IMPACT OF REPLACING COARSE AGGREGATE WITH RECYCLED GLASS ON THE FLEXURAL PROPERTIES OF GREEN CONCRETE

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Abstract
The construction sector's continuous progress has led to a permanent transition from natural aggregate use toward recycled glass materials. The construction sector requires this transformation because it strives to discover better and more sustainable building material techniques. This research explores how glass aggregates affect concrete rheological properties and strength measurements and flexural characteristics. Tests on workability and compressive strength and flexural strength were carried out following previously established criteria. Concrete mixtures with glass aggregates achieved their best performance at a 2.5% glass aggregate volume ratio as they reached 16MPa compressive strength compared to 17.1MPa for the control mix. The compressive strength dropped substantially from this threshold point while the control mix consistently demonstrated superior performance compared to each modified mixture. The addition of glass aggregates results in changes to concrete workability. Additions of glass aggregate at 2.5% or 5% improved mixture workability though higher percentages decreased workability showing the requirement for water content adjustment and mixture structure amendments. Matches with 2.5% of glass aggregates for concrete exhibit superior effects based on the experimental analysis yet fail to perform well beyond this specific percentage threshold.

Introduction

The volume composition of concrete consists largely of aggregate which constitutes 80 percent while aggregate characteristics determine both price effectiveness along with behavior of fresh concrete and its hardened state (Hudson, 2019). The construction industry strives to develop modern approaches that build better sustainable materials with enhanced performance outcomes. Today's construction relies heavily on concrete which requires specific properties from its components to function properly. Recent research indicates glass aggregates find increased market demand as sustainable materials since they offer environmental benefits over conventional sand and gravel aggregate materials (Shayan & Xu, 2004). Abrasion-tested glass debris from recycled materials allow builders to adopt environmentally-friendly construction practices and decrease product discharge (Gupta, 2020). The properties of shape texture and grading affect fresh concrete bleeding and workability and segregation during production and determine strength and stiffness along with shrinkage creep density and permeability and durability in hardened concrete. Reports by Lafrenz (2017) show deteriorating construction quality and reduced durability when constructors use incorrect mixture ratios or allow material grade variations.

Flexural performance, strength, and rheology can be affected by glass particles in concrete. Concrete needs workability, slump, and viscosity to mix, transport, and place (Ferrara *et. al.,* 2007). The shape and surface roughness of glass aggregates might affect these properties, hence more study is needed (Topçu & Canbaz, 2004). Compressive, tensile, and flexural strength indicate concrete's ability to withstand loads and stresses. Early research on glass aggregates and these properties has found mixed results, with some showing downsides and others showing improvements (Taha & Nounu, 2008). These variations must be understood to optimise mix designs and assure concrete reliability in structural applications. Concrete using glass aggregates must be ductile and fracture-resistant. Concrete's flexural strength determines beam and slab load-bearing capacity (Ismail & Al-Hashmi, 2009). Flexural qualities of glass-particle concrete reveal its architectural versatility.

Sand, gravel, crushed stone, crushed concrete, and recovered asphalt pavement are aggregates. These components are the main constituent in concrete, mortar, and asphalt mixes for bulk, strength, and durability (Shayan & Xu, 2004; Topçu & Canbaz, 2004). Concrete is made from inert aggregate, cement, water, and other additions. In sustainable building, recycled and waste aggregates are prioritised. Aggregates are recycled from crushed concrete, asphalt, and other building debris. Recycling these materials minimises natural resource use and landfill space while giving a sustainable building option. Industrial wastes are elements or materials originating from various human industrial and non-domestic activities that have to be dumped as waste (Adeala & Soyemi, 2021). Concrete is mostly aggregates, 60–80% of its volume. Concrete's qualities and performance depend on its aggregates, which make up most of its volume. Workability, strength, and durability of concrete depend on aggregate choices (Neville, 2011).

Recycled glass aggregate (RGA) is crushed post-consumer glass trash that is shaped for concrete application. Recycled glass replaces sand and gravel in concrete (Shayan & Xu, 2004; Topçu & Canbaz, 2004). This method tackles glass trash disposal's environmental issues and may improve sustainability and resource conservation (Gupta et al., 2020). Recycled glass aggregates represent a sustainable material alternative to natural aggregates used in concrete production. According to Shayan and Xu (2004) and Topçu and Canbaz (2004) the processing steps used in combination with glass composition influence the features of glass aggregates. The range of tiny powers to coarse particles present in these aggregates affects how concrete mixes perform. Glass aggregate properties depend on glass manufacturing conditions and particle embodiment methods as well as dimensional composition variations which restrict specific concrete applications (Ferrara et. al., 2007; Ismail & Al-Hashmi, 2009). The understanding of variability must exist for effective concrete mix design optimization and structural element performance guarantee (Taha & Nounu, 2008; Gupta et. al, 2020).

Projects studying sustainable environmental aggregate substitutes have remained active for several years. The use of recycled waste glass, rubber and plastic reduces both building debris generation and consumption of natural aggregates. Studies show glass aggregates become widely used because they enhance concrete resistant qualities alongside its overall appearance (Shayan & Xu, 2004). Cement concrete containing glass exhibits lower water uptake and enhanced strength properties which results in decreased workability according to Gjorv (2017). Higher glass aggregate contents in concrete result in mixtures that become difficult to handle during construction activities.

This paper conducted an empirical research study to investigate the mechanical performance of recycled concrete aggregates (Topçu and Canbaz, 2004). This study methodically studied the impact of recycled aggregate ratio levels on concrete's three main performance areas including strength and durability together with workability properties. Researchers performed exhaustive trials as well as studies in order to achieve optimal concrete mix designs resulting in desired performance outcomes. Topçu and Canbaz's empirical review studied recycled aggregates' impacts on concrete's compressive, flexural, and durability properties such freeze-thaw cycles and chloride penetration. They examined how aggregate quality, particle size distribution, and replacement ratios affected mechanical qualities. They found both pros and cons of employing recycled aggregates in concrete. Slump test measures concrete workability. It is the most common and oldest concrete workability test. Freshly mixed concrete is used. ASTM C 143 is a slump test standard. Topcu, *et. al.,* (2004) found that waste glass in concrete mixtures reduced slump by 0.2%. Inefficient waste glass geometry caused this drop. In their 2017 experiment, Andrić, *et. al.,* employed 0.45 water cement ratio and discarded glass as aggregate in concrete. A 1.5% drop in concrete mixture workability was noted. Concrete's compressive strength is its highest resistance to axial compression loading. Per pound per inch square (psi) or Kilo-newton per millimetre square. One of the most essential concrete mechanical tests is compressive strength. It easily illustrates the impact of concrete additives and concrete constituents. As previously done, compressive strength tests show the impact of extra wasted glass. As waste glass rises, compressive strength falls in most experiments (de Castro & de Brito, 2013). Topcu, *et. al.,* (2004) cured concrete samples with varying waste glass percentages for 28 days. Concrete without waste glass compressed 2.04-23.50 MPa. As waste glass grew, compressive strength decreased. Compressive strength decreased 8% for 15% waste glass and 15% for 30%. It dropped 31% for 45% waste glass. Due to poor waste glass-cement paste adhesion.

Ling, *et. al.,* (2011) tested concrete developing strength using ceramic tiles as coarse aggregate. Concrete with 0.5 water-cement ratio has 20MPa strength. Both compressive and split tensile strengths increased by 4.84% and 13.30% at 20% replacement. Flexure strength is highest at 10% replacement, 4.84% higher than standard concrete. Ahmed, *et. al.,* (2012) found that fragile ceramic materials waste a lot when manufacturing, shipping, and fixing. Crushed waste ceramic tiles replaced natural coarse aggregates in concrete at 10%, 20%, 30%, 40%, and 50%. The study found that ceramic tile aggregate improves concrete's compression and flexural strength.

Some research found that waste glass aggregate size affects concrete compressive strength. Due to waste glass's pozzolanic characteristics. Ildir et al. 2010 discovered that 80 um aggregate enhanced concrete compressive strength from 30-35 MPa. Concrete specimens are tested for split tensile strength. Because concrete is fragile, tensile forces break it. The tensile strength test indicates the concrete cracking load. Tensile strength varies when discarded glass is used as concrete aggregate. Tensile strength increased or decreased in various trials. Topcu et al. 2004 found a 10% drop in concrete tensile strength. Concrete absorbs energy in an impact test. Impact tests measure toughness, fracture resistance, and impact strength (Rehacek et al., 2015). Impact tests are usually done on fiber-added or regular concrete specimens. Concrete studies using discarded glass as aggregate do not test for impact. This thesis will use the impact test to enhance concrete's mechanical qualities. Water absorption capacity is a key concrete durability test. It predicts permeability and sulphate attack resistance (Zhang & Zong, 2014). ASTM C 642-13 defines water absorption as the weight increase of oven-dry concrete after a given duration in water. Waste glass as aggregate in concrete may decrease its absorption capacity. Glass' impermeability should alter concrete's permeability. Taha & Nounu (2008) found that discarded glass decreased concrete water absorption and micro-cracks and moisture migration.

ASTM C1293-08 defines alkali-silica deterioration as expansion higher than 0.04% per year. Almesfer (2013) found that waste glass samples expand more owing to expansion gel. 20 They saw 0.802% growth for 12% waste glass, 0.777% for 24%, and 0.583% for 0%. Shi, (2019) found that recycled waste glass aggregate increased alkali-silica reactivity in concrete. Fly ash also boosts alkali-silica reactivity. Aruna et al. (2015) in their investigation, they replaced coarse aggregates with 20mm tile waste, partial cement with fly-ash, and 0%, 5%, 10%, 15%, 20%, and 30% tile waste. Maximum compressive strength is achieved after 25% replacement. Compressive strength drops 15–20% with 25% tile aggregate substitution. At 0%, 15%, 20%, 25%, and 30%; Meyer, & Baxter, (2003) reuses coarse aggregate by waste glasses. M20 concrete is used. The article recommends replacing waste tile aggregate with 5-30% and using it in M10, M15, etc. mixtures. Subramani & Ravi, (2015). This research should provide appealing ways to utilise hard-plastic trash as coarse aggregate. Based on this analysis, plastic waste is used as coarse aggregate rather than fine aggregate. Whatever the plastic content, quality decreased over 20%.

Patil et al. (2010).This study proposes replacing coarse aggregate in concrete with plastic recycled aggregate. Six beams/cylinders and 48 specimens were cast from varied plastic percentages (0, 10, 20, 30, 40, and 50%) utilised to substitute coarse aggregate in concrete mixtures. Many experiments have shown that replacing aggregate with recycled plastic concrete reduces concrete density. With increasing coarse aggregate substitution with recycled plastic aggregate, compressive strength decreased for 7 and 28 days. They suggest replacing 20% to meet strength requirements. Again, these researchers only studied compressive strength and no other essential concrete qualities. Their study does not employ concrete admixtures to compensate for strength loss.

This research aims to systematically examine the influence of aggregate factors on the flexural performance, strength properties, and rheological features of concrete including glass aggregates. This project is to promote the advancement of environmentally friendly construction techniques and contribute to the knowledge base on sustainable concrete materials via comprehensive testing and analysis of recycled glass as a substitute for coarse aggregate. This study examines how aggregate strength and flexural performance affect concrete containing glass aggregates. It tests concrete mix designs with varying recycled glass aggregate proportions, workability, flow, viscosity, and compressive, tensile, and flexural strengths.

Materials and Method

All concrete mixes in this experiment used ASTM C150-compliant Ordinary Portland Cement (OPC). Fine and Coarse Aggregates are natural sand (particle size < 4.75 mm) and crushed granite (particle size ½ inch (12.5mm)), whereas Glass Aggregates are recycled glass cullet treated to comparable particle sizes. Multiple tests were performed on the materials in this study to assure quality for concrete manufacturing. Sieve analysis, specific gravity, water absorption, and workability were tested. Standards were followed for each test to ensure accuracy and dependability.

Fine and coarse aggregate representative samples were sieved. Sun-drying all samples eliminated surface moisture, which might distort weight readings and reduce accuracy. The dried samples were put on a stack of sieves in diminishing mesh sizes, from biggest to smallest. Each sample was agitated for 10 minutes with a manual sieve shaker to ensure particle separation across sieve sizes. After that, each filter was carefully dismantled and its retained material weight was recorded. To determine the particle size distribution for each coarse aggregate size and ensure concrete manufacturing requirements, this procedure was essential. By weighing the retained material on each filter, the samples' particle size fraction percentages were calculated. The cumulative data was tabulated to show particle size distribution. To verify aggregate size appropriateness in concrete mix design, grading results were compared to industry norms. Based on these results, concrete mix proportions and water-cement ratios were adjusted to optimise performance.

Concrete mixes will be designed with varying proportions of glass aggregates replacing natural coarse aggregates at 0%, 2.5%, 5%, 7.5%, 10%, 12.5% and 15% by volume. A control mix with 100% natural aggregates will be included for comparison. The water-cement ratio will be kept constant across all mixes to isolate the effect of aggregate type on concrete properties. Concrete Sample will be prepared by thoroughly mixing the ingredients in a laboratory mixer. The fresh concrete will be cast into molds to form standard test specimens, including cubes (for compressive strength tests), cylinders (for splitting tensile strength tests), and beams (for flexural strength tests). The specimens will be cured in water at 23°C for specified periods before testing. All other materials are typically available from local store with reputable cement suppliers. Ensuring the aggregates meet the required specifications for the project. A total of concrete cubes were prepared. These hardened samples were subjected to compressive strength testing at 7, 14, and 28 days using a compression testing machine to evaluate their performance over time. A mix ratio of 1:2:4 was used, with precise weighing of the concrete batching constituents. For the aggregate component, glass aggregates were employed, with a blend of crushed glass and natural aggregates. The study began with control groups consisting of 100% crushed glass and 100% natural aggregates. Subsequently, various blends were tested: 90% crushed glass with 10% natural aggregates, 80% crushed glass with 20% natural aggregates, 70% crushed glass with 30% natural aggregates, 60% crushed glass with 40% natural aggregates, and 50% crushed glass with 50% natural aggregates. Each blend was prepared according to these specified ratios.

The aggregates were thoroughly mixed before the addition of water, maintaining a water-to-cement ratio of 0.5. Once all ingredients were combined to form the concrete mixture, it was poured into molds in approximately 50 mm layers. Each layer was compacted using a tamping rod with 25 uniform blows. The surface of the mortar was leveled with a trowel, and the molds were covered with moist bags to ensure proper curing. The samples were kept in this environment for 24 hours before being de-molded and stored in the laboratory for further curing. We measured the weights of each component in the concrete. 13.4 kilogram of cement was measured after 21.0 kg of glass. Spades were used to combine these two until a homogenous mixture was achieved. Next, measured 44.7 kg of aggregates were added, then 6.7 kg of water. After mixing for five minutes, the slump test was conducted.

Figure 1

Compressive strength tests will be conducted on cube specimens at 7, 14, and 28 days of curing using a universal testing machine (ASTM C39). Flexural strength tests was carried out on beam specimens at 28 days of curing using the third-point loading method (ASTM C78). Additional tests, such as water absorption (ASTM C642), was conducted to evaluate the durability of concrete with glass aggregates.

Figure 3: Concrete Placed in Moulds Figure 4: Curing of Concrete Samples

After a 24-hour hardening period, the cast cubes were taken out of the molds. Then, for the appropriate length of days, they will be immersed in a tough that contains water to determine their compressive strength. This will be carried out in order to maintain the concrete's low, consistent temperature.

The specimens will be removed from the water and cleaned to remove any remaining moisture after curing. Weight will be recorded for each cube. Clean the testing apparatus's bearing surface and insert the specimen to load the cube cast's opposing sides. The specimen will be centre on the machine's base plate. The movable component will be manually turned to touch the specimen's top. The weight will be given gradually without shock until the specimen fails. The failure type's anomalies and maximum load-to-weight ratio were noted.

Figure 5: Compressive Strength Test

Results and Discussion

The results derived from the experimental investigations of concrete samples incorporating varying percentages of glass aggregates are discussed. The primary aim of this research is to evaluate how the substitution of traditional aggregates with glass aggregates impacts the flexural properties and durability of concrete. To analyze the compressive strength of concrete at different curing ages (7, 14, and 28 days) with varying percentages of glass aggregates. Likewise, the workability of concrete mixtures were assessed using the slump test. Also, to evaluate the durability characteristics of concrete with glass aggregates through water absorption and finally, the flexural test was carried out using a 150 x 150 x 600 mm beam placed under a three point loading system.

Workability Assessment

Workability is a critical factor in concrete mix design, as it affects the ease of handling, placing, and finishing. The workability of the concrete mixtures was assessed through slump tests, with results indicating varying degrees of consistency based on the glass aggregate proportions (Table 1). From Table 2, it can be seen that as the amount of glass in the concrete matrix increases, the slump decreases. The slump test results showed that concrete mixtures with lower percentages of glass aggregates (specifically 2.5% and 5%) exhibited higher slump values, indicative of better workability.

Table 1: Result of the Slump Test

% Glass Aggregate	Slump Value (mm)
0.0%	90
2.5%	110
5.0%	100
7.5%	80
10.0%	70
12.5%	60
15%	50

An increase in glass aggregate content above 5% resulted in concrete mix stiffness through reduced slump performances. The manipulative properties of concrete decrease as glass aggregates demonstrate inherent tendencies to absorb water and modify the mix fluidity. The findings demonstrate that proper optimization between water content and aggregates proportions leads to proper workability maintenance while maintaining concrete mechanical qualities.

Compressive Strength

The data presented in Table 4.2 displays clear proof of how concrete cube compressive strength responds to different recycled glass percentage concentrations during 7, 14, and 28-day curing periods. The structural performance and durability of concrete heavily depend on its compressive strength because it determines both strength under load and material lifetime. The 0% mix demonstrated an increase from 11.04 MPa at 7 days to 17.148 MPa at 28 days, indicating the positive effect of extended curing on strength development as cement hydration continues.

Table 2: Compressive Strength Results

	7 days (MPa)	14 days (MPa)	28 days (MPa)
0%	11.040	15.434	17.148
2.5%	14.174	14.405	16.056
5,0%	10.866	13.984	15.538
7.5%	11.673	13.952	15.502
10.0%	9.489	10.293	11.437
12.5%	6.007	9.388	10.431
15.0%	12.736	12.533	13.926

For the 2.5%, the initial compressive strength was 14.174 MPa at 7 days, slightly reduced from the 0%, implying that no recycled glass may contribute favorably to early strength. However, by 28 days, the strength reached only 16.056 MPa, indicating that the rate of strength gain decreases over time for increased percentage of glass. The 5% exhibited a lower early strength of 10.866 MPa but increased significantly to 15.538 MPa at 28 days, suggesting that this percentage benefits from extended curing, as hydration enhances strength. The 7.5% had another increase to 11.673 MPa at 7 days, with a slower increase to 15.502 MPa at 28 days, suggesting that this percentage can result in more void, potentially weakening the bond strength. However, the 10% showed a bad performance with a strength of 9.489 MPa at 7 days, increasing to 11.437 MPa by 28 days, indicating that while higher percentages may initially limit early strength, they do not contribute effectively to the concrete's long-term performance. In summary, smaller percentages yield higher early strength, but larger percentages have a bad performance over time. Achieving the optimal recycled glass percentage is essential for balancing workability and compressive strength, which is vital for structural applications. The findings underscore the role of proper curing and mix design in achieving the required mechanical properties, with potential for future studies to examine the impact of factors like water-cement ratio and admixtures on concrete performance with different recycled glass percentages.

Flexural Strength

The flexural strength results presented in Table 3 indicate the performance of concrete beams with various recycled glass percentages after 7, and 28 days of curing. Overall, the flexural strength increased with time, beginning at 4.408 MPa at 7 days and reaching 12.175 MPa at 28 days. This upward trend underscores the importance of adequate curing to allow the concrete to develop its strength over time. Focusing on the 0%, the flexural strength at 7 days was slightly higher than the overall average at 9.175 MPa, but it increased to only 12.175 MPa by 28 days. This modest growth suggests that while smaller percentages may contribute positively to early performance, they significantly enhance long-term flexural strength.

Table 3: Flexural Strength Results

	Strength	
(%)	28days	7days
0.0	12.175	9.175
2.5	11.380	8.380
5.0	11.032	8.000
7.5	11.006	8.012
10.0	8.120	5.134
12.5	7.406	4.408
15.0	9.887	6.848

These findings, which outlines the testing and assessment of flexural strength in concrete. The observed trends emphasize the need for careful selection of recycled glass percentages to optimize both workability and mechanical properties. Smaller percentages appear to enhance early strength, while the long-term performance may depend more on proper curing and the overall mix composition. Future research could delve deeper into how varying types of cement and supplementary materials influence these mechanical properties, providing further insights into the best practices for concrete mix design.

Conclusion

Concrete mixes incorporating glass aggregates exhibited varying compressive strengths, with the optimal performance recorded at 2.5% glass aggregate substitution. Compressive strength decreased significantly as the percentage of glass aggregates increased beyond this point, with the control mix outperforming all modified mixes. The addition of glass aggregates affected the workability of concrete. Lower percentages (2.5% and 5%) resulted in improved workability, while higher percentages led to reduced workability, indicating a need for adjustments in water content and mix design.

The study concludes that incorporating glass aggregates into concrete can be advantageous if done judiciously. Specifically, a substitution of up to 2.5% can enhance the mechanical properties of concrete without significantly compromising its durability. However, as the percentage of glass aggregates increases, there is a clear trend of decreasing strength, workability, and durability. Therefore, while glass aggregates present a sustainable alternative for concrete production, careful consideration must be given to their proportions in order to maintain the desired performance characteristics.

References

Adeala, A. J. & Soyemi, O. B. (2021). Engineering Properties of Crushed-Fine Glass as Partial Replacement of Fine Aggregate in Concrete- (Engineering Properties/Effects of crushed fine glass as partial replacement of fine aggregate in concrete). International Journal of Women in Technical Education and Employment (IJOWITED), The Federal Polytechnic, Ilaro Chapter, 2(1), 86-94

Ahmed Ashraf, W., & Noor, M. A. (2012). Influence of aggregate characteristics on the mechanical properties of high-performance concrete. Journal of Building Engineering, 29, 101159.

ASTM International. (2020). Standard specification for Portland cement (ASTM C150/C150M-20). ASTM International.

de Castro, S., & de Brito, J. (2013). Evaluation of the durability of concrete made with crushed glass aggregates. Journal of Cleaner Production, 41, 7-14.

Ferrara, L., Park, Y.-D., & Shah, S. P. (2007). A method for mix-design of fiber-reinforced self-compacting concrete. Cement and Concrete Research, 37(6), 957-971.

Gjorv, O. E. (2017). Durability design of concrete structures in severe environments. CRC Press.

Gupta, T., Siddique, S., Belarbi, R., & Sharma, R. K. (2020). Recycling of reclaimed glass in concrete: A sustainable and durable solution. Journal of Cleaner Production, 256, 120607.

Hudson, (2019). Properties of high-performance concrete made with recycled fine ceramic and coarse mixed aggregates. Construction and Building Materials, 68, 618-626.

Ismail, Z. Z., & Al-Hashmi, E. A. (2009). Recycling of waste glass as a partial replacement for fine aggregate in concrete. Waste Management, 29(2), 655-659.

Ling, T. C., Poon, C. S., & Kou, S. C. (2011). Feasibility of using recycled glass in architectural cement mortars. Cement and Concrete Composites, 33(8), 848-854. https://doi.org/10.1016/j.cemconcomp.2011.05.008

Meyer, C., & Baxter, S. (2003). Use of recycled glass for concrete masonry blocks. ACI Materials Journal, 100(3), 202-207.

Neville, A. M. (2011). Properties of Concrete. Pearson Education Limited.

Rehacek, S., Hunka, P., Citek, D., Kolisko, J., & Simunek, I. (2015). Impact testing of concrete using a drop-weight impact machine. Advanced Materials Research, 1106, 225-228.

Shayan, A., & Xu, A. (2004). Value-added utilization of waste glass in concrete. Cement and Concrete Research, 34(1), 81-89.

Subramani, T., & Ravi, G. (2015). Experimental investigation of coarse aggregate with steel slag in concrete. IOSR Journal of Engineering, 5(5), 64-73.

Taha, B., & Nounu, G. (2008). Properties of concrete contains mixed colour waste recycled glass as sand and cement replacement. Construction and Building Materials, 22(5), 713-720.

Topçu, İ. B., & Canbaz, M. (2004). Properties of concrete containing waste glass. Cement and Concrete Research, 34(2), 267-274.

Topçu, I. B., & Canbaz, M. (2007). Effect of crushed glass aggregates on the physical and mechanical properties of concrete. Materials Journal, 104(5), 383-386.

Zhang, S. P., & Zong, L. (2014). Evaluation of relationship between water absorption and durability of concrete materials. Advances in Materials Science and Engineering, 2014(1), 650373.