Wrya A. Abdullah
Department of Civil Engineering, College of Engineering, University of Sulaimani, Sulaimania, Iraq.
Wrya.faraj@univsul.edu.iq

Mohamed R. AbdulKadir
Department of Civil Engineering, College of Engineering, University of Sulaimani, Sulaimania, Iraq.

Muhammad A. Muhammad
Department of Civil Engineering, College of Engineering, University of Sulaimani, Sulaimania, Iraq.

Received on: 5/10/2017
Accepted on: 25/1/2018
Published online: 25/8/2018

Effect of High Temperature on Mechanical Properties of Rubberized Concrete Using Recycled Tire Rubber as Fine Aggregate Replacement

Abstract- *Effects of various elevated heating temperatures on mechanical properties of normal concrete containing recycled tire rubber as a fine aggregate (RTRFA) has been investigated in this paper. Five different concrete mixes were prepared in the laboratory. In each mix Ordinary Portland Cement, natural coarse and fine aggregate, water and RTRFA are used with fine aggregate replacement ratios (0%, 6%, 12%, 18% and 24%) by weight. In the laboratory, 60 cylindrical specimens (100mm diameter × 200mm high) and 60 cubic specimens (150×150×150mm^3) were prepared. The concrete specimens were exposed to four different heating temperatures: Control (Not heated), 200, 400, and 600°C, and tested according to British standards to observe the post-heating mechanical properties. These properties included density and mass loss, split tensile strength and compressive strength. The results showed a linear decrease in compressive strength with higher temperature degrees and percent replacement of fine aggregate by RTRFA. Moreover, the concrete's tensile strength fluctuated as it increased at 6% of rubber replacement then linearly declined at further replacement rates. Finally, some crucial conclusions of heating rubberized concrete have been drawn.*

Keywords- *high heating Temperature, Rubberized concrete, Mechanical properties, recycled tire rubber*

How to cite this article: W.A. Abdullah, M.R. Abdulkadir and M.A. Muhammad, "Effect of High Temperature on Mechanical Properties of Rubberized Concrete Using Recycled Tire Rubber as Fine Aggregate Replacement," *Engineering and Technology Journal*, Vol. 36, Part A, No. 8, pp. xx-yy, 2018.

1. Introduction

There is a global concern on saving energy and reducing carbon dioxide rate by improving the quality of materials and using resources to their maximum limit. Further, the production of the waste tire increased across the globe as a result of the growth of transportation and usage of cars. Therefore, the usage of rubberized concrete has recently gained popularity across the globe because of the global concerns on the environment issues [1].

The inclusion of waste rubber tire as aggregates affects mechanical properties of concrete. It improves some of its properties such as toughness, impact resistance, energy absorption, and sound and thermal isolation. However, it reduces some other mechanical properties such as its compressive strength, split tensile strength, workability [2–4]. It is suggested to use rubcrete as vibration dampers, or where blast or impact resistance is required, and to use rubcrete as a foundation pad for rotating machinery and railway stations [5]. Moreover, it can be used as shock absorber in buildings designed to resist earthquake waves [6]. Furthermore, the presence of rubber in concrete reduces water absorption by avoiding water propagation and contributes in providing a better protection to the steel reinforcement against water [7].

Regarding addition of rubber as fine aggregate replacement, Aiello and Leuzzi [8] replaced 0, 15, 30, 50 and 75% of the fine aggregate with the same volume of rubber. They reported a drastic decrease in both density and compressive strength because of change in its specific gravity. Atahan and Yücel [9] used a volume replacement of fine aggregate with rubber by 0, 20, 40, 60, 80 and 100%. They noticed a continuous decay in the compressive strength of the samples until the loss of 93% of its strength when 100% of the fine aggregate is replaced with rubber. They, also, reported a significant loss in concrete's elastic modulus that reached 96% of loss for 100% of the aggregate replacement. Moreover, Batayneh et al. [10] used 6 different mixes with rubber as replacement of the fine aggregate up to 100% by volume. Their results showed that despite of the loss in compressive strength, rubberized concrete still has some strength to be used as a lightweight concrete. In this regard, they recommended utilizing these kinds of mixes in partition walls, road barriers, pavement, sidewalks. Al-Shathr et al. [11] have used four types of fine aggregates including chopped rubber tires, chopped

https://doi.org/10.30684/etj.36.8A.10
2412-0758/University of Technology-Iraq, Baghdad, Iraq

plastic wastes, to produce lightweight cement mortar. They have concluded that it is possible to produce lightweight cement mortar with compressive strength satisfying the requirements of clay brick used in partitions.

Additionally, Deepak and Naidu [12] confirmed that rubber improves the fire-resistant property of the concrete despite of losing its compressive and tensile strength. In addition, Benazzouk et al. [13] used crumb rubber sized between 1 to 4mm in the concrete with the volume ratio of 0, 10, 20, 30, and 40%. They suggested using rubberized concrete for aggressive environments because when used in concrete, rubber will decrease the air content of the concrete thus the water absorption will decrease. Numerous number of research can be found in the literature on the effects of elevated temperature on normal and high strength concretes and its well established that concrete exposed to high temperatures loses its compressive strength more than 60% when heated to 800°C and probably complete damage when heated above 1000°C [14–17]. This loss of compressive strength increases with the increase of normal compressive strength of the concrete and heating temperature [18]. However, the effects of heating to beyond 350°C is slightly lessened on a concrete reinforced with steel fibers [19]. Tests on self-compacting concrete exposed to fire have also shown loss of compressive strength [20]. It was noticed that the SCC lost (12-16%) of its compressive strength when heated to 400°C and the loss increased to (49-58%) after heating to 700°C.

Kantasiri et al. [21] investigated rubberized concrete as a lightweight concrete containing rubber subjected to elevated temperatures. They had four different mixes using 3, 5, 10, and 15% rubber as a coarse aggregate in their mixes. After exposing the samples to a temperature of 800°C, they noticed a loss in weight from temperatures of 373°C to 400°C resulting in a decrease in density. They also noted a dramatic decrease in compressive strength (from 12 MPa to 3 MPa) for the samples that contained larger amount of rubber (15%). Guo et al. tested 5 different mixes of crumb rubber replacements [0,4%,8%,12% and 16%] with steel fibers of 1% and heated them for four different temperatures [0, 200, 400, and 600]. They tested their samples for mass loss, compressive strength, young's modulus and energy absorb [22].

2. Research Significance

From the research review, it is obvious that rubberized concrete needs further research to understand the behavior of rubber inside the concrete in different environments. For example, heat is a threat for structures and buildings in Civil Engineering as it causes a reduction in their strength [14]. Therefore, there is a great need to investigate rubberized concrete exposed to heating with various temperatures, as there is insufficient research in this regard in the literature.

3. Experimental Program

I. Materials

Local materials have been used to make the concrete. Portland cement (Type 1) produced locally in Tasluja Cement Plant, in Iraq, was used in all mixes. The maximum size of the natural fine aggregate was 4.75mm and the natural round coarse aggregate had the maximum size of 10mm. Recycled tire rubber (max. size=4.75mm) was used to partially replace the fine aggregate. The crumb rubber was produced by grinding old tires in a grinding machine.

The aggregates and recycled rubber used in the experiments were tested to find their physical properties. Their sieve analysis was in accordance with BS 882:1992 and particle size grading of both fine and coarse aggregates is in the range of limit specifications as shown in Figures 1 and 2. In addition, Figure 3 shows the sieve analysis result of the recycled rubber, in which 98% particles passed 4.75mm sieve. Further, Table 1 presents the aggregate's test results of specific gravity, water absorptions, according to (ASTM C127 & C128-98), and compact and uncompact bulk density confirming to (BS 812: Part 2: 1995).

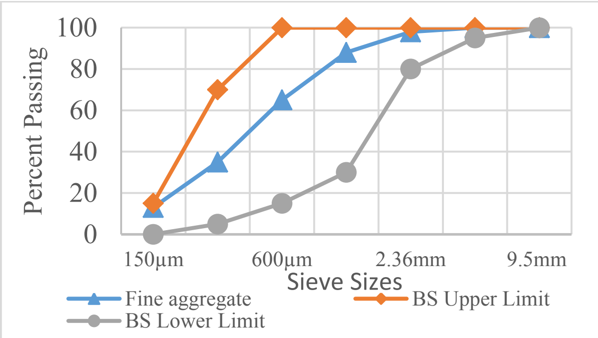

Figure 1: Particle size distribution of fine aggregate

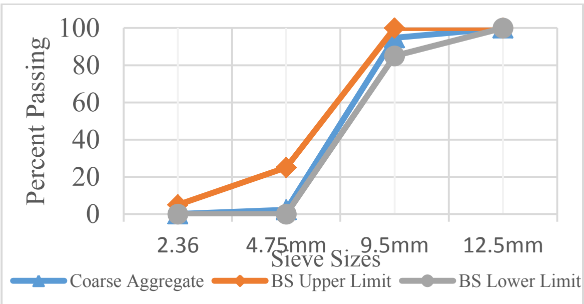

Figure 2: Particle size distribution of coarse aggregate

Table 1: Aggregate tests and Characteristics

Characteristics	Coarse aggregate	Fine aggregate	Tire Rubber
Fineness Modulus, unit less	2.03	2.01	N/A
Max. particle size, mm	10	4.75	4.75
compacted dry density, kg/m³	1679	1552	677
Not compact dry density, kg/m³	1565	1322	576
water absorption, %	0.96	N/A	N/A
the bulk specific gravity, Dry	2.62	2.46	N/A
the bulk specific gravity, SSD	2.64	2.59	N/A
the Apparent specific gravity	2.68	2.84	N/A
Particle surface	Round	Natural	Round, dry
Evaporation point	N/A	N/A	260 °C
Source of aggregate	river	river	Tire grinding machine

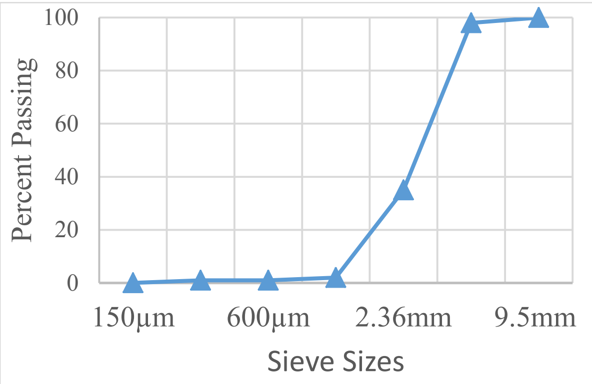

Figure 3 Particle size distribution of recycled tire rubber fine

II. Concrete mix design

The design of concrete mix without fine tire rubber replacement was in accordance with ACI 211.1 for the aggregate of max size 10 mm, and a slump 0f 100-140mm, with water absorption of 1% and 5% moisture content of sand. Moreover, the mean compressive strength for the concrete mix was designed to be 40 MPa. Very high compressive strength is targeted because it is proven that the presence of rubber in the concrete will reduce its strength [2-4]. The situation will be aggravated particularly when it is burnt. Therefore, after designing, the masses of concrete mix ingredients were 592,695,792 and 205 kg per cubic meter of concrete for cement, sand, gravel and water respectively (mix proportion 1:1.179:1.34 by weight). Finally, the w/c ratio for the mix was 0.393 to achieve the required strength and workability.

III. Specimen preparation

Five mixes were prepared using fine aggregate partially replaced with a specified percentage of recycled tire rubber (0% control, 6%, 12%, 18% and 24%) by weight despite the change in volume because of its practicality as usually the batching in concrete plants is being produced using weight of each ingredient. Consequently, the required concrete batch was prepared for each mix based on mix design proportions. Concrete specimens of cubes (150*150*150mm^3) and cylinders (100mm diameter and 200mm height) for five different mixes were prepared. The concrete poured into the specimen molds with two layers with 5sec - 10 sec vibration each time on a table vibrator. In total, there were three cubic samples for compressive strength and three-cylinder samples for split tensile strength for each mix for each temperature exposure to observe their performance after being subjected to four different heating temperatures (no heat, 200 °C, 400 °C and 600 °C).

IV. Tests on fresh concrete

Slump cone test was used to measure the workability of the different fresh concrete mixes according to ASTM C143. The slump almost remained constant until 12% replacement and hereafter the slump decreased considerably from 140mm to 110 mm at 24% replacement as shown in Figure 4, which shows the relationship between the workability of fresh concrete (Slump) and percent replacement of fine aggregate.
When the concrete was in its fresh state, density of the mixes was also measured by weighing cubic specimens after being vibrated. Figure 5 shows the results of fresh concrete density corresponding to sand percent replacements. The fresh density declines linearly with increasing replacement amount of fine aggregate by recycled tire rubber, which is mostly because of the difference in the dry density of fine aggregate and recycled tire rubber.

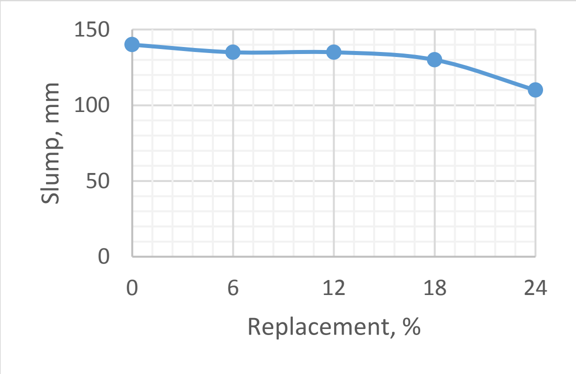

Figure 4: The relationship between the workability of fresh concrete (Slump) and percent replacement of fine aggregate

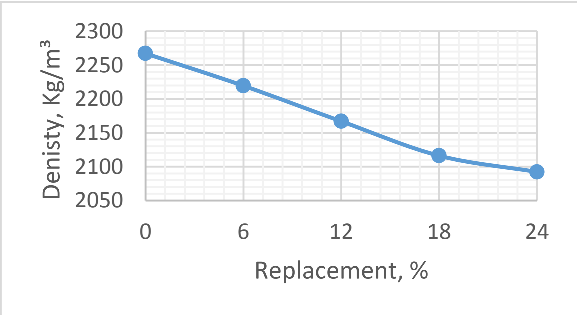

Figure 5: The relationship between fresh concrete density and percent replacement of fine aggregate

V. Heating process

After 28 days in water, 9 samples for each mix were prepared to be heated to 3 different temperatures (200°C, 400°C and 600°C). The following procedure was followed for each temperature level separately. The samples were put and heated in an electric oven usually used for heating ceramic sculptures as shown in Figure 6. The temperature inside the oven is controlled automatically and can reach 1200°C with different heating and cooling rate control. After putting the samples inside the oven, the heating temperature and its rate in the oven was set to reach the required temperature as shown in Figure 7 and remain at that temperature for another hour then it gradually cools off at the same rate of the heating. After the specified time, all samples were removed from the oven and brought to laboratory to carry out further tests on them such as weighing them and finding their compressive and split tensile strengths.

Figure 6: Oven used for heating the samples

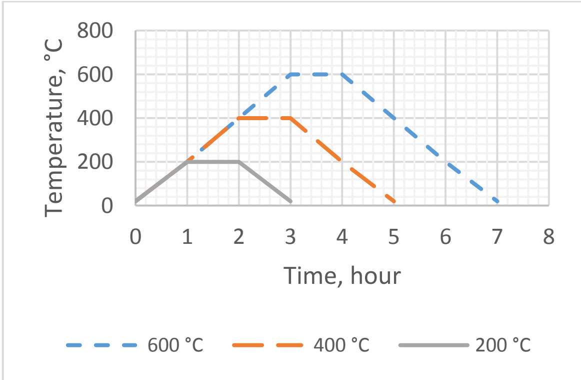

Figure 7: Time – temperature relationship for the tested specimens

VI. Tests on hardened concrete

The specimens were tested after their exposure to the required temperatures. These tests included (weighing samples, compression strength of cubic samples, and indirect tensile strength for cylindrical samples). Firstly, masses were recorded using electronic scale of 0.5g of accuracy to find the percent mass loss for each sample after heating. Finally, cubic concrete samples were crushed under compression testing machine with a loading rate of 0.6 MPa/sec to find their compressive strength in accordance with British Standards 12390-3:2009. The cylindrical specimens were tested for indirect split tensile strength using the same compression testing machine with a loading rate of 0.06 MPa/sec.

4. Results and Discussion

I. Mass loss

All the samples lost weight after heating as illustrated in Figure 8 and 9. Those graphs show the percent mass losses of both cubic and cylindrical samples at elevated temperatures of (200°C, 400°C and 600°C) with respect to the corresponding percent replacement of RTRFA. The average of three specimen masses has been recorded before and after heating the samples.

When heated to 200°C, the samples experienced a little change in their mass loss regarding the percent of rubber content in the concrete as in both Figures 8 and 9. This change fluctuated about 1.5% across Figure 8 and 1% in Figure 9 regardless of the amount of the rubber in concrete which is from 0-24% rubber replacement. This little change is because the elevated temperature (200°C) could evaporate the water entrapped in the concrete but it was insufficient to evaporate the rubber in the samples as its evaporation temperature was tested by the authors to be 260°C as presented in Table 1. Moreover, in samples heated for 400°C, a higher percentage of mass loss can be noted. This percentage increases slightly in a linear manner in Figure 8 as the percent of rubber increases in the samples. For example, the percent mass loss in the concrete with 0% rubber content was 4.4% and this rose to 7.85% when the rubber containing in concrete is increased to 24%. Overall, the percent mass loss was higher when the samples heated for 400 °C than 200 °C. The high loss in mass happened when samples were heated to 600 °C. As it can be noted from Figures 8 and 9, the percent mass loss reached its peak when the samples were heated to 600 °C with increasing percent replacement to 24%. However, there was a concrete explosion and spalling in cubic samples with 12% and 18% of rubber replacement which is the reason behind the peak mass loss of about 24.5% and 19% respectively as it can be seen in Figures 8 and 12 b and 12 c. The above mass losses can be attributed to the evaporation of entrapped water and RTRFA particles heated in the ovens.
When compared with the results obtained by other researchers such as Guo, Y. C. et al. (2014) even though they have used the replacement of crumb rubber by volume. They obtained the percent mass loss of about 10%, 9%, and 6% corresponding to (600°C, 400°C, and 200°C with 12% rubber replacement. The results are reasonable if the percent replacements in this paper converted to be by volume. Knowing the density of the rubber and sand which are 576 kg/m^3, 1322 kg/m^3, 6% by weight approximately corresponds to 12% by volume.

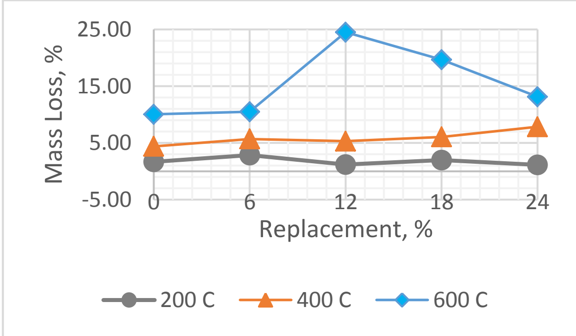

Figure 8: percent mass loss in cubes corresponding to percent sand replacement

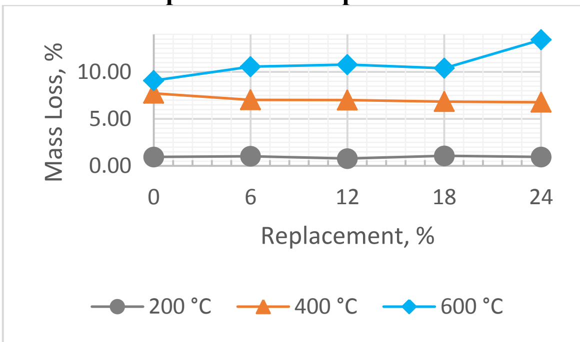

Figure 9: percent mass loss in cylinders corresponding to percent sand replacement

II. Compressive strength

Figure 10 shows the results of compressive strength (fcu) for the samples with no heat and three periods of heating corresponding to their percent replacement of RTRFA (0, 6, 12, 18 and 24%). From Figure 10, it can be noted that, regardless of the heating temperature, the compressive strength of the samples dropped drastically with increasing the rubber content. This decrease can be clearly perceived when compressive strength in 0% rubber content was 57 MPa for no heat and dropped to 29 MPa when the percentage increased to 24%. Another factor that affected the compressive strength was the period of heating of the samples. For instance, the compressive strength of the samples heated to 200 °C decreased linearly from 50 MPa to 26 MPa for the rubber contents of 0% and 24 % respectively. Greater loss in compressive strength can be seen as the temperature elevated and reached 600 °C. As in percent mass loss, the greatest loss in compressive strength was when heating temperature reached 600 °C. There is a linear decline in compressive strength from 31 MPa, for 0% of rubber in concrete, to 10 MPa, for 24% of rubber in concrete. The results are compared with the results obtained by other researchers such as Guo et al. [22] even though they have used the replacement of crumb rubber by volume. They obtained a linear decline in compressive strength. For example, when they replaced 12% of the fine aggregate with rubber the compressive strength decreased form 38 MPa to 10 MPa linearly when heated to 600°C. This linear reduction in compressive strength shows the validity of the achievement presented in this paper as they have used different mixes with having reinforced steel fibers in their mix. Further, other properties of their mix were different such as water cement ration, rubber size, and density of the other ingredients.

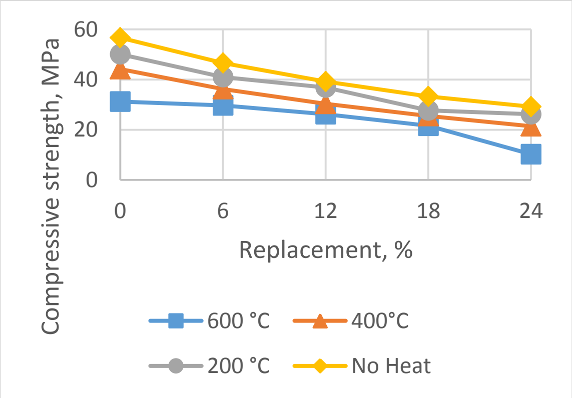

Figure 10: Compressive strength verses % sand replacement for each heating temperature exposure

III. Tensile strength

Figure 11 illustrates the results of split tensile strength of the concrete corresponding to various percent rubber replacements. Tensile strength dropped from 4 MPa to 2.57 MPa with increasing the rubber content from 6% to 24%. For the "No-heat "specimens, the spilt tensile strength at 0% replacement was 2.9 MPa which is lower than that of 6% replacements (4 MPa). This may be due to the higher compressive strength of the concrete at 0% rubber content that makes the specimens more brittle. Another reason is the bridging of the gaps between the crack through the rubber in the vicinity of the cracks after applying the loads. Moreover, there is a linear decrease of tensile strength for samples containing more than 6% as in Figure 11. For example, from 6% replacement afterwards (12%, 18% and 24%), split tensile strength considerably declined to 3.3 MPa, 2.75 MPa, and 2.57 MPa respectively. A similar pattern for the change in tensile strength can be observed for samples heated to 200 °C. As the compressive strength of the concrete decreases its tensile strength curve takes a more logical shape and decreases linearly. For instance, when heated to 400 °C, the tensile of the concrete decreases in a semi-liner manner (2.8 MPa, 2.71 MPa, 2.25 MPa, 2.11 MPa and 2 MPa) for 0%, 6%, 12%, 18% and 24 % rubber replacement respectively.

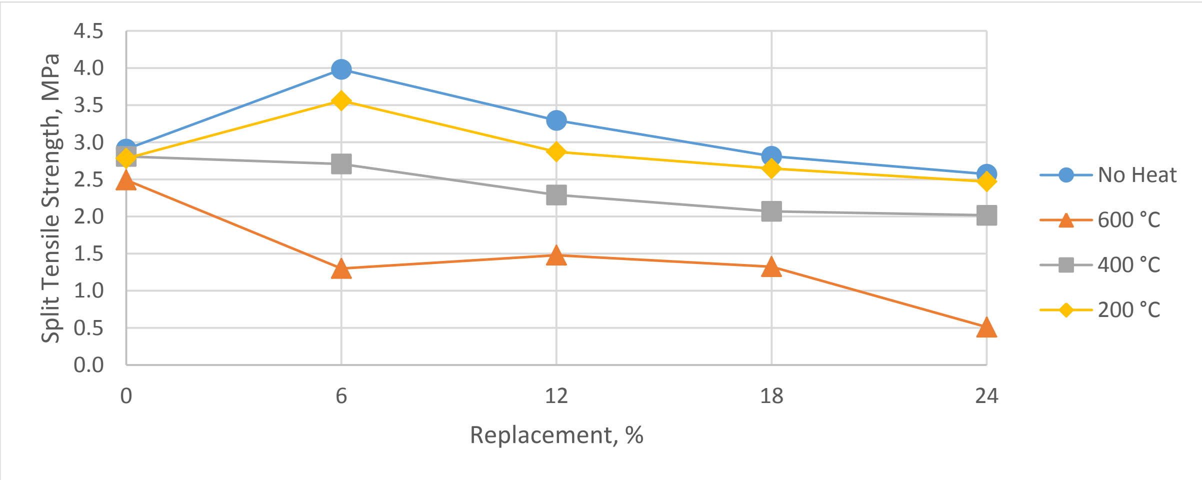

Figure 10: Tensile strength verses % sand replacement for each heating temperature exposure

IV. Concrete spalling and explosion

When the samples were put in the oven, they were put horizontally and vertically on top of each other keeping a distance of 5 cm between two adjacent samples horizontally. This gap was to provide the same environment for all the samples as shown in Figure 12 a. In that case, some of the samples were directly heated from three sides of the heaters inside the oven. Additionally, the temperature of the oven was increased from room temperature of 25°C to 600 °C in 3 hours. These could interpret the spalling and explosion failure of some of the samples after heating in the oven as shown in Figures 12 b, c and d. These samples were from the second mix contained only 12% of rubber and third mix with 18% of rubber as a replacement for sand. Apart from these failures surface cracks are noted in all of the samples regardless of the rubber percentage content. Furthermore, the outside color of the samples remained dark grey color for samples heated to 200 °C, however, samples heated to 400°C and 600 °C gained a yellowish color representing the burning sign on them as it can be seen in Figure 12 d. On top of these, some of the samples gained the black color of the rubber on the sides, which can be interpreted as the sign of evaporation of the tire particles in these temperatures 400°C and 600°C as shown in Figure 12 b. Finally, the oven was equipped with ventilation system therefore; a scent of burnt rubber was spread across the laboratory that confirms the evaporation of the rubber particles. This evaporation led to a decrease in density and mass loss percentage and consequently decreasing both compressive and tensile strengths of the concrete.

a. Before heating
b. After heating spalling for 600°C
c. After heating spalling for 600°C
d. After heating spalling for 600°C

Figure ١١: Samples before and after heating in the electric oven

5. Conclusions

In this research, the performance of rubberized concrete (containing RTRFA) subjected to three different temperatures was investigated including post-heating mechanical properties. From the experimental results, the following conclusions can be drawn:

1. RTRFA has no effect on workability of the concrete in terms of slump at lower rate of 6% rubber content which was 135mm comparing with the control sample. However, the slump decreased slightly to 110mm with the increase of percent replacement of fine aggregate by RTRFA at greater amount up to 24.%
2. Because of the differences in the unit weight of RTRFA and the natural fine aggregate, fresh density of the concrete decline linearly with increasing masses of RTRFA . Fresh density at 0% replacement is equal to 2267 kg/m^3 while this value decreased to 2092 kg/m^3 at 24% rubber replacement.
3. When heated to higher degrees the rubberized concrete loses more mass because rubber evaporates at temperatures of more than 260°C along with water evaporation.
4. Compressive strength reduces with higher rubber content and increasing temperature of heating. For instance, for control specimens with 0% of rubber, the compressive strength of the concrete was 57 MPa while it reduced to 31 MPa when heated to 600°C. Further, that compressive strength of 57 MPa declined linearly 10 MPa at 24 % replacement and heated to 600°C.
5. Generally, the split tensile strength linearly decreases with the increasing rubber content after 6% and with increasing the heating temperature. For example, when heated to 400°C, the specimen lost 0.8 MPa of its split tensile strength when decreased form 2.8 MPa to 2.0 MPa.
6. The total mass loss of the concrete increased with higher percentage of rubber concrete and heating temperature. For the cylindrical specimens, the mass loss has increased form 9% to 13.4% corresponding to 0%, and 24% of rubber content while heated to 600°C.

References

[١] M. Thakur, B. Singh, and M. Tech, “Innovative Application of Waste Tyre in Concrete Mixes,” vol. 3, no. 2, pp. 79–91, 2016.

[٢] R. Siddique and T. R. Naik, “Properties of concrete containing scrap-tire rubber - An overview,” Waste Manag., vol. 24, no. 6, pp. 563–569, 2004.

[٣] L. Li, S. Ruan, and L. Zeng, “Mechanical properties and constitutive equations of concrete containing a low volume of tire rubber particles,” Constr. Build. Mater., vol. 70, pp. 291–308, 2014.

[٤] B.S. Mohammed, K.M. Anwar Hossain, J.T. Eng Swee, G. Wong, and M. Abdullahi, “Properties of crumb rubber hollow concrete block,” J. Clean. Prod., vol. 23, no. 1, pp. 57–67, 2012.

[٥] N.I. Fattuhi and L.A. Clark, “Cement-based materials containing shredded scrap truck tyre rubber,” Constr. Build. Mater., vol. 10, no. 4, pp. 229–236, 1996.

[٦] I.B. Topçu, “The properties of rubberized concretes,” Cem. Concr. Res., vol. 25, no. 2, pp. 304–310, 1995.

[٧] A. Benazzouk, O. Douzane, T. Langlet, K. Mezreb, J. M. Roucoult, and M. Quéneudec, “Physico-mechanical properties and water absorption of cement composite containing shredded rubber wastes,” Cem. Concr. Compos, vol. 29, no. 10, pp. 732–740, 2007.

[٨] M.A. Aiello and F. Leuzzi, “Waste tyre rubberized concrete: Properties at fresh and hardened state,” Waste Manag., vol. 30, no. 8–9, pp. 1696–1704, 2010.

[٩] A.O. Atahan and A.Ö. Yücel, “Crumb rubber in concrete: Static and dynamic evaluation,” Constr. Build. Mater, vol. 36, pp. 617–622, 2012.

[١٠] M.K. Batayneh, I. Marie, and I. Asi, “Promoting the use of crumb rubber concrete in developing countries,” Waste Manag., vol. 28, no. 11, pp. 2171–2176, 2008.

[١١] B. Al-Shathr, “Effect of Using Plastic and Rubber Wastes as Fine Aggregate on Some Properties of Cement Mortar,” Eng. Tech. J., vol. 3, no. 8, pp. 1688–1699, 2016.

[١٢] W.S. Deepak and G.T. Naidu, “Effect on Compressive Strength of Concrete Using Sea Sand As a Partial Replacement for Fine Aggregate,” vol. 14, no. 1, pp. 2319–2322, 2015.

[١٣] A. Benazzouk, O. Douzane, and M. Quéneudec, “Transport of fluids in cement-rubber composites,” Cem. Concr. Compos, vol. 26, no. 1, pp. 21–29, 2004.

[١٤] W. Wang, C. Lu, Y. Li, and Q. Li, “An investigation on thermal conductivity of fly ash concrete after elevated temperature exposure,” Constr. Build. Mater, vol. 148, pp. 148–154, 2017.

[١٥] M. Yaqub and C.G. Bailey, “Repair of fire damaged circular reinforced concrete columns with FRP composites,” UK, 1, 2011.

[١٦] Y. Zhai, Z. Deng, N. Li, and R. Xu, “Study on compressive mechanical capabilities of concrete after high temperature exposure and thermo-damage constitutive model,” Constr. Build. Mater, vol. 68, pp. 777–782, 2014.

[١٧] M. Li, C. Qian, and W. Sun, “Mechanical properties of high-strength concrete after fire,” vol. 34, no. November 2003, pp. 1001–1005, 2004.

[١٨] A. Ahmed and D. Maeroof, “The Effect of High Temperatures on the Mechanical Properties of Concrete with Different Strengths at Different Mixing Ratio,” Kirkuk Univ. J. /Scientific Stud., vol. 10, no. 4, pp. 44–70, 2015.

[١٩] L.W.I. Khalil, “Influence of High Temperature on Steel Fiber Reinforced Concrete,” J. Eng. Dev., vol. 10, no. 2, pp. 139–150, 2006.

[٢٠] M.A.A. Ali, “Residual Mechanical Properties of Self-Compacting Concrete Exposed to Elevated Temperatures,” Eng. Technol., vol. 29, no. 7, pp. 1386–1399, 2011.

[٢١] T. Kantasiri, P. Kasemsiri, U. Pongsa, and S. Hiziroglu, “Properties of Light Weight Concrete Containing Crumb Rubber Subjected to High Temperature,” Key Eng. Mater., vol. 718, pp. 177–183, 2016.

[22] Y.C. Guo, J. H. Zhang, G.M. Chen, and Z.H. Xie, “Compressive behaviour of concrete structures incorporating recycled concrete aggregates, rubber crumb and reinforced with steel fibre, subjected to elevated temperatures,” J. Clean. Prod., vol. 72, pp. 193–203, 2014.