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Experimental study of concrete made with granite and iron powders as partial replacement of sand

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ABSTRACT

Granite Powder (GP) and Iron Powder (IP) are industrial byproducts generated from the granite polishing and milling industry in powder form respectively. These byproducts are left largely unused and are hazardous materials to human health because they are airborne and can be easily inhaled. An experimental investigation has been carried out to explore the possibility of using the granite powder and iron powder as a partial replacement of sand in concrete. Twenty cubes and ten beams of concrete with GP and twenty cubes and ten beams of concrete with IP were prepared and tested. The percentages of GP and IP added to replace sand were 5%, 10%, 15%, and 20% of the sand by weight. It was observed that substitution of 10% of sand by weight with granite powder in concrete was the most effective in increasing the compressive and flexural strength compared to other ratios. The test resulted showed that for 10% ratio of GP in concrete, the increase in the compressive strength was about 30% compared to normal concrete. Similar results were also observed for the flexure. It was also observed that substitution of up to 20% of sand by weight with iron powder in concrete resulted in an increase in compressive and flexural strength of the concrete.

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1. Introduction

Concrete is the single most widely used construction material in the world today. It is used in buildings, bridges, sidewalks, highway pavements, house construction, dams, and many other applications. The key to a strong and durable concrete are the mix proportions between the various components. Less cement paste can lead to more voids, thus less strength and durability while more cement paste can lead to more shrinkage and less durability. The gradation and the ratio of fine aggregates to coarse aggregates can affect strength and porosity. The mix design should also achieve the desired workability of concrete so as to prevent segregation and allow for ease of placement. Typically, a concrete mix is about 10% to 15% cement, 25% to 30% sand, 40% to 45% percent aggregate and 15% to 20% water. Entrained air (5% to 7%) is also added to concrete to improve durability. Concrete should have enough compressive strength and flexural strength to support applied loads. At the same time it should have good durability to increase its design life and reduce maintenance costs [1]. In general, durable concrete will have good resistance to freeze and thaw, abrasion, sulfate reactions, ultraviolet radiation, seawater, alkali-silica reaction, and chlorides. The gradation and maximum size of aggregates are important parameters in any concrete mix. They affect relative proportions in mix, workability, economy, porosity and shrinkage of concrete. Granite powder, a waste material from the granite polishing industry, is a promising material for use in concrete similar to those of pozzolanic materials such as silica fume, fly ash, slag, and others. These products can be used as a filler material (substituting sand) to reduce the void content in concrete. Granite powder is an industrial byproduct obtained from crushing of granite stone and granite stone polishing industry in a powder form. It is also generated from recycling marble tops, terrazzo, granite pavers, and stone scraps and discards. If left on its own and is not properly collected and stored, the fine granite powder can be easily be airborne and will cause health problems and environmental pollution.

Inhalation of granite powder fine particles is a health hazard and is a cause of lung diseases especially for people living near granite mills. In this present work, granite powder is used as partial replacement of sand in concrete in different percentage and the associated compressive strength, flexural, and splitting tensile strengths of concrete have been evaluated. By doing so, natural resources of sand can be preserved and the health hazards of these industrial wastes are minimized.

Recycling of granite dust will prevent these wastes from ending up in landfills and provides affordable, eco-friendly, solid stone for various uses. Recycled tiles made from recycled glass or wastes from mines or factories have been used for floors, countertops, and walls [2]. Ceramic

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tiles may be made from factory waste (known as post-industrial waste) generated by the production of conventional tiles. Debris series from fireclay tiles combine post-industrial and post-consumer recycled wastes. The Debris series tile consists of 26% recycled granite dust (post-industrial waste) from a granite cutting operation. It also contains 26% recycled glass (post-consumer waste).

Perez et al. [3] conducted a study on the use of recycled marble tops as partial replacement of sand in concrete. The paper points out that the researchers have analyzed the effect of replacing cement, sand, and coarse aggregate with marble byproduct in many countries, but there is a lack of research analyzing the use of marble waste in the United States. This is especially true for postindustrial byproducts such as countertop installation waste, or postconsumer products after a building deconstruction. They highlight the advantages of using such recycled materials in concrete because of potential cost, regulatory and green certification benefits. In particular, they mention that the cost of delivering waste materials to landfills and the landfills' fees are especially high in localities that have stringent environmental regulations such as the San Francisco Bay Area. Results from their study showed that marble, terrazzo and granite countertop waste from construction finishes activities can be effectively used as a replacement for up to 30% coarse and fine aggregate in concrete without negatively affecting the slump, the 7-day compressive strength or the 28-day compressive strength. The use of such byproducts in concrete, rather than disposing them in a landfill, significantly reduces the impact of such materials on the environment. Their research concludes that the most practical, environmentally friendly, and cost efficient use of the recycled materials (marble, terrazzo and granite) in a project is to be a partial coarse aggregate substitute. According to the Leadership in Energy and Environmental Design (LEED) system developed by the US Green Building Council (USGBC), credits are given for reducing construction and demolition waste disposed in landfills and incineration facilities by recovering, reusing, and recycling materials. In addition, the main cost will be incurred in storing and collecting granite powder and iron powder hazard materials. Thus recycling these materials and using as partial replacement of sand in concrete will be beneficial both environmentally and economically.

Industrial wastes from the steel industry such as iron ore tailings and iron powder wastes from steel production can be hazardous to the environment. Stockpiling this material near production sites can results in soil and ground water contamination. Alzaed [4] evaluated the effects of iron fillings on the compressive and tensile strength of concrete. His results showed that both the compressive strength and tensile strength increased with the addition of iron fillings to the mix. Kala [5] conducted tests on granite powder as a partial sand replacement in high performance concrete and showed the beneficial effects on its mechanical properties. Of all the six mixtures he considered, concrete with 25% of granite powder (GP25) was found to be superior to other percentages of granite powder concrete as well as conventional. Prabhu et al. [6] studied the influence of Foundry Sand in concrete its strength and durability. Their results revealed that compared to the concrete mixtures with a substitution rate of 30%, the control mixture had a compressive strength about 6.3% higher. The results from durability tests of concrete mixtures containing foundry sand up to 30% were relatively close to those of the control mixture. Kumar et al., [7] studied the compressive strength of concrete by replacing cement with ceramic waste and utilizing the same in construction industry. Kumar et al., [8] investigated the effect of using quarry dust as a possible substitute for cement in concrete. They evaluated various concrete mixes with partial replacement of cement with varying percentage of quarry dust (10%, 15%, 20%, 25%, 30%, 35%, and 40%). From the experimental studies, they reported that 25% partial replacement of cement with quarry dust showed improvement in hardened of concrete. Mustafa et al., [9] conducted a review on fly ash-based geopolymer concrete without cement and found that the compressive strength increased with the increasing fly ash fineness and thus reducing the porosity. Also, the fly ash-based geopolymer provided better resistance against aggressive environment and elevated temperature compared to normal concrete. Baboo et al., [10] studied the influence of the marble powder/granules in concrete mix and found an increase in the workability and compressive strength with an increase in the content of waste marble powder/granules. Alzboon et al. [11] studied the effect of using stone cutting waste on the compression strength and slump characteristics of concrete and showed that the treated sludge generated from the stone cutting processes can be regarded as a source of water used in concrete mixes.

One of the most important benefits of substituting granite powder in concrete is on human health. The controlled collection of granite dust from industrial facilities will reduce the amount of silica in the air thus reducing the risk of silicosis [12]. Workers involved in manufacturing, grinding, finishing, and installing natural and manufactured stone and granite countertops are at risk for significant crystalline silica exposure. Studies have shown that workers who inhale very small crystalline silica particles are at risk for silicosis – an incurable, progressively disabling and sometimes fatal lung disease [13]. The US Department of Labor and the US National Institute of Occupational Safety and Health (NIOSH) recommends that employers install and maintain engineering controls to eliminate or reduce the amount of silica in the air and the build-up of dust on equipment and surfaces. Examples of controls include: exhaust ventilation and dust collection systems, water sprays, wet drilling, enclosed cabs, and drill platform skirts. NIOSH recommends that employers control exposure to respirable crystalline silica so that no worker is exposed to a time-weighted average concentration of silica greater than 50 $\mu g/m^3$ of air, as determined by a full-shift sample for up to a 10-h workday of a 40-h workweek. The Occupational Safety and Health Administration (OSHA) permissible limit of pure quartz silica exposure is about 100 $\mu g/m^3$ [13]. Sirianni et al. [14] reported significant differences in particle size distributions in silica content of granite quarries in Vermont depending on the extent of ventilation and the nature and activity of work performed. The researchers concluded that such variability in silica content raises concerns about the adequacy of silica exposure assessment.

Vijayalakshmi et al. [15] evaluated the durability of concrete made with granite powder. They studied durability properties such as water permeability, rapid chloride penetration (RCPT), carbonation depth, sulfate resistance and electrical resistivity. Their results showed that the replacement of natural sand with granite powder (GP) waste up to 15% of any formulation is favorable for the concrete making without adversely affecting the strength and durability. They recommended to chemically bleaching the GP prior to blending in the concrete to increase the sulfate resistance.

Singh et al. [16,17] suggested that 25–40% of river sand can be substituted by the granite cutting waste (GCW) with a favorable influence on the investigated parameters. Their results showed that the optimum amount of GCW to be used in concrete depends on the water-cement ratio of concrete. Singh et al. [18] published a study reviewing past research on replacing sand with granite dust. Their review showed that granite dust has increased the mechanical properties of concrete and has the potential to produce durable concrete. Their review of previous research showed that granite dust concrete exhibits enhanced dense and compact concrete matrix at optimum percentage replacement levels. Zhao et al. [19] studied the use of iron ore tailings in ultra-high strength concrete. Their results showed comparable results between the concrete with iron ore tailing less than 40% and the control concrete.

Results from this study and from studies by others referenced in this introduction showed that there are advantages to concrete when granite powder is used to partially replace sand in the concrete mix. The benefits of using granite powder as partial replacement of sand not only can enhance strength but also preserve the natural resources of sand and also keeps these powder particles from being airborne into the atmosphere causing health hazard to humans, in particular children.

2. Research significance

Granite powder and iron powder industrial byproducts resulting from the granite stone crushing and polishing and from the steel production respectively. These byproducts can be used as partial replacement of sand in concrete. When used in certain proportions, granite powder and iron powder have shown to increase the compressive strength, flexural strength, and splitting tensile strength of concrete. The experimental research conducted in this study showed the mechanical properties of concrete have improved when granite powder and iron powder were used as partial replacement of sand in specified percentages. In addition, the use of these powders as a partial replacement of sand will reduce the consumption of sand in the construction industry thus preserving more of these natural resources. Recycling of these byproducts and using them in concrete will reduce their health hazards and their impact on the environment.

3. Experimental investigation

The experimental program comprised of preparing concrete cubes, beams, and cylinders with and without granite or iron powder replacement. The concrete mix included Portland cement, sand, granite powder or iron powder, coarse aggregates, superplasticizer, and water. The cubes were used to test the concrete compressive strength. The beams and the cylinders were used to test the flexural strength and split tensile strength respectively.

3.1. Materials

The material used in this study included the following: Ordinary Portland cement, coarse aggregates, fine aggregates (sand), granite powder, iron powder, water, and superplasticizers. The cement was Type I Portland cement. The coarse aggregates were crushed angular coarse aggregate 10 mm to 20 mm (3/8in to 3/4 in) in size. The specific gravity of the aggregates was 2.72 and fineness modulus was 4.2. The sand was approximately 2 mm in diameter and has a specific gravity of 2.65 and a fineness modulus equal to 2.3. The specific gravity of granite powder was 2.53 and the fineness modulus was approximately 2.4 with a particle size less than 90 μm. Typical chemical analysis of the granite powder is shown in Table 1. The source of iron powder was iron melting induction furnace and its chemical composition is shown in Table 2. The gradation of granite powder, iron powder, and sand is shown in Fig. 1. The water used for the mix was potable water available locally. The water was free from concentrated acids and organic substances. A superplasticizer was used to improve the workability of concrete. A 0.5% by weight of cement water-reducing superplasticizer was added to improve the workability of concrete. The superplasticizer was Universal Polycarboxylate based High-efficiency Concrete Water Reducer Plasticize from a commercial supplier from Latvia.

Table 1
Chemical composition of granite powder used in this study.

Chemical compound	Weight (%)
SiO_2	64.5
TiO_2	0.67
Al_2O_3	12.01
Fe_2O_3	5.77
MgO	0.57
MnO	0.39
CaO	4.80
Na_2O	5.92
K_2O	5.26
P_2O5	0.07

Table 2
Chemical composition of iron powder used this study.

Chemical compound	Weight (%)
SiO_2	2.41
TiO_2	0.72
Al_2O_3	1.81
Fe_2O_3	89.0
MgO	0.23
MnO	2.16
CaO	0.45
Na_2O	0.66
K_2O	1.64
P_2O5	0.34
Ni	0.002
Cu	0.003

3.2. Preparation of granite powder test specimens

The granite powder was collected from granite crushing and polishing sites and was dried before use. The cement and granite powder were first mixed thoroughly. Further sand and coarse aggregate were added to the mix. The materials were mixed in dry conditions for few minutes. Once all the materials were mixed well, the super plasticizer was added to water and water containing super plasticizer was added to the dry mix in a standard concrete mixer. The resulting concrete mix was used to prepare 150 × 150 × 150 mm (6 in×6 in×6 in) cubes and 100 × 100 × 500 mm (4 in × 4 in × 20 in)beams, and 150 mm × 300 mm(6 in × 12 in) cylinders. The concrete was poured into the molds and was compacted 25 blows by a compaction rod. After that the cubes, beams, and cylinders were vibrated for 1 to 2 min on a vibrating machine and then the top surface of the specimens was finished using a trowel. After that, the molds were left to dry for 24 h. The specimens were then removed from the molds and were cured in water tank for curing for 28 days. The curing time was not a parameter in this study and hence no comparisons were made for the effect of granite powder (GP) on curing time. Several mixes were prepared with different percentages of granite powder as partial replacement of sand. All other ingredients were kept the same. The percentages of granite powder used were 0%, 5%, 10%, 15%, and 20% of sand. The mix proportions for the mixes tested in this study are shown in Table 3. A total of five mixes were tested: MG0, MG5, MG10, MG15, and MG20 containing 0%, 5%, 10%, 15%, and 20% of GP by weight respectively. This concrete with granite powder had a slump equal to 80 mm (3.2 in) and the compaction factor was 0.95. Plasticizing admixtures are added to a concrete mixture to make the mix workable without additional water especially for use in ready mixed concrete.

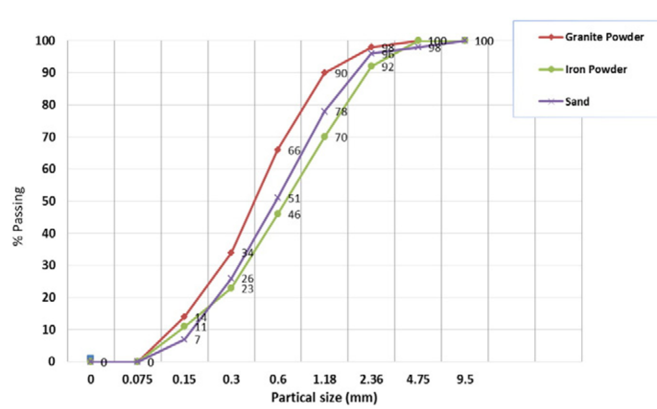

Fig. 1. Grain size distribution of granite powder, iron powder, and sand.

Table 3
Mix design proportions for various granite powder (GP) ratios (kg/m^3).

Mix	Cement	Sand (FA)	Coarse agg (CA)	Water	GP	Mix proportion C: W: FA: CA: GP
MG0	410	620	1250	165	0	1: 0.4: 1.51: 3.05: 0.000
MG5	410	589	1250	165	31	1: 0.4: 1.43: 3.05: 0.075
MG10	410	558	1250	165	62	1: 0.4: 1.36: 3.05: 0.150
MG15	410	525	1250	165	95	1: 0.4: 1.28: 3.05: 0.225
MG20	410	496	1250	165	124	1: 0.4: 1.20: 3.05: 0.305

C—Cement; W—Water; FA—Fine aggregate; CA—Coarse aggregate; GP—Granite Powder.

3.3. Preparation of iron powder test specimens

The iron powder is primarily made from iron oxide fines with traces of other chemicals. The preparation of concrete specimens with iron powder was similar to those of the granite powder specimens. Table 4 shows the mix designs of concrete with various iron powder ratios. The percentages of iron powder used were 0%, 5%, 10%, 15%, and 20% of sand. Five mixes were tested: MI0, MI5, MI10, MI15, and MI20 containing 0%, 5%, 10%, 15%, and 20% of IP by weight respectively. This concrete with iron powder had similar slump values compared to GP mixes.

4. Testing of concrete cubes, cylinders and beams

Compression tests, split-cylinder tensile tests, and flexural tests were conducted on concrete cubes, concrete cylinders, and concrete beams respectively. The compressive strength tests were according to ASTM C39 while the flexural strength tests and the splitting tensile strength tests were done according to ASTM C78 and ASTM C496 respectively. Tests were performed at 7 days and 28 days. The compressive tests were conducted using 2000 kN (450 kips) compressive testing machine. Forty cubes were prepared and twenty were tested at 7 days and the remaining twenty were tested at 28 days. Flexural test and splitting tensile test specimens were tested using 1000 kN (225 kips) testing machine. Figs. 2 and 3 show photos of the compression testing machine and flexural test machine respectively. Twenty beams were prepared and ten were tested at 7 days and the remaining ten were tested at 28 days. Similarly for the cylinders, twenty cylinders were prepared and ten were tested at 7 days and the remaining ten were tested at 28 days. The test results of the cubes, beams, and cylinders of concrete made with GP and IP were compared to the test results of the normal concrete (control) specimens.

5. Test results of granite powder (Gp) concrete mixes

5.1. Compressive strength

The compressive strength of the cubes was determined for control specimens and for specimens with various percentages of granite powder. The average compressive strength of control cubes (Mix MG0) was 35.8 N/mm^2 (5.2 ksi). The cubes with granite powder showed higher compressive strength. The compressive strengths of mix designs MG5 (5% GP), MG10 (10% GP), MG15 (15% GP) and MG20 (20% GP) were

Fig. 2. Testing of cube specimens in compression.

47.1 N/mm^2 (6.84 ksi), 48.9 N/mm^2 (7.1 ksi), 42.9 N/mm^2 (6.22 ksi), 38.7 N/mm^2 (5.61 ksi) respectively. The test showed that the optimum percentage of granite powder to achieve the maximum increase in compressive strength was 10%. For 20% partial replacement of sand with granite powder the increase in the compressive strength was relatively small. The values of compressive strengths of cubes made with different percentages of granite powder replacement of sand are given in Table 5 and also graphically presented in Fig. 4.

5.2. Flexural strength

The flexural strength of concrete at failure or modulus of rupture was measured using beam specimens. The modulus of rupture is determined by testing twenty beam specimens 100 mm × 100 mm × 500 mm over a span length L = 400 mm in a 4-point loading set up as shown in Fig. 5.

The flexural strength (modulus of rupture) was determined using the bending stress formula. The section modulus of the cross section was 166,667 mm^3 (10.17 in^3) and load P was recorded by the data acquisition system. The flexural strength of the beams was determined for the control beams as well as the beams with various percentages of granite powder. The flexural strength of control beams at 28 days (Mix MG0) was 3.23 N/mm^2 (469 psi). The beams with granite powder showed higher flexural strength. The flexural strengths of mix designs MG5 (5% GP), MG10 (10% GP), MG15 (15% GP) and MG20 (20% GP)

Table 4
Mix design proportions for various iron powder ratios (kg/m^3).

Mix	Cement	Sand (FA)	Coarse agg (CA)	Water	IP	Mix proportion C: W: FA: CA: GP
MI0	410	620	1250	165	0	1: 0.4: 1.51: 3.05: 0.000
MI5	410	589	1250	165	31	1: 0.4: 1.43: 3.05: 0.076
MI10	410	558	1250	165	62	1: 0.4: 1.36: 3.05: 0.152
MI15	410	525	1250	165	95	1: 0.4: 1.28: 3.05: 0.226
MI20	410	496	1250	165	124	1: 0.4: 1.21: 3.05: 0.302

C—Cement; W—Water; FA—Fine aggregate; CA—Coarse aggregate; GP—Granite Powder.

Fig. 3. Testing of beam specimens in flexure.

Table 5
Compressive strengths of cubes with different proportions of (GP).

Mix design	% of granite powder	Compressive strength (N/mm^2) at 7 days	Compressive strength (N/mm^2) at 28 days	% Increase in strength at 7 days	% Increase in strength at 28 days
MG0	0	25.1	35.8	–	–
MG5	5	32.9	47.1	31.1	31.4
MG10	**10**	**34.2**	**48.9**	**36.3**	**36.6**
MG15	15	30.0	42.9	19.5	19.8
MG20	20	27.1	38.7	8.00	8.10

Table 6
Flexural strength of beams with different proportions of (GP).

Mix design	% of granite powder	Flexural strength (N/mm^2) at 7 days	Flexural strength (N/mm^2) at 28 days	% Increase in strength at 7 days	% Increase in strength at 28 days
MG0	0	2.26	3.23	–	–
MG5	5	2.53	3.61	11.9	11.8
MG10	10	3.23	4.62	42.9	43.0
MG15	15	2.30	3.49	1.77	8.0
MG20	20	2.27	3.24	1.01	0.3

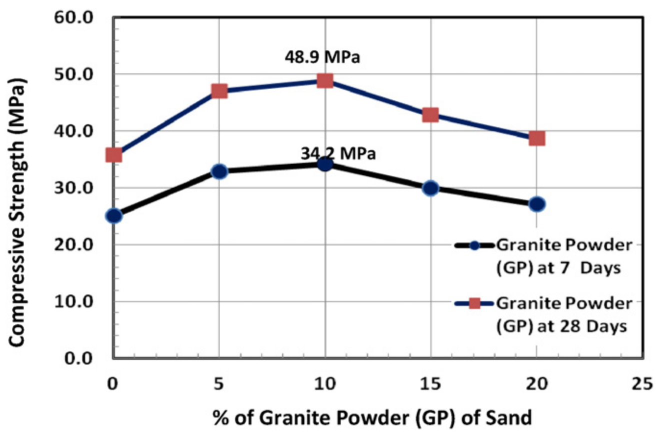

Fig. 4. Compressive strengths of cubes with different proportions of (GP).

were 3.61 N/mm^2 (524 psi), 4.62 N/mm^2 (670 psi), 3.49 N/mm^2 (506 psi), 3.42 N/mm^2 (496 psi) respectively. The tests showed that the optimum percentage of granite powder to achieve the maximum increase in flexural strength was 10%. For 20% partial replacement of sand with granite powder the increase in the flexural strength was relatively small. The values of flexural strengths of beams made with different percentages of granite powder of sand are given in Table 6 and also presented graphically in Fig. 6.

5.3. Split tensile strength

The tensile strength of concrete was determined indirectly using the split-cylinder strength test. The indirect test is widely accepted test method to determine the tensile strength of concrete given the difficulty and variability associated with the direct tensile tests. The split-cylinder tensile strength was determined by testing twenty 150 mm × 300 mm (6 in × 12 in) cylinders. Ten cylinders were tested at 7 days and ten cylinders were tested at 28 days. The split-cylinder tensile strength was determined using Eq. (1):

$$f_t = \frac{2P}{\pi LD} \quad (1)$$

where P is the cylinder failure load, L is the cylinder length equal to 300 mm, and D is the cylinder diameter equal to 150 mm. The split tensile strength of the cylinders was determined for the control cylinders as well as the cylinders with various percentages of granite powder. The split tensile strength of the control cylinders at 28 days (Mix MG0) was 2.62 N/mm^2 (380 psi). The cylinders with granite powder showed higher flexural strength compared to control mixes. The split tensile strength of mix designs MG5 (5% GP), MG10 (10% GP), MG15 (15% GP) and MG20 (20% GP) were 2.71 N/mm^2 (393 psi), 3.0 N/mm^2 (435 psi), 2.39 N/mm^2 (347 psi), 1.98 N/mm^2 (287 psi) respectively. The tests showed that the optimum percentage of granite powder to achieve the maximum increase in split tensile strength was 15% compared to an optimum value of 10% for compression and flexural strengths. For 20% partial replacement of sand with granite powder, the split tensile strength was lower than the control cylinders. This observation was different than those of compression and flexural strength. For compression and flexural strength, the 20% replacement of granite powder showed a modest increase rather than a decrease in strength. The values of split tensile strength of cylinders made with different percentages of granite powder of sand are shown in Table 7 and also presented graphically in Fig. 7.

5.4. Summary of test results of granite powder (GP) specimens

The concrete mix with granite powder (GP) in concrete showed good workability and had slump values similar to those of normal concrete mixes. The ingredients were easy to mix, pour, transport, finish and demold. The compressive strength of concrete increased with the addition of granite powder (GP) as partial replacement of sand. This results in more surface area that allows more Using 10% granite powder (GP) in concrete gave the best result (highest increase in compressive strength) compared to other ratios. The increase in this case was 36%. The same observation for the compression strength was observed for the flexural strength. With 10% GP replacement, the increase in flexural strength was about 43%. For the split-cylinder tensile strength, the optimum value of the percentage of (GP) in concrete was 15% compared to 10% for flexural and compressive strength. The increase in tensile strength for 15% and 10% of (GP) was approximately 30% and 15% respectively. For 20% (GP) in concrete the split tensile strength was lower than that of the control mix.

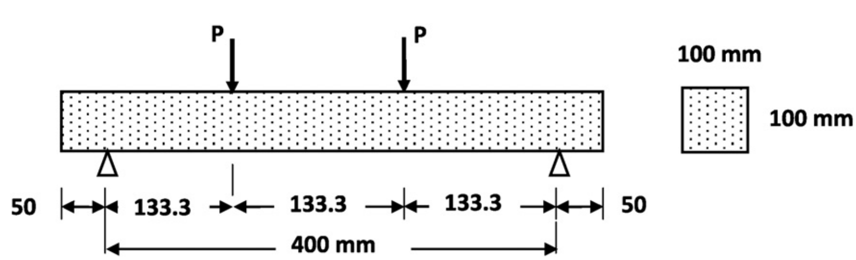

Fig. 5. Flexure test-up of concrete beams.

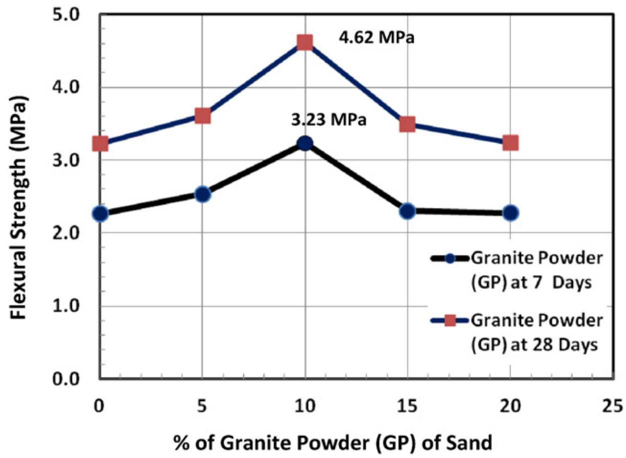

Fig. 6. Flexural strengths of beams with different proportions of (GP).

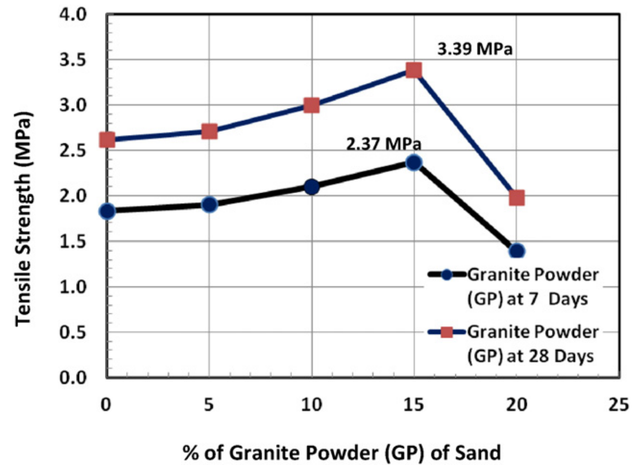

Fig. 7. Split tensile strength of cylinders with different proportions of (GP).

6. Test results of iron powder (Ip) concrete mixes

6.1. Compressive strength

The compressive strength of the cubes was determined for control specimens and for specimens with various percentages of granite powder. The compressive strength of control cubes (Mix MI0) at 28 days was 35.8 N/mm^2 (5.2 ksi). The cubes with granite powder showed higher compressive strength. The compressive strengths of mix designs MI5 (5% IP), MI10 (10% IP), MI15 (15% IP) and MI20 (20% IP) were 40.5 N/mm^2 (5.88 ksi), 42.6 N/mm^2 (6.18 ksi), 47.5 N/mm^2 (6.89 ksi), 47.7 N/mm^2 (6.92 ksi) respectively. The test showed that unlike the GP tests, the iron powder (IP) specimens showed an increase in compressive strength beyond 10%. At 15% and 20%, the increase was almost the same suggesting that 15% seems to be an optimum value. The values of compressive strengths of cubes made with different percentages of iron powder (IP) replacement of sand are presented in Table 8 and also shown graphically in Fig. 8.

6.2. Flexural strength

The flexural strength at failure or modulus of rupture of concrete made with iron powder was measured using beam specimens similar to those made with granite powder as shown in Fig. 8 earlier. The flexural strength of the beams was determined for the control beams as well as the beams with various percentages of iron powder. The flexural strength of control beams at 28 days (Mix MI0) was 3.36 N/mm^2 (487 psi). The beams with iron powder showed higher flexural strength than the control beam. The flexural strengths of mix designs MI5 (5% IP), MG10 (10% IP), MI15 (15% IP) and MI20 (20% IP) were 3.91 N/mm^2 (567 psi), 4.29 N/mm^2 (623 psi), 4.61 N/mm^2 (669 psi), 4.87 N/mm^2 (706 psi) respectively.

The tests showed that the flexural strength of concrete specimens with IP continued to increase with the increase with iron powder content. At 20% iron powder content, the increase of flexural strength was the maximum increase and was approximately 45%. The rate of increase in flexural strength was higher than that of the compressive strength. The values of flexural strengths of beams made with different percentages of granite powder of sand are presented in Table 9 and also graphically shown in Fig. 9.

6.3. Split tensile strength

The tensile strength of concrete made with iron powder (IP) was determined similar to those specimens made with (IP). Ten cylinders were tested at 7 days and ten cylinders were tested at 28 days. The split tensile strength of the control cylinders at 28 days (Mix MI0) was 2.8 N/mm^2 (406 psi). The cylinders with granite powder showed higher flexural strength. The split tensile strength of mix designs MI5 (5% IP), MI10 (10% IP), MI15 (15% IP) and MI20 (20% IP) were 3.0 N/mm^2 (435 psi), 3.05 N/mm^2 (443 psi), 3.15 N/mm^2 (457 psi), 3.21 N/mm^2 (466 psi) respectively. The tests showed that the split tensile strength of concrete specimens with IP continued to increase with the increase with iron powder content. At 20% iron powder content, the increase of tensile strength was the maximum increase and was approximately 14.3% at 28 days. The rate of increase in split tensile strength was higher than that of the compressive strength but was lower than that of the flexural strength. The values of flexural strengths of beams made with different percentages of iron powder (IP) of sand are presented in Table 10 and also graphically shown in Fig. 10.

6.4. Summary of test results of iron powder (IP) specimens

The concrete mix with iron powder (IP) in concrete showed good workability and had slump values similar to those of normal concrete mixes. The compressive strength of concrete increased with the addition of iron powder (IP) as partial replacement of sand. The results showed that the compressive strength continues to increase with increased iron powder ratio. At 10%, the increase was 19% and at 20% was 33%. For flexural strength, the increase in strength was 27% and 44.9% for 10% and 20% ratios respectively. The tensile strength of

Table 7
Split tensile strength of cylinders with different proportions of (GP).

Mix design	% of granite powder	Split tensile strength (N/mm^2) at 7 days	Split tensile strength (N/mm^2) at 28 days	% Increase in strength at 7 days	% Increase in strength at 28 days
MG0	0	1.83	2.62	–	–
MG5	5	1.90	2.71	3.82	3.44
MG10	10	2.10	3.00	14.76	14.5
MG15	15	2.37	3.39	29.51	29.4
MG20	20	1.39	1.98	−24.1	−24.4

Table 8
Compressive strengths of cubes with different proportions of (IP).

Mix design	% of granite powder	Compressive strength (N/mm^2) at 7 days	Compressive strength (N/mm^2) at 28 days	% Increase in strength at 7 days	% Increase in strength at 28 days
MI0	0	25.1	35.8	–	–
MI5	5	28.35	40.5	13.1	13.1
MI10	10	29.8	42.6	18.9	19.0
MI15	15	33.25	47.5	32.7	32.7
MI20	20	33.4	47.7	33.3	33.2

Table 9
Flexural strength of beams with different proportions of (IP).

Mix design	% of granite powder	Flexural strength (N/mm^2) at 7 days	Flexural strength (N/mm^2) at 28 days	% Increase in strength at 7 days	% Increase in strength at 28 days
MI0	0	2.35	3.36	–	–
MI5	5	2.74	3.91	16.6	16.4
MI10	10	3.00	4.29	27.6	27.7
MI15	15	3.23	4.61	37.4	37.2
MI20	20	3.41	4.87	45.1	44.9

concrete with iron powder also increased with the addition of iron powder as partial replacement of sand. The increase in split tensile strength was 8% and 14% for 10% iron powder ratio and 0% iron powder ratio respectively.

7. Comparison of test results from granite powder (GP) and iron powder (IP) specimens

Comparing the results of (GP) and (IP), the results show that up to 10% powder replacement, the granite powder (GP) shows more increase in compressive strength compared to iron powder (IP). For 15% and 20% partial replacement, the iron powder (IP) showed more increase in compressive strength compared to granite powder (GP). Fig. 11 shows a comparison of the compressive strength of concrete with granite powder and iron powder. Comparing the results of flexural strength of (GP) and (IP), it is observed in Fig. 12 that at 5% powder replacement, the iron powder (IP) shows slightly less increase in flexural strength than granite powder (GP). At 10% powder ratio, the specimens with granite powder (GP) shows slightly more increase in flexural strength than iron powder (IP) specimens. For ratios more than 10%, the increase in flexural strength of the granite powder (GP) specimens was significantly less than those of iron powder (IP) specimens. Fig. 13 shows a comparison of the tensile strength of concrete with granite powder and iron powder. With more than 5% iron powder (IP) content, the increase in tensile strength is less pronounced. At 20% powder content, the tensile strength using granite powder (GP) is significantly less than that of iron powder (IP). Actually, they were smaller than the control mixes.

8. Discussion of results

The experimental investigation carried out in this study showed that partial replacement of sand in concrete with granite powder (GP) or Iron Powder (IP) enhances its compressive strength, flexural strength, and tensile strength. The particle size is very important for the physical and chemical contributions of granite powder and iron powder in concrete. Because the particle size of granite powder is smaller than sand, they were able to fill the voids between sand particles similar to the way sand particles fill the void between coarser aggregates thus resulting in less voids and higher density and strength. In addition, because the particle size is smaller than sand, the surface area will be larger. Because of higher surface area of granite powder compared to sand, the concrete is expected to have higher strength due to more bonded areas with hydrating cement. Although the granite powder generally has less silicon oxide content compared to sand and that not all granite powder may react chemically with cement, the filler effect will bring improvements in the concrete. In the case of the iron powder, the increase in strength may be attributed to the modest increase in fineness of particles especially in the smaller diameter particles. It also may be attributed to the higher percentage of iron oxide in the iron powder. The test results showed that the best gain in compressive strength and flexural strength was with 10% granite powder ratio. Beyond 10%, the increase was less. It seems beyond this percentage, the filling effect of granite powder is not optimized. Typically an optimal size distribution in concrete will give higher density and fewer voids. If the particle size distribution is not optimal, the concrete will have more voids leading to lower strength. It seems that as the surface area increases, more hydrating cement is needed to bond these areas. If the water-cement ratio and added admixtures are not enough to hydrate enough cement, then the increased surface area of granite powder would not all be bonded and therefore less strength was observed with increased ratios of granite powder. Similar results were also observed by other researchers [5,11,15,16,17,and 18]. The results of iron powder showed that the compressive strength, flexural strength and tensile strength increased with higher iron powder ratios. The maximum ratio of iron powder as partial replacement of sand was limited to 20% in this study and therefore the trends in the change in mechanical properties of concrete with ratios higher than 20% are not available. However, the results for compressive strength and split tensile strength seem to level off at 20%. For flexural strength the increase was still noticeable at 20%. The gradation, the surface geometry, and the presence of higher

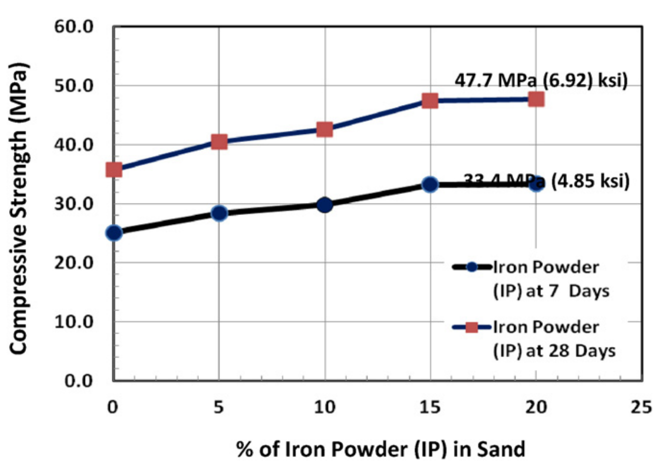

Fig. 8. Compressive strengths of cubes with different proportions of (IP).

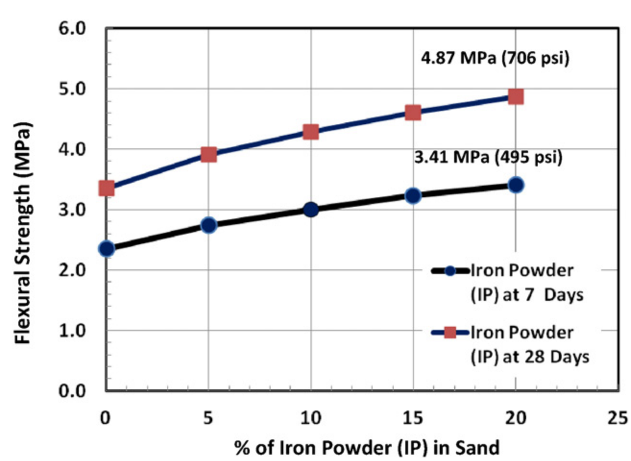

Fig. 9. Flexural strengths of beams with different proportions of iron powder (IP).

Table 10
Split tensile strength of cylinders with different proportions of (IP).

Mix design	% of granite powder	Split tensile strength (N/mm^2) at 7 days	Split tensile strength (N/mm^2) at 28 days	% Increase in strength at 7 days	% Increase in strength at 28 days
MI0	0	1.95	2.8	–	–
MI5	5	2.1	3.0	7.7	7.1
MI10	10	2.1	3.05	7.7	8.2
MI15	15	2.2	3.15	12.8	12.5
MI20	20	2.25	3.21	15.4	14.3

percentages of iron oxide are likely reasons for the increase in strength of iron powder concrete. The difference in behavior between granite powder concrete and iron powder concrete beyond the 10% ratio is shown in Figs. 11, 12, and 13. This difference can be attributed to the difference in chemical composition, gradation, and bonding mechanisms of these materials.

9. Conclusions

Based on the results of this study, the following conclusions can be drawn:

1. The concrete mix made using granite powder (GP) and iron powder (IP) as partial replacement of sand showed good workability and fluidity similar to normal concrete mixes.

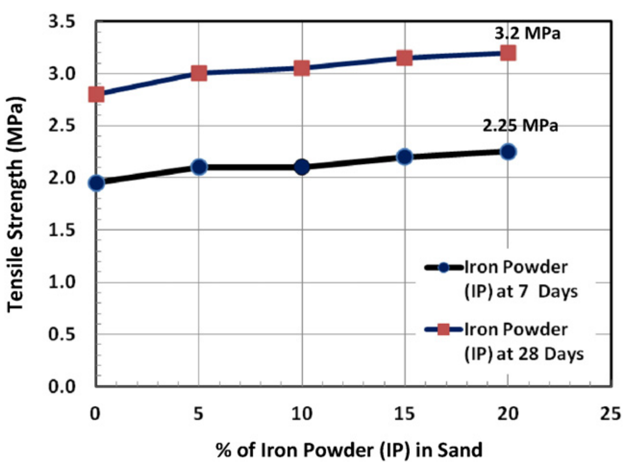

Fig. 10. Split tensile strength of cylinders with different proportions of (IP).

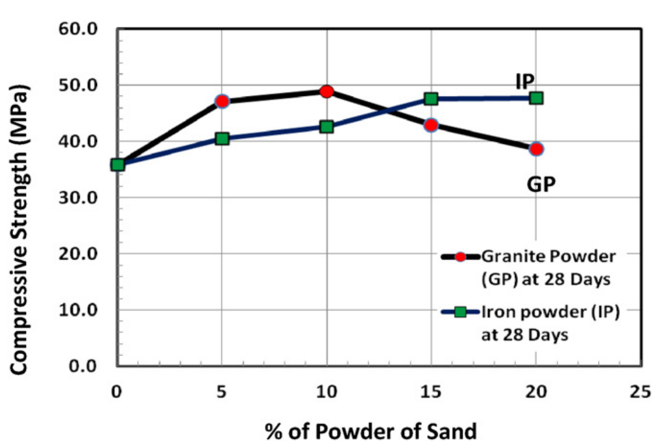

Fig. 11. Effect of % of (GP) and (IP) on the compressive strength of concrete.

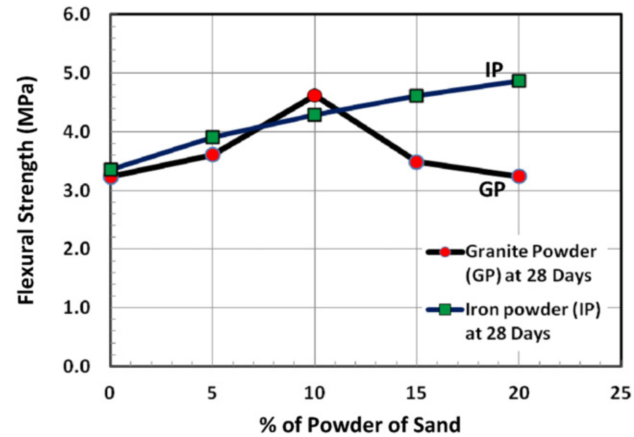

Fig. 12. Effect of % of (GP) and (IP) on the flexural strength of concrete.

2. The compressive strength of concrete increased with the addition of granite powder (GP) as partial replacement of sand. Using 10% granite powder (GP) in concrete gave the best result (highest increase in compressive strength) compared to other ratios.
3. Similar to the observations in the compressive strength, the flexural strength of concrete increased with the addition of granite powder (GP) as partial replacement of sand. The maximum increase was observed for 10% GP ratio.
4. For the split-cylinder tensile strength, the optimum value of the percentage of (GP) in concrete was 15% compared to 10% for flexural and compressive strength. The increase in tensile strength for 15% and 10% of (GP) was approximately 30% and 15% respectively. For 20% (GP) in concrete the split tensile strength was actually lower than that of the control mix.
5. For mixes with iron powder (IP), the compressive, flexural, and tensile strengths all increased with the increase in the (IP) ratio. Unlike the granite powder (GP), the increase in strengths continued to concrete with the increase in the (IP) ratio. The increase was more pronounced in flexural strength compared compressive and tensile strengths.
6. This study was limited to the evaluation of the mechanical properties of concrete with granite powder and iron powder as well its workability and fluidity. The longer-term performance of concrete with granite powder and iron powder was not part of this study. Durability is important for the proper use of this material in structural as well as non-structural applications and will be investigated in a future study.

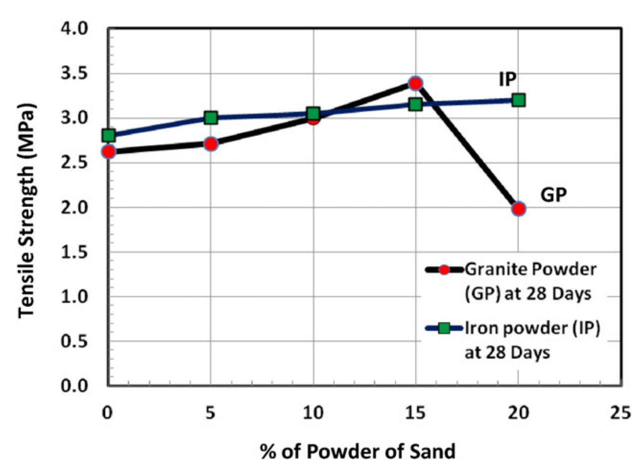

Fig. 13. Effect of % of (GP) and (IP) on the tensile strength of concrete.

7. This study as well studies in other countries have shown the viability of producing concrete with granite powder and iron powder byproducts. This will encourage producers and environmental groups to continue collecting and storing these hazardous airborne fines. Life-cycle cost analysis for the use of these materials compared to current concrete material also needs to be addressed in future research.

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References

[1] A.M. Neville, 'Properties of concrete, Trans-Atlantic Publications, Inc. fifth ed., 2012 (5the Edition).
[2] D. Chiras, Environmentally-Friendly Recycled Tile, Mother Earthly News, Topeka, Kansas, 2009http://www.motherearthnews.com.
[3] N. Perez, C. Gaedicke, F. Shahbadglou, Using countertop and construction waste for green concrete, 50th ASC Annual International Conference, 2014.
[4] A. Alzaed, Effect of iron filings in concrete compression and tensile strength, Int. J. Recent Dev. Eng. Technol. Vol 3 (Issue 4) (2014) 121–125.
[5] F. Kala, 'effect of granite powder on strength properties of concrete', Int. J. Eng. Sci. Res. Invent. Vol. 1 (Issue 12) (2013) 36–50.
[6] G. Prabhu, J.K. Bang, B.J. Lee, J.H. Hyun, Y.Y. Kim, Mechanical and durability properties of concrete made with used foundry sand as fine aggregate, Adv. Mater. Sci. Eng. J. Volume 2o15 (2015) (Article ID 161753, 11 pages).
[7] A. Kumar, D. Raval, I.N. Patel, J.K. Pitroda, Ceramic waste: Effective replacement of cement for establishing sustainable concrete, Int. J. Eng. Trends Tech. (IJETT) 4 (6) (2013) 2324–2329.
[8] N.V.S. Kumar, P.B. Rao, M.L.N.K. Sai, Experimental study on partial replacement of cement with quarry dust, Int. J. Adv. Eng. Res. Stud. (Issue III) (2013) 136–137.
[9] M. Mustafa, H. Al-Bakri, H. Mohammed, I. Kamarudin, N. Khairul, Y. Zarina, Review on fly-ash-based geopolymer concrete without Portland cement, J. Eng. Technol. Res. 3 (1) (2011) 1–4.
[10] R. Baboo, N.H. Khan, K. Abhishek, R.S. Tabin, S.K. Duggal, Influence of marble powder/granules in concrete mix, Int. J. Civ. Struct. Eng. 1 (4) (2011) 827–834.
[11] K.K. Alzboon, K.N. Mahasneh, Effect of using stone cutting waste on the compression strength and slump characteristics of concrete, Int. J. Civil Environ. Eng. 1 (4) (2009) 168–173.
[12] Criteria for a Recommended Standard: Occupational Exposure to Crystalline Silica, US Department of Health and Human Services (DHHS), National Institute for Occupational Safety and Health (NIOSH) publication no. 75–120, 1974 (1974).
[13] OSHA/NIOSH, Hazard alert: Worker Exposure to Silica During Countertop Manufacturing, Finishing and Installation, NIOSH Publication No. 2015–106, 2015.
[14] G. Siriann, D.D. Hosgood III, M. Slade, J. Borak, Particle size distribution and particle size-related crystalline silica content in granite quarry dust, J. Occup. Environ. Hyg. Vol 5 (Issue 5) (2008) 279–285.
[15] M. Vijayalakshmi, A.S.S. Sekar, G.G. Prabhu, Strength and durability properties of concrete made with granite industry waste, Constr. Build. Mater. 46 (2013) 1–7.
[16] S. Singh, S. Khan, R. Khandelwal, A. Chugh, R. Nagar, Performance of sustainable concrete containing granite cutting waste, J. Clean. Prod. 119 (2016) 86–98.
[17] S. Singh, R. Nagar, V. Agrawal, Review on properties of sustainable concrete using granite dust as replacement for river sand, J. Clean. Prod. 126 (2016) 74–87.
[18] S. Singh, R. Nagar, V. Agrawal, A. Tiwari, S. Siddique, Review on properties of sustainable concrete using granite dust as replacement for river sand, J. Clean. Prod. (2016).
[19] S. Zhao, J. Fan, W. Sun, Utilization of iron ore tailings as fine aggregate in ultra-high performance concrete, J. Constr. Build. Mater. 50 (2014) 540–548 (Elsevier).