ISSN:1687-1006

The Egyptian International Journal of Engineering Sciences and Technology

Vol. 29 (2020) 1–13

http://www.eijest.zu.edu.eg

Effect of Elevated Temperature on Concrete Containing Waste Tires Rubber

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A R T I C L E I N F O

Article history:
Received 09 January 2020
Received in revised form 09 February 2020
Accepted 15 February 2020
Available online 20 February 2020

Keywords:
Rubcrete
Crumb Rubber
High Daily Temperature
Elevated Temperature
Compressive Strength
Flexural Strength
Tensile Strength

A B S T R A C T

Our present study aims to investigate the optimal use of waste tire rubber as a fine aggregate in concrete and their sensitivity to high temperature effect. Five different concrete compositions were prepared: a reference concrete (RC) made with natural fine aggregate (sand) and coarse aggregate (dolomite) and four concrete mixes with replacement rates of 4%, 8%, 12% and 16% of sand by crumb rubber from waste tires. For the effect of elevated temperature: Similar specimens were exposed to a period of 4 hours to temperature of 70°C, to study the effect of high daily temperature, and a period of 2 hours for both temperatures 200° C and 400° C to study the effect of fire. After cooling down to ambient temperature, the compressive strength, flexural strength and the splitting tensile strength were measured and compared with the values that obtained before fire exposure. The in-hand study indicates a gradual decrease in compressive, splitting and flexural strengths of concrete for partial substitution of crumb rubber aggregate in concrete. In addition, more decrease in these strength values are resulted after exposing the similar specimens to high temperature. While the inclusion of rubber particles reduces the rate of compressive strength loss at high temperature.

1. INTRODUCTION

Crumb rubber concrete (CRC) is a type of concrete that incorporates crumb rubber particles from waste tires as a partial substitution for the fine aggregates in conventional concrete. The reason for using waste tire rubber into concrete as a partial substitution for the natural aggregates is to achieve three objectives: first, to improve some of the properties of ordinary concrete, second is to rid the environment of the increased waste tires year after year, third is to reduce natural resource demand for concrete production. Various authors have studied the properties of concrete containing waste rubber aggregates. The use of crumb rubber as a replacement for sand in concrete resulted in a vast beneficial use of tires. Crumb rubber can be a light weight substitute for natural aggregates as its unit weight is less than half of that of natural aggregate [1]. Concrete workability decreases as the percentage of rubber particles increases [2-5]. Admixtures made with crumb rubber were more workable than those with coarse tire rubber or those with a combination of coarse rubber and fine rubber [6-8]. Gradual decrease in compressive strength was noticed as the percentage of rubber increased [9-13]. The addition of coarse rubber in concrete reduces the compressive strength more than the addition of fine rubber [14]. The splitting tensile strength of rubcrete is less than the value of normal concrete [14]. On the other hand, the toughness and ability to absorb fracture energy were improved in rubcrete [15]. Flexural strength decreases as the percentage of rubber increases

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depending on size of rubber particles utilized [16, 17]. Even though rubber particles decrease the flexural strength of concrete; rubcrete specimens do not collapse suddenly under bending load through the flexural test because of high deformations of rubber particles [18]. The rubcrete showed possible advantages in minimizing the vibration and impact effect due to the unique elasticity properties of the waste rubber particles [19]. The use of only coarse rubber aggregate affects the properties of rubberized concrete more negatively than do only fine rubber aggregate. Furthermore, the plastic energy capacity of the normal concrete has increased by adding rubber particles. Rubcrete has shown high strains, particularly under the impact effects because of its high plastic energy capacities. Even though rubberized concrete generally has a reduction in compressive strength that may limit its use in certain structural, it possesses a number of desirable properties, such as higher toughness, lower density and higher impact resistance compared to normal concrete. Only a few studies are found concerning with fire resistance. It was noticed that residual mechanical properties of rubberized concrete are noticeably more affected than those of normal concrete, particularly for elevated temperatures, this reduction doesn't prevent it from being used in structural applications [20]. Recent studies reported a reduction of the compressive strength and tensile strength after fire for rubberized concrete [21, 22, 23]. Despite this reduction, the incorporation of rubber particles in concrete reduces the risk of explosive spalling of concrete at high temperatures [24]. Other researchers investigated the behavior of concrete containing recycled aggregate, steel fiber and crumb rubber when subjected to high temperatures. The samples were exposed for 2 hours at 200° C, 400° C and 600° C temperature. They observed that high quantity of rubber particles leads to significant loss of compressive strength at high temperature [25]. Some authors assessed the mechanical properties of rubberized concrete, heated to a temperature of 600° C. They observed that the incorporation of rubber doesn't lead to a significant addition loss in strength, given that the lost strength values obtained were 64% for the normal concrete and 70% for rubberized concrete [26]. Others investigated the performance of crumb rubber mortar when exposed to high temperature of 150° C, 200° C, 300° C and 400° C. They observed that inclusion of rubber particles has a slight effect on the residual properties of concrete up to 300° C and significant effect when temperature reaches 400° C [27].

2. Experimental program

2.1. Material

Ordinary Portland cement (CEM I 52.5 N) with specific gravity of 3.15 were used for the concrete mixes in this study. The fine aggregate used is natural sand with grain size from 5 mm to 0.15 mm, specific gravity 2.6 and Fineness modulus 2.6. The Coarse aggregate used is crushed dolomite graded from 20 mm to 5 mm, specific gravity 2.65 and water absorption rate of 0.85%.

In this study, crumb rubber was used as partial replacement of fine aggregates. The crumb rubber with graded size ≤ 5 mm, specific gravity 0.935 and a melting temperature of 170° C.

2. 2. Mix proportions

In order to study & evaluate the mechanical properties of the rubber concrete, and study the effect of elevated temperatures on it, five different concrete mixtures were prepared with rubber rates of: 0, 4, 8, 12 and 16 % by volume replacement of natural sand. To study the effect of elevated temperature: Specimens were subjected to elevated temperatures (70° C, 200° C and 400° C). All concrete mixes used the same W/C of 0. 5. Details of the mix proportions of control mix (Normal Concrete) and four different mixes contain different percentages of Crumb aggregates (C4, C8, C12 and C16) are summarized in Table 1.

A total of 210 samples of concrete with five different concrete mixtures were carried out; 75 samples were tested at room temperature and 135 samples were tested after being exposed to high temperatures.

2.3. Specimen preparation

All mix proportions were mixed together in a concrete mixer with capacity of about 0.1 m3. The coarse aggregate (dolomite), fine aggregate (sand/fine rubber) and cement were mixed in dry state for about one minute. Mixing water was added gradually to the dry mixed materials during the next two minutes until reaching a homogenous mixture.

Various concrete specimens (cubes 100 × 100 × 100 mm), (prisms 500 × 100 × 100 mm) and (cylinders 100 × 200 mm) with a diameter of 100 mm and height of 200 mm were prepared. After mixing, fresh concrete was cast in the forms. The specimens were stored in room temperature for 24 hours and then cured for 28 days in potable water.

Table 1. Mix constituent

Mix ID	W/C	Cement	Coarse aggregate	Fine aggregate		Water	Rubber		Total
			Wt	Volume	Wt		Volume	Wt	
		kg/m³	kg/m³	%age	kg/m³	kg/m³	%age	kg/m³	kg/m³
Normal Concrete (NC)	0.5	400	1110	100	670	200	0	0	2380
C 4	0.5	400	1110	96	643.2	200	4	9.6	2362.8
C 8	0.5	400	1110	92	616.4	200	8	19.2	2345.6
C 12	0.5	400	1110	88	589.6	200	12	28.8	2328.4
C 16	0.5	400	1110	84	562.8	200	16	38.6	2311.4

2.4. Test method

For each concrete mix; 15 cubs, 15 prisms and 12 cylinders were casted. 6 specimens (3 specimens after 7 days and 3 specimens after 28 days from cubs and cylinder, moreover 3 specimens after 28 days from cylinder) were tested at room temperature without being heated (at the room temperature of 25° C), the remaining 9 specimens from each type were divided into 3 groups and subjected to 3 temperature exposure conditions after 28 days (70° C for four hours and 200° C , 400° C for two hours) in an electrical furnace. In the furnace, the specimens will heat from the room temperature to the prescribed temperatures. The specimens will naturally cool down to the room temperature.

The slump test was carried out according to ASTM C143 [28]. The test was carried out after mixing. Compression test was carried out according to Egyptian Code No. 203 [29], on cubes of 100 mm side length. This test was performed after 7 and 28 days using hydraulic testing machine. Flexure test was carried out on the prismatic specimens of 500 × 100 × 100 mm dimensions and tested on 300 mm clear span. This test was performed after 7 and 28 days to measure the flexural capacity of the concrete prisms. Splitting tensile strength was carried out according to BS standard [30], using standard cylinder of 100 mm diameter and 200 mm height. This test was performed after 28 days using 1000 kN universal testing machine.

For performing the fire tests, an electric oven with a thermostat which can attain a maximum temperature of 1300° C and a control switch, was used. The used furnace could achieve a high heating rate speed that is somewhat similar to actual fire conditions. The dimensions of the oven hole are 520*520*300 mm, provided with insulator material and the outer body is stiff steel. In order to examine the sensitivity of studied mixes to temperatures effect, we exposed them to three degree of temperatures: 70° C, 200° C and 400° C. We avoided going beyond 400° C because the portlandite starts to decompose at about 450° C, the sand aggregates at about 570° C and Ca (OH)2 at about 600° C [27, 31]. In this case, we have 4 materials decompose at the same time, so it is very difficult to separate the rubber aggregates effect alone beyond 400° C.

3. Results and discussions

3.1 Fresh Concrete Properties

3.1.1 Workability

After mixing, slump is measured for each concrete mixture. A decrease in slump is observed when the percentage of rubber content increased as shown in Table (2). The slump decreased from 75 mm to 65 mm when the percentage of rubber increased from 0% to 16%. The reduction in slump may be attributed to the irregular shape; relatively rough surface of rubber particles and the low inter particle friction between the rubber and other materials of concrete

Table 2. Slump of concrete at different rubber contents

Rubber Content (%)	Slump (mm)
0	75
4	72
8	70
12	68
16	65

3.2 Hardened Concrete Properties

3.2.1 Compressive Strength

The variations in compressive strength obtained at 7 and 28 days for Normal Concrete (NC) and mixes containing different percentages of Crumb rubber (C 4, C 8, C 12, and C 16) are presented in Fig. 1. Partial substitution of crumb rubber aggregate in concrete caused a gradual decrease in compressive strength at all ages. Fig. 2 shows the relation between percentages of crumb rubber aggregates and compressive strength after 7 days. The maximum compressive strength (27.7MPa) was obtained for the control mix and the minimum value (24MPa) for the mix with 16 % crumb rubber. This reduction is around 13.35 %. Same trend was observed for the compressive strength at 28 days.

The results in Fig. 3 show a reduction in the compressive strength from 33.85 to 30.6 MPa as the crumb rubber percentage increases from 0 % to 16 % respectively. This reduction ratio is around 9.6%.

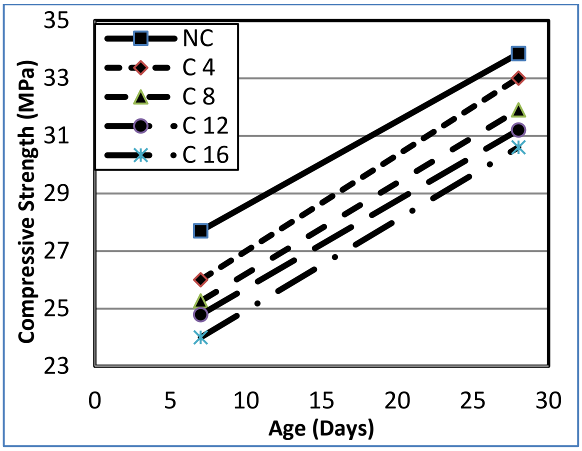

Fig. 1. Variation of compressive strength at 7 and 28 days

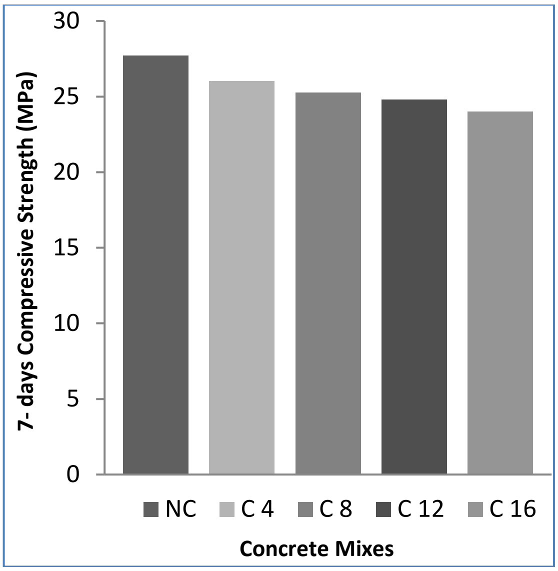

Fig. 2. Relation between percentages of crumb rubber aggregates and compressive strength after 7 days

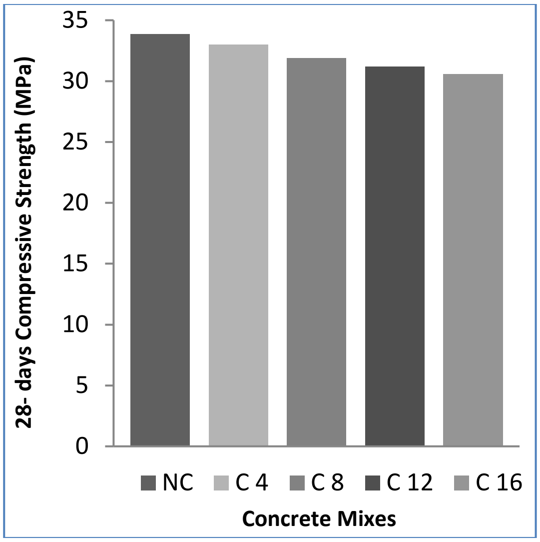

Fig. 3. Relation between percentages of crumb rubber aggregates and compressive strength after 28 days

Fig. 4 shows the relation between percentages of crumb rubber aggregates and loss of compressive strength at 7 and 28 days. The results show that the addition of rubber aggregates resulted in a reduction in compressive strengths of concrete compared to the control concrete. More reduction in strength value is found as the percentage of rubber aggregate increases. It is observed that the crumb concrete shows an increase in the compressive strengths with time from 7 to 28 days if compared with the normal concrete mixtures.

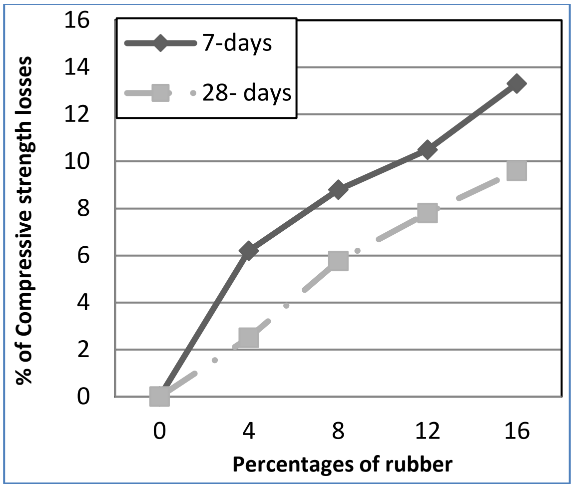

Fig. 4. The loss of compressive strength with different percentage of crumb rubber

The reduction in compressive strength of crumb concrete can be explained due to the following reasons: low compressive strength of rubber aggregate, weak interfacial bond between rubber aggregate particles and the paste, absence of adhesion between the rubber aggregate and the cement-paste. The rubber aggregate particles are considered as voids in the concrete matrix. This conclusion about compressive strength of rubberized concrete agreed with many investigations [32-34].

3.2.2 Splitting Tensile Strength

The variations in tensile strength obtained at 28 days with respect to the percentage of crumb rubber are presented in fig. 5. This figure shows that the replacement of natural aggregates with different percentages of crumb rubber aggregates leads to direct reduction in concrete splitting tensile strength. The maximum tensile strength (3.1 MPa) was obtained for the control mix with 0 % crumb rubber and the minimum value (2.86 MPa) for the mix with 16% crumb rubber. This reduction is around 7.75 %. The decrease in the tensile strength with the rubber content is lower than that in the compressive strength.

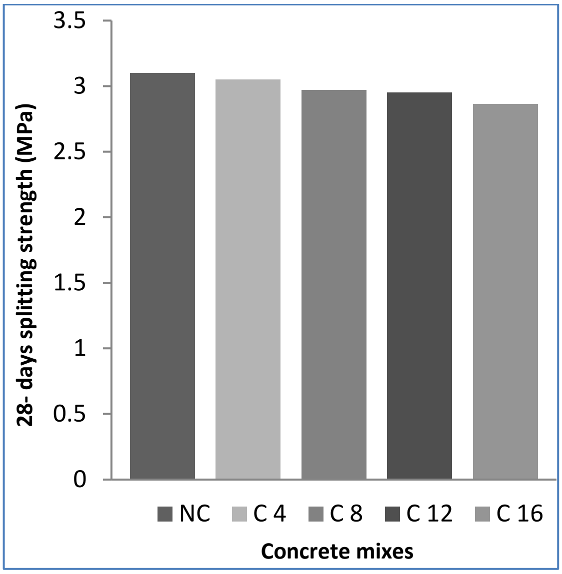

Fig. 5. Relation between percentages of crumb rubber aggregates and splitting tensile strength after 28 days.

Tyre rubber particles as a soft material act as a barrier against crack growth in the concrete. So, tensile strength in rubberized concrete should be higher than the normal concrete. However, results showed the opposite of this assumption. The reason for this behavior may be because of the following reasons: The interface zone between rubber aggregates and cement-paste may act as a micro-crack because of weak bonding between the materials (rubber aggregates and cement-paste); "It was observed that after rupture of samples, the rubber aggregate could be easily removed from concrete by fingers, which denoting clearly week bond as shown in fig. 6." the weak bond accelerates concrete breakdown. The rubber particles have a negative effect on the splitting tensile strength due to its low strength. Similar findings about tensile strength of rubberized concrete were reported by other researchers [35, 36].

Fig. 6. Crumb concrete cylinder sample after splitting into two halves under splitting tensile test.

3.2.3 Relation between Compressive and Tensile Strength

The effect of different replacement percentages of crumb rubber aggregates in concrete mixtures on the relation between compressive and tensile strength of concrete was also calculated and presented in fig. 7.

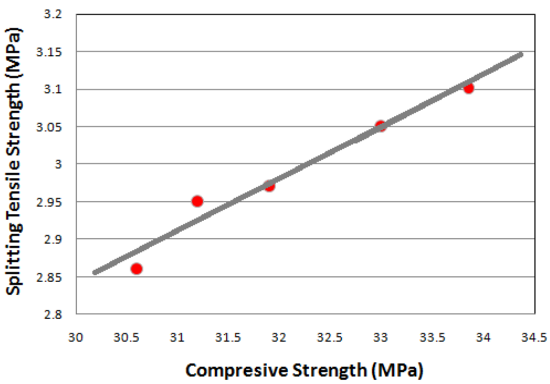

Fig. 7. Relation between compressive strength and tensile strength for crumb concrete.

The average splitting tensile strength to compressive strength ratio for crumb concrete having different percentages of crumb rubber aggregate is 9.3 which is very close to that of NC, 9.2.

3.2.4 Flexural Strength

The variations in flexural strength obtained at 7 and 28 days with respect to the percentage of crumb rubber are presented in fig. 8. Gradual decrease in flexure strength was noticed as the percentage of crumb rubber increased.

Fig. 9 shows the relation between percentages of crumb rubber aggregates and flexure strength in MPa after 28 days. It is observed that the flexural strength of crumb concrete decreases as the percentage of crumb rubber increases. The maximum flexure strength (4.74MPa) was obtained for the control mix and the minimum value (4.35MPa) for the mix with 16% crumb rubber. This reduction is around 8.22%.

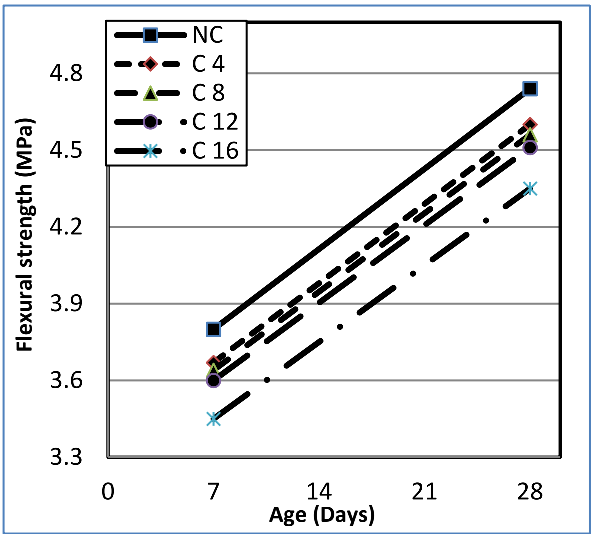

Fig. 8. Variation of flexural strength with different ages.

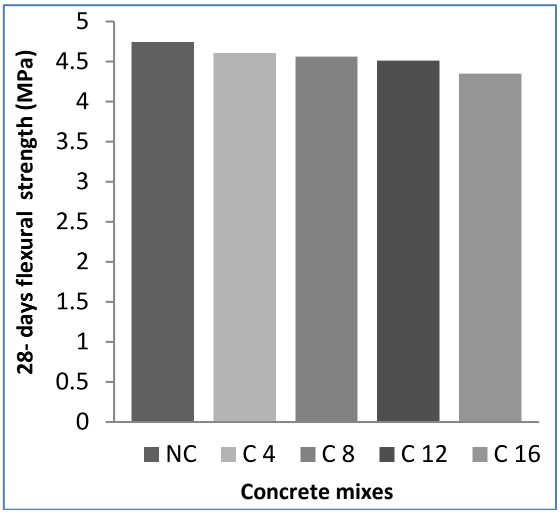

Fig. 9. Variation of flexural strength with different rubber content

This reduction in flexural strength may be attributed to weak bond of rubber particles and cement paste; "It was observed that after rupture of samples, the rubber aggregate could be easily removed from concrete by fingers, which denoting clearly week bond. "Therefore, the concrete fails in tension zone before the concrete in compression zone reaches its ultimate value. This conclusion agreed with many investigations [17, 32, 34, 37].

3.3 Effect of fire and high daily temperature

3.3.1 Visual Inspection

3.3.1.1 Colour and appearance changes

The surface colour of the samples underwent considerable changes; the apparent change within the colour of the specimens is identified by visual inspections after exposure to elevated temperatures. At room temperature the concrete was light grey, Samples of control mix became brighter because of water loss at high temperatures, while samples of rubcrete mix gained brown and black colour, due to the dispersion of carbon black which is a part of the rubber tires.

3.3.1.2 Crack and spalling behavior

After removal from the furnace, samples exhibited no signs of explosive spalling. However, specimens presented cracks at their surface, the width and length of cracks increased with the increasing in temperature. For concrete subjected to elevated temperatures, stresses in the concrete caused by the water evaporation, drying shrinkage, thermal expansion and interaction of them led to the cracking of concrete [38].

At the target temperature of 70° C and 200° C nearly no cracks appeared on the surfaces of specimens. At the target temperature of 400° C, micro-cracks appeared on the surfaces of all the specimens but there was a slight decrease in the number of cracks with the increasing percentages of crumb rubber. Loss of cement hydration water between 300° C and 400° C, which leads to a loss in strength and causes superficial cracks to appear. Crumb rubber helps to relieve the inception and growth of cracks in concrete under high temperatures. This is because of the fact that rubber is melted under the temperature of about 170° C, providing area for the evaporated water to escape from the concrete, so reducing the pore pressure caused by the water vapor, one of the main reasons resulting in the cracking of concrete under high temperature [39]. Fig. 10 illustrates the cracks in the heated cube, cylinder and prism at 400° C for two hours.

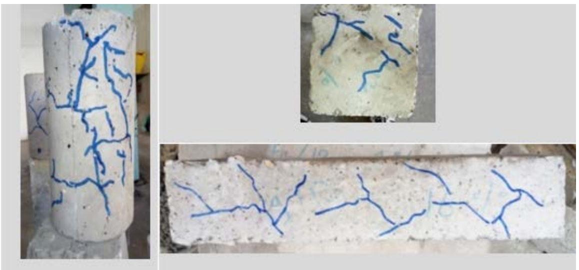

Fig. 10. Specimens after heating (400° C) in oven for two hours

3.3.2 Compressive Strength

Fig. 11 shows the summary of results for the effects of temperature on compressive strength of concretes without or with crumb rubber. It is observed that the compressive strength decreases with the increase in temperature and the percentage of crumb rubber. The reduction in compressive strengths is up to 9.6% at 16% crumb rubber for unheated specimens. However, when concrete subjected to elevated temperature, compressive strength was reduced by (10.3% – 18.7%) at 200° C and (19.2% - 26.5%) at 400° C compared with normal concrete, for concrete containing rubber (0%-16%)

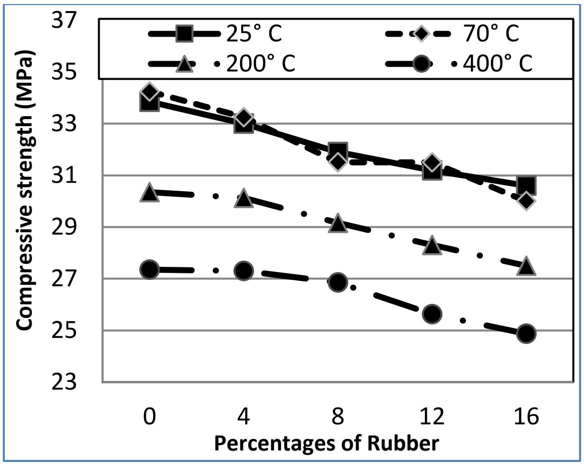

Fig. 11. Compressive strength versus rubber content at different temperature

Fig. 12 shows the results of compressive strength values for all mixes at different temperature. It can be seen from this figure that, for the unheated concrete specimens (25° C), while increasing the rubber content from 4 % to 16 % by volume of sand leads to the decrease of compressive strength from 2.5 % to 9.6 %. After exposure to high temperature, it is observed that for both normal concrete and crumb concrete, a slight increase in compressive strength at 70° C and then there was a reduction in compressive strength with the increase in temperature. Similar observation was observed by other researchers [40], they observed an increase in compressive strength when temperature increased from 27° C up to 150° C for normal concrete and rubber fibber concrete and then there was a reduction in compressive strength with increasing temperature.

The increase in compressive strength at 70° C may be attributed to the drop in calcium hydroxide and unhydrated area fraction which is beneficial for the micro structure [41]. It should also be noted that the concrete mixes suffered the highest loss in compressive strength at the temperature between 200° C and 400° C. This might be attributed to that calcium silicate hydrate (C-S-H), the main source of concrete strength, which decomposes at about 400° C [42].

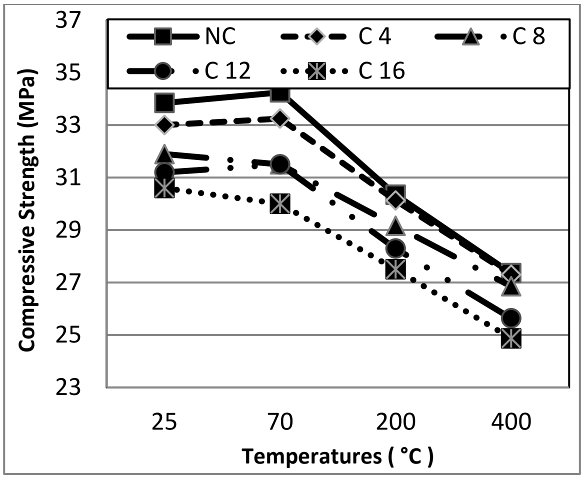

Fig. 12. Residual Compressive strength versus temperature for concrete with different rubber content

Fig. 13 shows the ratio between compressive strength at different exposure temperature and the compressive strength for the reference temperature of 25° C, for the different mixes of concrete. The results obtained shows that the inclusion of rubber particles reduces the rate of concrete strength loss. This is mainly as a result of rubber particles, once melted at 170° C, it leaves space for water vapour to escape and thus helps to release the pore pressure, and that will reduce its damage on the concrete structure [43]. It should be noted that the inclusion of rubber results in a slight decrease within the compressive strength losses after exposure to high temperature “compared with losses in control mix”, but leads to a reduction in concrete strength for the unheated specimens as mentioned above, and this indicates that we should find the optimal amount of rubber content which should be included to attain a balanced compressive strength for both heated and unheated specimens. Moreover, it is also observed that the slope of concrete containing 4% rubber has the same slope of control mix up to 70° C and then the slope improved than the slope of normal concrete at high temperature which indicated that this percentages can improve the performance of concrete.

Generally, the compressive strengths are adversely affected by increasing temperature and the inclusion of rubber “the inclusion of rubber reduces the rate of concrete strength loss for the elevated temperatures”. Similar observation was observed by other researchers [22], they observed that the loss in compressive strength of specimens containing rubber aggregates was roughly similar to that of RC.

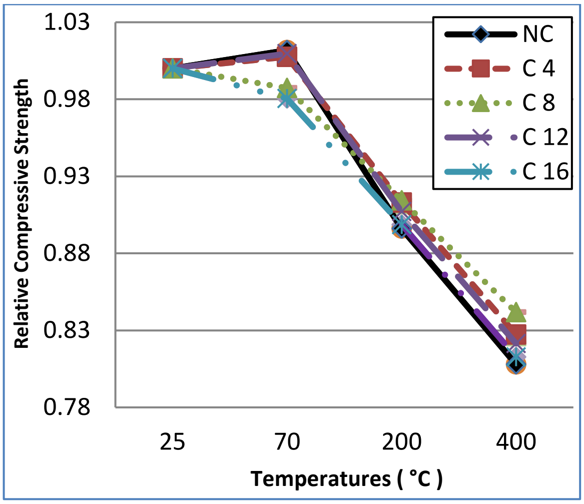

Fig. 13. Relative compressive strength versus temperature for concrete with different percentage of crumb rubber

3.3.3 Splitting tensile strength

Fig. 14 shows the effect of elevated temperature on splitting tensile strength of concrete containing different ratios of rubber. It is observed that the splitting tensile strength decreases with the increase in temperature and the percentage of crumb rubber. The reduction in splitting tensile strengths is up to 7.7% at 16% crumb rubber for unheated specimens. However, when concrete subjected to elevated temperature, splitting tensile strength was reduced by (6.4% - 16%) at 70° C, (17% - 27%) at 200° C and (28.4% – 32.9%) at 400° C compared with normal concrete, for concrete containing rubber (0%-16%).

Fig. 15 shows the ratio between splitting tensile strength at different exposure temperature and the splitting strength for the reference temperature of 25° C, for the different mixes of concrete. The results obtained show that, unlike compressive strength, the splitting tensile strength of all concrete compositions presents considerable losses at all exposure temperature. As to increase the proportion of rubber content from 0 % to 16 % by volume of sand leads to a decrease in splitting strength from 6.4 % to 9 % at temperature 70° C, and from 17 % to 21 % at temperature 200° C. At temperature 400° C, it can be seen that the inclusion of crumb rubber does not lead to a significant additional loss, as the percentages of loss for different mixes and for control mix almost equal and ranges between 27 % and 28 %. It is also observed that the losses in concrete mixture containing 4% rubber is almost equal to that in control mix as shown in figure, as the slope of concrete containing 4% rubber has the same slope of control mix.

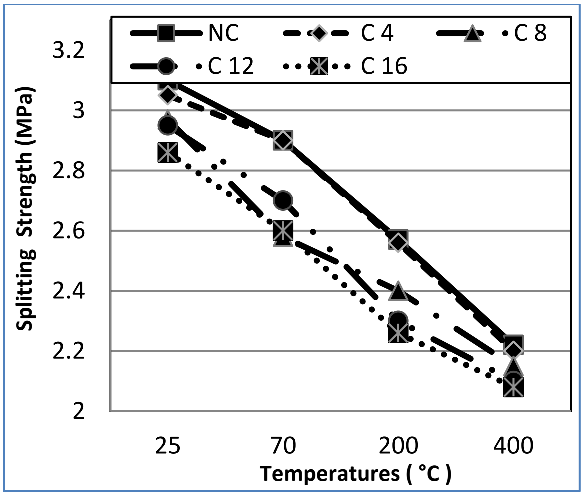

Fig. 14. Splitting Tensile strength versus rubber content at different temperature

The loss in residual splitting tensile strength crumb concrete mixes is shown to be greater than that of the control mix. The reason for this is at higher temperatures, rubber deteriorates, making more voids within the concrete and causing greater loss of strength. This conclusion agreed with many investigations [21, 26].

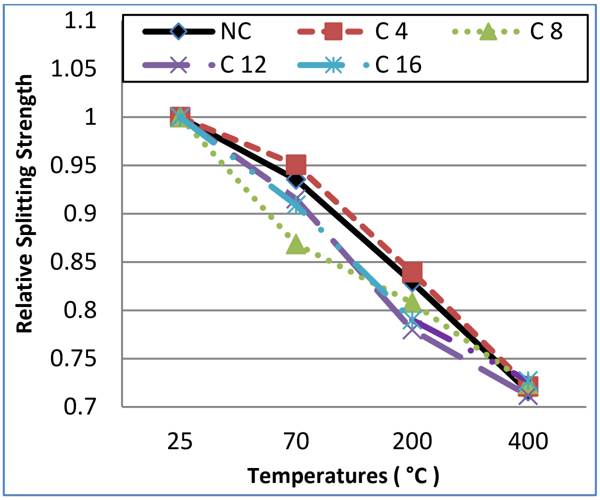

Fig. 15. Relative splitting tensile strength versus temperature for concrete with different percentage of crumb rubber

3.3.4 Flexural Strength (Modulus of Rupture)

Fig. 16 shows the effect of elevated temperature on flexural strength of concrete containing different ratios of rubber. It is observed that the flexural strength is adversely affected by increasing temperature and increasing the rubber content within the concrete. The reduction in flexural strengths is up to 8.2% at 16% crumb rubber for unheated specimens. However, when concrete subjected to elevated temperature, flexural strength was reduced by (4% - 15.6%) at 70° C, (19.8% - 37.3%) at 200° C and (36.7% - 43.45%) at 400° C compared with normal concrete, for concrete containing rubber (0%-16%).

Fig. 17 shows the ratio between flexural strength at different exposure temperature and the flexural strength for the reference temperature of 25° C**,** for the different mixes of concrete. It is observed that increasing the rubber content from 0 % to 16 % by volume of sand leads to a decrease in flexural strength from 4 % to 8 % at temperature 70° C, and from 19.8 % to 31.7 % at temperature 200° C, and from 36 % to 38.4 % at temperature 400° C. The results obtained show that for all concrete compositions, there is a moderate decrease in residual flexural strength and the loss in crumb concrete mixes is greater than that of the control mix, in spite, the losses in concrete mixture containing 4% rubber is almost equal to that in control mix, as the slope of concrete containing 4% rubber has the same slope of control mix while that containing 8%, 12% and 16% not the same trend.

Generally, the inclusion of rubber reduces the flexural strength of concrete with increasing temperature. The reduction in flexural strength can be related to the same parameters influences the concrete tensile strength, is that at higher temperatures, rubber deteriorates, making more voids within the concrete and causing greater loss of strength

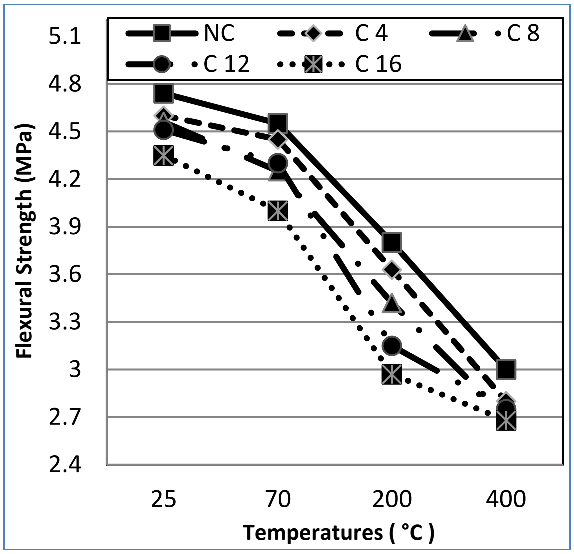

Fig. 16. Flexural strength versus rubber content at different temperature

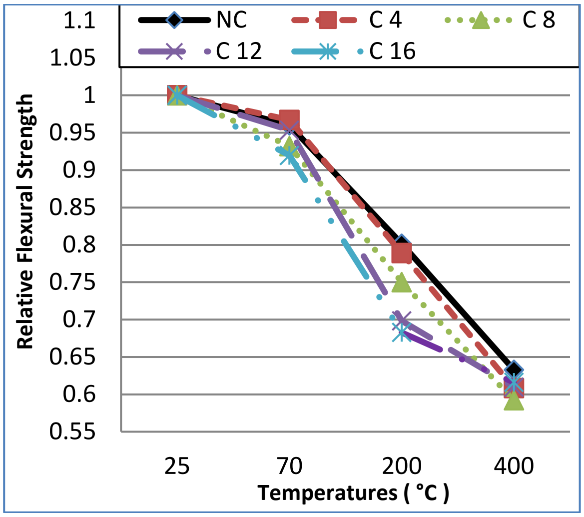

Fig. 17. Relative flexural strength versus temperature for concrete with different percentage of crumb rubber

3.3.5 Mass loss

The effect of rubber content on mass lost under different elevated temperatures is shown in fig. 18. It can be seen that for all the concrete mixtures, mass loss increases with the increase of temperature. It can be seen that the inclusion of crumb rubber in concrete does not lead to a significant additional loss mass of samples under higher temperatures, as the percentages of mass loss for different mixes and for control mix almost equal. A possible explanation is that at higher temperatures, the effect of the melting of rubber to the total mass loss is almost equal to the effect of water evaporation from this part of sand (The part of sand that has been replaced by crumb rubber).

From fig. 19 it can be seen that for all the concrete mixtures, mass loss increases with the increase of temperature. It is also shown that the most of the mass lost occurs during the temperature from 25° C to 200° C. This behavior is attributed to the evaporation of water, and thus leading to the mass loss of concrete during the heating process between 25° C and 200° C. Furthermore, crumb rubber particles melt at a temperature of around 170° C, which contributes to the mass loss of the crumb concrete.

For 400° C, there is a slight increase in the mass losses of crumb concrete compared to the normal concrete. This behavior may be attributed to the decomposition of rubber particles beyond 200° C and because of generation of voids in crumb concrete due to decomposition of rubber particles. This result is similar to that found by other authors for rubberized concrete [21, 22].

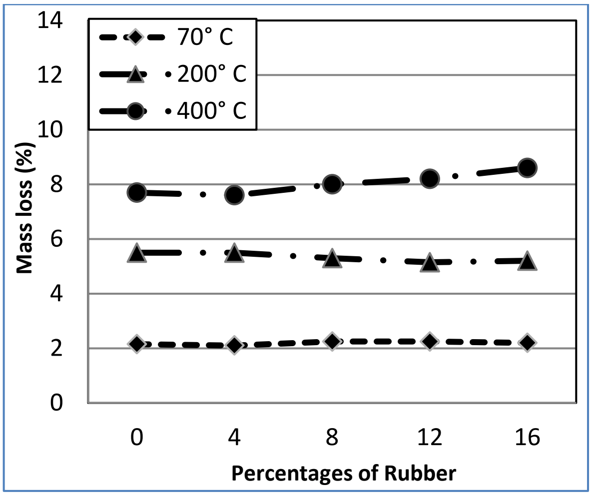

Fig. 18. Mass loss ratios of different concrete mixes after exposure to high temperatures

The mass loss above 200° C is mainly because of the decomposition of C-S-H at about 400° C. As concrete includes capillary water and physically absorbed water (Gel water) and chemically bound water in calcium silicate hydrate (C-S-H) and calcium hydroxide (Ca (OH)2) [44]. Capillary water and physically absorbed water take up a large amount of cement-paste weight and can be released from concrete by evaporation when the temperature is about 200° C or above [45]. On the other hand, chemically bound water is a part of cement hydrate compound sand which called non-evaporable water because it cannot be removed from cement-paste before the decomposition of the C-S-H at high temperature.

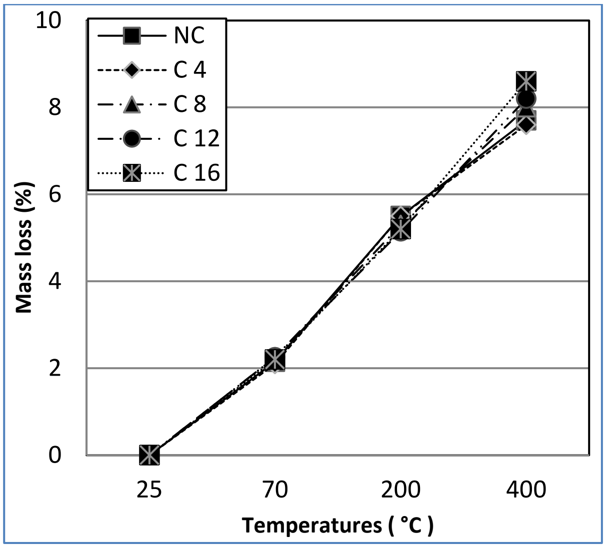

Fig. 19. Effect of high temperature on the mass loss of concrete containing different percentage of rubber

3. CONCLUSIONS

This study aims to investigate the optimal use of waste tire rubber as a fine aggregate in concrete and their sensitivity to high temperature effect. The following conclusion are found:

a) Effect of Crumb Rubber on Concrete Properties

- The workability of crumb rubber concrete decreases with increase in crumb rubber content.
- Partial substitution of crumb rubber aggregate in concrete caused a gradual decrease in compressive and tensile strengths of concrete.
- The effect of fine rubber aggregate on concrete tensile strength was less than its effect on compressive strength. The reduction in the compressive strength was around 9.6%, while reduction in the tensile strength was around

7.75% for concrete mix containing 16% crumb rubber.

- The average splitting tensile strength to compressive strength ratio for crumb rubber concrete having different percentages of crumb rubber aggregate was 9.3 which is very close to that of normal concrete.
- Using rubber aggregate reduces the flexural strength of concrete; the maximum flexure strength (4.74MPa) was obtained for the control mix and the minimum value (4.35MPa) for the mix with 16% crumb rubber. This reduction is around 8.22%. But this reduction in flexural strength was less than that in compressive strength.

b) Behavior of Crumb Rubber Concrete under Elevated Temperature

- Crumb rubber helps to relieve the inception and growth of cracks in concrete under high temperatures.
- At the target temperature of 70° C and 200° C, nearly no cracks appeared on the surfaces of specimens. However, at temperature of 400° C, micro-cracks appeared on the surfaces of all the specimens, and slight decrease in the number of cracks with the increasing percentages of crumb rubber.
- Compressive strength decreases with the increase in temperature.
- A slight increase in compressive strength at 70° C, because of drop in calcium hydroxide and unhydrated area fraction.
- The highest loss in compressive strength in concrete was noticed at the temperature between 200° C and 400° C, because of the decomposition of calcium silicate hydrate (C-S-H)
- The inclusion of rubber particles reduces the rate of compressive strength loss as a result of rubber particles, once melted at 170° C, it leaves space for water vapour to escape and thus helps to release the pore pressure
- The inclusion of rubber results in a slight decrease within the compressive strength losses after exposure to high temperature “compared with losses in control mix”, but leads to a reduction in concrete strength for the unheated specimens.
- The splitting tensile strength is adversely affected by increasing temperature and increasing the rubber content within the concrete.
- The splitting tensile strength of all crumb concrete mixes was much more reduced with increased temperature than the compressive strength, when concrete subjected to elevated temperature, splitting strength was reduced by (6.4 - 16%) at 70°C, (17 - 27%) at 200° C and (28.4 - 32.9%) at 400° C compared with normal concrete, for concrete containing rubber (0%-16%).
- The flexural strength is adversely affected by increasing temperature and increasing the rubber content within the concrete.
- The reduction in flexural strengths is up to 8.2% at 16% crumb rubber for unheated specimens. However, when concrete subjected to elevated temperature, flexural strength was reduced by (4% - 15.6%) at 70° C, (19.8% - 37.3%) at 200° C and (36.7% - 43.45%) at 400° C compared with normal concrete, for concrete containing rubber (0%-16%).
- The inclusion of crumb rubber in concrete does not lead to a significant additional loss in mass of samples under high temperatures.
- About (5 %) is the optimum value of rubber that can be added to concrete, which achieves the best results in mechanical properties at room temperature and improve the performance of concrete in the case of fires.

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