E3S Web of Conferences **596**, 01029 (2024) https://doi.org/10.1051/e3sconf/202459601029
ICCMES 2024

A Review on Sustainable Utilisation of Zinc Mine Tailing in Concrete Production

Haris Maqbool Rather[1], and *Murtaza* Hasan[2*]

[1,2] Department of Civil Engineering, Chandigarh University, Mohali, 140301, India

Abstract. India is among the largest mineral and metal producers globally, including coal, iron ore, bauxite, and zinc. These resources are extracted and processed to create tonnes of mine tailings which are usually disposed into waste or tailings dams. It is estimated that around 80 million tons of mine tailings every year in the country. Zinc tailing is a byproduct from zinc extraction during production that contains several hazardous components like iron, silica, zinc, lead, aluminium oxides cadmium amongst others. These impurities often have adverse effects on people's health as well as the environment surrounding dumping sites. Nonetheless, in recent years, the utilisation of waste materials in concrete production has become popular due to its ability to enhance the sustainability of the construction industry. The purpose of this review paper is to look into the possibility of replacing some of the fine aggregates and cement in concrete and mortar with zinc tailings. The use of zinc tailing as a substitute for cement in concrete could be an effective way to reuse industrial waste and decrease the environmental impacts associated with cement production. Zinc tailings have diverse physical and chemical properties making them suitable for various construction purposes. The studies have shown that, ideally, the zinc tailing should be 5-20% of the weight of cementitious ingredients. It has been proven that this helps to enhance workability, compressive strength and durability in concretes. Thorough investigations need to be carried out to establish the long term durability and environmental sustainability of these materials although they have been found to reduce pollution and promote sustainable development.

1 Introduction

As global efforts to achieve environment-friendly development increase, the construction industry has prioritized the production of alternative materials produced from industrial wastes [1-4]. Zinc tailings, the waste products of zinc mining, are one such material that has demonstrated potential. Zinc ore is extracted in the form of lumps or boulders of varying sizes at zinc mines using under-ground or open blasts as shown in Figure 1 [2]. These lumps or boulders are primarily crushed to a size of 150mm. Secondary and tertiary crushers then lower the material size to 10mm. Because of their large-scale production, these tailings, also known as lead-zinc sulphide tailings (LRT), pose a twofold challenge in terms of disposal and environmental impact [2, 5]. Several studies have emphasized the negative effects of tailing waste disposal, such as land degradation, harm to aquatic life and flora, visual impairment, aesthetic loss, air pollution, and groundwater contamination [5-7]. It is expected to have produced 34.47 thousand tonnes of zinc by 2023. Currently, tailings are used for underground mine back-filling, with any excess deposited in tailing dams at various mines locations. The mixing of lead-zinc tailings into building materials has several benefits including lower pollution, higher economic returns, and support for sustainability [8-10]. This methodology is extremely promising and beneficial for improving tailings resource potential [7]. Various studies have found that the disposal of mine tailings waste has resulted in a slew of problems, including soil degradation, negative effects on aquatic life and flora, visual blight, loss of aesthetic value, air pollution, and groundwater contamination [11-13]. Therefore, the present review paper aims to look into the potential utilization of zinc tailings as a cement and fine aggregates replacement in concrete/mortar and road construction so it helps to better reuse of zinc tailings. The authors collected zinc tailing from the zinc tailing pond of Zawar, Hindustan Zinc Limited, Rajasthan, India to perform a physiochemical analysis.

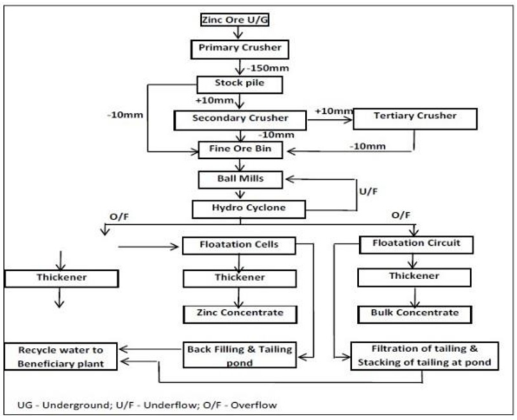

Fig. 1. Flow chart for generation of Tailing [10]

* Corresponding author: murtaza.e12019@cumail.in

© The Authors, published by EDP Sciences. This is an open access article distributed under the terms of the Creative Commons Attribution License 4.0 (https://creativecommons.org/licenses/by/4.0/).

2 Physicochemical Properties of Zinc Tailing

2.1 Physical Properties

The physical characteristics of tailings show minimal variation across different types. Tailings are typically categorized into sand, silt, and clay size fractions using diverse methodologies employed by various mining operators [9]. Indian zinc tailing comprises 30% sand, 56% silt, and 14% clay-sized particles [2,8]. The gravity value falls between 2.4 to 2.71. Particularly, the tiny particle dimension of zinc tailing waste approaches that of cement particles, which typically pass through a 75-micron screen. Advances in grinding technology have in-creased both clay and silt concentration in tailings, with some studies indicating optimal tailing dimensions of less than 1 mm when utilized as aggregate [11-12]. Generally, tailings exhibit rough and irregular surfaces due to differences in the ability of mineral grinding [14]. Grinding techniques have been employed by various researchers to diminish the particle size of zinc tailing waste [8]. In the present paper, authors also performed Scanning electron microscopy (SEM) on zinc tailing waste collected from the zinc tailing pond of Zawar, Hindustan Zinc Limited, Rajasthan, India as shown in Fig. 2.

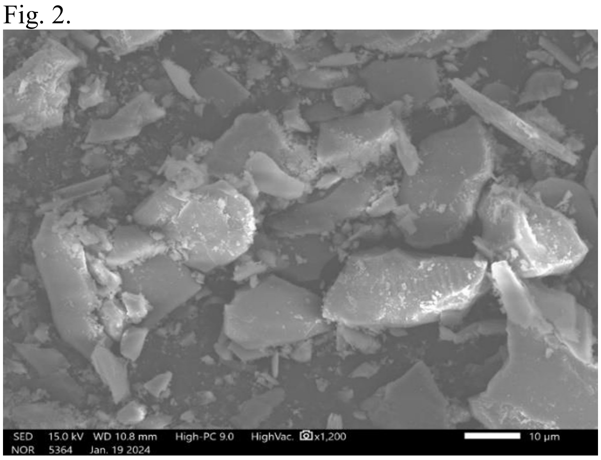

Fig. 2. Scanning electron microscopy mage of zinc tailing

2.2 Chemical Characteristic

Table 1 presents the chemical compositions of the tailings used by various authors. The compositions are predominantly composed of SiO_2, Al_2O_3, CaO, and Fe_2O_3. However, the concentration of these oxides varies greatly amongst types of tailings. Lead-zinc tailings, for example, with SiO_2 concentrations ranging from 35.50 to 69.92% and Al_2O_3 concentrations ranging from 3.99 to 8.62% [2,8,15-16]. This wide range presents hurdles for material researchers attempting to understand tailings composition and possibilities for reuse [14]. Zinc tailings also contain hazardous components such as iron, silica, lead, zinc, aluminum oxides, and cadmium. To mitigate the health and safety issues connected with zinc tailings, a complete strategy is required, which includes effective dust control, ventilation, PPE, handling standards, and worker training. These techniques will improve construction handling and processing while reducing potential health risks and environmental pollution. Despite their low metal concentration, lead-zinc tailings retain reuse potential due to their high silica-alumina oxide content. Comparing their chemical composition to clay reveals surprising similarities, particularly in SiO_2, Fe_2O_3, and Al_2O_3 levels. Moreover, the predominant minerals in lead-zinc tailings-quartz, feldspar, and clay-bear a resemblance to natural sand minerals [17]. Suggesting their suitability as substitutes for sand in cement or construction material production [18]. Standardised pre-treatment and material characterisation processes should be developed to mitigate variability in the mineral composition of zinc tailings. Targeted chemical adjustments, quality control tests, and consistent blending ratios can minimise inconsistencies in concrete quality. Standardisation will lead to improved structural integrity and material dependability. The mineral phases present in lead-zinc tailings exhibit significant diversity, as illustrated by Fig. 3. The XRD graph revealed the presence of calcite, quartz, mica, and pyrite, with calcite showing the highest peak. This indicates that calcite is the dominant mineral in zinc tailing. Previous studies have identified various mineral phases such as calcite, dolomite, quartz, kaolinite, galena, pyrite, and gypsum, while others indicate differing mineral compositions, including quartz, orthoclase, barite, albite, chlorite, dolomite, calcite, and barite [15,16].

Table 1. Chemical composition of zinc tailings

Authors/compositions	**Sinha et al. (2022) [10]**	**Agrawal et al. (2021) [8]**	**Sigvardsen et al. (2018) [15]**	**Lin et al. (2016) [16]**
SiO_2	57.29	40.4	35.5	66.23
Al_2O_3	8.62	3.99	6.8	7.67
Cu_2O	7.17	-	-	-
Fe_2O_3/FeO	0.12	4.61	-	2.45
CaO	9	16.9	13.6	8.51
MgO	8.23	8.62	4	1.78
Na_2O	0.92	-	< 0.7	0.54
SO_3	-	-	2	-
ZnO	3.89	-	-	-
K_2O	2.27	-	4.1	0.65
PbO_2	2.48	-	-	-
LOI	-	25.48	5.1±0.5	3.83

 https://doi.org/10.1051/e3sconf/202459601029

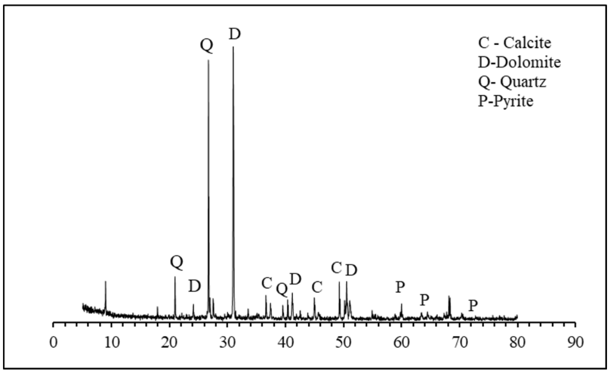

Fig. 3. XRD spectra of zinc tailing

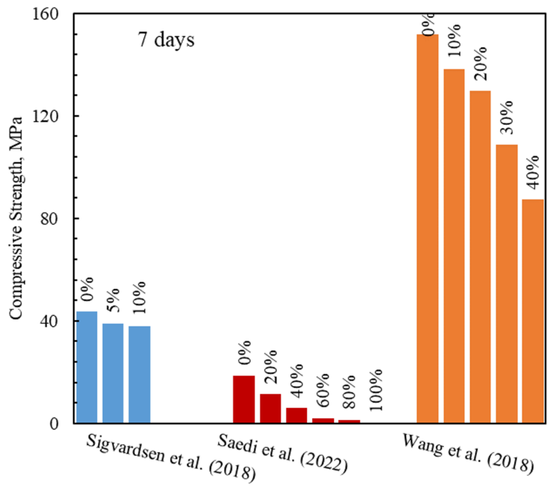

Fig. 4. Variation of 7 days compressive strength of concrete with zinc tailing percentage.

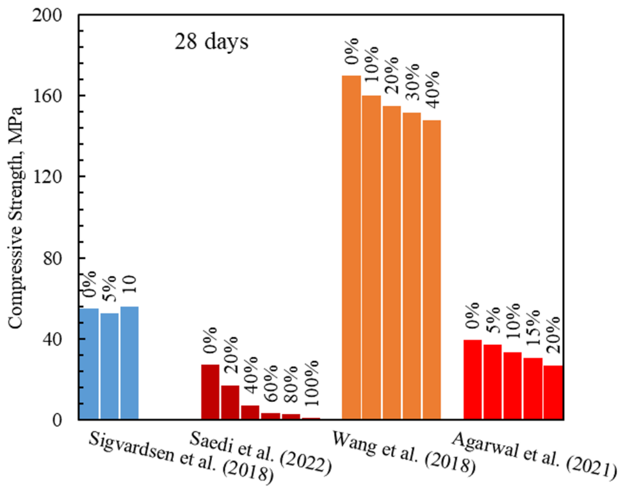

Fig. 5. Variation of 28 days compressive strength of concrete with zinc tailing percentage.

3 Effect of Zinc Tailings on Mechanical Properties of Concrete/Mortar

3.1 Compressive Strength

Incorporating zinc tailings into concrete creates a complex scenario affecting compressive strength, which is influenced by elements such as tailings proportion, mineralogical composition, and curing conditions. Because tailings require more water for similar workability, concrete containing fine aggregates frequently has a greater water-to-cement ratio, resulting in lower compressive strength than control specimens. High zinc tailings concentrations impair early-age compressive strength, with 7-day strength changing between investigations [10,15,18]. The variation of 7 and 28 days compressive strength of concrete with the percentage of tailing studied by various authors is shown in Fig. 4 and 5. Sigvardsen et al. (2018) [15] found that substituting up to 10% of cement with tailings resulted in a nearly 13% loss in 7-day strength, whereas 5% substitution achieved 95% of the normal strength of concrete by 28 days. However, more than 10% replacement diminished 28-day strength. Wang et al. (2018) [17] revealed that proportional decrease in the compressive strength with increasing lead-zinc tailings percentage in Ultra-High-Performance Concrete (UHPC), implying a feasible limit of 30% to maintain satisfactory long-term strength. Saedi et al. (2022) [21] identified that substituting cement with mine waste, particularly at 40-60% replacement levels, considerably boosted 28-day strength, albeit with delayed hydration. They suggested up to 20% replacement without improved approaches. Agarwal et al. (2022) [8] exposed a little advantage: a 5% substitution provided equivalent 28-day endurance to plain concrete.

3.2 Flexural Strength

The variation of 7 and 28 days flexural strength of concrete with the percentage of tailing studied by various authors is shown in Fig. 6 and 7. Zhou et al. (2021) [22] identified that incorporating lead-zinc sulfide tailings (LRT) in concrete mixtures decreased flexural strength compared to normal concrete (OPC) at all curing ages (7, 28 days), but when the LRT addition was less than 47%, specimens met the MU15 benchmark for autoclaved lime sand brick strength, indicating suitability for construction applications. Sinha et al. (2023) [2] tested the flexural strength of concrete mixes with tailings and found a substantial increase in flexural strength at 7 days, ranging from 10-17%, compared to the control mix without tailings, showing robust early-age strength growth. Furthermore, replacing up to 40% of the fine aggregate with tailings increased flexural strength after 28 days by 10-17%.

Sani et al. (2023) [23] found that adding jarosite at 5% and 10% as partial cement replacement increased the flexural strength of a 25% re-used pavement asphalt (FRAP) mortar mix, but any amount of FRAP reduced flexural strength after 28 days compared to the control mix, with the most significant reduction of 41.6% observed in the mix containing 100% FRAP (mix 100R), indicating that FRAP content harms flexural strength.

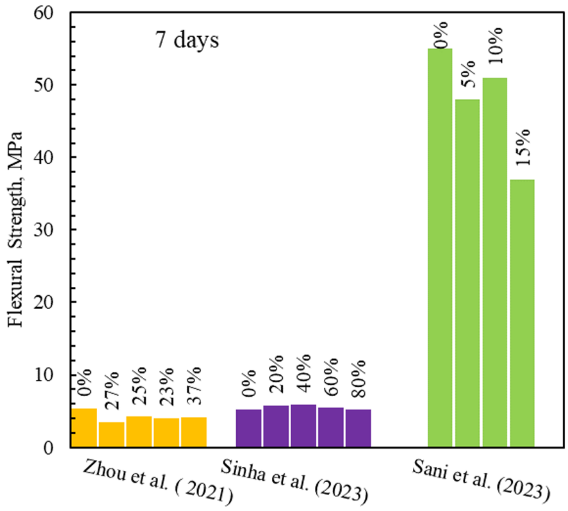

Fig. 6. Variation of 7 days flexural strength of concrete with zinc tailing percentage

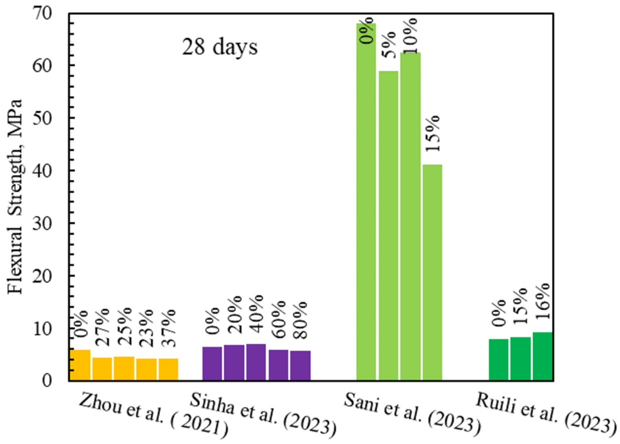

Fig. 7. Variation of 28 days flexural strength of concrete with zinc tailing percentage

4 Utilization of Zinc Tailing Waste in Road Embankment

Zinc tailings, a byproduct of mining, show promise as a road embankment mate-rial. Stability analyses suggest that embankments can be built up to 6 meters tall, however, stability declines with height and is especially crucial during sudden water table drops [10]. The utilization of zinc tailing by various researchers in road construction is presented in Table 2. Even under these conditions, embankments meet the basic safety requirements for seismic activity. Fortunately, zinc tailings settle extremely little and have a good load-bearing capability, which could reduce pavement thickness. To prevent erosion from loose tailings, a soil cover is required. Overall, zinc tailings have potential as embankment foundations due to their high CBR value and resistant modulus, but more research is needed to validate their durability and environmental impact [2,10,24, 26, 27]. The many cost-benefit analyses of employing zinc tailings as construction materials in India show that zinc tailings can be beneficial. Zinc tailings would generally be obtained free or at a minimum fee from mining industries and save raw material costs for the user compared to other conventional aggregates as used in sand or gravel. It also has the potential for lower environmental disposal costs by mining companies and can help conserve resources. However, there are also some economic issues: processing costs, transportation, and the cost of obeying environmental rules.

Table 2. Zinc tailing used in road construction

Authors	Test conducted	Main properties	Utilization	Reference
Teredesai (2005)	UCS, modulus of elasticity, and seismic modulus.	The application of stabilizing agents resulted in large increases in UCS and elastic modulus.	laboratory testing and on a 0.6-mile test road, 10% CFA or CKD was applied to MT as the roadway basis.	[25]
Desogus et al. (2013)	Solidification test, leaching test and stabilization.	The combined use of FeCl3—KH2PO4 decreases the leachability of Pb, As, and P.	The inertization of the mining waste studied is due both to physical encapsulation and to the formation of stable compounds for the additives used.	[24]

Argane et al. (2016)	Thermogravimetric analysis (TGA), XRD, SEM, MIP and Durability.	increasing water demand leads to increasing porosity, while the cement matrix limits Pb and Zn dissolution.	MT has traditionally been used as an aggregate for rendering mortars.	[11]
Sinha et al. (2022)	Unconfined compressive strength test, indirect torsional strength test, durability test, SEM-EDS, and X-ray diffraction.	It has a high tensile strength (121 Mpa), which indicates a great cracking tolerance.	It can be used to substitute fine aggregate in GSB and bottom layer building at a rate of 2-5%.	[10]

5 Conclusions

Zinc tailings hold huge potential as an sustainable construction material if these problems associated with processing and waste management are overcome. Recent studies have pointed out suitability for various usages, especially for pavement and subgrade treatments in embankments, where their peculiar properties can play an important role in serviceability. Further confirmation of their application viability in road embankments is obtained by mechanical stability and load-bearing capacity. Early-stage compressive strength test results have shown excellent enhancements in the mechanical properties of concrete/mortar mix zinc tailing. However, further studies shall be conducted in the aspect of field performance with a guarantee of long-term performance and environmental sustainability of the material. The key durability tests include compressive strength, freeze-thaw resistance, permeability, and ASR testing. Scaling up would need material property standardisation, rigorous performance validation, and regulatory certification to ensure uniform quality and wider usage in India's building sector. Environmental sustainability might be ascertained through leaching tests, life cycle assessments, and ecotoxicity studies. Further findings will be validated through field performance monitoring. Use of these methods may ensure comprehensive material performance and ecological understanding so that zinc tailings can be safely used as concrete for sustainable construction and resource conservations. Zinc tailings provide a bright prospect to reduce pollution and push forward sustainable development in the construction field.

Regulatory bodies play a crucial role by setting safety standards, enforcing environmental guidelines, and promoting sustainable practices for using zinc tailings in construction. They need to establish clear protocols for handling, processing, and disposal while encouraging innovation and incentivizing industries to adopt eco-friendly, circular economy approaches.

References

1. Hasan, M., Khan, M.A., Alsabhan, A.H., Almajid, A.A., Alam, S., Khan, M.A., Biswas, T., & Pu, J. Geotechnical Behaviour of Fly Ash–Bentonite Used in Layers. Appl. Sci. 12, 1421 (2022). https://doi.org/10.3390/app12031421
2. Sinha, A.K., Havanagi, V.G., & Singh, A.P. Characterisation of zinc tailing for bituminous road construction. Indian Highways 51(7), 28–36 (2023).
3. Farooq, F., & Hasan, M. Geotechnical Behaviour and Utilisation of Sustainable Waste with Expensive Soil in Rural Roads as Subgrade Material. Indian Geotech J. (2024). https://doi.org/10.1007/s40098-024-00934-5
4. Hasan, M., Khan, M.A., & Alam, J. Permeability characteristic of fly ash treated with bentonite. In Proceedings of Indian Geotechnical Conference IGC, December (2014) 18–22.
5. Sharma, R.S., & Al-Busaidi, T.S. Groundwater pollution due to a tailings dam. Eng. Geol. 60(1–4), 235–244 (2001). https://doi.org/10.1016/S0013-7952(00)00104-6
6. IMYB. Lead and zinc. In Indian Minerals Yearbook, 58th ed. Nagpur, India: Indian Bureau of Mines, Government of India, Indira Bhavan, Civil Lines (2019).
7. Jiang, F., Ren, B., Hursthouse, A.S., & Zhou, Y. Trace Metal Pollution in Topsoil Surrounding the Xiangtan Manganese Mine Area (South-Central China): Source Identification, Spatial Distribution and Assessment of Potential Ecological Risks. Int. J. Environ. Res. Public Health 15, 2412 (2018).
8. Agrawal, Y., Gupta, T., & Chaudhary, S. Effect of mechanically treated and untreated zinc tailing waste as a cement substitute in concrete production: An experimental and statistical analysis. Environ. Sci. Pollut. Res., 1–26 (2022).
9. Wang, C., Harbottle, D., Liu, Q.X., & Xu, Z.H. Current state of fine mineral tailings treatment: A critical review on theory and practice. Miner. Eng. 58, 113–131 (2014).
10. Sinha, A.K., Havanagi, V.G., Sreekantan, P.G., & Chandra, S. Geotechnical characterisation of zinc tailing waste material for road construction. Geomech. Geoeng. 17(6), 1984–2004 (2022).
11. Argane, R., El Adnani, M., Benzaazoua, M., Bouzahzah, H., Khalil, A., Hakkou, R., & Taha, Y. Geochemical behavior and environmental risks related to the use of abandoned base-metal tailings as construction material in the upper-Moulouya district, Morocco. Environ. Sci. Pollut. Res. 23(1), 598–611 (2016).

12. Santana, J.N., Da Silva, S.N., Silva, G.C., Mendes, J.C., & Peixoto, R.A.F. Technical and Environmental Feasibility of Interlocking Concrete Pavers with Iron Ore Tailings from Tailings Dams. J. Mater. Civ. Eng. 29(9) (2017).
13. Zhao, S.J., Fan, J.J., & Sun, W. Utilization of iron ore tailings as fine aggregate in ultra-high-performance concrete. Constr. Build. Mater. 50, 540–548 (2014).
14. Gou, M., Zhou, L., & Then, N.W.Y. Utilization of tailings in cement and concrete: A review. Sci. Eng. Compos. Mater. 26(1), 449–464 (2019).
15. Sigvardsen, N.M., Nielsen, M.R., Potier, C., Ottosen, L.M., & Jensen, P.E. Utilization of mine tailings as partial cement replacement. Mod. Environ. Sci. Eng. 4(4), 365–374 (2018).
16. Lin, G., Wang, C.L., Qiao, C.Y., Cui, H.L., Chen, L., & Yu, S. Preparation and properties of autoclaved aerated concrete containing lead-zinc tailings. Rev. Romana Mater. Rom. J. Mater. 46, 334–342 (2016).
17. Wang, X., Yu, R., Shui, Z., Zhao, Z., Song, Q., Yang, B., & Fan, D. Development of a novel cleaner construction product: Ultra-high performance concrete incorporating lead-zinc tailings. J. Clean. Prod. 196, 172–182 (2018).
18. Nayak, A., Jena, M.S., & Mandre, N.R. Beneficiation of lead-zinc ores–a review. Miner. Process. Extr. Metall. Rev. 43(5), 564–583 (2022).
19. Akinyemi, B.A., Alaba, P.A., & Rashedi, A. Selected performance of alkali-activated mine tailings as cementitious composites: A review. J. Build. Eng. 50, 104154 (2022).
20. Nouairi, J., Hajjaji, W., Costa, C.S., Senff, L., Patinha, C., da Silva, E.F., Labrincha, J.A., Rocha, F., & Medhioub, M. Study of Zn-Pb ore tailings and their potential in cement technology. J. Afr. Earth Sci. 139, 165–172 (2018).
21. Saedi, A., Jamshidi-Zanjani, A., Darban, A.K., Mohseni, M., & Nejati, H. Utilization of lead–zinc mine tailings as cement substitutes in concrete construction: Effect of sulfide content. J. Build. Eng. 57, 104865 (2022).
22. Zhou, Y., Duan, X., Chen, T., Yan, B., & Li, L. Mechanical properties and toxicity risks of lead-zinc sulfide tailing-based construction materials. Mater. 14(11), 2940 (2021).
23. Saini, S.K., Sahdeo, S.K., Ransinchung, R.N., Kumar, G.D., & Kumar, P. Performance of cement mortar mixes containing fine reclaimed asphalt pavement aggregates and zinc waste. Adv. Cement Res., 1–13 (2023).
24. Desogus, P., Manca, P.P., Orru, G., & Zucca, A. Stabilization–solidification treatment of mine tailings using Portland cement, potassium dihydrogen phosphate and ferric chloride hexahydrate. Miner. Eng. 45, 47–54 (2013).
25. Teredesai, R.V. Stabilization of Pile Run Chat for Roadway Base Application. Ph.D. Thesis, University of Oklahoma, Norman, OK, USA (2005).
26. Bhatt, P., Sinha, A., Dayana P J, M., Geetha Sreekantan, P., Hasan, M. (2024). 'Performance Evaluation of Zinc Tailing Waste Material for Embankment Construction: Experimental and Numerical Investigation', Journal of Min-ing and Environment, 15(4), pp. 1177-1191. doi: 10.22044/jme.2024.13368.2459
27. Bhatt P, Sinha AK, Mariya DP, Hasan M. Strength and deformation behaviour of zinc tailing waste material for embankment construction. InIOP Conference Series: Earth and Environmental Science 2024 Jun 1 (Vol. 1326, No. 1, p. 012057). IOP Publishing.