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Research article

Enhancing durability and sustainability of industrial floors: A comparative analysis of dry-shake surface hardeners

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ABSTRACT

This study investigates the development of a cost-effective and sustainable dry-shake surface hardener for enhancing the durability of industrial concrete floors. Utilizing locally sourced materials, the research aimed at not only ensuring the hardener's strength and finish but also its economic viability and environmental friendliness. Fourteen unique mixtures were formulated by altering the sand ratios and incorporating superplasticizers to optimize the composition. These mixtures underwent rigorous testing over 7, 14, and 28 days, evaluating their compressive and flexural strengths, flowability, water absorption, and impact resistance. The findings revealed that the modified floor hardener, specifically the FH-12 mixture, exhibited superior performance across all tested parameters. It showed higher compressive and flexural strengths, enhanced impact resistance, and reduced water absorption compared to other variants and commercially available hardeners. Notably, the use of finer coarse sand and the adjustment of superplasticizer quantities significantly contributed to these outcomes. This breakthrough demonstrates the potential of employing locally available materials to create a durable, cost-effective, and environmentally friendly solution for industrial flooring. The study underscores the importance of material characterization and methodical formulation in developing construction materials that meet the dual criteria of performance and sustainability. This option is preferred for its lower environmental impact and compatibility with sustainable practices, contributing to Sustainable Development Goal 9 on industry, innovation, and infrastructure. It highlights the role of floor hardeners in global sustainability efforts.

1. Introduction

There are numerous applications of concrete in construction, which is why safety guidelines are important for its usage and manufacture. When exposed to adverse climate conditions such as erosion due to sulfates, corrosion of reinforcement due to chloride intrusion, carbonation, and freeze-thaw cycles, concrete structures can be damaged. In addition, it may be damaged by impact loading or by a variety of different loading patterns [1]. According to EN 1992 [2], structures that are durable exhibit properties such as

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serviceability, strength, and stability over their expected service lives without requiring excessive maintenance [3]. Industrial concrete floors must meet several very specific requirements, including flatness, crack resistance, and load-carrying capacity. As industrial floors deteriorate, their service life is reduced and dust accumulates on their surface due to wear and tear. Increases in reinforcement ratio do not significantly contribute to the prevention of failure due to impact loads.

It is common for rigid bodies to impact concrete structures during their service life due to material handling, movement of objects, and intentional aggression. There will be a large dynamic load applied to the floor slab construction in the event of a blast load or a falling object. As a result of the decreased lateral load-bearing capacity of the concrete floor, failure due to punching shear and loss of moment resistance severely weakens the structure. Due to this, there are two failure modes: local and global, the latter occurring when the floor diaphragms that transmit load laterally weaken to the point where the building collapses [4]. During industrial operations, floors are abraded by friction between the concrete surface and trolley tires or the movement of moving parts of machines [5]. Concrete durability performance might be affected by environmental factors, including wetting and drying [6], frost action [7], sulfate attack [8], hot sodium exposure [9], high temperatures [10], and others. In concrete structures, material deterioration is usually the first sign of durability problems. Concrete flooring can be subjected to impact loading due to vehicle impacts, ship impacts, airplane impacts, rockfall impacts, windborne debris impacts, missile impacts, etc.

Impact-loaded structures are not only determined by their strength but also by their ability to absorb energy. A significant factor in these situations is the size, mass, and velocity of the impactor. An impactor with a large mass but a low velocity, despite having the same kinetic energy, affects structures differently than one with a small mass but a high velocity [11]. Moreover, mass also affects the structure's response. The impact can occur as a result of a large object being struck by a small impactor, a large impactor striking a small object, or an impact between similar masses. Compared to the other two cases, the third is relatively rare. First-case scenarios, such as shooting a bullet at a structure, can result in localized damage. In contrast, the impact of a collision between two comparable masses, such as a vehicle or rock fall, remains unknown.

Several techniques have been developed recently to protect concrete floors exposed to water [12,13]. These techniques can be classified into four categories: (1) rebar coated with epoxy resin (2) anticorrosion agent, (3) re-alkalizing concrete, and (4) concrete surface modification [14]. As a result of their limited applicability and lack of clarity about their results and expected service life, there is little acceptance of the first two techniques. A third technique has a high cost, which makes it unpopular. Consequently, the concrete surface treatment method, 4th technique, has gained more acceptance because of its ability to protect concrete from aggressive elements and impact forces [15]. In concrete surfaces along roads and surfaces in industrial areas, concrete surface treatment methods provide a low-cost and effective surface that resists abrasion, diffusion of chemicals, and flexural stresses [16].

There are two types of surface treatments, namely dry-shake surface hardener admixtures (DSHA) and liquid surface treatment admixtures (LSTA). Depending on its specific gravity, DSHA is classified as either non-metallic or metallic. DSHA is applied to a fresh concrete surface [17,18]. In general, non-metallic DSHA is divided into four categories: (1) Floor Hardener (2) Light reflective floor hardener (3) Emery floor hardener (4) Trap Rock floor hardener. The type 1 mixture is composed of fine-grained nonmetallic aggregates, plasticizers, and binding agents [19]. Because of its non-rusting properties, it can be used indoors or outdoors. The type 2 mixtures contain finely ground silica aggregates, coloring agents, plasticizers, and cementing agents. With its increased reflectivity (60 %) and increased abrasion resistance, it has been designed to provide better lighting levels. In type 3, cement and graded emery aggregates are mixed to produce a wear-resistant concrete floor hardener. Type 4 is a mixture of finely graded trap rock aggregates, additives, and cement, which is designed to provide greater abrasion resistance on floors and slabs. In the presence of water, DSHA forms an extra waterproof and highly durable layer. A trowel is used to compress and level the concrete surface after DSHA is reacted with water. The metallic floor hardeners, on the other hand, use graded iron aggregates in a high-strength cementitious binder. Consequently, it provides a dense, tough surface that resists abrasion and impact from industrial machinery. The material is also used in areas with a high level of traffic to reinforce and protect iron armored joints.

In recent decades, many studies have been conducted on LSTA for hard-state concrete [18]. García et al., 2008, found that DSHA significantly improved the wearing resistance, stability against chemical attacks, and porosity in four concrete specimens [16]. Knapton 1999, compared non-metallic and metallic DSHA combinations to control mixtures for abrasion resistance. The findings showed that metallic DSHA had the greatest abrasion resistance [20]. Franzoni et al., 2013 examined how inorganic surface treatments affect concrete abrasion resistance [21]. The research examined concrete surfaces treated with sodium, ethyl, and nano-silica silicates for wear resistance. Sodium silicate gives better results as it makes a protection layer. Pan et al., covered surface coatings, impregnations containing hydrophobic agents, pore blockers, and multifunctional liquid surface treatments for concrete. Permeability of air, adhesive strength, and resistance to cracks were also addressed in relation to concrete surface treatments. He also explains how surface treatments affect concrete's mechanical characteristics and durability [15]. Acrylic, polyurethane, epoxy, silicones, sodium silicate siloxanes, and surface treatments with nano-SiO_2 were explored.

In addition, physical and mechanical properties, water absorption, migration of chloride, resistance to carbonate attack, attack by sulfates, and freezing-thawing characteristics vary with surface treatments. Jia et al., examined concrete treated with fluosilicate or sodium silicate for water permeability and absorption. A magnesium fluosilicate admixture decreased water permeability by 52 % and enhanced water absorption by 10 % by physically closing the capillary gap [22]. Jones et al., examined how exposure temperature affected chloride diffusion parameters of 7 typical surface treatments. Based on a chloride diffusion study conducted on exposed concrete and sintered glass substrates, it was revealed that all methods of surface treatment are most effective at low and moderate temperatures, yet the chloride flow varies significantly depending on the treatment technique [23]. Moon et al., assessed the longevity of concrete coated with inorganic materials and concrete-treated surfaces. Coated hardened mortar and concrete specimens withstand exposure to chloride, temperature changes, and oxidation better than uncoated samples [1].

It is evident from the literature that several studies have been conducted on the use of surface treatments for concrete [1,14,15, 20–23]. However, limited research has been conducted on the effects of using non-metallic DSHA in industrial concrete floors. So, this study aims to provide information about the results of DSHA under impact loading and durability performance of industrial concrete floors. To determine the effect of DSHA on the physical, mechanical, and durability performance of concrete, compressive strength, flexural strength, water absorption, and impact tests were conducted. In the study "Improving the Performance of Heavy Industry Concrete Floors," by Elfatah, S. A. 2024, examines the impact of superplasticizer (SP) additions to concrete mixes on the durability and maintenance costs of industrial concrete floors. The research finds that a 1 % SP addition significantly enhances concrete properties, reducing creep strain by up to 28 % and maintenance costs by 30 %. The study emphasizes the economic and practical benefits of using high-quality concrete mixes with SP for industrial floors, highlighting their improved strength, elasticity, and longevity [24].

The study "Effects of surface hardeners on the performance of concrete floors prepared with different mixture proportions" by Padilha, F. et al., 2023 explores the effectiveness of surface hardeners in enhancing the durability and resistance of concrete floors [25]. The study investigates the impact of cementitious and liquid hardeners on concrete floors surface hardness, compressive strength, flexural tensile strength, and bleeding, using different water/cement ratios, curing ages, and cement types. They concluded that cementitious hardeners significantly improve surface hardness, especially in mixtures with higher water/cement content, thereby reducing the occurrence of pathological manifestations. This comprehensive study underscores the importance of selecting appropriate surface treatments to enhance the performance of concrete floors in industrial settings.

The study by Kupers, L. et al., 2018 investigates into the intricacies of enhancing the wear resistance of concrete floors. Through comprehensive experimentation, they identify key factors influencing wear resistance, including concrete composition, curing methods, and post-treatment applications [26]. Findings reveal that using harder aggregates and controlling the water/cement ratio are pivotal for improving wear resistance, while the impact of after-treatments appears limited. This research, the development of floor hardener, has a significant impact on the field of civil engineering for the following reasons: (1) Will enhance durability and longevity, (2) Cost savings and sustainability, (3) Improved functionality and safety, (4) Advancement in industry standards. In addition to improving durability, reducing costs, improving safety, and enabling informed decision-making, this research will contribute to the development of sustainable and resilient concrete flooring systems. In the long run, the findings will prove beneficial to professionals involved in the design, construction, and maintenance of various structures, resulting in safer, more functional, and economically viable buildings.

The research presented in this article offers a pioneering approach to the development of cost-effective and sustainable dry-shake surface hardeners, aiming to enhance the durability of industrial concrete floors. What sets this study apart is its emphasis on tailoring fine aggregate with different fine materials in manufacturing dry shake floor hardener. Moreover, performance of floor hardener under impact load makes this study more interesting for the researchers, which ensure not only superior strength and finish but also economic viability and environmental friendliness. This study presents a breakthrough mixture which demonstrates unparalleled performance across multiple parameters, surpassing both conventional variants and commercially available options. This emphasizes on the transformative potential of leveraging indigenous resources to engineer durable, eco-conscious solutions for industrial flooring.

Fig. 1. Materials used for floor hardener as (a) Cement; (b) Fine sand; (c) Coarse sand; (d) Finer coarse sand.

2. Materials and methods

2.1. Materials

Ordinary Portland Cement (OPC) [27], three different sands (Fine, Coarse-1, and Coarse-2), and a Superplasticizer were used to prepare the floor hardener as shown in Fig. 1(a-d). OPC type-1 according to ASTM C150/C150 M, 2022 was used as binder material [28]. The chemical composition and physical properties of OPC are shown in Table 1. The particle sizes and physical properties of both fine and coarse sands are shown in Fig. 2 and Table 2, respectively. The graph presents a comparison of grain size distributions for different sand types against the upper and lower limits set by ASTM and EN standards. The Fine sand falls within the acceptable range, satisfying both the lower and upper limits prescribed by the standards. In contrast, the coarse sand and fine sand samples do not meet the criteria, as their distributions fall below the lower limits set by both the ASTM and EN standards, indicating a finer particle size than the standards permit for certain applications. Superplasticizer (Sodium Naphthalene Formaldehyde-A) was used to provide high water reduction, improved workability, and increased flowability. It also provides a better surface finish, is compatible with various types of cement, and some types offers extended workability.

2.2. Mix proportions

Various proportions of coarse sands were replaced with finer sand by percentage, shown in Table 3, to measure the mechanical and durability properties of floor hardener. The volume fractions of cement, SNF, and water-to-cement (w/c) ratio were kept constant for all the mixture proportions. In the mix design, a cement content of 40 %, SNF content of 0.25 %, and w/c content of 0.14 % were used. The fine sand-to-cement ratio varies from 0.6 to 1.025 by weight, and the water ratio kept same w.r.t cement. All the materials were mixed in a dry state with the addition of water for absorption, followed by the addition of cement. The constituents were mixed for 7–8 min.

2.3. Methods

In the realm of construction materials research, the compressive strength according to ASTM C109 [29] of floor hardener is a paramount characteristic that dictates their suitability for specific applications. The preparation phase of the floor hardener for compressive strength according to ASTM C-109 [29] involves an exhaustive mixing process to ensure homogeneity of the mixture. Following the preparation, the floor hardener was cast into cube molds with dimensions of 50 mm × 50 mm x 50 mm. The casting process was executed with utmost care, filling the molds in layers and compacting each layer adequately to eliminate air voids, thereby ensuring uniform density and consistency across the specimens. Subsequent to casting, the surfaces of the mortar within the molds were leveled to guarantee that they were flat and perpendicular to the sides of the molds, a prerequisite for accurate testing. Post-casting, the specimens were subjected to a meticulous curing regime. Initially, they were stored in a moist environment at a controlled temperature of 23 ± 2 °C for a duration of 24 h, facilitating the onset of the hydration process. Thereafter, the specimens were demolded and immersed in water, continuing the curing process until the predetermined testing age was reached.

The compressive strength testing was conducted at designated age 7, 14, and 28 days, to evaluate the progression of strength development within the floor hardener. This testing was carried out using a compression testing machine, which applies a load to the specimen until failure. Fig. 3(a-c) shows the preparation process of specimens for different testing.

To evaluate the flexural strength of floor hardener according to ASTM C348-21 [30], the process begins with meticulous sample preparation, followed by a structured testing procedure. Initially, materials were thoroughly mixed to ensure a homogeneous blend, a critical step for achieving consistent test results. This mixture was then cast into designated molds (40 mm × 40 mm x 160 mm), with each layer compacted carefully to eliminate any air pockets and achieve a uniform density throughout the specimen. Following casting, the specimens undergo a specific curing regimen: they were stored in a moist environment maintained at 23 ± 2 °C for the first 24 h to initiate the hydration process. After this initial phase, the specimens were demolded and submerged in water, continuing the curing process until they reach the age specified for testing.

The testing phase was carried out with precision, applying a loading rate of 0.9–1.2 MPa/min to the specimens. This controlled rate was essential for accurately assessing the material's resistance to bending forces. Using a three-point bending setup, stress was applied to the specimen until failure occurs. This approach was designed to simulate the material's ability to withstand bending stresses, providing valuable data on its structural integrity and durability. The maximum load at which each specimen fails was recorded, and from this data, the flexural strength, or modulus of rupture, was calculated. The schematic and testing diagrams for compression and flexural are shown in Fig. 4(a-d).

The impact load testing [31] procedure for evaluating floor hardeners is crucial for determining their suitability in industrial settings, where floors are frequently subjected to heavy and dynamic loads. This procedure begins with the preparation of concrete

Table 1
Chemical and physical properties of OPC.

Oxide composition	SiO_2 %	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	SO_3	LOI	Specific gravity kg/m^3	Specific Surface Area (SSA) m^2/kg
	20.41	6.53	3.01	63.28	1.84	0.17	3.22	1.54	3.11	373

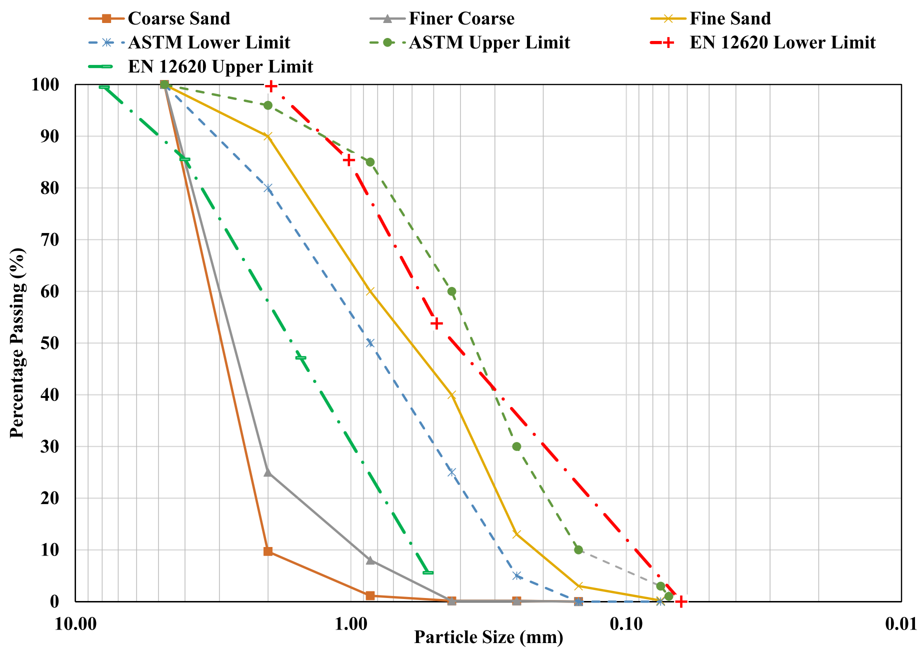


Fig. 2. Particle size distribution curves of different sands used.

Table 2
Physical properties of fine and coarse sands.

Description	Unit	Fine Sand	Coarse & Finer Coarse
Moisture Absorption	%	1.45	1.60
Moisture Content	%	1.08	1.05
Bulk Specific Gravity (oven dry)	g/cc	2.60	2.55
Bulk Specific Gravity (SSD)	g/cc	2.63	2.56
Apparent Specific Gravity	g/cc	2.70	2.68
Fineness Modulus	-	2.52	2.80

Table 3
Mix proportions.

Mixtures	Cement	Fine Sand	Coarse Sand	Finer Coarse Sand	SNF	w/c
	%	%	%	%	%	%
FH-01	40	41	19	–	0.25	0.14
FH-02	40	38	22	–	0.25	0.14
FH-03	40	35	25	–	0.25	0.14
FH-04	40	32	28	–	0.25	0.14
FH-05	40	29	29	–	0.25	0.14
FH-06	40	27	33	–	0.25	0.14
FH-07	40	24	36	–	0.25	0.14
FH-08	40	41	–	19	0.25	0.14
FH-09	40	38	–	22	0.25	0.14
FH-10	40	35	–	25	0.25	0.14
FH-11	40	32	–	28	0.25	0.14
FH-12	40	29	–	29	0.25	0.14
FH-13	40	27	–	33	0.25	0.14
FH-14	40	24	–	36	0.25	0.14

slabs, cast using the floor hardener mix to specific dimensions of 600 mm × 600 mm x 150 mm. To assess the impact load on the floor hardener, the impact mass was physically hoisted by hand and thereafter allowed to fall freely under the influence of gravity from a predetermined height shown in Fig. 5(a and b). As a precaution against rebound, sand was strategically placed under the slab to absorb impact effectively. Once the first fracture became perceptible on the surface, the quantity of impact strikes was documented as the initial crack. The test was further prolonged until the crack expanded or the specimen fractured, resulting in contact with at least three

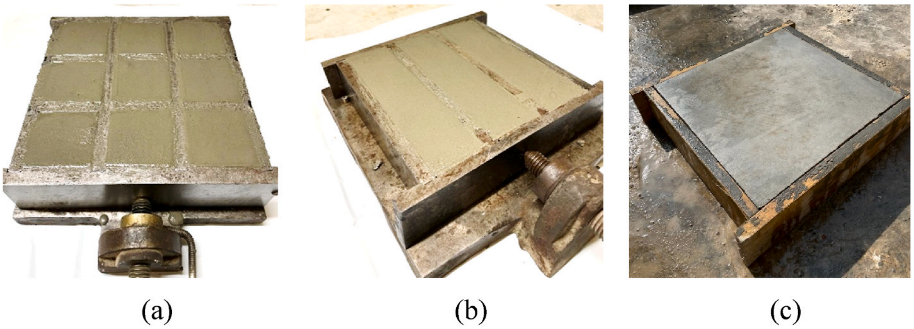


Fig. 3. Preparation of specimens (a) casting of cubes for compression test; (b) casting of prism for flexure test; (c) casting of slab for impact load test.

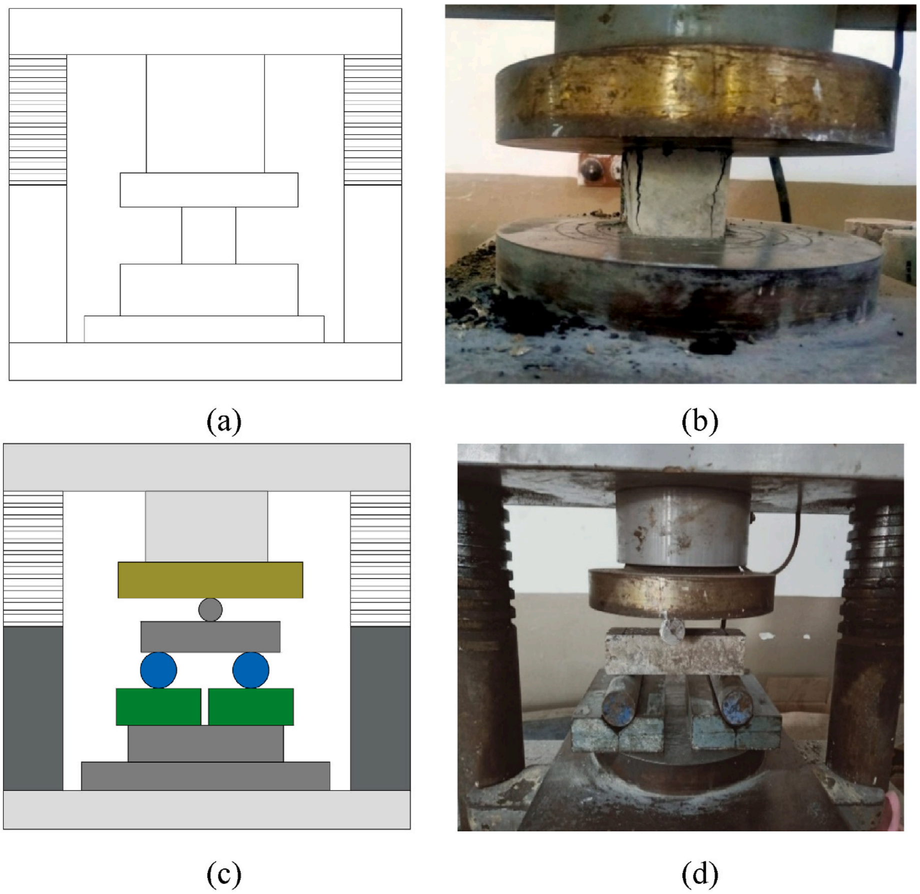
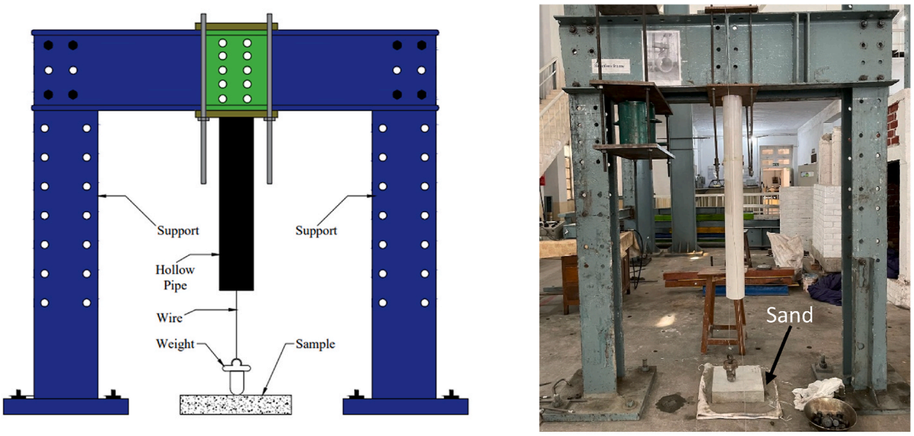


Fig. 4. Compressive and flexure strength testing diagrams (a & b) Schematic and testing diagram for compression; (c & d) Schematic and testing diagram for flexure.

of the four sides of the slab. As a final step, the number of blows was recorded to document the final crack.

To measure water absorption according to ASTM C642-21 [32], oven-dried specimens were weighed first and then immersed in water for 48 h. When the specimens have been immersed in water for 48 h, they are weighted in SSD condition. Water absorption was determined by calculating the difference in weight between the specimens under the above-mentioned conditions. For flowability of the floor hardener, place the mold firmly in the center of the tabletop after cleaning and wetting it. Fill it into two layers and each layer should be one-half of the mold's volume and tamp each layer 25 times with a tamping rod. Remove excess material after tamping the top layer. Pull the mold upward steadily. Drop table 15 times in 15 s at 12.5 mm. Calculate the mean diameter of the floor hardener spread in its 6 directions.

To test the flowability of a surface floor hardener, first prepare the material according to ASTM C-1437 [33] to achieve the required



(a) (b)

Fig. 5. (a) Schematic, and (b) experimental procedure of impact resistance test.

consistency. Then, place a mold on the center of a flow table and fill it with the hardener mix in two layers, compacting each with a tamping rod for uniformity. Level the mix with a spatula or trowel, and carefully remove the mold. Activate the flow table to perform a series of drops (typically 25 drops in 15 s) to spread the mix. Measure the diameter of the spread material in two perpendicular directions, calculate the average, and determine the flowability as a percentage by comparing this average spread diameter to the original diameter of the material in the mold, multiplied by 100. The results, along with procedural deviations or specific observations, were reported to evaluate the flowability of the hardener and its effectiveness in creating a uniform, durable surface. Water absorption and flowability test figures are shown in Fig. 6(a and b).

3. Results and discussions

3.1. Flowability

Fig. 7 shows the flow table consistency values for various floor hardener mixes. Flow table tests were performed according to ASTM C-1437, 2013 [33] and EN 1015-11, 2006 [34] to determine the workability, consistency, and cohesiveness of floor hardener. As expected, by adding finer coarse sand to the floor hardener mixes, the consistency of floor hardeners was improved, regardless of mix variation. FH-12 and FH-13 show high spread flow at a very small number of blows, which means they were very flowable and more consistent mixes, due to lesser voids and finer coarse sand making them workable. Workability plays a crucial role in the construction cycle [35,36]. Workability refers to the collective manifestation of several qualities, including consistency, elasticity, and cohesiveness [37]. Workability was frequently measured by consistency and other properties were difficult to measure [38]. Plasticizer dosage also affected the workability of floor hardener and it increased the flowability [39,40]. The reason behind this was related to the role of plasticizers in reducing the water-to-cement ratio while maintaining or enhancing the workability of the cementitious mixtures. Plasticizers were high-range water-reducing agents that disperse the cement particles in the mix, leading to a more fluid mixture without the need for additional water. This dispersion effect allows for easier handling and placement of the mix. Consequently, the enhanced flowability and workability due to the plasticizer dosage contribute significantly to the overall performance of the floor hardener, facilitating its application and achieving a smoother, more consistent surface finish [41,42]. Fig. 8(a and b) shows the visual

(a) (b)

Fig. 6. (a) Water absorption; (b) Flow table test.

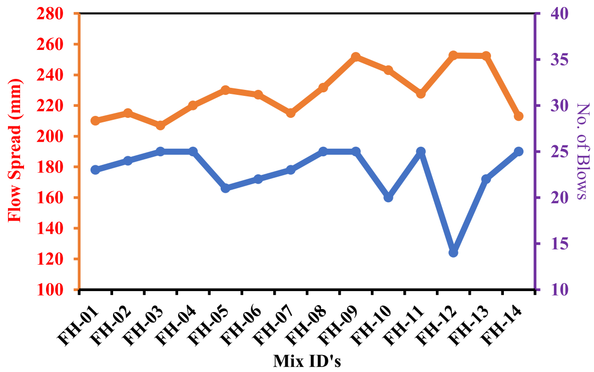


Fig. 7. Flowability measured by flow table test.

distribution of floor hardener after conducting a flow table test with different mixes.

3.2. Compressive strength

Fig. 9(a) shows the compressive strength results, which average values obtained from three identical specimens, and Fig. 9(b) showing the compressive strength results comparison with available market floor hardeners. ASTM-C109, 2020 specifies that the compressive strength should be more than 41.6 MPa, and all mixes show higher strengths [29]. It was observed that all specimens tested increased in compressive strength with time. The compressive strength for FH-12 reached 70, 88, and 100 MPa at 7, 14, and 28 days, respectively. Specimens cast with finer coarse sand showed more strength on 7-, 14-, and 28-days w.r.t to coarse sand used as FH-10,11,12, and 13. Compared to FH-5, FH-12 showed increases in compressive strength at 7, 14, and 28 days of 11.65 %, 12.33 %, and 11.77 %. According to the results, finer coarse sand replaced with floor hardener significantly improved its compressive strength. This was due to the greater production of hydration products from CSH [43]. Due to its small particle size, finer coarse sand improves the structure of pores [44–46]. Overall, as the curing age increased, the compressive strength increased as well [47]. The compressive strength of all the mixes was higher at 28 days compared with samples available on the market. When cement, water, aggregates, and additives were mixed together, a noticeable increase in temperature occurs. This was due to the exothermic reaction between cement and water, a process that releases heat. The exothermic nature of the reaction between cement and water in concrete accelerated the curing process, enhances compressive strength, decreases porosity, and boosts both durability and overall quality. There were more studies founded similar results [14,48].

3.3. Flexural strength

A flexural test, also called a three-point load test, determines the flexural strength and behavior of materials, especially brittle materials like ceramics, concrete, and composites. Fig. 10 showing the results of flexural strength of floor hardeners. Floor hardener prisms showed a positive relationship between curing time and flexural strength. Specimens from FH-8 to FH-14 showed more flexural strength as compared to FH-1 to FH-7 due to the use of finer coarse sand. Due to the proper proportion of finer coarse sand within the specimens and the formation of CSH, prisms have increased in flexural strength. The maximum flexural strength shown by FH-12 was 7.96 MPa and the lowest flexural strength was 3.84 MPa as FH-06.

Smaller particles fill gaps more effectively, reducing porosity and increasing particle interlocking [49]. This, in turn, led to improved cohesion and packing density, ultimately contributing to better flexural strength [50,51]. On the other hand, the presence of

(a) (b)

Fig. 8. Spread of different floor hardeners (a) Flowability with finer coarse sand; (b) Flowability with coarse sand.

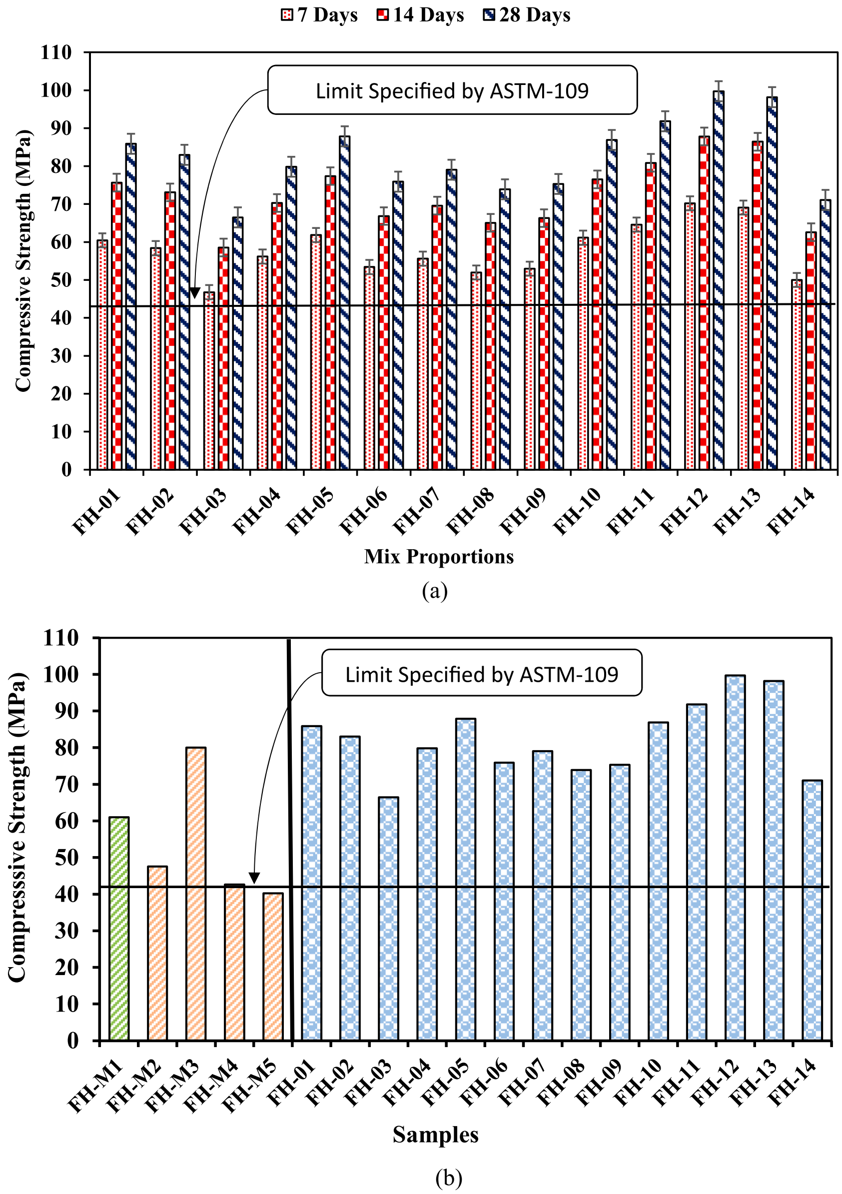


Fig. 9. (a) Compressive strength mix proportions; (b) 28-days compressive strength comparison with available market samples.

coarser sand in FH-01 to FH-07 resulted in the formation of bigger voids, which might hinder the effectiveness of particle packing. Thus, cohesion and tensile resistance were reduced, resulting in a drop in flexural strength. Moreover, the size of the sand particles had an impact on the required amount of water and the ease of handling the material. The results highlight the need for carefully selecting materials and controlling particle size throughout the process of floor hardener mix design to enhance flexural strength. An analysis of the fracture surface was conducted to determine whether the fracture occurred as a result of tension failure, compression failure, or shear failure, shown in Fig. 11. The results indicate that a significant proportion of the samples exhibited a distinct failure mode characterized by pure tension failure. Different floor hardeners exhibit different flexural strengths depending on several factors. In the presence of finer coarse sand, floor hardeners with improved confinement conditions showed better flexural behavior [52]. Loads increased continuously after the first crack. The load increased slowly as the crack developed. Floor Hardener was crushed according to its peak load.

3.4. Impact load

The low-velocity impact test was carried out by ACI 544-2R [53]. There was the use of cost-effective testing equipment for conducting repeated drop-weight impact tests, which serve the purpose of qualitatively assessing and comparing the impact performance

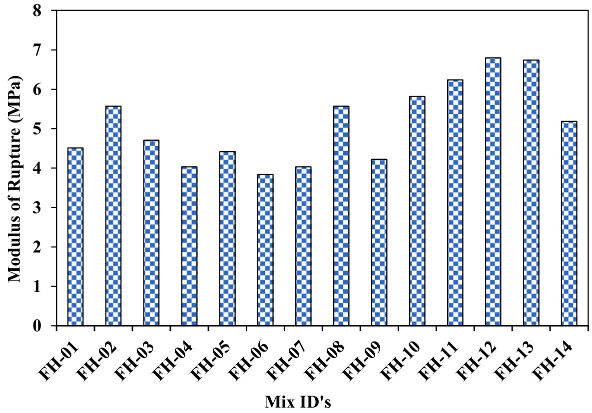


Fig. 10. Modulus of rupture of specimens at 28-days.

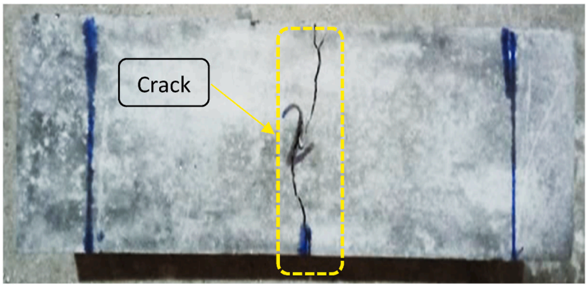


Fig. 11. Failure pattern (Pure bending failure).

of various floor hardener mixes. For various floor hardener mixtures, Fig. 12 illustrates the impact load test results in terms of how many blows it takes to initiate and reach the final crack. Slabs 1 and 2 possess the highest strength after FH-12 and 13 when compared to other mixes. It was due to concrete slabs being less brittle and don't show cracks early. Floor hardener surfaces were more brittle as compared to concrete slab specimens. The increased number of blows for the final crack was the usage of finer coarse sand because it absorbs more impact and disputes the impact forces. Significant research has employed repeated impact tests in the past few years. A similar study also found the same results [14,54,55]. A number of alternative studies have investigated the impact performance of alternative materials and additives. These materials include crumb rubber [54,56,57], recycled materials [58–60], natural fibers [61,62], nanomaterials [61,63], and other compounds [64]. Studies show high variation in impact numbers, requiring more specimens to meet confidence criteria but reducing overall test reliability [65]. There were different factors affecting the results of floor hardener, including the presence of cracks in any direction and an inadequate definition of accepted failures.

Crack patterns on different mixes of floor hardener shown in Fig. 13(a and b). There was a difference in crack formation due to the different characteristics of each mix in terms of surface hardness and durability. Some mixes show a single line crack that starts in the center and moves toward two faces suggesting a greater concentration of stress on one side. Usually, this occurs due to poor workmanship or an inhomogeneous concrete mix. So, it can be concluded from the results that floor hardener has less impact resistance at higher loads but it has more resistance against initial cracking. It has been demonstrated that the FH-12 and FH-13 exhibit the highest impact resistance among trail mixes and can absorb 687 J of energy.

3.5. Absorption test

Fig. 14 shows the water absorption results for floor hardeners which were performed by ASTM C642 [32]. Finer coarse sand was added to the floor hardener, which reduced its ability to absorb water. Because finer coarse sand has a lower porosity, there was a decrease in water absorption. Floor hardener absorbs more water when coarse sand increases the porosity and voids. The coarser the sand, the more voids were available for the absorption of water [66]. The reduction in water absorption was observed along with a reduction in capillary action [67], reduced pore volume in FH-12 and FH-13 by utilizing a lower water-to-cement ratio, and improved compactness within the samples [68,69]. According to the study, the addition of coarser sand to floor hardener positively affects the absorption of water [70]. Results show that water absorption was positively correlated with the duration of time and coarse sand amount used [71].

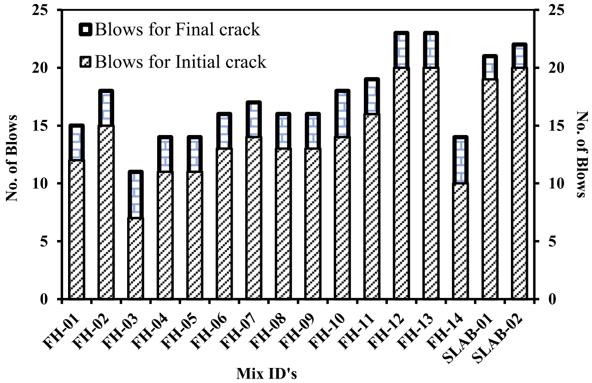


Fig. 12. Low velocity impact tests.

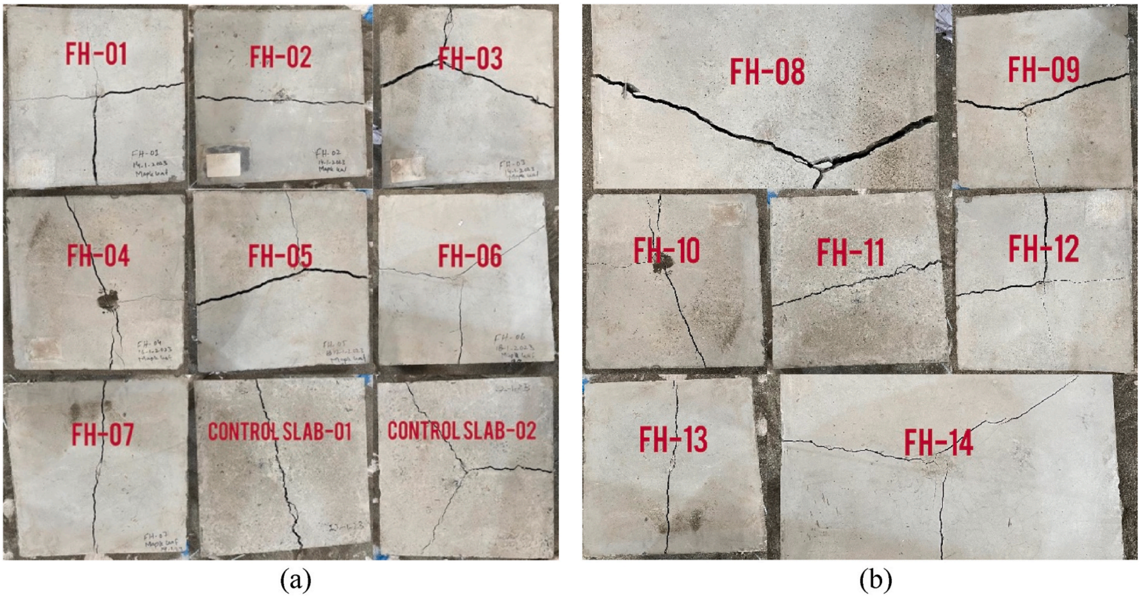


Fig. 13. Images of concrete slabs after appearance of cracks (a) DSHA using coarse sand, (b) DSHA using fine coarser sand.

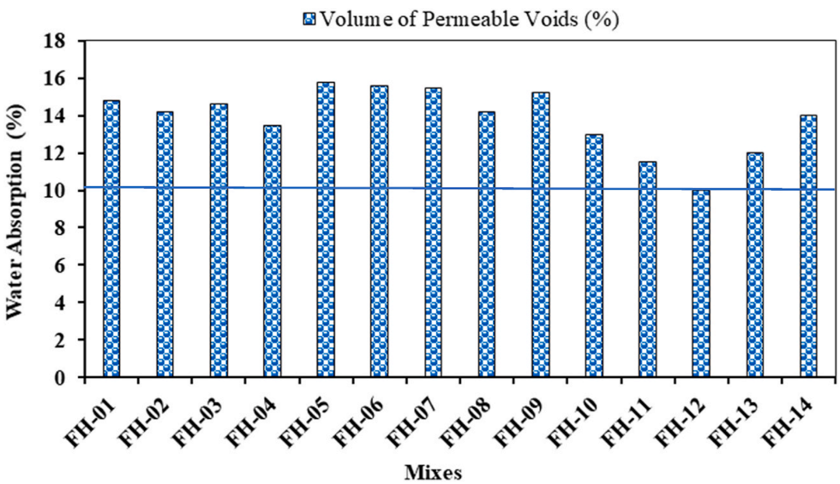


Fig. 14. Effect of sand on absorption of floor hardeners.

4. Conclusion

In this study, the effect of DSHA application on compressive and flexural strength, flowability, water absorption, and impact test behavior of concrete mixtures with different fine, coarse sand, and finer coarse sand ratios were investigated. The following results were obtained in accordance with the methods and materials used in the study:

1. The compressive strength and the flexural strength were positively influenced by the application of DHA in concrete mixtures. The DSHA surface, however, had a negative impact on impact strength since it has a higher brittleness than concrete.
2. It was found that the DSHA mixture FH-12 performed the best in terms of mechanical and resistance properties compared to all other mixtures. The FH-12 has higher impact resistance, less water absorption, as well as a higher modulus of rupture, which gives it higher compression strength than other trail mixes.
3. Due to the application of local materials (fine and coarse) instead of silica sand, the overall price of the finished product (DSHA) is 30–40 % lower than that of its competitors.
4. It was found that compressive strength and flexural strength have a close relationship. It is the additional strength gained as a result of the application of a floor hardener that accounts for this relationship.

5. Future recommendations

Future research could focus on exploring alternative materials and compositions, conducting long-term performance and durability studies, and undertaking comparative studies with other hardening techniques. It could also delve into the impact of different environmental conditions, scaling up and industrial application, as well as health and safety implications.

Data availability statement

Data will be available upon request.

CRediT authorship contribution statement

Wasim Abbass: Writing – original draft, Data curation, Conceptualization. **Muhammad Hasham Kashif:** Writing – original draft, Investigation, Formal analysis. **Muneeb Ahmed:** Validation, Software, Resources, Project administration. **Fahid Aslam:** Writing – review & editing, Validation, Software, Conceptualization. **Ali Ahmed:** Writing – review & editing, Visualization, Validation, Supervision. **Abdullah Mohamed:** Supervision, Software, Resources, Methodology.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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