Physical and Thermo-Physical Properties of High Strength Concrete Containing Raw Rice Husk after High Temperature Effect

B. Akturk, N. Yuzer, N. Kabay

Abstract—High temperature is one of the most detrimental effects that cause important changes in concrete's mechanical, physical, and thermo-physical properties. As a result of these changes, especially high strength concrete (HSC), may exhibit damages such as cracks and spallings. To overcome this problem, incorporating polymer fibers such as polypropylene (PP) in concrete is a very well-known method. In this study, using RRH, as a sustainable material, instead of PP fiber in HSC to prevent spallings and improve physical and thermo-physical properties were investigated. Therefore, seven HSC mixtures with 0.25 water to binder ratio were prepared incorporating silica fume and blast furnace slag. PP and RRH were used at 0.2-0.5% and 0.5-3% by weight of cement, respectively. All specimens were subjected to high temperatures (20 (control), 300, 600 and 900°C) with a heating rate of 2.5°C/min and after cooling, residual physical and thermo-physical properties were determined.

Keywords—High temperature, high strength concrete, polypropylene fiber, raw rice husk, thermo-physical properties.

I. INTRODUCTION

HIGH temperature is one of the most detrimental effect that cause durability problems in constructions. This effect can cause permanent damages in constructions, can shorten the service life and may cause casualties, thus affecting the construction's sustainability [1]. When concrete is exposed to a high temperature effect such as fire, important changes may occur in its mechanical, physical, and thermo-physical properties. As a result of these changes, especially high strength concrete (HSC) may exhibit damages such as cracks and spallings [2]-[4]. Spalling is the violent or non-violent breaking off of layers or pieces of concrete from the surface when it is exposed to high temperatures which have been observed in many laboratory tests [5].

Incorporating synthetic, polymer fibers such as polypropylene (PP) into concrete is a common and very well-known method. PP fibers melt in low temperatures (~160°C) and provide micro pores (20-30μm) and thus decrease the vapor pressure and prevent spallings in concrete [6].

Xiao and Falkner [7] reported that high performance concretes containing PP fibers are effective to prevent spallings under high temperatures. Further, Filho and Sanjuan

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[8] reported that using low volume of PP in concrete is extremely effective in reducing free plastic shrinkage, in retarding the first crack appearance and in controlling crack development. Also, according to Nili and Afroughsabet, using PP between 0.2-0.5% by volume increases the compressive strength of concrete [9].

Besides these advantages, using PP fibers in concrete causes some difficulties such as aggravating the workability. In addition, PP fibers decompose at high temperatures and release harmful gases such as CO, CO_2 and mixed organic compounds [6].Furthermore, PP fibers are produced 53.4 million tons every year in all over the world and for each tons of production, 9.9 kg air, waste and water pollution occurs [10]. According to Purohit and Orzel, CO levels generated by the combustion of polypropylene were sufficient to produce lethal effects [11]. Therefore, in this study it is aimed to assess the usability of raw rice husk (RRH) in HSC production instead of PP fibers.

Rice is one of the main nutriments and is produced hundreds of million tons every year (701.1 million tons in 2010, according to the United Nations) all over the world. RRH is about 20% of the overall rice production [12]. Recycling of RRH may help to overcome possible stocking problems. RRH has been used in many applications; owing to its high energy capacity, as bio fuel to power boilers, as lightweight aggregate in lightweight concrete, its ash as a supplementary material and pozzolan in concrete, as insulation material owing to its lower thermal conductivity coefficient (0.036-0.086 W/mK) and would provide a decrease in the concrete's thermal conductivity in case of fire[13].In addition, RRH contains active carbon and is also used as a color and odor remover due to its high adsorbent capability. Additionally, it facilitates the release of vapor by generating micro pores and channels in concrete. In this manner, the use of RRH in concrete is thought to prevent spallings during fire. Additionally, the use of RRH in concrete is expected to absorb harmful gases due to its higher surface area and it is also expected that RRH could facilitate the release of vapor by generating micro pores and channels in concrete [14].

Many researchers used RRH's ashes as a pozzolan and investigated its effects on concrete. However, there are limited numbers of studies about using RRH as an additive in concrete. Yuzer et al. [15] conducted a series of research in normal strength concrete containing RRH as 1.5%, 3% and 5% of cement by weight and studied the compressive strength of concrete at elevated temperatures (300, 600 and 900°C).

They reported a loss of 4%, 16% and 25% in compressive strength of concrete by the increase in the amount of RRH. They also noted that 1.5% of RRH addition did not significantly affect the strength and that the compressive strength was reduced by 6%, 34% and 60% at 300, 600 and 900°C respectively.

In this research, RRH and PP fibers were added into concrete at 0.5-3% and 0.2-0.5% by weight of cement, respectively. Cement and water to binder ratio was fixed as 450kg/m³ and 0.25, respectively. Silica fume and blast furnace slag was used in all concrete mixes at 7% and 10% by weight of cement respectively and HSCs were produced. Residual physical and thermo-physical properties such as water absorption, pore ratio, vapor diffusion resistance factor and thermal conductivity coefficient of the HSC were determined in all specimens in the temperature range from 20 to 900°C.

II. EXPERIMENTAL DETAILS

A. Materials

A total of seven concrete mixes were prepared with ordinary Portland cement (CEM I 42.5R), two types of pozzolans; silica fume and blast furnace slag, three type of aggregates; limestone based coarse aggregates with maximum size of 12mm, crushed limestone and natural river sand with maximum size of 4 mm and superplasticizer (SP).

Physical properties of aggregates are presented in Table I and the chemical composition of cement and pozzolans are given in Table II. As additives, PP fibers and RRH are used. Physical properties of PP fiber and RRH are given in Tables III and IV. Sieve analysis results of RRH are presented in Fig. 1.

TABLE I
PHYSICAL PROPERTIES OF AGGREGATES

Material	Particle Density (g/cm³)	Aggregate Max. Size (mm)
Limestone coarse aggregate	2.76	12
Crushed limestone sand	2.72	4
Natural river sand	2.61	4

TABLE II
CHEMICAL COMPOSITION OF CEMENT AND POZZOLANS

Chemical composition	Cement	Silica fume	Blast Furnace Slag
CaO (%)	64.31	<1	33.75
SiO_2 (%)	19.75	>85	40.96
Al_2O_3 (%)	4.28	-	13.22
Fe_2O_3 (%)	3.48	-	1.15
MgO (%)	1.14	-	7.25
SO_3 (%)	2.7	< 2	0.35
Loss on ignition	2.57	< 4	0
Specific gravity(g/cm³)	3.15	2.33	2.78
Specific surface (Blaine, cm²/g)	3591	-	5465

TABLE III
PHYSICAL PROPERTIES OF POLYPROPYLENE FIBER

Material	Density (g/cm³)	Aspect ratio	Length(mm)	Melting point (°C)
Polypropylene fiber	0.91	24-32	19	160

TABLE IV
PHYSICAL PROPERTIES OF RAW RICE HUSK

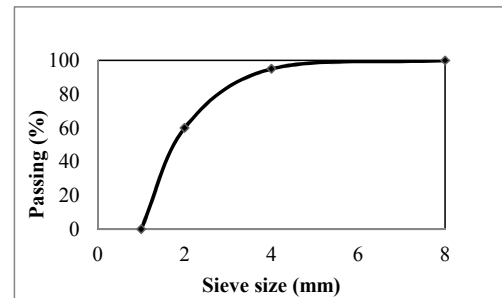| Material	Density (g/cm³)	Water absorption (%)	Length(mm)
Raw rice husk	0.122	124	8

Fig. 1 Sieve analysis of RRH

B. Concrete Mix Proportions and Curing

Totally, seven concrete mixtures were prepared. As additives, PP fiber and RRH were used and concrete series were coded according to the additives and their amounts in concrete. All additive amounts were calculated by weight of cement. PP fibers were 19mm long and were used at three different dosages as 0.2%, 0.4% and 0.5%. The proportions of RRHs were 0.5, 1.5 and 3% by weight of cement. Similar nominations for PP and RRH were used, for example, PP-0.5 and RRH-0.5 contain the same amount of additives to compare their effects on HSC.

The main component of the super plasticizer (SP) admixture was a modified polycarboxylate polymer. In order to maintain a slump value of 16±2cm, SP was used at varying dosages between 1.4 and 1.9%.

Concrete mix proportions were determined for 1m³ according to the relevant Turkish Standard TS 802 and mix proportions are presented in Table V. The amount of water was adjusted in RRH mixes. This was accomplished by taking the water absorption of RRH into account.

TABLE V
CONCRETE MIX PROPORTIONS

Mixture Code	N	PP-0.2	PP-0.4	PP-0.5	RRH-0.5	RRH-1.5	RRH-3
Cement (kg/m³)	450	450	450	450	450	450	450
Water (kg/m³)	127.5	127.5	127.5	127.5	127.5	127.5	127.5
Coarse Aggregate (kg/m³)	1128	1126	1126	1126	1098	1037	943
Crushed sand(kg/m³)	371	371	371	371	361	341	310
Natural Sand (kg/m³)	355	355	355	355	345	326	297
Silica Fume (kg/m³)	31.5	31.5	31.5	31.5	31.5	31.5	31.5
Blast Furnace Slag (kg/m³)	45	45	45	45	45	45	45
PP(kg/m³)	-	0.9	1.8	2.25	-	-	-
RRH(kg/m³)	-	-	-	-	2.25	6.75	13.5
Superplasticizer (%)	1.7	1.75	1.8	1.9	1.4	1.5	1.6

For each mixture Φ100/200 mm cylindrical, 100*100*100

mm cubic and 200*200*40 mm prismatic specimens were cast and kept in water for 28 days. Then, they were air-dried in the laboratory for another 26 days and to evaporate free water and oven dried at 100±5°C for 48 hours, before the high temperature effect. After this period, the specimens were subjected to a heating-cooling regime, as described in Fig. 2. All tests were performed at 56 days.

C. Testing Procedure

The specimens were heated in an electric furnace at the age of 56 days. The heating rate was 2.5°C/min. All specimens were kept for 2 hours at the target temperature and then allowed to cool naturally to the room temperature in furnace. All tests were conducted at room temperature. Temperature-time curve of the furnace is given in Fig. 2.
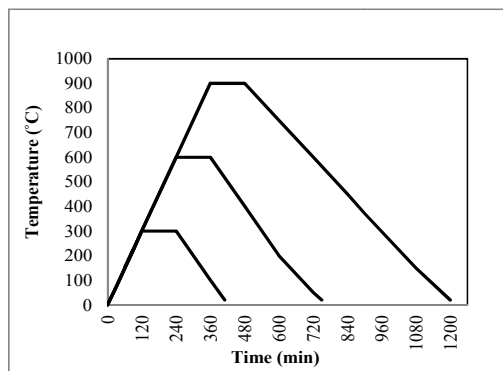
Fig. 2 Heating-cooling curves

D. Physical Testing

After exposed to high temperature, unit weight, pore ratio and water absorption were determined for each series according to ASTM C642-06 on 4 specimens. In this test, 100*100*100mm cube specimens were cut using a diamond saw in order to obtain 100*100*40 mm prismatic specimens and test was conducted on these specimens [16]. Average values of unit weight, pore ratio and water absorption are shown in Figs. 7-9, respectively.

E. Thermo-Physical Testing

Vapor diffusion resistance factor (VDRF) and thermal conductivity were determined for all series. VDRF is a parameter related to the pore structure of specimens. It is well known that as the pore ratio increases, spalling risk of concretes decrease. To determine the VDRF of the specimens, they were placed in vapor-tight cups containing a $CaCl_2$ sorbent. The cups were then placed in a controlled atmosphere cabinet at constant air temperature with 20±2°C and relative humidity at 85±3%. All specimens were weighed at 24 h time intervals in order to determine the quantity of moisture diffused through the specimen. The VDRF was determined according to TS EN 12086 on five cylindrical specimens with dimensions of Φ100/40 mm [17].

Thermal conductivity of concrete increases with increasing moisture content. Since water has conductivity about 25 times that of air, it is clear that when the air in the pores has been partially displaced by water or moisture, the concrete must have greater conductivity [18].

The thermal conductivity of concrete was determined according to TS ISO 8302 on twoprismatic specimens with dimensions of 200*200*40mm [19]. Test is performed using a double sided apparatus (Fig. 3). Specimens were placed on either side of the hot surface assembly. The heat transferred through the specimens is equal to the power supplied to the main heater. Thermal equilibrium is established when temperature and voltage readings are steady and after that thermal conductivity was determined according to (1).

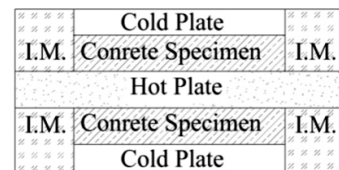$$\lambda = \frac{\Phi d}{A(T_1 - T_2)} \tag{1}$$

Fig. 3 Thermal conductivity test setup
*I.M.: Insulation material

In this equation, λ is the thermal conductivity, Φ is the power, d is the thickness of the specimen, A is the specimen area and T_1 and T_2 are the surface temperatures of the specimens.

III. RESULTS AND DISCUSSIONS

A. Spalling and Crack Observations

Increasing temperature causes a vapor pressure build up within the concrete. Especially in HSC, spalling is a major problem due to its very low porosity [20]. As explosive spalling is governed by a vapor-pressure mechanism, it is reasonable to consider that concrete incorporating PP fiber can provide a benefit to concrete so as to prevent it from explosive spalling, due to the fact that it melts at a temperature around 160°C and hence moisture in concrete can escape through inter-connected pores of concrete [21].

During high temperature effect, explosive spallings occurred (Fig. 4) in reference concrete (N) at 425°C and in RRH-0.5 and RRH-1.5 at 455°C. Spalling was prevented effectively in all PP series; however, only RRH-3 was successful in preventing spalling among all RRH series.
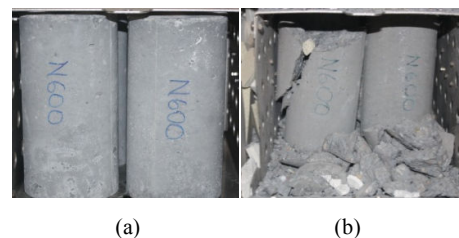

(a)   (b)

Fig. 4 N series before (a) and after (b) explosive spalling

After subjected to high temperatures, the damage on concrete specimens can be roughly detected by observing their surfaces. So, assessment of fire-damaged concrete usually starts with visual observations of cracks, color change and spalling [22]. The concrete surfaces after exposed to high temperatures can be seen from Fig. 5. Until 300°C, there was no visible crack on the surface of the specimens. The concrete started to crack when the temperature increased to 600°C but this effect was not significant at that temperature. The cracks became very pronounced at 900°C and all specimens collapsed within three days (Fig. 5).
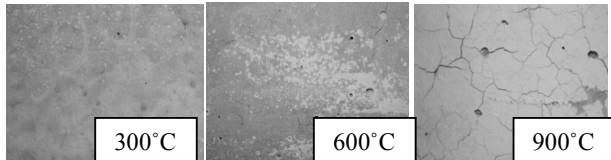

Fig. 5 Surface texture of the concrete specimens exposed to high temperature

B. Physical Tests

The average values of unit weight, pore ratio and water absorption tests are presented in Fig. 7, Fig. 8 and Fig. 9, respectively.

After exposed to 900°C, all specimens collapsed within three days (Fig. 6). Thus, no measurement could be taken at this temperature.

Fig. 6 Decomposition of a specimen exposed to 900°C

Unit weight, pore ratio and water absorption percentages were calculated according to ASTM C642-06 [16].Unit weight of normal weight concretes ranges between 2000-2600kg/m³[23].

As the temperature increases to 300°C, free and chemically bound water vaporizes and generated micro pores causes a decrease in the unit weight. At 400°C, cement hydrates and calcium hydroxide starts to decompose and that causes additional drops [24], [25].

At room temperature, unit weight of all series was in the range of 2450 and 2540kg/m³. Since the addition of RRH produce more pores, unit weight decreases with the increase of RRH. At 300°C, vaporization of free and chemically water results in a slight drop in unit weight. This decrease was about 3% in all series. As the temperature reached to 600°C, due to explosive spalling, test could only be conducted on PP series and RRH-3 series. As a result of the tests, RRH-3 mix possessed the minimum unit weight as 2270kg/m³ while PP-0.4 mix had the maximum with 2360kg/m³ (Fig. 7).
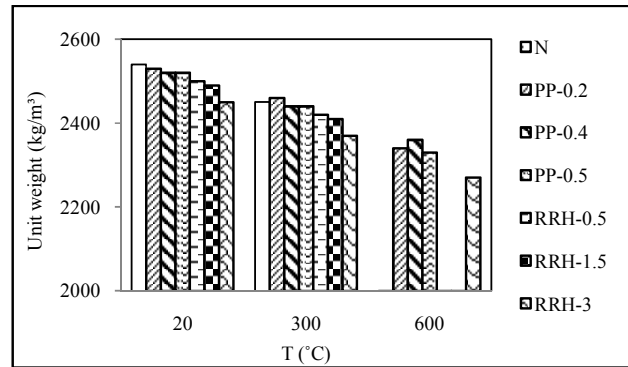

Fig. 7 Effect of temperature on unit weight of HSC with PP and RRH
* No measurements could be taken from N, RRH-0.5 and RRH- 1.5 series due to spalling

The pore ratio and water absorption percentages were calculated according to ASTM C642-06 [16]. These two parameters are related with each other. It is known that as the pore ratio increases, water absorption amount increases. It can be seen from Figs. 8 and 9 the pore ratio and water absorption amounts of concretes increased with an increase in the additive amounts and temperature. At 20°C, while the pore ratio of reference concrete (N) was 1.9%, in RRH-3 that value was 4.7%. From 20 to 300°C, pore ratio showed a great increase of about 400%. This phenomenon could be explained by vaporization of free and chemical bound water at 300°C and by the formation of micro cracks. The increase in the temperature from 300 to 600°C,the highest increase was observed in PP-0.5 and RRH-3 series, with 35%.

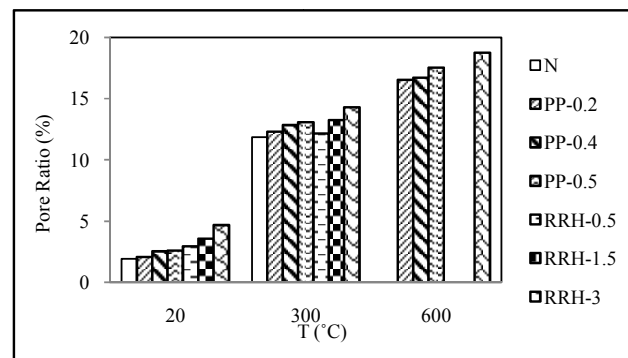Water absorption results showed the same trend with pore ratio (Fig. 9).

Fig. 8 Effect of temperature on pore ratio of HSC with PP and RRH
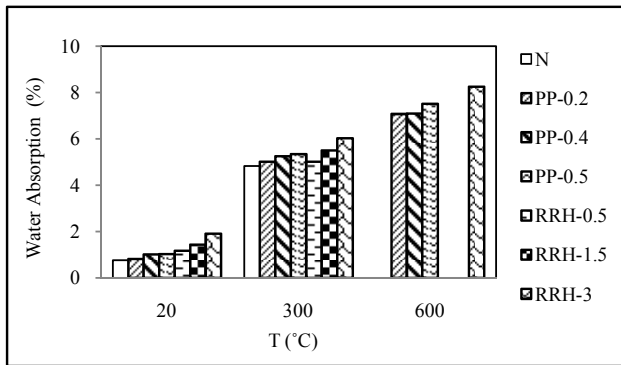** No measurements could be taken from N, RRH-0.5 and RRH- 1.5 series due to spalling*

Fig. 9 Effect of temperature on water absorption of HSC with PP and RRH
No measurements could be taken from N, RRH-0.5 and RRH- 1.5 series due to spalling

C. Thermo-Physical Tests

The thermal conductivity of conventional normal and high strength concrete at room temperature ranges between 2.3 and 2.8W/mK [18]. The measured thermal conductivity of all series is shown in Fig. 10 as a function of temperature. Considering all concrete series and temperatures, thermal conductivity ranged between 2.62 and 1.85W/mK at room temperature. Due to its low thermal conductivity (0.036-0.086W/mK) concrete series containing RRH had lower values compared to mixes with PP fibers (Fig. 10).

After exposure to 300˚C, thermal conductivity of reference concrete (N) and PP series decreased by about 10 and 8% considering their initial thermal conductivity, respectively. After this temperature, at 600°C and 900°C, as PP amount increased, thermal conductivity decreased. In RRH series, no significant change was observed until 600°C and at 900°C RRH-3 had the lowest value with 1.46W/mK among all series.
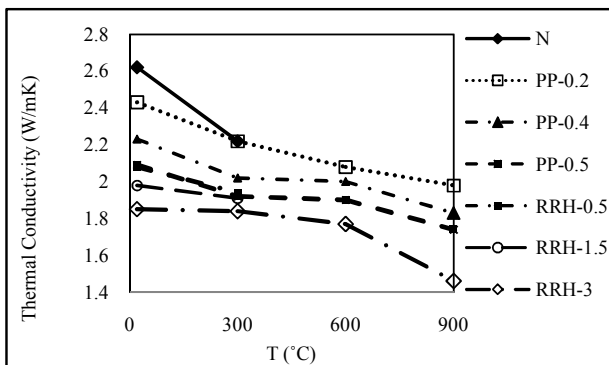

Fig. 10 Effect of temperature on thermal conductivity of HSC with PP and RRH
No measurements could be taken from N, RRH-0.5 and RRH- 1.5 series due to spalling

As the temperature and additive amounts increased, VDRF decreased due to the increase in pore ratio. At 300˚C, VDRF of all series began to reduce drastically about 50%. This reduction could be explained by vaporization of free and chemically bound water. At 600°C, PP-0.2 had the maximum value with 43, while RRH-3 had the lowest with 23 (Fig. 11).
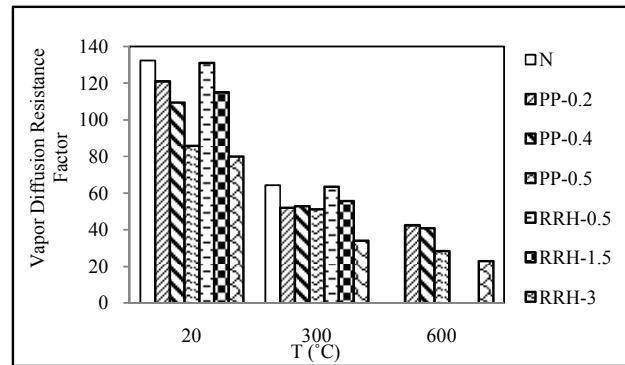

Fig. 11 Effect of temperature on VDRF of HSC with PP and RRH
No measurements could be taken from N, RRH-0.5 and RRH- 1.5 series due to spalling

IV. CONCLUSIONS

The addition of raw rice husk into the concrete was found to be effective in preventing explosive spalling. Experimental results showed that when raw rice husk (RRH) was added 3% by weight of cement, explosive spalling didn't occur.

The increase in temperature resulted in increase in pore ratio and water absorption. This increase is remarkable especially at 300˚C due to the vaporization of free and chemically bound water. At all temperatures RRH mixes possessed the maximum pore ratio and water absorption values.

Since RRH has a low thermal conductivity, all series containing RRH showed lower thermal conductivity values compared to those with polypropylene fibers (PP). Also, RRH decreased the vapor diffusion resistance factor at all temperatures and possessed lower values compared to series containing PP.

The results obtained from this study confirm that raw rice husk, as a sustainable material, when used at definite ratios, can effectively prevent spalling and thus can be a suitable alternative to PP.

It may be concluded that since RRH has ability to decrease thermal conductivity of concrete, heat transmission will be delayed in case of a fire. Thus, addition of RRH in concrete may help to decrease casualties, especially when used as a coating material in important buildings such as tunnels.

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