Kurdistan Journal of Applied Research (KJAR)
Print-ISSN: 2411-7684 | Electronic-ISSN: 2411-7706

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Effect of Impact Load on Concrete Containing Recycled Tire Rubber Aggregate With and Without Fire Exposure

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Article Info

Volume 5 – Issue 1 – June 2020

DOI:
10.24017/science.2020.1.4

Article history:

Received 08 February 2020
Accepted 29 March 2020

Keywords:

Recycled Tire Rubber Aggregate, Rubberized concrete, Replacement, Impact Energy, Fire Exposure, Impact Load, Drop Weight Impact Test.

ABSTRACT

Over one billion tires are disposed into environment each year and this has become a major environmental issue in the globe. Recycling of these waste tire rubbers in concrete has gained attention from researchers all around the world. In this study, the impact resistance of rubberized concrete exposed to fire is investigated experimentally in the laboratory. For that purpose, sixty specimens were made with five different mixes replacing their sand content partially with different percentages of tire rubber by weight ratios of 0% control, 6%, 12%, 18% and 24%. The water/cement ratio was kept constant at 0.393 in all the mixes. In each mix, fifteen concrete specimens with the size of (150 x 150 x 73) mm were prepared to expose to fire. Every three specimens were gradually exposed to fire for four various durations of (0, 15, 30, and 45) minute. Each specimen was then tested in a drop-weight impact machine by dropping 2240-gr and 4500-gr hammers from heights of 280 mm and 450 mm. The average impact energy of three identical specimens required for the occurrence of final fracture was calculated. The investigational results are compared with results of control samples. It is found that the impact energy considerably increased with an increase of the rubber replacement. It is, also, noted that any increase in the burning period of specimens results in a reduction of the impact energy and more early crushing of the rubberized concrete.

1. INTRODUCTION

There are numerous examples of possible impact loadings in which structures or structural elements may be subjected to such loads and they shall be considered in design [1]. The most common construction material is concrete as it is generally used in almost all engineering projects such as aircraft industry, bridge decks, and pavements. Therefore, understanding the behavior of concrete subjected to impact is vital. One of the important concrete properties needed when exposed to impact loading is its energy absorption [2-3]. Despite of this fact, it is proven that the concrete response under impact loads is very problematic and several failure modes may be detected [4]. Therefore, more research is needed to be carried out on impact resistance of concrete in general and rubberized concrete in particular even though it is revealed that the addition of some percentage of rubber in concrete leads to a considerable increase of its impact resistance [2].

Many studies have examined the effect of impact loading on the rubberized concrete [5]. Some techniques such as, a Modified Charpy Impact test, Split Hopkinson pressure bar test, Fired Projectile, and drop-weight apparatus, have been used to study the behavior of concrete under the dynamic loads.

Taha et al. [6] studied concrete beams of (100 x 100 x 500) mm made with the rubber aggregates replacement ratios of (0, 25, 50, 75, and 100)% by volume of both coarse and fine aggregates. The impact test was performed by falling a 10-kg hammer onto the midspan of the beam from height of 60 mm. Their results revealed that the impact resistance of rubberized concrete increases with an increase in rubber ratio up to 50% replacement of sand. However, any further rubber ratio than 50% causes a drop in the impact resistance of the specimens.

Al-Tayeb et al [7] replaced fine aggregate by fine rubber with ratios of (5, 10 and 20) % replacements by volume to investigate the effect of the impact loads on performance of the concrete. They made three beams of sizes of (400 x 100 x 50) mm of the concrete mix with and without rubber. The beam specimens were repeatedly subjected to 20 N weight from 300 mm height in drop-weight impact machine. Their results show that the amount of fracture energies for 5, 10 and 20 % replacements increased approximately by (72, 109, and 198)% respectively. However, Vadivel et al [8] conducted impact tests on the disc specimens (150mm diameter x 64 mm thickness) made with concrete containing 6% replacement of both fine and coarse aggregate by waste tire rubber aggregates. A steel ball from drop weigh equipment was created and manually operated by dropping 3.5-kg compaction hammer from height of 1.22 m. The test results show that 6% replacement of both fine and coarse aggregate with rubber aggregates significantly improved the impact resistance by 83%.

Sadrmomtazi and Zanoosh [9] studied the performance of concrete containing waste tire rubber under the impact loads at high velocities. They prepared cubic specimens with (0, 10, 20, 30, 40 and 50)% replacement of fine aggregate with rubber. Impact tests were carried out with gas gun device using the small projectile of 29-gr ball of 19 mm in diameter. The concrete specimens were subjected to the projectile at impact velocity of 150 m/s. both Penetration depth and average crater area were measured. The results show that the concrete contained rubber particles is softer than normal concrete and the depth of the penetration is reduced in rubberized concretes. Specimens containing 30% of rubber had lower penetration depth than that of other specimens. Malagavelli et al [10] examined the effect of impact loads on rubberized concrete made with different ratios of (0, 10, 20)% replacement of coarse aggregate with rubber aggregates. At the age of 28 days, concrete cubes of (100x100x100) mm were repeatedly tested against 1.811-kg ball of 55 mm diameter. The ball was freely dropped from the height of 1.95 m. The number of blows were recorded at both first crack and fracture of concrete cubes. Their results show that the impact resistance of the concrete at the replacements of 10% and 20 % are improved by 60% and 120 % at first visual crack, and 33% and 78 % at fracture respectively.

One of the notable points about rubberized concrete is that it undergoes the reduction of some mechanical properties where it is exposed to fire [11-13]. Despite of this fact, and to the knowledge of the authors, no work can be found in the literature reporting the impact resistance of rubberized concrete exposed to fire. The main aim of the current work is to investigate the post-fire impact resistance of normal concrete incorporating tire rubber as a partial replacement of fine aggregate. Four different tire rubber replacement ratios of (6, 12, 18, and 24)% by weight are used as a partial replacement of the fine aggregate.

2. EXPERIMENTAL PROGRAM

2.1 Materials

All materials used in the concrete mixes are locally available in Sulaymaniyah city, Iraq (35° 34' 0.7104" N and 45° 24' 57.9852" E). Ordinary Portland cement (CEM I /42.5 R) produced according to EN 197-1:2011 is used in all the mixes [14]. Fine aggregates are natural sand having maximum particle size of 4.75 mm and saturated specific gravity of 2.59. The basalt based coarse aggregates are also natural having round shape with maximum particle size of 10 mm and saturated specific gravity of 2.64. In this study rubbers, namely crumb rubber, were used as partial replacement of fine aggregates. These rubber aggregates were commercially available, spread on sports yard for safety requirements. In the factory they are produced from mechanical grinding of waste tires. The rubber aggregates used here were in dry condition, dispersed particles, and had maximum size of 4.75 mm with compacted dry density of 677 kg/m³. Further, no admixtures or additive materials are used in this study.

The summary of some physical properties of aggregates are shown in Table 1. Moreover, Particle size distribution of recycled tire rubber aggregates, coarse and fine aggregates is shown in Figure 1.

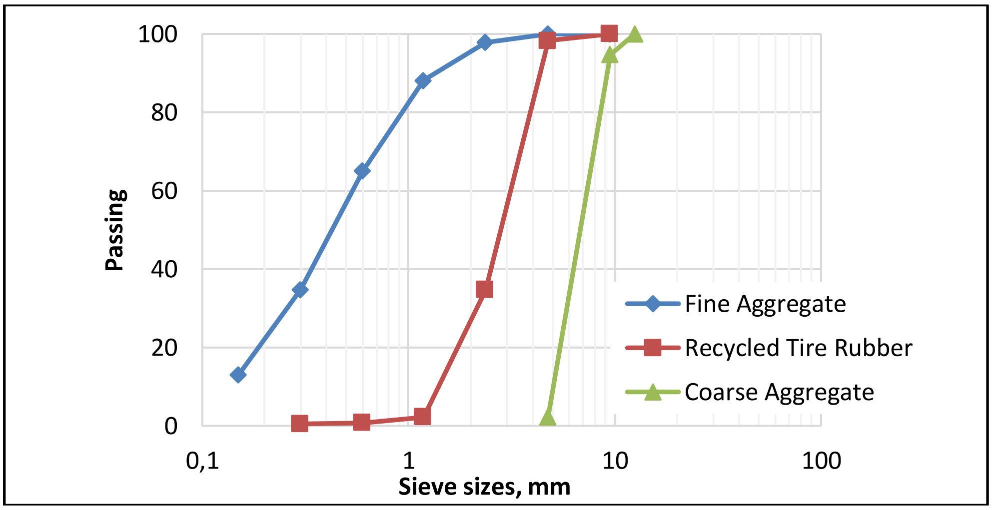


Figure 1: Particle size distribution

Table 1: Properties of aggregate used to make specimens

Properties	Gravel	Sand	Rubber
Fineness Modulus, unitless	2.03	2.01	-
Max. particle size, mm	10	4.75	4.75
Compact dry density, kg/m³	1679	1552	677
Uncompact dry density, kg/m³	1565	1322	576
Water absorption, %	0.96	-	-
Bulk specific gravity, Dry	2.62	2.46	-
Bulk specific gravity, SSD	2.64	2.59	-
Apparent specific gravity	2.68	2.84	-
Particle surface	Round	-	Round, dry
Source	river	river	Recycled tire

2.2 Mix proportion

Concrete with mean compressive strength of 40 MPa is designed as the controlled mix in accordance with ACI 211.1 [15]. The actual physical properties of aggregates used in mix proportion is to predict workability of 100-140 mm slump. The mix proportion used to make the control specimens for cement, sand, gravel (1:1.179:1.34) respectively. The water/cement ratio for the mix was 0.393 for all the mixes. Five mixes were prepared for this study. One of them was normal concrete without tire rubber, called control mix (0%). The rest of the mixes were rubberized by partially replacing fine aggregates with recycled tire rubber of different ratios of (6, 12, 18 and 24)% by weight. The original concrete mix used for testing the impact resistance of tire rubber particles are presented in Table 2.

Table 2: Batch mix proportions

Mix No	**Replacement, %**	**Cement, kg**	**Sand, kg**	**Gravel, kg**	**Water, kg**	**Rubber, kg**
Mix 1	0	84	99	113	33	0
Mix 2	6	84	93.06	113	33	5.94
Mix 3	12	84	87.12	113	33	11.88
Mix 4	18	84	81.18	113	33	17.82
Mix 5	24	84	75.24	113	33	23.76

2.3 Specimens preparation

Both fine and coarse aggregates were first dry-mixed manually for 2–3 minute on a clean dry steel container of (4 x 2 x 0.2) m. The tire rubber aggregates were then spread in the container and mixed with both fine and coarse aggregate to ensure the uniform distribution of rubber particles. The cement was added to the dry mix of the aggregates and well mixed together. The desired amount of water was added to the mix and all together was mixed until a uniform concrete mix was obtained. The slump of the concrete mixes were between 140 mm and 110 mm.

Molds of cubic specimens (150 x 150 x 150) mm were already oiled and placed on a large table shaker. The concrete mix was poured into molds in two separate layers each vibrated about 5 seconds. The specimen's surface was levelled and kept in the molds for 24 hours. The specimens were then demolded and stored in water for 28 days. All specimens were prepared and treated under the same environmental conditions. Three cubic specimens (150 x 150 x 150) mm from the mixes were tested at the age of 28 days to find the average compressive strengths as given in Table 3. Also, six identical cubes for each mix from the same batch were taken. After 28 days, the cubic specimens were saw cut in to two equal pieces with sizes of (150 x 150 x 73) mm using circular cutting machine with 4 mm thickness. In total, sixty specimens were prepared for impact testing. They were divided into four categories of firing periods of (0 "without fire", 15, 30, and 45) minutes with respect to the percentage of the rubber (0%, 6%, 12%, 18% and 24%).

Table 3: Average compressive strength of different mixes

Mix No	Replacement, %	Specimen ID	Ultimate load, kN	Compressive strength, MPa	Average compressive strength, MPa
Mix 1	0	FH001	1283	57.022	57
		FH002	1267.3	56.324	
		FH003	1274.7	56.653	
Mix 2	6	FH101	1057.5	47.000	47
		FH102	1074.4	47.751	
		FH103	1011.6	44.960	
Mix 3	12	FH201	885.6	39.360	39
		FH202	912	40.533	
		FH203	846.5	37.622	
Mix 4	18	FH301	770.9	34.262	33
		FH302	782.8	34.791	
		FH303	691.3	30.724	
Mix 5	24	FH401	642.5	28.556	29
		FH402	647.5	28.778	
		FH403	679.1	30.182	

2.4 Specimens burning procedure

According to duration of fire exposure, specimens prepared from five different mixes for impact test were distributed into four groups: no fire, 15, 30, and 45 minute, as shown in Table 4. Three specimens from each mix , 15 specimens in total, were used as references for comparison purpose so they were not burnt at all. On the other hand, three specimens from each mix were exposed to elevated fire for specific durations of (15, 30 and 45) minutes, respectively, using a gas furnace. The furnace was manually built in the laboratory with the dimensions of (1000 mm long, 800 mm wide and 500 mm high) as shown in Figure 2. The furnace walls were made with the high thermal bricks of size (80 x 120 x 240) mm. Two steel plate lids used to cover the top of the furnace. They were filled with 5cm of fine aggregate to cover the furnace top during burning the specimens. Two liquified petroleum gas burners were fixed inside the furnace, and each one was continuously connected to cylinder gas bottle with a capacity of 12.5-Liter. To precisely record the temperature of the specimens during burning process, two thermocouples were attached to record temperature every 5 minute. One of the thermocouples was placed at the bottom of the specimens with the direct contact to fire, and the other was attached to top surface of the specimens. Additionally, the laser thermometer was used to observe the temperature at different places of the sample sides.

Table 4: Specimens distribution

Mix No	% Replacement	No Fire	15 minute	30 minute	45 minute
Mix 1	0	3	3	3	3
Mix 2	6	3	3	3	3
Mix 3	12	3	3	3	3
Mix 4	18	3	3	3	3
Mix 5	24	3	3	3	3
Total		15	15	15	15

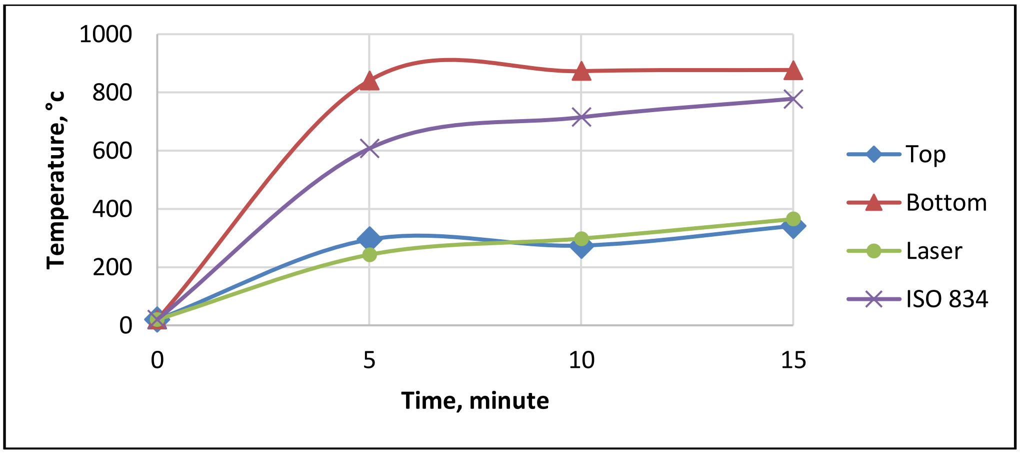
After the fire exposure for the desired periods, they were removed from the furnace, and were left on sand stockpile in the laboratory condition for normal cooling in air. The mass of specimens were measured using an electronic scale of 0.5g accuracy, before and after the fire exposure.

Figure 2: Furnace

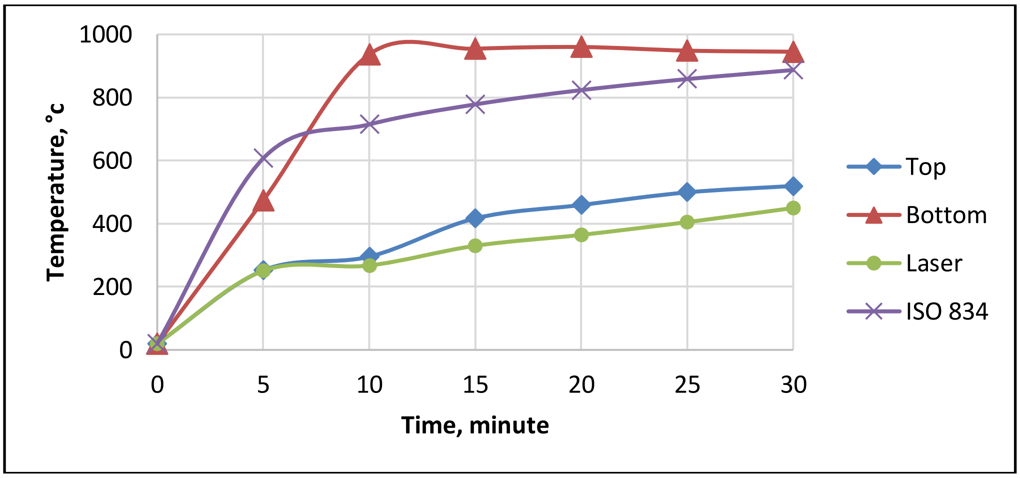
Figures 3a-c show the temperature-time curves for the burning periods of 15, 30, and 45 minute. In each diagram, three observation trend curves are drawn representing three various locations inside the furnace during the fire. The Laser trend represents the average of two values on both side surfaces of the specimens. Top and Bottom represent two different values of temperature of the specimens which are beneath and directly above them. The temperature of fire monitored by thermocouples and increased from air temperature 20 °C reached to maximum temperatures of 873, 955, 963 for the firing periods of 15, 30, and 45 minute, respectively. Additionally, ISO 834 curve [16] is shown as the standard reference of time-temperature history which characterize the fire exposure by using equation (1).

$$\mathrm{T_t} = 20 + 345 \log_{10}(8 \times \mathrm{t} - 1) \ldots\ldots\ldots\ldots\ldots (1)$$

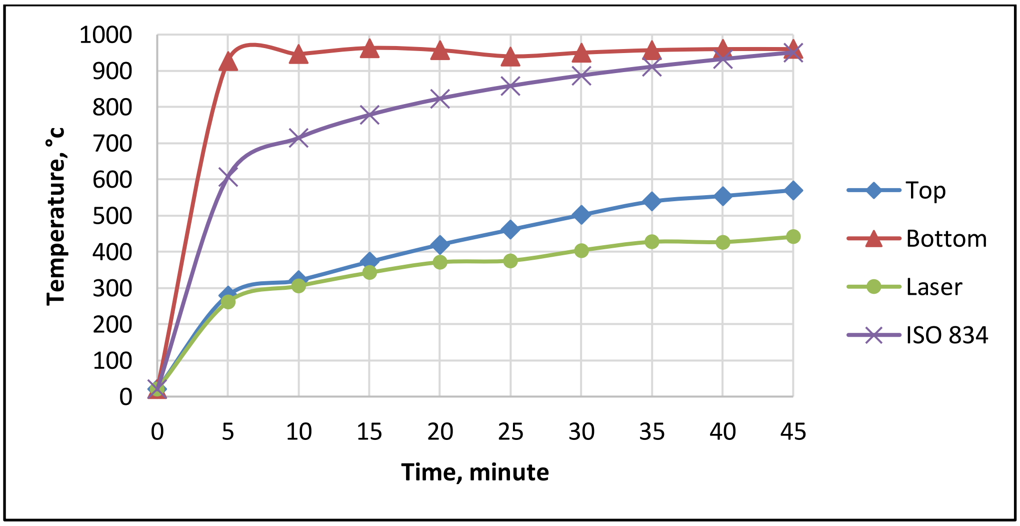
Where T is temperature in (°C) and t is time in minutes.



(a) Time period = 15 minute



(b) Time period = 30 minute



(c) Time period = 45 minute

Figure 3: Time temperature curves of specimens subjected to fire for: (a) 15 minute (b) 30 minute, (c) 45 minute

2.5 Impact loading Instrument

Special impact instrument was designed and fabricated by the authors in the laboratory to implement impact tests according to the technique of drop weight from height, as shown in Figure 4. The specimens were placed on a base plate within the positioning basket with the flat surface facing up. The steel ball is positioned on top at the center of the specimen. The ball was used to transfer the impact loads from the drop hammer onto the specimen surface. A cantilever lever arm held by vertical steel column having a heavy steel base used to carry the hammer straight up and drop it during the test. The drop hammers were placed with its base upon the steel ball and detained there on the middle of the specimen surface.

Two kinds of drop hammers were used each for a specific case. The impact tests on the reference specimens were performed manually using 4.5 kg hammer dropped from height of 450mm. The specimens exposed to fire were expected to show early crushing of their faces before observing their fracture cracks. Therefore, a lighter hammer of 2.24-kg with the drop height of 280 mm was used on the samples exposed to fire. The hammer was dropped repeatedly, and the number of blows required to cause cracking and ultimate failure was recorded. Ultimate failures were clearly recognized as the opening of cracks and splitting in to pieces on the base plate. The impact energy absorbed by the specimen up to failure was calculated using the equation (2), as used by Taha et. al. [6].

$$IE = \sum_{i=1}^{N} w_i \, h_i \dots\dots\dots\dots\dots\dots\dots. (2)$$

Where, w_i is equal to drop hammer weight in Newton, h_i is the drop height in meter, N represents the total number of blows up to failure, and IE represents the impact energy in N.m.

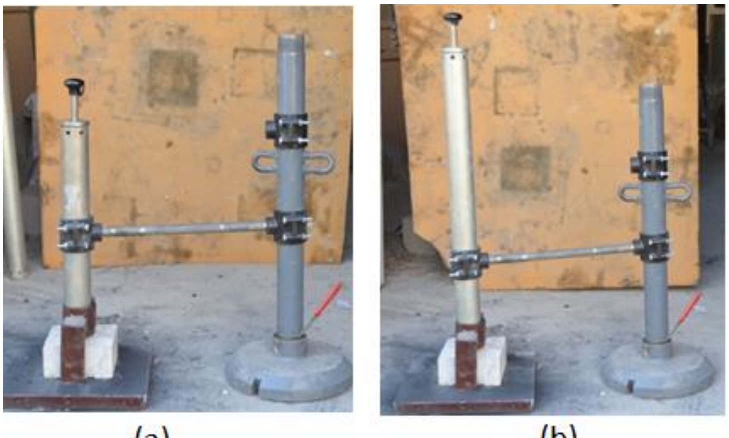


Figure 4: Fabricated impact instrument used for testing: (a) Hammer weight=2.24 kg, (b) Hammer weight=4.5 kg

3. RESULTS AND DISCUSSIONS

3.1 Mass Loss

The use of recycled tire rubber particles as a replacement of fine aggregates in concrete resulted in a decrease in the density of both fresh and hardened concrete as presented in Table 5. Compared to the normal concrete, the densities of fresh mixes with replacement ratios of 6, 12, 18, 24% decreased by 2.07, 4.41, 6.66, and 7.72% respectively. The reduction in densities of rubberized concrete and mortar reported by pervious researchers [5,17-18]. The reduction in density of fresh concrete containing tire rubber fine aggregate can be attributed to two reasons. Firstly, tire rubber particles are capable of entrapping air in the concrete due to their rough surface texture. Secondly, tire rubber particles have low density compared to the natural aggregates. Moreover, an increase in tire rubber particles content resulted in a further decrease in the concrete density.

Table 5: Fresh concrete density and slump

Mix ID	Replacement, %	Density, kg/m³	Slump, mm
Mix 1	0	2267	140
Mix 2	6	2220	135
Mix 3	12	2167	135
Mix 4	18	2116	130
Mix 5	24	2092	110

Table 6 gives the details of masses of specimens before and after fire exposures and their percent loss of masses. The specimens were weighed to record their masses (m 1) before burning, and they were weighed again after normal cooling in the air to record their masses (m 2) after burning. These two data were used to determine the percent mass losses of each specimens due to the fire. Those specimens without fire exposure were also weighed to record their masses (m) before testing as given in Table 6.

Figure 5 represent the average masses of three specimens in all cases before fires exposure with respect to their rubber content. It is evident that rubber content reduced the mass of concrete. Looking at the average mases for trend of “No fire”, masses decreased from 3640 g to 3425 g at 0% and 24% replacement, respectively. The variation in specimen masses of the same mix is related to nonhomogeneous behavior of concrete which is not taken into account in this study.

Figure 6 shows the average percent mass loss of three different mixes exposed to fire for three various burning periods namely15, 30 and 45 minutes. It is observed that there is more mass loss of the concrete with increasing burning periods in all cases. At 0% replacement, percent mass loss is 5.37% at burning period of 15 minutes, and the mass loss considerably increases to 9.14% at fire periods of 30 minutes. Furthermore, at 24% replacement, percent mass loss is 6.62% at burning period of 15 minute, and the mass loss noticeably increased to 9.79% at fire periods of 30 minutes. The percent mass losses, also, increase with increasing the rubber content. For instance, at burning period of 45 minutes, it can be noticed that the percent mass loss is only 10.28 % for 0% replacement, and jumps to 11.94% at 24% rubber content despite of a little fluctuation in the whole pattern. So, considering all the time periods, the percent mass loss increases with an increase in rubber content. This observation is reliable compared with those of the previous studies [11-12, 20]. Further reasons for this mass loss can be interpreted as at lower temperatures up to 80˚C the surface water absorbed starts to evaporate. Also, the decomposition of tire rubber particles rapidly begins at higher temperatures of 300 ˚C and above.

Table 6: specimen masses and their percent mass losses

Mix ID	No fire	15 minute				30 minute				45 minute			
	m, g	m 1, g	m 2, g	% loss	Average % loss	m 1, g	m 2, g	% loss	Average %loss	m 1, g	m 2, g	% loss	Average % loss
1	3619	3595	3416	4.98	5.37	3687	3351	9.11	9.14	3749	3360	10.38	10.28
	3613	3686	3492	5.26		3627	3291	9.26		3700	3323	10.19	
	3689	3687	3471	5.86		3706	3371	9.04		3737	3353	10.28	
2	3596	3469	3270	5.74	5.72	3605	3267	9.38	9.37	3706	3331	10.12	9.94
	3593	3653	3445	5.69		3592	3255	9.38		3585	3232	9.85	
	3622	3571	3366	5.74		3472	3147	9.36		3574	3222	9.85	
3	3555	3619	3405	5.91	5.85	3495	3165	9.44	9.39	3565	3202	10.18	10.63
	3480	3490	3300	5.44		3544	3213	9.34		3514	3125	11.07	
	3629	3422	3210	6.20		3440	3117	9.39		3549	3152	11.19	
4	3548	3391	3192	5.87	6.13	3415	3092	9.46	9.68	3430	3026	11.78	11.53
	3517	3587	3370	6.05		3498	3156	9.78		3467	3085	11.02	
	3520	3490	3264	6.48		3464	3124	9.82		3428	3024	11.79	
5	3529	3595	3367	6.34	6.62	3437	3148	8.41	9.79	3404	3000	11.87	11.94
	3374	3370	3140	6.82		3410	3039	10.88		3488	3065	12.13	
	3371	3467	3235	6.69		3465	3116	10.07		3297	2907	11.83	

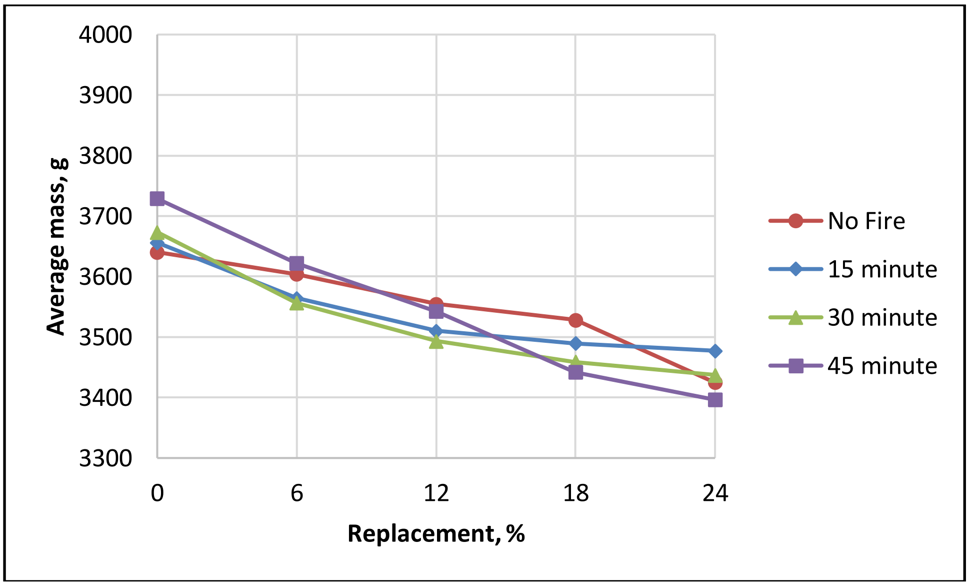


Figure 5: Average specimen masses corresponding to rubber content before fire

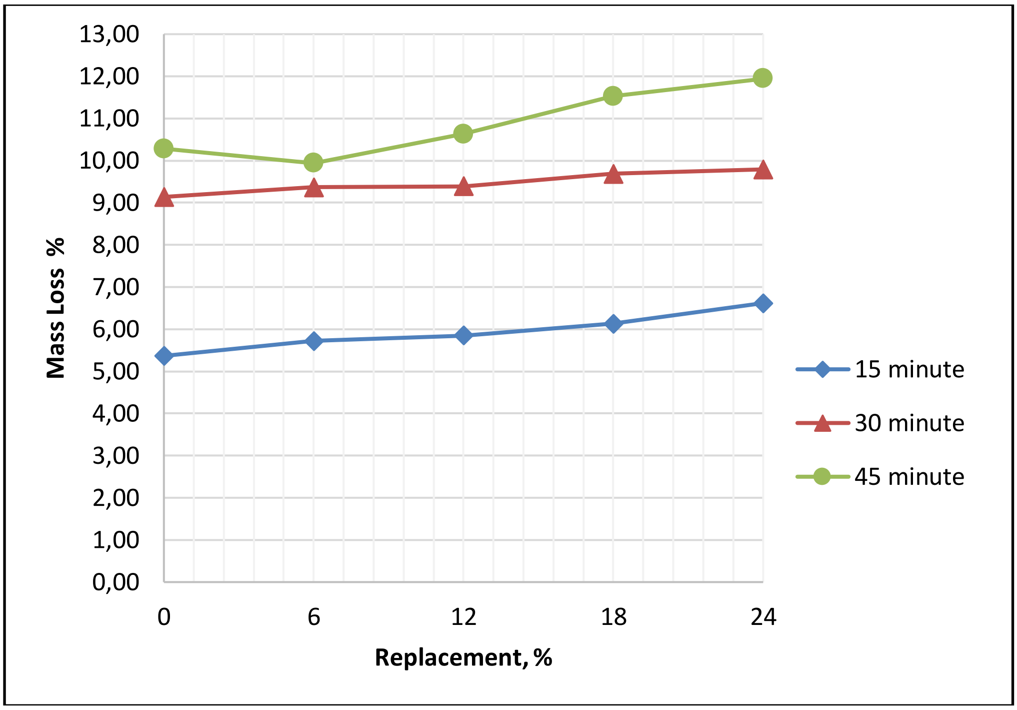


Figure 6: Percent mass loss after burning

3.2 Impact Energy

Table 7 shows the number of blows required to observe failure in the specimens. The data are the average of three mixes under impact loads. For specimens without burning them, the increase in the number of blows was 11, 16, 19, and 25 with the presence of 6, 12, 18, and 24% tire rubber aggregate, respectively, compared to the reference specimen at the air temperature. It is evident that number of blows rise with increasing replacement levels of tire rubber in concrete. This increase proportionally leads to an increase in the impact energy absorbed by the specimens. Table 7 also shows the number of blows leading to ultimate failure regarding to both replacement levels and burning periods of burnt specimens. In each case, the result is an average of three specimens. Failing the specimens needs more blows with increasing the rubber contents. However, number of blows significantly decrease compared to those of the identical specimens without burning. For the trend of "15 minutes" in Table 6, the number of hammer drops is 14 at 0% replacement. That number has increased to reach 109 blows with increasing rubber content to 24%. The number of blows for various burning periods is slightly reduced with an increase of burning durations. For instance, at 12% rubber content, the repetitions of impact loads are 23, 13 and 10 for the time periods of 15, 30 and 45 minutes respectively.

Table 7: Average number of impact loads vs fire exposure

Mix No.	**Replacement, %**	**Average number of blows at failure**			
		Control specimens without fire	Fire exposure periods		
			15 minute	30 minute	45 minute
Mix 1	0	144	14	10	8
Mix 2	6	155	16	12	9
Mix 3	12	160	23	13	10
Mix 4	18	163	52	52	43
Mix 5	24	169	109	102	46

Table 8: Average impact energy in (N.m) corresponding to rubber content and fire exposure periods

	Rubber content				
Fire duration, minute	**0%**	**6%**	**12%**	**18%**	**24%**
0	2851	3069	3169	3238	3351
15	84	96	139	320	669
30	59	72	80	320	628
45	47	57	62	265	285

Impact energy mainly depends on the number of blows because both drop height and hammer weight were constant in each trial. The reduction in number of blows results in a decrease in their corresponding impact energy. Average impact energy of three specimens corresponding to percent replacement and the duration exposed to fire are summarised in Table 8. It is evident that increase in rubber content leads to an increase in impact energy. From Table 8, The amount of impact energy with the inclusion of rubber replacement without fire increased with the level of rubber content. Impact energy is 2851 N.m at 0% replacement, and it linearly increases till reaching 3351 N.m at 24% replacement. Different ratios of increase in impact energy of rubberized concrete were previously reported by some researchers in the literature [3, 10, 21-22]. A possible reason might be due to the ability of the tire rubber particles to allow for large deformations. The rubber particles delay the widening of cracks and stopping early full disintegration of the concrete specimens.

Figure 7 shows the impact energy considering percent replacements of tire rubber for the time periods of 15, 30, and 45 minutes. For example, at 6% replacement, impact energies are 96, 57, and 62 for the periods of 15, 30, and 45 minutes respectively. The longer the specimens exposed to fire, the more the loss of their impact energies will be. In comparison with impact energies obtained from the specimens without burning from Figure 7, the results of burnt specimens experience a vast reduction in their impact energies. At 24% rubber content, for example, the impact energy reduced from 3351 N.m to (669, 628, and 285) N.m for burning time periods of 15, 30, and 45 minutes respectively due to the fire exposure. This decrease in impact resistance is due to the cavities made when the water and the rubber inside the samples evaporated caused disintegration between particles. The results roughly remain unaffected for rubber replacements above 18% for 45 minutes. A possible reason is the weak bond between rubber particles and concrete paste. Early crushing of concrete samples was observed during the test. Figure 8 represents the relation of impact energy in vertical axis and duration of fire exposures (0, 15, 30 and 45) minute in horizontal axis. It is evident that the impact energy reduced sharply at the duration of 15 minute and then slightly decreased again towards duration of 45 minute. This means the larger amount of rubber evaporated during the first 15 minute of fire exposure. In summary, while an advantageous use of aggregate rubbers in concrete is resistance to impact loads, they leads to worth condition for concrete during fire in terms of impact loading.

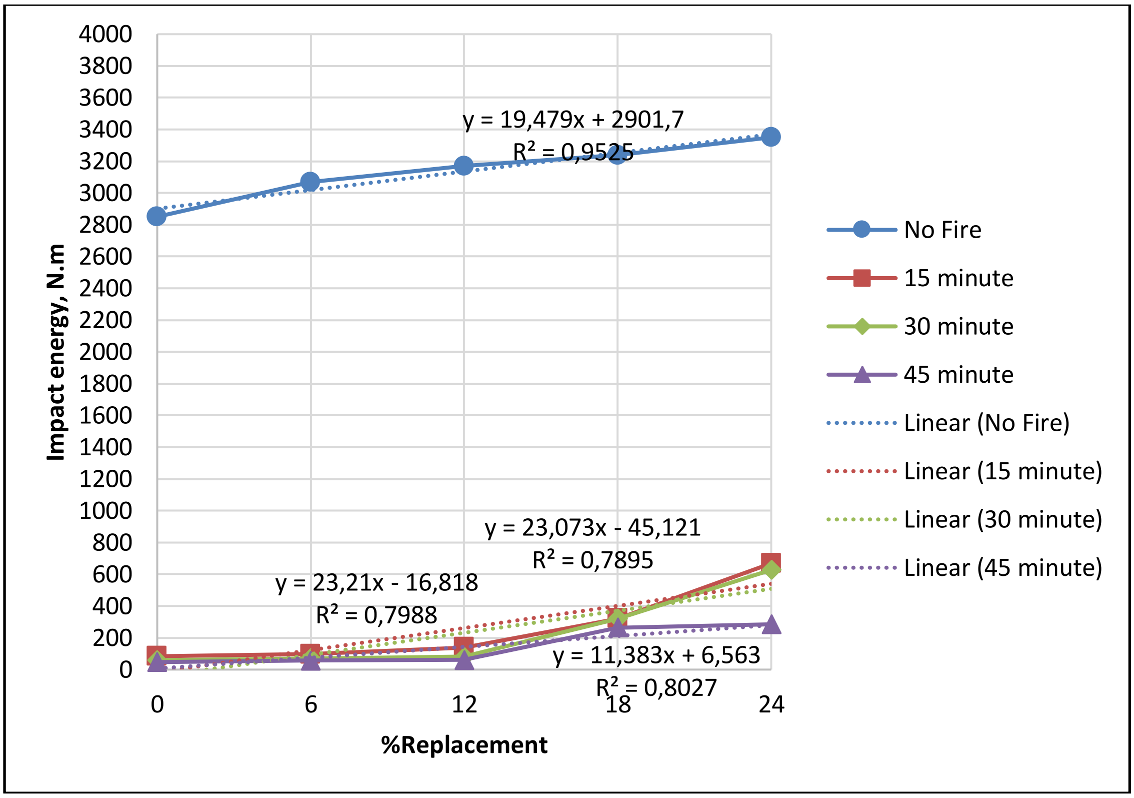


Figure 7: Impact energy vs percent replacement for different fire durations

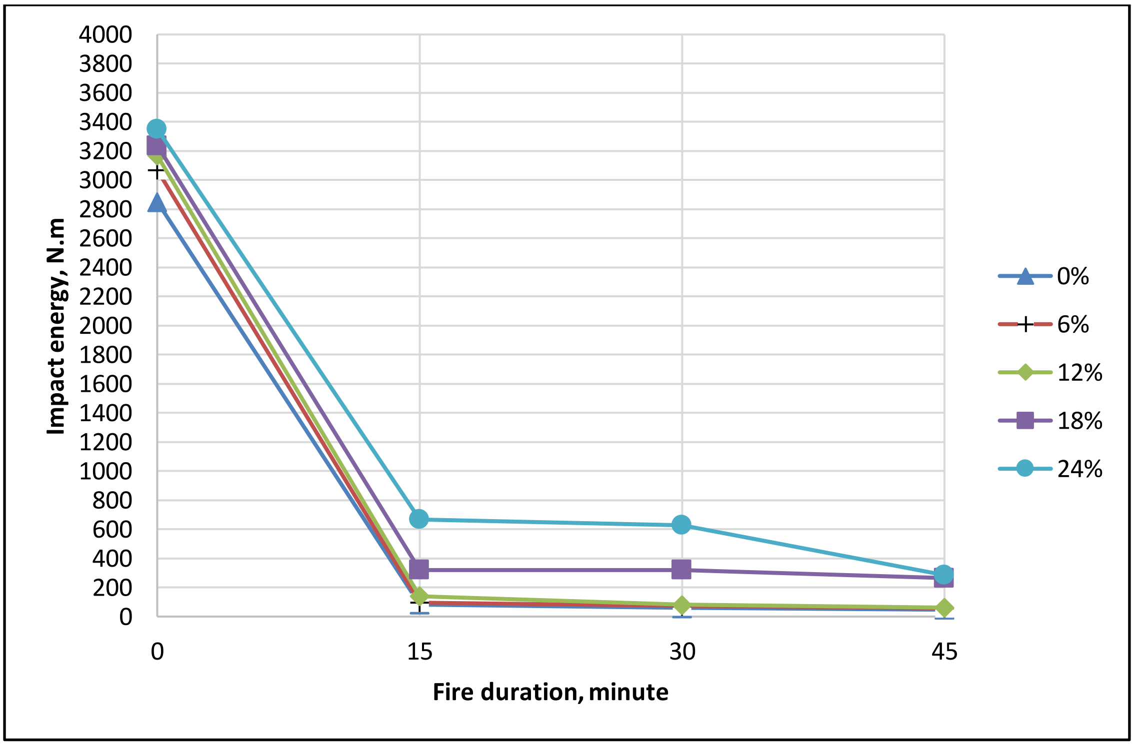


Figure 8: Impact energy vs fire duration for different mixes

Linear regression analysis have been made to propose a mathematical model equations based on the experimental work as the summary of equations given in Table 9. Impact energy (y) in (N.m) can be estimated according to percent rubber content (x) by weight corresponding to exposure periods.

Table 9 : linear equations of impact energy for various fire exposure

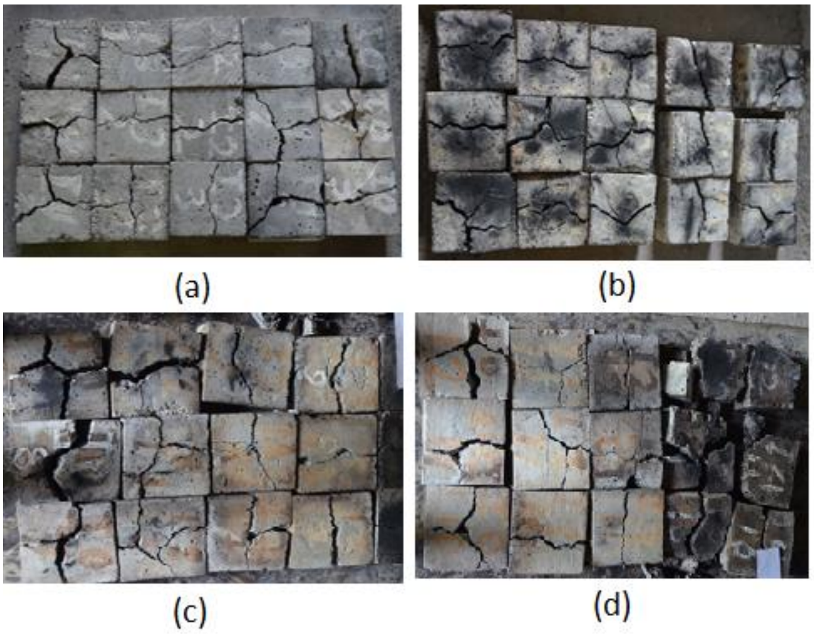
Fire exposure, minute	**R^2**	**Equation**
0	0.9525	y = 19.479x + 2901.7
15	0.7988	y = 23.21x - 16.818
30	0.7895	y = 23.073x - 45.121
45	0.8027	y = 11.383x + 6.563

3.3 Visual observations and failure modes

When the specimens were in the furnace, it was noted that the specimens ignited on the fire and their colors changed to red. Even after the turning off the gas burner, the ignition continued for a while, nearly 15 minutes, in the specimens with higher percent replacements of tire rubber 18 and 24%. Moreover, smoke and gas released outside of the furnace. These gas emissions were mainly related to the evaporation of water and tire rubber in concrete. Sometimes explosive sound was heard when the specimens were on fire. The reason beyond these noises might be the evaporating of tire rubber particles and releasing of entrained air in concrete. After removing the specimens from the furnace, no signs of explosive spalling were seen on their surfaces as it can be seen in Figure 9. On the other hand, after fire exposure, all specimens experienced cracks and small holes on their surface. The dimension and size of these cracks and holes were different and increased with increasing of both burning periods and the amount of rubber content. The color of the of the specimens also experienced significant variations, becoming brownish and black colors as in Figure 9. This change in surface colors of specimens is attributed to the dispersion of carbon which is one of the components of the tire rubber particles. Similar visual observation have also being noticed in the literature[11, 23].

Figure 9: Specimen surface of 24% rubber content sample and 45 minutes of burning period

Figures 10a-d show the failure modes of specimens in all cases of rubber replacement ratios exposed to (0 “without fire”, 15, 30 and 45) minutes respectively, after the performance of impact tests. They have been split into two or three main pieces extending from the center into the edges of the specimens. the specimens containing higher percent replacements underwent spalling during the test. For the specimens exposed to fire for 45 minutes with 24% of rubber content, high rate of early crushing was observed as shown in Figure 11. The crushing is a negative response from specimens as reaction to burning which results in a decrease in the impact energy.



(a) (b)

(c) (d)

Figure 10: Failure modes: (a) Control specimens without fire exposure (b) Specimens exposed to 15 minute fire exposure, (c) Specimens exposed to 30 minute fire exposure (d) Specimens exposed to 45 minute fire exposure

Figure 11: Crushing at early impact loads of a specimen containing 24% rubber exposed to 45 minute fire exposure

4. CONCLUSION

The objective of this study was to investigate the effect of fire exposure of different time periods on the rubberized concrete under impact loads. The study was undertaken for five sand replacement ratios (0, 6, 12, 18, and 24)% with waste tire rubber with 0.339

water/cement ratio. All specimens were exposed to three different exposure durations of (15, 30 and 45) minutes. The influences of both rubber content and fire exposure duration on the impact resistance properties of concrete are significant. The following findings can be concluded:

1. The concrete mass has reduced as the level of rubber content increases. For specimens tested at fire exposure of 45 minute, average of masses decreased from 3729g at 0% replacement to 3396g at 24% replacement. These reductions in masses have occurred to the other cases.
2. The mass of rubberized decreased with the increase of rubber content. Additionally, the percent mass loss of the rubberized concrete also increased with the increasing of fire exposure durations. For instance, at 18% replacement, the percent mass loss was 6.13% for the duration of 15 minutes while it is considerably increased to 11.53% for the duration of 45 minute. This is due to water loss and decomposition of rubber particles in the concrete.
3. The energy absorption capacity of rubberized concrete was higher than that of a normal concrete. It was observed that impact energy increased from 2851N.m at 0% replacement to 3351 N.m at 24% replacement. This increase in impact energy is due to the presence of rubber particles which absorb more energy and work as elastic springs in the concrete sample.
4. Regarding the specimens of normal concrete (without rubber) after fire exposure, the impact energy massively reduced from 3351 N.m in air condition to 84 and 47 N.m for the burning durations of 15 and 45 minutes. This reduction in impact energy may be happened owing to the weak bond between cement paste and aggregates.
5. As for the rubberized concrete specimens after fire exposure, the impact energy of the rubberized concrete decreased with an increase in fire exposure time periods. For example, at replacement level of 12% of rubber, the impact energy reduced from 139 N.m for the fire duration of 15 minutes to 62 N.m for the fire duration of 45 minutes. So, the more specimens burnt the more impact energy loss will be in all cases.
6. The specimens containing higher levels of rubber content exposed to fire, they experienced ignition during fire exposure and even after they were removed from the furnace. Moreover, spalling of the concrete increased with increasing of rubber content. Any replacement of sand above 18% and any burning time periods above 30 minute results in spalling of the specimens under impact loads.
7. Some linear equations have been proposed to calculate impact energy with respect to rubber content, considering the duration of fire exposure.

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