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COMPARATIVE STUDY ON DIFFERENT RATIOS OF FOUNDRY AND WASTE FOUNDRY SAND IN CONCRETE

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Abstract

In this study, the fresh and hardened properties of concrete made with foundry sand (FS) and waste foundry sand (WFS) were investigated. Sand was replaced with 10, 20 and 30 percent of FS and WFS in order to study the effect of heat and subsequent process reactions on concrete properties. Slump, compressive strength, indirect tensile strength, flexural strength, ultrasonic pulse velocity (UPV), modulus of elasticity and durability parameters such as water absorption & permeability, chloride penetration and alkali silica reaction (ASR) were conducted in different substituting of FS and WFS. The results showed that the use of FS increases the compressive, flexural and tensile strength, UPV and modulus of elasticity of concrete. In contrast, WFS increases water absorption and permeability, chlorine penetration and tensile strength. According to the results, the replacement of 10% WFS has the lowest reduction compared to the control mixture. In the indirect tensile strength test, replacement of both types of foundry sands was faced with increasing resistance. In all of the mix designs, the concrete workability compared to the control mixture was reduced. The SEM results of mixtures with 30% FS replacement reveal better compaction and no porous in transition zone (TZ).

Key words: reuse, solid waste management, sustainable development, waste foundry sand

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1. Introduction

The construction industry has been growing rapidly and it is needed to produce sustainable materials with recycled wastes to preserve the environment and natural resources. Excessive consumption and utilization of concrete in this industry has led to the use of concrete constitutive raw materials such as aggregates. On the other hand, development of industries such as casting has caused significant waste production (Cedillo-González et al., 2020; Henriques and Coelho, 2019).

A large amount of WFS has annually entered into the environment. Thus, the reuse of these materials can be considered as an effective step to reach sustainable development. Partial replacement of concrete aggregate with WFS not only reduces the problems of land-fill shortage and negative consequence of WFS burying environmental impact but also cuts down natural resources' consumption. Foundry operation in factories are using various types of sand and other additives for mold metals casting process. The mentioned material could be recyclable several time till the stiffening process happens. In addition, chemical binders play limitation role in reusing sand. In the United States, the waste of foundry factories buried in landfills was about nine million tons required lots of land and good disposal management. The waste of a foundry plant can include slag, used foundry sand, ash, metal, and so on, imposing annually 665-675 million dollars on governments. These huge waste and future environmental costs caused to consider a new scenario called the reuse and optimization of this sand (Siddique and Singh, 2011).

Concrete is known as the indispensable construction material composed of aggregates, cement, water and admixtures. Every single material

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contributed in concrete production plays an important role in its strength and durability. Hence, partial replacement of material can make a great impact on the concrete properties. Using waste materials, could be a plausible way to reduce construction costs as well as preventing environmental damage (Smit et al., 2014). In recent years, many waste materials such as glass, plastics, construction waste material, copper slag and WFS as concrete aggregates have been replaced (Aggarwal and Siddique, 2014; Saha et al., 2019; Shahbaz and Lalotra, 2018). WFS can also be applied in cement and mortar production (Korać et al., 2006), road construction industry, soil stabilization, concrete reinforcement and asphalt concrete (Bakis et al., 2006; Torres et al., 2017).

Although high quality of aggregates is widely found in Iran, it doesn't have good grading because of high fineness modulus (FM) of sand (based on ASTM C33). Therefore, partial replacement of fine grading of FS and WFS make them as a viable solution to lessen the FM value as well as increase strength. Many researchers have documented the use of WFS as a part of concrete mixture. The findings suggest positive influence of WFS as a replacement on different concrete parameters. They investigated the effect of WFS replacement with fine aggregate on slump, water absorption, compressive strength, flexural strength, tensile strength, abrasion resistance and modulus of elasticity (Guney et al., 2010; Khatib and Ellis, 2001; Siddique et al., 2009; Siddique and Singh, 2011; Singh and Siddique, 2012). The effect of replacing concrete fine aggregates with 5, 10 and 15% WFS on the concrete slump was studied. The slump result of fresh concrete showed considerable reduction with increase in the amount of WFS (Guney et al., 2010). In another study, fine aggregates were replaced with 10, 20, 30, 40 and 50 percent of aluminum casting WFS. The results showed a significant decrease in concrete workability by replacing of WFS (Ganapathy et al., 2014). Furthermore, similar report concluded that the increase in the WFS percentage cause a significant decrease in slump (Aggarwal and Siddique, 2014; Ganapathy et al., 2014; Khatib et al., 2010). Research results have shown that the water absorption of concrete with 5%WFS was higher than concrete without WFS at the age of 56 days, while water absorption decreased for the higher WFS content (10% and 15%). The void ratio of samples with and without WFS was the same as the results of the water absorption test. The reduction of void ratio was occurred for those samples with replacement ratio of WFS > 5% for all ages (Guney et al., 2010). However, another research showed no change in water absorption of concrete containing WFS (Salokhe and Desai, 2013). Unlike the above results, in another study, with an increase in the WFS amount, the amount of water absorption increased too. The study of the effects of partial replacement of aggregate and cement by FS and fly ash showed that concrete containing FS and fly ash had better ductility and mechanical properties than normal concrete (Shahbaz and Lalotra, 2018) which are in agreement with previous studies (Singh and Siddique, 2012). The impact of WFS replacement in self-compacting concrete was studied. The results showed that with increasing replacement percentage from 5 to 30, the compressive strength of 7, 28, 90, and 365 days decreased (Sandhu and Siddique, 2019). Most recently, M5P algorithm and gene expression programming was used to model the concrete compressive strength, modulus of elasticity, flexural strength, and splitting tensile strength of the concrete containing WFS. The results indicated that the proposed models can provide reliable predictions of the target mechanical properties (Behnood and Golafshani, 2020; Iqbal et al., 2020).

Although many studies have already been done to investigate the use of WFS as aggregate in concrete, there is no available comparison between FS and WFS focusing on different properties of concrete and durability parameters. The aim of the present study is to determine mechanical properties of concrete containing different percentages of FS and WFS replacement. In addition, Microstructure analysis of mixtures with and without WFS and FS using scanning electron microscope (SEM) images were also performed.

2. Material and methods

2.1. Materials

In this study, the cement used was Portland cement type II produced by Tehran cement company. The physical and chemical cement properties are given in Table 1. The aggregates used were gravel having 19 mm maximum size particle and the twice-washed natural sand with a maximum size of 5 mm. The FS and WFS were obtained from a factory near Tehran. Metals poured in the foundry's factory were cast iron, copper and aluminum with sodium silicate binder. The wastes from these sands were sieved for further usage. A set of gradation curves of sand, gravel, FS and WFS is represented in Fig. 1. As shown in Fig.1, the WFS grading is partially larger than the FS one due to the bonding of some of the FS grains in the casting process. The natural color of FS is orange, but following the casting process, heat and mixing with sodium silicate, the WFS color turn into the grey. The physical properties of FS and WFS are according to ASTM C127-88 and ASTM C128-88 which are presented in Table 2. Based on the ASTM C494 standard, polycarboxylate-based superplasticizer and retarder was used in all tests. According to ASTM E1621 standard, XRF test on FS and WFS was conducted and represent in Table 2.

The chemical composition of the WFS depends on the type of metal produced in the casting and the type of adhesive. The chemical composition of sand casting may affect its performance. For example, hydrophilic surface of silica sand is a key reason for water absorption. Fig. 2 represents the structure of both sand types using FTIR spectroscopy. The peaks at the center 1080 cm^{-1} belongs to the structure of the

Si-O-Si silica network. The presence of the anchored propyl group was confirmed by C–H stretching vibrations that revealed at 2933 and 2875 cm^{-1} (Balbay and Acikgoz, 2016). The appearance of peaks at the spectral range with the wavelength 1600 cm^{-1} and 2300 cm^{-1} are attributed to vibrations of carbon impurity atoms in the sample. The existence of carbon in the WFS can be seen via two strong absorption bands at 1630 and 2210 cm^{-1}. The strong characteristic absorption bands at 400–700 cm^{-1} were attributed to the Fe-O stretching vibration and the Ti-O bending vibration. The peak at 3482 cm^{-1} was intensified, due to the stretching vibrations of -OH on the TiO_2 surface, which were bound with adsorbed water molecules (Alizadeh et al., 2018).

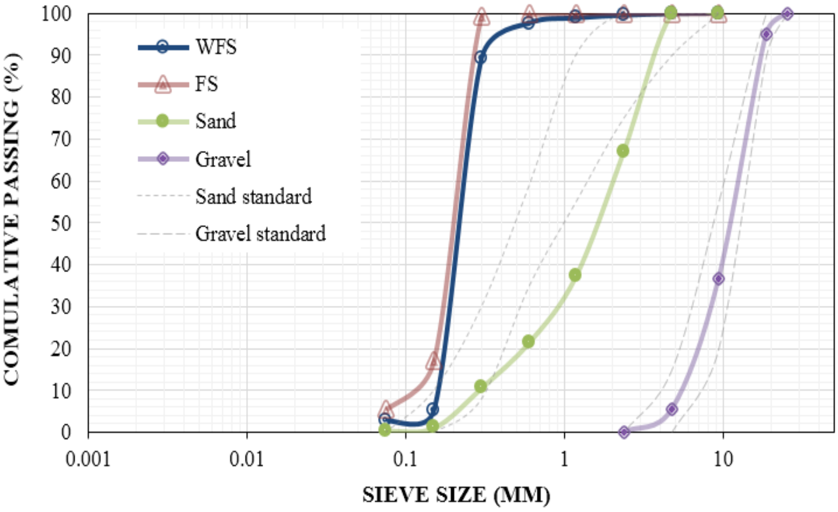


Fig. 1. Gradation of sand, gravel FS and WFS

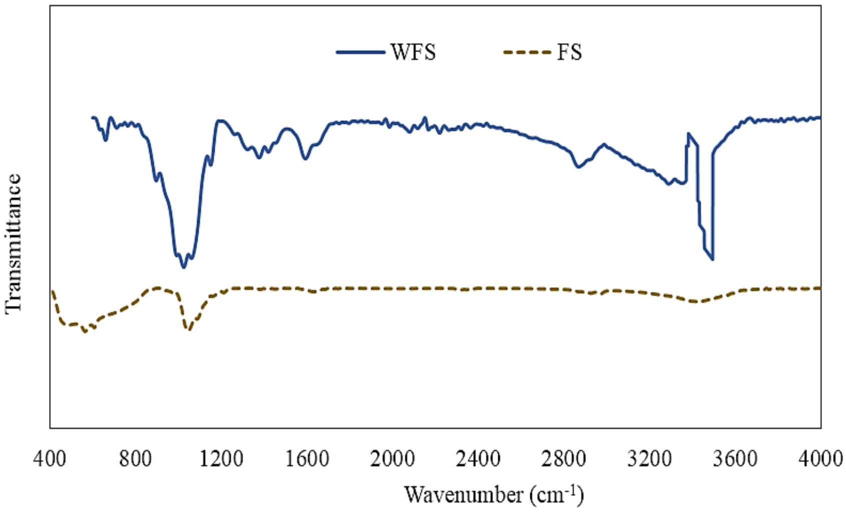


Fig. 2. FTIR of FS & WFS

Table 1. Chemical & physical analysis of the Portland cement type II

Chemical analysis	***Results (%)***	***Physical analysis***	***Results***
SiO_2	21.27	Compressive strength (3 days)	180 (kg/cm^2)
Al_2O_3	4.95	Compressive strength (7 days)	300 (kg/cm^2)
Fe_2O_3	4.30	Compressive strength (28 days)	420 (kg/cm^2)
CaO	62.95	Fineness (Blain method)	3170 (cm^2/gr)
MgO	1.55	Density	3.08 gr/cm^3
SO_3	2.62	Initial Time of Setting	75 min
Na_2O	0.49	Final Time of Setting	120 min
K_2O	0.65	Loss on ignition	2.11 (%)
C_3A	5.84	Insoluble residue	0.57 (%)
C_2S	25.05	Autoclave expansion	0.1 (%)
C_3S	47.74	Heat of hydration	45 (cal/g)
C_4AF	13.08		

Table 2. Chemical & physical analysis of the FS and WFS

Chemical analysis	***FS (%)***	***WFS (%)***	***American Foundry society***	***Physical analysis***	***WFS***	***FS***
SiO_2	98.1	88.14	87.91	Specific gravity (SSD) (g/cm^3)	1.57	1.56
Al_2O_3	1.1	2.04	4.70	apparent specific gravity (g/cm^3)	1.59	1.58
Fe_2O_3	0.1	5.46	0.94	bulk specific gravity (g/cm^3)	1.55	1.54
CaO	0.06	1.267	0.14	Finesse Modules	0.83	1.09
MgO	-	0.108	0.3	Sinter point*	<1400	<1400
SO_3	-	0.417	0.09	Loss on ignition (%)	4.5	0.3
Na_2O	0.5	1.83	0.19	Mohs Hardness**	7	7
K_2O	0.5	0.323	0.25	Segar refractoriness***	1600	1710
TiO_2	-	0.35	0.15	Moisture content (%)	-	0.1

The temperature at which a solid mass transforms or compresses without reaching the melting point. ** classified from 1 to 10 * The heat resistance of refractory materials*

2.2. Mix design and sample preparation

The concrete mix proportion was designed according to Iranian national mix design. For all mixtures, a constant water-cement ratio (W/C) and superplasticizer content were fixed at 0.55 and 0.3% weight of cement, respectively. The fine aggregates of concrete were replaced with 0, 10, 20 and 30% FS and WFS, while the other concrete elements were constant. The proportion of each mixture for one cubic meter of concrete is summarized in Table 3. By partial replacement of foundry sand, the fineness modulus decreases and falls into a better range. Conventional sand, FS and WFS fineness modulus were 3.62, 0.83 and 1.09, respectively. After replacing different percentages of WFS, this value was reduced to 3.37, 3.12 and 2.86 for B-10, B-20 and B-30 samples. Manufacturing and curing of all mixtures were based on ASTM C192. After daily mixing proportion, the specimens were poured into the molds. Then, samples were tested at the age of 3, 7, 28 and 90 days.

2.3. Testing procedure

Slump flow was determined according ASTM C143. The 150 mm concrete cubes were cast for compressive strength, cylinders of size 150 mm × 300 mm for splitting tensile strength and beams of size 100 × 100× 500 mm for flexural strength according ASTM C943-17, ASTM C293 and ASTM C496. All parameters measured three times at 3, 7, 28 and 90 days of curing period and reported on average.

Microstructure study of FS, WFS and partially replaced concrete is carried out through the Scanning Electron Microscopy (SEM) (model: VEGA\TESCAN-XMU) located in Razi metallurgical research center.

3. Results and discussion

3.1. Fresh concrete properties

The slump of concretes containing 0, 10, 20 and 30% FS and WFS are assessed and the result is given in Fig. 3. In most mixture patterns of FS and WFS, the fluidity and slump were decreased. The results showed that the slump changed the mixture containing FS and WFS compared to the control mix design. It can be understood that the replacement of FS in concrete reduces the slump of concrete. In addition, the increasing of replacement rate affects the workability of concrete. The unit weight of the mixtures was nearly constant with or without WFS (Table 3). Comparing these results with previous studies showed that the decreasing slump trend was similar to the other results (Aggarwal and Siddique, 2014; Ganapathy et al., 2014; Guney et al., 2010; Khatib et al., 2010). In another study, Ganapathy et al replaced concrete fine aggregate with 10, 20, 30, 40, and 50 percent aluminum FS which similar results were obtained (Ganapathy et al., 2014). This slump reduction can be attributed to the fine particle size. It means that higher surface area and water absorption may lead to a significant decrease in concrete performance.

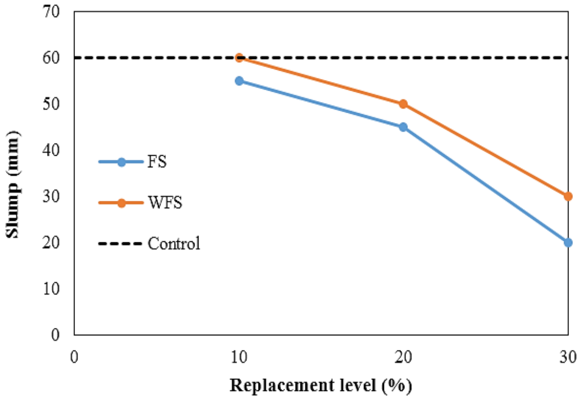


Fig. 3. Results of slump changes of mixture containing FS and WFS compared to the control mix

3.2. Hardened concrete properties

3.2.1. Compressive strength

The compressive strength test of the specimens was carried out according BS 1881 standards. Fig 4 shows the changing compressive strength of all mixture in different ages of 3, 7, 28 and 90 days. The compressive strength of all FS samples are gradually increased as the replacement percentage ratio of FS increased at the constant age. As a comparative example, the parameter value for A10 and A20 (age of 3d) are 18.5 and 21.07 MPa, respectively, which are 0.4% and 3.1% higher than control mix. The parameter value also increased with the increasing of the concrete age.

Table 3. Mix proportion of concrete specimens

Specimens	***C***	***A-10***	***A-20***	***A-30***	***B-10***	***B-20***	***B-30***
Cement (kg/m^3)	350	350	350	350	350	350	350
Sand (kg/m^3)	1000	900	800	700	900	800	700
Gravel (kg/m^3)	800	800	800	800	800	800	800
FS (%)	0	10	20	30	0	0	0
WFS (%)	0	0	0	0	10	20	30
Water (kg/m^3)	192.5	192.5	192.5	192.5	192.5	192.5	192.5
W/C	0.55	0.55	0.55	0.55	0.55	0.55	0.55
FS (kg/m^3)	0	100	200	300	0	0	0
WFS (kg/m^3)	0	0	0	0	100	200	300
Super plasticizer (kg/m^3)	3.67	3.6	3.62	3.61	3.66	3.7	3.72
Slump (cm)	6.0	5.5	4.5	2.0	6.0	5.0	3.0
Concrete unit weight (kg/cm^3)	2380	2375	2376	2370	2370	2375	2378

The parameter value of the specimen of A20 is 18.5 and 23.93 MPa for the age of 3 and 7 d, respectively, which are 3.1% and 13% higher than the control because of likely fine grading and fineness modulus of foundry sand, which made better grading and increased the strength.

On the other hand, 3-day compressive strength of B-10, B-20 and B-30 decreased from 17.94 MPa to 15.07, 14.21 and 13.22 MPa. 7-day strength decreased from 21.17 to 19.25, 17.76 and 16.88 MPa and 28-day strength decreased from 28.33 to 26.55, 25.37 and 24.56 MPa. The percentages of decrease in compressive strength of B-30 were 35.7%, 25.7% and 15.3% at the age of 3, 7 and 28 days, respectively, which 28-days decrease was more noticeable. Therefore, it is evident that the B-10 mixture is the nearest mixture to the control, in terms of compressive strength.

The interconnection between cement paste and aggregate is known as interfacial transition zone (ITZ) that is one of the important parameters affecting the mechanical properties of concrete. ITZ is the weakest ring in the concrete chain and acts as a bridge between cement paste and aggregate. The presence of adhesives like sodium silicate, make transition zone of the WFS mixtures to be more porous than the control mixture. These adhesives can also cause the cement paste and aggregate to not be adhered that limiting stress transferring, as a result, makes concrete failure to occur. Thus, the trend of fineness modulus in the FS mixed by conventional sand is not an effective factor for the increase in strength.

The results of sand replacement were similar to other studies (Aggarwal and Siddique, 2014; Khatib and Ellis, 2001; Siddique Siddique and Singh, 2011), that is, by increasing WFS replacement percentage, the compressive strength decreased . The results of FS replacement were similar to studies that in mixture containing 5% fly ash, the rise of FS replacement from 10 to 20%, enhanced the compressive strength value from 6 to 15% (Shahbaz and Lalotra, 2018).

3.2.2. Splitting tensile strength

Indirect tensile strength test (Brazilian test) was performed for FS and WFS at the age of 7, 28 and 90 days. Tensile splitting and compressive strength and strength of the concretes are related to each other. According to Fig. 5, as the percentage of FS and WFS increases, the tensile strength increases too. On the other hand, the relative strength values for FS and WFS were shown different pattern. Concrete with higher FS content (A-10, A-20 and A-30) shows higher values from 24.96, 28.82 and 28.96 kg/cm^2, respectively. While, the values decrease with the rise of WFS amount, the tensile strength of the mixtures was more than that of the control mix. The values of B-10, B-20 and B-30 were 27.34, 26.69 and 21.49, respectively, was higher than that of mixture without sand replacement (20.84 kg/cm^2).

The higher tensile strength of the mixture contained WFS compared to the control mixture could be due to the fine particles and adhesives acting as fillers and increase the tensile strength. The results of this study showed that when WFS contribution percentage increase (5%, 10%, 15% and 20%), the tensile strength trend had a gradual decline (3.55%, 8.27%, 10.4% and 6.38%) which was in agreement with Singh and Siddique experiment. Furthermore, the result of study by Siddique et al. showed that Tensile strength increased almost linearly with increasing percentage of WFS replacement (Siddique et al., 2009).

3.2.2. Flexural strength

The trend of flexural strength is available in Fig. 6. The results were similar to compressive strength and it was observed that with increasing FS percentage, flexural strength increased, but the effect of its waste on flexural strength was negative. As shown in Fig. 6 for mixture contains FS, flexural strength increased considerable. The control strength was 3.52 and by adding FS content, flexural strength reaches 3.61, 3.66, and 3.83 MPa for A-10, A-20, and A-30 respectively. The highest increase in strength was for 30% of FS replacement. The value decreased from 3.52 to 3.35, 3.24 and 2.94 MPa for samples B-10, B-20 and B-30, respectively. Similar to compressive strength, it could be due to the lack of sufficient compression and the presence of cavities in ITZ causing the stress not to be transferred. As a result, replacing 10% of WFS have the closest strength to the control mixture.

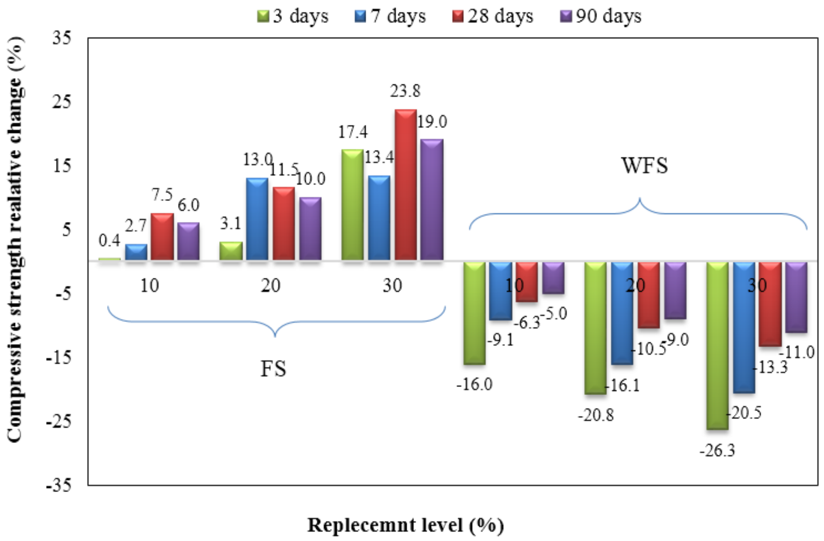
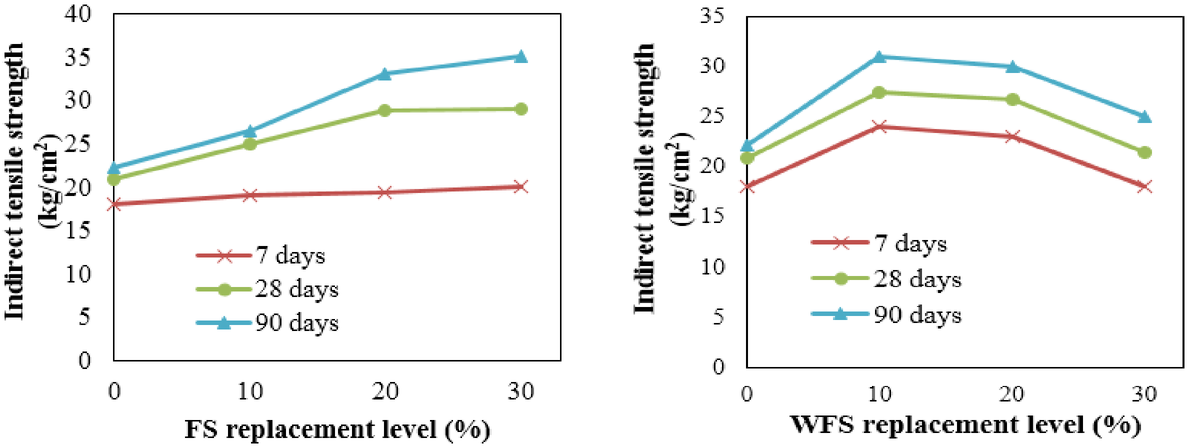


Fig. 4. Results of 3, 7, 28- and 90-days compressive strength changes of mixes replaced by different percentages of FS&WFS compared to the control mix



(a) (b)

Fig. 5. Results of 3, 7, 28 and days Indirect tensile strength by different percentages of FS&WFS compared to the control mix

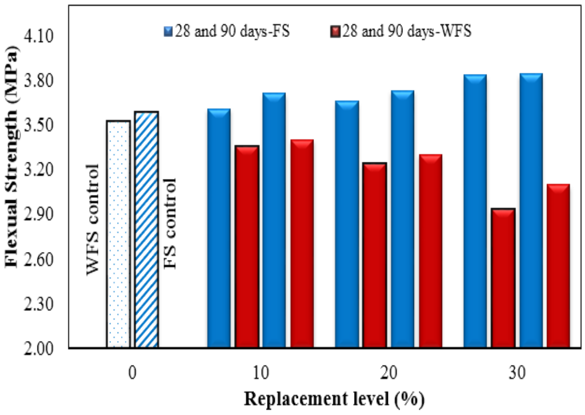


Fig. 6. Flexural strength of FS and WFS mixture at 28 and 90 days

3.2.2. Ultrasonic pulse velocity (UPV)

UPV measures the elastic properties of concrete as well as applies to determine some qualitative parameters like dynamic modulus and thus compressive strength. The UPV test could be applied for determining the uniformity of concrete, estimating the strength of concrete, modulus of elasticity, checking the degree of hydration, durability, detecting the damaged layer of concrete and estimating the depth of crack. The use of this method is proposed in BS 1881: Part 203 as well as in ASTM C597. For the samples, the longitudinal (or pressure) transfer method was used. According to Fig. 7, the results showed that in all samples, prolonging the processing time increased the rate of wave velocity owing to the improvement of cement hydration reactions. As the amount of WFS increased, the amount of UPV decreased in all samples. As an example, the reduction achieved from 4179 to 4069 m/s for sample with 20% replacement ratio at 28 day. The slowing of the waves is directly correlated with the decrease in compressive strength of concrete containing WFS. On the other hand, with the increase in FS percentage, the speed of the waves also increased. Therefore, the rate of velocity at 28 days showed a 2% increase in 20% replacement. Other researchers have reported similar results. In the Khatib et al. (2010) study, for example, an increase in replacement percentage of WFS from 20 to 100%, the UPV decreased from 3600 to about 2800 at 28 days.

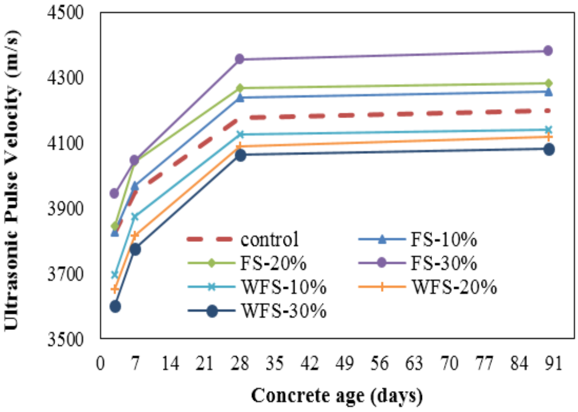


Fig. 7. Ultrasonic pulse velocity of FS and WFS samples

3.2.5. Modulus of elasticity

The modulus of elasticity reflects the ability to deform concrete in an elastic state. Fig. 8 illustrates elasticity modulus change with respect to different WFS and FS variation replacement. As it can be seen, the rise in WFS replacement percentage from 10 to 30% cause a decrease in the modulus of elasticity from 25.7 to 24.76 GPA whereas further increase of the replacement percentage, cause the reduction in elasticity. This tendency is also observed in compressive strength, splitting tensile strength and flexural strength criteria. In contrast, the elasticity modulus of all replacement percentage of FS containing samples increased. At maximum replacement ratio, it was raised by 11.3% compared to the control sample. These findings agree with Manoharan et al report the 28-day results of control and trial mixture (20% WFS) were 23.6 and 25.4 GPa respectively.

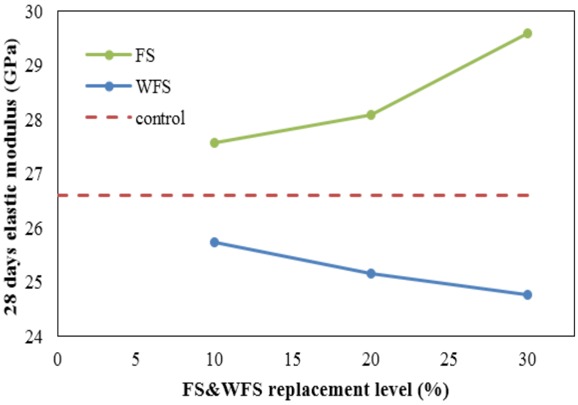


Fig. 8. Elastic modulus of FS and WFS samples

3.3. Durability parameters

3.3.1. Water absorption & permeability

Concrete water absorption results showed that with increasing WFS replacement percentage, this parameter increased. After 28 days in the sample containing 20% of WFS, the 28-day water absorption increased from 1.5% to 2.1% in the control sample. In the sample containing FS under similar conditions, this amount decreased from 1.5% to 1%. The increase in water absorption of sample containing WFS is associated with a decrease in the compressive strength of the concrete. Although replacing the WFS with the sand used in the concrete mixing design increase the fine grains amount in the concrete mix, the presence of contaminants around the WFS grains reduce the adhesion of these particles to the cement paste.

Although the water permeability rate in concrete differs from that of concrete water absorption, under similar conditions the infiltration rate of WFS has increased with increasing permeability rate. The results showed that with the rise of WFS content by 20%, the pressure penetration rate according to related ASTM C1202 increased by 1.5 times. Under the same conditions, replacing 20% of the FS, the water penetration rate was reduced to 30%.

3.3.1. Chloride penetration

The results of measuring the charge passed of solution containing chlorine from the concrete with 20% replacement of WSF and FS led to achieve permeability values equals to 600 and 400 Coulombs, respectively. The results are in the range of very low chloride ion penetration, according to ASTM C1202. Increasing the percentage of WFS substitution by up to 30%, allow more charge to pass through and subsequently increasing permeability values more than 1100 Coulombs, which is in the low permeability range. However, under similar conditions for FS the charge passed were negligible. These results for 20 percent replacement are similar to those reported by some others (Aggarwal and Siddique, 2014).

3.3.2. Alkali silica reaction (ASR)

ASR can occur in concretes made with aggregates containing reactive silica. ASTM C1260, mortar-bar method, was used to evaluate the effect of replacing sand with FS & WFS in ASR. According to standard, water to cement ratio (cement materials) and aggregate to cement ratio were considered 0.47 and 2.25, respectively. For each experiment, at least three test specimens (25×25×285 mm) were made. Having been filled, the molds placed in moist room for a night. Then, prior to place all sample in the oven at temperature of 80C, the initial reading was conducted. After that, it left in the laboratory environment with an ambient temperature of 25°C and relative humidity less than 50%. Initial readings were read after 24 hours and then the samples were placed in a container with sufficient 1N-NaOH solution and final readings were done after two weeks. To determine the rate of increasing expansion, sample size was measured every two days. Fig. 9 shows the effect of WFS as sand replacement in the ASR expansion. Expansions of less than 0.10 % at 16 days after casting shows innocuous behavior in most cases. Expansions of more than 0.20 % at 16 days after casting are indicative of potentially deleterious expansion. As shown in Fig. 9, the replacement of 20% sand with FS and WFS, increased ASR expansion nearly 23 and 3% respectively. Because of different silica phase's polymorph, related to the various alloy casting temperature, different phases included alpha quartz, tridymite, and alpha cristobelite were observed in WFS and ASR expansion.

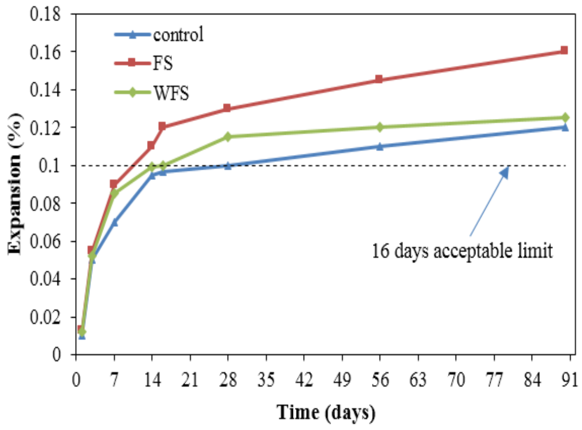


Fig. 9. Expansion of FS and WFS samples in ASR

3.4. Microstructural analysis

SEM analysis was performed to compare the density and porosity of two specimens containing 30% FS and WFS with the control specimen. The morphology of control, A-30 and B-30 is clearly seen in Fig. 10 with different magnification. Based on SEM result, the highest strength belongs to the A-30 with 30% replacement FS which has low porosity and high density and uniformity. On the other side, B -30 has the lowest compressive and flexural strength with high porosity and no adhesion between aggregates. Due to the relatively same size of the FS and WFS particles, this lack of compression and adhesion of the B-30 is likely attributed to the excessive adhesion and overheating of the particles, causing weakness in the ITZ.

But in the case of A-30, the pre-process of foundry sand particles run as filler and reduce the conventional sand fineness modulus, resulting in good aggregation and acceptable compression. The particle structures of the control, A30 and B30 specimens are crystalline, subhedral and filamentous and needle shape, respectively. EDX analysis was also done for control, A30 and B30 species which are given in Table 4.

Table 4. Normalized concentration in weight percent of the element for control, A-30 and B-30 samples

Element	*control*	*A-30*	*B-30*
Oxygen	54.29	78.59	52.09
Magnesium	0.45	0.27	0.29
Aluminum	1.82	0.95	1.32
Silicon	10.75	6.78	7.51
Potassium	0.43	0.22	0.38
Calcium	30.59	12.36	36.61
Iron	1.69	0.84	1.79

The results of fresh and hardened properties and durability of concrete were compared with previous literatures and presented in Table 5.

4. Conclusions

In the present study, comprehensive comparison between FS and WFS as a replacement of fine aggregate was made to investigate the performance of different parameters on concrete. Since the presence of fine-grained sand particles increased the water absorption, increasing the FS and WFS replacement percentage resulted in the decline of both concrete slump and workability.

Table 5. Summary of comparative results

Replacement level of WFS (%)	*Slump*	*Compressive strength*	*Splitting tensile strength*	*Flexural strength*	*UPV*	*Modulus of elasticity*	*Water absorption*	*Water permeability*	*Chloride penetration*	*ASR*	*References*
5-25% (20% compared)	27% ↙	6.8% ↗	27% ↗	7.4% ↗	1.1 %↗	7.6% ↗	1.0 % ↙	---	18.8 %↙	---	Manoharan et al. (2018)
10-40% (20% compared)	“5% ↗	28% ↙	19.5% ↙	---	---	2.1% ↙	16% ↗	---	---	---	Basar and Aksoy (2012)
10-50% (20% compared)	8% ↙	1.7% ↙	6% ↙	0.9% ↙	0.0 %	3.5% ↙	---	---	---	---	Ganapathy et al. (2014)
5-15% (15% compared)	62.5% ↙	14% ↙	14% ↙	---	---	9% ↙	4% ↙	---	---	---	Guney et al. (2010)
5-20 (20% compared)	11% ↙	23.3% ↗	8.2% ↗	---	0.95 % ↗	4.2% ↗	---	---	15% ↙	---	Siddique and Singh (2011)
10-30 (20% compared)	50% ↙	10.5% ↙	28% ↗	8% ↙	2.7% ↙	5.7% ↙	40% ↗	50% ↗	12% ↙	3% ↗	This study

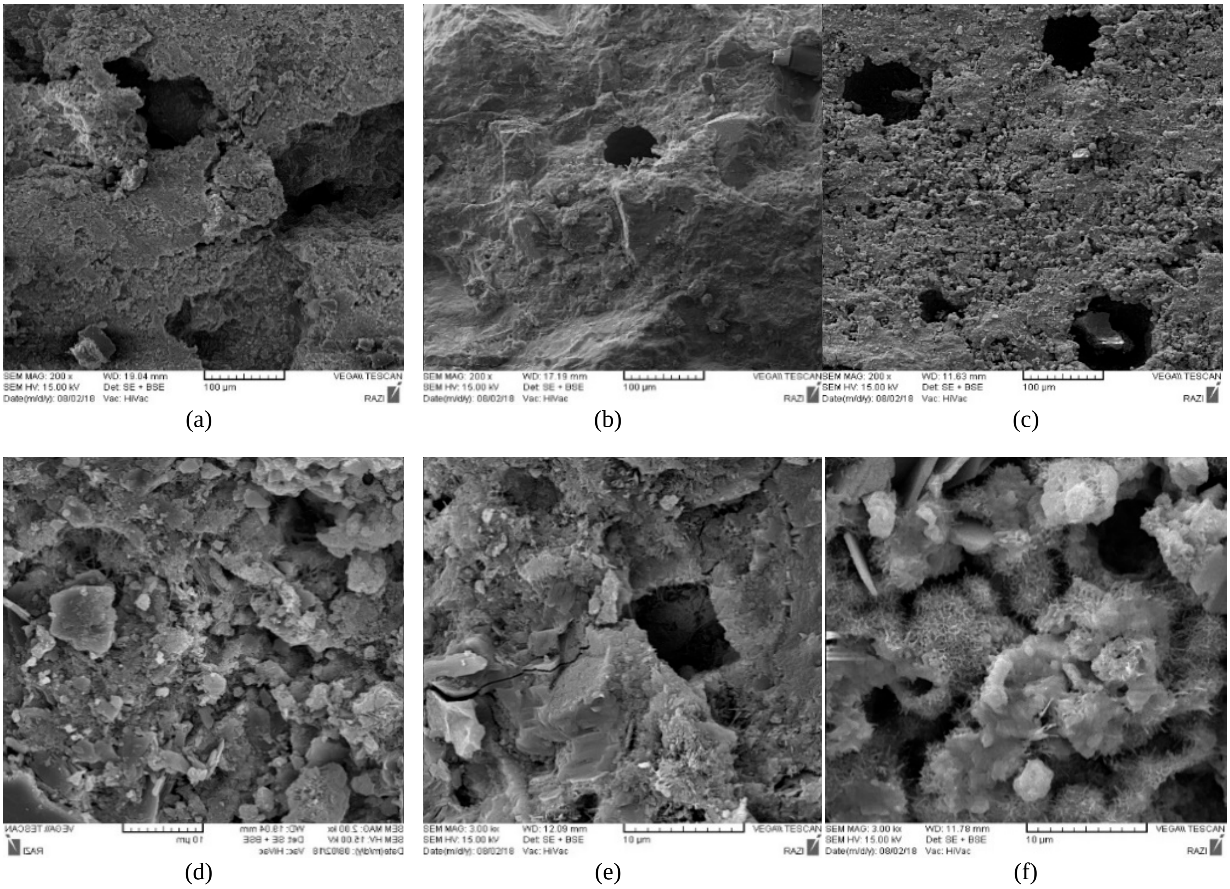


Fig. 10. SEM analysis of concrete samples: (a) control sample with magnification of 100 μm (b) A-30 sample with magnification of 100 μm (c)) B-30 sample with magnification of 100 μm (d) control sample with magnification of 10 μm (e) A-30 sample with magnification of 10 μm (f) B-30 sample with magnification of 10 μm

In terms of grading, both FS and WFS made good combination with conventional sand and reduced the fineness modulus. Compressive and flexural strength rate of the concrete containing FS enhanced with increasing replacement rates. Comparatively, these parameters decreased as the percentage of WFS replacement increased. The reason can be ascribed to the presence of adhesives and overheating of the foundry sand particles. Moreover, and their deformation can reduce the adhesion between the cement and the aggregates, resulting in a decrease in density.

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