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Workability, mechanical properties and durability of self-compacting concrete containing red mud, and granite and marble waste powder

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ABSTRACT: To maintain the uniformity and cohesiveness of self-compacting concrete (SCC), sustainable use of waste powder like waste marble powder (WMP) and waste granite powder (WGP) as filler replacement, and red mud (RM) as a cement replacement has been investigated. Also, the mechanical properties and durability of SCC containing WMP, WGP, and RM were measured by compressive strength (CS), splitting tensile strength (TS), water absorption (WA), ultrasonic pulse velocity (UPV), and acid sulfuric attack tests in the laboratory. When the total amount of filler material (limestone powder (LP)) was replaced by WMP or WGP, the workability, the mechanical properties, and the durability of SCC did not significantly change. Using RM up to 2.5% cement replacement improved the mechanical properties and durability of SCC. However, the higher content of RM in SCC mixes could adversely affect the mechanical properties and durability of SCC. The application of stone waste powder like WMP, WGP, and industrial by-products like RM could lead to a greener and more sustainable SCC mix without sacrificing the SCC's mechanical properties and its durability.

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1- Introduction

To realize the concept of sustainable development, the idea of reusing waste in concrete production has become popular. Chandru et al. [1] claimed that adding certain amounts of powdered residues to concrete increases its performance, mechanical properties and durability. Recently, the effect of various types of industrial wastes with pozzolanic properties, such as blast furnace slag, fly ash, metakaolin, and silica fume, on the properties of various types of concrete has been extensively studied. In recent years, WMP and WGP have also been widely used as additives or fine-grained alternatives in the production of SCC. Reuse of such waste powder and industrial by-products in concrete production can be considered environmentally vital because it reduces cement consumption and the corresponded CO_2 production.

RM, a material with fine grains and high alkalinity (pH: 10-12), is known as a by-product of aluminum plants [2]. According to the recent findings, global production of RM reaches 117 million tons per year. The chemical composition of RM can vary depending on the bauxite source as well as the aluminum production procedure. In this research, RM was collected from the surrounding area of the Jajarm alumina factory. Hematite (Fe_2O_3), calcite ($CaCO_3$) and anatase (TiO_2) minerals were identified in the raw sample of RM. Also, the oxides in RM based on the results of XRF analysis are: CaO, SiO_2, Fe_2O_3, Al_2O_3, TiO_2, Na_2O, MgO, and K_2O. This material has a specific weight of about 5400 kg/m^3 and the specific surface area of its particles is equal to 26.75 m^2/gr [2, 3]. According to a sustainable point of view and in order to avoid environmental pollution, the use of by-products such as RM in the production of building materials such as brick, ceramic and concrete has been considered recently. The physical and chemical properties of RM make it an effective material as an alternative to cement in concrete and use in the construction industry. For example, the high pH of RM increases the compatibility between concrete and steel rebars in concrete structures [9]. Also, fine grains of RM could provide a denser concrete matrix and improve the mechanical properties of concrete [4].

2- Methodology

Thirteen SCC mixes were produced according to EFNARC [5] standard, using RM as a cement substitute in 2.5, 5, 7.5 and 10% percentages. Also, three different filler materials (LP, WMP, and WGP) were used in these mixes. The values of the different SCC's components are shown in Table 1.

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Table 1. Different components of SCC mixes

	W[1]	C[2]	RM[3]	LP[4]	WGP[5]	WMP[6]	S[7]	CA[8]	SP[9]
CRL	183.5	400	0	100	0	0	975	525	7
A1	183.5	390	10	100	0	0	975	525	7
A2	183.5	380	20	100	0	0	975	525	7
A3	183.5	370	30	100	0	0	975	525	7
A4	183.5	360	40	100	0	0	975	525	7
B1	183.5	390	10	0	100	0	975	525	7
B2	183.5	380	20	0	100	0	975	525	7
B3	183.5	370	30	0	100	0	975	525	7
B4	183.5	360	40	0	100	0	975	525	7
C1	183.5	390	10	0	0	100	975	525	7
C2	183.5	380	20	0	0	100	975	525	7
C3	183.5	370	30	0	0	100	975	525	7
C4	183.5	360	40	0	0	100	975	525	7

[1]water (kg/m^3), [2]cement (kg/m^3), [3]red mud (kg/m^3), [4]limestone powder (kg/m^3), [5]waste granite powder (kg/m^3), [6]waste marble powder (kg/m^3), [7]sand (kg/m^3), [8]coarse aggregate (kg/m^3), [9]superplasticizer (kg/m^3).

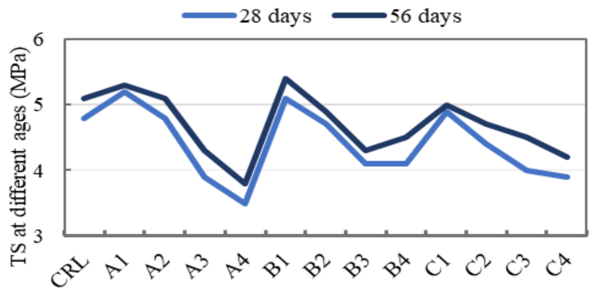

Fig. 2. Phase velocity dispersion curves for a steel pipe with outer diameter of 220 mm and wall thickness of 4.8 mm

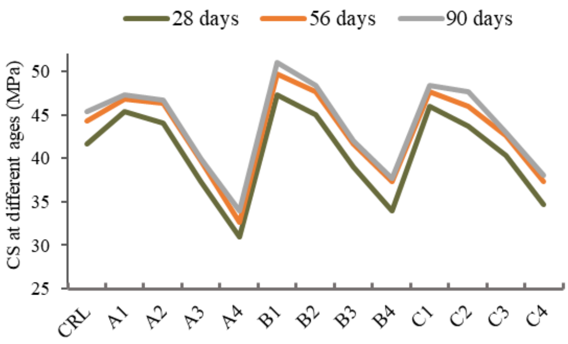

Fig. 1. The CS of SCC samples at different ages

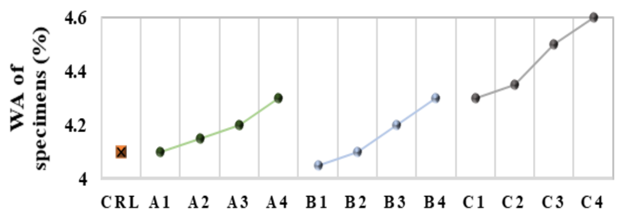

Fig. 3. the WA of different SCC samples at 28 days

3- Results and Discussion

3- 1- Workability

In this study, slump flow and T500 time tests were performed to evaluate the flowability and cohesiveness of fresh SCC mixes. Based on the results, it is observed that the values of slump flow for all the mixes are ranged between 580 and 700 mm. By increasing RM replacement levels, the slump flow and T500 time decreased and increased, respectively. Similar findings have been reported by Ahmadi and Shekarchi [6]. The physical properties of WMP and WGP such as size, shape, and texture affect the flowability of SCC. LP and WGP, due to their irregular shape and fineness, increase the contact between the aggregates and the cement paste, and as a result, increase the viscosity of SCC [7].

3- 2- Mechanical properties

Measurement of mechanical properties of SCC mixes has been performed by CS test (at three ages) and TS test (at two ages) as can be seen in Figure 2 and Figure 3, respectively. The low content of RM replacement (2.5%) increased the CS of the samples. In fact, the filler effect of RM particles, especially at early ages increased the density of the SCC matrix [8].

Also, the results demonstrate a more desirable effect of WGP and WMP incorporation on the CS of SCC specimens compared to the specimens containing LP. The highest TS values corresponded to the samples with 2.5% RM as cement replacement. Also, increasing RM content up to 5% does not change the TS of the specimens. As mentioned before [9], the low content of RM, due to the filling effect can have a positive influence on the TS of the specimens.

3- 3- Durability

As can be seen in Figure 4, the use of WGP as a replacement for LP has no adverse effect on the WA results. However, WMP incorporation in SCC could increase the WA of the samples. In addition, by increasing the content of RM the WA of the samples increases. Figure 5 shows that the control sample has the highest durability with 9% reduction in CS. While the sample containing 10% RM as cement replacement and WGP as a filler replacement shows the lowest CS after 28 days under sulfuric acid attack. This phenomenon is related to the porous nature and large surface area of RM particles, which raises the porosity of concrete matrix [10].

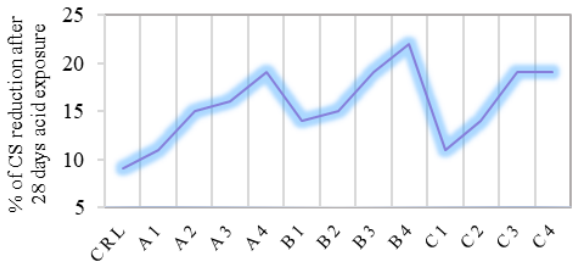

Fig. 4. The percentage of CS reduction after 28 days at sulfuric acid exposure

4- Conclusion

In the present study, the optimal percentage of RM as cement replacement in SCC mixes incorporating WMP and WGP as filler material replacement was investigated. Workability, the mechanical properties and durability of SCC were measured. The use of waste powder such as WMP and WGP as well as RM increases the need for superplasticizers in the production of SCC. On the other hand, replacing 2.5% of cement with RM leads to an increase in the mechanical properties of SC. The durability of SCC does not change significantly with restricted amount of RM, WMP, and WGP.

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