Heat Response of Concrete Embedded with Recycled Tire Rubber: Strength and Durability Analysis

Carlos M. Alvarez*[1], Helena R. Da Silva[2] & Pedro S. Goncalves[3]
*[1]Professor of Structural Engineering, Department of Civil Engineering, Faculty of Engineering, Universidade de Lisboa, Lisbon, Portugal
[2]Professor of Materials Science, Faculty of Engineering, Universidade do Porto, Porto, Portugal
[3]Postgraduate Student, Department of Civil Engineering, Faculty of Engineering, Universidade de Lisboa, Lisbon, Portugal

ABSTRACT
Rubberized concrete is like normal concrete but with replacement part of aggregate (fine or coarse) by waste tires rubber, in this paper only a part of coarse aggregate was replaced by crushedrubber. The objective of this paper is to study the effect of elevated temperatures on concrete containing waste tires rubber which used in civil construction like in rigid concrete pavement. Five different ratios of rubber were used as a replacement of the volume of coarse aggregates of concrete by 2.5%, 5%, 10%, 15% and 20%. Various concrete specimens; slabs, prisms, cubes and cylinders were used. Specimens were exposed to different temperatures (50° C and 70° C for five hours and 300° C for two hours). From results, flexural strength decreases significantly with the increase in the proportion of rubber content in concrete and elevated temperature. While the compressive strength was more sensitive to temperatures where the compressive strength of the concrete containing the rubber is adversely affected by increasing temperature. Also, it was noticed that the splitting tensile strength was very sensitive to temperature than the compressive strength.

KEYWORDS: Elevated Temperature; Rubber; Compressive Strength; Flexural Strength; Tensile Strength.

I. INTRODUCTION
Fountain solution is a water-based mixture specially formulated to dampen lithographic printing plates before Recently, the use of rubber concrete has been considered in civil engineering. First studies were carried out in the early 1990s in Arizona in United State of America [1], to achieve two objectives: first, to improve some of the properties of ordinary concrete. The second objective is to rid the environment of the increased waste tires year after year. Thus, it is important to understand the effect of the elevated temperature on rubberized concrete characteristics, like compressive strength, flexural strength, and tensile strength. From the literature review, the compressive strength of concrete decreasing with increasing temperatures, [2, 3&4]. Figure 1 shows the relationship between compressive strengths and elevated temperature for rubberized concrete. It was observed that the compressive strength reduced with the rising of temperature, [5]. While, replacing the aggregate with an appropriate amount of rubber in the concrete would improve some of its properties, but the risk of exposure to high temperatures, which may lead to spalling [6]. Also, the rubber concrete should not be used in case of the high-temperature condition [7]. The effect of higher temperatures on the strength of rubberized concrete is less than the effect of freezing and thaw, [8]. But, the high temperatures may have harmful effects on rubber concrete such as spalling and surface cracking and therefore suggested to be used in conditions not exceeding 100 ° C [9].

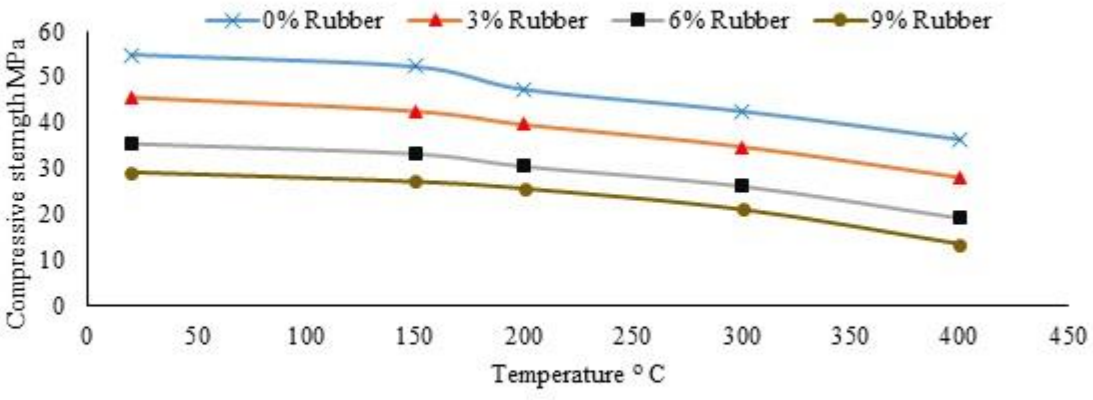

Figure 1: Relationship between Compressive strength of rubberized concrete and elevated temperature, [5].

The second characteristic of the rubberized concrete, which is affected by elevated temperature, is the flexural strength. Figure2shows the relation between the flexural strengths and the elevated temperature for rubberized concrete where it was observed that the flexural strength reduces with the rising of temperature,[5].

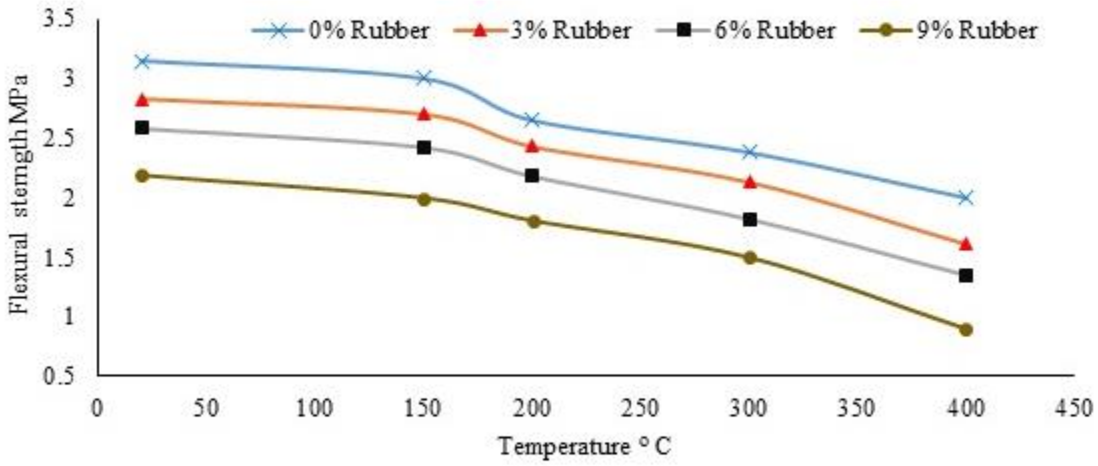

Figure 2: Relationship between flexural strength of rubberized concrete and elevated temperature, [5].

Another characteristic of the concrete, which is affected by elevated temperature, is the splitting tensile strength. Where, the splitting tensile strength decreased with increasing temperatures [4&10]. Figure 3 shows the relation between splitting strengths and elevated temperature for concrete where was observed the splitting tensile strength reduced with the temperature rising.

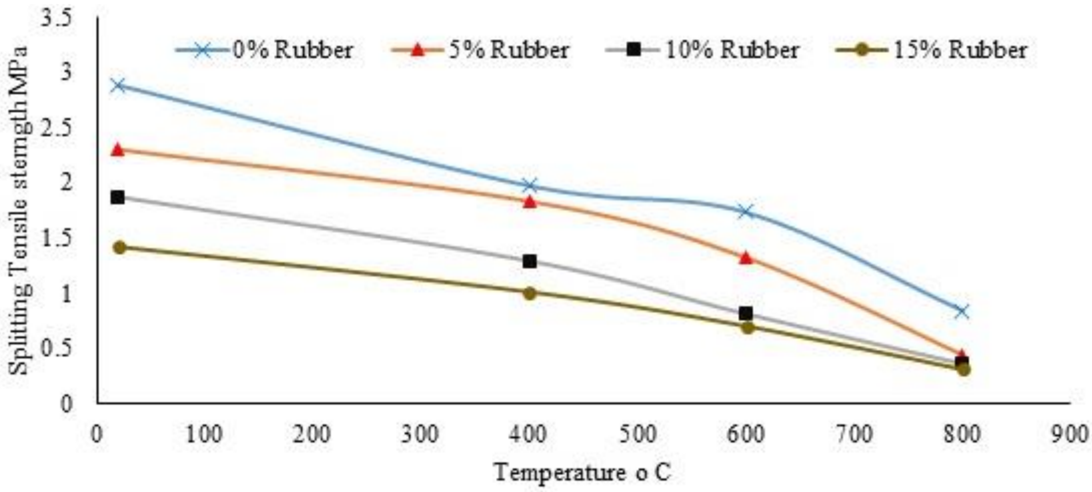

Figure 3: Relationship between splitting tensile strength of rubberized concrete and elevated temperature, [10].

II. MATERIALS AND EXPERIMENTAL PROGRAM

The fine aggregate used was natural sand with grain size from 4.75 mm to 0.15 mm, a specific gravity 2.5, and bulk density 1530kg/m3. Coarse aggregate used was crushed dolomite graded from 20 mm to 4.75 mm with a specific gravity 2.71 and bulk density 1350kg/m³. The cement used is sulphate resistant cement CEM/SR3 42.5 N.It was locally produced with 28 days compressive strength of 42.5 MPa. The chemical and physical characteristics of cement satisfy the Egyptian Standard Specification [11]. Plasticizer namely Sikament - R 2004 locally produced was used with 1.2 kg/Lt density, andit complies with ASTM C494 type G [12]. Recycled tires were used from Hana Misr Company in the industrial area of Ismailia, Egypt, where the company recycled waste tires for industrial purposes. The materials were of different grades and the research dealt with the replacement of coarse aggregates so that the rubber was classified by the sieve analysis (as shown in Figure 4) to conform to the coarse aggregate gradient in order to obtain the correct proportionsof rubber in the concrete mix as shown in Figure 5 below. Waste tire rubber graded 4.75 mm to 10 mm with a specific gravity 1.019 and bulk density 370 kg/m³.

Figure 4: Sieve analysis for rubber

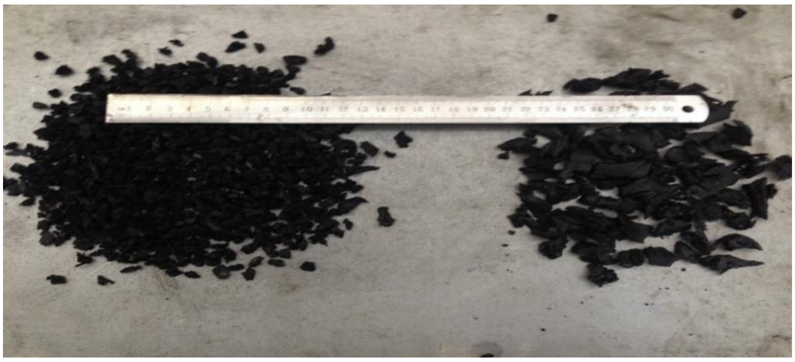

Figure 5: Gradient for Rubber

Mixing, Casting, and Curing Processes

Table 1 shows the mix proportions of control mix (without rubber) and five different mixes contain different

Table 1:proportions of mixtures with different rubber replacement ratios.

Mix ID	W/C	Cement	Fine agg.	Coarse aggregate			Water	Rubber			Total
			Wt	Volume		Wt		Volume		Wt	
		kg/m³	kg/m³	%	m³	kg/m³	kg/m³	%	m³	kg/m³	kg/m³
Control mix F_{cu} 30	0.47	360	615	100	0.94	1280	170	0	0	0	2417
C.A-2.5 %	0.47	360	615	97.5	0.92	1248	170	2.5	0.02	8.70	2394
C.A-5 %	0.47	360	615	95	0.89	1216	170	5	0.05	17.41	2370
C.A-10%	0.47	360	615	90	0.847	1152	170	10	0.09	34.82	2324
C.A-15 %	0.47	360	615	85	0.800	1088	170	15	0.14	52.24	2277
C.A-20%	0.47	360	615	80	0.753	1024	170	20	0.19	69.65	2231

replacement ratios of rubber.Various concrete specimens (slabs 80 × 80 × 10 cm), (prisms 50 × 10 × 10 cm), (cubes 15 × 15 × 15 cm) and (cylinders 10 × 20 cm) were prepared. Five different percentages of rubber replacement by the volume of coarse aggregate 2.5%, 5%, 10%, 15% and 20%. After mixing, slump is measured for all mixes and their values are between (17-20 cm)as shown in Figure 6.

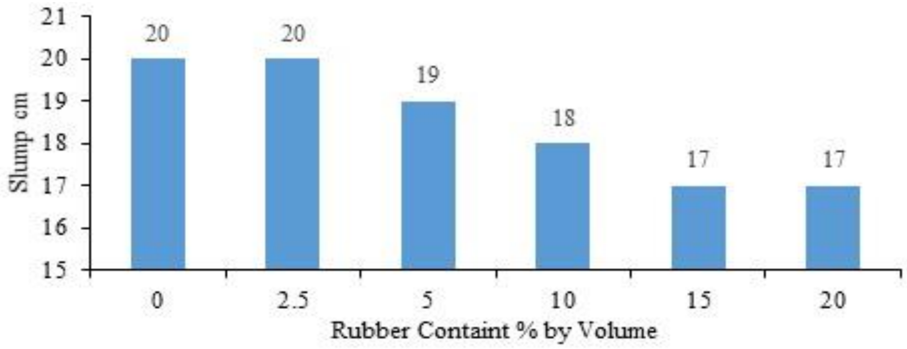

Figure 6: Slump of mix vs. different rubber contents

Specimens of slabs and prisms were used to measure flexural strength, cubes for measuring compressive strength and cylinders for measuring splitting tensile strength. The specimens cured in water 28 days date of testing. Some specimens subjected to temperatures of 50 and 70 ° C. They were placed in an oven shown in Figure 7a for 5 hours. Also to study the effect of high temperature,specimensare subjected to a temperature of 300 ° C by an oven shown in Figure 7b for two hours. Time – Temperature rise curve of the oven (a) and oven (b) are shown in Figure 8 and Figure 9 respectively. The concrete specimens are then taken away from the oven and left at the room temperature to cool for 24 hours andthen tested in compressive, flexural and tensile strength.

(a) *(b)*

Figure 7: Heating Oven (a) For 50 and 70 o C, (b)For 300 o C

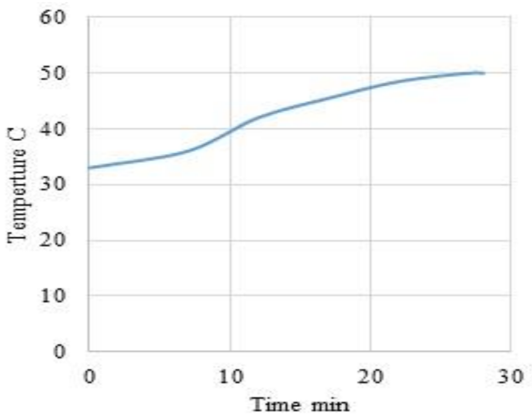

Figure 8: Time – Temperature rise curve of oven (a).

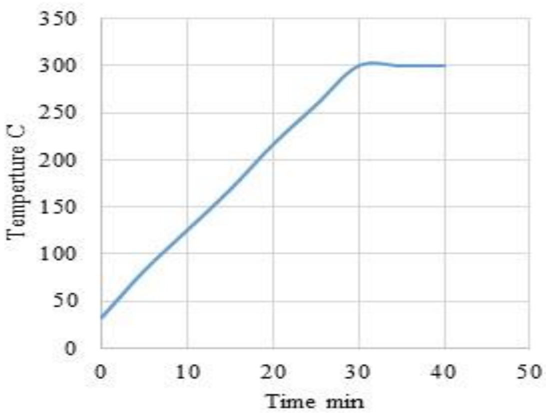

Figure 9: Time – Temperature rise curve of oven (b).

III. TEST RESULTS AND DISCUSSIONS

The properties which were taken into consideration in this paper were the compressive strength, the flexural strength, and the tensile strength at the temperature of 50, 70 and 300 oC of the concrete specimens whichcontaining different proportion of rubber, in addition to those tested at room temperature.

Compressive strength

Compressive strength tests were performed according to BS 1881-116:1983. The results of the compressive strength test on concrete specimens containing different percentages of rubber after exposure to different temperatures of 50, 70 and 300 ° C, are shown in Table 2 below. The first groupwhich was tested at room temperature show that the compressive strength of the specimens containing rubber in the proportions of 0%, 2.5%, 5%, 10%, 15% and 20% arereduced by 9%, 15%, 22%, 30% and 34%, respectively comparing with conventional concrete. While the second group which were exposed to temperature 50° C, shows that the amount of reduction in the compressive strength of the specimens are 3%, 16%, 18%, 25%, 31% and 36%, respectively compared with conventional concrete. Also, the third group which were exposed to temperature 70° C, shows that the amount of reduction in the compressive strength of the specimens containing rubber are 9%, 13%, 19%, 31%, 32% and 40%, respectively. The last group were exposed to temperature 300° C, where the specimens (cubes, prisms and cylinders) were in the oven for one hour it was noticed that the smell of rubber which was burning and after the two hours the cracks were observed due to the high temperature and the color of the specimens are pale due to evaporation of water in the concrete as shown in Figure 10.The amount of reduction in the compressive strength of the specimens containing rubber are 18%, 19%, 19%, 29%,37% and 38%, respectively compared to conventional concrete. Figure 11 shows the summary of results for the four groups. The compressive strengths areadversely affected by increasing temperature and increasing the rubber content in the concrete.

Figure 10: Cube after heating (300oC) in oven for two hours

Table 2: Compressive strength test results for specimens exposed to temperatures 50, 70 and 300 ° C

Rubber Content %	compressive Strength kg/cm^2							
	25° C		50° C		70° C		300° C	
		Droop		Droop		Droop		Droop
0	442	Conventional	430	3%	404	9%	364	18%
2.5	404	9%	373	16%	384	13%	360	19%
5	375	15%	363	18%	360	19%	356	19%
10	345	22%	331	25%	305	31%	314	29%
15	311	30%	303	31%	301	32%	279	37%
20	293	34%	282	36%	241	45%	276	38%

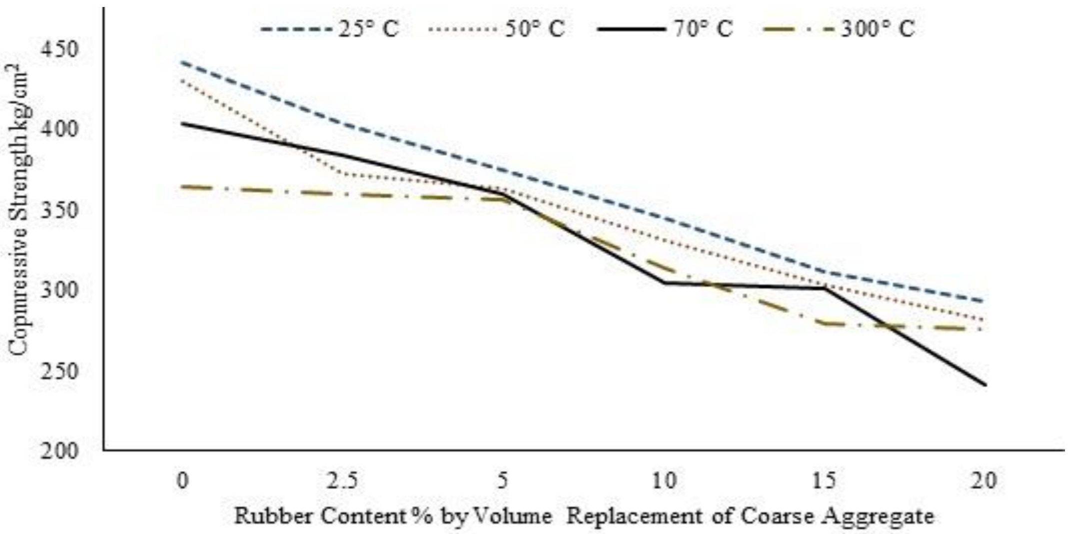

Figure 11: Compressive strength vs. Rubber Content

Flexural Strength (Modulus of Rupture)

The tested specimens are concrete slab with dimensions (80× 80×10) cm and prisms with dimensions (50× 10×10) cm.They were tested in 4 points of loading using the hydraulic universal testing machine equipped with front-opening hydraulic grips with capacity 300 tons) according to ASTM C 78. Table 3shows the results of the flexural test on concrete specimens with different rubber proportion as a replacement of coarse aggregates, before and after exposed to elevated temperature. The first group are tested in room temperature where it was noted that the amount of reduction in the flexural strength of the specimens containing rubber in the proportions of 0%, 2.5%, 5%, 10%, 15% and 20%are reducedby6%, 6%, 11%, 11% and 20% compared with the conventional concrete. The second group were exposed to temperature 50° C, and it was noted that the amount of reduction in the flexural strength of the specimens are 6%, 11%, 11%, 16%, 20% and 25%, respectively compared with conventional concrete. The third group which were exposed to temperature 70° C, it was noted that the amount of reduction in the flexural strength of the specimens containing rubber are 26%, 33%, 40%, 41%, 42% and 44%, respectively. In the last group of specimens tested after exposure to a temperature of 300 ° C had a reduction in flexural strength of 37%, 40%, 50%, 65%, 72% and 68%, respectively compared with conventional concrete. It was noted that some cracks are appear on specimens as shown in Figure 12 and the amount of reduction in flexural strength decreases significantly with the increase in the proportion of rubber content in concrete. Figure 13, shows the results of the flexural strength is adversely affected by increasing temperature and increasing the rubber content in the concrete.

Table 3: Flexural strength test results for specimens exposed to temperatures 50, 70 and 300° C

Rubber Content %	Flexural Strength kg/cm2							
	Slab specimens 80×80×10 cm		Prism Specimens 50×10×10 cm					
	25 C		50 C		70 C		300 C	
		Droop		Droop		Droop		Droop
0	64	Conventional	60	6%	47	26%	40	37%
2.5	60	6%	57	11%	43	33%	39	40%
5	60	6%	57	11%	39	40%	32	50%
10	57	11%	54	16%	38	41%	23	65%
15	57	11%	51	20%	37	42%	18	72%
20	51	20%	48	25%	36	44%	20	68%

Figure 12: specimen after heating (300oC) in oven for two hours

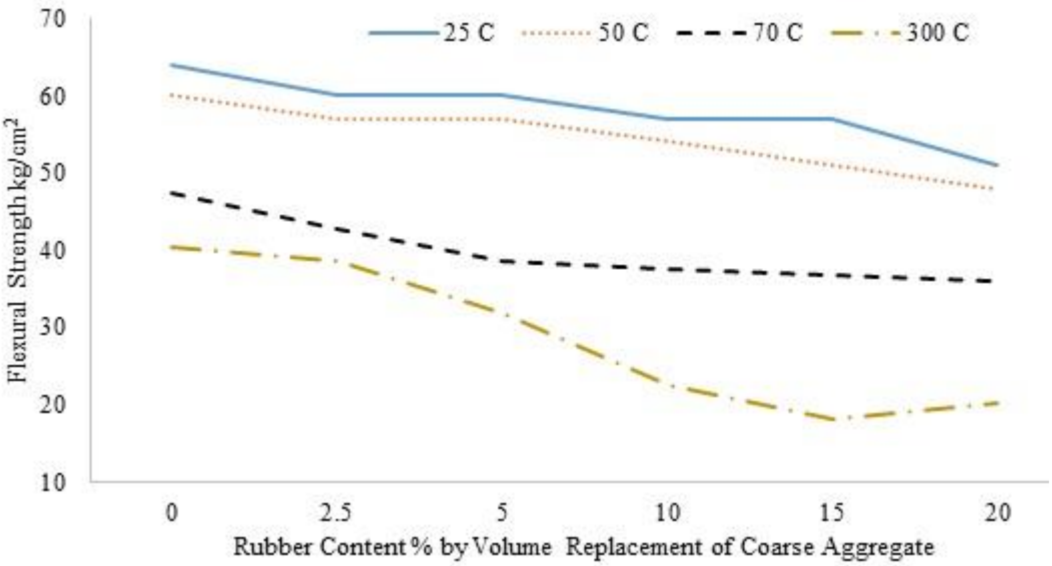

Figure 13: Flexural strength vs. Rubber Content

Splitting tensile strength

The results of the splitting tensile strength test for the concrete specimens containing different percentages of rubber were shown in Table 4before and after exposure to temperatures 50 and 70 for five hours and temperature of 300 ° C for two hours.

Table 4: Splitting tensile strength test results for specimens exposed to temperatures 50, 70 and 300 ° C

Rubber Content %	Splitting Tensile Strength kg/cm2							
	25° C		50° C		70° C		300° C	
		Droop		Droop		Droop		Droop
0	43.40	Conventional	40.00	8%	34.90	20%	31.70	27%
2.5	38.00	12%	35.00	19%	30.50	30%	29.80	31%
5	32.80	24%	28.70	34%	27.80	36%	22.50	48%
10	29.10	33%	23.00	47%	22.00	49%	20.50	53%
15	23.40	46%	22.60	48%	21.70	50%	19.10	56%
20	20.00	54%	19.70	55%	16.30	62%	13.00	70%

The splitting tensile strength results for the first group which were tested at room temperature (25° C) and containing0%, 2.5%, 5%, 10%, 15% and 20% rubber are decreased by 12%, 24%, 33%, 46% and 54% respectively, compared with conventional concrete. While the second group after exposure to 50 ° C, the reductionsare in amounts of 8%, 19%, 34%, 47%, 48% and 55% respectively, compared with conventional concrete. The third group, which was exposed to a temperature of 70 ° C, the test results indicated that the reductions in splitting are 20%, 30%, 36%, 49%, 50% and 62%, respectively compared with conventional concrete. The last group, which was exposed to a temperature of 300 ° C, the results showed that the splitting tensile strengthare decreasedby 27%, 31%, 48%, 53%, 56% and 70% compared to conventional concrete. Also, it was noticed that cylinder is suffered from different cracks as shows in Figure 14.

Figure 14: Cylinder after heating (300oC) in oven for two hours

Figure 15, shows the effect of elevated temperature on splitting tensile strength of concrete containing different ratios of rubber.The tensile strength is adversely affected by increasing temperature and increasing the rubber content in the concrete.

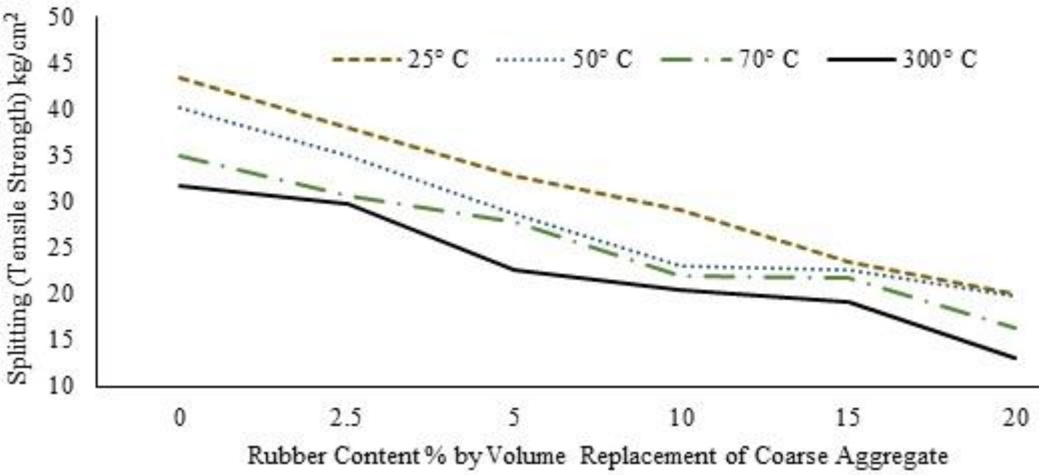

Figure 15: Splitting (Tensile strength) vs. Rubber Content

IV. CONCLUSIONS

Based on the experimentalresults, the following conclusions can be summarized:

1. Compressive, flexural and splitting tensile strengths were reduced by increasing of rubber content.
2. The compressive strength was sensitive to temperatures where the compressive strength of the concrete containing the rubber is adversely affected by increasing temperature. The reduction in compressive strengths is up to 34% at 25° C. However, when concrete subjected to elevated temperature
3. The reduction in flexural strengths is up to 20% at 25°C.However, when concrete subjected to elevated temperature, flexural strength was reduced by (6-25%) at 50°C, (26-44%) at 70°C and (37-68%) at 300°C.
4. The reduction in splitting tensile strength is up to 54% at 25° C.However, when concrete subjected to elevated temperature splitting tensile strength was reduced by (8-55%) at 50° C, (20-62%) at 70° C and (27-70%) at 300° C.

V. ACKNOWLEDGEMENT

We would like to express our deep appreciation and gratitude to all those who helped us in Suez Canal Authority laboratory and Faculty of Engineering laboratories.

VI. REFERENCES

[1] Kaloush K., Way G. & Zhu H. (2005). "Properties of crumb rubber concrete". Journal of the Transportation Research Board. ISSN: 0361-1981. Volume 1914. PP.8-14.

[2] Chan Y. N., Peng G. F., & Anson M. (1999). "Residual strength and pore structure of high-strength concrete and normal strength concrete after exposure to high temperatures". Cement and Concrete Composites. Volume: 21. Issue: 1. PP. 23-27.

[3] Yaragal S., Narayan K. B., Venkataramana K., Kulkarni K., Gowda H. C., Reddy G. R. & Sharma A. (2010)." Studies on normal strength concrete cubes subjected to elevated temperatures". Journal of Structural Fire Engineering. Volume: 1. Issue: 4. PP. 249-262.

[4] Ahmed S. M. A. (2013). "Effect of the elevated temperature on compacting concrete reinforced by steel fiber". Thesis (Master) University of Babylon. Iraq.

[5] Guelmine. L., Hadjab. H., &Benazzouk. A. (2016). "Effect of elevated temperatures on physical and mechanical properties of recycled rubber mortar". Construction and Building Materials. Volume: 126. PP. 77-85.

[6] Haibo Z., Mifeng G., Xiaoxing L. &Xuemao G. (2014). "Effect of rubber particle modification on properties of rubberized concrete". Journal of Wuhan University of Technology-Mater. Sci. Ed.Volume: 29. Issue: 4. PP. 763-768.

[7] Deshpande N., Kulkarni S. S., Pawar T. &Gunde V. (2014). "Experimental investigation on strength characteristics of concrete using tyre rubber as aggregates in concrete". International Journal of Applied Engineering Research and Development (IJAERD). Volume: 1. Issue: 4. PP. 97-108.

[8] Gadkar S. A. (2013)." Freeze-thaw durability of Portland cement concrete due to addition of crumb rubber aggregates ". Thesis (PhD). Clemson University. UAS.

[9] Siringi G. M. (2012). "Properties of Concrete With Tire Derived Aggregate and Crumb Rubber as a Lightweight Substitute For Mineral Aggregates In The Concrete Mix". Thesis (PhD). University of Texas. USA.

[10] Marques, A. M. (2010). "Fire behaviour of concrete made with recycled rubber aggregates" .Thesis (Doctoral). University of Lisbon. Portugal.

[11] ES: 4756-1/ 2009.Cement. Part :(1).Composition, Specifications and conformity criteria for common cement.

[12] ASTM C 494 - C 494M. (2005)." Chemical Admixtures for Concrete"American Society for Testing and Materials.