Study of the Influence of the Aggressive Environment on the Behavior of Reactive Powder Concrete

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Reactive Powder Concrete, Compression, Flexion, Durability, Aggressive environments.

Abstract
Reactive Powder Concrete (RPC) currently represents the family of cementitious matrix materials with properties the most exceptional mechanics and durability. This study aims to investigate the physico-mechanical properties, and the durability in a sulphated environment of a reactive powder concrete using materials available in our region, we have integrated materials rich in silica (slag, silica fume and crushed quartz) in Portland cement with 15, 23 and 25%, respectively. After The remove of the specimens from the mold and place the RPC in the curing box under steam curing conditions of 90 °C for 72h, let them cool naturally for 24 h, the test pieces are immersed in water at 20 °C, this process is repeated in flexion and compression. From this study we can make the following conclusions: The incorporation of additions increases the compressive and flexural tensile strengths, which gives an improvement in the compactness of the mixtures by the pozzolanic effect of these last, by removing the particle size phase in the RPC and the affluence of dune sand (southern Algeria) and slag (industrial waste from the iron ore blast furnace), because Na2SO4 has a major effect on the compressive strength notably for non-fibrous formulations. NaOH improve the compressive strength for all formulation.

1. Introduction
Many researchers have studied various aspects of RPC, starting with Richard and Cherezy (1995), Jörg Jungwirth (2002), Collepardi, (2003), Gao, (2005), Brandt, (2008), Tafraoui, (2009), Hannawayya, (2010), Wille, (2011), and Chadli et al. (2018, 2020) [1, 2, 3, 4, 5, 6, 7, 8, 9, 10]. However, the proper selection of materials, their production process and their proportionately influences the mechanical performance and rheological properties of RPC.

The term reactive powder concrete (RPC) has been used to describe a reinforced fiber, super-plasticity, silica fume - cement mixture with very low water-cement ratio (w / c) characterized by the presence of very fine quartz sand (0.15-0.40 mm) instead of the ordinary aggregate Al-Obaidi et al. (2020) [11].

The absence of common aggregate was considered by the inventors to be a key portion of the micro-structure and performance of RPC. In fact, it is not concrete because there is no coarse aggregate in the cement mix, to reduce the heterogeneity between the cement matrix and the aggregate. The persuade of the type of silica fume and Portland cement on the performance of reactive powdered concrete mixtures (RPC) was investigated, only using CaO - Portland cement free, in combination with a brand of white silica fume. The w / c ratio was as low as 0.20, and the compressive strength was as high as 180 MPa at 3 days after heat treatment at 150 °C. However, a strong reduction in early compressive force was recorded. The replacement of white silica vapors with other types of silica vapors (gray or dark), as well as the substitution of other Portland cements with Portland cement without CaO resulted in an increase in w / c and a reduction in strength compressive (110-160 MPa). However, with these mixtures there was no reduction in compressive force early on Junquan et al. (2020) [12].

The compressive load and the bending load of reactive powder concrete and RPC reinforced with corrugated steel fibers and whip fibers at the ends were investigated. The composition of RPC, which has been optimized by trial and by varying different ingredients, was used with a water cement ratio of 0.20. Corrugated steel fibers were used 0.4 mm dia. and 13mm long whip fibers at the 12mm long ends were incorporated into the concrete Zhidong and Fizhong. (2018) [13].

Concrete exhibits high ductility with typical energy absorption values approaching those reserved for metals Faiz Uddin et al. (2020) [14]. Due to its durability and exceptional mechanical properties, UHPC has been widely used in thin concrete structure in China, such as steel bridge pavement, wet joint, small prefabricated components Ingrid and Rein (2020) [15]. However, due to the extremely low water-binder ratio of around 0.2 and the generally high binder content of 800 to 1200 kg / m³ in UHPC, the shrinkage of UHPC is greater than that of concrete, conventional high performance (HPC) Yiwei Liu et al. (2020) [16].

RPC also has extraordinary durability parameters such as abrasion resistance and reduced permeability to chloride. These durability improvements reduce maintenance costs and extend the life of a structure. RPC is a material whose potential has not yet been identified. It should therefore be used to contain the structures of nuclear power plants and protect military installations Caruso et al. (2020) [17].

The durability of concrete has become increasingly important in recent years, as there has been a push to extend the life expectancy of existing and planned infrastructure. Many of the improvements that have been found to change the behavior of concrete at the material level have been incorporated into the next generation of concrete. Although much of the emphasis on this type of concrete has centered on mechanical and / or structural behaviors, in near and far terms, durability behaviors are inexorably linked to mechanical behaviors. In order to effectively use this new generation of concrete, components and structures will need to be optimized to fully utilize the mechanical and durability properties without any unnecessary waste of materials SujaH et al. [18]. The aim of this work is to study certain mechanical, physical properties of reactive powder concrete (RPC) including compression,
Steel fibers (SF) The fibers used are wire-drawn steel products, made in Algeria by the company GRANITEX located in Oued-Smar (Algeria) of the MEDAFAC type, in the form of wavy rods these fibers have a length of 50 mm and a thickness of 0.6 ± 0.09 mm its geometry and its technical characteristics allow it to offer concrete high toughness. MEDAFAC steel fibers are packaged in 40 Kg cardboard boxes.

Figure 2. Steel fibers

The adjuvant: (SP) (NFP 18-103)

The adjuvant used in our study is a new generation “MEDAFLOW 30” type high water-reducing superplasticizer. It is a solution of Polycarboxylates, manufactured in Algeria by the company GRANITEX located in Oued-Smar (Algeria).

The mixing water (W) the mixing water used in our study is drinking water “tap water” supplied to the civil engineering laboratory at the University of Mohamed Khider Biskra (Algeria).

2.2. Mixing and curing process

The molds of the concrete test pieces of dimension 40 × 40 × 160 mm are prepared. The molds are then covered with oil before pouring to facilitate demoulding of the concrete after 24 hours. Each RPC formula is poured into 1 mold (three test specimens). All RPCs are prepared in a mortar mixer.

Obtaining the desired mixing design for the production of RPC requires a specially designed mixing procedure, as the properties of RPCs depend not only on the order in which the ingredients are added in the mixture, but also on the speed and the duration of the mixture. The following mixing procedure was therefore used:

The dry components consisting of silica fume (SF), Portland cement, quartz and ground slag were mixed slowly for about 7 min. The superplasticizer (SP) was added to the water and the entire mixture of quartz and ground slag were mixed slowly for about 7 min. The mixture was then stirred at a gradually increasing speed for about 10 min. add the metallic fiber and mix for 3-6 min.

Start the RPC in the mold in a humid place at a temperature of 20 °C and 95% for cent relative humidity (RH) for 24 h. Then remove the mold and place the RPC in the curing box under steam curing conditions of 90°C for 72h. After that, let them cool naturally for 24 h, and the test pieces are immersed in water at 20 °C. the specimens are broken in flexion and compression.

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2. Materials and methods

2.1. Material

Cement (C) We used a single type of cement for all of our mixes. It is a CPA CEM I 42.5 N HRS from the Enfidha cement plant (Tunisia). Its chemical compositions and particle size determined by laser granulometer (Master-sizer 2000) of cement are shown in Table 1 and Figure 1.

Crushed quartz (CQ) Ground quartz is a powder, with an average diameter between 10 and 15 μm, produced by grinding a sand very rich in silica (SiO2> 98%) generally used in glassware.

Crushed slag (CS) The chemical composition of the addition was determined in the AIN LAKBIRA cement laboratory. SETIF (Algeria).

Crushed sand (CS) The silica fume used in our study is a MEDAPLAST HP manufactured in Algeria by the company GRANITEX located in Oued-Smar (Algeria).

The chemical compositions of cement, silica fume, slag and quartz powder are shown in Table 1 and Figure 1.

With the exception of cement, which is of Tunisian origin, (which was used because of the difficulties of obtaining a local CEM I cement), the materials used are of local origin. The chemical composition and particle size determined by laser granulometer (Master-sizer 2000) of cement are shown in Table 1 and Figure 1.

The additions

All the additions, of fineness greater than that of cements, can be used as a substitute for cements.

The sand (S) The sand used within the framework of our experimental study is a sand of dune passed through a sieve of 0.5mm therefore the largest diameter and 500 μm, this sand was taken from the region of Oued Souf (Algeria), it is appreciated for these good characteristics.

Table 1. Chemical Compositions of Cement, Silica Fume, Slag and Quartz Powder (%)

<table>
<thead>
<tr>
<th>Component</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>SiO2</td>
<td>20.62</td>
</tr>
<tr>
<td>Al2O3</td>
<td>4.31</td>
</tr>
<tr>
<td>Fe2O3</td>
<td>4.94</td>
</tr>
<tr>
<td>CaO</td>
<td>63.24</td>
</tr>
<tr>
<td>MgO</td>
<td>2.01</td>
</tr>
<tr>
<td>K2O</td>
<td>1.1</td>
</tr>
<tr>
<td>SO3</td>
<td>1.85</td>
</tr>
</tbody>
</table>

Cement (C) 20.62
Silica fume (SF) 4.31
Crushed quartz (CQ) 4.94
Crushed slag (CS) 63.24
Cl− Loss on ignition 2.01

Figure 1. Particle size distributions of cement

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Table 2. Composition of RPC based on substitution of additions

<table>
<thead>
<tr>
<th>Component</th>
<th>C (kg/m³)</th>
<th>S (kg/m³)</th>
<th>SF (kg/m³)</th>
<th>W/C</th>
<th>SP (kg/m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>RPC1</td>
<td>800</td>
<td>1144</td>
<td>260</td>
<td>0</td>
<td>240</td>
</tr>
<tr>
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<td>260</td>
<td>0</td>
<td>240</td>
</tr>
<tr>
<td>RPC3</td>
<td>800</td>
<td>1144</td>
<td>260</td>
<td>0</td>
<td>240</td>
</tr>
<tr>
<td>RPC4</td>
<td>800</td>
<td>1144</td>
<td>260</td>
<td>0</td>
<td>240</td>
</tr>
<tr>
<td>RPC5</td>
<td>800</td>
<td>1144</td>
<td>260</td>
<td>0</td>
<td>240</td>
</tr>
</tbody>
</table>

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2.3.2. Results and discussion

The results obtained are in the following tables.

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3. Discussions

3.1. Compressive strength test

The compressive strength of concrete is the most important property of concrete. The purpose of the compression test is to determine the crush strength of hardened concrete and carried out on 40 x 40 x 160 mm prism specimens because RPC does not contain coarse aggregates and the maximum particle size is of 600 μ. Here, to determine the average compressive strength, three cubes of each concrete mix are tested after 14, 28 and 45 days, tested under a compression testing machine with a capacity of 180 tons. According to figure 3., the compressive strength reaches up to 74 MPa for the reinforced fibers for a hardening at 20 ° C. Curing in hot water (80 ° C) gives a compressive strength at 3 days equal to (80-90) % of that of 28 days. The compressive strength at 7 days is (93-97) % of that at 28 days. At 20 ° C, the compressive strength at 3 days is (57-65) % of that of the compressive strength at 28 days and at 7 days equal to (75) % of the compressive strength at 28 days.

The results presented by the histogram of figure 3., shows that RPC resistance increases over time RPC3 based on (23% SF - 15% crushed slag - 25% crushed quartz) has the best compression resistance value at 14 days and 28 days and 45 days by addition to concrete and the RC14Days/RC28Days ratio is in the order of 76%, showing that more than 70% of the resistance is acquired. The RPC1 based on (23% SF) is recorded a low resistance by input to other concrete. It is also noted that the RPC2 based on silica (23% SF - 15% crushed slag) made in the very low W/C ratio gave less compression resistance than other RPC concrete to higher W/C ratios, which is confirmed by the RPC2. So there is no improvement in compressive strength with lower W/C. Between 28 days and 45 days, the resistance obtained does not show a significant increase for all the mixtures. This shows that the hydration of the cement is disturbed. The added rate of steel fibers plays a role in reducing cracks in RPC due to shrinkage, which is the starting point for failure under compressive loads. After start-up, the compressive load resistance of the samples is resisted due to the better structure of the RPC materials. Adding more steel fiber to RPC does not have the same effect with lower doses of steel fiber but has a positive effect on compressive strength. These results correspond to results of Chadli et al. (2020) [10].

It can be concluded that the experimental results of flexing traction resistance of RPC concretes reinforced with steel fibers demonstrate the greater efficiency of fibers for this type of solicitation. These results correspond to results of Chadli et al. (2020) [10].

3.2. Flexural tensile strength test

Flexural tensile strength test this done by a 300 KN press and a 3-point bending traction device, the drag resistance values of the RPC studied over time are given in figure 4.

Based on the results presented in the histogram of Figure 4 for the two concretes (fibrous and non-fibrous), we found an increased resistance to traction according to time, this result is consistent with the results found in the literature. In our study, it is noted that RPC with steel fibers are stronger than fiber less RPC. Maximum resistance obtained at RPC5 at 45 days.

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3.3. Resistance to aggressive environments test

Regardless of the type of formulation (fibre or non-fibrous), an increase in compression resistance has been recorded for all formulations but it appears that the presence of metallic fiber causes a significant increase compared to non-fibrous formulations. These results correspond to results of Chadli et al. (2018) [9].
3.4. X-ray diffraction analysis

X-ray diffraction is applied to identify products formed in RPC preserved in 5% sodium sulphates, and 10% sodium hydroxide (NaOH). This analysis revealed the appearance of crystalline phases at the surface of samples exposed to aggressive environments.

The diffractometer used is coupled with a computer system. Powdered samples were collected from the surface of the 45 days test tubes. The tests were done at the DRX laboratory at Biskra University. The device used is a Diffractometry (D8 ADVANCE BRUKER).

The use of the two X’Pert High Score and Origin Pro software allows the exploitation and tracing of results is formed from the diagram (diffraction diagram or diffractogram).

A review of the diffractograms cited above shows figure 8, 9, 10 and 11:

In mode preservation (Na2SO4), Portlandite fixation is more important in the formulation of RPC1 versus RPC3 according to the following eq 1:

\[
\text{Ca(OH)2} - \text{Na2SO4} - 2\text{H2O} \rightarrow \text{CaSO4} \cdot 2\text{H2O} - 2\text{NaOH}
\]  

This is explained by the low intensity of portlandite in the formulation of RPC1 compared to RPC3. This proves that the incorporation of the additions has a benign effect on resistance to Na2SO4.

In a mode preservation (NaOH), the characteristic rais of portlandite \(2\theta = 26.91\) is more intense in the formulation of RPC1 compared to RPC3 as well as to the other mode of preservation (1 and 2) this justify the increase in resistance to compression of formulations retained at (NaOH). These results correspond to results of Chadli et al. (2018) [9].

4. Conclusion

In this research, the influence of three types of additions on the mechanical properties of reactive powder concrete with and without metal fiber at an early age and long-term often RPC concretes made from local materials was studied.

After reviewing the results, we can conclude that:

- The compressive strength of the concrete is improved by thermal treatment, regardless of the dosage as a substitute for addition.
- The use of crushed quartz requires heat treatment.
- The flexural resistance of fibrous concretes is much higher than that of non-fibrous concrete.
- Cement class, fine additions and the W/C ratio are very important factors for fibrous reactive powder concrete.
- Mechanical resistance to the ages of (28 days) of RPC2, RPC3 and RPC4 with substitution additions exceeds those of other RPC, which means that these additions have a pouzzolanic role that results in the formation of second-generation C-S-H.
- The heat treatment and the presence of metal fibers are the major parameters making it possible to obtain high mechanical performances, both in flexion and in compression.
- The kinetic formation of the C-S-H by the additions depends on their fineness of their silica content.
FS silica smoke does not have a good improvement on compression resistance which is restored to their finest lower fine which affects the W/C ratio.

The highest mechanical resistance of RPC (125 MPa) in compression are achieved using the ratios; S/C = 1.43 and W/C = 0.21, SP/C = 0.027, and (18.9 MPa) in flexural tensile strength using ratios; S/C = 1.43, W/C = 0.21, SP/C = 0.027 and SF/C = 0.23.

CPA 42, 5 class cement, fine dune sand, very fine, silica-rich additions, thermal treatment of more than 90 degrees Celsius, and metal fibers can give concrete exceptional performance.

Among the two aggressive media (NaOH, Na2SO4), NaOH remains the most harmful medium with respect to the durability of RPC. The presence of mineral additions improves the durability of concrete compared to that which does not include mineral additions.

NaOH does not have a significant influence on the compressive strength of RPC and therefore its durability.

The study of the microstructure is a very effective tool which allows to access different phase forms in the cement matrix to confirm the mechanical properties of concrete and consequently their durability.

Declaration of Conflict of Interests

The authors declare that there is no conflict of interest.

References


[2.] Jörg Jungwirth, Aurelio Muttoni, Underspanned Bridge Structures in Reactive Powder Concrete (RPC), Swiss Federal Institute of Technology Structural Concrete Laboratory CH 1015 Lausanne (January 2002).


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