

Mechanical Properties and Released Gas Analysis of High Strength Concrete with Polypropylene and Raw Rice Husk under High Temperature Effect

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Abstract—When concrete is exposed to high temperatures, some changes may occur in its physical and mechanical properties. 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 well-known method. In high temperatures, PP decomposes and releases harmful gases such as CO and CO₂. This study researches the use of raw rice husk (RRH) as a sustainable material, instead of PP fibers considering its several favorable properties, and its usability in HSC. RRH and PP fibers were incorporated in concrete at 0.5-3% and 0.2-0.5% by weight of cement, respectively. Concrete specimens were exposed to 20 (control), 300, 600 and 900°C. Under these temperatures, residual compressive and splitting tensile strength was determined. During the high temperature effect, the amount of released harmful gases was measured by a gas detector.

Keywords—Gas analysis, high temperature, high strength concrete, polypropylene fibers, raw rice husk.

I. INTRODUCTION

ONE of the most detrimental effects that cause durability problems in constructions is high temperature. This effect can cause permanent damages in constructions, can shorten the service life and may cause casualties, thus affecting the construction's sustainability. When concrete is exposed to high temperatures for some reasons such as fire, some changes may occur in its physical and mechanical properties. As a result of these changes, especially in high strength concrete (HSC), concrete may exhibit damages such as cracks and spallings [1]-[3]. Explosive spalling, which refers to a sudden and violent breaking away of a surface layer concrete, has been observed in many laboratory tests of HSC specimens [4], [5].

To overcome this problem, incorporating polymer fibers such as polypropylene (PP), synthetic fibers, etc., in concrete is a common and well-known method. PP fibers melt in low temperatures (~160°C), provide micro pores and thus decrease the vapor pressure and prevent spallings in concrete [6].

Kalifa et al. reported that an amount of 1kg/m³ of PP fiber addition would be sufficient to avoid spalling of concrete [1]. Diederichs et al. and Nishida et al. found that the use of 0.1%

of PP fiber provided a decrease in thermal stress induced spalling damage of HSCs, compared to those with no fiber [7]. Therefore, in this study, in order to prevent spalling due to high temperature effect, concretes containing various amounts of PP fiber were cast.

Beside these advantages, PP decomposes in high temperatures and release harmful gases such as CO, CO₂ and mixed organic compounds [8]. CO levels generated by the combustion of polypropylene were sufficient to produce the lethal effects [9]. It is also well known that during the production of PP fibers, significant air, environmental and waste pollution occurs. Every year 53.4 million tons of PP fibers are produced in all over the world and for each tons of production, 9.9kg (air, water and waste) pollution occurs [10]. This study researches the use of raw rice husk (RRH) instead of PP fibers considering its several favorable properties, and its usability in HSC.

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 and RRH is about 20% of the overall production [11]. RRH has been used in many applications; as fuel in rural areas, as raw material in refractory production in countries such as Egypt and Japan, as lightweight aggregate in lightweight concrete, as an insulation material owing to its lower thermal conductivity coefficient (0,036-0,086 W/mK) and its ash as a pozzolan in concrete [12]. Active carbon is obtained by burning RRH in air-free conditions. Due to its high active carbon content, RRH is also used in industry as color and scent compensator. Additionally, the use of RRH in concrete is expected to absorb harmful gases due to its silica content and higher surface area and it is also expected that RRH could facilitate the release of vapor by generating micro pores and channels in concrete [13]. Yuzer et al. performed 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 [14].

In this study, RRH and PP fibers were incorporated in HSC at 0.5-3% and 0.2-0.5% by weight of cement (450kg/m³) respectively. Silica fume and blast furnace slag were used in

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all concrete mixes and HSCs were produced. Concrete specimens were exposed to 20 (control), 300, 600 and 900°C. Under these temperatures, residual compressive and splitting tensile strength was determined. During the high temperature effect, the amount of the released harmful gases (CO and CO₂) was measured by a gas detector.

II. EXPERIMENTAL DETAILS

A. Materials

Concretes were prepared by using Portland cement (CEM I 42.5R), two types of pozzolanas (silica fume and blast furnace slag), aggregates (limestone coarse aggregates, natural river sand and crushed limestone) and superplasticizer. Physical properties of aggregates are presented in Table I. As additives, PP and RRH are used. The chemical composition of cement and pozzolanas are given in Table II. Physical properties of PP fiber and sieve analysis results of RRH are presented in Tables III and IV.

TABLE I
PHYSICAL PROPERTIES OF AGGREGATES

Material	Particle Density (g/cm ³)	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 POZZOLANAS

Chemical composition	Cement	Silica fume	Blast Furnace Slag
CaO (%)	64.31	<1	33.75
SiO ₂ (%)	19.75	>85	40.96
Al ₂ O ₃ (%)	4.28	-	13.22
Fe ₂ O 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/cm ³)	3.15	2.33	2.78
Specific surface (Blaine, cm ² /g)	3591	-	5465

TABLE III
PHYSICAL PROPERTIES OF POLYPROPYLENE FIBERS

Chemical composition	Density (g/cm ³)	Length (mm)	Aspect Ratio	Melting Point (°C)
Homopolymer polypropylene	0.91	19	24-32	160

TABLE IV
SIEVE ANALYSIS OF RAW RICE HUSK

Sieve Size (mm)	1	2	4	8
Passing	0	60	100	100

B. Concrete Mixture Proportions

Seven concrete mixtures were made using Portland cement, silica fume and blast furnace slag with constant water to binder ratio (25%). Cement weight was kept constant at 450 kg/m³.

Superplasticizer was used at varying dosages between 1.4% to 1.9% of binder by weight to maintain a slump value of 16±2cm.

Pozzolanas are widely used in HSC. Silica fume makes the pore structure of concrete much denser. Silica fume and blast furnace slag was added to mixes as 7% and 10% of cement by weight respectively. PP fibers were 19mm long and were used at 3 different dosages (from 0.2% to 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.

Concrete mix proportions were determined for 1m³ according to the relevant Turkish Standard TS 802 and mix proportions are presented in Table V.

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

For each mixture Φ 100/200mm cylindrical specimens were cast in steel moulds and compacted with a vibrating table. The specimens were kept in water for 28 days. After 28 days, concrete specimens were kept in laboratory conditions and then oven dried at 100±5°C for 48 hours to evaporate free water. After this period, the specimens were subjected to a proper heating-cooling cycle, as described in Fig. 1. The tests were performed at 56 days.

C. Testing Procedure

At the age of 56 days, the specimens were heated in an electric furnace. The heating rate was 2.5°C/min. All specimens were kept for 2 hours at the target temperature and allowed to cool naturally to the room temperature in furnace. Mechanical tests were conducted at room temperature. Temperature-time curve of the furnace is given in Fig. 1.

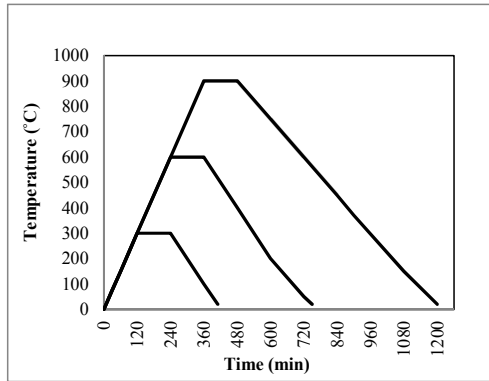


Fig. 1 Heating-cooling curves

After exposed to 900°C, all specimens collapsed within three days. This phenomenon is explained by the decomposition of hydrates, which starts at 400°C and almost ends at 900°C (Fig. 2) [15].



Fig. 2 Decomposition of a specimen exposed to 900°C

D. Mechanical Testing

After exposed to high temperature, compressive and splitting tensile strengths were determined for each series.

Compressive strength was determined according to EN 12390-3 and the test was conducted on 6 cylindrical specimens. Splitting tensile strength test was conducted on 4 cylindrical ($\Phi 100/200\text{mm}$) specimens according to EN 12396.

Average compressive and splitting tensile strength values are shown in Figs. 4 and 5, respectively; and standard deviation values of test results are given in Table VI.

E. Gas Measurement

During high temperature effect, released CO and CO₂ amounts were determined by gas detector for each series. 6 cylindrical specimens ($\Phi 100/200\text{mm}$) with a total volume of 9.5dm³ were placed to the electrical furnace. While the specimens were heated, gas measurements were taken in regular intervals from the stack of the furnace. Maximum values among the all obtained data were considered for the evaluation.

TABLE VI

STANDARD DEVIATION VALUES OF MECHANICAL TESTS

Experiments	Series	Temperature (°C)			
		20	300	600	900
Compressive strength (MPa)	N	15	12	*	*
	PP-0.2	10	17	4	15
	PP-0.4	7	8	6	0
	PP-0.5	10	19	3	2
	RRH-0.5	6	17	*	*
	RRH-1.5	7	17	*	*
	RRH-3	13	10	2	4
Splitting tensile strength (MPa)	N	1.3	0.5	*	*
	PP-0.2	0.8	0.4	0.1	0
	PP-0.4	0.2	0.5	0.3	0
	PP-0.5	0.7	0.7	0	0.1
	RRH-0.5	1.6	0.7	*	*
	RRH-1.5	1.4	0.5	*	*
	RRH-3	1.5	0.6	0.3	0.1

* No measurements could have been taken from N, RRH-0.5 and RRH-1.5 series due to spalling.

III. RESULTS AND DISCUSSIONS

A. Compressive Strength

The residual compressive strength of the concrete mixtures was determined after exposed to different temperatures. The variation of the compressive strength values with temperature is shown in Fig. 4. PP fibers did not have any significant effect on the strength of HSCs at room temperature, whereas, RRH caused a slight drop. In all series, as the temperature increased to 300°C, the compressive strength decreased by almost 20% due to vaporization of free and chemically bound water. The maximum loss was seen in RRH-3 mixture with 31%.

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. Between 300 and 600°C, in reference concrete mixes (N) at 425°C and in RRH-0.5 and RRH-1.5 at 455°C explosive spallings occurred (Fig. 3). Spalling was prevented effectively in all PP series; however, only RRH-3 was successful in preventing spalling among all RRH series.



Fig. 3 Explosive spalling at 425°C on N series

As seen in Fig. 4, at 900°C, all series could keep only about 10% of their original strength.

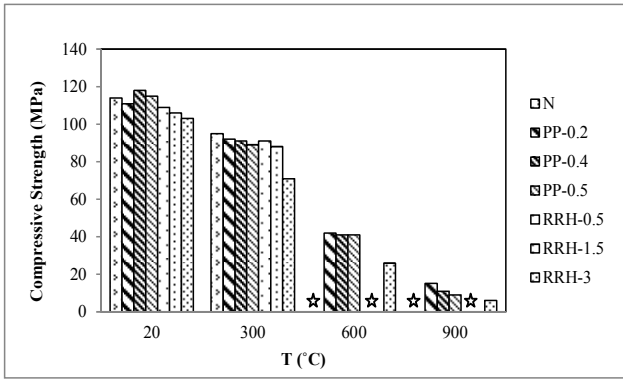


Fig. 4 Effect of temperature on compressive strength of HSC with PP and RRH

* No measurements could have been taken from N, RRH-0.5 and RRH-1.5 series due to spalling.

B. Splitting Tensile Strength

The results of splitting tensile strength tests of concrete specimens are given in Fig. 5. It can be seen that splitting tensile strength of HSC with PP decreased compared to the reference concrete produced without fibers (N). This decrease is significant especially in RRH series.

At 20°C, reference concrete possessed the maximum splitting tensile strength whereas RRH-3 possessed the minimum. As temperature increased to 300°C, all series could keep almost 85% of their original strengths. At 600 and 900°C, however, these values were only 30% and 9%, respectively. Using RRH results in a slight drop compared to PP series and increase in temperature caused a further decrease in all series (Fig. 5).

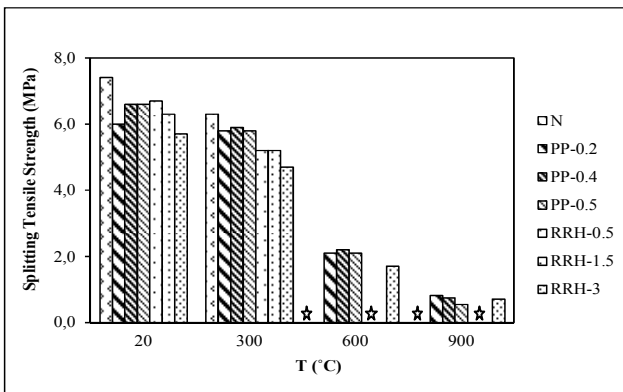


Fig. 5 Effect of temperature on splitting tensile strength of HSC with PP and RRH

☆ No measurements could have been taken from N, RRH-0.5 and RRH-1.5 series due to spillings.

It is well known that under high temperature PP fibers start to melt. According to thermogravimetric analysis of PP; melting starts at 160°C, detectable pyrolysis start at 325°C, peak of pyrolysis-vaporization are 458 and 469°C and pyrolysis completes at 475°C and all PP are vaporized at this temperature. Combustion of PP occurs at 550°C (Fig. 6) [8].

Therefore, at 550°C harmful gas release is expected to show its peak.

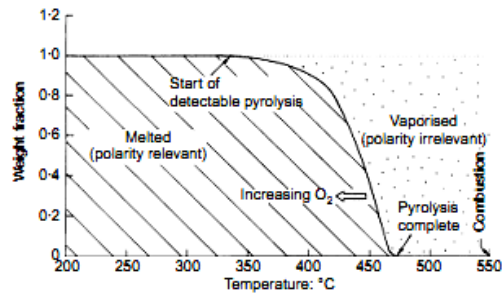


Fig. 6 Loss of weight fraction in temperature of PP

RRH is an organic and inorganic composite biomaterial. Organic part is composed of cellulose, hemicellulose and lignin, inorganic part is composed of a high amount of silica, K^+ , Na^+ , Ca^{2+} , Mg^{2+} , and Cl^- [16]. Chemical formula of cellulose and lignin are $(C_6H_{10}O_5)_n$ and $C_9H_{10}O_2$ respectively. To determine the combustion temperature of RRH under high temperature, thermogravimetric analysis (TGA) was conducted.

According to TGA results, at 100°C, free water vaporized causing a 10% loss of weight and between 220 and 450°C, weight loss reaches 82% due to structural degradation. It can be concluded that, starting from 450°C, RRH turns into ashes (Fig. 7). Thus, starting from 450°C, harmful gas release will be higher in RRH series during high temperature effect.

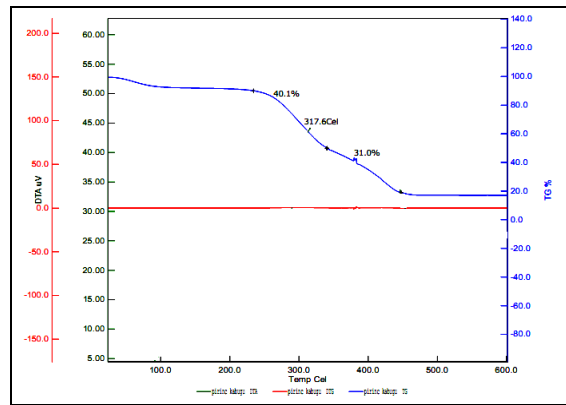


Fig. 7 TGA of raw rice husk

RRH and its ashes have the ability to absorb harmful gases owing to its morphological structure. Also, SiO_2 and other gases released from concrete prevent access of O_2 into concrete. As a result, RRH cannot burn completely in concrete and that can be seen from SEM pictures (Fig. 8) [13].

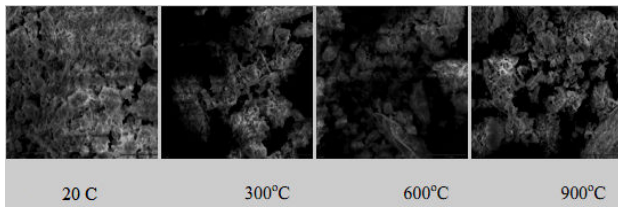


Fig. 8 SEM pictures of concrete with raw rice husk

It can be concluded that using RRH in concrete as an additive may prevent harmful gas formation in high temperatures. Besides, between 600-900°C, high amounts of CO₂ releases in consequence of decarbonation of CaCO₃ [17]. So, between these temperatures high amount of CO₂ release is expected.

CO and CO₂ releases from concrete through decomposition and combustion of PP and RRH. As temperature increases to 300°C, PP and RRH starts to decompose and as a consequence of this CO and CO₂ release occurs. Higher amount of PP and RRH in concrete causes a higher amount of harmful gas release in all temperatures.

At 300°C, PP-0.5 has the maximum and N (reference concrete) has the minimum values of CO₂. In reference concrete (N) at 425°C and in RRH-0.5 and RRH-1.5 at 455°C, explosive spallings occurred (Fig. 3). Thus, no gas measurements could have been taken from these series at high temperatures. At 600°C, PP-0.2 has the minimum and PP-0.5 has the maximum values for CO₂ and still all these values are well below for human fatality (5%). As temperature increased to 900°C, a greater increase in CO₂ release took place in all series, with values ranging between 3% and 12% due to decarbonation of calcareous aggregates (Fig. 9).

It can be seen that the results of CO release were similar to CO₂ results. At 300°C, PP-0.2 has the minimum and RRH-3 has the maximum CO values with 588 and 2013 mg/m³, respectively. There is a slight difference between RRH-3 and PP-0.5. At 600°C, all series, except PP-0.2, have almost the same values (6220 mg/m³). When temperature increased to 900°C, great increase took place in PP-0.4, PP-0.5 and RRH-3 series, with values ranging between about 6000 and 14000 mg/m³. At this temperature, RRH-3 caused a lower amount of CO emission compared to PP-0.4 and PP-0.5 (Fig. 10). This could be due to RRH absorbing some amount of harmful gases or causing a lower amount of harmful gases.

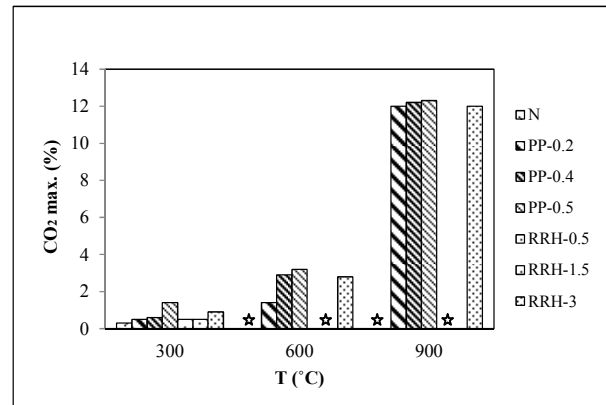


Fig. 9 The amount of CO₂ during temperature effect

☆ No gas measurements could have been taken from N, RRH-0.5 and RRH-1.5 series due to spallings.

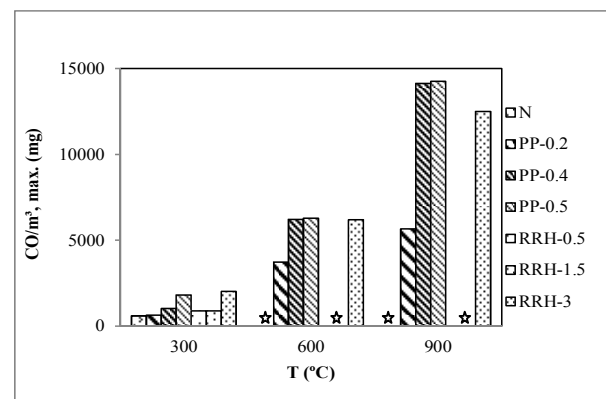


Fig. 10 The amount of CO during temperature effect

☆ No gas measurements could have been taken from N, RRH-0.5 and RRH-1.5 series due to spallings.

IV. CONCLUSIONS

An increase in the temperature caused a decrease in the mechanical properties of all mixes. This decrease was notable especially in series with polypropylene fiber (PP) and raw rive husk (RRH). The inclusion of RRH caused a higher decrease in mechanical strength of concretes at 20°C when compared to those with PP. However all concrete series still can be classified as HSC.

As the temperature increased, explosive spalling occurred in N, RRH-0.5 and RRH-1.5 series at 425 and 455°C. However, in all PP series spalling was prevented effectively. Thus, it may be said that, the amount of RRH should be at least 3% by weight of cement to prevent explosive spalling.

Until 600°C, all CO₂ and CO emission values are lower than the threshold values for human health. In PP series, as the additive amount increased, released harmful gas amounts also increased. At 900°C, RRH caused lower CO release compared to PP-0.4 and PP-0.5. It can be concluded that RRH either released a lower amount of harmful gases or absorbed some of the released ones, resulting in a lower net emission. To observe the effect of absorption capability of RRH in HSC

more properly, some specimens with an even higher RRH content might be prepared; and their gas release results might be compared with the existing ones.

The results obtained from this study confirm that RRH, as a sustainable material, when used at definite ratios, can effectively prevent spallings and thus can be a suitable alternative to PP. Since RRH releases a lower amount of harmful gases at high temperatures, the use of RRH in high strength concrete will help to decrease casualties in case of fire. Using higher amount of RRH and its effects on HSC should be further researched.

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