Application of mine tailings sand as construction material – a review

Jacob Ikotun[1*], and *Rhoda* Adeyeye[1], *Mike* Otieno[2]

[1]Civil Engineering, Durban University of Technology, Pietermaritzburg, South Africa
[2]School of Civil Engineering and Environmental Engineering, University of Witwatersrand, Johannesburg, South Africa

Abstract. Abstract. Tailings are found during the exploration and processing of mineral ores. They contain a mixture of grounded rocks, processed effluent, and some trace elements that have the potential to damage the environment. Recent urbanisation has led to a large stockpile of tailings in many mining environment constituting health hazard. It becomes very important to develop disposal techniques that will reduce the huge mountain of tailings in mining environment. One of such method is the application of tailings in sustainable concrete production. It is shown that physical and chemical characteristics of tailings are comparable to crusher sand used in engineering construction and therefore, tailings can be used to partially replace sand in bituminous and concrete mixtures. In this review, specific interest has been given to iron, copper, and gold tailings, this is due to their dominance in mining areas of Kwa-Zulu Natal province of South Africa.

1 Introduction

Tailings are mining waste produced from processes of excavation, extraction, physical and chemical treatment of mineral ores [1]. It is reported that out of over 315 million tons of tailings generated yearly in South Africa, 105 million tons are from gold tailings [2]. Tailings are usually disposed into the surface impoundments. However, tailings storage facilities are liable to failure causing ecological disaster [3]. This suggests the need for a comprehensive framework for the management of mine tailings that promotes sustainable development in mining areas. Characteristics of tailings depend on the type of mineral ore as different minerals co-exist with different compounds such as silicon and iron; minerals such as pyrite and quartz, and heavy metals such as arsenic, lead, and uranium as found in 419 mine tailings samples collected from four different mine sites in South Africa [4].

Tailings contain rocks, heavy metals, oils (hydrocarbons), and water in the form of chlorides or sulphate solution [1], [3]. The presence of chemicals in tailings render its application impracticable in construction works. This necessitates its treatment to less hazardous waste before discharging to landfills or reusing as construction material [5]. The present mining wastes disposal legislations in many countries as reported by many studies are not sustainable. The high rise in disposal tax has resulted in the re-use of treated tailings [6]. Ramanathan et al and Kiventerä et al [7] [8] reported that tailings are less reactive, even under alkaline conditions, hence, they are inert material that can be used to partially replace natural sand in engineering construction.

1.1 Physical and chemical characteristics of tailings

The physical and chemical characteristics of a material determine its usefulness as engineering and construction materials. Tables 1 and 2 show the physical and chemical properties of typical tailings [9]–[41]. From Tables 1 and 2, it can be deduced that the selected properties of the tailings are comparable to normal sand used in engineering construction. This comparison offers tailings as a potential use in concrete mixtures as an alternative source of sand in sustainable concrete production [42]. However, it is important to ascertain the behaviour of individual tailing in concrete in relation to strength and durability.

2 Application of tailings as construction materials

Stone and sand are part of the main constituent of concrete and bituminous mixtures. In South Africa, natural rock has been the main source of sand [43]. Natural rock is crushed into stone and sand aggregates for their use in concrete and bituminous mixtures for road construction [44]–[47]. However, mining natural rock as a construction material has not been sustainable due to the exploitation of the natural resources and the fact that the physical features and natural scene of the immediate environment

* Corresponding author: JacobI@dut.ac.za

are destroyed during sourcing and processing. This necessitates an alternative source of sand for concrete production.

Table 1. Comparison of physical properties of typical tailings and crusher sand

Physical properties	Andesite crusher sand	Gold tailings	Iron tailings
Fineness modulus	3.23 – 3.5	0.28 – 2.84	1.05 – 2.55
Specific gravity	2.41 – 2.91	2.6 – 3.46	2.60 – 3.51
Density (g/cm^3)	2.11 – 2.36	1.40 – 6.7	1.27 – 2.62
Water absorption range (%)	0.63 – 2.04	7.15	0.9 – 7.0
Specific surface area range (m^2/g)		0.036 – 7.2	2.63 – 5.69
Shape	Angular	Angular	Angular

Table 2. Comparison of the chemical composition of typical tailings and crusher sand.

Chemical composition	Andesite crusher sand	Gold tailings	Iron tailings
SiO_2	21.19 – 61.93	40.5 – 89.25	37.20 – 71.00
Al_2O_3	2.09 – 20.24	6.10 – 17.09	1.22 – 27.03
Fe_2O_3	4.21 – 7.36	0.84 – 28.97	7.04 – 27.03
CaO	2.77 – 9.0	0.30 – 14.96	0.03 – 12.97
MgO	1.61 – 4.82	0.08 – 6.97	0.30 – 7.10
SO_3	0.38 – 2.7	0.05 – 3.9	0.03 – 2.02
Na_2O	1.07 – 3.39	0.02 – 3.04	0.46 – 3.45
K_2O	1.13 – 3.95	0.55 – 5.32	0.04 – 2.62

Tailings constitute stable minerals, such as shale, quartz, sand, and limestone [4]. The presence of these minerals in coarse and finely graded tailings presume their potential use as engineering and construction materials. The coarse and finely graded tailings can be used to replace stone and sand in concrete and bituminous mixtures, while the sub-micron powder can be used as filler in concrete to improve the fresh and hardened properties of the resulting matrix [18], [48], [49]. Even though the reusability of tailings as engineering and construction materials has generated interest among relevant stakeholders and researchers, more research are required to see its wider application as a construction material. This review examines different applications of tailings as a construction material. The attempt is to place less demand on the exploitation of natural rock.

2.1 Application of tailings in bituminous mixtures

Bituminous mixtures consist of bitumen, fillers, fine and coarse aggregate in proportion to form a durable matrix. They are used in road surfacing and as protective coating for construction materials such as concrete, steel, wood and steel. Fillers are important ingredient in bituminous mixture; they are inert materials that pass a 75-micron sieve [46]. Fillers may be limestone, cement, stone dust, brick dust, or fly ash. They perform their function by filling the interstices between the larger aggregates [50], [51]. The mixture of filler and bitumen forms a high consistence binder that can be used to cement large aggregates together. Fillers are an important part of bituminous mixtures they offer stability during mixing and laying at any temperature. Tenza-Abril et al [52] investigated bituminous mixture that contained tailings. Tailing samples were taken from different mining locations and used as filler in the bituminous mixture, the performance was compared with using limestone as filler. The result indicate that for tailings to be used in the bituminous mix, they need to pass through milling operations to satisfy the grading requirements of fine and coarse aggregates used in asphaltic pavement. A proper aggregate size distribution influences the load bearing capacity and the important properties of the asphaltic mixture which prevent rutting in asphaltic concrete pavements [53].

2.2. Application of tailings in concrete mixtures

Concrete is a mixture of binders, water, admixture, and aggregates (sand and stone). Aggregates occupy 65 to 80% of concrete volume [43]. This indicates the massive use of natural aggregates in concrete production. Sand as a natural fine aggregate is usually sourced through mining exploration. Sourcing and processing of sand from natural aggregates deposits and natural rock destroy the aesthetics of the environment. This inspires several studies into the use of tailings as a sand replacement in concrete mixtures.

Several studies reported the effects of iron tailings as a sand substitute in concrete. Otieno and Odoro [31] investigated the workability and compressive strength of Kimberlite tailings' concrete. Oritola et al [19], Sabat et al [55], Tian et al [56] investigated the workability of concrete made with different percentage of iron tailings partially replacing sand. The studies recorded lower workability for every percentage replacement compared to reference concretes. This can be attributed to the high-water absorption and large specific surface area of iron tailings. Al Muttaqii et al [30] examined the compressive and tensile strengths of concrete samples with varying percentages of iron tailings replacing sand. It was observed that the compressive and tensile strengths of the concrete with iron tailings were higher than that of the reference concrete. The increase in the compressive and tensile strengths were because of the well-filled pore structure by the finer particle of iron tailings, and the rough texture of iron tailings that aided the interlocking of the tailings particles. Similar trend was also observed with flexural strength of the concrete. However, a different trend was observed when copper and Kimberlite tailings were used individually to partially replaced sand in the concrete. This shows that tailings type affect the strength properties of concrete.

3 Discussion

The urgency of effective tailings disposal aroused the interest of researchers in concrete material. It was aided by the similarity between the properties of sand and tailings. This review shows that the physical properties and chemical composition of tailings as a sand replacement have a great influence on fresh concrete and mechanical properties of hardened concrete. The different types of tailings do not have an exact effect on concrete, though some have a similar impact on concrete. The literature revealed that iron tailings and gold tailings lower the workability of concrete while copper tailings raised the workability. The research works on the compressive strength of concrete containing iron and gold tailings give a suitable result up to a reasonable percentage. However, the reports on the compressive strength of concrete produced with copper tailings are conflicting. Iron, copper, and gold tailings have a similar trend in the tensile strength of concrete. The impact of copper and gold tailings on the flexural strength of concrete are alike. In contrast, iron tailings show contradictory performance on the flexural strength of concrete.

Moreover, literature revealed some suitable performance of iron, copper, and gold tailings in place of sand despite the varied proportion of these tailings. Fig. 1 and Fig. 2 show the maximum percentage replacements of sand with iron tailings and copper tailings as recommended by various authors respectively. Based on the maximum percentage replacement, it was suggested that the concrete containing iron, copper, and gold tailings can be in the construction of light and medium concrete of various kinds. The investigation on the mechanical properties is yet to present any decisive pattern that can be applied to a specific tailing. Also, each of the researchers used different assessments with several agreeing perceptions. Therefore, a detailed study is necessitated to carry on a series of standardised tests to obtain a uniform trend on the mechanical properties and serve as a frame for forthcoming tests. Also, there are limited study on the durability performance of concrete prepared with tailings as a sand substitute. Thus, a comprehensive investigation should be performed on the durability performance of the concrete containing tailings.

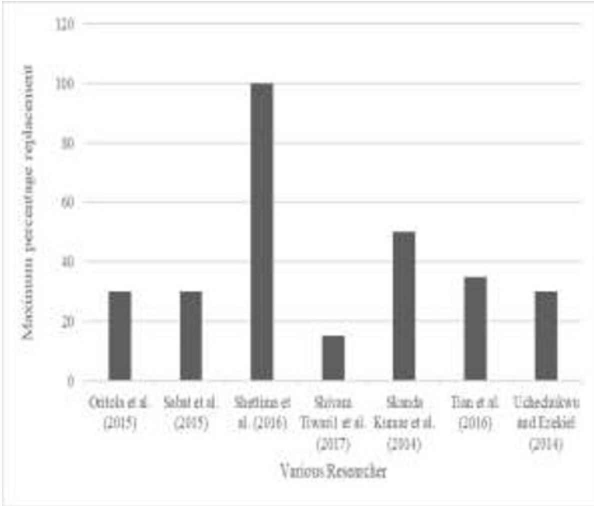

Fig. 1. Maximum percentage of iron tailings in concrete as recommended by various researchers

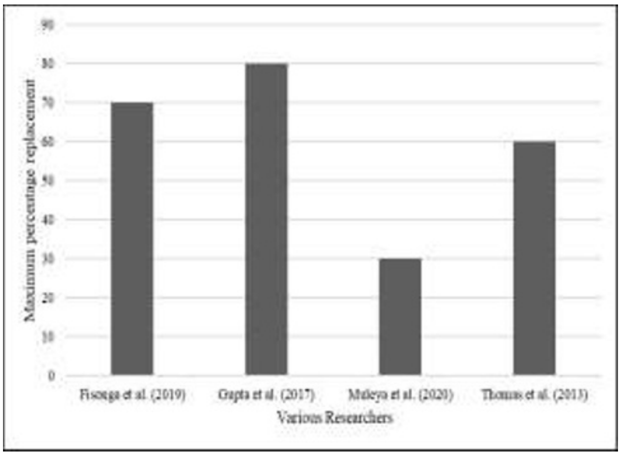

Fig. 2. Maximum percentage of copper tailings in concrete as recommended by various researchers

4 Conclusion

The increasing stockpile tailings are posing a threat to the environment. The need for the effective disposal of tailings draws the attention of concrete materials researchers to examine the feasibility of tailings replacing sand in a concrete mixture. The investigations prove how tailings such as iron, copper, and gold are feasible as a sand substitute in concrete. The studies give some suitable results of the tailings in concrete. Tailings as partial or full substitution of sand will benefit the construction and mining industry as well as the mining community such as KwaZulu Natal province. The benefit includes the promotion of the cost-benefit of fine aggregate in concrete production, alleviation of the environmental effect of sand mining for engineering construction, and mitigation of tailings disposal problem. Thus, the advancement of the current awareness of the application of tailings as a sand substitute in concrete will contribute to cleaner and sustainable mining environment for the next few decades.

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