Utilization of Waste Tires in the Production of Non-Structural Portland Cement Concrete

By

Prof. Osama A. Abaza

Abstract

This paper aims to explore the potential utilization of waste crumb tires in various Portland Cement Concrete categories for the production of non-structural Portland cement concrete.

Fine aggregate (sand) was replaced using volumetric method by waste crumb tires with 0, 25, 50, 75, and 100% replacements for the various PCC categories of B-150, 200, 250, 300, and B-450 kg/cm^2.

Physical characteristics on fresh and hardened concrete were studied by various tests. Concrete mixes which contained waste crumb were compared with those that had 0% replacement.

Compressive strength, density, and modulus of elasticity decreased as the percent replacement by waste crumb tires increased; water absorption initially decreased and started to increase after an increasing in the percent of replacement, slump showed no significant change. Abrasion resistance, noise and thermal insulation increased as the percent replacement increased.

Finally it is recommended to use waste crumb tires for non-structural Portland cement concrete, such as floor rips, partitions, back stone concrete, concrete blocks, and other non-structural uses.

1. Introduction

The waste problem considered as one of the most crucial problems facing the world as a source of the environmental pollution.

During last recent years, many improvements in West Bank have occurred in all parts of life such as social, industrial, economical etc. Like all countries in the world, this will lead to generate new ways of living and increase the human requirements, and will also increase types and quantities of the waste in the West Bank, without any active processes to provide solution to this problem.

Waste rubber tires cause serious environmental problems all over the world. One of the potential means of utilizing the waste tires is to process this waste material for the protection of the environment and society. It is suggested to use this waste tires as an additive in Portland cement concrete (PCC) mixes for non-structural applications, which would partially help in solving this problem.

The objective of this paper is to investigate the utilization of rubber tires in the form of shredded tires (crumbs) in PCC for non-structural concrete through investigating its impact on the physical characteristics of PCC as compressive strength, workability, water absorption (porosity), noise insulation, thermal insulation, and abrasion.

Disposal of tires has become one of the serious problems for the environment. Land-filling is becoming unacceptable for waste tires because of the rapid depletion of available sites for waste disposal.

2. **Background**

The use of rubber waste shredded tires was studied in the past by many researchers.

A systematic experimental study was performed recently for improving strength and toughness of Rubber Modified Concrete (RMC) (Xi et al. 2003).

In the study of the development of waste tire modified concrete, two types of waste tire configurations were evaluated (Guoqiang et al. 2004). One was in the form of chips, or particles and the other was in the form of fibers.

Another research was done using Chopped Worn-Out Tires in production of light weight concrete masonry units (Al-Hadithi et al. 1999).

Raghvan et al. (1998) reported that mortars incorporating rubber shreds achieved workability (defined as the ease with which mortar/concrete can be mixed, transported and placed) comparable to or better than a control mortar without rubber particles.

Khatib and Bayomy (1999) investigated the workability of rubber concrete and reported that there was a decrease in slump with increase in rubber content as a percentage of total aggregate volume.

Another research was done using Chopped Worn-Out Tires in production of light weight concrete masonry units (Al-Hadithi et al. 1999). This research, generally aimed at defining the possibility of using chopped worn-out tires to produce lightweight concrete building units.

3. Work Procedure

The basic ingredients of PCC and its products, which were used in this research work were normal Portland cement (Cement type 1), Natural Coarse aggregate (sedimentary rock source), Natural Fine aggregate (sand), Water (fresh drinkable water), and Grinded tires (fine crumb tires).

3.1 Raw Material Tests

The raw materials used in this research work were tested for the purpose of identification of basic physical characteristics using the following tests:

- Sieve analysis. (ASTM C-136)
- Specific gravity and water absorption. (ASTM C-127)
- Abrasion (Lose Angles abrasion test). (ASTM C-88)
- Amount of fines and injurious particles (Sand equivalent) (ASTM D-2419).

3.2 Plain Portland Cement Concrete Mixes

Standard Portland cement concrete mixes without crumb rubber were made with different grades and different water cement ratios. These mixes were used as a reference standard comparison mixes. Such mixes reflect the local design mixes used by the ready mix plants. Table 1 shows the mix ingredients for a batch of 0.01 cubic meters.

Table (1): Mix ingredients (kg/0.01m^3 of PCC)

Concrete Grade	B-150	B-200	B-250	B-300	B-450
Coarse aggregate	12.95	12.95	12.50	12.50	12.50
Fine aggregate (sand)	5.0	5.2	5.8	5.8	5.5
Cement	2.0	2.2	2.6	2.9	4.7
Water	1.9	1.95	1.9	1.8	2.0
W/C	0.95	0.89	0.73	0.62	0.43

3.3 Crumb Portland Cement Concrete Mixes

Portland cement concrete mixes utilizing crumb waste tires by volumetric replacement of sand with different proportions of replacements, basically 25, 50, 75, and 100% replacements were made. Table 2 shows the replacement of fine aggregate (sand) in different proportions by the crumb waste tires volumetric for B-150 grade as an example.

By dividing the weight of sand to be replaced by crumb waste tires by its specific gravity, the volume of sand was obtained; this volume is to be replaced by volume of crumb tire waste converted to weight using the following physical characteristics which was tested as a part of this thesis:

Table (2): Grade B-150 of PCC for batch mix

B-150		
0.0% of sand by weight is to be replaced by shredded tires		
Weight of sand (gm)	Volume of sand (cm^3)	Equivalent Weight of shredded tires (Kg)
5000	1893.9	0.0
25% of sand by weight is to be replaced by shredded tires		
Weight of sand (gm)	Volume of sand (cm^3)	Equivalent Weight of shredded tires (Kg)
1250	473.5	0.540
50% of sand by weight is to be replaced by shredded tires		
Weight of sand (gm)	Volume of sand (cm3)	Equivalent Weight of shredded tires (Kg)
2500	947.0	1.080
75% of sand by weight is to be replaced by shredded tires		
Weight of sand (gm)	Volume of sand (cm^3)	Equivalent Weight of shredded tires (Kg)
3750	1420.5	1.619
100% of sand by weight is to be replaced by shredded tires		
Weight of sand (gm)	Volume of sand (cm^3)	Equivalent Weight of shredded tires (Kg)
5000	1893.9	2.159

3.4 Tests on PCC

Slump test was made on fresh concrete to measure the effect of change in ingredients on workability according to the addition of crumb waste tires.

The following tests on hardened concrete were made using four specimens (cubes) from each proportion made:

- Compressive Strength (PS-55): It is worth to note that the Palestinian standard requires a 7 days curing while the ASTM standards require a curing conditions 28 days curing after casting the molds.

- Water Absorption (ASTM C-642).

- Abrasion (ASTM C-944).

- Modulus of Elasticity (ASTM C-469).

- Weight before replacement and weight after replacement.

3.4 Thermal and Sound Insulation testing

For sound and thermal insulation, a concrete wood mold having a dimension of 15x15x5cm was made, three specimens of each proportion were made with 0.0%, 25%, 50%, 75% and 100% crumbed waste tires with properties same as that of concrete cubes mixes.

A wooden box was made in a way that the heat will be directly move or transfer from one chamber having constant temperature exposed on one of the faces of the specimen for a period of time through the specimen to another chamber. The temperature was measured until the temperature became constant in the two faces of concrete specimen using a laser thermometer (High Temperature Infrared Thermometer, Type K/J/T/E/R). Figures 3.2, 3.3, and 3.4 show the mechanism of the testing.

Figure 3.2: Wooden box face with two opening one for source and the other for measuring (40x40x100cm Dimension)

Figure 3.3: Wooden box back (the other face) with one opening for measuring.

Figure 3.4: Specimen location (at the middle of the wooden box) with frame dimension 15x15x15 cm

The same procedure was made for testing the sound insulation using a constant noise source and a noise measuring device (Sound Level Meter Auto range, RS – 232).

4. Experimental Results and discussion

4.1 Materials Testing Results

The physical characteristics of the materials which were obtained from tests results mentioned that were made on lab:

- Dry Rodded Weight of Sand = 1.431 g/cm3
- Dry Rodded Weight of crumbed tires waste = 0.640 g/cm3
- Specific Gravity of Sand = 2.644 g/cm3
- Specific Gravity of crumbed waste tires = 1.140 g/cm3

Table 3 summarizes the tests results of the properties of materials used in this research. Notice that these materials are used locally in West Bank by concrete plants, and Figure 1 gives the specification of aggregates used in the mixes.

Table (3): Materials tests results

RESULTS OF AGGREGATE TESTING											
1- Gradation (AASHTO T-27)											
Sieve No.	**1"**	**3/4"**	**1/2"**	**3/8"**	**# 4**	**# 8**	**# 16**	**# 30**	**# 50**	**# 100**	**# 200**
Coarse agg.	100	75	59	54	26	11	3.9	3.3	2.8	2.5	2.4
Fine agg.	-	-	100	100	99.0	97.0	92.2	64.6	26.3	6.1	3.9
Shredded tires, (crumb)	-	-	-	-	-	-	-	100	47.4	26.7	0.0

No.	**Type of test**	**Standard**	**Unit**	**Result**		
				Coarse agg.	**Fine agg.**	**Shredded tires**
2.	Bulk specific gravity	ASTM C-127	-	2.560	2.521	1.131
3.	Sp.Gr. (Saturated surface Dry – SSD)		-	2.621	2.640	1.140
4.	Sp.Gr. (Apparent)		-	2.716	2.734	1.152
5.	Water absorption		%	1.02	0.5	-
6.	Los Angeles abrasion	ASTM C-88	%	30.1	-	-
7.	Sand equivalent	ASTM D-2419	-	-	66.0	-
8.	Clay lumps and friable particles	ASTM-C142	%	1.1	-	-

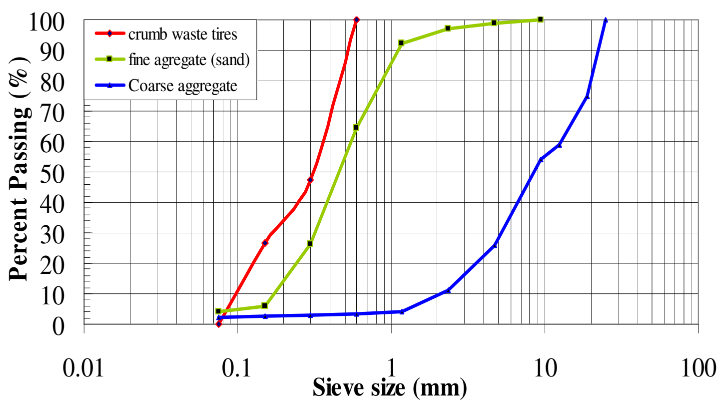

Figure 1: Particle size distribution

4.2 Compressive Strength

As a result of a volumetric replacement of sand by crumb waste tires, compressive strength decreases as percent of crumb waste tires increases as shown in Figure 2.

Figure 2 shows how compressive strength changed with percent of volumetric replacement of sand by waste crumb tires relative to the specified compressive strength.

Notice actual compressive strength at 0, 25, 50, 75, and 100% replacement for grades B-150, 200, 250, 300, and B-450, actual compressive strength differences are less decreased at concrete grades B-150 and B-200 versus replacement, differences of compressive strength increases at concrete grades B-250, 300, and B-450 versus replacement.

As an example; for concrete grade of B-450 the differences between compressive strengths are 39.7, 20.0, 36.5, and 36.0%, while for concrete grade of B-200 the differences are 13.1, 28.1, 30.1, and 21.8%.

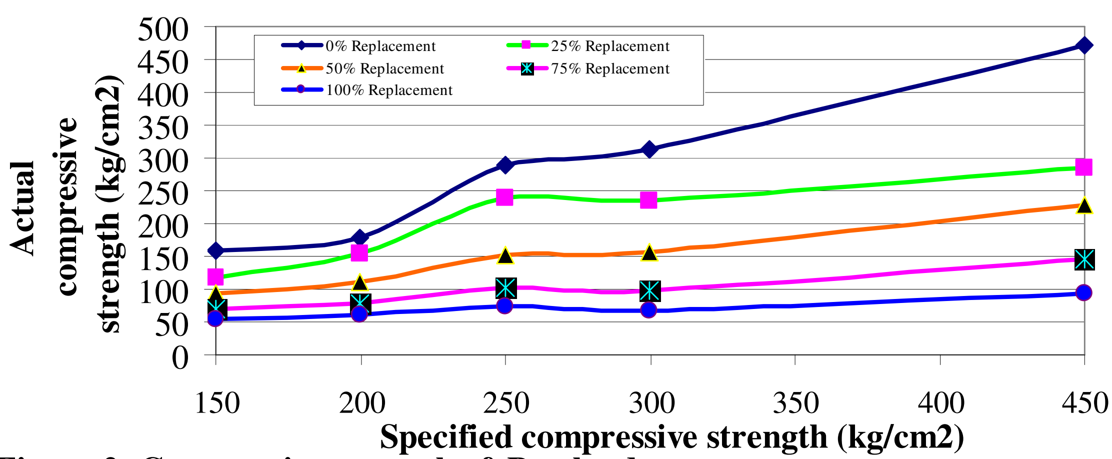

Figure 2: Compressive strength of Portland cement concrete for various percentages of replacements of crumbed waste tires

Figure 2 shows how actual compressive strength decreased at specified compressive strength with increasing percent of replacement of waste crumb tires. This happened because as replacement increases, bonding between aggregate particles and cement decrease, and because of the weakness of waste crumb rubber particles with comparison to sand.

4.3 Density

Density of concrete also decreases as crumb waste tires increases, see Figure 3 which presents how density decreases when crumb waste tire increases.

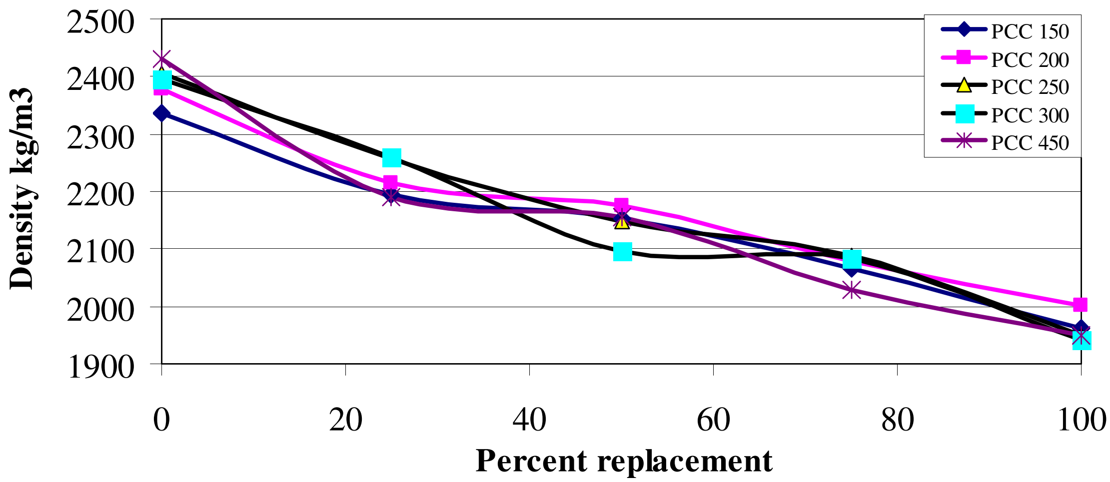

Figure 3: Perecent replacement by crumb waste tire versus density for various categories of concrete

Theses differences show slight differences in densities between different PCC categories versus replacement, but the decreases for each type on density reaches between (16-19%) at 100% replacement.

Generally, density decreases as percent replacement increases since waste crumb rubber has lower specific gravity than sand.

4.4 Water Absorption

Water absorption decreases at 25% replacement and pounces back approximately to its original value at 50% replacement and starts to increase as waste crumb tires increases (see Figure 4 for PCC-150).

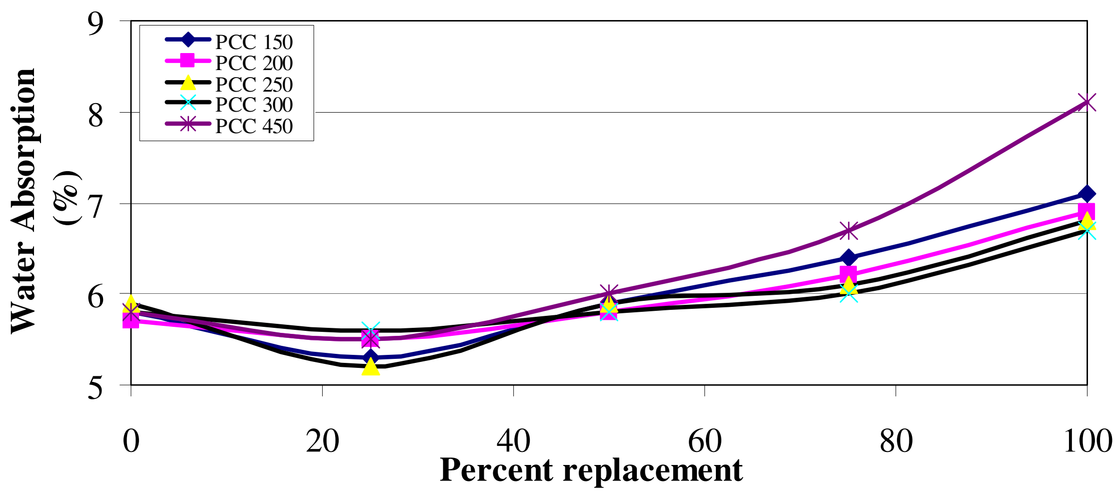

Figure 4: Perecent replacement by crumb waste tire versus Water Absorption for various categories of concrete

This leads to the idea that water absorption decreased at 25% replacement since voids are decreased but occasional vacuums existed when waste crumb tires replacement increased which causes an increase in water absorption. In addition, weakness of bonding between particles will increase absorption which permits water to enter through voids in the interface between the crumbs and the cement paste as a result of increasing waste crumb tires. It is worth to note that the waste crumb tires have smaller particle size compared to that of sand as seen in Figure 1.

4.5 Slump (Consistency)

Slump is an expression of consistency, as slump increases the concrete blend is more consistent. Figure 5 shows slump versus replacement for different PCC categories.

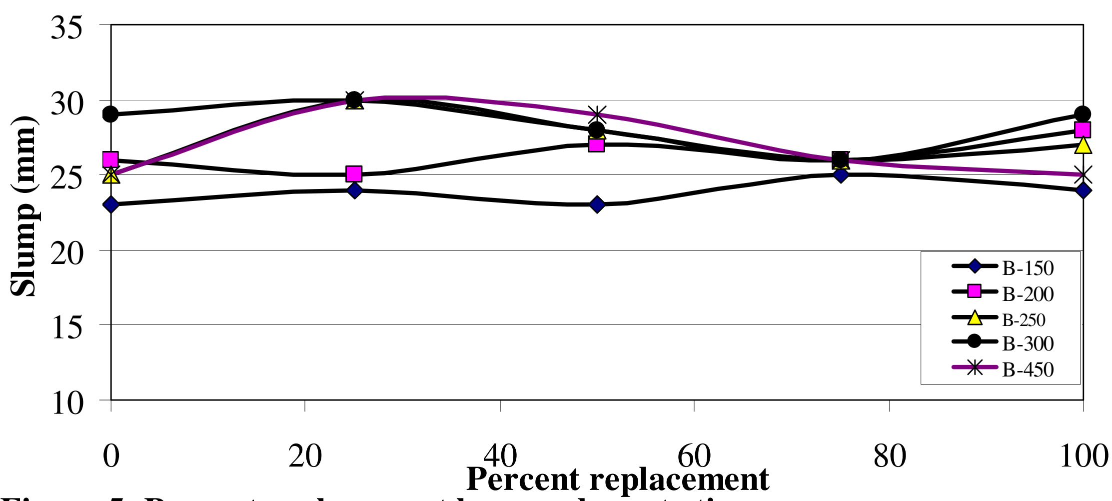

Figure 5: Percent replacement by crumb waste tires versus slump for various PCC categories

Slump showed little change in consistency during all mixing; slump ranges from 20-30 mm, there was no effect of increasing waste crumb tires replacement on consistency. This is because of the coarseness of the mixes and the existence of high adhesion forces between waste crumb particles and aggregate particles which prevents mixes to be more consistent.

4.6 Abrasion

Figure 6 represents abrasion test results for concrete versus percent replacement for.

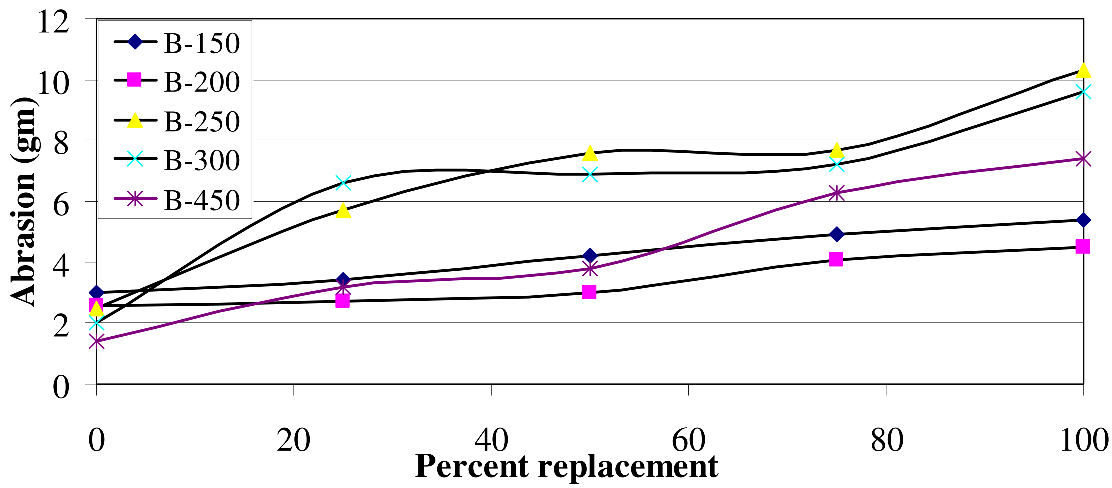

Figure 6: Percent replacement by crumb waste tires versus abrasion for various PCC categories

It is noticed that abrasion increases when replacement increases, this is because of the increase of waste crumb tires replacement. This happened because of the existing of fine crumb waste tires which has a weak resistance and of the weakness of bonding between the blend particles due to increasing of waste crumb tires percent replacement. On the other hand sand has a coarse surface texture and because of the nature micro structures of sand (silica quarts) that made bonding stronger with comparison to rubber.

4.7 Modulus of Elasticity

Figure 7 shows modulus of elasticity versus replacement of waste crumb tires for different categories of PCC.

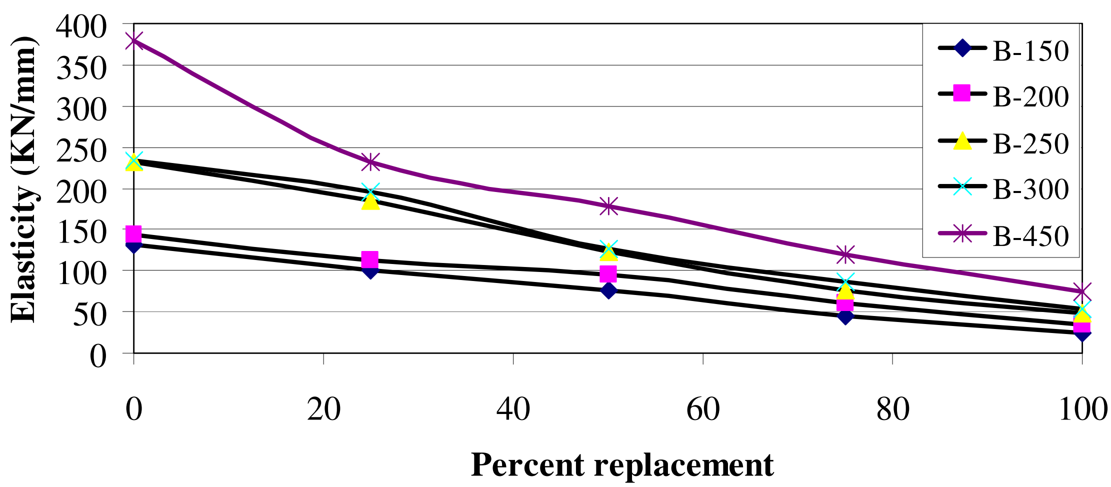

Figure 7: Percent replacement by crumb waste tires versus elasticity for various PCC categories

Modulus of elasticity decreased as waste crumb tires replacement increased.

4.8 Noise Insulation

Figure 8 shows results of noise insulation at low level of noise (86.5 dp), this Figure presents percent replacement of waste crumb tires versus percent reduction of noise at low level for various PCC categories.

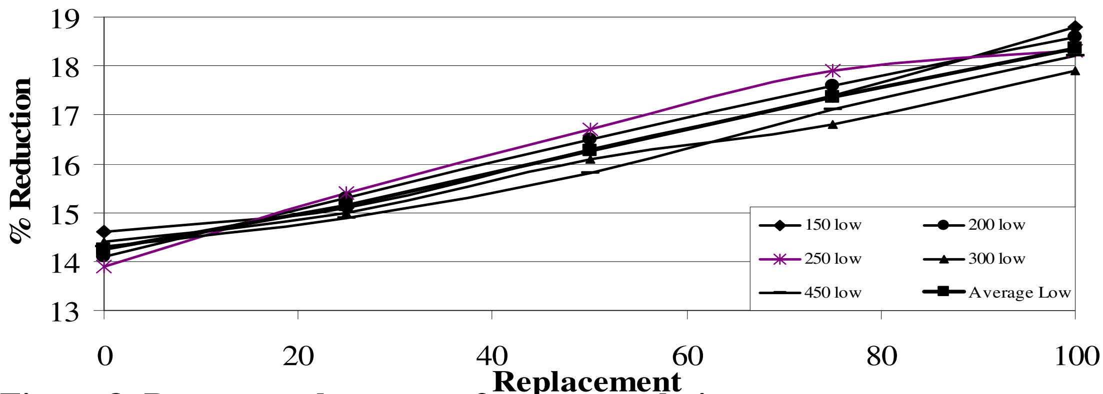

Figure 8: Percent replacement of waste crumb tires versus reduction of noise at low level for various PCC categories

Figure 8 shows obviously the behavior of noise, as replacement increased, higher reduction of noise, this means that when replacement increased insulation increased.

From the above Figure the reduction increased from 14% at 0% replacement to approximately 19% at 100% replacement.

Figure 9 also presents percent replacement of waste crumb tires versus percent reduction of noise at high noise level (98.6 dp) for various PCC categories.

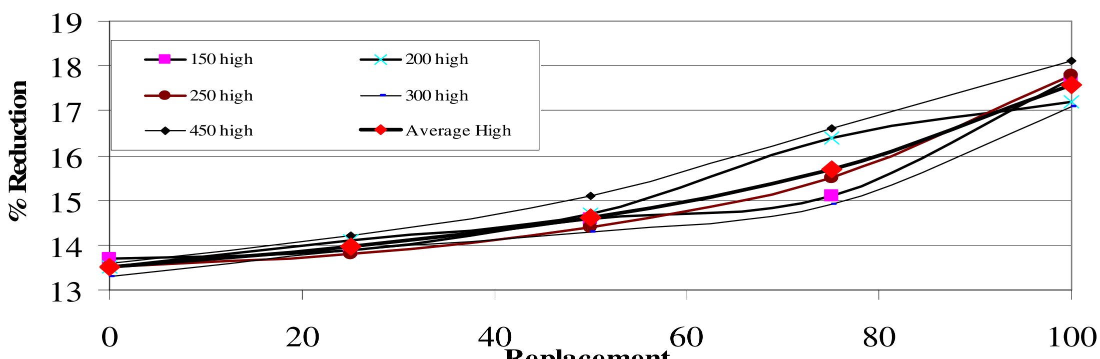

Figure 9: Percent replacement of waste crumb tires versus noise reduction at high level for various PCC

The above Figure shows the same behavior as low noise level but with less noise reduction or less insulation. Reduction of noise increased from 13.5% approximately at 0.0% replacement to 18% at 100% replacement.

Figure 10 shows percent replacement versus averages of noise reduction at low and high levels.

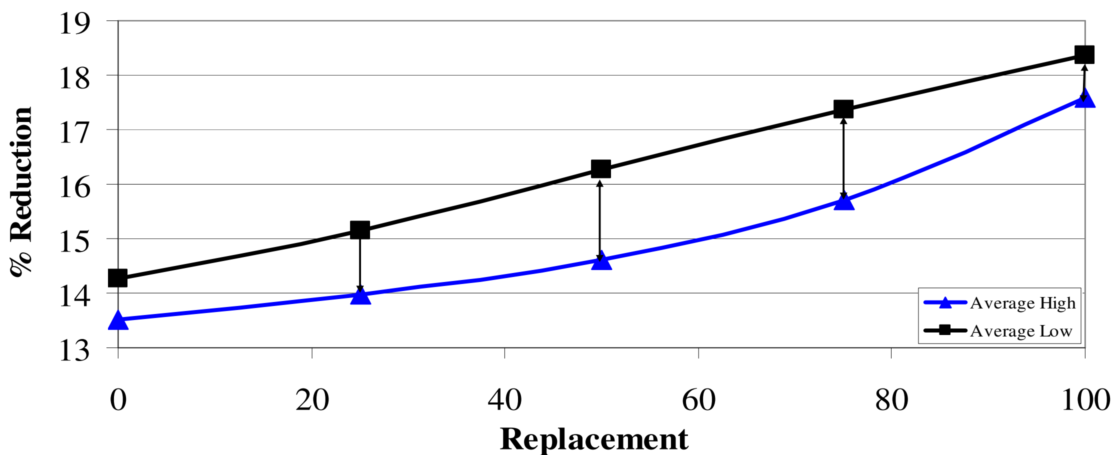

Figure 10: Percent replacement of waste crumb tires versus average reduction of noise at low and high level

At low noise level higher insulation of noise occurred than high level of noise which easily noticed from Figure 5.16.

The difference between reduction of noise at low level and high level, at 0, 25, 50, 75, and 100% is 0.74, 1.16, 1.66, 1.66, and 0.78 respectively, that gives higher increasing at low level of 5.5, 8.3, 11.4, 10.6, and 4.4% than the high noise level with an overall average of 8.0%.

The more the material is brittle it will have lower noise insulation; the more the material is elastic it will have higher noise insulation. This means that when percent replacement increased concrete absorption of noise increased.

Concrete with different percent replacement can isolate noise at low level better than high noise level, since concrete can absorb vibration at low level better than high level.

4.9 Thermal Insulation

Figure 11 shows results of thermal insulation at a constant source of heat (54 C°), this Figure presents percent replacement of waste crumb tires versus percent reduction of temperature for various PCC categories.

Figure 11 shows that percent reduction in temperature increased as waste crumb tires replacement increased, that leads the fact that thermal insulation increased as the percent replacement increased. No significant changes can be noticed between various PCC categories.

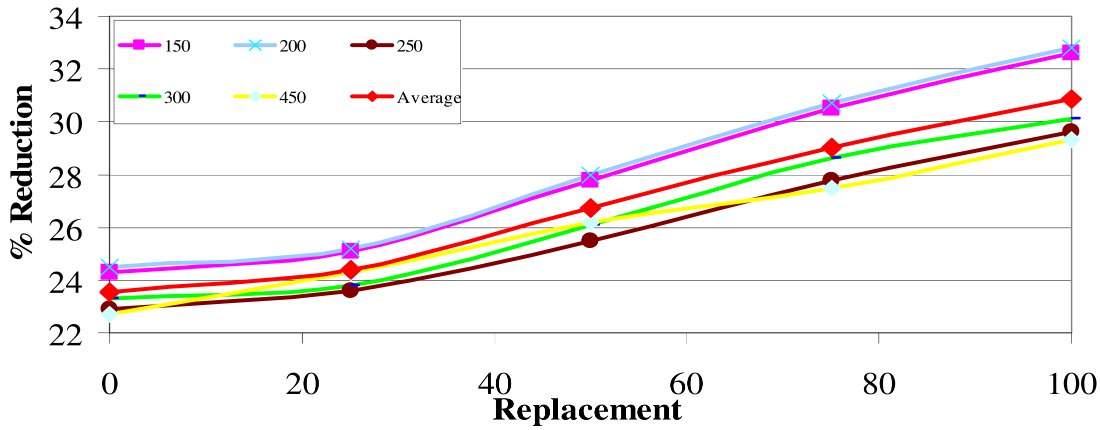

Figure 11: Percent replacement of waste crumb tires versus temperature reduction for various PCC categories

Figure 12 shows the average percent reduction of temperature versus percent replacement of waste crumb tires for all PCC categories.

Average reduction increased as percent replacement increased, at 0, 25, 50, 75, and 100% replacement percent reduction is 23.5, 24.4, 26.7, 29.0, and 30.9% respectively, which means that thermal insulation increased 3.8, 13.6, 23.4, and 31.5% from zero percent replacement.

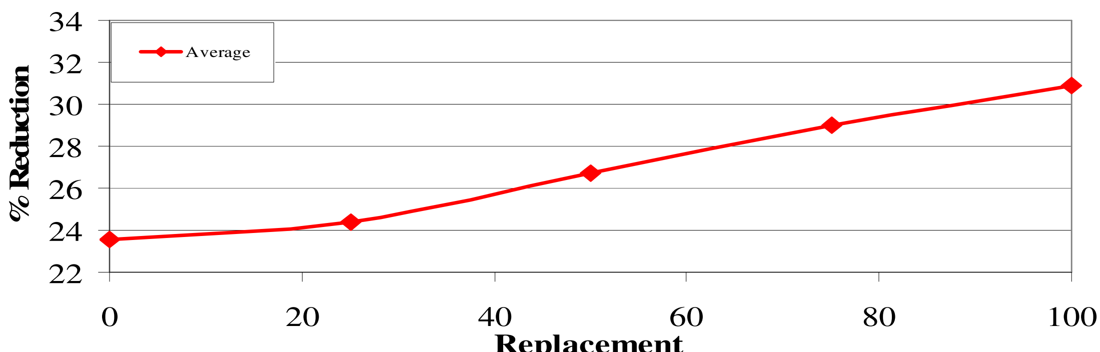

Figure 12: Percent replacement of waste crumb tires versus average temperature reduction for various PCC

This behavior happened because when the material density is lowered thermal insulation increased, and because of lower conductivity that rubber has with comparison of concrete.

5. Conclusions and Recommendations

6.1 Conclusions

Based on the results and analysis done as a part of this research, the following can be concluded:

1. Compressive strength decreases as the percent of waste crumb tire replacement increases for various PCC categories.
2. Density decreases as the percent of waste crumb tire replacement increases for various PCC categories.
3. Water absorption decreases at 25% replacement and pounces back approximately to its original value at 50% replacement, and then starts to increase as waste crumb tires increases.
4. Slump test results showed no change in consistency during all mixes; there was no effect of increasing waste crumb tires replacement on consistency.
5. Abrasion increases as waste crumb tires increases.
6. Modulus of elasticity decreases as waste crumb tires replacement increases.
7. Noise insulation increases as percent of crumb waste tires increases. At low noise levels, higher insulation of noise occurred than that of high levels of noise.
8. Thermal insulation increases as waste crumb tires percent increases.

5.2 Recommendations

Based on the conclusions drawn above and the laboratory observations, the following are recommended:

1. Since the addition of crumb tires decreases compressive strength, it is recommended to use waste crumb tires for non structural Portland cement concrete in buildings such as floor slabs, floor ribs, under ground slabs, behind building stones and in partitions etc.
2. It is recommended to use percent of replacements in the vicinity of 25% in the PCC, since compressive strength still within the acceptable range, also good thermal and noise insulation can be achieved.
3. It is recommended to use replacements in an increment of 10% for better identification behavioral changes in the physical characteristics in future research.
4. It is recommended to study the effect of larger sizes of shredded tires on PCC.
5. It is recommended to further test the physical characteristics of PCC through shrinkage limit, permeability etc.
6. It is recommended to explore the effect of other raw materials in these mixes and study the changes in physical characteristics.
7. Using waste crumb tires in the production of concrete blocks, ribbed concrete block, and for paving is strongly recommended.

References

Al-Akhras, N.M., Smadi, M.M., (2002). *Properties of tire rubber ash mortar*. **Proceedings of the International Conference on Sustainable Concrete Construction**, University of Dundee, Scotland, UK, pp 805–814.

Al-Hadithi A. I., (1999). *Using chopped worn-out tires in production of light weight concrete masonry units*. **Jordan Second Civil Engineering Conference**, 16-17 November 1999, pp 301-319.

Ali, N.A., Amos, A.D., Roberts, M. (1993). *Use of ground rubber tires in Portland cement concrete*. **Proceedings of the International Conference on Concrete**, University of Dundee, Scotland, UK, pp 379–390.

Annual Book of ASTM Standards, (1985). *Concrete and Mineral Aggregates*, volume 04.02.

Benazzouk, A., Queneudec, M. (2002). *Durability of cement–rubber composites under freeze thaw cycles*. **Proceedings of the International Conference on Sustainable Concrete Construction**, University of Dundee, Scotland, UK, pp 356–362.

Bignozzi, M.C., and Sandrolini, F. (2006). *Tire rubber recycling in self compacting concrete.* **Cement and Concrete Research** 36 (2006) pp 735-739.

Biel, T.D., Lee, H. (1996). *Magnesium oxychloride cement concrete with recycled tire rubber*. Transportation Research Record, No. 1561, **Transportation Research Board**, Washington, DC, pp 6–12.

Blumenthal M. (1998). *What's new with ground rubber?* **Biocycle**, March 1998 V39n3 pp 40 (3).

California Integrated Waste Management Board (CIWMB), and the Department of Energy Contracting Officer, (1994). *Part of a report UCLLNL/DOE – Waste Tires.*

DiChristina, M., (1994). *Mired in tires*. (Junk tires) **Popular science**, Oct. 1994 v245n4 pp 62(4).

Eldin, N.N., Senouci, A.B. (1993). *Rubber-tire particles as concrete aggregates*. **ASCE Journal of Materials in Civil Engineering** 5 (4), pp 478–496.

Fattuhi, N.I., Clark, N.A. (1996). *Cement-based materials containing tire rubber*. **Journal of Construction and Building Materials** 10 (4), pp 229–236.

Fedro., D., Ahmad, S., Savas, B.Z. (1996). *Mechanical properties of concrete with ground waste tire rubber*. Transportation Research Board, Report No. 1532, **Transportation Research Board**, Washington, DC, pp 66–72.

Goulias, D.G., Ali, A.H. (1997). *Non-destructive evaluation of rubber modified concrete*. **Proceedings of a Special Conference, ASCE**, New York, pp 111–120.

Heitzman, M. (1992). *Design and construction of asphalt paving materials with crumb rubber*. Transportation Research Record No. 1339, **Transportation Research Board**, Washington, DC.

Hernandez-Olivares, F., Barluenga, G., Bollati, M., Witoszek, B. (2002). *Static and dynamic behavior of recycled tire rubber-filled concrete*. **Cement and Concrete Research** 32 (10), pp 1587–1596

Hossain, M, Sadeq, M, Funk, L, and Maag, R, (1995). "*A study of chunk rubber from recycled tires as a road construction materials*". **Proceedings of the 10th Annual Conference on Hazardous Waste Research**, Kansas State University, Manhattan, pp 188-197.

Israeli Central Bureau of Statistics, (2005) Israel.

Khatib, Z.K., Bayomy, F.M. (1999). *Rubberized Portland cement concrete*. **ASCE Journal of Materials in Civil Engineering** 11 (3), pp 206–213.

Khosla, N.P., Trogdon, J.T. (1990). *Use of ground rubber in asphalt paving mixtures*. **Technical Report**, Department of Civil Engineering, North Carolina State University, Raleigh.

Lee, H.S., Lee, H., Moon, J.S., Jung, H.W. (1998). *Development of tire-added latex concrete.* **ACI Materials Journal** 95 (4), pp 356–364.

Li, G., Stubblefied, M. A., Garrick, G., Eggers, J., Abdie, C., and Haung, B. (2004). *Development of waste tire modified concrete*. **Concrete and Cement Research** 34, pp 309-319.

Li, G., Garrick, G., Eggers, J., Abdie, C., Stubblefied, M. A., and Pang, S. (2004). *Waste tire fiber modified concrete*. **Composites** Part B, 35, pp 305-312.

Naik, T.R, Singh, S.S. (1991). *Utilization of discarded tires as construction materials for transportation facilities*. Report No. CBU-1991-02, UWM Center for By-products Utilization. University of Wisconsin-Milwaukee, Milwaukee, pp 16.

Naik, T.R., Singh, S.S. (1995). *Effects of scrap-tire rubber on properties of hot-mix asphaltic concrete* - a laboratory investigation. Report No. CBU 1995-02, **UWM Center for By-products Utilization**, University of Wisconsin-Milwaukee, Milwaukee, pp 93.

Naik, T.R., Singh, S.S., Wendorf, R.B. (1995). *Applications of scrap tire rubber in asphaltic materials*: state of the art assessment. Report No. CBU 1995-02, **UWM Center for By-products Utilization**, University of Wisconsin-Milwaukee, Milwaukee, pp 49.

Paine, K.A., Dhir, R.K., Moroney, R., Kopasakis, K. (2002). *Use of crumb rubber to achieve freeze thaw resisting concrete*. **Proceedings of the International Conference on Concrete for Extreme Conditions**, University of Dundee, Scotland, UK, pp 486–498.

Palestinian Standards (PS-55-2001). *Methods of testing concrete*, (part 1-5). Palestine Standards Institute, Palestine.

Papakonstantinou, C. G., and Tobolski, M. J. (2006). *Use of waste tire steel beads in Portland cement concrete*. **Cement and Concrete**

Research.

Paul, J. (1985). ***Encyclopedia of Polymer Science and Engineering***. 14, 787-802.

Pierce, C.E., Blackwell, M.C. (2003). *Potential of scrap tire rubber as lightweight aggregate in flowable fill*. **Waste Management** 23 (3), pp 197–208.

Raghvan, D., Huynh, H., Ferraris, C.F. (1998). *Workability, mechanical properties and chemical stability of a recycled tire rubber-filled cementitious composite*. **Journal of Materials Science** 33 (7), pp 1745–1752.

Read, J., Dodson, T., Thomas, J. (1991). *Experimental project – use of shredded tires for lightweight fill*. **Oregon Department of Transportation**, Post Construction Report for Project No. DTFH -71-90-501-OR-11, Salem, OR.

Rostami, H., Lepore, J., Silverstraim, T., Zundi, I. (1993). *Use of recycled rubber tires in concrete*. Proceedings of the International Conference on Concrete 2000, University of Dundee, Scotland, UK, Rubber Manufacturer's Association, 2000. Washington, DC pp 391–399.

Rubber Manufacture's Association, (2003). USA *(Civil Engineering Applications)*.<http://www.epa.gov/epaoswer/nonhw/muncpl/tires/civil_eng.htm> January 3rd 2007.

Savas, B.Z., Ahmad, S., Fedro., D. (1996). *Freeze–thaw durability of concrete with ground waste tire rubber*. Transportation Research Record No. 1574, **Transportation Research Board**, Washington, DC, **Scrap Tire Management Council**, 1998. Scrap-tires Use, Washington, DC pp 80–88.

Segre, N., Joekes, I. (2000). *Use of tire rubber particles as addition to cement paste*. Cement and Concrete Research 30 (9), pp 1421–1425.

Singh, S.S. (1993). *Innovative applications of scrap-tires*. **Wisconsin Professional Engineer**, 14–17.

Siddique, R., Naik, T. R. (2004). *Properties of concrete containing scrap-tire rubber – an overview*. **Waste Management**, 24, pp 563-569.

Tantala, M.W., Lepore, J.A., Zandi, I. (1996). *Quasi-elastic behavior of rubber included concrete*. **Proceedings of the 12th International Conference on Solid Waste Technology and Management**, Philadelphia, PA.

Topcu, I.B. (1995). *The properties of rubberized concrete*. **Cement and Concrete Research** 25 (2), pp 304–310.

Topcu, I.B., Avcular, N. (1997a). *Analysis of rubberized concrete as a composite material*. **Cement and Concrete Research** 27 (8), pp 1135–1139

Topcu, I.B., Avcular, N. (1997b). *Collision behaviors of rubberized concrete*. **Cement and Concrete Research** 27 (12), pp 1893–1898.

Tortum, A., Celik, C., and Aydia, A. C. (2005) *Determination of the optimum conditions for tire rubber in asphalt concrete*. **Building and Environment**, 40, pp 1492-1504.

Yoon, S., Prezzi, M., Siddiki, N. Z., Kim, B. (2006). *Construction of a test embankment using a sand-tire shred mixture as fill material*. **Waste Management**, 26, pp 1033-1044.