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The effect of granulate porosity on the evolution of the thermal conductivity of an resin concrete exposed to high temperatures

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Abstract. *As the aggregates occupy about three-quarters of the volume of concrete, it's not surprising that their properties can, not only, to limit its resistance, but also to affect the durability and structural performance of concrete. In this context, the study's main objective to study the influence of the aggregate porosity on the evolution of the thermal conductivity of a resin concrete exposed to high temperatures. the experimental results show that the porosity of the aggregates has a significant influence on the evolution of the thermal conductivity of the concretes tested.*

Key words: *aggregates, porosity, durability, thermal conductivity, concrete, temperature*

1. Introduction

The presence of internal pores in the aggregates is directly related to the density of the aggregates and indeed the characteristics of these pores are very important in the study of aggregate properties [6]. The porosity of aggregates and their absorption influence some of their properties: their bond with the hydrated cement paste, their chemical stability and resistance to abrasion [8]. The size of the aggregate pores is very variable: the larger ones can be seen under a microscope or even with the naked eye; the smallest are barely larger than the pores of the cement paste. Some pores are completely inside the aggregates; others emerge on the surface [1].

The cement paste, due to its viscosity, cannot penetrate to a great depth as it does in the largest pores; it is then the overall volume of the grains which is considered as solid for the determination of the quantities or proportions of aggregates in the concrete [4]. Whatever it is, water can penetrate the pores; the amount and the rate of penetration depending on their size, their communication with each other and their total volume [5]. When all the aggregate pores are full of water, that is when the latter are saturated and superficially dry, if left in dry air, some of the water in the pores will evaporate and the aggregates will no longer be superficially dry [4]. Prolonged drying in an oven will reduce the humidity in the aggregates until no more water evaporates, the aggregates will be called dry [3].

in the porous space of aggregates we can distinguish two groups of voids: open pores and closed pores. The open pores form a continuous or blind porous system in the material [14]. The closed pores are isolated and are not interconnected. Only the open pore system can contribute to the transport of the material in the material [2]. the pores are interconnected, the higher the water absorption [6] [7]. The open porosity of the aggregates is an important characteristic which directly influences their hygrometric property and consequently the workability of the concrete and the water behavior of the cement paste with which they are in contact [2]. Porosity is, by definition, the ratio of the volume of voids to the total volume [1] [8].

The elevation of temperature causes strong cangements at the microstructure of concrete changes that will drive a shift in mechanical properties especially [17]. Indeed, heating leads to a mechanical deterioration of the concrete through the formation of microcracks[10]. These increase the conductivity of the material and therefore make the transport phenomena even more important [6]. A knowledge of the thermal properties is necessary for descption the behavior of concrete at high temperatures [14].

The study of thermal conductivity is of great technological interest, especially for applications that require the use of materials based or with high thermal conductivity[1,6]. This physical magnitude characterizing the materials during the heat transfer caused by a temperature difference between two region of a same medium or between two media in cntact (conduction) [18]. it is not, strictly, a property of the material since it sometimes depends on a large number of parameters including the method of manufacture [15] [20] [21], the history and the nature of the material, the temperature, the pressure, the humidity , the presence of cracks and even the surface state [6]. From a numerical point of view, it is the amount of heat-energy transferred per unit of isothermal area in a unit of time under a unit temperature gradient [2]. The thermal conductivity of various materials is generally determined experimentally by measuring methods based mostly on measuring surface flux and temperature gradient [6] [14] . In this text, the main objective of this work is to study the influence of the porosity of aggregates on the evolution of the thermal conductivity of a resinous concrete exposed to high temperatures.

2. Procédure éxpérimentale

2.1. Matériaux

Five types of aggregates tested are of three different types: limestone, silico-limestone and silica. The characteristics of the aggregates are presented in table 1. For each density and intergranular porosity, the values retained are the average of three tests. They are named by their nature and their form: the first letter refers to the mineralogical nature of the aggregate used (C for limestone, SC for silico-limestone and S silicon), and the following letter distinguishes the shape of the aggregates: Rolled (R) or Crushed (C). Fine aggregates have a maximum diameter between 3 to 5 mm and large aggregates have a maximum diameter between 8 and 15 mm.

Tabel 1

Caracteristics of aggragates

Aggregates		Densities (Kg/m3)					intergranular porosity (%)
		ρ_{vra}	ρ_{rs}	ρ_{re}	ρ_{app}	ρ_{abs}	Pint
Sands	SC1-R	1621	2453	2443	2516	2615	34
	SC2-R	1662	2614	2654	2582	2503	37
	SSC-C	1500	2565	2667	2650	2734	44
Gravels	GC-C1	1350	2213	2631	2721	2700	49
	GC-C2	1420	2295	2675	2723	2700	47

A global analysis shows that, whatever the type of density, the classification according to their values remains identical. The actual densities of the aggregates vary between 2213 and 2614 kg / m^3, which corresponds to common aggregates of limestone and silico-limestone origin as indicated by their geological formation. Their apparent densities are between 1350 and 1662 kg / m^3. We also note that the limestone sands (SC2-R and SC1-R) are characterized by the lowest absolute densities and the sand-lime sand (SSC-C) which is characterized by the highest value. However, the aggregates (GC-C1 and GC-C2) have an identical density characteristic intrinsic to the material for which the voids volumes are not taken into account.

The values of the intergranular porosity are relatively close for the two classes of gravel GC-C1 and GC-C2 of limestone nature, slightly higher than that of sand-lime sand (SSC-C). the latter which has fine elements and a greater granular extent, has the highest intergranular porosity than limestone sands (SC1-R and SC1-R) carrying similar values. The open porosity of the aggregates is an important characteristic which directly influences their hygrometric property and consequently the workability of the concrete and the water behavior of the cement paste with which they are in contact [2]. Porosity is, by definition, the ratio of the volume of voids to the total volume. The results of the porosity calculations are presented in the form of a histogram in Figure 1.

Analysis of the total porosities shows that the highest values are obtained for limestone aggregates. We find in descending order the limestone sands (6.57% for SC1-R and 6.03% for SC2-R) then the limestone gravel (5.31% for GC-C2 and 5.24% for GC-C1), and the sand-lime sand (2.45% for SSC-C). The highest open porosity is also observed for GC-C1 gravel (3.3%). Those of limestone sands are close (between

2.90% and 2.78%). The minimum value is measured for sand-lime sand SSC-C (0.64%) unlike water absorption. The minimum value corresponds to that of sand-lime sand, as for the total porosity. The aggregate porosities are comparable. It can also be noted that the porosity accessible to water represents 44 to 46% of the total porosity for limestone sands, 33% for gravel GC-C2, and 26% for sand-lime sand. However, this ratio reaches a value greater than 60% for the gravel GC-C2. Finally, there is a certain variability in the closed porosity values and a classification which does not follow those of the open or total porosities. Limestone aggregates are characterized by the highest values of closed porosity.

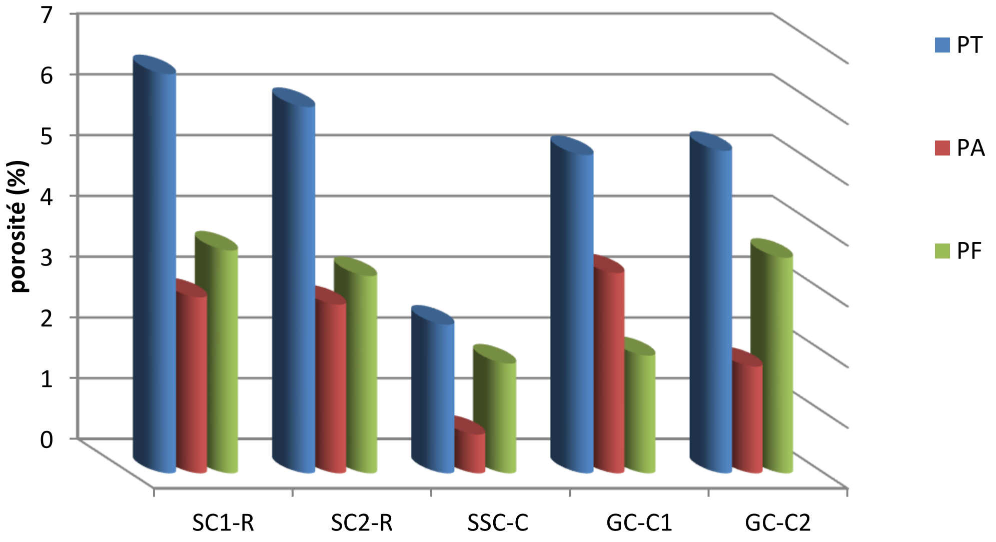

Fig. 1. Closed, total and accessible porosities with water of the various aggregates

2.1. Making of concrete

The epoxy resin used in this study is issue a mixture of Eponal 371V1 resin and hardener of the same denomination. A super-plasticizer type Cimfluid 3020, based on modified plycaboxylates, was used to ensure satisfactory plasticity of the different formulations without varying the amount of binder paste relative to that of the granular skeleton. This adjuvant, in accordance with the standard [EN 206-1], has a density of 1078 kg / m3, a dry extract of 30.81% [NF EN 480-8] and a viscosity of 59 cps at 25 °C. The recommended dosage varies from 0.2 to 2.5 kg per 100 kg of cement a mineral flame retardant was used the pure polymer concrete fireproofing.

Before proceeding with the actual manufacture proper of the resin concrete, preliminaries steps are necessary to obtain a product identical to itself and to minimize the effect of the elements related to the state and the quality of the incoming materials. in the composition of the resin concrete to be manufactured and as well also to the method of manufacture. The constituents must therefore be stored under favorable conditions according to the instructions of the manufacturer or the rules of the state of the art .Indeed, granulats should be dried at 105 °C, for more; 24 hours and the resin must be stored in the room at temperature-controlled. The measurements were performed on samples. The prismatic moulds were filled on three layers, and each layer received 40 shots with a metal bar. This phase is moving by the levelling of the upper surface of the specimens, with a rule according to saw movement Demolding of the samples are conserved in the room controlled at temperature and humidity (25 ° C and 50% RH), until a maturity of the experimental tests. The surfaces of the samples have been rectified with a diamond disc, to get two surfaces enough that were sufficiently level so that there was as little air as possible between the probe and the samples.

2.3. Thermal conductivity measurement

As part of this experimental study, the Hot Disk method was used to experimentally measure the thermal conductivity of the varieties of concrete tested using prismatic test pieces (4x7x14 cm) after 90 days. It represents the most robust technique for direct and absolute measurement of this thermal property which therefore does not require any prior calibration or any corrective factor [2]. In order to ensure a constant water content, the test pieces were kept in an oven until their mass did not change more than 0.2%. The Hot Disk probe is placed between two samples of the same concrete tested. This probe is used both as a heat source and as a temperature sensor. The system is based on the technology of the transient plane source ("Transient Plane Source" in English), in which the variation of electrical resistance linked to a variation of temperature [ISO 22007-2].

The principle of the TPS method consists in providing constant power for a limited time to the Hot Disk probe in order to raise the temperature of the type of concrete studied by a few degrees. It is also the probe which is used to measure the rise in temperature, thanks to the recording of the variation of its electrical resistance via a very precise Wheastone bridge [6]. The characteristics of the temperature increase, directly linked to the evolution of the electrical resistance of the probe, are precisely recorded and the analysis of this variation (transient regime) [9]. It is interesting to mention, that no contact agent (water, thermal paste, ...) was required because the effects of contact resistance are systematically detected by the device and removed by the operator [13].

2.4. Thermal cycle

In this study, we applied a hot heating cycle the ambient temperature to 25°C until exposure temperatures (bearing) equal to 105 ° C, 150 ° C, 200 ° C and 250 ° by means of an oven. The specimens were placed in an oven in a way allowing the heat to be distributed homogeneously in the enclosure with a ventilation system. A K type thermocouple is placed in contact with the surface of a control sample and another is embedded in the center in order to determine changes in temperature. Measurements of thermal conductivity of concrete studies were performed according to the following steps:

- ✓ Measurement of the thermal conductivity at room temperature. The measurement was performed three times with a regular time interval of 45 min.
- ✓ Heating the specimen at a rate of 1 °C/min, until the next measurement temperature.
- ✓ Maintenance of the temperature measurement for 15 h to ensure the heat and water homogeneity of the sample.
- ✓ Each measurement of thermal conductivity was carried out 3 times with a time interval of 45 min.
- ✓ Heating the specimen to the next temperature and repeating the cycle until the last temperature measurement (250 °C).

3. Experimental results

The variations in residual compressive strength and its deviation, for the three of the concrete mixes B (CR), B (C'-R) and B (SC-C), as a function of temperature, are plotted on Figures 2 and 3 respectively.

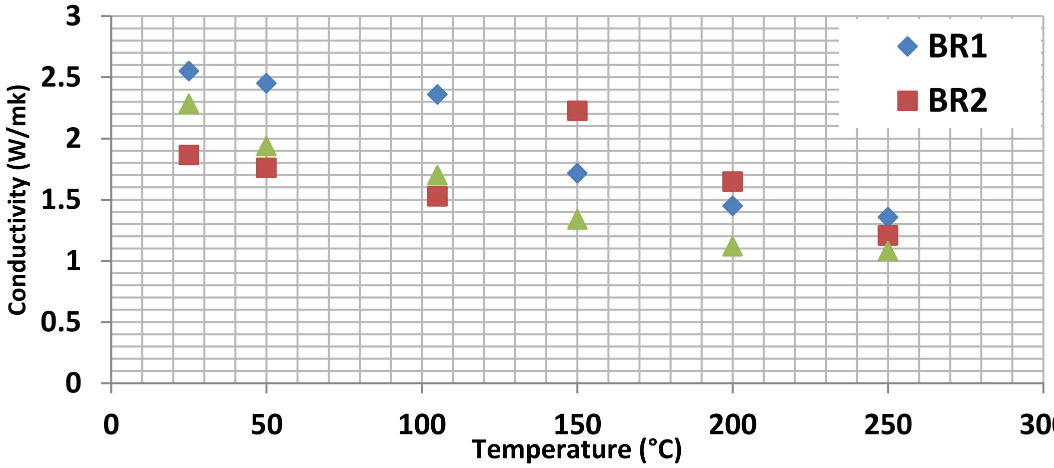

Fig. 2. Evolution of the thermal conductivity of concretes tested as a function of temperature

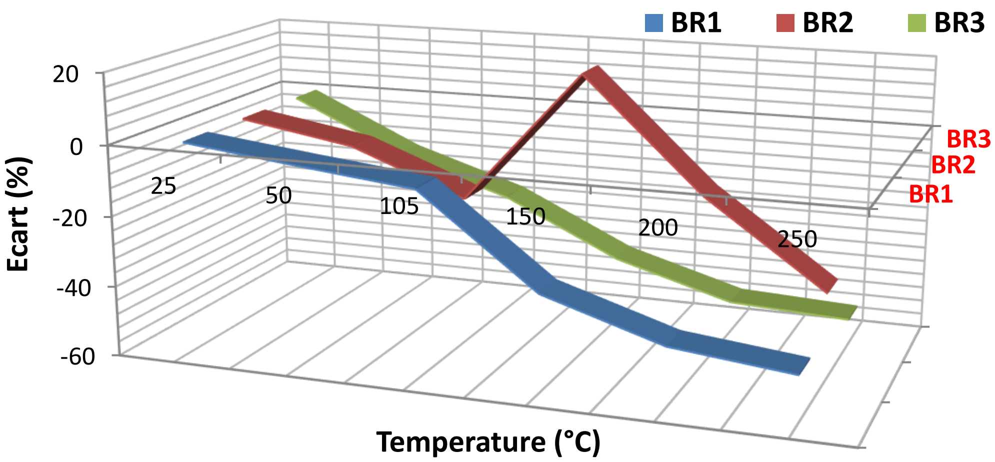

Fig. 3. Evolution of the ecart of thermal conductivity of concretes tested as a function of temperature

From these figures, we mainly notice that the thermal conductivity, for the three types of concrete tested, varies as a function of temperature. We can distinguish three consecutive phases in the evolution of compressive strength with temperature:

Phase (I) (ranging from 25 ° C to 105 ° C): in this first phase, the thermal conductivity of the different concretes is significantly lower than that recorded at room temperature. Between 25 ° C and 50 ° C, the composition BR1 has good thermal conductivity than that of the concretes BR3 and BR2 respectively. It reaches values higher than 2.4 W / mk when it is heated to 50 ° C.

Phase II (from 105 ° C to 200 ° C): In this temperature range, there have been various changes in thermal conductivity as a function of temperature. BR2 concrete has an equivalent increase from 105 ° C to 150 ° C and then a slight decrease from 150 ° C to 200 ° C. On the other hand, the two mixtures of concretes BR1 and BR3 show a strong decrease in thermal conductivity, reaching values less than 1.10 W / mk, when it is heated to 200 ° C.

Phase (III) (ranging from 200 ° C to 250 ° C): For temperatures between 200 ° C and 250 ° C, we observe that the positioning of the evolution values of the thermal conductivities begins to show gaps lines, that is to say the three categories of concrete, formulated based on different types of aggregate and porosity, do not keep the same classification of the evolution of thermal conductivity with respect to temperature.

The analysis of these experimental results allows us to make the following interpretations:

the decrease in the thermal conductivity of the concretes tested for temperatures between 25 ° C and 250 ° C, is mainly linked to the evaporation of free water. According to several authors [1], [9] and [10], this evaporation has been observed when the concrete is exposed to temperatures between 30 and 90 ° C. According to different studies [5], [9], and [14], the thermal conductivity of concrete depends on the thermal conductivity of each of its components according to more complex mixing laws than that used for the specific heat [5]. In particular, these mixing laws take into account the spatial distribution of the components in addition to the volume proportions of each. However, it is generally accepted that the thermal conductivity of concrete depends essentially on that of aggregates (Bazant and Kaplan 1996 [9]).

According to various studies [1], [2], [8], [9] [10] and [12], the presence of water in the form of steam at high temperature can also modify the physical and chemical structure of the cement paste. According to Basheer and al., the combination of hygrothermal conditions, can cause changes in the nature of hydrates [7]. These changes depend mainly on the C / S ratio (CaO / SiO_2), the temperature and the pressure prevailing in the material [2]. The value of this ratio influences the formation of various forms of hydrates resulting in the creation of various forms of hydrates with different mechanical properties [9]. It is necessary to mention that the properties of the material will also depend on the interaction between the paste and the aggregates and on the behavior of the transition halo [5].

In addition, the remarkable variation in the difference noted in the evolution of the thermal conductivity from one concrete to another, during the temperature variation, can be explained by the effect of the mineralogical nature of the constituent aggregates of these concretes on the evolution of thermal conductivity with temperature. According to several authors [1], [4] and [13], the behavior of aggregates at high temperatures is completely different. Similarly differents authors have shown that limestone aggregates exhibit good thermal behavior at high temperatures [1] [4] [9] [12] [13] [16] [18] and [19], and Benoudjafer also confirmed that the type of aggregate influences the behavior of concrete at high temperatures [16]. The loss of thermal conductivity is considerably less when the aggregate does not contain silica (some forms of silica undergo a dimensional change); this is the case with limestones [9].

4. Conclusion

The evolution of thermal conductivity varies with temperature. The causes of this variation are the same as that of the variation in mechanical resistance to compression (leaving water and increasing porosity REF. Leaving water by drying makes it possible to cause a non-negligible reduction in the conductivity of the material, because it is characterized by a high thermal conductivity, on the other hand, the creation of voids is due to the increase in porosity and the appearance of cracks.

The objective of this study was to study the influence of the porosity of aggregates on the thermal conductivity of the varieties of concrete tested. The materials which are the subject of this study are concretes of composition set up especially for the needs of the study. The characteristics studied were established in the reference state and compared with those determined at the various thermal gradients.

The synthesis of the observations and the experiments carried out noted that the evolution of thermal conductivity is strongly linked to the departure of free water, and to the evolution of the microstructure of concretes. This results in the variation of the porosity during the experimental procedure. Among the parameters significantly influencing the behavior of concrete material at high temperature is the presence of water in the material.

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