Hardened Properties of Self-Compacting Concrete Incorporating Recycled Granite Waste as Fine Aggregate

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Abstract

The present paper investigates the hardened properties of self-compacting concrete by reusing granite waste to replace natural fin aggregates. The reuse of solid wastes as powder or aggregates allows us to produce sustainable concretes that have lower environmental impacts and reduced cost. In this work, granite waste was used as a partial replacement to natural river sand in self-compacting concrete (SCC). For this purpose, four mixtures were designed in which three contained a combination of river sand (RS) and recycled granite (RG) and one only included river sand (RS) as reference mix. Compressive strength, flexural strength, ultrasonic pulse velocity and water absorption were investigated for the hardened SCC at 28 days of hydration. The results showed that the introduction of RG has no effect on compressive strength of SCC. Adding 30% of RG increased flexural strength by 12%. According to ultrasonic pulse velocity results, the use of RG resulted in more compactness and homogeneous SCC. In addition, SCC including RG showed less water absorption.

Keywords: Self-compacting concrete; Recycled granite; Compressive strength; Flexural strength; Water absorption

1 Introduction

Self-compacting concrete (SCC) is an innovative concrete that can flow and fill all the form work without vibration or compaction. Concrete industry consumes large quantities of natural resources especially in the form of aggregates (60-70% by volume of concrete). In the same time, important amount of waste is generated and deposit in landfill, causing serious environmental problems. The use of waste in concrete industry as a partial substitution of cement and aggregates has become an attractive alternative from environmental and economical points of view Boucedra et al., (2020); Shaikh, (2016); Ouldkhaou et al., (2020), Boukhelkhal et al., (2017); Djelloul et al., (2018) and (Sadek et al., 2016). The performance of concretes may be affected by the homogeneities and the characteristics (shape, texture, specific gravity, water absorption) of recycled aggregates Chen et al., (2003); Cabral et al., (2010) and Oliveira et al., (2011),e.g., recycled aggregates have been showed to reduce the workability of concrete because of their high water absorption (Leite et al., 2013). It was reported that the use of coal bottom ash as replacement of sand has no negative effect on the durability and strength of concrete until a substitution level of 50% (Singh & Siddique, 2016). The incorporation of recycled glass was found to increase the slump flow of SCC (Ali & Al-Tersawy, 2012). However, mechanical properties decreased by increasing the recycled glass content.

Granite is a very hard magmatic rock consisting of silicates (quartz, feldspar and mica 75%), alumina (15%) and other metal oxides (10%) (Lemaître, 2012). Granite stone is characterized by its solidity, its impermeability and its variety in textures and colors. This noble stone is widely used for manufacturing ornamental and decorative pieces. However, granite industry generates significant quantities of waste from sawing, shaping and lustration of granite block. This waste is generally rejected which can cause serious environmental problems. The incorporation of this waste into concrete as powder to partially replace cement, or as aggregate by substituting natural aggregates is an interesting solution that can contribute to reduce the environmental impact and the cost production of concretes. This paper examines the possible use of granite waste as recycled fine aggregates in order to produce sustainable self-compacting concrete. Recycled granite was incorporated as a partial replacement to river sand (10%, 20% and 30% by volume).

2 Materials And Methods

2.1 Materials

The cement used for the preparation of different mixtures is blended in cement (CEM II, 42.5). It has specific gravity and fineness of 3.09 g/cm^3 and 380 m²/kg, respectively, the chemical composition of cement is presented in Table 1.These properties meet the Algerian standard NA 442 as well as the European standard EN 197-1.

Table 1: Chemical composition of cement

Element (%)	**Cement**
SiO_2	18.21
CaO	62.54
MgO	2.23
Al_2O_3	3.62
Fe_2O_3	4.18
SO_3	1.85
K_2O	0.42
T_iO_2	0.21
Na_2O	0.07
P_2O_5	0.22
Loss ignition	1.72

As fine aggregate (FA), river sand characterized by granular class of 0/5, and a continuous particles size distribution was used. Recycled granite was used as a partial substitution of river sand (10, 20 and 30%). For coarse aggregate (CA), two classes 3/8 and 8/15 were used. The physical properties of aggregates are given in Table 2. Particles size distribution of fine and coarse aggregates is plotted in Figure 2. The median diameter of RS and RG is 0.51 and 0.8 mm, respectively. The proportion of fine particles is higher in RG (12%) as compared to RS (2%). The super plasticizer used is a polycarboxylates based High-Range Water Reducers (HRWR). It has a specific gravity and pH of 1.07g/cm^3 and 8, respectively. Locally available potable water was used for mixing SCC constituents.

Table 2: Physical properties of aggregates

Properties	**River sand**	**Recycled granite**	**C.A 8/15**	**C.A 3/8**
Absorption (%)	0.84	2.44	3.48	4.85
Density	2.62	2.72	2.58	
Fineness modulus	2.20	2.65	-	-

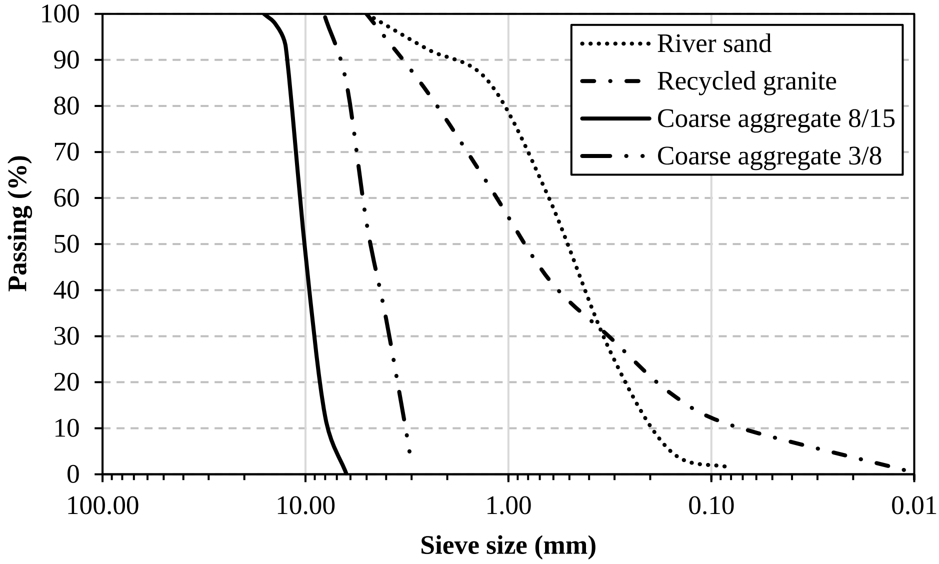

Fig. 1: Particles size distribution of used aggregates

2.2 Mix Proportion Design

To study the effect of RG on some hardened properties of SCC, four mixtures were prepared. The control mix includes only RS as a fine aggregate, whereas in the other mixtures, RS was partially substituted by RG at ratios of 10, 20 and 30%. In all SCC mixtures, the amount of binder, w/b ratio and dosage of SP were kept equal to 470 kg/m^3, 0.4 and 0.8-0.9%, respectively.

Table 3: Mix proportions of SCC

Mixture	w/c	River sand (kg)	Recycled granite (kg)	Cement (kg)	C.A 8/15 (kg)	C.A 3/8 (kg)	SP (%)	SP (kg)	Eau (kg)
100RS	0,4	868.10	-	461.56	534.08	263.25	0.90	4.15	221.89
10RG		781.29	90.12						
20RG		694.49	180.23						
30RG		607.69	270.34				0.80	3.69	222.22

2.3 Testing Procedures

From each concrete mixture prismatic specimens 7×7×28 cm in sizes were cast. After casting, all specimens were covered with plastic sheets for 24 hours. After that, the specimens were unmolded and transferred to conservation in conditioned room at 20 ± 2 ºC and 100% relative humidity until the time of test. For each mix, three specimens were used to determine flexural strength and ultrasonic pulse velocity and six specimens to measure compressive strength at 28 days. These tests were conducted in accordance with European Standard (EN 196-1, 2002). Ultrasonic pulse velocity test was also carried out in agreement with American Standard (ASTM C597-16, 2016).

For water absorption by immersion test, three specimens of 70×70×280 mm in sizes from each mixture were cured in water for 28 days and dried after that at 105 ± 5 °C for 72 hours until, the specimens were weighed M_0 and immediately immersed in water at approximately 21 °C for not less than 48 hours before being weighed M_1 (ASTM C642-97, 1997). The coefficient of water absorption by immersion A_i is given by the following equation:

$$A_i = \left(\frac{M_1 - M_0}{M_0}\right) \times 100 \qquad (1)$$

Where

M_1: saturated mass (g); M_0: dried mass (g); A_i : coefficient of water absorption by immersion (%).

3 Results And Discussion

3.1 Compressive strength

The influence of recycled granite aggregates on 28-days compressive strength of SCC is shown in Figure 2. Compressive strength values are in the range of 38.03 and 40.20 MPa. As can be seen in this figure, the compressive strength is slightly decreased by increasing RG content. The mixtures contain 20% and 30% of RG developed a similar compressive strength as compared to reference mix (about 40 MPa) at 28 days. The reason behind this increment is the high percentage of fine particles in RG, which improved the compactness and therefore the resistance of SCC. In their work, Gupta & Vyes (2018) reported that the substitution of fine natural aggregate in cement mortar by waste granite powder improved the mechanical properties such as compressive strength. The use of crushed brick as a partial replacement of sand was found to decrease the compressive strength of concretes (Debieb & Kenai, 2008).

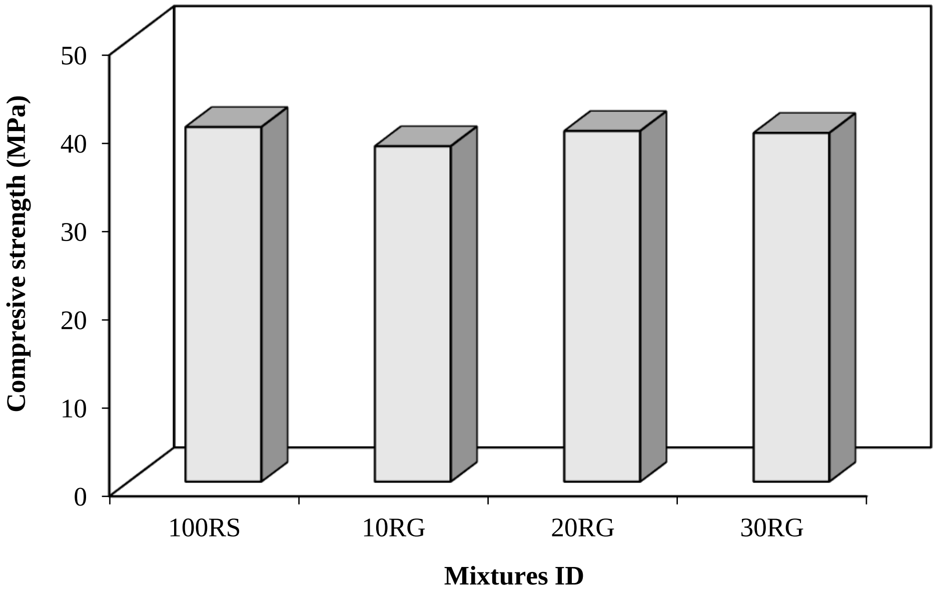

Fig. 2: Variation of 28 days-compressive strength vs RG content

3.2 Flexural strength

Figure 3 depicts the variation of flexural strength as a function of the amount of RG. The values of flexural strength are in the range of 4.36 – 5.64 MPa. The introduction of 10% and 20% of RG slightly decreased the flexural strength; however, a substitution level of 30% resulted in higher flexural strength in comparison to control mixture. This may be attributed to the irregularities in shape and texture for granite particles in comparison to river sand that is characterized by smooth and spherical particles.

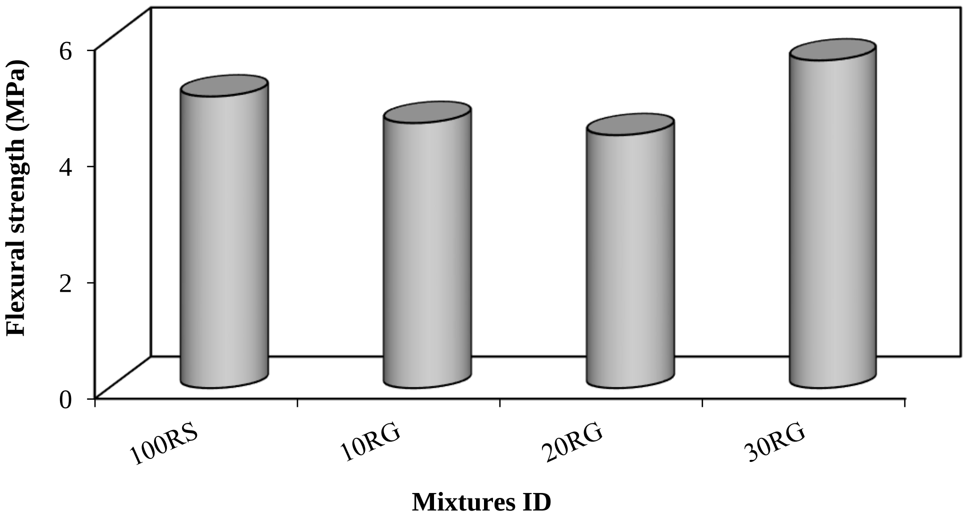

Fig. 3: Evolution of flexural strength of all SCC mixtures

3.3 Ultrasonic Pulse Velocity

The results of ultrasonic pulse velocity (UPV) test for various SCC mixtures are presented in Figure 4. UPV could be used to examine nondestructively the internal structure of concrete. The values of UPV are in the range of 4285–4405 m/s. The results revealed that UPV increased by increasing RG content. It was observed that 30RG mix has the highest value of UPV. The reason behind the increase in UPV could be due to the predominance of fine particles (<100 µm) in recycled granite in comparison to river sand as can be observed in figure 1.Whitehurst [29] classified the concretes according to their quality as following: excellent, good, moderate, bad and very bad for an UPV values above 4500 m/s, 3500 / 4500 m/s,3000 / 3500 m/s, 2000 / 3000 m/s, and lower or equal to 2000 m/s, respectively. This classification indicated that all the tested mixtures have a good quality.

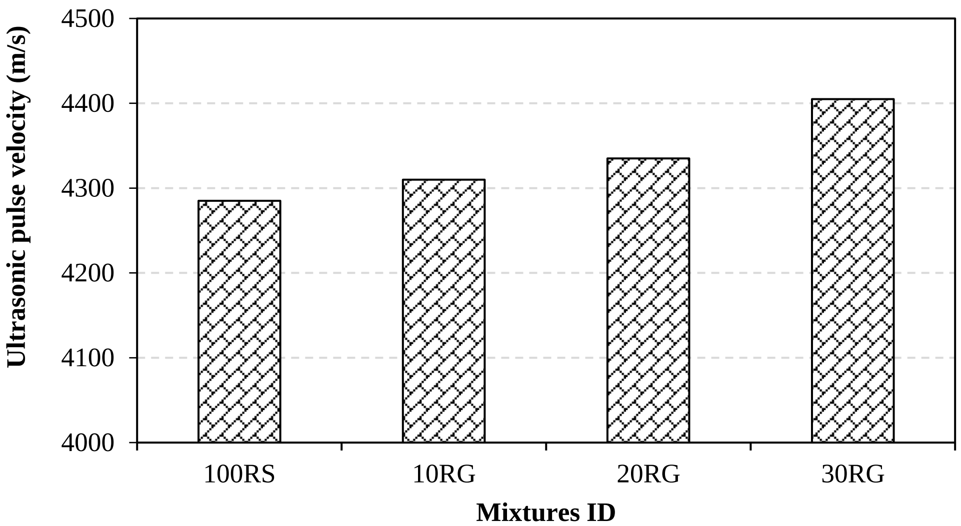

Fig. 4: Variation of ultrasonic pulse velocity of all mixtures

3.4 Water Absorption

The results of water absorption test are illustrated, in Figure 4. The values of water absorbed by immersion are in the range of 3.09 - 4.27 %. The results showed that water absorption decreased by increasing the amount of RG. Water absorption coefficient of mixtures with RG replacements of 10%, 20% and 30% is decreased by about 5%, 20% and 28% in comparison with control mixture, respectively. This result may be attributed to the filling effect of recycled granite in which fine particles filled the voids and contributed to better packing of mixtures with RG.

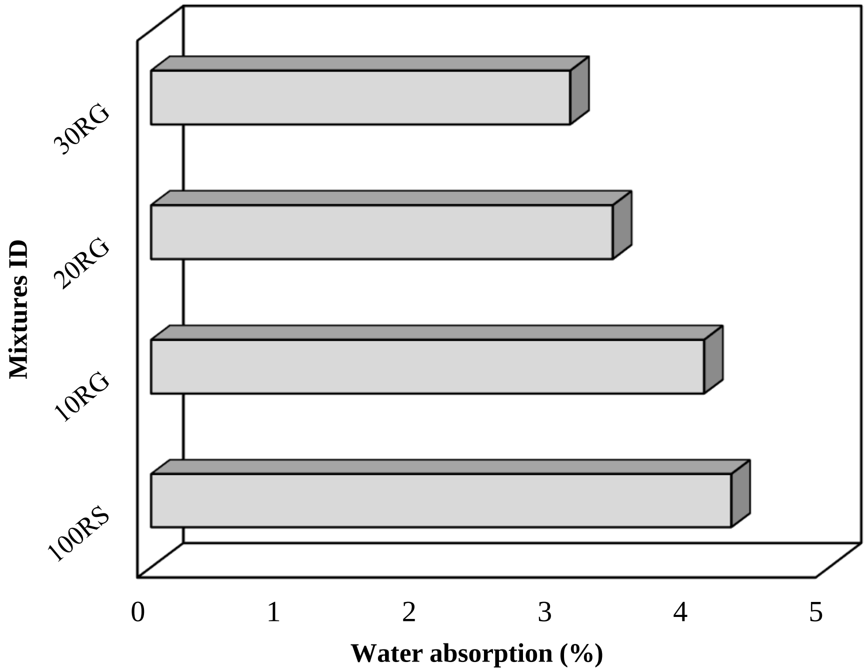

Fig. 5: Variation of water absorption of all mixtures

4 Conclusion

Based on the experimental results and evaluation of SCC with RG, the following conclusions can be drawn:

- All SCC mixtures have developed similar compressive strengths. SCC mixture included 30% RG exhibited the highest flexural strength.
- Mixtures containing recycled granite showed superiors ultrasonic pulse velocity values in comparison to control mix. This indicated the positive effect of RG in improving the density and homogeneities of SCC mixtures. Waster absorption of self-compacting concrete can be reduced by using recycled granite.
- Recycled granite waste may be successfully used as fine aggregate to produce green and low cost self-compacting concrete.

From the above conclusions, an optimum percentage of recycled granite of 30% can be recommended to manufacture sustainable self-compacting concrete.

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