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# Behavior of self-compacting concrete made with marble and tile wastes exposed to external sulfate attack

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## HIGHLIGHTS

- Effect of marbles wastes and tiles factories on the behavior of SCC under external sulfate attack.
- The behavior of SCC with Waste is evaluated by mass variation and dynamic elastic modulus.
- The resistance of SCC with Waste to external sulfate attack is better than the ordinary vibrated concrete.

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## ABSTRACT

The evaluation of the incorporation of industrials wastes from marbles and tiles factories in the formulation of self-compacting concrete (SCC) usually requires the understanding of their effects on the rheological behavior SCC in the fresh state and on the mechanical performances of these concretes in the hardened state. But, for a long-term behavior, it is imperative to study of their influence on the durability of these types of concrete against chemical degradations that may exist through the waters or aggressive soils. In the present work, samples of different types of self-compacting concretes incorporating wastes from marbles, marble tiles and gravel tiles (SCCWs) were exposed to different forms of external sulfate attack. This study compares the behaviors of these samples to those of a reference self-compacting concrete (SCCR) made with limestone filler SCCR and an ordinary vibrated concrete (OVC).

The samples of different concretes were immersed in seawater, in a sodium sulfate solution (liquid form of sulfate attack) and potable water chosen as a reference. Other samples of these concretes were also placed in a vehicle battery charging hall to ensure their exposure to gaseous form in sulfate through the release of sulfur dioxide gas in the hall.

To evaluate the behavior of the concrete samples against different forms of external sulfate attack, the change in their masses was monitored as well as the determination of their dynamic elastic modulus by the ultrasonic test was performed. Multiple measurements of these properties were taken for each 60 days of exposure and up to twenty months period. The results of the carried out testing showed that SCCWs have good resistance to external sulfate attack, even in severe exposure to the sulfate with sodium sulfate solution, and especially for the self-compacting concrete made with marble waste.



## 1. Introduction

The self-compacting concrete (SCC) is used even in the most complex shapes and can pass through the densest reinforcement without requiring the means of vibration that is to say, it is recommended concrete to use for works of the great projects (buildings, bridges, ...). The structures of these projects require high mechanical performances and durability of the concrete used.

The study of incorporation of Tunisian wastes (W1: Waste of marble, W2: Waste of marble tile and W3: Waste of gravel tile) in the SCC, were published in a previous research paper [1]. These wastes were identified and their physical and chemical characteristics were exposed in [1]. Moreover, their particle size distributions and their compactness are given also in the same previous paper. This latter was aimed to the valuation of these industrial wastes dumped in huge quantities in order to find solutions to environmental problems that they pose and also reduce the cost of the cubic meter unit (1 $m^3$) of SCC.

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This valuation requires not only a good formulation of SCC incorporating these industrial wastes (SCCWs) but also to ensure rheological behaviors in fresh state and to obtain sufficient mechanical performances of these SCCWs in the hardened state.

To complete this evaluation, we must also consider the long-term durability of these concretes as the exposure to the external sulfate attack, which is the most severe. Indeed, this attack presents a chemical effect on concrete and has negative impacts on its durability. The sulfate ions can have several origins: natural, organic or come from industrial pollution [2–3].

Hence, soils containing gypsum ($CaSO_4{\cdot}2H_2O$) and hence sulfate, with high concentrations (greater than 5%) can cause degradation of concrete. Similarly clay soils may contain pyrites ($FeS_2$) that oxidize to sulfates in contact with air and moisture to form sulfuric acid ($H_2SO_4$). This sulfuric acid strongly attack the concrete slabs that are founded on these soils and causes corrosion and cracking of the slabs and therefore structures stability problems [2].

Furthermore, and as biological origin, the decomposition of organic materials in silos and storage tanks as well as in sanitation sewage can cause the formation of hydrogen sulfide ($H_2S$: very toxic gas). In concretes, anaerobic bacteria convert the sulfate $SO_4^{2-}$ and they produce $H_2S$ that is released to the surface. On the surface, the $H_2S$ is then decomposed in the form of sulfur by aerobic bacteria. The sulfur is eventually turned into $H_2SO_4$, a strong acid and a very corrosive to concrete) [2,3].

Moreover, Chemical industrial pollution, such as battery manufacturing plants for vehicles, may cause the spread in the air of sulfur dioxide ($SO_2$) following the dissolution of sulfuric acid [4]. This gas causes loss of mechanical performance of concrete.

In this context, this present study was initiated for a better understanding of the durability of SCCWs incorporating wastes fillers from marbles and tiles factories. The fresh and hardened states properties of these SCCWs were already analyzed in the previous paper [1]. Then, the durability results would be compared to those of a reference of two types of concrete, self-compacting concrete made using limestone filler (SCCR) and ordinary vibrated concrete (OVC).

Since the mid 19th century, L. Vicat [5] studied the chemical deterioration of the OVC caused by the presence of sulfate ions in the seawater. He showed that the $MgCl_2$ and $MgSO_4$ magnesium salts are the most aggressive for concrete. Many other studies have been made on the durability of OVC. For SCC which differs from OVC by the existence of some types of additions increasing its volume of paste to ensure its fluidity at fresh state, there are several studies of the durability of this concrete under the effect of external sulfate attack. M.R. Khelifa [4] has studied the durability of concrete exposed of the external sulfate attack. The SCC samples were immersed in a solution dosed with 5% $Na_2SO_4$ and subject for six months to a full immersion or different cycles of immersion/drying. The author observed that sample's degradation by external sulfate attack depends on the type of cement used and also Water/Cement ratio. The experimental results also showed that the damage was more pronounced in the case of immersion/drying cycles than for full immersion of the samples. Y. Senhadji et al. [6] studied the sulfate attack of samples of which the cement is partially substituted by proportions of limestone filler between 10% and 30%. The test results showed that the samples that have highest replacement levels of limestone filler were more susceptible to sulfate attack. S. Boualleg and M. Bencheikh [7] have exposed test samples of paste or mortar cement (pouzzolannique or limestone) to chemical treatments, namely, ammonium nitrate, magnesium sulfate, sodium sulfate, sodium chloride and sulfuric acid for a period of three months. They found that the durability performance of pastes and mortars with pozzolan cement were better than those prepared with limestone.

K. Behfarnia and O. Farshadfar [8] studied the effects of various pozzolanic binders such as fumed silica, zeolite and metakaoline on SCC's durability in a magnesium sulfate environment. The results of their tests showed that SCCs with metakaoline and zeolite are more durable than those with silica fume. H. Siad et al. [9] studied the effects of mineral additives (limestone filler, fly ash and natural pozzolan) on the behavior of SCCs immersed in a sodium sulfate solution. According to their findings, natural pozzolan is the most beneficial additive for an SCC in a rich sodium sulfate environment.

R. Deepthy and M P. Mathews [10] studied the durability of SCC based fly ash as an additive through the immersion of samples in solutions with different proportions of sulfate ions and chloride. The experimental results show that the compressive strengths of immersed samples decreases with increasing concentration of sulfate and chloride solutions. Similarly, there are weight losses of these samples and they're proportional to the duration of exposure.

Recently, Boudali S. et al. [11] have studied the attack of sulfate of the mixtures incorporating recycled concrete aggregates and fines; their results show that they have a better behavior for sulfate attack than those with natural aggregates and natural pozzolana.

In this paper, three different forms of external sulfate attacks testing of concretes samples prepared in advance were realized. The first type of these tests was to immerse the samples in seawater, while for the second type, the samples were immersed in a sodium sulfate solution (5% $Na_2SO_4$), and for the third type, the samples were exposed to the polluted environment of sulfur dioxide ($SO_2$) from a battery charging hall. The evaluation of the behavior of SCCWs exposure to external sulfate attack is monitored through tracking the change in mass of the samples and the change in the dynamic elastic modulus determined by the ultrasonic test. Parallel to these external sulfate attack tests, a reference test was also completed by immersing the same types of samples in potable water at a temperature 20 ± 2 °C to facilitate the interpretation of results.

## 2. Experimental procedures

### 2.1. Materials

The major materials that were used in this research are:

- A Portland cement CEM I 42.5 produced by the factory CAT – Jebel Jeloud in Tunis according to standard NT47.30 [12].
- A gravel provided by the crushing quarry of Jebel Ressas in Tunis with a maximum nominal size 16 mm and alluvial silica sand from a the quarry Borj Hfaiedh with a maximum size of 4 mm. These concretes aggregates characteristics are defined in the standard NT 21.30 [13] and their specifications are the same as in the previous paper [1].
- The additives used are:
  - The limestone filler (LF) produced by the group "Omya" that is chosen to make the control or Reference Self-Compacting Concrete (SCCR).
  - The industrial wastes fillers provided by two Tunisian factories of marble and tiles. These are classed of three types (W1: Waste of marble, W2: Waste of marble tile and W3: Waste of gravel tile).

Their chemical characteristics are presented in Table 1.

- A superplasticizer, high water reducer polyvalent (SIKA VISCOCRETE TEMPO 12).