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Optical Microscopic Characterization Of Polypropylene And Steel Fiber Reinforced Concrete At Evaluated Temperatures

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***Abstract*—Interest in the behavior of concrete at a high temperature mainly results from the many cases of fires taking place in buildings, high-rise buildings, tunnels, and drilling platform structures. Fundamental issues related to the impact of high temperature on concrete involve identification of the complex changes that take place in concrete while heated.**

This paper describes the behavior of concrete during heating in high temperature and the mechanical and physic changes in its structure. It is focused in the relationship between compressive strength and loss in weight of steel fibers and polypropylene reinforced concrete, treated at 200 ^{0}C, 400 ^{0}C and 600 ^{0}C.

This concerns both the physical and chemical changes taking place in the cement matrix, as well Research has demonstrated that changes in the strength of concrete as a function of temperature are related to concrete composition the type of aggregate used, the water/cement ratio, the presence of pozzolans additives, etc. Important factors are also the rate of heating and the time of

concrete exposure to high temperature. The comparison of a standard concrete to a SFRC and PPFRC are also given by studying various mixture in diverse ratio and sizes of fiber added.

12 series of concrete were cast using CEM II 32.5 R, local sand and local gravel with maximum size of 25 mm. Each series contained the same mix, ratio aggregate/cement of 2.67 and water/cement of 0.5. The main difference between the above series is the volume fraction of steel fiber and polypropylene fibers. Compressive strength and optical microscopy examination have been performed on 12 series of concrete.

Keywords*— *polypropylene fibers, steel fibers, concrete, temperature, compressive strength, optical microscopy .

I. Introduction

During a fire, the temperature may reach up to 11000C in buildings and even up to 13500C in tunnels, leading to severe damage in a concrete structure [1]. However, in some special cases, even much lower temperature, may cause explosive destruction of concrete, thus endangering the bearing capacity of the concrete element.[2]

The increase in temperature results in water evaporation, C-S-H gel dehydration, calcium hydroxide and calcium aluminates decomposition, etc.[3],[5]

Along with the increase in temperature, changes in the aggregate take place. Due to those changes, concrete strength and modulus of elasticity gradually decreases, and when the temperature exceeds ca. 3000C, the decline in strength becomes more rapid. When the 5000C threshold is passed, the compressive strength of concrete usually drops by 50% to 60%, and the concrete is considered fully damaged. [4]

- Impact of temperature effect on cement microstructure

During heating, ettringite decomposes first, even before the temperature reaches 100°C. C-S-H gel dehydration is progressive and takes place from the very beginning of material heating. It is worth noting that the structure of the cement paste is partially damaged due to dehydration at the temperature of 105°C, which is standard for the drying of materials. As soon as cement paste is heated to temperature of 500–5500 C, the portlandite content rapidly drops, as it decomposes according to the following reaction: [6]

$$Ca(OH)_2 \rightarrow CaO + H_2O$$

The portlandite decomposition reaction explains the observed increase in CaO content .The CaO created in this reaction makes the elements made of the Portland cement practically redundant after cooling. The dehydration process of the C-S-H gel reduces its volume, which in turn increases the porosity of the cement matrix. Moreover, during heating, the cement paste experiences a slight expansion up to temperature of approximately 200°C [5] although the intense shrinkage begins as soon as this temperature is exceeded. [7]

Aggregate

Aggregates occupy 70–80% of the volume of concrete and thus heavily influence its thermal behavior. The term “thermal stability of aggregates” is employed to describe aggregates effect on concrete performance at high temperature. [5]

Considering concrete behavior at high temperature, a suitable aggregate would be one with a low thermal strains coefficient as well as negligible residual strains. Another aspect necessary to be considered is the absence of peaks along the differential thermal analysis (DTA) and thermo gravimetric analysis (TGA) curves, which indicates no weight loss and no thermal reaction. [8]

Mineralogical composition determines aggregate thermal strains, since all minerals differ in their thermal expansion properties. The type of minerals governs the chemical and physical changes that take place during heating. For example: quartz aggregates and sands change at 574°C due to the β−α quartz inversion. [9]

The carbonate stones (limestone and dolomite) are stable up to 600◦C.

At higher temperature, carbonate aggregate decomposes into CaO and CO2 (700°C). Additionally, the CaO formed during decarbonation may hydrate when cooling, with a consequent 44% expansion. The polymineralic stones may be prone to the disintegration that results from the thermal incompatibility of its components.[10]

For those stones differences in thermal strain can cause inter-crystalline stresses and failure. The further heating of aggregate leads to its melting. The melting temperature varies along the mineralogical composition, for most igneous rock it is above 1000°C. The melting temperature of granites is 1210–1250°C, while basalts melt at 1050°C, which is accompanied by gas release and expansion.[11]

Table 1: The list of changes of concrete at high temperature

Temperature ranges	Change
20–200^{0}C	slow capillary water loss and reduction in cohesive forces as water expands
80–150^{0}C	
150–170^{0}C	Ettringite dehydration C-S-H gel dehydration;
300–400^{0}C	gypsum decomposition ($CaSO_4$ $2H_2O$); physically bound water loss;
460–540^{0}C	approx. 350°C break up of some siliceous aggregates 374°C critical temperature of water;
500–600^{0}C	
600–800^{0}C	Portlandite decomposition $Ca(OH)_2 \rightarrow CaO + H_2O$
800–1000^{0}C	573° C quartz phase change
930–960^{0}C	β−α in aggregates and sands;
	second phase of the C-S-H decomposition, formation of β-C_2S;
1050°C	dolomite decomposition
1300° C	calcite decomposition $CaCO_3 \rightarrow CaO+CO_2$ carbon dioxide release; ceramic binding initiation which replaces hydraulic bonds; basalt melting;
	total decomposition of concrete, melting.

Physical and mechanical properties changes of heated concrete

It is generally agreed [13, 14] that when heated to between 300°C and 600°C concrete containing siliceous aggregates will turn red; between 600 ^{0}C and 900 ^{0}C, whitish-grey; and between 900 ^{0}C and 1000 ^{0}C, a buff color is present. The color change of heated concrete results principally from the gradual water removal and dehydration of the cement paste, but also transformations occurring within the aggregate [15–16]. The most intense color change, the appearance of red coloration, is observed for siliceous riverbed aggregates containing iron.

This coloration is caused by the oxidation of mineral components [13–14]. While siliceous aggregates turn red when heated, the aggregates containing calcium carbonate get whitish. Due to calcination process $CaCO_3$ turns to lime and give pale shades of white and grey.

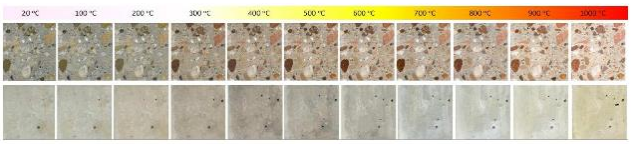

Fig 1: Color change of heated concrete: surface with exposed aggregates and external surface of the concrete specimen

II. MATERIALS AND METHOD

Experimental design

In order to investigate the relationship between compressive strength and loss in weight of steel fibers and polypropylene reinforced concrete, treated at 200 0C, 400 0C and 600 0C a series of 12 concrete samples were cast using CEM II 32.5 R, local sand and local gravel with maximum size of 25 mm. Each series contained the same mix, ratio aggregate/cement of 2.67 and water/cement of 0.5. The main difference between the above series is the volume fraction of steel fiber and polypropylene fibers. The hooked end steel fibers are 0.7 mm in diameter, and 30 and 50 mm in length with an aspect ratio of 67 and 47. Also, three different types of PP (polypropylene) fibers are used with different length of 3mm, 6 mm and 12 mm.

Mix design

The percentages of steel fibers used in the mixtures are 0, 25% and 0.5% by the volume of concrete. The percentage of PP fibers used in the above experiments is respectively 0.1% and 0.2% by the volume of concrete. The mix proportion of concrete is shown in Table 2. Some of the properties of steel fibers and polypropylene fibers used in this study are shown in Table 3 and Table 4.

Table 2: Mix proportions of concrete

Contents	Specific gravity kg/m^3
Sand	900
Cement	400
Coarse Aggregate 10-25 mm	670
Coarse Aggregate 5-10 mm	300
Water	200
Superplasticiziers	1
Ratio aggregate : cement	2.67
Ratio water : cement	0.5

Table 3: Properties of hooked-end steel fibers

Symbols of steel fibers	SF1	SF2
Fiber Length	50 mm	30 mm
Fiber Width	0.75 mm	0.75 mm
Aspect Ratio	67	44
Tensile Strength	>1100MPa	> 1450 MPa

Table 4: Properties of polypropylene fibers

Symbols of polypropylene fibers	PP1	PP2	PP3
Fiber Length	12 mm	6 mm	3 mm
Modulus of Elasticity	3900 N/mm^2	3700 N/mm^2	3500 N/mm^2
Extensibility	400 N/mm^2	370 N/mm^2	320 N/mm^2
Melting Point	170 ^{o}C	170 oC	170^{0}C
Elictrical Conductivity	Zero	Zero	Zero

In the figures below are shown images from steel fibers and polypropylene fibers used in the study

Figure 2 : Steel Fiber of length 3 cm and 5 cm

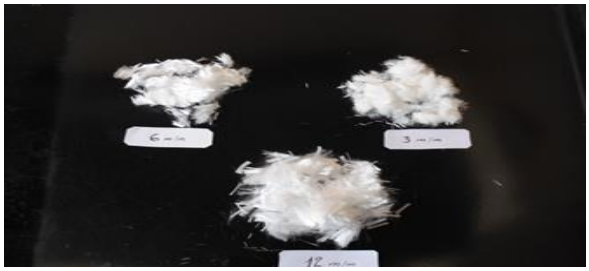

Figure 3 : Polypropylene fiber of length 3mm, 6mm and 12 mm.

Sample preparation and handling

The specimens were prepared by using cubic molding of 10cm X 10 cm. The specimens were heated in three different temperatures 200 0C, 400 0C, 600 0C by using an electrical furnace. The specimens were heated slowly at a constant rate of 200C/ min. Once the required temperature was attained, samples were cooled down until the time of testing for about 20-24 hours. In figure 4 the following procedures are shown to describe the preparation of samples in the mixing machine as per ASTM C 1116-91 standards

Figure 4: Mixing of samples in the mixture machine

Figure 5 .Compressive strength test on compressive test machine

Testing samples

The compressive strength of twelve mixtures are recorded in four different temperatures respectively 200 C, 200°C, 400°C, 600°C as described at EN 12390-3:1999.

(a) (b) (c)

Figure 6: Samples after heat exposure at (a) 200°C, (b) 400°C and (c) 600°C

IV. RESULTS AND DISCUSSION

Below are shown the results of compressive strength of 12 mixtures of hybrid reinforced concrete.

Table 1: Compressive Strength of mixture of 0.5 % of steel fiber with 0.2 % polypropylene fibers by the volume of concrete

Mixing Ratio	R1 N/mm^2 20 ^{0}C	R2 N/mm^2 200 ^{0}C	R3 N/mm^2 400^{0}C	R4 N/mm^2 600 ^{0}C
Standard	33.52	32.09	27.8	26.81
SF1-P1	37.1	36.1	35.1	33.9
SF1-P2	34.1	33.3	30.3	28.65
SF1-P3	35.9	31.41	30.9	30.06
SF2-P1	31.9	31.51	30.5	29.78
SF2-P2	36.29	27.52	26.8	25.5
SF2-P3	36.39	34.16	32.3	31.7

Table 2: Compressive strength of Mixture of 0.25 % of steel fibers with 0.1% polypropylene fibers by the volume of concrete

Mixing Ratio	R1 N/mm^2 20 ^{0}C	R2 N/mm^2 200 ^{0}C	R3 N/mm^2 400^{0}C	R4 N/mm^2 600 ^{0}C
SF1-P1	28.83	26.04	27.1	28.2
SF1-P2	35.04	31.63	31.19	30.92
SF1-P3	35.25	30.93	29.7	28.38
SF2-P1	30	28.7	26.67	22.42
SF2-P2	32	29.3	28.3	27.67
SF2-P3	32.5	31.9	28.1	23.57

In the figures below are represented some of images obtained by optical microscopy techniques

Figure 7 : Standard sample of concrete at room temperature

Figure 8 : Standard sample of concrete at 200^0 C

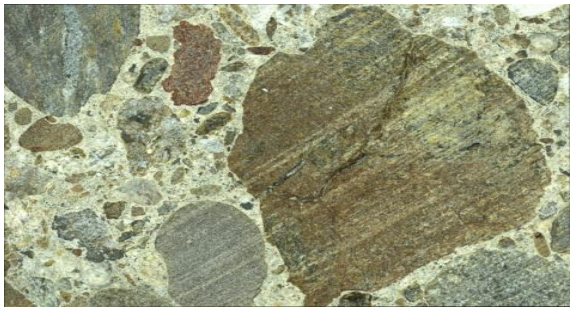

Figure 9: Standard Sample of concrete at 400^0C

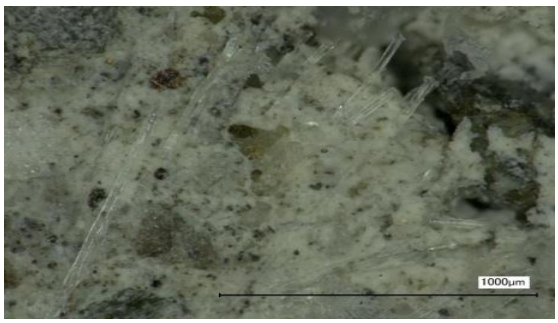

Figure10 : Polypropylene Sample of concrete at room temperature

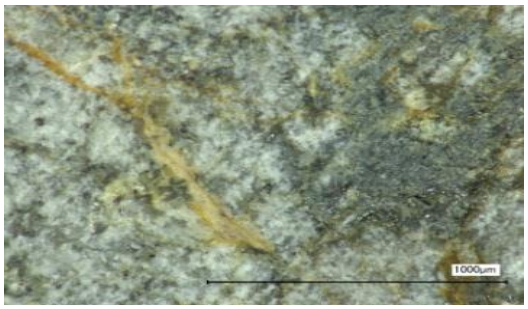

Figure 11 : Polypropylene Sample of concrete at 200^0C

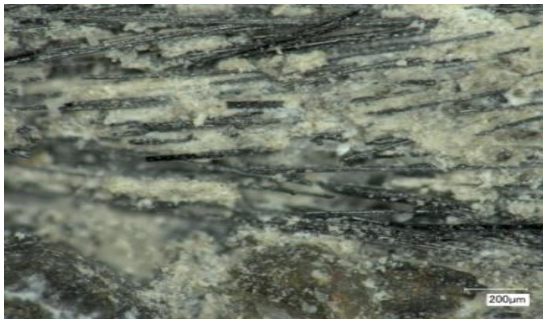

Figure 12 : Polypropylene sample of concrete at 400^0C

Figure 13 : Steel sample of concrete at room temperature

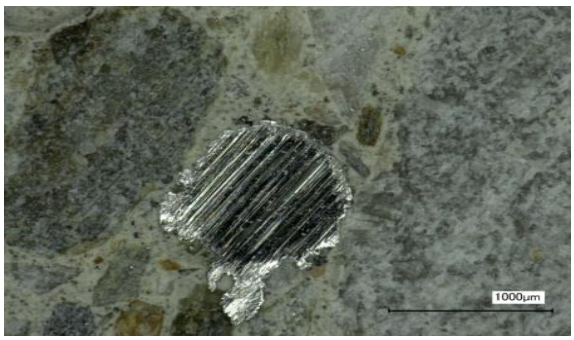

Figure 14 : Steel Sample of concrete at 200^0 C

Figure 15 : Steel Sample of concrete at 400 ^{0}C

The results and the figures obtained by optical microscope confirm the obvious difference in compression strength as well as the appearance of cracks this resulted more clear at the specimen of steel fiber concrete samples. It is observed the coloration of aggregates which turned red almost at 400 ^{0}C because of siliceous contain also the melt of polypropylene fibers and carbonatation of steel fibers.

V.CONCLUSIONS

1.It has been concluded the color change of concrete due to heating. The aggregate of concrete turned red

2.It was observed the melting of polypropylene fiber at 200 ^{0}C and total degradation at 400 ^{0}C and the oxidation of steel fiber at 400 ^{0}C

3.It was observed cracks of standard sample and steel reinforced concrete at 200 and 400 C

4.No cracks has been observed at all concrete with polypropylene fiber .

The compressive strength of fiber-reinforced concrete was higher than that for the plain concrete for all heating temperature up to 600 0C.

5. Fiber-reinforced concrete with 0.5 % steel fibers 5 cm(SF1) in length in combination with 0.2 % polypropylene fibers 12 mm(P1) in length has a superior behavior after exposure to a high temperature.

6. Fiber-reinforced concrete with 0.25 % steel fiber (SF2) 3cm in length in combination with 0.1 % polypropylene 3mm(P3) in length has shown the lowest value of compressive strength after heat exposure.

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