https://doi.org/10.48047/AFJBS.6.Si4.2024.3892-3898

African Journal of Biological Sciences

Journal homepage: http://www.afjbs.com

Research Paper Open Access

EXPERIMENTAL INVESTIGATIONS ON EFFECT OF BASALT COMPOSITE FIBERS AND OIL SHALE ASH ON SPECIAL CONCRETE

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Article History
Volume 6, Issue Si4, 2024
Received: 15 May 2024
Accepted: 25 June 2024
doi: 10.48047/AFJBS.6.Si4.2024.3892-3898

Abstract: The weakest phase of concrete is the interfacial transition zone (ITZ), which has a higher porosity and is more susceptible to microcracks. This study investigates the ITZ in fiber-reinforced concrete by utilizing oil shale ash (OSA) as a supplementary cementitious material (SCM) and macro-basalt fibers (BFs) to improve the properties of the concrete and reduce its carbon footprint. Six substantial blends in with 10%-30% OSA and a consistent 8.0 kg/m³ BF portion were tried. SEM pictures and mechanical tests showed that OSA further developed holding and densified the ITZ microstructure, keeping up with flexural strength up to 20% substitution and diminishing compressive strength by 6.7%, while bringing down the an Earth-wide temperature boost potential by 19.24 kg CO2 identical with 10% OSA. Because of their inert filler behavior and incomplete reaction, higher OSA replacements had a negative impact on mechanical properties.

Keywords: interfacial transition zone (ITZ); fibre–paste transition zone; basalt fibres (BFs); oil shale ash(OSA); supplementary cementitious materials (SCMs); microstructure analysis; mechanical properties

1. Introduction

Concrete, the most widely used building material, is constantly being improved to improve its strength, durability, and performance as a whole. The interfacial transition zone

(ITZ), which forms between the paste and aggregates, is one significant focus area. The glue total ITZ is viewed as the most fragile period of cement because of the greater porosity and bigger translucent stages in this zone contrasted and the mass glue. It is likewise the zone where the breaks start, further proliferating and harming the substantial when the most extreme stacking is reached. As a result, microcracking, which frequently begins and spreads within the ITZ, creates the impression that the ITZ is the concrete's weakest phase. Strands have acquired significance as an important expansion to substantial blends since they oversee the flexural strength and other mechanical qualities of the substantial. Filaments upgrade bonds by precisely interlocking the network and totals, decreasing the potential for debonding and further developing burden move across the ITZ [1-2].

Additionally, the structure's overall durability is enhanced and crack propagation is slowed down by the fibers' role as reinforcement within the concrete. A paste–aggregate ITZ resembles a fiber–paste ITZ, despite the positive influence of fibres. A concentrate on elite execution fibre reinforced concrete uncovered comparable hardness values in the ITZ between the total and the glue as in the ITZ between the steel filaments and the glue. The development of the ITZ happens as little cover particles show a lower pressing thickness when they experience an enormous surface region, like that of filaments, making a "wall impact". This prompt expanded porosity and an expansion in the recurrence of stages with low moduli, including pores and low-thickness calcium silicate hydrate (CSH) close to the strands. Additionally, the ITZ is distinguished by its high concentration of calcium hydroxide (CH) crystals that have grown to maturity. There are a few ways to mix that can get rid of the wall effect. These include using a binder with a mixture of cement, micro silica, or other SCMs and a well-graded binder, among other things [3-4].

To address the weakness of the ITZ and further optimize it, the incorporation of supplementary cementitious materials (SCMs) has been extensively researched. By doing so, the CO2 footprint of concrete can be reduced. Particle sizes and chemical compositions of SCMs like fly ash, slag, silica fume, and metakaolin can increase packing density and provide additional reactivity delay in the ITZ [9]. By making up for shortfalls, giving extra cementitious gel, and advancing the relieving conditions, SCMs decrease porosity and improve the ITZ's solidarity and toughness. Improved crack control, durability, and structural integrity are just a few of the benefits provided by fibers, which are essential for enhancing the performance of concrete.

They spread out stresses, limiting the spread of cracks and brittle failure. Tensile strength, toughness, resistance to impact, cyclic loading, and shrinkage cracking are all improved by fibers. Fibers are an efficient method for extending the service life and ensuring the long-term durability of concrete structures due to their versatility in form and material. The focus of this article is on the concrete's fiber–paste ITZ and the synergistic effects of oil shale ash (OSA) and macro-basalt fibers (BFs) on its properties. In hazardous waste management, specifically in storage packaging for low-level radioactive waste (LRW), low-strength concrete is used to encapsulate LRW before it is placed in larger containers. This is a targeted use of designed concrete types.

In order to guarantee that the entire packaging will protect against radiation, it is necessary to have a thorough understanding of the ITZ. This experimental study examines the microstructure of the mixtures using OSA as an SCM with varying percentages of cement replacement and a constant amount of BFs in the concrete mix. To this end, the observed cross-sectional SEM images of the samples are used to compare the mechanical properties of fresh and hardened concrete mixes containing BFs and OSA. Additionally, the global warming potential calculation demonstrates the concrete environmental benefits of OSA application [5-7].

2. Methodology

Concrete mixes were prepared with a constant fiber dose of 8.0 kg per m3 of concrete and a variable OSA dose of 10 to 30% by cement weight for the analyses of the fiber–paste ITZ. The materials utilized were Portland limestone concrete (PLC) CEM II/ALL 42.5 N from Schwenk concrete Latvia, dolomite powder and fine totals got from Saulkane, Latvia, and OSA acquired from Eesti Power Plant, Estonia, where oil shale is singed with no expansion of biomass. The OSA's chemical composition was determined using a Rigaku Primus II spectrometer and a PLC provided by the produce using X-ray fluorescence spectroscopy (XRF) on Li2B4O7-LiBO2-LiI + sample-fused glasses. Although OSA has been categorized as a pozzolanic material in the literature, its chemical composition suggests otherwise. According to ASTM C618-22, it does not contain enough pozzolanic oxides to qualify as a class C pozzolan material. The OSA had a D50 particle size of 26.9 m on average. The amount of anhydrite in this type of OSA is approximately 14.57 weight percent, and 11.61 weight percent of amorphous phase Because OSA is waste, its mineralogy and distribution of particle sizes can vary from batch to batch.

Deutsche Basalt Faser GmbH's coated–chopped composite BFs have a rectangular cross-section, average dimensions of 0.55 mm to 0.36 mm, and are made up of filaments with a density of 1.9 g/cm3. The objective compressive strength of a reference concrete mix (C) without OSA was set at 15 MPa after 28 days. A laboratory mixer was used to make mixes containing OSA in replacement ratios of 10, 15, 20, 25, and 30% by weight of cement. Table 1 displays the proportions of all six mixes, which were designed to provide sufficient paste for fiber dispersion and anchoring. Additionally, the concrete mixes were made to be used as fillers and shielding agents in low-level hazardous waste storage. The low-level hazardous waste can be mixed and poured into a steel drum thanks to those concrete types' low strength and workable consistency [8].

Table 1. Mix designs.

MIX	**PLC(Kg)**	**OSA(kg)**	**DP(kg)**	**MS(kg)**	**Aggregates (kg)SP**			**Water**	**SP**	**Fibre**
					0–1.0 mm	**0.3–2.5mm**	**4–8 mm**			
C	252.0	0.0	217	13	570	955	55	228	6.3	8.0
OSA10	223.0	26	217	13	570	955	55	228	6.3	8.0
OSA15	215	39	217	13	570	955	55	228	6.3	8.0
OSA20	202	52	217	13	570	955	55	228	6.3	8.0
OSA25	189	64	217	13	570	955	55	228	6.3	8.0
OSA30	175.0	75.0	217	13	570	955	55	228	6.3	8.0

PLC = Portland limestone cement; OSA = Oil shale ash; DP = dolomite powder; MS = micro-silica; andSP = superplasticiser.

Particle size distribution influences how PLC and OSA are distributed. (PSD) of each mix individually. With the exception of micro-silica, the PSDs and grading curves of the individual powder materials were analyzed because the packing density can be affected by the right proportion of each material. The experimental work's flow. Using a tilting drum mixer, the concrete was mixed. The required materials were mixed as follows: (1) half of the cement, powders, and aggregates were dry mixed; (2) half of the water was poured into the mixer; (3) the remaining cement, powders, and aggregates were added; (4) the remaining water and SP were then added to achieve the desired workability; and (5) the BFs were spread into the rotating mixer to ensure that the fibers were distributed uniformly. A slump test with a target slump of 220–250 mm was used to measure the consistency of the fresh concrete. After 24 hours of initial curing under cover, the concrete was moved to the water storage tank and formed into molds. The 28-day-old samples' compressive and flexural strengths were assessed. SEM was used for a microstructural analysis to comprehend the concrete's fiber–paste ITZ [9].

3. Results and Discussion

Through a comprehensive examination of fiber–paste ITZ using SEM images, the obtained results are first discussed on the microscale. The slump, compression, and bending results are then presented in an evaluation of the concrete's mechanical performance. The results of the global warming potential of concrete mixes with OSA replacement, which demonstrate the additional advantage of using this SCM, complete the discussion [10].

3.1. Examination of Fibre–Paste ITZ

The SEM show that few basalt fibers are implanted in the substantial grid, and it appears to be that the tar of the BFs is upset. It is difficult to determine the diameter of each BF's individual ITZ because each BF is surrounded by its own ITZ. However, by combining and overlapping, the individual ITZs of the fibers contribute to the fiber-paste ITZ network as a whole. At the point when the obliteration of the glue starts because of outside stacking, the strands give solidarity to the glue somewhat. The SEM sample is cut out of a larger sample so that the BFs can be seen on the surface being analyzed. A strand can crack because of the example readiness, as can be noticed. Moreover, there are noticeable holes between strands where neither the pitch nor cementitious glue infiltrated and ineffectively framed fastener hydration items between and around the singular basalt fibers.

Each basalt microfibre's resin coating is damaged, and the binder of the analysed concrete is in direct contact with the basalt microfibres where the fiber ITZs are formed. The fiber ITZs contain the primary hydration products, CSH, CH, and ettringite, upon closer examination. XRF analyses revealed that the OSA used in this study contains 5.45 weight percent SO3 and 14.5 percent anhydrite.

As a result, more ettringite and sulfur-containing formations are formed, particularly in ITZs with more space and water. The chemical composition of the OSA indicates that the weight percentage of SO3 is slightly higher than that required for SCMs by EN 450-1 and ASTM C618-22. The presence of sufficient sulfate ions in the solution is necessary for ettringite formation. Ettringite will continue to react with the remaining C3A after gypsum is exhausted, resulting in the formation of monosulphoaluminate hydrate. Not all ettringite is turned into monosulphoaluminate hydrate because the OSA contains too much sulphur. High-thickness CSH is prevalently present in the mass glue, and low-thickness CSH with a bigger distance between layers loaded up with water particles is probably going to be available in the ITZs.

Extra CSH is framed by the response between the antacid folio and silicates from the BFs that are not adequately covered by the full-scale BF tar. Improved properties at the fiber–paste interface can be attributed to the chemical bonding and interaction that can be seen on the BF surface. It should be noted that secondary deposition or precipitation could be the cause of the CSH products on the surface of the BFs. If the silica-rich BFs lose their coating and are directly exposed to the alkaline cement paste, a reaction that results in the formation of a thin layer of CSH on the surface of the fiber can cause secondary deposition [11-12].

3.2. MotorizedPossessions of Concrete Combinations

The conclusion that additional SCMs, particularly microsilica, should be used was reached after conducting a thorough analysis of the concrete paste that only contained OSA and cement. In addition, dolomite powder was utilized to produce a paste with a greater volume to facilitate BFs. Lower-strength concrete mixes were developed and tested as this testing served as a pre-study for the utilization of BFs. The new substantial's functionality and the solidified substantial's properties, in particular compressive and flexural qualities. The majority of the prepared mixes had a slump of 220 mm, and their workability ranged from 180 to 230 mm.

Every one of the blends aside from OSA20 fulfilled the objective rut of 220-250 mm. A water/binder ratio of 0.47 and a rather high SP dose of 6.36 kg per m3 ensured sufficient workability. 20.9% of the mix weight was the total weight of the binder, which was 481.83 kg per m3. The grading of the binder that occurred as a result of the substitution of OSA for cement was insignificant, primarily affecting particle sizes between 1.65 and 12.7 micrometers. The compressive experimental outcomes show that the expansion of OSA to the fiber substantial combination brought about a dynamic diminishing in the compressive strength with the expansion in OSA in the blend.

Consequently, it is viewed as that OSA contributed as a latent filler as opposed to as a folio. OSA has a greater impact on compressive strength than it does on flexural strength, where BFs play a significant role. The compressive strength decreased by 6.7% with a cement replacement of 10%, which may still be relevant for reducing the potential for global warming by 19.24 kg CO2 equivalent per 1 m3 of concrete. Strength tests were performed at 28 days old enough, which may be too soon to arrive at the maximum capacity of OSA as a SCM with postponed response. The blend in with 15% OSA had a 11.2% lower compressive strength than the reference blend yet simply 4.5% lower contrasted with OSA10, while the OSA20 blend had a 19.4% lower compressive strength contrasted with the reference blend. As a result, even if additional tests are conducted using a longer curing time, the OSA15 mix might still be promising.

However, for a variety of reasons, the strength of mixes with higher OSA contents may be compromised. First, it's possible that OSA remained in the concrete without being hydrated and only served as a filler. The dilution effect, which delays pozzolanic activity or hydration due to a lack of CH supply, may also result in a decrease in the quantity of hydration products overall. At long last, there is plausible that these blends require better compaction to keep away from the arrangement of voids, which cause lower substantial strength.

3.3. ConservationalAids of By means of OSA

Because OSA is a waste product, its additional advantages are demonstrated by quantifying its impact on the environment. The prepared mixes' carbon footprint was significantly reduced by OSA. To demonstrate the positive effect, the individual mixes without fibers had their global warming potential (GWP) calculated. For the computation, the Norwegian stage for the Ecological Item Announcement (EPD) estimation given by LCA.no [51] was utilized, taking into account just unrefined substances (Segment A1). It very well may be seen how the carbon impression diminishes with the supplanting of PLC with OSA in the substantial blend.

4. Conclusions

The microstructure of fiber–paste ITZs containing various doses of OSA as a partial cement replacement and a constant dose of BFs was evaluated through an experimental program. In addition, it was examined how the alterations in the microstructure affected the mechanical properties afterwards. The following conclusions can be drawn from the strength and SEM observation results.

- Taking into account the impact of OSA substitution: a. Concrete composites have a lower EPD and carbon footprint due to the presence of OSA.
- Fiber ITZs contain more ettringite after OSA replacement.

- To determine how OSA affects the microstructure of concrete, additional strength testing at higher ages, such as 56 and 90 days, is necessary.
- Glue ITZs appear to be satisfactory for concrete with OSA at a portion of up to 10%.
- With no expectation of additional delayed reactions between hydration products and the OSA, higher replacement percentages result in decreased compressive strength and poor ITZs. It very well might be reasoned that supplanting concrete with OSA by up to 10% furnishes concrete with adequate properties, while higher supplanting with OSA is pertinent for applications where strength isn't unequivocal, for example, the embodiment of low-level radiative waste in steel drums. In such a case, high OSA substitution proportions would be furthermore useful because of low GWP.
- Taking into account the presence of BFs in the blend:
- During the mixing process, it has been observed that the coating of BFs is damaged, and each basalt microfibre comes into direct contact with the concrete matrix.
- The alkaline exposure of BFs results in the formation of a thin layer of CSH on their surface.
- Mixes containing up to 20% OSA replacement in the concrete mix tend to have relatively constant flexural strengths.
- 10% OSA replacement in the mix is considered sufficient for the utilization of BFs if compressive strength is the determining factor for concrete application.

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