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# Effect of Self-Curing Admixture and Sand Type on the Mechanical and Microstructural Properties of Concrete in Hot Climate Conditions

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## ABSTRACT

The performance of concrete in hot and arid regions, where summer temperatures typically range between 40 and 50°C, is critically affected by the rapid evaporation of mix water. This study systematically investigates the influence of elevated temperatures characteristic of these climates on both the fresh and hardened properties of concrete, with a focus on formulation variables. Three distinct sand types—calcareous, silico-calcareous, and siliceous—were utilized in conjunction with superplasticizers and curing agents to discern their effects under simulated hot weather conditions. These conditions replicated an ambient temperature of 50°C for dry materials and water, a wind speed of 12 km/h, and a relative humidity of 10%, to emulate the average shaded environment in desert regions. Workability and compressive strength were evaluated, alongside a microstructural analysis conducted via Scanning Electron Microscopy (SEM) and X-ray Diffraction (XRD). It was observed that mixtures containing siliceous or silico-calcareous sands exhibited enhanced fluidity, while those with calcareous sand demonstrated superior compressive strength. Microstructural examinations revealed a denser matrix in the calcareous sand-based concrete when compared to its counterparts. Notably, the incorporation of curing compounds and superplasticizers was found to augment the compressive strength, particularly in calcareous sand mixtures, under hot weather conditions. This research offers critical insights into optimizing concrete formulations to mitigate the adverse effects of hot weather concreting, providing a valuable resource for concrete technologists in similar climatic zones.

## 1. INTRODUCTION

The mechanical and physical properties of concrete are more complex compared to other materials, as they are influenced by various environmental factors, particularly in hot conditions [1-3]. Placing concrete in warmer climates and conditions presents additional challenges [4]. During summer, temperatures in some hot regions can soar to 50°C. The aggressiveness of these regions is further evidenced by rapid temperature variations of up to 50°C in a single day, humidity levels below 15%, wind speeds reaching 6 m/s, and intense solar radiation of 600 W/m$^2$ [4]. These factors can elevate the surface temperature of concrete to 80°C on a typical summer day [5]. Consequently, this high temperature leads to increased water evaporation, which has a detrimental impact on the properties of concrete [6-8]. Therefore, hot climates result in heightened demand for mixing water, significant slump loss, increased plastic shrinkage, reduced setting time, and challenges in finishing [9]. Moreover, concreting in hot weather reduces the strength and durability of concrete [10].

Mouret et al. [11] conducted a study on the effects of aggregate temperature ranging from 20 to 70°C on concrete properties. They concluded that high aggregate temperatures lead to increased water demand and a 15% decrease in compressive strength of the concrete. Hasanain et al. [12] investigated the impacts of using shaded and unshaded aggregates on fresh concrete characteristics. The results showed that shaded aggregates reduce mix water loss by 50% compared to unshaded aggregates. Consequently, Al-Negheimish and Alhozaimy [13] demonstrated that maintaining the evaporation rate of mix water below 0.2 kg/m2 can mitigate the development of plastic shrinkage. Almusallam [14] fabricated concrete samples in a controlled chamber at temperatures ranging from 30°C to 45°C. He concluded that concreting at 45°C increases the compressive strength of concretes at an early age, although it diminishes over time.

Yahiaoui et al. [15] and Liu et al. [16] demonstrated that the incorporation of silica fume, fly ash, and ground slag improves the durability of concretes produced in a hot climate. Khan et al. [2] proposed regression models indicating that wet curing and high temperatures (25°C to 45°C) of concrete in situ have a positive impact on concrete strength and pulse rate, while both factors have a negative effect on water absorption. Additionally, the mineralogical composition of the sand influences the properties of concrete in both its fresh and hardened states. For instance, the use of calcareous sand in concrete reduces workability and increases long-term strength compared to concrete based on siliceous sand [17, 18]. Consequently, the compressive strength and modulus of elasticity of concrete with calcareous aggregates are slightly higher than those found in the case of quartz aggregates [19-21]. Furthermore, Ortiz et al. [22] and Alhozaimy [23] demonstrated that the workability of mortar decreases depending on the temperature of the sand. The above review indicates that previous research has primarily focused on evaluating the effect of hot weather on concrete properties under laboratory conditions, which do not accurately represent real-world conditions. Furthermore, previous studies have assessed the impact of aggregate temperature, mineral additions (such as silica fume, slag, etc [24].), and curing methods on the behavior of concrete produced in a hot climate. However, very few studies have been conducted on the influence of the mineralogical nature of the sand and the chemical curing products on the behavior of concretes in the short and long term. Therefore, this article aims to study the effect of sand type (calcareous, silico-calcareous, and siliceous sand), chemical additives (superplasticizer and curing products), on the physical and mechanical properties of concretes produced in a hot climate (Temperature: 50℃, air velocity: 12 km/h, humidity: 10%). Fresh state performance (fluidity), mechanical properties (compressive strength), and microstructural properties (SEM and XRD) were studied for ordinary concretes, considering different curing periods of 2, 7, 28, and 180 days. Ultimately, the authors believe that the results of the present study can assist concrete technologists in determining the optimal formulation to achieve concrete with the desired properties for hot weather conditions.

This investigation into the impact of hot climate conditions and formulation parameters on the properties of concrete provides insights that can inform strategies for addressing challenges related to rapid evaporation of mixing water and its effects on both fresh and hardened concrete properties. By highlighting the specific implications for construction practices in hot regions, we aim to underscore the practical relevance and significance of our research.

## 2. EXPERIMENTAL

### 2.1. Materials

2.1.1 Aggregates

Three distinct types of sand were employed in this study, namely: calcareous sand (C), silico-calcareous sand (SC), and silica sand (S) (see Figure 1).

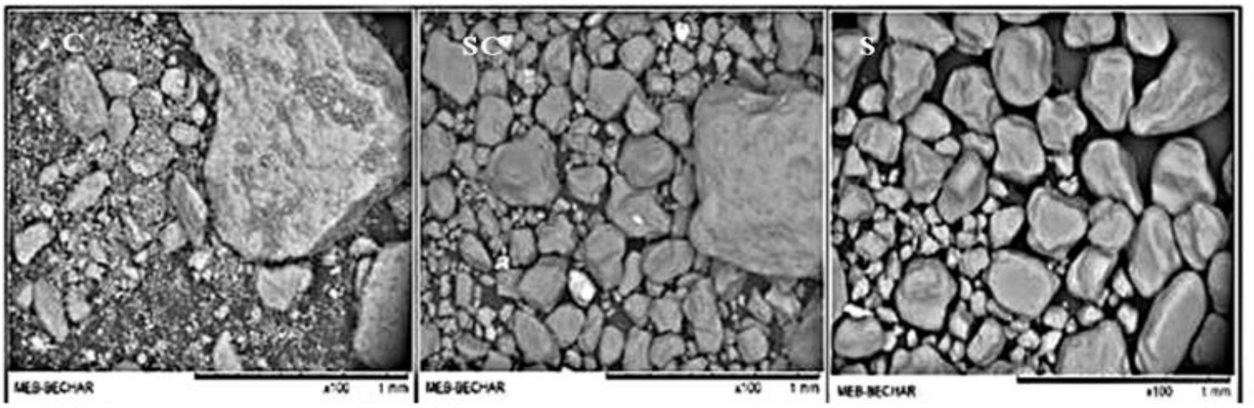

**Figure 1.** Observation by SEM of the different sands used

**Table 1.** Chemical analysis of used sands (%)

| Oxide (%) | $SiO_2$ | $Al_2O_3$ | $Fe_2O_3$ | Cao | MgO | $SO_3$ | $K_2O$ | $Na_2O$ | $P_2O_5$ | $TiO_2$ | LOI |
|---|---|---|---|---|---|---|---|---|---|---|---|
| C | 2.99 | 0.17 | 0.14 | 93.93 | 0.31 | 0.12 | 0.01 | 0.01 | 0.02 | 0.01 | 2.29 |
| SC | 42.85 | 2.07 | 2 | 45.69 | 1.57 | 0.1 | 0.4 | 0.04 | 0.05 | 0.14 | 5.09 |
| S | 97.12 | 0.83 | 0.3 | 0.67 | 0.07 | 0.02 | 0.09 | 0.01 | 0.01 | 0.05 | 0.83 |

**Table 2.** Physical properties of aggregates.

| Physical Characteristics | C* | SC** | S*** | Coarse Aggregates |
|---|---|---|---|---|
| Specific density (g/cm$^3$) | 2.56 | 2.56 | 2.6 | 2.67 |
| Apparent density (g/cm$^3$) | 1.50 | 1.72 | 1.69 | 1.48 |
| Fineness modulus | 2.80 | 2.20 | 2.10 | ----- |
| Piston sand equivalent (%) | 62.34 | 82.82 | 85.00 | ------ |
| Absorption coefficient (%) | 9.32 | 6.44 | 4.20 | 1.00 |
| Flatness Coefficient (%) | ---- | ---- | ---- | 12.0 |

Tables 1 and 2 provide information on the chemical compositions and physical characteristics of various types of sand. Calcareous sand exhibits a consistent particle size distribution ranging from 0.08 to 5 mm, with a fraction of smaller grains (less than 0.08 mm) comprising 12% of the total (see Figure 2). Additionally, both SC and S sands also demonstrate a continuous particle size distribution, with a maximum grain diameter of approximately 5 mm. However, the proportion of fine grains (less than 0.08 mm) in these sands is 3% and 5%, respectively (refer to Figure 2). These characteristics adhere to the NF P 18-540 standard [25]. Table 2 displays the physical properties of the aggregates. This table reveals that the sand equivalent and absorption coefficient values are elevated for C. This can be attributed to the substantial presence of fine particles, approximately 10%. On the other hand, coarse aggregates demonstrate consistent particle size distribution curves and standard physical properties.

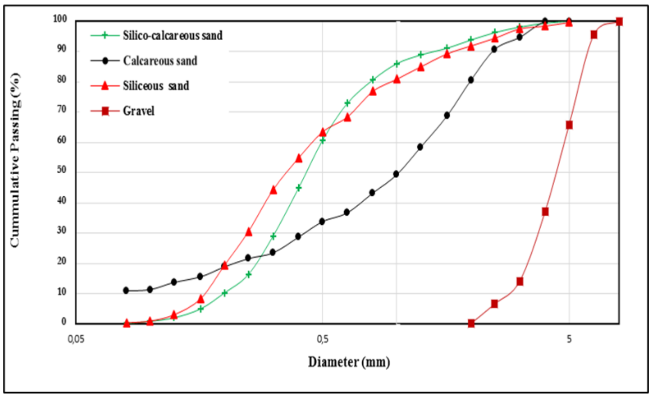

**Figure 2.** Particle size distribution of aggregates used

2.1.2 Cement

The cement employed in this investigation is a Portland cement with a classification of 42.5 CEM II/A. It possesses a specific gravity of 3.05 g/cm³ and a Blaine specific surface area measuring 3746 cm²/g. The chemical and mineralogical compositions of this cement can be found in Table 3.

**Table 3.** Chemical properties of cement used (%)

| Oxyde | $SiO_2$ | $Al_2O_3$ | $Fe_2O_3$ | CaO | MgO | $SO_3$ | $K_2O$ | $Na_2O$ | CaO l | $Cl^-$ | In | P.f |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Cement | 19.96 | 4.82 | 3.05 | 61.75 | 1.41 | 3.22 | 0.64 | 0.16 | 1.10 | 0.01 | 2.34 | 4.61 |
| Compound composition (Bogue (%)) | | | | | | | | | | | | |
| $C_3S$ | $C_2S$ | $C_3A$ | $C_4AF$ | | | | | | | | | |
| 56 | 19 | 08 | 10 | | | | | | | | | |

2.1.3 Admixtures

The superplasticizer utilized in this context is formulated using a modified polycarboxylate, adhering to a weight-to-cement ratio limited to 1%, as stipulated in accordance with BS EN 934-2 standards [26]. The curing compound used was SIKA ANTI SOL E40, with a dosage of 200 g/m².

## 2.2 Mix proportions

Three different families of concrete were prepared based on Dreux formulation method [27]. Mix proportions are shown in Table 4.

**Table 4.** Mix proportions

| Mixed with (kg/m³) | N-C-SP | N-SC-SP | N-S-SP |
|---|---|---|---|
| Sand | 787.1 | 693.5 | 735.8 |
| Gravel (3/8) | 888.6 | 1039.4 | 1022.3 |
| Cement | 350 | 350 | 350 |
| Superplasticizer | 3.50 | 1.05 | 1.05 |
| W/ C | 0.50 | 0.50 | 0.50 |

## 2.3 Specimen preparation, curing and testing

Prior to mixing, the aggregates were subjected to a 24-hour period in an oven at 50°C until a consistent mass was attained. Subsequently, the dry mixture of aggregates and cement was stirred for 3 minutes. Water was added gradually over the course of another 3 minutes until a uniform blend was achieved. The resulting mixture was cast into steel molds with dimensions of 40 mm x 40 mm x 160 mm. Following this, the specimens underwent a hot curing process within a controlled chamber, maintaining a temperature of 50°C, a relative humidity of 10%, and an airspeed of 12 km/h for a duration of 24 hours. Further details regarding this procedure can be found elsewhere [28].

After demolding, the specimens were immersed in water at a controlled temperature of 20 ± 2°C until the time of mechanical testing at 2, 7, 28, and 180 days. Under normal curing conditions, the temperature and relative humidity were maintained at 20°C and 60%, respectively. At the specified curing intervals, the specimens underwent compressive strength testing in accordance with NF EN 12390-5 [29]. The methodological program is presented in Figure 4.

2.3.1 Controlled chamber

To simulate hot weather conditions, a controlled chamber was created, allowing for the precise control of three key parameters: temperature, relative humidity, and airspeed. An electric resistance heater was employed to generate heat, and temperature control was maintained using a thermocouple. For controlling airspeed, two electric mounts were connected at each end, housing a 20 cm diameter fan. A miniature station was utilized to regulate the wind speed (see Figure 3). To adjust relative humidity, a digital controller equipped with a humidity sensor was employed.

**Figure 3.** The climatic chamber used

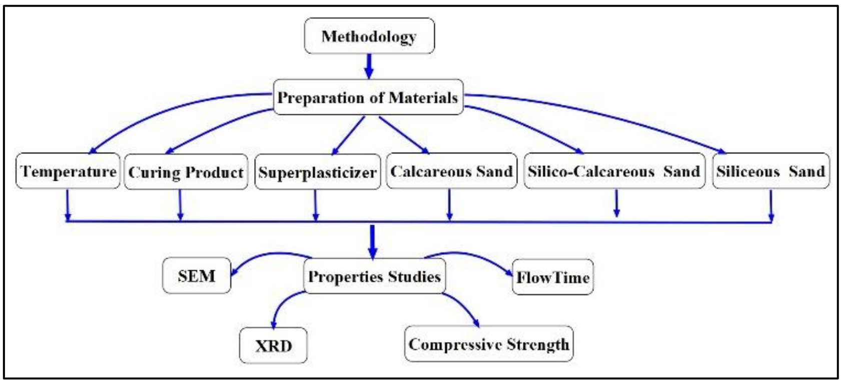

**Figure 4.** Methodology program

## 3. RESULTS AND DISCUSSION

### 3.1 Consistence

Figure 5 and Table 5 illustrates the impact of sand type on concrete flow time relative to the absorption coefficient of the aggregates (as per NF P 18-555 standard [30]) and the climatic condition. and environmental conditions. As depicted in Figure 5, it is evident that concrete flow time decreases when produced under hot weather conditions in comparison to those produced under normal curing conditions. This observation aligns with the findings of Mouret et al. [11], who reported an increased rate of water evaporation during hot weather concrete placement, negatively affecting the workability of concrete.

Furthermore, other researchers, such as Hasanain et al. [12], concluded that elevated aggregate temperatures result in higher water demand and a 15% decrease in concrete compressive strength. Additionally, concrete composed of calcareous sand exhibits a further reduction in consistency compared to silico-calcareous and silica sand concrete, with reductions of 15% and 13%, respectively. This can be attributed to the higher absorption rate of limestone sand (9.3%) in contrast to silico-calcareous (6.4%) and siliceous (4.6%) sands.

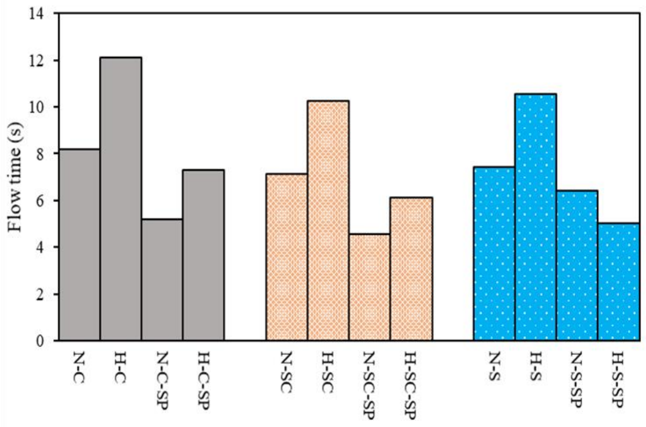

**Figure 5.** Influence of superplasticizer on the flow time of concrete containing different types of sand

To ensure that concrete meets the required technical specifications, any loss of consistency must be addressed at the construction site, allowing for proper concrete placement and compaction. In such cases, a certain quantity of superplasticizer is added to attain the desired consistency. The influence of sand type and the presence of superplasticizer on concrete workability is depicted in Figure 5. The results indicate that the use of superplasticizer significantly enhances consistency, by approximately 40%, for concrete prepared under normal conditions, regardless of the sand type. Furthermore, a notable reduction in flow time is observed in concrete containing superplasticizer and produced under hot conditions. It's evident that the extent and trend of concrete consistency loss vary based on ambient temperature, initial workability levels, and the adsorption capacity of the cement additives used [22].

### 3.2 Effect of superplasticizer and curing compounds on compressive strength of concrete

3.2.1 Effect of the nature of the sand

Figure 6 illustrates the impact of sand type on the compressive strength of concrete produced under two different climatic conditions, namely hot and ambient weather. Across all conditions and compositions, it is evident that concrete formulated with limestone sand exhibits significantly higher compressive strength in comparison to concrete mixes using silico-calcareous or siliceous sand.

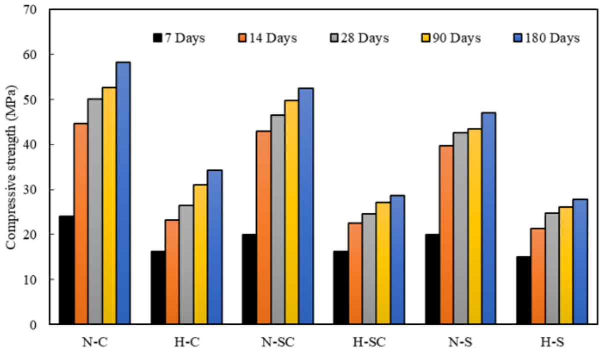

**Figure 6.** Effect of the nature of the sand on the compressive strength of concrete

This finding is corroborated by the outcomes reported in the study conducted by Aquino et al. [31]. The limestone fines (CaO) present in the sand actively participate in the cement hydration process [32]. This phenomenon effectively fills the pores, enhancing the compactness and overall strength of the concrete mixture. Consequently, Aquino et al. [31]

demonstrated that the inclusion of limestone fines in the sand leads to increased strength and reduced drying shrinkage in concrete. They attributed this strength enhancement to the higher density and hardness of limestone fines compared to river sand. Additionally, the sharp-edged morphology of calcareous sand particles (as depicted in Figure 1) promotes better adhesion to the cement paste, as opposed to the rounded grains of silico-calcareous and siliceous sands.

### 3.2.2 Effect of superplasticizer

Figure 7 shows the effect of the superplasticizer on the compressive strength of concrete mixes using various types of sand under hot climatic conditions.

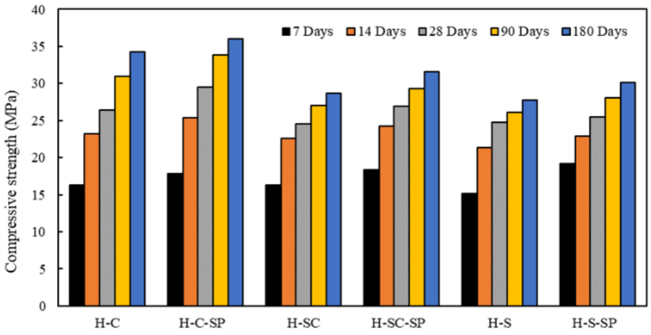

**Figure 7.** Effect of superplasticizer on the compressive strength of concretes

Observing Figure 7, it is evident that the inclusion of a superplasticizer enhances the compressive strength of concrete in hot weather conditions when compared to concrete without a superplasticizer. At 180 days, the increase in strength is approximately 5% for calcareous concrete, 10% for siliceous concrete, and 8.6% for silico-calcareous concrete. This boost in strength can be attributed to the interaction between the cement and the chemical admixture, which improves the rheological properties of fresh concrete. This, in turn, facilitates ease of placement and thorough compaction of the concrete with a superplasticizer, ultimately resulting in an increase in concrete strength. [33].

### 3.2.3 Effect of curing compounds

Figure 8 represents the influence of the curing compound on the compressive strength of concrete mixtures utilizing various types of sand under hot climatic conditions.

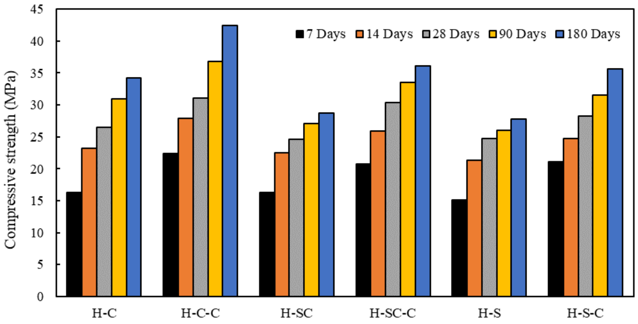

**Figure 8.** Effect of curing compound on concrete compressive strength

The application of a curing agent enhances the compressive strength in hot weather when compared to concrete without a curing agent. At 180 days, the rate of increase is 32% for limestone concrete, 25% for siliceous concrete, and 23% for silico-calcareous concrete.

This significant improvement in strength was confirmed by researchers [34, 35] who conducted a comparative study between water curing and curing with the use of curing agents. Their findings demonstrated that concrete treated with curing admixtures outperforms that cured solely in water. This underscores the beneficial impact of curing agents on concrete strength in hot climate conditions.

**Table 5.** Compressive strenght and consistency results

| Mix | Flow Time (S) | Compressive Strength (Mpa) | | | | |
|---|---|---|---|---|---|---|
| | | 7 D | 14 D | 28 D | 90 D | 180 |
| **NC-L** | 8.2 | 24 | 44.66 | 50.1 | 52.66 | 58.2 |
| **HWC-L** | 12.13 | 16.32 | 23.17 | 26.45 | 30.98 | 34.21 |
| **HWC-L +SP** | 7.32 | 17.82 | 25.4 | 29.56 | 33.87 | 36.02 |
| **HWC-L +PC** | / | 22.33 | 27.88 | 31.12 | 36.78 | 42.48 |
| **HWC-L +PC+SP** | / | 23.87 | 30.15 | 37.18 | 45.3 | 49.92 |
| **NC-SC** | 7.12 | 20.02 | 43 | 46.47 | 49.74 | 52.43 |
| **NWC-SC** | 10.26 | 16.3 | 22.56 | 24.58 | 27.08 | 28.67 |
| **HWC-SC+SP** | 6.14 | 18.33 | 24.28 | 26.97 | 29.28 | 31.54 |
| **HWC -SC+PC** | / | 20.7 | 25.85 | 30.34 | 33.52 | 36.13 |
| **HWC -SC+SP+PC** | / | 22.26 | 29.48 | 31.8 | 36.25 | 40.22 |
| **NC-S** | 7.44 | 20 | 39.63 | 42.66 | 43.52 | 47.09 |
| **HWC -S** | 10.54 | 15.12 | 21.36 | 24.75 | 26.07 | 27.73 |
| **HWC-S +SP** | 6.4 | 19.15 | 22.9 | 25.52 | 28.05 | 30.12 |
| **HWC -S+PC** | / | 21.12 | 24.77 | 28.3 | 31.52 | 35.65 |
| **HWC -S+SP+PC** | / | 19.85 | 27.91 | 31.2 | 34.15 | 37.17 |

### 3.4 X-ray diffraction and microstructure analysis

In this study, XRD (X-ray diffraction) analysis was conducted on concrete samples exposed to simulated hot climate conditions. The analysis was performed on powdered concrete that passed through an 80-micron sieve and had been cured for 180 days.

Figure 9 displays the XRD spectra for concrete mixes based on different types of sands formulated in hot weather. In the case of H-C (limestone-based concrete), multiple calcite peaks were observed, which is expected due to the presence of limestone sand. Additionally, a significant peak corresponding to portlandite was identified, stemming from the contribution of calcite in limestone sand fines to the formation of calcium hydroxide [36, 37].

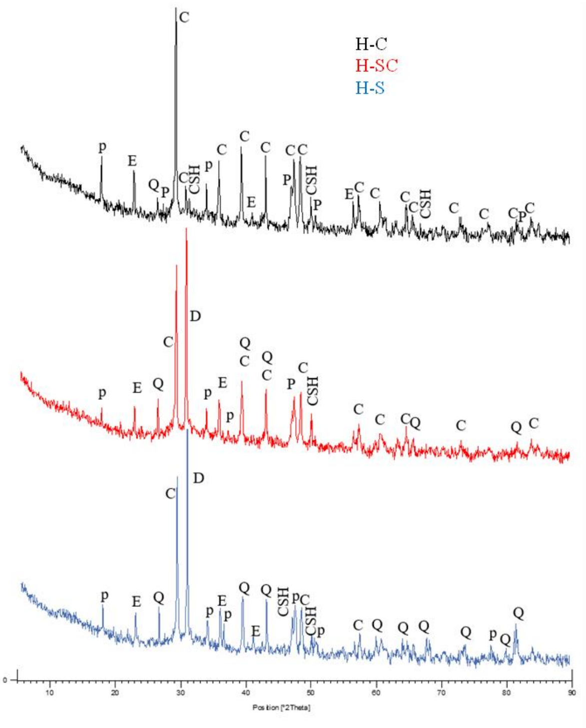

**Figure 9.** XRD analysis of hot curing concrete with different sands [E: Ettringite, P: Portlandite, Q: Quartz, C: Calcite, CSH: Calcium silicate hydrate and Ca: carboaluminates D: Dolomite Q: Quartz]

The XRD spectrum also revealed a few peaks related to Ettringite, representing primary Ettringite ($3CaO \cdot Al_2O_3 \cdot 3CaSO_4 \cdot 32H_2O$). These results originate from the reaction of gypsum added to clinker during the manufacturing process.

For sand-lime concrete exposed to hot climate conditions for 180 days, several peaks corresponding to Calcite, Quartz, and the emergence of Dolomite CaMg $(CO_3)_2$ were observed. This is attributed to the presence of silica in the sand. Additionally, the presence of crystallized (or semi-crystallized) CSH gel peaks was noted, with the CSH content appearing lower than that in concrete containing calcareous sand. In the case of concrete with silica sand, there were peaks corresponding to quartz in the XRD spectrum, along with some calcite and dolomite peaks.

### 3.5. SEM observation

Figure 10 presents the SEM (Scanning Electron Microscope) analysis of various concrete formulations after 180 days of exposure to hot weather conditions. In the SEM images of concrete based on calcareous sand, a compact cement paste is observed. This compactness results from the presence of plate-shaped CSH (calcium silicate hydrate) hydration products, which can either be crystallized or partially crystallized, as confirmed by XRD analysis (Figure 10). Furthermore, C3A (tricalcium aluminate) reacts with $CaCO_3$ (calcium carbonate) in the limestone to form both a tricarbonate 'hexagonal prism' phase ($C_3A \cdot 3CaCO_3 \cdot 30H_2O$) and a monocarbonate 'hexagonal plate' phase ($C_3A \cdot 3CaCO_3 \cdot 11H_2O$).

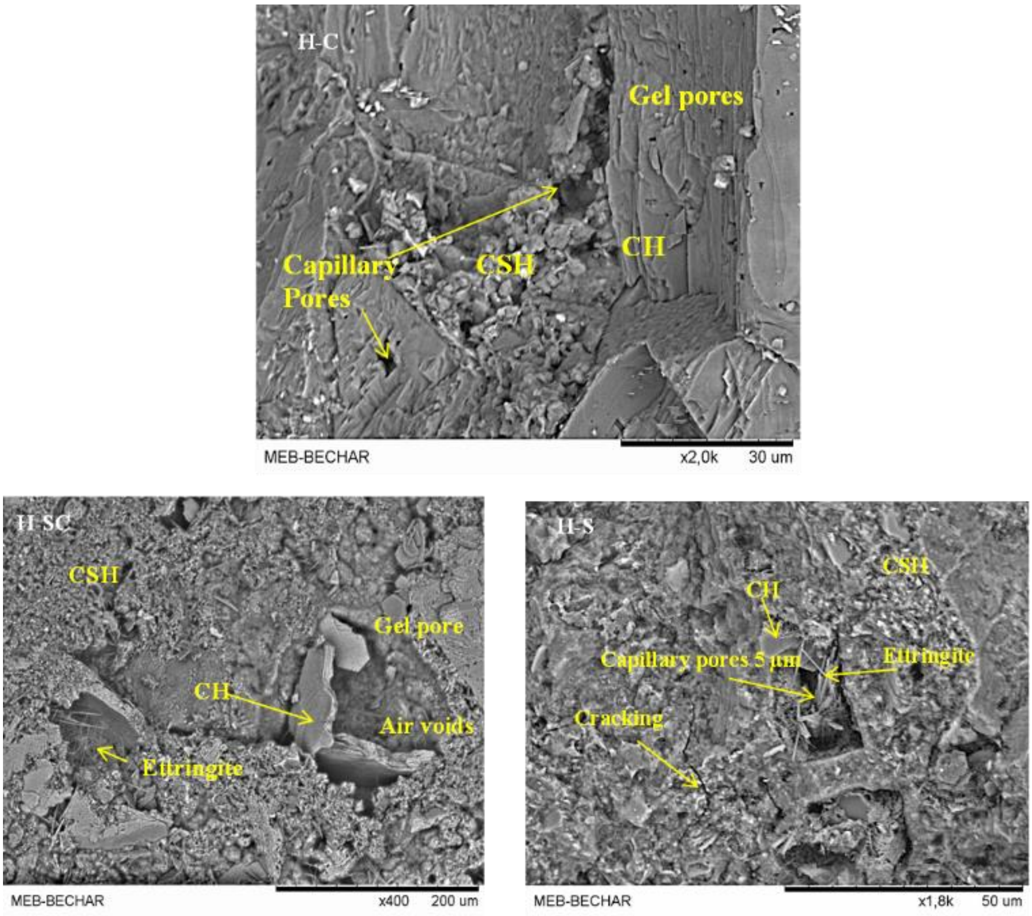

**Figure 10.** SEM observation of different concretes

The presence of CH (Calcium Hydroxide), in hexagonal form, is also evident, indicating a high content of $Ca(OH)_2$ in the concrete due to the presence of calcareous sand [36]. In hot climates, concrete experiences rapid water evaporation, leading to the formation of capillary pores. However, the presence of limestone fines in the sand helps in absorbing the heat of the water, promoting subsequent hydration. Additionally, limestone acts as nucleation sites for hydration products [38, 39]. As a result, this concrete exhibit relatively high compressive strength (approximately 48 MPa). In contrast, concrete containing silico-calcareous sand shows less dense and unstratified $Ca(OH)_2$ formations. This is attributed to reduced cement hydration caused by the hot weather and the lower limestone content. Notably, a significant amount of needle shaped Ettringite is observed compared to calcareous sand concrete.

The SEM images also reveal relatively large gel pore diameters (3-5 μm), possibly due to the accelerated hydration caused by temperature, resulting in inhomogeneous hydration products [40]. Furthermore, higher temperatures accelerate the evaporation of free water, leading to the formation of capillary pores and alterations in hydration products (Portlandite and Ettringite) due to hydrodynamic forces, as per prior research [41, 42]. These factors may explain the lower strength of silica sand concrete in hot climates.

Microstructural cracks are apparent in the concrete containing silica sand, which could be attributed to the hot climate [43-46]. These cracks may account for the reduced strength observed in this concrete mixture compared to others.

## 4. CONCLUSIONS

This study evaluated the impact of three types of sand on the fresh and strength properties of concrete in hot weather. Based on the results, the following conclusions can be drawn:

- Consistency: Concrete made with siliceous and silico-calcareous sands exhibited better consistency under all climate conditions (normal or hot weather) due to the high water absorption of limestone compared to other sands. The use of a superplasticizer improved the consistency of all concretes by approximately 40%, even for concrete exposed to hot weather, compared to concrete without a superplasticizer.
- Strength loss in hot weather: All concrete samples experienced a reduction in strength compared to normal conditions. However, concrete incorporating limestone sand demonstrated superior compressive strength, regardless of the curing conditions.
- Compressive strength in hot climate: The presence of limestone in concrete resulted in a significantly higher compressive strength of 34.2 MPa compared to H-SC and H-S, which exhibited strengths of 28.6 MPa and 27.7 MPa, respectively. The limestone fines (CaO) present in the sand actively participate in the cement hydration process.
- Microstructure observation: According to SEM observations, it is concluded that H-C has a more compact microstructure than H-SC and H-S due to the reactivity of limestone fines with cement hydration products. This compactness results from the presence of plate-shaped CSH (calcium silicate hydrate) hydration products, which can either be crystallized or partially crystallized, as confirmed by XRD analysis.
- Enhanced mechanical performance: The incorporation of a curing agent and a superplasticizer improved the mechanical performance of concrete in hot weather. Specifically, the compressive strength of H-C-SP, H-CS-SP, and H-S-SP increased by 32%, 25%, and 23%, respectively.

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## NOMENCLATURE

| | |
|---|---|
| C | calcareous sand |
| S | siliceous sand |
| Sc | silico-calcareous sand |
| N-C | normal curing concrete with calcareous sand |
| N-S | normal curing concrete with siliceous sand |
| N-SC | normal curing concrete with silico-calcareous sand |
| N-C-SP | normal curing concrete based on calcareous sand with superplasticizer |
| N-S-SP | normal curing concrete based on siliceous sand with superplasticizer |
| N-SC-SP | normal curing concrete based on silico-calcareous sand with superplasticizer |
| H-C | hot curing concrete with calcareous sand |
| H-S | hot curing concrete with siliceous sand |
| H-SC | hot curing concrete with silico-calcareous sand |
| H-C-SP | hot curing concrete based on calcareous sand with superplasticizer |
| H-S-SP | hot curing concrete based on siliceous sand with superplasticizer |
| H-SC-SP | hot curing concrete based on silico-calcareous sand with superplasticizer |
| H-C-C | hot curing concrete based on calcareous sand with curing compound |
| H-S-C | hot curing concrete based on siliceous sand with curing compound |
| H-SC-C | hot curing concrete based on silico-calcareous sand with curing compound |