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Improving corrosion resistance of steel rebars in concrete with marble and granite waste dust as partial cement replacement

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HIGHLIGHTS

- Marble and granite dust (MGD) incorporation did not significantly decrease concrete strength.
- Replacing cement by an adequate MGD content improved corrosion resistance.
- Using 20% MGD as cement replacement showed higher values of OCP and EIS.
- Water absorption should not be the only parameter for corrosion assessment in reinforced concrete.

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ABSTRACT

In this research, the effect of marble and granite waste dust (MGWD) as partial cement replacement (up to 20%) on the mechanical and corrosion behaviour of concrete specimens was investigated. Water cured specimens were kept in a 3.5% by weight of NaCl solution for 92 days. Uniaxial compression and water absorption tests, open circuit potential (OCP), electrochemical impedance spectroscopy (EIS) and Scanning Electron Microscopy (SEM) analysis were conducted. The compressive strength test results showed insignificant negative effect from using MGWD. OCP and EIS measurements revealed that specimens with 20% cement replacement have higher potentials and corrosion resistance than all the others.

1. Introduction

In recent years, the production of waste materials has increased due to the growth of industrial activities around the world. The high consumption of natural resources has led to greater environmental degradation. On the other hand, most of these waste materials have negative effects on the environment. Concrete is the most widely used construction material around the world [1]. Therefore, recycling and reusing these industrial wastes in concrete production could be considered an effective way to reduce the environmental impacts of these polluting materials. In addition, using these waste materials in concrete production has the potential to make significant environmental and economic contributions.

In past decades, a variety of waste materials, such as marble and granite waste dust (MGWD), tire rubbers, metallic based furnace slag, silica fume, fly ash and lime stone, have been widely used in concrete production [2–7]. Previous researches have shown that using these waste materials in concrete production can improve its properties, namely its compressive strength, workability and durability [3–8]. MGWDs is considered a by-product obtained during marble and granite boulders processing, which includes shaping, sawing, cutting and polishing for different applications. The marble and granite industry generates large amounts of MGWD during the production process, specifically the cutting process of marble and granite rocks. The produced waste dust could be used in different applications, for instance as filler, cement replacement or modifying materials in concrete production [2,9–34]. Ergün's [18]

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investigation showed that using 5.0% and 7.5% of waste marble dust as partial cement replacement leads to an increase in compressive strength. Shirule et al. [19] reported that the compressive and splitting tensile strength of concrete specimens increases with the use of waste marble dust up to 10% as partial cement replacement. Aliabdo et al. [20] studied the effect of marble waste dust as partial cement or sand replacement at 5%, 7.5%, 10% and 15% by mass. The test results showed that using marble waste dust as partial cement or sand replacement improves the mechanical properties of concrete, mainly due to a filler effect. Demirel [21] reported that the reduction of porosity was associated with the filler effect of marble dust on cement hydration. Khodabakhshian et al. [22] also reported that the strength and durability of concrete containing waste marble dust as partial cement replacement tend to decline for replacement ratios over 10% but satisfactory results were obtained below that level of replacement. According to Abukersh and Fairfield [23], using granite dust as partial cement replacement at 20–50% significantly reduces the compressive strength of concrete specimens while the effect on the tensile strength is negligible. It was also reported that using granite sludge as partial cement replacement (up to 7.5%) increases the durability of concrete mixes without affecting their strength and workability [24]. Arivumangai and Felixkala [25] also reported that using 25% granite dust as addition has a positive effect on the strength and durability of concrete mixes.

Since the production of cement, the primary component of concrete, is one of the main causes of air pollution due namely to CO_2 emissions, the use of MGWD as partial replacement of cement has the potential to significantly reduce these emissions as a result of lower cement production. Previous researches have been shown that replacing 10% of cement used in concrete production with marble dust would reduce the CO_2 emissions by 12% [18,35]. According to the data collected in 2014, replacing 10% of cement with marble dust would reduce the world CO_2 emissions from 3.95 to 3.55 billion tones [1]. Therefore, using MGWD as replacement of cement could introduce a new technology and material that reduces the use of cement in concrete production.

There is an important durability problems in reinforced concrete (RC) members and structures, the corrosion of steel rebars embedded in them, which can reduce their service life due to the penetration of harmful chemicals and ions into a highly permeable concrete matrix, as shown by previous researches [36]. In fact, damage due to the corrosion of steel rebars has been identified as the primary cause of significant number of structural failures over the past century [37]. This phenomenon can be particularly serious in environments with chloride penetration and carbonation risks. Steel rebars embedded in concrete are normally in a passive state due to the high alkalinity of the pore solution of concrete, which provides an ideal environment that can protect the steel rebars from corrosion. The alkalinity mainly depends on the type of the cement used in concrete production. However, alkalinity is important but is not the only aspect governing reinforcement corrosion initiation and (later on) serious corrosion development [38]. In addition the corrosion process of steel rebar embedded in concrete also depends on the electrochemical potential of the steel and the existence of voids at the interface between steel rebar and concrete, as well as the presence of aggressive ions such as chloride and sulphate [36,39].

As there is a lack of information on the effect of MGWD, as partial replacement of cement, on the corrosion behaviour of RC members, the aim of this research is to evaluate the influence of these two waste materials on the mechanical and corrosion behaviour of reinforcement concrete. Different proportion of MGWD were used as cement replacement in order to produce several concrete mixes and, after preparation of RC specimens, the corrosion performance of the steel rebars was evaluated for 92 days of exposure to a 3.5% NaCl solution using potential measurements as well as impedance spectroscopy.

2. Experimental program

2.1. Materials

Concrete in this study is produced under controlled conditions at room temperature using Portland cement, water, fine and coarse aggregates. The cement used was manufactured by Zaveh Cement Company complying with the Type II Portland cement requirements, as stated in ASTM C150. The chemical composition of cement is presented in Table 1. The coarse aggregate used is crushed limestone and the fine aggregate is river sand acquired locally.

The range of the coarse and fine aggregate is mostly between 0.3–10 mm and 5–20 mm, respectively. The particle size distributions of both the fine and coarse aggregate are shown in Fig. 1. MGWD was obtained from a local marble and granite processing factory. The granite and marble slurry were first completely dried in an oven to produce dust before replacing part of the cement, in order to control the water/binder ratio. The specific gravity of the marble and granite waste dust used in this study is 2.50 and 2.61, respectively. The chemical composition of MGWD and its particle size distribution are given in Table 1 and shown in Fig. 2,

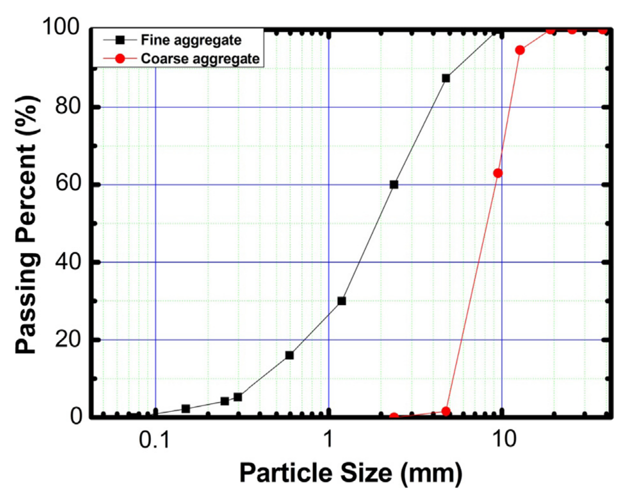

Fig. 1. Particle size distribution of fine and coarse aggregates.

Table 1
Chemical composition of the granite and marble dusts.

Material	Chemical composition (%)									
	SiO_2	CaO	Al_2O_3	Fe_2O_3	MgO	SO_3	K_2O	Na_2O	CL	LOI
Cement (Type II)	21.4	63.6	4.5	3.5	2.1	2.5	0.5	0.5	0.07	1.9
Granite	70.2	3.7	15.8	1.9	0.6	0.6	3.7	2.1	0.02	1.6
Marble	1.3	85.3	0.6	0.4	0.6	0.3	0.1	0.1	0.02	2.4