3rd Specialty Conference on Material Engineering & Applied Mechanics
3e Conférence spécialisée sur le génie des matériaux et mécanique appliquée

Montréal, Québec
May 29 to June 1, 2013 / *29 mai au 1 juin 2013*

PORTLAND CEMENT CONCRETE CONTAINING RUBBER-TIRE WASTE

Mohamed N. Abou-Zeid, Ezzat H. Fahmy, Salma Bahey, Ahmed Sultan, Aly Seif, Karim Dayhoum, and Yasser Srour

The Department of Construction and Architectural Engineering, The American University in Cairo, Egypt

Abstract: Waste tires constitute a true environmental problem in many parts of the world. When shredded, such tires can provide a source of rubber-like particles to be used as aggregates in variety of concrete mixtures. However, there is a need for more research on the properties of Portland cement concrete when incorporating rubber-aggregates
.
In this work, concrete mixtures are prepared using waste truck tires to partially replace coarse aggregates in three dosages. Additional two sets of rubber waste were treated using cement powder and silica fume prior to use in concrete. Fresh and hardened concrete testing was conducted including concrete impact resistance and stress-strain behaviour. Rubber mixtures had less density, lower strength but higher strain at failure. Conclusions and recommendations are derived to identify an adequate dosage range for rubber incorporation in concrete.

1 Introduction

Concrete is a widely used construction material that consumes massive amounts of natural resources (Karim et al. 2011). This includes large amounts of aggregates from quarries, rock crushers and river beds. Such natural aggregates are getting more scarce every day on one hand while good quality sources exist in remote areas thus are not economically feasible (Tarun and Seddiki 2002).

Since decades, attempts have been made to include several waste materials as aggregates in concrete including recycled demolished concrete, shattered glass bottles, scrap metals, slag and mineral wastes, foundry wastes to name but only a few (El Gammal et al 2010). The proposed waste materials in much of this work served to replace wholly or partially virgin aggregates in concrete mixtures. However, this replacement process faces several challenges. First, such waste materials do not necessarily exist in abundance in the vicinity of projects. Secondly, the waste particles are often contaminated by variety of impurities or foreign materials. Third, the waste materials themselves can vary according to the original industry from which they are obtained and thus their supply is inconsistent (Abou-Zeid et al 2005).

From a mere environmental point of view, the use of waste materials as aggregates is highly promoted and receives an increased attention. Clearly, their use will alleviate some of the demand on the depleting natural resources. Also, an adequate employment of such materials reduces the need for landfills and dumping locations that is beneficial particularly when taken into account that much of such wastes are non-biodegradable materials. In addition, the process of excavating and transporting natural aggregates are known to be energy intensive (Shenouda et al. 2007). Thus, using waste materials reduces such energy as well as the energy needed for remote distance transportation of waste products as well.

Rubber tire waste has been steadily accumulating over the past forty years. For instance, an estimated 500 million waste tires are accumulating each year in North America alone (Danko et al 2009). These tires are indeed non-biodegradable and occupy large volumes in landfills and dumping lots. It was also stated that the tires can represent a serious fire hazard when present in the vicinity of industrial zones and can harbour mosquitoes and other insects (Bahey et al 2012). Numerous investigators have attempted to use waste tires in a variety of applications including Portland cement as well as Asphalt cements concrete (Sallam et al. 2008 and Caines 2004 et al). In many of these investigations, encouraging results were obtained which in turn prompted other studies to pursue other feasible means for their implementation (e.g. Guneyis et al. 2004).

The objective of this work is to explore the technical feasibility of using waste rubber tires as partial replacement of coarse aggregates in Portland Cement Concrete. Concrete mixtures were prepared with 0, 10, 20 and 30% replacement of coarse aggregates by rubber waste. Attempts were also made to treat two types of this rubber by cement paste as well as silica fume in order to explore potential improvement in performance. Testing scheme covered both fresh and hardened concrete properties at various ages. Recommendations are provided for future use of this waste in concrete industry.

2 Experimental Program

2.1 Material Properties

Cement: Type I Ordinary Portland Cement Concrete with specific gravity of 3.15 and Blaine fineness of 365 m^2/kg.

Fine Aggregates: Natural siliceous river sand was used. The sand had absorption of 0.4%, S.S.D specific gravity of 2.55 and a fineness modulus of 2.85.

Coarse Aggregates: Well-graded crushed dolomite was used as coarse aggregates. The aggregates had absorption of 1.8%, maximum size of 38 mm and an S.S.D specific gravity of 2.57.

Silica Fume: Local undensified silica fume was used for treatment of waste tire aggregates. The material had SiO_2 content of 93% and an average particle size of 0.15 µm.

Water: Ordinary municipal tap water was in washing the aggregates as well as the production and curing of the concrete mixtures.

Waste rubber Coarse Aggregates: The rubber waste used was obtained from a commercial collector; that manufactures variety of products made out of waste rubber tires. These rubber tires were non-reinforced plain tires that were out of use. The tires were shredded using an industrial shredder to a maximum size of about 40 mm. Debris resulting from shredding was discarded through a sieving process. Upon testing, the waste rubber had absorption of about 2%, and an approximate specific gravity of 1.25. Figure 1 shows pictures of removed debris from the rubber chunks.

Fig 1: Preparation of rubber waste particles

Steel reinforcement: For the impact test, beams were reinforced with four 12-mm bars and 8-mm steel stirrups.

2.2 Concrete Mix Design

The characteristic concrete mixture that was used in this study had the proportions shown in Table 1 with a cement content of 400 kg/m^3 and a water-to-cement ratio of 0.45. Together with the control mix, other mixtures were prepared by partially replacing the coarse aggregates with 10, 20 and 30% by mass of waste rubber and adjusting the content of fine aggregates while accounting for difference in specific gravity between rubber waste and natural aggregates. Two extra 20% replacement mixtures were prepared in which rubber was treated. The treatment was carried out by wetting the rubber chunks and then gently mixing with either powder Portland cement or silica fume. In both cases, the rubber was left for three days prior to its use in concrete. Concrete mixing and casting of specimens were carried out according to ASTM standards.

Table 1: Control mix proportions

Item	Control	10%	20% mix	30% mix
Cement	400	400	400	400
Water	180	180	180	180
Fine aggregates	610	479	361	242
Coarse aggregates	1128	1015	902	790
Waste rubber	-	113	226	338

2.3 Tests

Fresh concrete: Slump, air content and unit weight tests were conducted in accordance with ASTM standards.

Hardened Concrete: The main hardened concrete tests are summarized in Table 2. The tests included conventional compressive and flexural strength testing as well as exposure to elevated temperature, stress-strain relationship in compression, and dynamic impact.

Table 2: Summary of hardened concrete Tests

Characteristics assessed	**Test**	**Specimen**	**Age of Testing**
Mechanical properties	Compressive strength	150x150x150 mm cubes	7-day, 28-day and 56-day
	Stress–strain relationship	150x50x50 mm prisms	28-day
	Flexural strength	750x150x150 mm beams	7-day and 28-day
	Load-deflection curves	1350x150x400 mm reinforced beams	28-day
Thermal properties	Elevated temperature	150x150x150 mm cubes	28-day
		750x150x150 mm beams	28-day
Dynamic properties	Dynamic impact test	1350x150x400 mm reinforced beams	28-day

Compressive Strength: The test is conducted to evaluate the strength of concrete using 150 mm cubes in accordance with British Standards [BS 1881].

Stress-Strain: This was done using the Material Testing System (MTS). This test is conducted on concrete prisms subjected to compression. Load and deformation were recorded and transformed into stress-strain values.

Flexural Strength: The test is conducted in accordance with the ASTM standards [ASTM C78/ C78M - 10] to measure the flexural strength of the mixes.

Load-Defection relationship: Deflection at mid-span of the tested beams was measured using dial gauge. The load deflection relationship was plotted for every beam.

Elevated Temperature: This test was conducted on both cubes and beams at temperatures of 200 ˚C for four hours. The cubes and beams were left to cool for one hour before testing.

Dynamic Impact Test: The testing rig was developed and manufactured in the Structural testing laboratory at the American University in Cairo to assess potential impact resistance of concrete beams. Figure 2 shows schematic views for testing rig. In this test, the beam was placed on the cladding. Then a pendulum of 350 kg mass was pulled back by an electric motor to the height of 1280 mm then was released to impact the specimen at the center. Load cells on the pendulum and claddings recorded data of the pendulum force (R_1) as well as the reaction forces (R_2, R_3). This process was repeated for 15 hits.

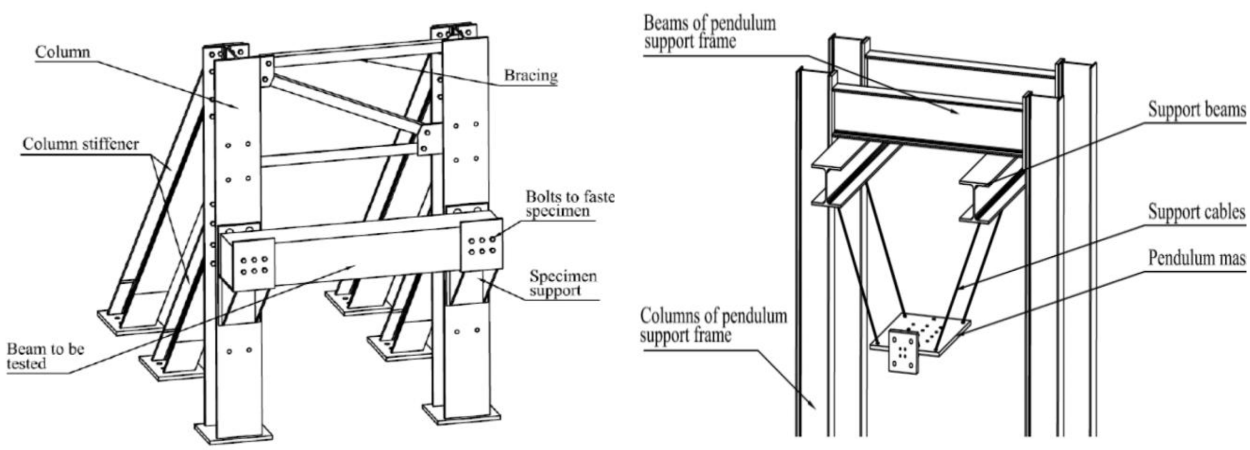

Figure 2: Impact machine apparatus

3 Test Results and Discussion

3.1 Fresh concrete results

The results of both the slump and air content came somewhat similar for all tested mixtures. For example, all mixtures had slump values in the range of 30 to 50 mm and air content in the range of 1.5 to 2.5%. Differences in the air content of various mixtures was in the range of 0.5%. Yet, the rubber containing mixtures had slightly less slump. Also, the unit weight results of the mixtures reflected the lighter nature of waste rubber as show in Table 3.

Table 3: Unit weight of the tested concrete mixes

Conventional concrete	Mix with 10% Rubber	Mix with 20% Rubber	Mix with 20% Rubber
2410 kg/m^3	2240 kg/m^3	2150 kg/m^3	2105kg/m^3

Thus and as expected, increasing the rubber content is accompanied by a reduction in the unit weight of the concrete mix and slight reduction in concrete slump.

3.2 Hardened concrete results

3.2.1 Mechanical properties

Compressive Strength: The results of the compressive test results are presented in Figure 3 for the mixtures under investigation. This includes the control, 10, 20 and 30% rubber-replacement mixtures as well two 20% rubber-replacement mixtures in which rubber was treated with cement (TCP) and treated with silica fume (TSF).

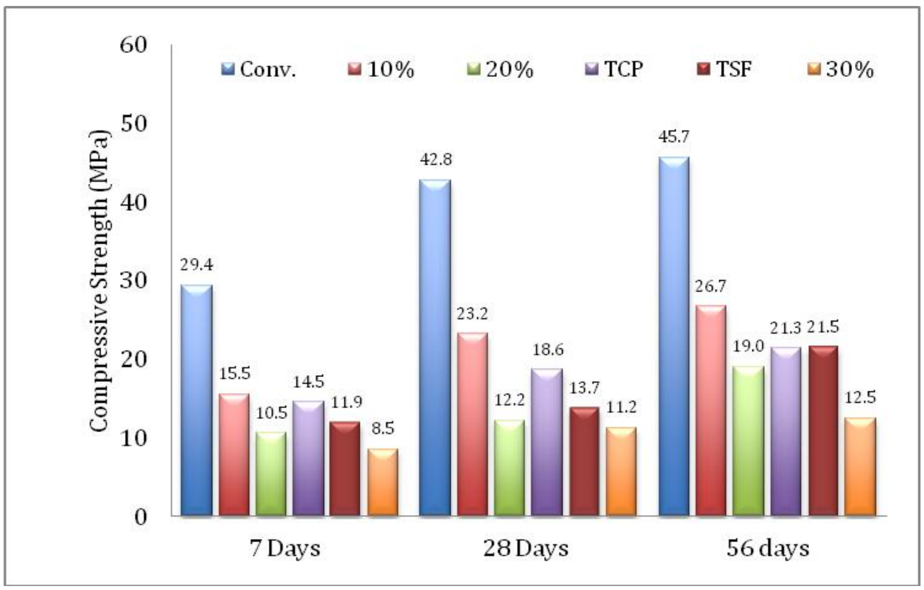

Fig. 3: Compressive strength results

The results in Figure 3 demonstrate that introducing the rubber as aggregate results in a reduction in compressive strength at almost all ages. For example, the 20% untreated rubber mix had a 28-day compressive strength of 12.2 MPa compared with a conventional mix of 42.8 MPa. This represents a sharp reduction in compressive strength that moves concrete more towards non-structural applications. It is also noticed from the results above that the reduction in compressive strength increases as the percent rubber replacement increases. For example, the conjugate 30% rubber mix had a compressive strength of 11.2 MPa. Yet, it is to be considered that the 10% rubber mix had a compressive strength of 23.3 MPa which is, more or less, close to the lower bound of some structural concrete design strength. It can also be noted that the gain in compressive strength between 7 and 28 days in the rubber-containing mixtures is less than that of the conventional concrete. That is to say that there is no much gain in strength for rubber mixtures between 7 and 28 days for example as well as between 28 and 56 days as well. That can be explained by the fact that the weaker rubber aggregates and/or rubber-cement paste interface remain the critical constituent in the concrete mix. In that sense, the hardening of the cement paste with time does not contribute massively to the compressive strength.

Treatment of rubber aggregates with either Portland cement of silica fume introduced an improvement in the compressive strength. For example, the 28-day strength of Portland cement and silica fume 20%

treated rubber mixtures, TCP and TSF, yielded a strength of 18.6 MPa and 13.7 MPa; respectively. The improvement is likely to be due to enhanced rubber aggregate-cement paste interface which delays failure and minimizes early interfacial cracking.

The previous discussion suggests that the rubber concrete associated with this work may not suit in that form most of the structural applications on the merits of only compressive strength. However, if attempts are to be made to increase the compressive strength and narrow the gap with conventional concrete, rubber replacement should not exceed 10% on one hand and the treatment of rubber can be recommended to enhance the compressive strength.

Stress – Strain Parameters: Test prisms of an aspect ratio of 3 were subjected to compression using The Material Test System machine (MTS). Upon concluding the compression tests, the maximum stress, maximum strain, the secant modulus of elasticity as well as the toughness per unit volume were calculated. A summary of the results is shown in Table 4.

Table 4: Summary of stress-strain test results for concrete prisms

Mixes	**Conventional Concrete**	**10% Rubber**	**20% Rubber**	**30% Rubber**	**TCP (20% Rubber)**	**TSF (20% Rubber)**
Modulus of elasticity (GPa)	12.65	3.60	3.29	2.73	6.05	5.06
Toughness (J/m^3)	0.088	0.031	0.023	0.025	0.054	0.051
Max. strain	0.007	0.011	0.011	0.012	0.014	0.015
Max. stress (MPa)	23.304	6.951	4.895	4.861	10.845	9.077

The results in Table 4 show once more a reduction in the modulus of elasticity upon introducing rubber aggregates to the mix. For example the mixtures made with no rubber and the one with 20% untreated rubber had moduli of elasticity of 12.65 and 3.29GPa, respectively. However, partial recovery of that loss took place when rubber waste aggregates was treated with Portland cement or silica fume. For example, the two treated mixtures had elastic moduli of 6.05 and 5.06 GPa, respectively.

While the maximum stress -as expected- remained weaker for the rubber concrete mixtures as a result of the weaker aggregates, the rubber mixtures had a significant increase in their maximum strain value. For example, the mixtures made with rubber had maximum strains ranging from 0.011 to 0.014 (1.1 to 1.4%) as compared to a maximum strain of 0.007 (0.7%) for the conventional concrete. This is due to the deformable nature of rubber waste compared to the more rigid natural aggregates.

In terms of toughness, the rubber concrete has less toughness than the conventional one. Yet, this has to be looked into while considering that the comparison is made between various categories of concrete strength. Thus, the strength was reduced but the strain was increased for the rubber concrete, the net result is a reduction in toughness that is not as low as would be expected in light of its lower strength alone. This suggests a possible higher toughness for rubber concrete if compared with concrete of same category. However, this latter statement needs to be validated in light of further experimental work.

Flexural Strength: The results of the 7 and 28-day flexural strength results are presented in Figure 4 for the mixtures under investigation in this work.

The results in Figure 4 have a similar trend to the compressive strength results discussed earlier. This can be observed in the lower strength with increasing the rubber content. However, the decrease is relatively small for the 10% rubber mixtures at 28 days. The decrease in strength is found to be more for the 20 and the 30% mixtures. Unlike the compressive strength results, treatment of rubber aggregates did not introduce significant effect at 28 days. This is thought to be due to a pop-out effect of the treated particles when subjected to flexural strength. The authors recommend further work to be conducted to explain such phenomena with the support of microscopic examination. The relatively weak results in flexural for the treated mixtures after 7 days could be due to the fact that the treatment powders (such as PC) spalls of the aggregates and the 3-days duration for treatment may have not been sufficient for good aggregate-cement bond. Thus, longer treatment durations are recommended. Again, the 10% rubber mixture exhibits acceptable performance in flexural strength and thus may be considered for lower bound strength in structural applications.

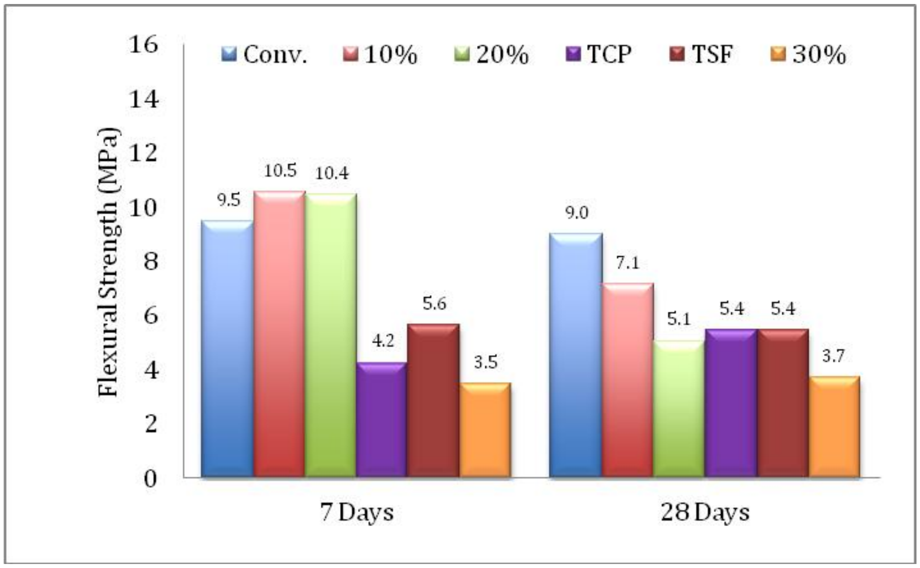

Fig 4: Flexural strength results

Load-Deflection Relationship: Figure 5 shows that load deflection relationship for the tested beams through the measurement of the mid-span deflection for the untreated rubber mixtures.

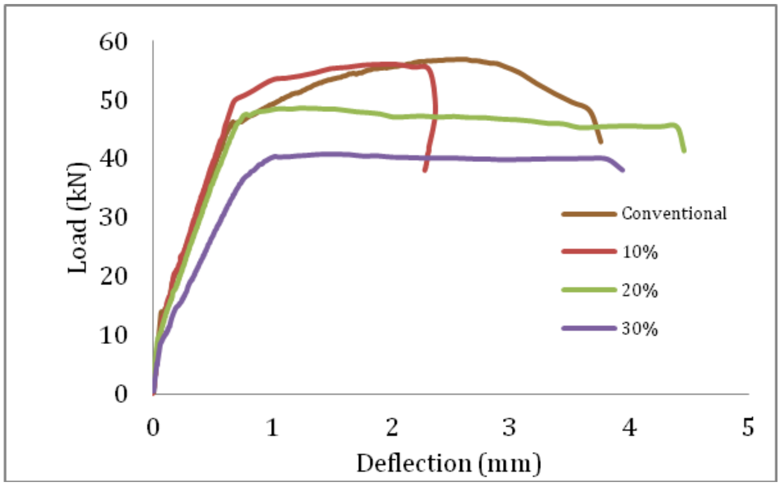

Fig 5: Mid-span flexural deflection for tested beams

Exposure to Elevated Temperature: Both concrete cubes and beams have been subjected to a temperature of 200 ^{o}C for 4 hours. The specimens were evaluated for potential weight loss as well as compressive strength and flexural strength post exposure. The results of the weight loss as well as the loss in strength are shown in Figures 6 and 7.

The results show a weight reduction for all mixtures that was in the range of 1.12 to 4.5% percent, with the higher values mainly for the rubber-containing concrete. These losses are likely due to some changes in the nature of the rubber and possible melting and evaporation as was witnessed through the odor while testing. However, the loss in weight is indeed small compare to the larger losses that occurred for both the compressive strength and the flexural strength. For example, the loss in flexural strength for the 10% waste rubber-containing mix reached a value of 91.5%. Such losses were not remedied by the treatment of the rubber by either cement or silica fume. The losses in compressive strength for the rubber mixtures were less when compared to the losses in flexural strength. This can be explained by the more cracking that was observation in the rubber containing concrete post exposure. In general, cracking is known to adversely influence the flexural strength more than the compressive strength as witnessed in this work. These results raises a flag of caution against using rubber containing concrete in structures exposed to elevated temperature and potential fire hazard conditions.

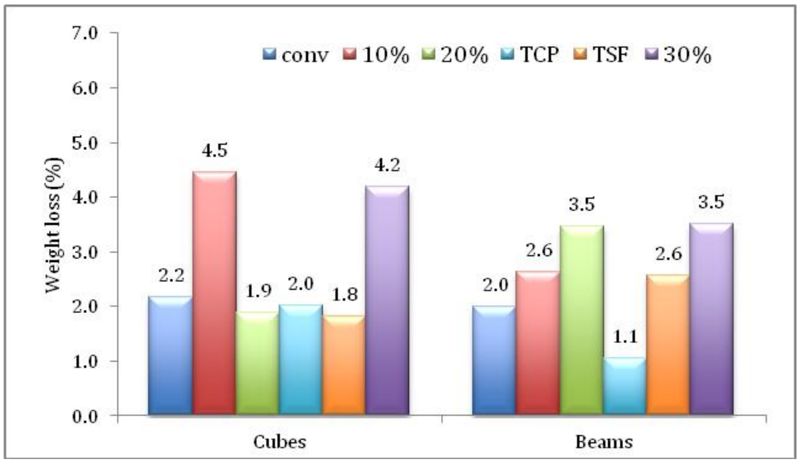

Fig 6: Percent weight loss post exposure to elevated temperature

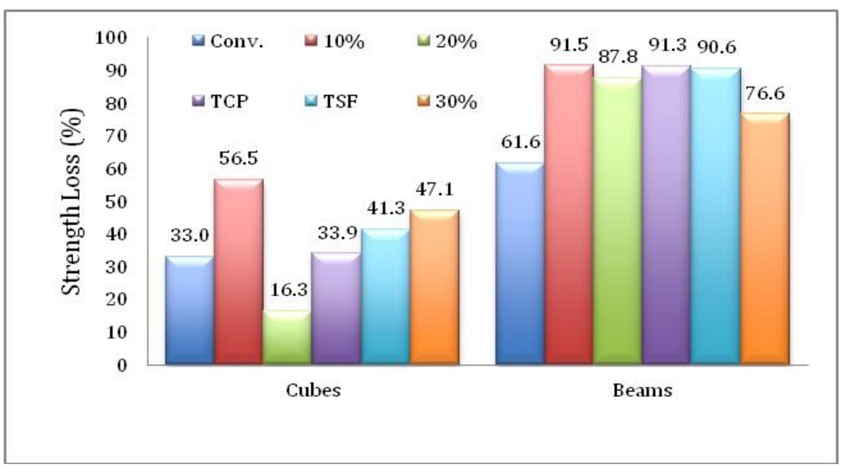

Fig 7: Percent strength loss post exposure to elevated temperature

Dynamic Impact Test: A summary of the results of the dynamic impact test are presented in table 5. In this table, the difference between the reaction forces and the impact force is shown in kN.

Table 5: Summary of the impact test results

Specimen	Average Difference (kN)	Crack width (mm)	Beam max deformation (mm)
Conventional	8.3	0.7	3.8
10%	6.3	2.6	6.3
20%	5.7	2.4	6.5
TSF	4.4	0.8	4.0

The results in the table show less difference between impact force and the reactions for the rubber containing mixtures. For example, the difference for the 10% rubber mix was 6.3 kN as compared to a 8.3 kN for the conventional mix. The less difference herein reflects a higher ability of the rubber beams to absorb impact energy before bouncing it back in the form of high reactions exceeding static loads impinging on beams. This was also accompanied by an increased deformation of the mid-span of beams upon impact.

The above results suggest that rubber concrete can be beneficial in absorbing dynamic energy. This can be useful in applications in which concrete, for example, serve as a shock absorber without necessarily possessing high design stress. Such statements need to be -again- validated through further work involving more sets of rubber types, rubber dosages and rubber treatment techniques.

4 Conclusions

Based on all the materials and techniques used as well as the parameters associated with this work, the following conclusions can be stated:

1. Rubber concrete had relatively lower density and slightly less workability compared to conventional concrete. However, it entrains/entraps air content that is similar to conventional concrete.
2. Rubber-aggregates introduce a significant reduction in compressive strength. This reduction is somewhat proportional to the increase in rubber content in the mix.
3. Limiting rubber content to about 10% and the treatment of rubber by Portland cement or silica fume can narrow the strength gap between rubber-containing and conventional concrete.
4. The rubber concrete tested had lower modulus of elasticity and higher maximum strain at failure compared to conventional concrete.
5. Exposure to elevated temperatures introduced a massive loss in both compressive and flexural strength of rubber concrete.
6. Rubber concrete mixtures seemed to have better dynamic toughness than that of conventional concrete.
7. Cracking as result of elevated temperature or impact were larger and wider for rubber containing concrete mixtures.

5 Recommendations

Since the use of waste rubber in Portland cement concrete is somewhat limited, the following recommendations can be drawn:

1. To conduct further testing involving different types of rubber, replacement dosage and treatments.

2. To explore surface roughening of rubber as means to enhance its bond with cement paste in order to possibly enhance mechanical properties.

3. To use of adequate water-reducers to overcome the drop in workability in rubber concrete.

4. To examine the feasibility of replacing, not only coarse aggregates, but also the fine aggregates with rubber waste particles in fill and lean concrete mixtures.

5. To conduct durability, creep and other long term properties in testing schemes in the presence of aggressive conditions.

6. To include reinforced tires, which are not covered by this study, in testing in order to explore the effect of reinforcing wires in improving the concrete quality.

7. To carry out pilot trials for low strength concrete segments with close monitoring of the service performance of such concrete.

Acknowledgement

This publication is based primarily based on the work of Salma Bahey, Ahmed Sultan, Aly Seif, Karim Dayhoum, and Yasser Srour in their project work at the American University in Cairo, the Department of Construction and Architectural Engineering in 2012.

References

Abou-Zeid, M.N., Shenouda, M.N., McCabe, S.L. and El-Tawil, F.A.. Reincarnation of Concrete: A Study investigates the Properties and Feasibility of Concrete made with Recycled Concrete as Aggregates. Concrete International, Volume 27th. No. 2, pp. 53-59, February, 2005.

Bahey, Salma. Sultan A., Seif A., Dayhoum, K. And Sorour, Y. Use of Rubber in Concrete. Project of CENG 490.The American University in Cairo.Fall 2012.

Naik, Tarun R., and RafatSiddique.Properties of Concrete Containing Scrap Tire Rubber.Thesis.The University of Wisconsin - Milwaukee, 2002.

El-Gammal, A., A. K. Abdel-Gawad, Y. El-Sherbini, and A. Shalaby.Compressive Strength of Concrete Utilizing Waste Tire Rubber.Civil Engineering Department, National Research Center, Giza, Egypt, 2010.

Danko, Michelle, Edgar Cano, and Jose Pena.Use of Recycled Tires as Partial Replacement of Coarse Aggregate in the Production of Concrete. Purdue Indiana, United States of America: Purdue University Calumet, 2009.

Caines, R, K Kew, and M J Kenny.The Use of Recycled Rubber Tyres in Concrete Construction. Glasgow: Strathprints Institutional Repository, 2004.

Guneyisi, Erhan, Mehmet Gesog˘ lu, and TuranOzturan. Properties of rubberized concretes containing silica fume. Istanbul, Turkey: Department of Civil Engineering, Bog˘azici University, 2004.

Sallam, H. E. M., A. S. Sherbini, M. H. Seleem, and M. M. Balaha."Impact Resistance of Rubberized Concrete."Engineering Research Journal 31.3 (2008): 265-71.

Shenouda, M., Abou-Zeid, M.N., McCabe, S.L and El-Tawil, F., “Concrete Recycling: Properties and feasibility”, World of Engineering Refereed Magazine, Issue No. 47, pp. 16-22. December 2007.

Karim. M.R, Zain, M.F.M., Jamil, M., and Lai, F.C., (2011), Significance of Waste Materials in Sustainable Concrete and Sustainable Development, International Conference on Biotechnology and Environment Management IPCBEE vol.18 (2011) IACSIT Press, Singapore, 43-47.