrete samples are presented in Fig. 9.3. Three beams were cast for each concrete mix, and an average of the results for each mix was used as the final value.

It can be observed in Fig. 9.3, for 2% fibre, that there was an increase in the flexural strength of 0.15 MPa and 0.03 MPa for partially cleaned and contaminated fibre

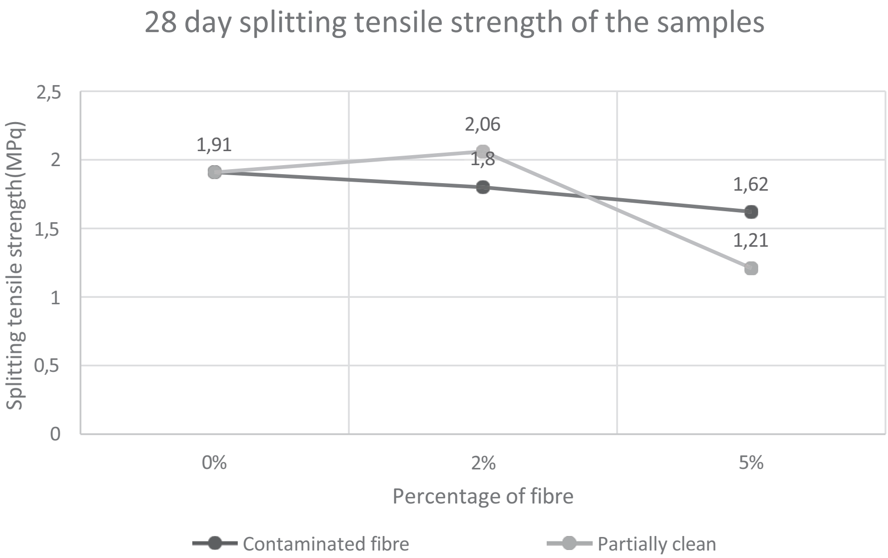

Fig. 9.2 28-day results for splitting tensile strength for the different concrete samples. (Naicker et al. 2015)

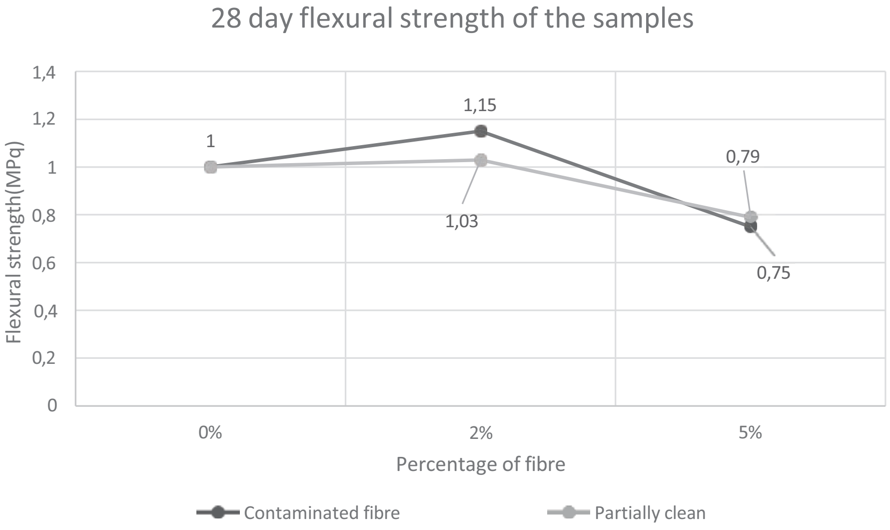

Fig. 9.3 28-day results for flexural strength of the different concrete samples. (Naicker et al. 2015)

respectfully when compared to the control mix. This was followed by a decline in the flexural strength in both partially clean and contaminated fibres, for the 5% fibre concrete samples. A similar trend was observed in the results published by Baricevic et al. (2018), with wet spray, air-entrained concrete. It is clear that more tests are required to identify the effects of increasing amounts of tyre fibres in concrete on the flexural strength of the material. During the tests, it was observed that the beams did not split into two separate pieces.

9.5 Paper Mill Sludge (PMS)

Pulp and paper mill residual solids (also called sludge) are composed mainly of cellulose fibers, moisture, and papermaking fillers (mostly kaolinitic clay and/or calcium carbonate) (Bajpai 2015). The main methods of disposing this type of sludge have been land application and land filling. Landfilling costs in Europe have risen due to the increasingly strict laws, taxes and decreasing capacities of landfills (Ochoa de Alda 2008). Paper mill sludge is also often incinerated in order to reduce the volume of the waste disposal and to recover heat (Fava et al. 2011).

Paper sludge has high water absorption. This property of paper sludge reduces its flow properties when used in cement mortar and concrete. Research conducted by Segui et al. (2012) included the use of paper sludge as hydraulic binder, the result of this experiement revealed that paper sludge as an hydraulic binder provided satisfactory strength as a whole. The use of PMS in clay bricks is one of the most researched applications of paper sludge reuse. Sutcu and Akkurt et al. (Segui et al. 2012) found that paper sludge in clay material reduced the combustion load during the firing process of bricks. In more recent studies, paper sludge was also used in energy recovery techniques. This includes pyrolysis, direct liquefaction, steam reforming, anaerobic digestion, and gasification (Singh et al. 2018). Many different ways of re-using waste PMS have been researched. These various applications include hydraulic binders, cementitious materials, polymer reinforcement, and fibreboards. These applications were researched due to PMS containing gehlenite, tricalcium aluminate, belite, metakaollinite, and mayenite (Singh et al. 2018). Any source of calcite and kaolin can be used as a pozzolanic addition in the manufacturing of cement. The pozzolanic reaction of PMS is as good as that of natural metakaolin. The presence of CaO and MgO in sludge creates volume instability. This limits the partial replacement of cementitious binder by sludge to 10%.

In South Africa, approximately 500,000 tons per annum of sludge is produced from pulp, tissue, and paper mills. This sludge waste is mostly landfilled, discharged into the ocean via a sea outfall pipeline, or incinerated. Implementation of environmental legislation, such as the National Environmental Management: Waste Act, 2008 (Act 59 of 2008) places the sector under considerable pressure to find better management practices for mill sludge disposal. However, apart from legislative pressure, pulp and paper mills can benefit from finding alternative methods of sludge management by producing value-added products to supplement the mills' income and reduce their carbon footprint. The difficulty with pulp and paper mill sludge is the variants in process conditions (from mill to mill) and the type of fibre feedstock (virgin fibre or recycled fibre), which result in the properties of mill sludge being different. Therefore, a single solution for mill sludge diversion from landfill is not realistic, and some beneficiation options might be better suited to certain mill types than others. A typical sludge contains about 60% organic matter and 40% inorganic matter. The inorganic matter can be beneficiated through the manufacture of bricks, whereas the organic matter can be beneficiated by the separation of fibres and converting them to nanocrystalline cellulose, as well as by the microbial processing of the sludge to produce biopolymer plastics (Godfrey et al. 2022; Jele et al. 2022).

This study was undertaken at the South African Research Chair Waste and Climate Change hosted at the University of KwaZulu-Natal headed by Prof C. Trois. We considered the elaboration of hybrid materials in the making of concrete bricks using PMS as a performance enhancer. All the sample testing undertaken were hardened state tests of concrete samples. All the tests were conducted after 28 days of curing and consisted of compressive strength test, splitting tensile strength tests, and flexural strength test (beam test). All testing was done in accordance with the South African National Standards.

9.5.1 Compressive Strength

As shown in Table 9.1, the concrete sample that contained 2% PMS fibres showed a 15.03 MPa reduction in compressive strength, which is a 35.04% loss in strength from the control sample. The concrete sample with 5% PMS fibres showed a reduction of 18.87 MPa in compressive strength, which is a 44% loss in compressive strength from the control sample. The concrete sample that contained 10% PMS fibres showed a significant loss of 37.73 MPa, which resulted in 87.97% reduction in compressive strength from the control sample. The loss in compressive strength of the samples with PMS fibres means that these samples cannot be graded as the same grade of concrete as the control mix.

For the test of the samples to be valid, the range between the compressive strengths of the samples needs to be within 15% of the mean compressive strength of the samples. It can be seen that all the samples fell within the required range of 15% and the tests are considered valid.

9.5.2 Splitting Tensile Strength

The concrete samples containing 2 and 5% PMS fibres both showed an increase of splitting tensile strength from the control sample (see Table 9.2). The sample with 2% PMS and 5% PMS samples showed a 1.27 MPa (59.53%) and 0.42 MPa (19.61%) increase in splitting tensile strengths, respectively, whereas the sample with 10% PMS showed a 0.9 MPa reduction in splitting tensile strength, which is a 42.51% reduction from the splitting tensile strength of the control mix.

It can be seen that the increase in PMS fibres in 2 and 5% concentration increased the average splitting tensile strength of the concrete. There is a drop in average splitting tensile strength from 2% PMS substitution to 10% PMS substitution. According to the concrete institute, one of the factors that affect concrete strength is the surface texture of aggregates. The PMS fibres consisted of inconsistent surface texture, as they were hand shredded and not uniform. This could have had aided in the increase in the splitting tensile strength of the concrete.

The decrease in tensile strength from the 2% PMS to 5% PMS to the 10% PMS samples can be attributed to the inconsistent size and geometry of the PMS fibres.

Table 9.1 Summary of 28-day compressive strength results. (Naicker et al. 2015)

Mix	Average 28-day compressive strength (MPa)	Percentage change in compressive strength (%)
0% PMS	42.89	0.00
2% PMS	27.86	35.04 Decrease
5% PMS	24.02	44.00 Decrease
10% PMS	5.16	87.97 Decrease

Table 9.2 Summary of 28-day splitting tensile strength results. (Naicker et al. 2015)

Mix	Average 28-day splitting tensile strength (MPa)	Percentage change in splitting tensile strength (%)
0% PMS	2.13	0.00
2% PMS	3.40	59.53 Increase
5% PMS	2.55	19.61 Increase
10% PMS	1.23	42.51 Decrease

Table 9.3 Summary of 28-day flexural strength results. (Naicker et al. 2015)

Mix	Average 28-day flexural strength (MPa)	Percentage change in flexural strength (%)
0% PMS	5.89	0.00
2% PMS	5.23	11.21 Decrease
5% PMS	4.80	18.49 Decrease
10% PMS	2.42	58.92 Decrease

The PMS fibres were hand shredded, and large unsorted PMS fibres have probably reduced concrete strength with higher concentrations of PMS.

9.5.3 Flexural Strength (Beam Test)

As shown in Table 9.3, the sample with 2% PMS showed a 0.66 MPa reduction in flexural strength, which is a 11.21% loss in flexural strength from the control sample. The 5% PMS samples showed a reduction of 1.09 MPa in flexural strength, which is 18.49% loss in strength from the control samples. The sample with 10% PMS fibers showed a 3.47 MPa reduction in flexural strength, which is a 58.92 loss in strength from the control sample.

9.6 Food Waste

Sharma et al. (2019) put forward the various problems that result from the inadequate management of organic waste. These include pollution of the natural environment, eutrophication, aesthetic degradation, greenhouse gas emissions, and impacts on public human health. Of the potential waste valorisation applications, organic pollutants release heavy metals that are a health hazard to both people and the environment (Sharma et al. 2019). Composting using organic waste has proven to be shown to reduce the amount of organic waste sent to landfills (Sharma et al. 2019). This agricultural recycling of organic waste ensures that landfilling costs are reduced, transportation costs of the waste are avoided, and conventional fertilisers that may be imported are substituted (Sharma et al. 2019).

One type of organic waste that has a good potential for alternative building materials within urban mining is bone. Research suggests that the use of bone within concrete production in its various forms is feasible. According to Bhat et al. (2012), bone is a slow-deteriorating, hard but light material with an extracellular matrix.

Bovine bone waste is widely produced within South Africa. Currently, the overwhelming majority of this waste stream is landfilled, contributing to waste management costs for local municipalities, as well as contributing to South Africa's climate change emissions through methane emitted from landfill. Thus, there is significant scope to valorise this waste stream within a South African context.

Using bone waste as an additive during the production of concrete has numerous benefits, including the preservation of natural resources and landfill airspace reduction (Abubakar et al. 2016). Some of the other benefits from the implementation of crushed bovine bones in concrete production are the improvement of livelihoods as valorisation of bone waste has the potential for job creation and consequentially improve the lives of those that generate bone waste which has demonstrated to be a resource. Another benefit from the implementation of crushed bovine bones in concrete production is the improvement of livelihoods as valorisation of bone waste has the potential for job creation. Bone waste has proved/shown to be a resource and has the potential to improve the lives of those that generate it. Furthermore, if this waste stream is successfully valorised, butcheries nationwide or markets such as bovine-head markets within informal markets sectors will economically benefit from selling bone waste for construction purposes. The addition of bone in concrete results in a light weight concrete with many structural benefits; lightweight concrete means that elements of structures such as beams, columns, and foundations may be designed at reduced sizes (Bhat et al. 2012).

Though this study has a broad national application, this work will speak to the study area of the bovine-head market at Warwick Junction Informal Market in Durban, South Africa. The market sells bovine-head meat and dumplings daily to the public in the Durban Central Business District (CBD). A total of 20 traders work at the market, and their tasks are divided into cookers and skinners. The market's most significant waste streams are bovine-head bones, skin, and residual wastes resulting from the market's activities.

The Warwick Junction Informal Markets (WJIM) are the biggest collection of informal markets in Southern Africa. WJIM comprise of nine markets of which two are the early morning market and the BHM. The BHM is a facility run by 20 traders who prepare bovine head meat and sell it to customers in the Durban CBD. One of the traders revealed that the bovine heads are acquired from various butcheries in the near vicinity. The current method of disposal at the market is direct disposal to the local municipal sanitary landfill, and the implications of this disposal method are undesirable. This case study aims to create a crushed bone hybrid concrete that is a sustainable alternative for conventional concrete while diverting this organic waste from landfills and mining this particular type of waste stream.

Table 9.4 Summary and comments on compressive strength test

Compressive strength		
%CBB in concrete mix	28-day CS (MPa)	Comments
0%	40.2	The 28-day compressive strength decreased with an increase in %CBB content as observed in previous literature. Overall, compressive strengths were greater than those achieved in previous literature
10%	33.7	
15%	29.7	
20%	27.6	

9.6.1 Experimental Investigation and Discussion

The compressive strengths achieved in MPa ranged between 27.6 and 40.2, as seen in Table 9.4. When compared to the range of 16.49 MPa to 24.29 MPa achieved in a study by Ogarekpe et al. (2017), this preliminary results surpassed expectations. The differences in strengths may have been influenced by type of bovine bones used. The bones used in this study were jaw bones, and because the study by Ogarekpe et al. does not specify which kind of bovine bones were used, a comparison in this regard cannot be made. Compressive and flexural strength (Table 9.5) in this study result decreased with an increase in the percentage of CBB content, and this was the predicted outcome observed in previous studies. According to South-African Standards, low-strength, medium-strength, and high-strength concretes have strengths of 15 MPa, 25 MPa, and 30 MPa, respectively. The 20% CBB concrete achieved a strength of 27.6 MPa which was above the medium-strength concrete strength; hence, concrete with a 20% CBB content could be applied as a medium-strength concrete. The applications of medium-strength concrete according to South African standards are footpaths, reinforced foundations, patio slabs, light-duty house floors, garage floors, and driveways. The flexural strength results as seen in Table 9.5 fluctuated with the 15% CBB content achieving a maximum strength of 3.3 MPa. The control specimens yielded greater strengths in comparison to the all the hybrid CBB concrete specimens.

9.7 Viability of the Waste Resource from the Different Waste Streams for Bricks

In terms of average compressive strength, some of the bricks incorporated with waste performed better than the control sample. Using South African standards for building requirements, a number of practical applications become apparent (see Table 9.6).

Table 9.5 Summary and comments on flexural strength test

Flexural strength		
%CBB in concrete mix	28-day FS (MPa)	Comments
0%	3.9	Flexural strength at 28 days reduced with an increase in CBB content and this relationship followed the same trend found in previous literature
10%	2.3	
15%	3.3	
20%	3.2	

Table 9.6 Suggested bricks with waste for various applications in functions of their compressive strength. (Mahdjoub et al. 2021)

Possible applications	Average required compressive strength for solid units (MPa)	Proposed brick specification
Single storey or the upper storey of a double storey building	4.0	Cow bones, glass, paper Mill Sludge, tyres nylon fibers
Lower storey of a double storey building	10.0	Cow bones, glass, paper mill sludge, tyres nylon fibers
Infill panels in concrete and steel-framed buildings of four storeys or less	4.0	Cow bones, glass, paper mll sludge, tyres nylon fibers
Free standing, retaining, parapet, and balustrade walls	5.0	Cow bones, glass, paper mill dludge, tyres nylon fibers

9.8 Conclusion

Waste from a broad perspective is a subject of concern for most emerging countries. In the context of Africa, the newly defined etymological terms of urban mining and circular economy are supposedly considered to be new concepts.

However, historically speaking, or traditionally speaking, African people have always applied, not knowingly, the concepts of urban mining and waste recovery as a secondary source of materials. Since the recognition of these concepts from the developing countries, more African countries have started reconsidering their modern approach to waste and materials and are now consciously moving towards urban mining.

This collection of investigation has articulated some possibilities for waste utilisation as a source of material for the creation of hybrid materials. Testing revealed that incorporation of waste into building material was viable, and this incorporation should be perceived as a performance enhancer method through urban mining. Developing this process could lead to income generation for the local economy of some developing countries. It could also initiate consistent and intensive waste mining adapted to the context of emerging states.

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