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Effect of Rubber Aggregates on the Thermophysical Properties of Self-Consolidating Concrete

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Abstract

In this work, our choice fell on the exploitation of rubber aggregates from used tires. In this context, an experimental study was conducted to provide more data on the effect of rubber aggregates on the thermophysical properties of self-consolidating concrete (SCC). To this end , four sets of rectangular specimens were prepared by varying the proportion of the rubber aggregates with percentages of 0%, 10%, 20% and 30% of the volume of gravel .Tests on hardened self-consolidating concrete rubber SCCR included measuring the thermal conductivity and the thermal diffusivity by the method of the boxes at steady and determining the specific heat . The results showed that the thermal conductivity and thermal diffusivity were decreased according to the increase of the percentage of rubber aggregates. This decrease was significantly improved thermal performance of the SCCR.

Keywords: Rubber aggregates; Self-consolidating concrete; Thermal conductivity; Thermal diffusivity; Specific heat

Nomenclature

T1	Temperature of upper face of sample	°C
T2	Temperature of down face of sample	°C
Ta	Ambient temperature	°C
TB	Temperature of the box	°C
S	Surface of sample	m^2
e	Thickness of sample	M
R	Heater	Ω
C	Over all heat transfer coefficient	W/m^2K
U	Potential difference	V
C_p	Specific heat	J/Kg.K
α	Thermal diffusivity	m^2/s
λ	Thermal conductivity	W/mK
ρ	Density	Kg/m^3
Φ	Heat flux	W

Introduction

Each year more than three million tires are discarded reaching the end of life. This is a cumbersome waste and environmental pollution ecology destabilizes [1]. The use of waste in construction materials can meet the need of conservation of natural aggregate resources (especially that the country can pose a significant lack in aggregate) and can also protect the environment by reducing landfill only to final waste [2]. Technological development in the manufacture of concrete through the creation of new additives allowed to make concrete more sophisticated including self-consolidating concrete (SCC). This material is characterized by its fluidity, ease of implementation and ability to fill formwork heavily armed. The possibility of designing a self-compacting concrete with rubber aggregates (SCCR) seems particularly interesting insofar as this material combines the properties of a SCC and of a material from the recycling of industrial waste which gives a cheapest composite [3,4]. Possible applications for this composite are very numerous. Examples include pavements, floors and walls [5]. These works are generally considered massive and sometimes they need to have more or less large thermal performance.

It is in this context that this work was developed; it is interested in providing a thorough analysis of the thermophysical properties of BAPC using local materials and incorporating rubber aggregates with percentages of 0%, 10%, 20% and 30% of the volume of gravel.

Experimental Study

Materials characteristics

The cement used was a CEM I 32.5 in conformity with Tunisian Standard NT 47.01produced by the Cement Company of GABES. It has an absolute density of 3.10 g/cm^3 and a Blaine specific surface of 380 m^2/Kg. The physical characteristics of the aggregates used in the preparation of concrete specimens are shown in Table 1.

The rubber aggregates are obtained by grinding used of-life tires following two particle-size cuts 0/4 and 4/8 (Figure 1). The actual density of rubber aggregates is equal to 0.95 g/cm^3.

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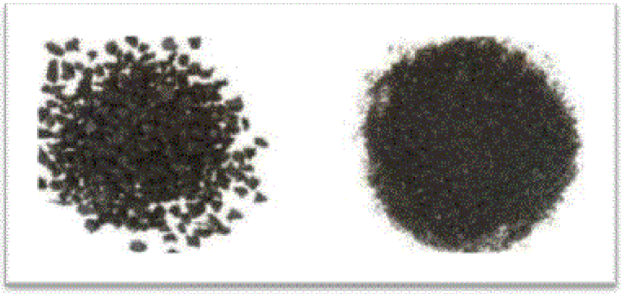

Figure 1: The rubber aggregates.

	Los Angeles (%)	Fineness modulus	Absorption (%)	Specific gravity (g/cm^3)
Sand 0/4	-	2.51	3.2	2.61
Gravel 4/8	34	-	2.5	2.73
Gravel 8/16	35	-	2.4	2.76

Table 1: Physical characteristics of the aggregates.

The employed admixture was a superplasticizer (SP) used to increase markedly the workability of concrete according to the requirements of NF EN 934-2+A1 [6]. The dosage was 1% by weight of cement. Its physicochemical characteristics of the used superplasticizer are given in Table 2.

Density	pH	Na_2OEq (%)	Dry extract (%)	Cl^-
1.06 ± 0.01	4.5 - 6.5	≤ 1%	28.0 - 31.0	≤ 0.1%

Table 2: Physicochemical characteristics of the super plasticizer.

Mixtures

Four sets of Parallelepiped specimens (270 mm x 270 mm x 40 mm) were prepared by varying the proportion of the rubber aggregates with percentages of 0%, 10%, 20% and 30% of the volume of gravel (Figure 2). The values (0, 10, 20, and 30) indicate the proportion of the rubber aggregates by substitution of the volume of gravel. The Self-Consolidating Concrete and the Self-Consolidating Concrete with Rubber aggregates were respectively designated as SCC and SCCR. The composition of all prepared mixtures is given in Table 3.

Effective water/cement ratio was 0.55 and kept constant in all mixtures. The parallelepiped specimens were used to determine the thermal conductivity and the thermal diffusivity of the different mixtures at the age of 28 days by the boxes method. Specific heat was predicted from the thermal conductivity and the thermal diffusivity data.

Test specimens were kept in their molds. After 24 h, they were removed from the mold and subjected to water curing at 20°C. At the correspondent age, the specimens were taken out and kept in laboratory conditions until testing time.

Test Procedures

Thermal conductivity measurement

The thermal conductivity for the mixtures was determined using parallelepiped specimens in accordance with the requirements of NF EN ISO 8990 [7]. The method used is the boxes method [8,9]. This is a device used in the laboratory of building physics that is capable to measuring thermal conductivity and thermal diffusivity of a material (Figure 3). The system consists of:

Boxes B1 and B2: manufactured against plated. They are isolated by the highly styrodure to prevent heat losses to the outside. A heating resistor (R) is placed inside the box B1to act as hot atmosphere.

- Enclosure: highly insulated chamber which acts as a cold atmosphere maintained at a temperature of θ = 4°C by a cooling system.
- Measuring strip: This is displayed on the different values of the temperatures sensed by temperature sensors platinum.
- The principle of measurement of the thermal conductivity is based on the realization of a unidirectional heat flow through the test sample and records the values of different temperatures.

Knowing that:

Where:

$$\phi_e=\phi_T+\phi_P \quad (1)$$

The flux emitted by the heating element is:

$$\phi_e=\frac{U^2}{R} \qquad (2)$$

The flux lost through the box is:

$$\phi_P=C.\left(T_B-T_a\right) \qquad (3)$$

The flux transmitted by conduction through the sample is:

$$\phi_T=\frac{\lambda\exp}{e}.S.\left(T_1-T_2\right) \qquad (4)$$

If we replace flows by their values, the following expression is obtained:

$$\frac{U^2}{R}=\frac{\lambda\exp}{e}.S.\left(T_1-T_2\right)+C.\left(T_B-T_a\right) \qquad (5)$$

According to equation (5), we can deduce the expression of the thermal conductivity λexp determined by the box method:

$$\lambda_{\exp}=\frac{e}{S.\left(T_1-T_2\right)}\left[\frac{U^2}{R}-C.\left(T_B-T_a\right)\right] \qquad (6)$$

Thermal diffusivity measurement

The thermal diffusivity measurements apparatus used in this study is the same as that for thermal conductivity measurement. In addition, the box (2) is fitted with an incandescent lamp of 1000 W at its superior face instead of the heating resistance (Figure 4). The internal faces of the box are reflective in order to homogenize the flow on the irradiated face of sample.

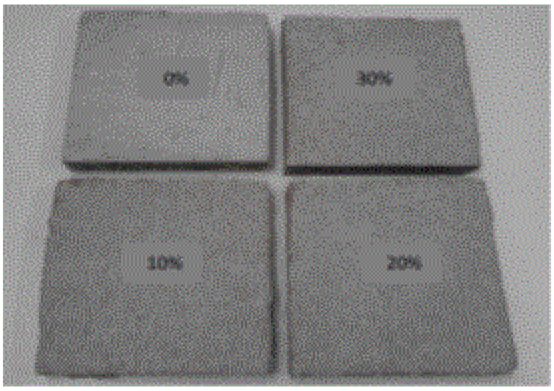

Figure 2: Parallelepiped Specimens tested.

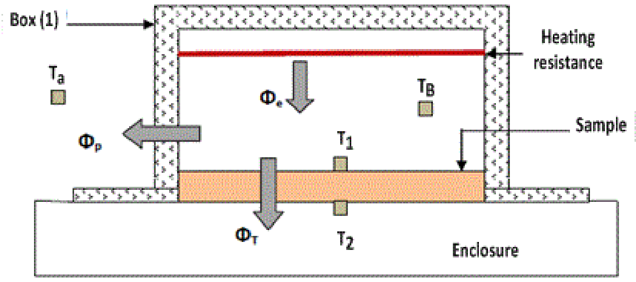

Figure 3: Thermal conductivity testing apparatus.

The principle of the experimental measurement method is to emit a heat flux, for a few seconds by means of the lamp, on one face of the sample and then the thermal diffusivity is evaluated from the temperature variation of the non-irradiated face of sample [10]. Using Degiovanni model based on the method of part-time [11], the thermal diffusivity is given as follows:

$$\alpha = \frac{\alpha 1/2+\alpha 2/3+\alpha 1/3}{3} \quad (7)$$

Where:

$$\alpha 1/2 = e^2\left[\frac{0.761t5/6-0.926t1/2}{(t5/6)^2}\right] \quad (8)$$

$$\alpha 2/3 = e^2\left[\frac{1.150t5/6-1.250t2/3}{(t5/6)^2}\right] \quad (9)$$

$$\alpha 1/3 = e^2\left[\frac{0.617t5/6-0.862t1/3}{(t5/6)^2}\right] \quad (10)$$

[$t_{i/j}$: the time corresponds to the ratio *i/j* of the maximum temperature (s)]

Specific heat

The specific heat (Cp) represents the heat amount required to raise the temperature by one degree of a mass unity of a material. More heat energy is required to increase the temperature of a substance with high specific heat capacity than when using low specific heat capacity material. Dividing heat capacity by the body's mass yields a specific heat capacity, which is no longer dependent on the amount of material but on the type of material and on the temperature.

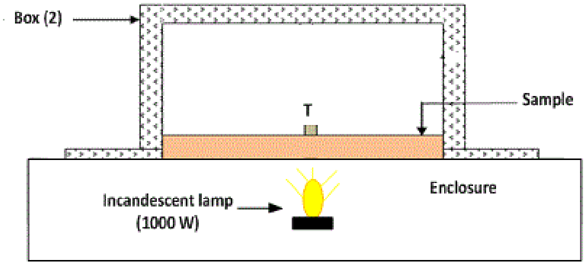

Figure 4: Thermal diffusivity testing apparatus.

The specific heat is determined from measurements of the thermal conductivity and diffusivity by using the following relation [12]:

$$Cp = \frac{\lambda \mathrm{exp}}{\rho . \alpha \mathrm{exp}} \quad (11)$$

Experimental Result and Discussion

Density of SCCR

Figure 5 shows the variation in dry density of the mixtures according to the content of the rubber aggregates. We note that the density decreases from 2150 kg/m^3 to 1702 kg/m^3 for content rubber aggregates ranging from 0% to 30% which corresponds to a reduction of about 21%, particularly useful in rehabilitation and relief structures. This is due to the low specific gravity of the rubber (0.95 Kg/m^3) compared to granulate (2.70 Kg/m^3) and to the increasing air entrainment in the matrix due to the nature non-polar of rubber [13].

Test results also revealed that the density of SCCR ranges from medium weight to normal weight depending on the percentage of rubber aggregates replacement.

Thermal conductivity

The results given in Figure 6 show that the addition of rubber aggregates considerably reduce the thermal conductivity of different mixtures of 1.3 W/m.K to 0.76 W/m.K. This decrease can be explained by the microstructure of mixtures. Indeed, air is trapped on the surface of rubber aggregates leading to an increase in the amount of air content.

Since the thermal conductivity of the air (0.025 W/m.K) is less than of the concrete (1.75 W/m.K), the air voids opposes the thermal transfer through the mixtures. In addition, rubber aggregates also restrain thermal flow because the thermal conductivity of the rubber aggregates (0.16 W/m.K) is less than that of aggregate (1.5 W/m.K).

Thermal diffusivity

Thermal diffusivity was determined experimentally on specimens having a parallelepiped shape with the box method. Figure 7 presents the results of the thermal diffusivity measurements. According to the results, we note that the incorporation of rubber aggregates considerably reduced the thermal diffusivity and hence improved the thermal insulation of different mixtures. For example, the SCC10R and SCC20R produced respectively a 32.95% and 42.28% reduction in thermal diffusivity.

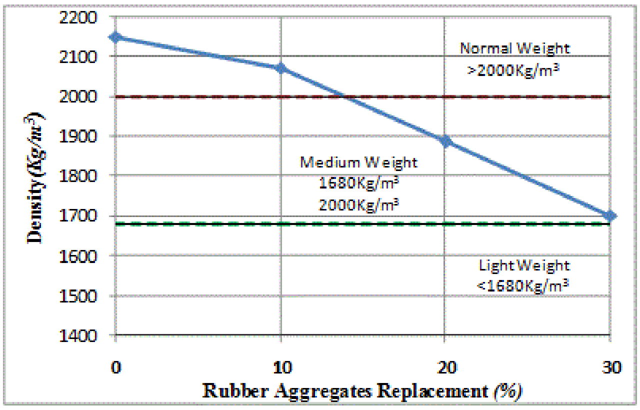

Figure 5: Effect of rubber aggregates on the dry density.

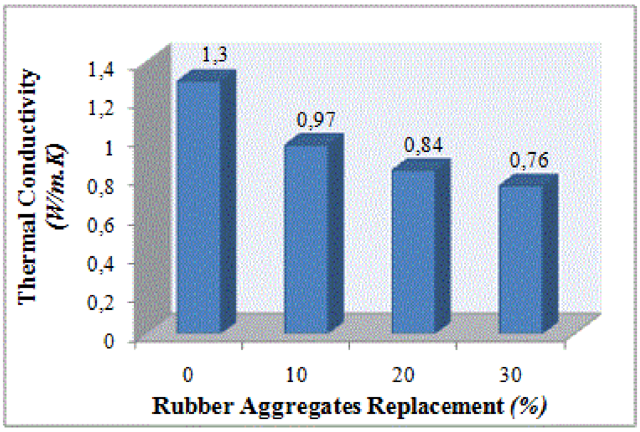

Figure 6: Effect of rubber aggregates on the thermal conductivity.

According to Figures 6 and 7, we note that a reduction of the thermal conductivity reduced the thermal diffusivity; this may be offset by the reduction in density necessary to achieve the lower thermal conductivity. For example, the SCC20R produced 35.38% reduction in thermal conductivity and also produced 42.28% reduction in thermal diffusivity.

Specific heat

The specific heat of the specimens was determined by calculation using equation (11) that combines thermal conductivity, density and thermal diffusivity into one value conform to the requirements of NF EN ISO 7345. According to the results shown in Figure 8, the specific heat of specimens was increased with increasing rubber aggregates replacement and can reach a value of 1380 J/Kg.K for a percentage of 30%. We note that thermal conductivity and specific heat varied in the opposite direction. For example, SCC30R produced 41.53% reduction in thermal conductivity and also produced 30% increasing in specific heat.

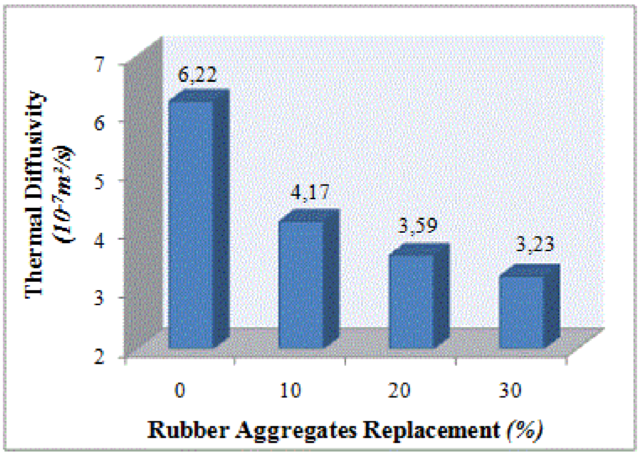

Figure 7: Effect of rubber aggregates on the thermal diffusivity.

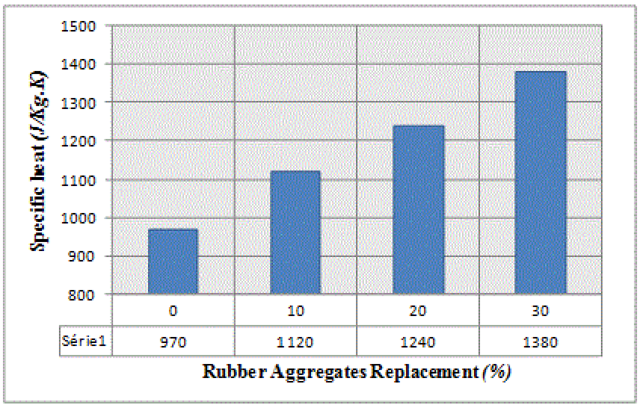

Figure 8: Effect of rubber aggregates on the specific heat.

Conclusion

The work presented concerning the effect of rubber aggregates on the thermophysical properties of SCC. An examination of the physico-mechanical behavior showed a reduction of the mixture up to 22% for a volume rubber content of 30%, which classifies the SCCR in the medium category.

The results also showed that the incorporation of rubber granulates allow reducing significantly the thermal conductivity of the mixtures. Furthermore, measurements of thermal diffusivity were highlighted SCCR capacity to transmit heat by conduction.

Furthermore, the addition of the rubber aggregates decreased the speed at which the heat is propagated in the material and thus increased specific heat to reach a value of 1380 J / kg.K for a percentage of 30%. This can affect the thermal performance of SCCR which were significantly improved by the incorporation of rubber aggregates.

Mixtures	W/C	Rubber [Kg]			Cement [Kg]	Water [Kg]	Gravel [Kg]		Sand [Kg]	Filers [Kg]	SP [Kg]
		%	0/4	4/8			4/8	8/16			
SCC0R	0.55	0	0	0	350	195	540	360	900	100	7.7
SCC10R	0.55	10	41.4	23.6	350	195	486	360	810	100	7.7
SCC20R	0.55	20	82.3	47.4	350	195	432	360	720	100	8.8
SCC30R	0.55	30	70.8	123.6	350	195	258	360	746	100	9.5

Table 3: Composition of the SCC and SCCR specimens.

Acknowledgments

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