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Original Paper

Behavior evaluation of self- compacting concrete exposed to elevated temperature

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Abstract

This paper presents an experimental study on the performance of self-compacted concrete (SCC) subjected to elevated temperature. Two SCC mixtures were tested. Microstructural properties were studied at ambient temperature and after heating. For each test, the specimens were heated at a rate of 1 C°/min up to different temperatures (150, 300, 450 and 600 C°). In order to ensure a uniform temperature throughout the specimen, the temperature was held constant at the target temperature for one hour before cooling. In addition, the specimen mass was measured before and after heating in order to determine the loss of water during the test. The results allowed us to analyze the degradation of SCC due to heating. Between 20 and 150 °C, it was associated to an evaporation of free water as well as to an increase in porosity of the tested concretes. Between 150 and 300 °C, in a similar way to the observed evolutions between 20 and 150 °C, due to the departure of bound water, corresponding to a large mass loss. The improvement in microstructure could be attributed to a modification of the bonding properties of the cement paste hydrates (rehydration of the paste due to the migration of water in the pores). Beyond 300 °C, the microstructure of the tested concretes deteriorated quickly. The specimens subjected to a heating up to 600 °C showed very weak physical properties (appearance of microcracking).

Keywords: Self-compacted concrete, microstructure, heating and cooling.

Introduction

In the structural design of buildings, in addition to normal gravity and lateral loads, it is in many cases necessary to design the structure to safely resist exposure of fire. However, it is usually necessary to guard against structural collapse for a given period of time (Shetty, M.S., 1988).

There are indeed rare researchers about temperature gradient and exposure time of the concrete indirect contact with the fire flames. In this study there is an attempt to investigate the effect of temperature gradient and exposure of SCC to a certain range of temperatures on microstructure at two different ages.

Preparation Specimens for Scanning Electronic Microscope (SEM) Technique:

SEM is very useful test to understand thoroughly the effect of type of fiber, fiber volume fraction, chemical and mineral admixtures on the microstructure of HSCC (Hybrid self-compacting concrete) sample and RSCC (Reference self-compacting concrete) mixes. This test helps to find reasons behind the behavior as improvement or disimprovement of different types of mixes and the effect of exposure to high temperature at different ages.

A slice from fracture surface specimen (concrete cube) to be examined is cut to a suitable thickness (3-5) mm, and oriented in any required manner to make polished section for examination by this technique. Most samples to be analyzed required, vacuum dried and then a conductive coating with the ultra-thin gold coating. Fig. (1), reveals the type of (SEM) equipment used for analysis the specimens in this study.

Fig. (1): (SEM) equipment used in study.

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Microstructure Observation

The microstructure test includes microstructure photograph of concrete samples at ages of 60 & 90 days, with and without exposure to high temperature. For this test a fragments were taken from HSCC and RSCC Sample job mixes. The total number of specimens is 30 concrete cubes, as detailed in Table (1).

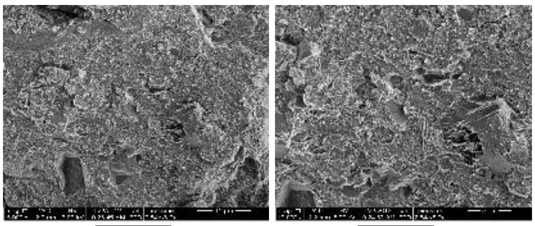
Type of mix	RSCC mix					HSCC mix				
Exposure Temperature, °C.	20	150	300	450	600	20	150	300	450	600
Number of samples (concrete cubes)	3	3	3	3	3	3	3	3	3	3

Table (1) Details of temperature exposure range and specimens number.

Effect of Admixture on Microstructure Development of Interfacial Zone

Reference Self Compacted Concrete RSCC (without Fiber):

The specimen does not contain any admixture. It is considered as control specimen. The (SEM) photographs results at an age of 60 days of curing revealed the typical cases of dens cement gel crystal of readily distributed shape in addition to uniform crystals from (C-H) layers Fig. (2); Plate a and b, continuous with curing for age of 90 days the cement gel developed to dendritic fibers like shapes and a mesh from a dens of interconnected fibers like was identified Fig.(3); Plates a and b.



a b

Fig. (2): Microstructure Development of RSCC Sample at age of 60 days.

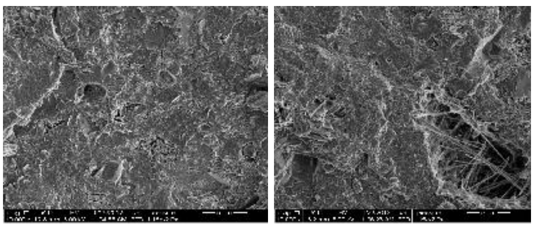


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Fig. (3): Microstructure Development of RSCC Sample at age of 90 days.

Two types of admixtures HRWRA and SF (High range water reducing admixture and Silica fume) were used in this study. Mineral admixtures were used as a partial replacement of cement, the purpose of using HRWRA is to disperse the cement particles in water more easily and to eliminate the weak phase of bond strength between polypropylene and steel fibers with bulk large (C-S-H) crystals. The same behavior for (HRWRA) also observed by (Chan, Y.W. and Victor, C.L., 1996).

The result of microstructure study revealed that this admixture is effective at later age. Good crystallization of (C-S-H) layer like dendritic shape are noticed which would developed to be tight in mesh shape from layer, as mentioned in above, that’s reflect a good to very good mechanical properties.

There are many reasons for silica fume addition to the cementitious composite. It is used as a partial replacement of cement to improve the quality of SCC mixes. It was found that (SF) in concrete mixes reduces their air voids, drying shrinkage and permeability (Habeeb, G.M., 2000). and hence it may dense the paste aggregate interface.

In this study the silica fume was used with high range water reducing admixture, the results of study by (SEM) revealed good growth of (C-S-H) crystals as dendritic or meshes shape in later ages and improved as age of specimens is increased. The use of silica fume with super plasticizer improved the workability of SCC mixes and also leads to good dispersion for polypropylene and steel fibers was also noticed by (Chung, D.D., 1999; Zeng, Q., 1989; Malhorta, H.L., 1956; Davis, H.S., 1976 and Noumwe, A.N *et al.*, 1994).

Reference Self Compacted Concrete RSCC (without Fiber) Exposed to High Temperature at an age of 60 Days:

Exposure to Temperature Rate of 150 C°

It has noted that; at this temperature began the re-cracks in the C-H layer as in Fig. (4); Plate a and b shift shape homogenized to Irregular for C-S-H layer, it can be seen clearly more where turned of C-H layer of irregular shape with a clear segregation in layers of C-H and the presence of longitudinal grooves, a honey-combed like shape with a separation between components and presence of dark areas which refers to pores (or slots) can be noticed, also turning of C-S-H layers to needle like shape (or short fibers) scattered in certain horizons as indicated by white color.

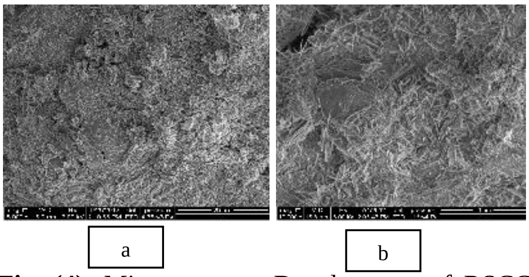


Fig. (4): Microstructure Development of RSCC Sample at age of 60 days and exposed to temperature rate of 150 C°.

Exposure to Temperature Rate of 300 C°

In Fig. (5); Plates a and b, it is clearly that the microstructure seems good and developed to be semi homogenous so that C-H and C-S-H layers can be thoroughly distinguished, it has noted some dark areas which refers to presence of pores, it can be concluded that a re-hydration was happened and leads to improvement in microstructure where C-H layers scattered in irregular shape with tops and downs and presence of dark areas which refers to presence of pores. it has noted also, an entanglement in needle like shape in dark areas (pores) and that means a re-combination is going forward to seal pores (or slots) in microstructure and this is agree with most of researches that a re-hydration occurs between 150 and 300 C° which means an improvement in mechanical properties.

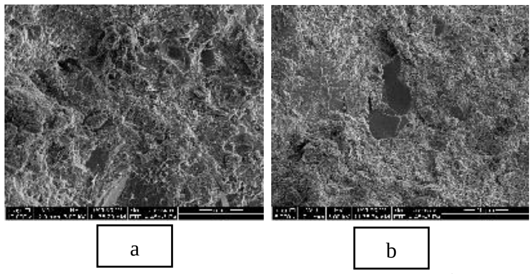


Fig. (5): Microstructure Development of RSCC Sample at age of 60 days and exposed to temperature rate of 300 C°.

Exposure to Temperature Rate of 450 C°

In Fig. (6); Plate a and b it has noted a turning in microstructure to irregular with recession in C-H layers and presence of dark areas, and the microstructure turns to be a clusters like shape which means weakness in bond forces between particles, it can be more readily the separation of C-H layer alone and in size ranging from 20 to 30 microns with irregular shape.

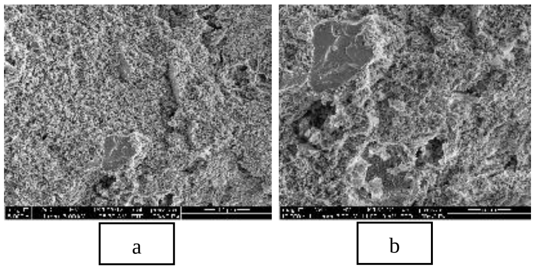


Fig. (6): Microstructure Development of RSCC Sample at age of 60 days and exposed to temperature rate of 450 C°.

Exposure to Temperature Rate of 600 C°

In Fig. (7) plates a and b, it has noted a flow like shape in microstructure with separation of both C-H and C-S-H layers with presence of tops, downs, and dark areas which means weakness in bond forces between particles.

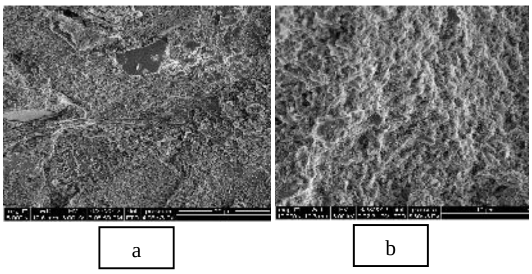
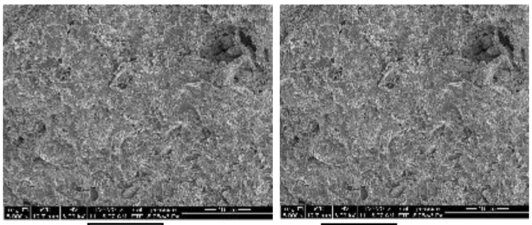


Fig. (7): Microstructure Development of RSCC Sample at age of 60 days and exposed to temperature rate of 600 C°.

Reference Self Compacted Concrete RSCC (without fibers) Exposed to High Temperature at an age of 90 Days

Exposure to Temperature Rate of 150 C°

It seems that the microstructure with development of curing differs dramatically, and this is can be more reading as compared with samples of 60 days age under the same conditions, in Fig. (8); Plates a and b indicate homogenous microstructure and well-connected with little dark areas which refer to pores (or slots), it seems still the microstructure keeps homogeneity and density and there is be noticeable growth in needle like shape which means progress in re-hydration.

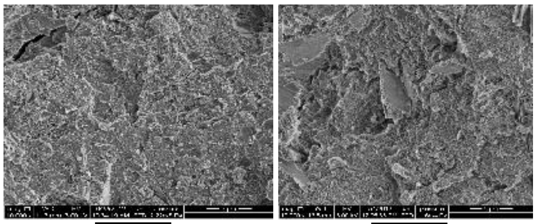


a b

Fig. (8): Microstructure Development of RSCC Sample at age of 90 days and exposed to temperature rate of 150 C°.

Exposure to Temperature Rate of 300 C°

The microstructure in Fig. (9); Plates a and b seems good in spite of presence two cracks in plate b, one is big and the other is small, but still the microstructure keeps homogeneity and density well defined, whereas dark color reflects great recession in C-H layer in certain corner with presence clear crack extend from right top corner and downwards in parallel manner with radial diagonal trace. The microstructure gets badness and noted that the C-H layer fragmented and randomly distributed in different levels with presence of dark areas of size 5 microns. The C-H layer is also fragmented and distributed in different levels. This indicating that the microstructure still keeps homogeneity and density well-defined and that C-S-H layer occupies wider areas compared to C-H layer. The generation of semi-hexagonal formations which indicate a growth in hydration (or Re-Hydration) at this rate of temperature exposure.

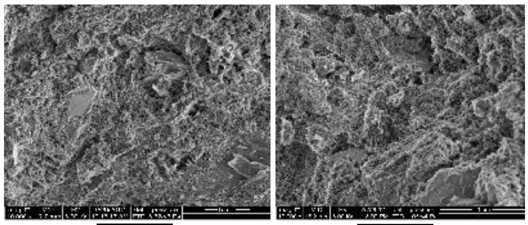


a b

Fig. (9): Microstructure Development of RSCC Sample at age of 90 days and exposed to temperature rate of 300 C°.

Exposure to Temperature Rate of 450 C°

In Fig.(10); Plates a and d show good microstructure and presence wide area of C-S-H layer and refer to start of weakness attached with dark areas which leads to unstable microstructure in reefs like shape. It shows that the microstructure gets more random and homogeneity and separation of both C-H and C-S-H layers. The microstructure gets cluster like shape with presence of dark areas.

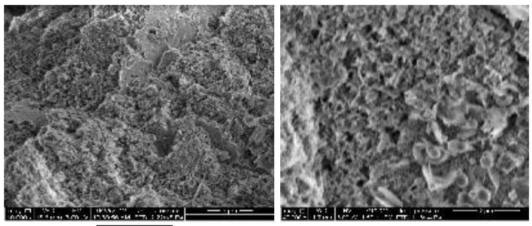


a b

Fig. (10): Microstructure Development of RSCC Sample at age of 90 days and exposed to temperature rate of 450 C°.

Exposure to Temperature Rate of 600 C°

In Fig. (11); plates a and b, it seems in general that the microstructure gets unstableness and perforation with increase in temperature rate and presence of irregularities, tops, and downs attached with dark areas which means weakness of bond forces between particles and decrease in Mechanical properties.

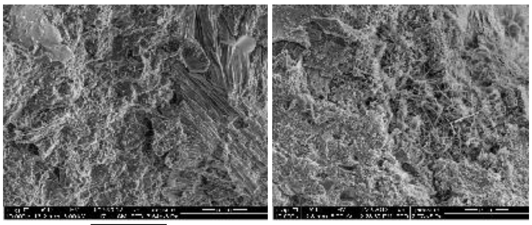


a b

Fig. (11): Microstructure Development of RSCC Sample at age of 90 days and exposed to temperature rate of 600 C°.

Hybrid Self Compacted Concrete at an age of 60 Days

In Fig. (12), it seems in general that the microstructure is well homogenous and dense as has shown in plates a and b, and that the PPF (Polypropylene fibers) intertwined in dark areas in an attempt to seal pores or slots which leads to more improvement in mechanical properties. It has shown semi-hexagonal formations in continuous manner which means progressive in re-hydration and growth.



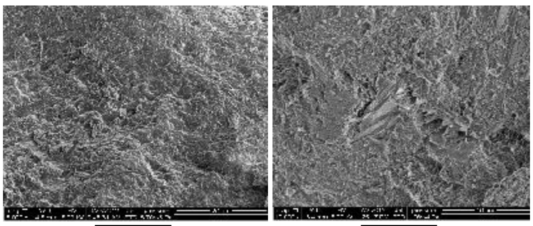
a b

Fig. (12): Microstructure Development of HSCC Sample at age of 60 days.

Hybrid Self Compacted Concrete and Exposed to High Temperature at an age of 60 Days

Exposure to Temperature Rate of 150 C°

In Fig. (13); Plates a and b show that still the microstructure keeps homogeneity and density well-defined and the microstructure forwards to be non-homogenous since C-S-H layer fragmented with presence of dark areas, the color turned to be darky with presence of clear crack in middle and this crack which indicates separation in microstructure.

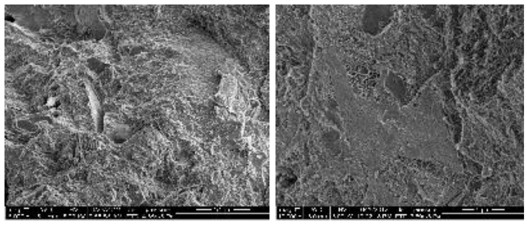


a b

Fig. (13): Microstructure Development of HSCC Sample at age of 90 days.

Exposure to Temperature Rate of 300 C°

In Fig. (14); Plates a and b, it has shown that the microstructure still keeps homogeneity and density well-defined, it is more readily the dispersion of PPF in well arrangement , it shows that the PPF are well dispersed and distributed all over darky areas which is an attempt to seal pores or slots. This reflecting homogeneous and dense microstructure with presence of distinguished C-H layer of size ranging from 5 to 15 microns and clear crack.

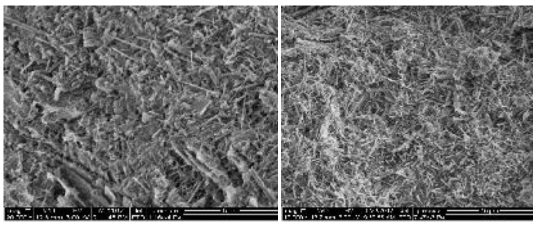


a b

Fig. (14): Microstructure Development of HSCC Sample at age of 60 days and exposed to temperature rate of 150 C°.

Exposure to Temperature Rate of 450 C°

In Fig. (15); Plates a and b it seems that the microstructure gets instability and turned to be like a reefs with distinguished separation in C-H layer and dark spots, and gets dendritic or X-Mas tree like shape and cluster like shape, all above like shapes are an indications (or signs) to weakness in bond forces between particles of microstructure which lead to decrease in mechanical properties.

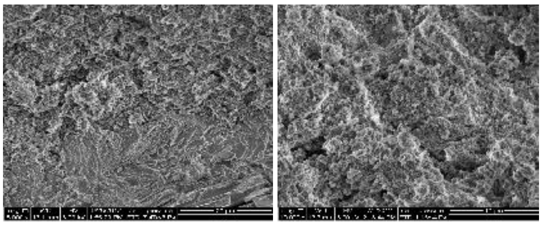


a b

Fig. (15): Microstructure Development of HSCC Sample at age of 60 days and exposed to temperature rate of 300 C°.

Exposure to Temperature Rate of 600 C°

In Fig. (16) seems in general Significant deterioration in microstructure at this rate of temperature exposure and turned to be like mountains and groves with more fragmentation in both C-H and C-S-H layers of distinguished heads and dark spots, also it has noted that both layers in above were arranged in vertical manner with existing part of them in horizontal planes which means a great destabilize in microstructure and the result is severe decreasing in mechanical properties.

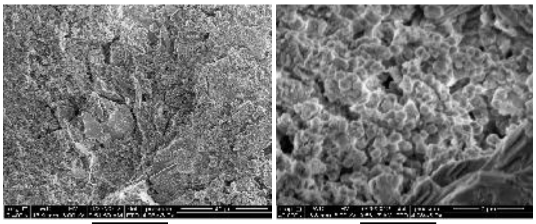


a b

Fig. (16): Microstructure Development of HSCC Sample at age of 60 days and exposed to temperature rate of 450 C°.

Hybrid Self Compacted Concrete at an age of 90 Days

In Fig. (17); Plates a and b reflect homogenous and dense microstructure with no or presence of little dark spots while in plate a dark spots are slightly more. The deterioration in microstructure is well-defined with recession of C-H layer inside deep hole of size ranging from 10 to 25 microns and presence of clear big cracks in surroundings.



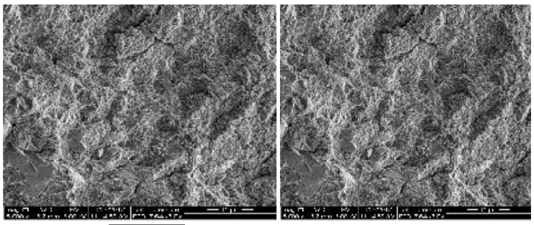
a b

Fig. (17): Microstructure Development of HSCC Sample at age of 60 days and exposed to temperature rate of 600 C°.

Hybrid Self Compacted Concrete and Exposed to High Temperature at an age of 90 Days

Exposure to Temperature Rate of 150 C°

In Fig. (18); Plates a and b reflect homogenous and dense microstructure. It can show clearly the intertwining of PPF and their proper distribution all over the microstructure, A growth like a needle shape in microstructure as well as hexagonal formations which refer to a re-hydration process.

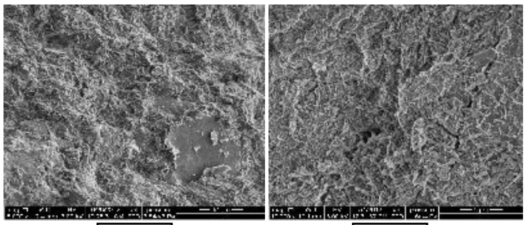


a b

Fig. (18): Microstructure Development of HSCC Sample at age of 90 days and exposed to temperature rate of 150 C°.

Exposure to Temperature Rate of 300 C°

In Fig. (19); Plates a and b, there is a distinguished development in microstructure with presence of C-H layer in certain area , a small portion turned to be honeycombed in shape of number 7 in Indian numeration. The formation is unreadable and undefined. It can notice lamination of C-H layer on sheets style in vertical plane with fragmentation and presence of cracks and dark spots but seem surface and not deep in spite of presence some cracks but still the PPF are intertwining all over above cracks and dark spots which is an attempt to crack arrest.

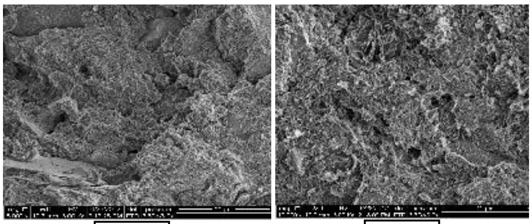


a b

Fig. (19): Microstructure Development of HSCC Sample at age of 60 days and exposed to temperature rate of 300 C°.

Exposure to Temperature Rate of 450 C°

In Fig. (20); Plate a it can be notice a fragmentation in C-H layer so that some sheets were distributed in certain corner within horizontal plane with presence of dark spots, and in plate b the microstructure gets instability and turned to be like a trash fill which means a great deterioration in microstructure Layers were scattered randomly with presence of dark spots and recession in C-H layer where PPF can be seen scatter distributed in little quantity over C-H layer.

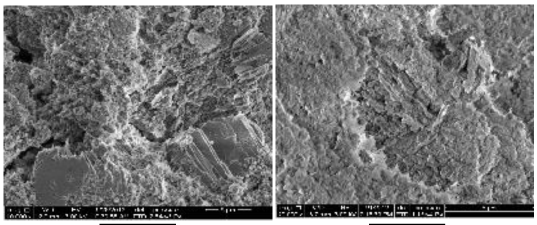


a b

Fig. (20): Microstructure Development of HSCC Sample at age of 60 days and exposed to temperature rate of 450 C°.

Exposure to Temperature Rate of 600 C°

In Fig. (21); Plate a it seems that the microstructure is not well defined since a deformation can be readily more and in plate b the separation of C-H and C-S-H layers has shown obviously and laminated in different inclined levels with presence of dark spots and cracks in surroundings which means great deterioration.



a b

Fig. (21): Microstructure Development of HSCC Sample at age of 60 days and exposed to temperature rate of 600 C°.

Results and Discussion:

This study concerns the behavior of SCC at high temperature. The physical properties of two SCC were determined after different heating cycles up to 150, 300, 450 and 600 °C. During a heating at 1 °C/min, six SCC specimens spalled at about 315 °C. Between 20 and 150 °C, it was associated to an evaporation of free water as well as to an increase in porosity of the tested concretes. This porosity increase is an expansion of the pores diameters and therefore leads to an increase in permeability. Between 150 and 300 °C, in a similar way to the observed evolutions between 20 and 150 °C, due to the departure of bound water, corresponding to a large mass loss. The improvement in microstructure could be attributed to a modification of the bonding properties of the cement paste hydrates (rehydration of the paste due to the migration of water in the pores). Beyond 300 °C, the microstructure of the tested concretes deteriorated quickly. The specimens subjected to a heating up to 600 °C showed very weak physical properties (appearance of microcracking). The physical properties change were due to the alteration of the porous network (departure of bound water and decomposition of hydrates) and to the microcracking. The connectivity of the pores and microcracks increased, thus the concrete permeability increased.

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الملخص العربى

يقدم هذا البحث دراسة تجريبية على أداء الخرسانة ذاتية الدمك عند تعرضها لدرجات حرارة مرتفعة. تم اختبار اثنين من الخلطات الخرسانية ذاتية الدمك و دراسة الخواص المجهرية عند درجة حرارة الغرفة وبعد التسخين. لكل اختبار، تم تسخين العينات بمعدل ١ ° C / دقيقة لتصل إلى درجات حرارة مختلفة (١٥٠، ٣٠٠، ٤٥٠ و ٦٠٠ ° C). من أجل ضمان توزيع الحرارة على العينة بأنتظام، تم أبقاء العينة في الفرن عند درجة الحرارة المستهدفة لمدة ساعة واحدة قبل التبريد. بالإضافة إلى ذلك، تم قياس كتلة العينة قبل وبعد التسخين من أجل تحديد فقدان الماء أثناء الاختبار. سمحت النتائج بتحليل تدهور البنية المجهرية للخرسانة ذاتية الدمك بسبب التعرض للارتفاع في درجات الحرارة. عند تعرض الخرسانة ذاتية الدمك لارتفاع في درجة الحرارة مابين ٢٠ – ١٥٠ درجة مئوية، أدى ذلك إلى تبخر الماء الحر وكذلك إلى زيادة في المسامية. وعند تعرض الخرسانة ذاتية الدمك لارتفاع في درجة الحرارة مابين ١٥٠ – ٣٠٠ درجة مئوية، تم ملاحظة تطورات مشابهة لتلك التي حدثت ما بين ٢٠ - ١٥٠ درجة مئوية، وذلك بسبب فقدان الماء المتحد والمنظر لفقدان كتلة كبيرة. ويمكن أن يعزى التحسن في البنية المجهرية إلى تعديل خصائص الترابط لهيدرات عجينة الأسمنت (عملية أعادة الإماهة لعجينة للسمنت بسبب هجرة الماء الموجود في المسامات). عند التعرض لأرتفاع في درجات الحرارة لأكثر من ٣٠٠ درجة مئوية، تدهورت البنية المجهرية للخرسانة ذاتية الدمك بوتيرة متسارعة. وأظهرت العينات التي تعرضت للتسخين إلى ٦٠٠ درجة مئوية خصائص مجهرية ضعيفة جدا (ظهور التشققات).