COSMOS: Journal of Engineering & Technology
A Refereed Research Journal
Vol 4 / No 1 / Jan - Jun 2014 ISSN: 2231-4210

A POSSIBLE OUTLET FOR USED WASTE TYRE RUBBER BASED CONCRETE

Devarasetty Venkateswara Rao[1]
T. Chandrasekhar Rao[2]

Abstract

Discarded vehicle tyres constitute one important part of solid waste which had historically been disposed of into landfills. Recent EU policies on the Landfilling of Waste (Council Directive 1999/31/EC) have however put a ban on the landfilling of whole or shredded tyres, creating an imminent need to investigate any possible viable uses of this waste product. An emerging use is the production of concrete, in which tyre rubber particles partially replace natural aggregates. This has the additional advantage of saving in natural aggregates used in the production of concrete which are becoming increasingly scarce. This research investigated a wide range of physical and mechanical properties of concrete containing recycled tyre aggregates, to assess its suitability as a construction material. The influence of factors such as rubber aggregate content and size, as well as curing time was also considered. The results showed that despite a great loss in strength, this type of concrete was acceptable for various applications requiring medium to low compressive strength. The quantities of concrete produced worldwide for such applications could ensure the viability of this product. Therefore, this type of concrete shows promise for becoming an additional sustainable solution for tyre rubber waste management.

Keywords: *Solid Waste Management, Used Vehicle Tyres, Rubberised Concrete Properties.*

Introduction

The management of worn tires poses a major problem for all third world countries. Also, with the increasing number of vehicles, the industrial development which several countries are currently knowing, and the small percent- age of recycled worn tires (retreaded or used for other purposes) due to the absence of an adequate plan for eliminating this waste, these countries know surely a major environmental problem. The absence of statistics on this subject does not enable us today estimate suitably the mass of worn tires thrown in nature or burned in public dumpsters. But if we compare these countries with the European Union countries which took this problem in charge, through legislation, recycling companies, re- search, we can say that many countries are postponing the solution to this problem, and that the mass of worn tires can only be considerable. One of the recommended solutions to solve this environmental problem is to incorporate rubber aggregates resulting from cutting worn tires in the cement concretes. On this subject, several studies concerning the use of rubber aggregates resulting from crushing worn tires were carried out. These research works showed that the benefits of associating rubber-cement in the development of cementing composites with high deformability and on the durability of these composites. Moreover, the benefit which we can gain from using the cement concretes for the roadways makes us think about multiplying the studies on. The cement composites that incorporate rubber aggregates since the rigidity of the cement concretes can make it possible either to de- crease the granular layer necessary to the asphalt road- way or to allow the use of less resistant concretes. This is the case with the use of concretes having a considerable part of rubber aggregates resulting from worn tires.

With a great ecological concern and in saving traditional aggregates, we have replaced a part of the conventional aggregates by rubber aggregates resulted from cut- ting worn tires. The study that we propose was realized in two stages, with two different teams, and in two distinct periods of time in order to test the repeatability of certain results and the significance of some factors.

Experimental Procedure, Material and Mixes

For this experiment scrap tyre aggregates ranging from 20-1 mm were obtained from McGrath Bros. These are meant to be used in particular for equestrian circuits. According to information obtained from the supplier, these contain mostly textile fibre rather than steel fibre however the latter could amount to 5% of the total rubber tyre aggregate. The material was sieved and split into two groups of tyre aggregate: coarse rubber aggregate (19-10mm) and fine rubber aggregate material (10-4.75 mm). These groups will be referred to

[1]*Asst. Professor & Research Scholar, Acharya Nagarajuna University, Nagarrjuna Nagar, Guntur*
[2]*DMS SVH College of Engineering, Machilipatnam*

as CRA (Coarse Rubber Aggregates) and FRA (Fine Rubber Aggregates). The shape of the rubber aggregate was observed to be sub-angular. Figure 1 shows the particle size distribution curves for the two groups of rubber aggregates (coarse and fine aggregate groups) together with those of the mineral aggregates which were used in the test and were partly replaced by the rubber aggregates. The mineral aggregates are referred to as CMA (Coarse Mineral Aggregates) and FMA (Fine Mineral Aggregates). It is noticeable that the particle size distribution of the rubber aggregates is very close to that of the respective mineral aggregates (coarse or fine) conforming to BS 882 (BSI, 1992) and satisfying the aggregate grading requirements.

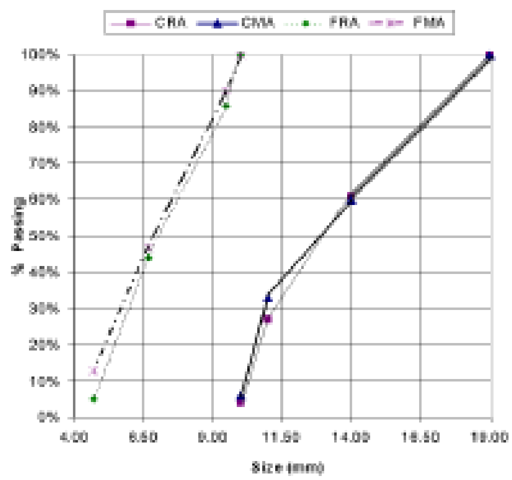

Figure 1. Particle size distribution of rubber and mineral aggregates used in the mixes

Ordinary Portland cement mix was used as the control mix (referred to as CM) for the purposes of comparison. This consisted of 1 part cement; 1.5 parts sand and 3 parts coarse aggregate (1:1.5:3). The mix design was according to BS 5328: Part 1 guidelines for RC40 (BSI, 1997). Two sets of mixes including rubber aggregate were then prepared for each test. In the first set of mixes, the coarse rubber aggregate (CRA) replaced part of the coarse mineral aggregate (CMA) of the control mix.

In the second, fine rubber aggregate (FRA) replaced partly fine mineral (stone) aggregate (FMA) of the control mix. Four different contents of rubber aggregate (by mass) were used to replace the mineral aggregate (10%, 20%, 30% and 40% respectively). The dry material comprising cement, sand, aggregate and rubber was well mixed before the water was gradually included. The water/cement ratio was kept constant (i.e. w/c =0.55) for all samples for consistency in the comparisons. The workability of all fresh mixes was then assessed using the slump test. The specimens were then placed in moulds and compacted. It should be noted that some difficulties were experienced during hand compaction of the samples (using a standard rammer) due to the tyre aggregates generating some spring action. Moreover, when using mechanical compaction (vibrating table), the finishing on the higher percentage samples (30% and 40%) containing coarse rubber aggregate was very poor with the top surface of the sample becoming irregular as the lighter material (rubber) was surfacing during compaction. The compacted specimens were demoulded 24 hours after casting and placed in a steel tub of water, to cure at a minimum temperature of 20^{o}C for 7 and 28 days respectively. A number of tests on the hardened mixes were then performed, including cube compressive strength (100mm and 70mm cubes), split-cylinder tensile strength, static modulus of elasticity of beams in compression and flexural strength test. The stress-strain behaviour of the cube samples was also continuously monitored during the compression tests, using a load cell and a displacement transducer connected to the ram. To assess repeatability, three specimens were tested for each mix. These gave repeatable results. The following sections show average values for each rubber percentage and test results.

Experimental Results

1. Workability of fresh concrete (Slump test)

Figure 2 shows average results for each rubber percentage from the slump test. These showed that most mixes for the rubber sizes and percentages used in this study, with the exception of the 40% mixes for either fine or coarse aggregates and the 30% mix for fine aggregates, had slump values corresponding to high to normal workability levels.

In fact, for small percentages of rubber (10%) the workability based on slump results comparable with those of the control mixes (0%). This is consistent with results reported by Raghavan et al., (1998) for mortars containing rubber particles. With further increase in rubber content, for both the fine and coarse rubber specimens, the mix became stiffer and less workable, which was reflected in the significant decrease in slump values.

The 40% coarse rubber tire mix in particular had too low slump values and was manually unworkable. The addition of fine aggregate rubber from 10% up to 40% rubber content maintained a linear decrease in slump values.

This was not the case for the coarse aggregate rubber content which experienced a decrease of about 50% from a 10% rubber content to a 20% rubber content, a

very small decrease in slump between 20% and 30% of rubber aggregate and then again a large decrease of about 33% between 30% and 40% of rubber aggregate. No particular trend was obvious as to whether the CRA or FRA mixes were more workable.

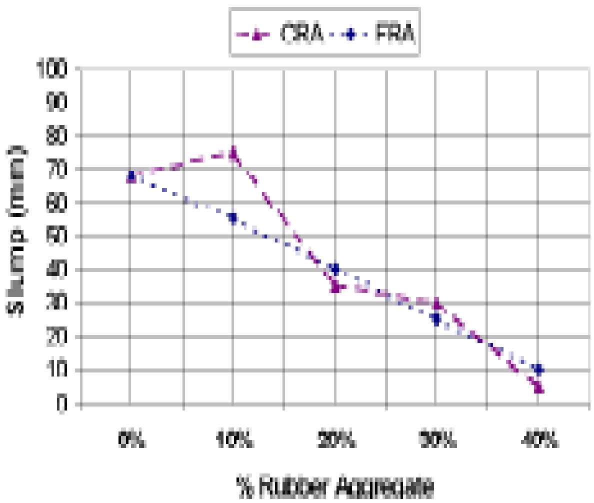

Figure 2. Average slump test results for each rubber percentage Density

Figures 3(a) and 3(b) show respectively the average densities for the 7 and 28 day-cured specimens prepared for cube compressive strength testing.

From the figures it can be seen that density reduces by the addition of rubber aggregates whether these are fine or coarse. In most cases, for the same rubber content the fine rubber aggregate mixes had lower densities than those containing coarse rubber aggregate.

The general density reduction was to be expected due to the low specific gravity of the rubber aggregates with respect to that of the mineral aggregates.

The reduction in density can be a desirable feature in a number of applications, including architectural applications such as nailing concrete, false facades, stone backing and interior construction (Siddique and Naik, 2004) as well as precast concrete blocks and slabs.

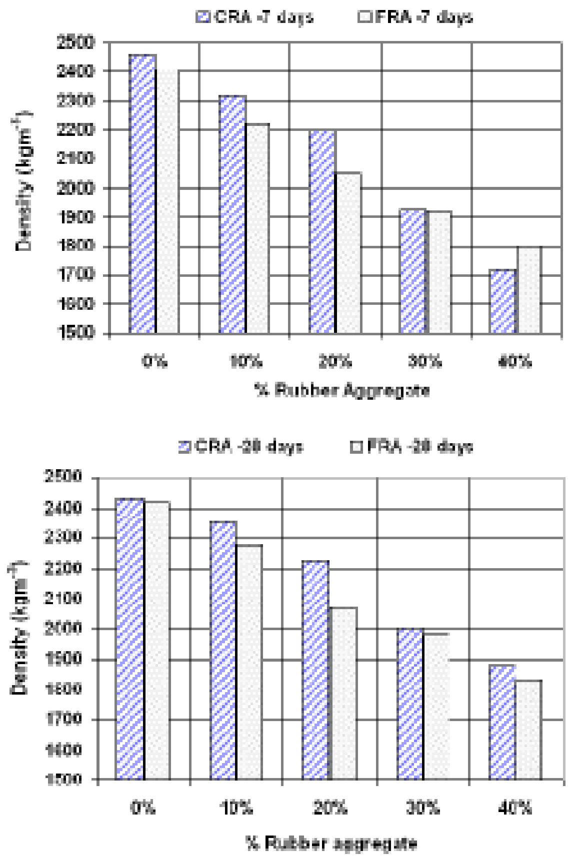

***Figure 3.* Density variation with rubber content (a) 7-day curing; (b) 28-day curing**

2. Cube compressive strength tests

These were performed in a Losenhausen (3MN) compression machine according to BS EN 12390-3:2002 (BSI, 2002). Figure 4(a) represents the relationship between average cube compressive strengths and the percentage of rubber aggregate for 7 and 28 days of curing respectively. It can be seen that there is a very considerable loss in strength with respect to the average results of the control mixes. The loss was greater with increasing tyre aggregate percentage, amounting to 94% of the control mix strength for the 40% rubber content. The strength losses with respect to the average control mix strengths are represented in Table 1.

Table 1
Average compressive strength loss for mixes containing rubber aggregate

Curing Time Days	Compressive Strength Loss							
	CRA				FRA			
	10%	20%	30%	40%	10%	20%	30%	40%
7	53%	76.6%	87.5%	94.3%	32%	60%	82.1%	89%
28	60.8%	77.9%	89.6%	92.6%	40.9%	68.3%	81.8%	88.3%

In this study it was found that for the same percentage of tyre rubber aggregate, coarse rubber aggregate had a higher compressive strength, than concrete containing finer rubber aggregate, which is consistent with Fattuhi and Clark (1996) but contradicts Eldin and Senouci (1993) and Topçu (1995). The relationship between the reduction in compressive strength and the rubber aggregate percentage was found to be nonlinear. It is noticeable that as opposed to the average values of the control mixes, the mixes with rubber aggregate showed very little increase in the compressive strengths between the 7th and the 28th day of curing (with the only exception of the 10% coarse rubber aggregate mix), which is consistent with results from other researchers (Eldin and Senouci, 1993). This is particularly true for the fine rubber aggregate mixes. The plot of compressive strength versus density (Figure 4(b)) indicates an exponential drop of strength with density in the concrete with rubber mixes. The large losses in compressive strength imply that rubber percentages above 10%-20% would not be suitable for most structural applications, where high compressive strengths are required. However this type of concrete could be used in low-strength-concrete applications e.g. sidewalks, driveways and selected road construction applications (Eldin and Senouci,1993).

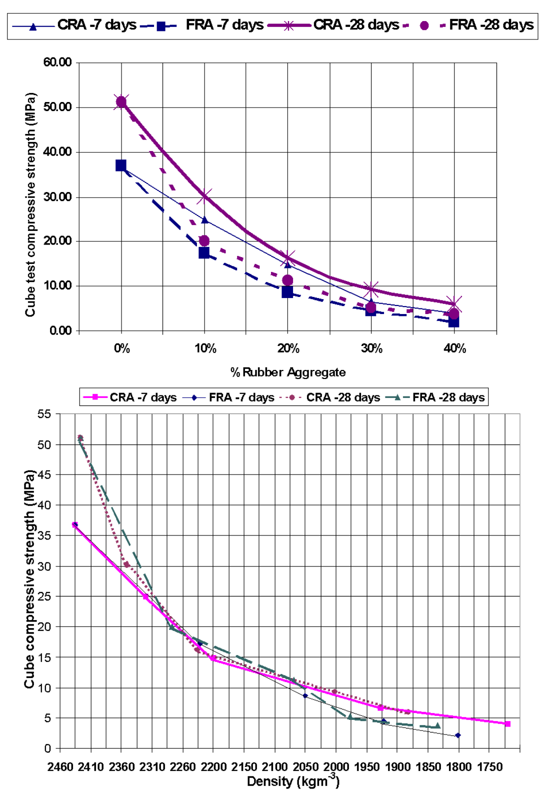

Figure 4. Compressive strength variation: (a) with rubber content; (b) with density

Direct comparisons of % losses with other researchers' results are not possible as cubes (and/or cylinders) of various sizes were used in other investigations. It is known that different shape and size of specimens influence the compressive strength of concrete. Moreover, rubber aggregate of different type, origin, shapes, sizes and grading was used across investigations. However the reduction in compressive strength due to rubber aggregate is consistent across the literature. A number of possible explanations have been suggested in the literature for this loss of strength. This has usually been attributed to the fact that the rubber particles act as voids in the cement matrix due to the lack of adhesion between the rubber and the cement matrix. It was also suggested that the lower specific gravity of the rubber particles compared to the cement paste causes cracks around the rubber particles to appear quickly upon loading which accelerates the failure of the specimens (Khatib and Bayomy, 1999). Conversely, Chou et al., (2007) attributed the loss of strength to the heterogeneous, hydrophobic rubber particles, leading to local imperfections in the hydration of cement and hence locally weaker concrete. This suggestion was supported by microscopic studies showing that the rubber particles distributed the water transfer to create channels prone to cracking, thus causing a loss in compressive strength. Due to the low compressive strengths of the mixes containing rubber aggregates which would not be acceptable in most cases, the following sections will present results for the rest of the tests for the mixes containing 10% of rubber aggregate only, as these showed the best compressive strength values of all mixes containing rubber aggregate.

References

1. Papakonstantinou, C. G., Tobolski, M. J. Use of Waste Tire Steel Beads in Portland Cement Concrete Cement and Concrete Research 36 (9) 2006: pp. 1686 – 1691.
2. Silvestraviciute, I., Sleinotaite Budriene, L. Possibility to Use Scrap Tires as an Alternative Fuel in Cement Industry Environmental Research, Engineering and Management 3(21) 2002: pp. 38 – 48 (in Lithuanian).
3. Segre, N., Joekes, I. Use of Tire Rubber Particles as Addition to Cement Paste Cement and Concrete Research 30 (9) 2000: pp. 1421 – 1425.
4. Shuaib, Ahmad; Fedroff, David; Sayas, Banu Zeynep Freeze-Thaw Durability of Concrete with Ground Waste Tire Rubber Transportation Research Record 1574–1997.
5. Kersevicius, V. Rubber Waste – Raw Materials for Building: Technical and Economical Aspects of Utilization Environmental Research, Engineering

and Management 3 (21) 2002: pp. 72 – 77 (in Lithuanian).
6. Hernandez-Olivares, F., Barluenga, G., Bollati, M., Witoszek, B. Static and Dynamic Behaviour of Recycled Tyre Rubber-filled Concrete Cement and Concrete Research 32 (10) 2002: pp. 1587 – 1596.
7. Skripkiunas, G., Grinys, A. Using Tires Rubber Waste for Modification of Concrete Properties Building and Architecture. Proceedings of Conference Kaunas: "Technology" 2005: pp. 132 – 137 ISBN 9955-09-851-1 (in Lithuanian).
8. Skripkiunas, G., Grinys, A. Using Tires Rubber Waste for Modification of Concrete Properties Science Days – 2005 Dnepropetrovsk, 2005: pp. 5 – 40 ISBN 966-7191-86-9 (in Russian).
9. Eldin, N. N., Senouci, A. B. Rubber Tire Particles as Concrete Aggregate Journal of Material Civil Engineering ASCE 5 (4) 1993: pp. 478 – 496.
10. Khatip, Z. K., Bayomy, F. M. Rubberized Portland Cement Concrete Journal of Material Civil Engineering ASCE 11 (3) 1999: pp. 206 – 213.
11. Topu, I. B., Avcular, N. Collision Behaviors of Rubberized Concrete Cement and Concrete Research 27 (12) 1997: pp. 1893 – 1898.
12. Lee, B. I., Burnett, L., Miller, T., Postage, B., Cuneo, J. Tyre Rubber Cement Matrix Composites Journal of Material Science Letter 12 (13) 1993: pp. 967 – 968.
13. Eldin, N. N., Senouci, A. B. Measurement and Prediction of the Strength of Rubberized Concrete Cement & Concrete Composites 18 1996: pp. 135 – 139.
14. Sheikin, E., Schekovskyj, J. V., Bruser, M. I. Properties and Composition Cement Based Concrete. Moscow: Stroiizdat, 1979: 344 p. (in Russian).
15. Li, G., Stubblefield, M. A., Garrick, G., Eggers, J., Abadie, Ch., Huang, B. Development of Waste Tire Modified Concrete Cement and Concrete Research 34 (12) 2004: pp. 2283 – 2289.
16. Skripkiunas, G., Grinys, A., Dauksys, M. Using Tires Rubber Waste for Modification of Concrete Properties Sustainable Construction Materials and Technologies International Conference Coventry 11 – 13 of June 2007. Taylor & Francis Group, London, ISBN 987-0-415-44689-1.
17. Guneyisi, E., Gesoglu, M., Ozturan, T. Properties of Rubberized Concretes Containing Silica Fume Cement and Concrete Research 34 (12) 2004: pp. 2309 – 2317.
18. Bignozzi, M. C., Sandrolini, F. Tyre Rubber Waste Recycling in Self-compacting Concrete Cement and Concrete Research 36 (4) 2006: pp. 735 – 739.
19. Anison, M. An Investigation into a Hypothetical Deformation and Failure Mechanism for Concrete Magazine of Concrete Research 6 (47) 1964: pp. 73 – 82.

COSMOS: Journal of Engineering & Technology
A Refereed Research Journal
Vol 4 / No 1 / Jan - Jun 2014 ISSN: 2231-4210

A POSSIBLE OUTLET FOR USED WASTE TYRE RUBBER BASED CONCRETE

Devarasetty Venkateswara Rao[1]
T. Chandrasekhar Rao[2]

Abstract

Discarded vehicle tyres constitute one important part of solid waste which had historically been disposed of into landfills. Recent EU policies on the Landfilling of Waste (Council Directive 1999/31/EC) have however put a ban on the landfilling of whole or shredded tyres, creating an imminent need to investigate any possible viable uses of this waste product. An emerging use is the production of concrete, in which tyre rubber particles partially replace natural aggregates. This has the additional advantage of saving in natural aggregates used in the production of concrete which are becoming increasingly scarce. This research investigated a wide range of physical and mechanical properties of concrete containing recycled tyre aggregates, to assess its suitability as a construction material. The influence of factors such as rubber aggregate content and size, as well as curing time was also considered. The results showed that despite a great loss in strength, this type of concrete was acceptable for various applications requiring medium to low compressive strength. The quantities of concrete produced worldwide for such applications could ensure the viability of this product. Therefore, this type of concrete shows promise for becoming an additional sustainable solution for tyre rubber waste management.

Keywords: *Solid Waste Management, Used Vehicle Tyres, Rubberised Concrete Properties.*

Introduction

The management of worn tires poses a major problem for all third world countries. Also, with the increasing number of vehicles, the industrial development which several countries are currently knowing, and the small percent- age of recycled worn tires (retreaded or used for other purposes) due to the absence of an adequate plan for eliminating this waste, these countries know surely a major environmental problem. The absence of statistics on this subject does not enable us today estimate suitably the mass of worn tires thrown in nature or burned in public dumpsters. But if we compare these countries with the European Union countries which took this problem in charge, through legislation, recycling companies, re- search, we can say that many countries are postponing the solution to this problem, and that the mass of worn tires can only be considerable. One of the recommended solutions to solve this environmental problem is to incorporate rubber aggregates resulting from cutting worn tires in the cement concretes. On this subject, several studies concerning the use of rubber aggregates resulting from crushing worn tires were carried out. These research works showed that the benefits of associating rubber-cement in the development of cementing composites with high deformability and on the durability of these composites. Moreover, the benefit which we can gain from using the cement concretes for the roadways makes us think about multiplying the studies on. The cement composites that incorporate rubber aggregates since the rigidity of the cement concretes can make it possible either to de- crease the granular layer necessary to the asphalt road- way or to allow the use of less resistant concretes. This is the case with the use of concretes having a considerable part of rubber aggregates resulting from worn tires.

With a great ecological concern and in saving traditional aggregates, we have replaced a part of the conventional aggregates by rubber aggregates resulted from cut- ting worn tires. The study that we propose was realized in two stages, with two different teams, and in two distinct periods of time in order to test the repeatability of certain results and the significance of some factors.

Experimental Procedure, Material and Mixes

For this experiment scrap tyre aggregates ranging from 20-1 mm were obtained from McGrath Bros. These are meant to be used in particular for equestrian circuits. According to information obtained from the supplier, these contain mostly textile fibre rather than steel fibre however the latter could amount to 5% of the total rubber tyre aggregate. The material was sieved and split into two groups of tyre aggregate: coarse rubber aggregate (19-10mm) and fine rubber aggregate material (10-4.75 mm). These groups will be referred to

[1]*Asst. Professor & Research Scholar, Acharya Nagarajuna University, Nagarrjuna Nagar, Guntur*
[2]*DMS SVH College of Engineering, Machilipatnam*

as CRA (Coarse Rubber Aggregates) and FRA (Fine Rubber Aggregates). The shape of the rubber aggregate was observed to be sub-angular. Figure 1 shows the particle size distribution curves for the two groups of rubber aggregates (coarse and fine aggregate groups) together with those of the mineral aggregates which were used in the test and were partly replaced by the rubber aggregates. The mineral aggregates are referred to as CMA (Coarse Mineral Aggregates) and FMA (Fine Mineral Aggregates). It is noticeable that the particle size distribution of the rubber aggregates is very close to that of the respective mineral aggregates (coarse or fine) conforming to BS 882 (BSI, 1992) and satisfying the aggregate grading requirements.

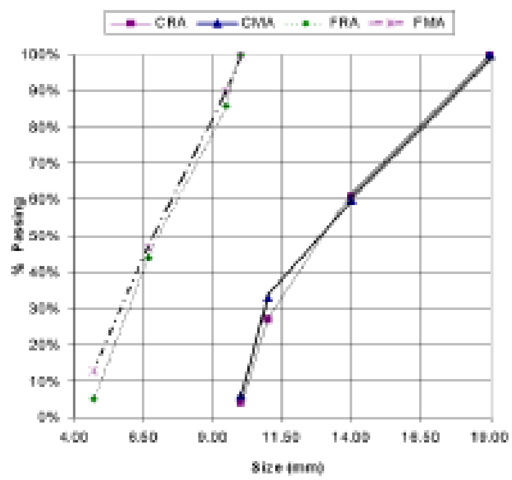

Figure 1. Particle size distribution of rubber and mineral aggregates used in the mixes

Ordinary Portland cement mix was used as the control mix (referred to as CM) for the purposes of comparison. This consisted of 1 part cement; 1.5 parts sand and 3 parts coarse aggregate (1:1.5:3). The mix design was according to BS 5328: Part 1 guidelines for RC40 (BSI, 1997). Two sets of mixes including rubber aggregate were then prepared for each test. In the first set of mixes, the coarse rubber aggregate (CRA) replaced part of the coarse mineral aggregate (CMA) of the control mix.

In the second, fine rubber aggregate (FRA) replaced partly fine mineral (stone) aggregate (FMA) of the control mix. Four different contents of rubber aggregate (by mass) were used to replace the mineral aggregate (10%, 20%, 30% and 40% respectively). The dry material comprising cement, sand, aggregate and rubber was well mixed before the water was gradually included. The water/cement ratio was kept constant (i.e. w/c =0.55) for all samples for consistency in the comparisons. The workability of all fresh mixes was then assessed using the slump test. The specimens were then placed in moulds and compacted. It should be noted that some difficulties were experienced during hand compaction of the samples (using a standard rammer) due to the tyre aggregates generating some spring action. Moreover, when using mechanical compaction (vibrating table), the finishing on the higher percentage samples (30% and 40%) containing coarse rubber aggregate was very poor with the top surface of the sample becoming irregular as the lighter material (rubber) was surfacing during compaction. The compacted specimens were demoulded 24 hours after casting and placed in a steel tub of water, to cure at a minimum temperature of 20^oC for 7 and 28 days respectively. A number of tests on the hardened mixes were then performed, including cube compressive strength (100mm and 70mm cubes), split-cylinder tensile strength, static modulus of elasticity of beams in compression and flexural strength test. The stress-strain behaviour of the cube samples was also continuously monitored during the compression tests, using a load cell and a displacement transducer connected to the ram. To assess repeatability, three specimens were tested for each mix. These gave repeatable results. The following sections show average values for each rubber percentage and test results.

Experimental Results

1. Workability of fresh concrete (Slump test)

Figure 2 shows average results for each rubber percentage from the slump test. These showed that most mixes for the rubber sizes and percentages used in this study, with the exception of the 40% mixes for either fine or coarse aggregates and the 30% mix for fine aggregates, had slump values corresponding to high to normal workability levels.

In fact, for small percentages of rubber (10%) the workability based on slump results comparable with those of the control mixes (0%). This is consistent with results reported by Raghavan et al., (1998) for mortars containing rubber particles. With further increase in rubber content, for both the fine and coarse rubber specimens, the mix became stiffer and less workable, which was reflected in the significant decrease in slump values.

The 40% coarse rubber tire mix in particular had too low slump values and was manually unworkable. The addition of fine aggregate rubber from 10% up to 40% rubber content maintained a linear decrease in slump values.

This was not the case for the coarse aggregate rubber content which experienced a decrease of about 50% from a 10% rubber content to a 20% rubber content, a

very small decrease in slump between 20% and 30% of rubber aggregate and then again a large decrease of about 33% between 30% and 40% of rubber aggregate. No particular trend was obvious as to whether the CRA or FRA mixes were more workable.

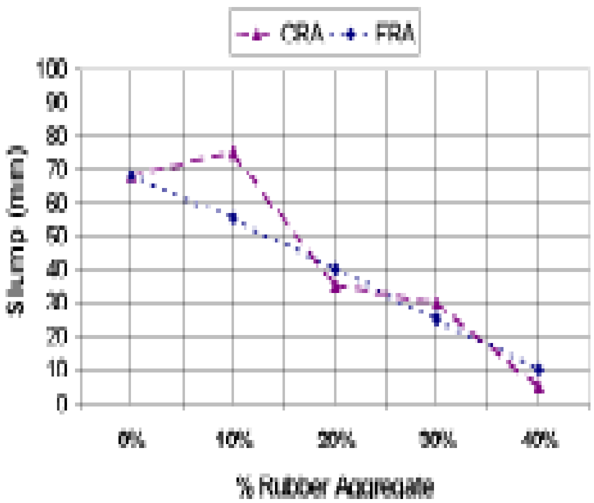

Figure 2. Average slump test results for each rubber percentage Density

Figures 3(a) and 3(b) show respectively the average densities for the 7 and 28 day-cured specimens prepared for cube compressive strength testing.

From the figures it can be seen that density reduces by the addition of rubber aggregates whether these are fine or coarse. In most cases, for the same rubber content the fine rubber aggregate mixes had lower densities than those containing coarse rubber aggregate.

The general density reduction was to be expected due to the low specific gravity of the rubber aggregates with respect to that of the mineral aggregates.

The reduction in density can be a desirable feature in a number of applications, including architectural applications such as nailing concrete, false facades, stone backing and interior construction (Siddique and Naik, 2004) as well as precast concrete blocks and slabs.

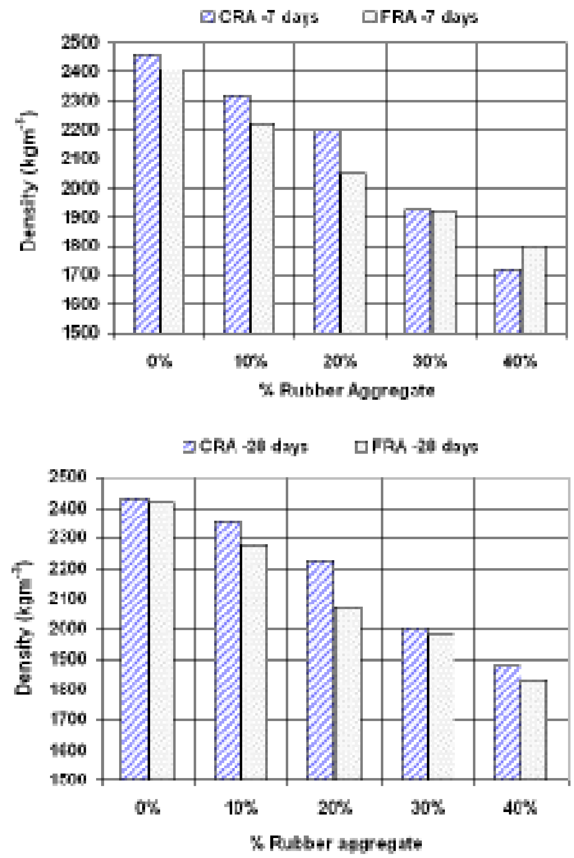

***Figure 3.* Density variation with rubber content (a) 7-day curing; (b) 28-day curing**

2. Cube compressive strength tests

These were performed in a Losenhausen (3MN) compression machine according to BS EN 12390-3:2002 (BSI, 2002). Figure 4(a) represents the relationship between average cube compressive strengths and the percentage of rubber aggregate for 7 and 28 days of curing respectively. It can be seen that there is a very considerable loss in strength with respect to the average results of the control mixes. The loss was greater with increasing tyre aggregate percentage, amounting to 94% of the control mix strength for the 40% rubber content. The strength losses with respect to the average control mix strengths are represented in Table 1.

Table 1
Average compressive strength loss for mixes containing rubber aggregate

Curing Time Days	Compressive Strength Loss							
	CRA				FRA			
	10%	20%	30%	40%	10%	20%	30%	40%
7	53%	76.6%	87.5%	94.3%	32%	60%	82.1%	89%
28	60.8%	77.9%	89.6%	92.6%	40.9%	68.3%	81.8%	88.3%

In this study it was found that for the same percentage of tyre rubber aggregate, coarse rubber aggregate had a higher compressive strength, than concrete containing finer rubber aggregate, which is consistent with Fattuhi and Clark (1996) but contradicts Eldin and Senouci (1993) and Topçu (1995). The relationship between the reduction in compressive strength and the rubber aggregate percentage was found to be nonlinear. It is noticeable that as opposed to the average values of the control mixes, the mixes with rubber aggregate showed very little increase in the compressive strengths between the 7th and the 28th day of curing (with the only exception of the 10% coarse rubber aggregate mix), which is consistent with results from other researchers (Eldin and Senouci, 1993). This is particularly true for the fine rubber aggregate mixes. The plot of compressive strength versus density (Figure 4(b)) indicates an exponential drop of strength with density in the concrete with rubber mixes. The large losses in compressive strength imply that rubber percentages above 10%-20% would not be suitable for most structural applications, where high compressive strengths are required. However this type of concrete could be used in low-strength-concrete applications e.g. sidewalks, driveways and selected road construction applications (Eldin and Senouci,1993).

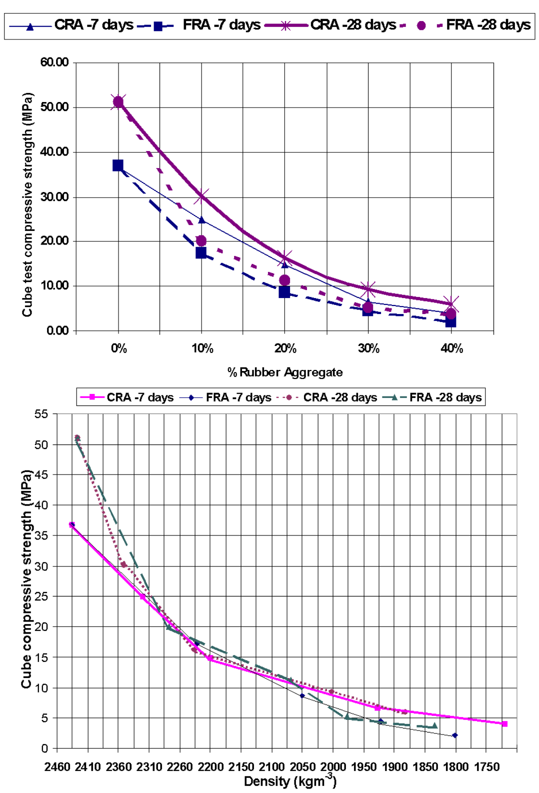

Figure 4. Compressive strength variation: (a) with rubber content; (b) with density

Direct comparisons of % losses with other researchers' results are not possible as cubes (and/or cylinders) of various sizes were used in other investigations. It is known that different shape and size of specimens influence the compressive strength of concrete. Moreover, rubber aggregate of different type, origin, shapes, sizes and grading was used across investigations. However the reduction in compressive strength due to rubber aggregate is consistent across the literature. A number of possible explanations have been suggested in the literature for this loss of strength. This has usually been attributed to the fact that the rubber particles act as voids in the cement matrix due to the lack of adhesion between the rubber and the cement matrix. It was also suggested that the lower specific gravity of the rubber particles compared to the cement paste causes cracks around the rubber particles to appear quickly upon loading which accelerates the failure of the specimens (Khatib and Bayomy, 1999). Conversely, Chou et al., (2007) attributed the loss of strength to the heterogeneous, hydrophobic rubber particles, leading to local imperfections in the hydration of cement and hence locally weaker concrete. This suggestion was supported by microscopic studies showing that the rubber particles distributed the water transfer to create channels prone to cracking, thus causing a loss in compressive strength. Due to the low compressive strengths of the mixes containing rubber aggregates which would not be acceptable in most cases, the following sections will present results for the rest of the tests for the mixes containing 10% of rubber aggregate only, as these showed the best compressive strength values of all mixes containing rubber aggregate.

References

1. Papakonstantinou, C. G., Tobolski, M. J. Use of Waste Tire Steel Beads in Portland Cement Concrete Cement and Concrete Research 36 (9) 2006: pp. 1686 – 1691.
2. Silvestraviciute, I., Sleinotaite Budriene, L. Possibility to Use Scrap Tires as an Alternative Fuel in Cement Industry Environmental Research, Engineering and Management 3(21) 2002: pp. 38 – 48 (in Lithuanian).
3. Segre, N., Joekes, I. Use of Tire Rubber Particles as Addition to Cement Paste Cement and Concrete Research 30 (9) 2000: pp. 1421 – 1425.
4. Shuaib, Ahmad; Fedroff, David; Sayas, Banu Zeynep Freeze-Thaw Durability of Concrete with Ground Waste Tire Rubber Transportation Research Record 1574–1997.
5. Kersevicius, V. Rubber Waste – Raw Materials for Building: Technical and Economical Aspects of Utilization Environmental Research, Engineering

and Management 3 (21) 2002: pp. 72 – 77 (in Lithuanian).
6. Hernandez-Olivares, F., Barluenga, G., Bollati, M., Witoszek, B. Static and Dynamic Behaviour of Recycled Tyre Rubber-filled Concrete Cement and Concrete Research 32 (10) 2002: pp. 1587 – 1596.
7. Skripkiunas, G., Grinys, A. Using Tires Rubber Waste for Modification of Concrete Properties Building and Architecture. Proceedings of Conference Kaunas: "Technology" 2005: pp. 132 – 137 ISBN 9955-09-851-1 (in Lithuanian).
8. Skripkiunas, G., Grinys, A. Using Tires Rubber Waste for Modification of Concrete Properties Science Days – 2005 Dnepropetrovsk, 2005: pp. 5 – 40 ISBN 966-7191-86-9 (in Russian).
9. Eldin, N. N., Senouci, A. B. Rubber Tire Particles as Concrete Aggregate Journal of Material Civil Engineering ASCE 5 (4) 1993: pp. 478 – 496.
10. Khatip, Z. K., Bayomy, F. M. Rubberized Portland Cement Concrete Journal of Material Civil Engineering ASCE 11 (3) 1999: pp. 206 – 213.
11. Topu, I. B., Avcular, N. Collision Behaviors of Rubberized Concrete Cement and Concrete Research 27 (12) 1997: pp. 1893 – 1898.
12. Lee, B. I., Burnett, L., Miller, T., Postage, B., Cuneo, J. Tyre Rubber Cement Matrix Composites Journal of Material Science Letter 12 (13) 1993: pp. 967 – 968.
13. Eldin, N. N., Senouci, A. B. Measurement and Prediction of the Strength of Rubberized Concrete Cement & Concrete Composites 18 1996: pp. 135 – 139.
14. Sheikin, E., Schekovskyj, J. V., Bruser, M. I. Properties and Composition Cement Based Concrete. Moscow: Stroiizdat, 1979: 344 p. (in Russian).
15. Li, G., Stubblefield, M. A., Garrick, G., Eggers, J., Abadie, Ch., Huang, B. Development of Waste Tire Modified Concrete Cement and Concrete Research 34 (12) 2004: pp. 2283 – 2289.
16. Skripkiunas, G., Grinys, A., Dauksys, M. Using Tires Rubber Waste for Modification of Concrete Properties Sustainable Construction Materials and Technologies International Conference Coventry 11 – 13 of June 2007. Taylor & Francis Group, London, ISBN 987-0-415-44689-1.
17. Guneyisi, E., Gesoglu, M., Ozturan, T. Properties of Rubberized Concretes Containing Silica Fume Cement and Concrete Research 34 (12) 2004: pp. 2309 – 2317.
18. Bignozzi, M. C., Sandrolini, F. Tyre Rubber Waste Recycling in Self-compacting Concrete Cement and Concrete Research 36 (4) 2006: pp. 735 – 739.
19. Anison, M. An Investigation into a Hypothetical Deformation and Failure Mechanism for Concrete Magazine of Concrete Research 6 (47) 1964: pp. 73 – 82.

COSMOS: Journal of Engineering & Technology
A Refereed Research Journal
Vol 4 / No 1 / Jan - Jun 2014 ISSN: 2231-4210

A POSSIBLE OUTLET FOR USED WASTE TYRE RUBBER BASED CONCRETE

Devarasetty Venkateswara Rao[1]
T. Chandrasekhar Rao[2]

Abstract

Discarded vehicle tyres constitute one important part of solid waste which had historically been disposed of into landfills. Recent EU policies on the Landfilling of Waste (Council Directive 1999/31/EC) have however put a ban on the landfilling of whole or shredded tyres, creating an imminent need to investigate any possible viable uses of this waste product. An emerging use is the production of concrete, in which tyre rubber particles partially replace natural aggregates. This has the additional advantage of saving in natural aggregates used in the production of concrete which are becoming increasingly scarce. This research investigated a wide range of physical and mechanical properties of concrete containing recycled tyre aggregates, to assess its suitability as a construction material. The influence of factors such as rubber aggregate content and size, as well as curing time was also considered. The results showed that despite a great loss in strength, this type of concrete was acceptable for various applications requiring medium to low compressive strength. The quantities of concrete produced worldwide for such applications could ensure the viability of this product. Therefore, this type of concrete shows promise for becoming an additional sustainable solution for tyre rubber waste management.

Keywords: *Solid Waste Management, Used Vehicle Tyres, Rubberised Concrete Properties.*

Introduction

The management of worn tires poses a major problem for all third world countries. Also, with the increasing number of vehicles, the industrial development which several countries are currently knowing, and the small percent- age of recycled worn tires (retreaded or used for other purposes) due to the absence of an adequate plan for eliminating this waste, these countries know surely a major environmental problem. The absence of statistics on this subject does not enable us today estimate suitably the mass of worn tires thrown in nature or burned in public dumpsters. But if we compare these countries with the European Union countries which took this problem in charge, through legislation, recycling companies, re- search, we can say that many countries are postponing the solution to this problem, and that the mass of worn tires can only be considerable. One of the recommended solutions to solve this environmental problem is to incorporate rubber aggregates resulting from cutting worn tires in the cement concretes. On this subject, several studies concerning the use of rubber aggregates resulting from crushing worn tires were carried out. These research works showed that the benefits of associating rubber-cement in the development of cementing composites with high deformability and on the durability of these composites. Moreover, the benefit which we can gain from using the cement concretes for the roadways makes us think about multiplying the studies on. The cement composites that incorporate rubber aggregates since the rigidity of the cement concretes can make it possible either to de- crease the granular layer necessary to the asphalt road- way or to allow the use of less resistant concretes. This is the case with the use of concretes having a considerable part of rubber aggregates resulting from worn tires.

With a great ecological concern and in saving traditional aggregates, we have replaced a part of the conventional aggregates by rubber aggregates resulted from cut- ting worn tires. The study that we propose was realized in two stages, with two different teams, and in two distinct periods of time in order to test the repeatability of certain results and the significance of some factors.

Experimental Procedure, Material and Mixes

For this experiment scrap tyre aggregates ranging from 20-1 mm were obtained from McGrath Bros. These are meant to be used in particular for equestrian circuits. According to information obtained from the supplier, these contain mostly textile fibre rather than steel fibre however the latter could amount to 5% of the total rubber tyre aggregate. The material was sieved and split into two groups of tyre aggregate: coarse rubber aggregate (19-10mm) and fine rubber aggregate material (10-4.75 mm). These groups will be referred to

[1]*Asst. Professor & Research Scholar, Acharya Nagarajuna University, Nagarrjuna Nagar, Guntur*
[2]*DMS SVH College of Engineering, Machilipatnam*

as CRA (Coarse Rubber Aggregates) and FRA (Fine Rubber Aggregates). The shape of the rubber aggregate was observed to be sub-angular. Figure 1 shows the particle size distribution curves for the two groups of rubber aggregates (coarse and fine aggregate groups) together with those of the mineral aggregates which were used in the test and were partly replaced by the rubber aggregates. The mineral aggregates are referred to as CMA (Coarse Mineral Aggregates) and FMA (Fine Mineral Aggregates). It is noticeable that the particle size distribution of the rubber aggregates is very close to that of the respective mineral aggregates (coarse or fine) conforming to BS 882 (BSI, 1992) and satisfying the aggregate grading requirements.

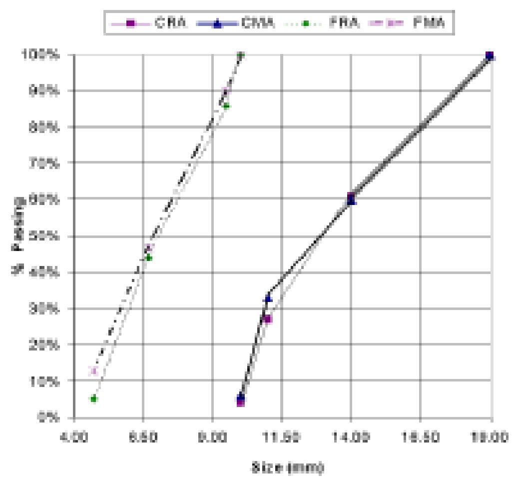

Figure 1. Particle size distribution of rubber and mineral aggregates used in the mixes

Ordinary Portland cement mix was used as the control mix (referred to as CM) for the purposes of comparison. This consisted of 1 part cement; 1.5 parts sand and 3 parts coarse aggregate (1:1.5:3). The mix design was according to BS 5328: Part 1 guidelines for RC40 (BSI, 1997). Two sets of mixes including rubber aggregate were then prepared for each test. In the first set of mixes, the coarse rubber aggregate (CRA) replaced part of the coarse mineral aggregate (CMA) of the control mix.

In the second, fine rubber aggregate (FRA) replaced partly fine mineral (stone) aggregate (FMA) of the control mix. Four different contents of rubber aggregate (by mass) were used to replace the mineral aggregate (10%, 20%, 30% and 40% respectively). The dry material comprising cement, sand, aggregate and rubber was well mixed before the water was gradually included. The water/cement ratio was kept constant (i.e. w/c =0.55) for all samples for consistency in the comparisons. The workability of all fresh mixes was then assessed using the slump test. The specimens were then placed in moulds and compacted. It should be noted that some difficulties were experienced during hand compaction of the samples (using a standard rammer) due to the tyre aggregates generating some spring action. Moreover, when using mechanical compaction (vibrating table), the finishing on the higher percentage samples (30% and 40%) containing coarse rubber aggregate was very poor with the top surface of the sample becoming irregular as the lighter material (rubber) was surfacing during compaction. The compacted specimens were demoulded 24 hours after casting and placed in a steel tub of water, to cure at a minimum temperature of 20^{o}C for 7 and 28 days respectively. A number of tests on the hardened mixes were then performed, including cube compressive strength (100mm and 70mm cubes), split-cylinder tensile strength, static modulus of elasticity of beams in compression and flexural strength test. The stress-strain behaviour of the cube samples was also continuously monitored during the compression tests, using a load cell and a displacement transducer connected to the ram. To assess repeatability, three specimens were tested for each mix. These gave repeatable results. The following sections show average values for each rubber percentage and test results.

Experimental Results

1. Workability of fresh concrete (Slump test)

Figure 2 shows average results for each rubber percentage from the slump test. These showed that most mixes for the rubber sizes and percentages used in this study, with the exception of the 40% mixes for either fine or coarse aggregates and the 30% mix for fine aggregates, had slump values corresponding to high to normal workability levels.

In fact, for small percentages of rubber (10%) the workability based on slump results comparable with those of the control mixes (0%). This is consistent with results reported by Raghavan et al., (1998) for mortars containing rubber particles. With further increase in rubber content, for both the fine and coarse rubber specimens, the mix became stiffer and less workable, which was reflected in the significant decrease in slump values.

The 40% coarse rubber tire mix in particular had too low slump values and was manually unworkable. The addition of fine aggregate rubber from 10% up to 40% rubber content maintained a linear decrease in slump values.

This was not the case for the coarse aggregate rubber content which experienced a decrease of about 50% from a 10% rubber content to a 20% rubber content, a

very small decrease in slump between 20% and 30% of rubber aggregate and then again a large decrease of about 33% between 30% and 40% of rubber aggregate. No particular trend was obvious as to whether the CRA or FRA mixes were more workable.

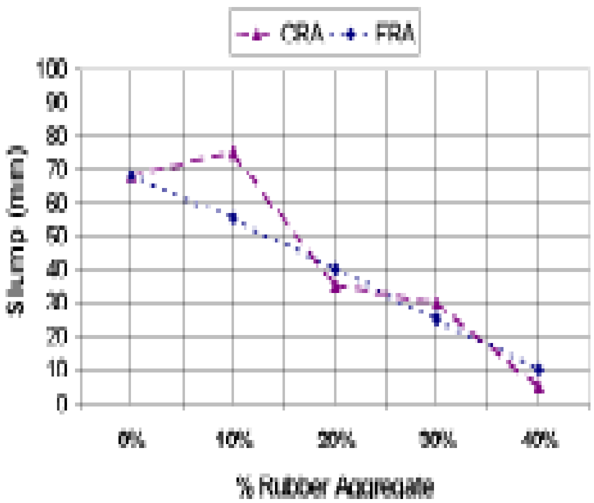

Figure 2. Average slump test results for each rubber percentage Density

Figures 3(a) and 3(b) show respectively the average densities for the 7 and 28 day-cured specimens prepared for cube compressive strength testing.

From the figures it can be seen that density reduces by the addition of rubber aggregates whether these are fine or coarse. In most cases, for the same rubber content the fine rubber aggregate mixes had lower densities than those containing coarse rubber aggregate.

The general density reduction was to be expected due to the low specific gravity of the rubber aggregates with respect to that of the mineral aggregates.

The reduction in density can be a desirable feature in a number of applications, including architectural applications such as nailing concrete, false facades, stone backing and interior construction (Siddique and Naik, 2004) as well as precast concrete blocks and slabs.

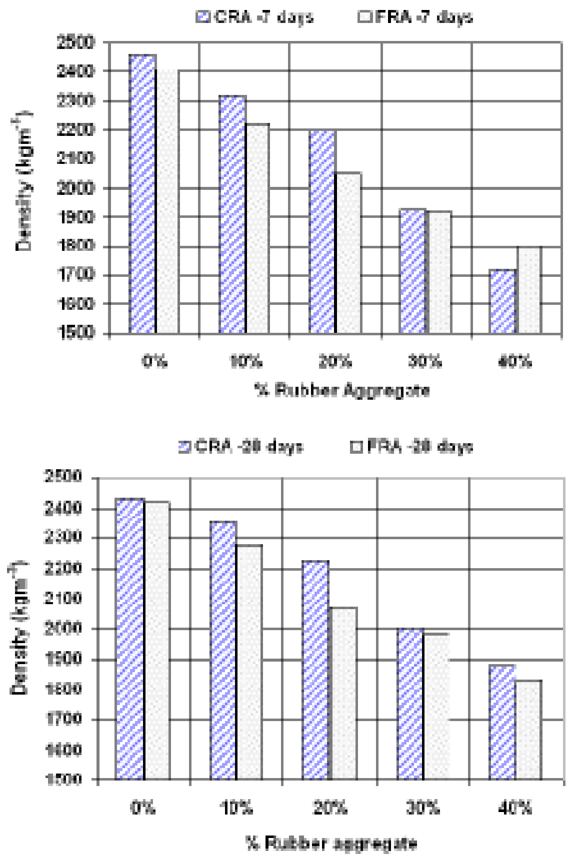

Figure 3. **Density variation with rubber content (a) 7-day curing; (b) 28-day curing**

2. Cube compressive strength tests

These were performed in a Losenhausen (3MN) compression machine according to BS EN 12390-3:2002 (BSI, 2002). Figure 4(a) represents the relationship between average cube compressive strengths and the percentage of rubber aggregate for 7 and 28 days of curing respectively. It can be seen that there is a very considerable loss in strength with respect to the average results of the control mixes. The loss was greater with increasing tyre aggregate percentage, amounting to 94% of the control mix strength for the 40% rubber content. The strength losses with respect to the average control mix strengths are represented in Table 1.

Table 1

Average compressive strength loss for mixes containing rubber aggregate

Curing Time Days	**Compressive Strength Loss**							
	CRA				**FRA**			
	10%	20%	30%	40%	10%	20%	30%	40%
7	53%	76.6%	87.5%	94.3%	32%	60%	82.1%	89%
28	60.8%	77.9%	89.6%	92.6%	40.9%	68.3%	81.8%	88.3%

In this study it was found that for the same percentage of tyre rubber aggregate, coarse rubber aggregate had a higher compressive strength, than concrete containing finer rubber aggregate, which is consistent with Fattuhi and Clark (1996) but contradicts Eldin and Senouci (1993) and Topçu (1995). The relationship between the reduction in compressive strength and the rubber aggregate percentage was found to be nonlinear. It is noticeable that as opposed to the average values of the control mixes, the mixes with rubber aggregate showed very little increase in the compressive strengths between the 7th and the 28th day of curing (with the only exception of the 10% coarse rubber aggregate mix), which is consistent with results from other researchers (Eldin and Senouci, 1993). This is particularly true for the fine rubber aggregate mixes. The plot of compressive strength versus density (Figure 4(b)) indicates an exponential drop of strength with density in the concrete with rubber mixes. The large losses in compressive strength imply that rubber percentages above 10%-20% would not be suitable for most structural applications, where high compressive strengths are required. However this type of concrete could be used in low-strength-concrete applications e.g. sidewalks, driveways and selected road construction applications (Eldin and Senouci,1993).

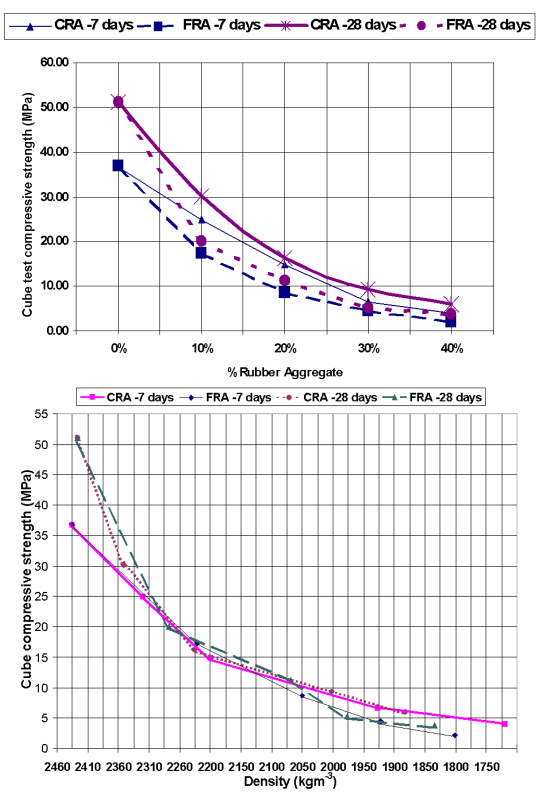

Figure 4. Compressive strength variation: (a) with rubber content; (b) with density

Direct comparisons of % losses with other researchers' results are not possible as cubes (and/or cylinders) of various sizes were used in other investigations. It is known that different shape and size of specimens influence the compressive strength of concrete. Moreover, rubber aggregate of different type, origin, shapes, sizes and grading was used across investigations. However the reduction in compressive strength due to rubber aggregate is consistent across the literature. A number of possible explanations have been suggested in the literature for this loss of strength. This has usually been attributed to the fact that the rubber particles act as voids in the cement matrix due to the lack of adhesion between the rubber and the cement matrix. It was also suggested that the lower specific gravity of the rubber particles compared to the cement paste causes cracks around the rubber particles to appear quickly upon loading which accelerates the failure of the specimens (Khatib and Bayomy, 1999). Conversely, Chou et al., (2007) attributed the loss of strength to the heterogeneous, hydrophobic rubber particles, leading to local imperfections in the hydration of cement and hence locally weaker concrete. This suggestion was supported by microscopic studies showing that the rubber particles distributed the water transfer to create channels prone to cracking, thus causing a loss in compressive strength. Due to the low compressive strengths of the mixes containing rubber aggregates which would not be acceptable in most cases, the following sections will present results for the rest of the tests for the mixes containing 10% of rubber aggregate only, as these showed the best compressive strength values of all mixes containing rubber aggregate.

References

1. Papakonstantinou, C. G., Tobolski, M. J. Use of Waste Tire Steel Beads in Portland Cement Concrete Cement and Concrete Research 36 (9) 2006: pp. 1686 – 1691.
2. Silvestraviciute, I., Sleinotaite Budriene, L. Possibility to Use Scrap Tires as an Alternative Fuel in Cement Industry Environmental Research, Engineering and Management 3(21) 2002: pp. 38 – 48 (in Lithuanian).
3. Segre, N., Joekes, I. Use of Tire Rubber Particles as Addition to Cement Paste Cement and Concrete Research 30 (9) 2000: pp. 1421 – 1425.
4. Shuaib, Ahmad; Fedroff, David; Sayas, Banu Zeynep Freeze-Thaw Durability of Concrete with Ground Waste Tire Rubber Transportation Research Record 1574–1997.
5. Kersevicius, V. Rubber Waste – Raw Materials for Building: Technical and Economical Aspects of Utilization Environmental Research, Engineering

and Management 3 (21) 2002: pp. 72 – 77 (in Lithuanian).
6. Hernandez-Olivares, F., Barluenga, G., Bollati, M., Witoszek, B. Static and Dynamic Behaviour of Recycled Tyre Rubber-filled Concrete Cement and Concrete Research 32 (10) 2002: pp. 1587 – 1596.
7. Skripkiunas, G., Grinys, A. Using Tires Rubber Waste for Modification of Concrete Properties Building and Architecture. Proceedings of Conference Kaunas: "Technology" 2005: pp. 132 – 137 ISBN 9955-09-851-1 (in Lithuanian).
8. Skripkiunas, G., Grinys, A. Using Tires Rubber Waste for Modification of Concrete Properties Science Days – 2005 Dnepropetrovsk, 2005: pp. 5 – 40 ISBN 966-7191-86-9 (in Russian).
9. Eldin, N. N., Senouci, A. B. Rubber Tire Particles as Concrete Aggregate Journal of Material Civil Engineering ASCE 5 (4) 1993: pp. 478 – 496.
10. Khatip, Z. K., Bayomy, F. M. Rubberized Portland Cement Concrete Journal of Material Civil Engineering ASCE 11 (3) 1999: pp. 206 – 213.
11. Topu, I. B., Avcular, N. Collision Behaviors of Rubberized Concrete Cement and Concrete Research 27 (12) 1997: pp. 1893 – 1898.
12. Lee, B. I., Burnett, L., Miller, T., Postage, B., Cuneo, J. Tyre Rubber Cement Matrix Composites Journal of Material Science Letter 12 (13) 1993: pp. 967 – 968.
13. Eldin, N. N., Senouci, A. B. Measurement and Prediction of the Strength of Rubberized Concrete Cement & Concrete Composites 18 1996: pp. 135 – 139.
14. Sheikin, E., Schekovskyj, J. V., Bruser, M. I. Properties and Composition Cement Based Concrete. Moscow: Stroiizdat, 1979: 344 p. (in Russian).
15. Li, G., Stubblefield, M. A., Garrick, G., Eggers, J., Abadie, Ch., Huang, B. Development of Waste Tire Modified Concrete Cement and Concrete Research 34 (12) 2004: pp. 2283 – 2289.
16. Skripkiunas, G., Grinys, A., Dauksys, M. Using Tires Rubber Waste for Modification of Concrete Properties Sustainable Construction Materials and Technologies International Conference Coventry 11 – 13 of June 2007. Taylor & Francis Group, London, ISBN 987-0-415-44689-1.
17. Guneyisi, E., Gesoglu, M., Ozturan, T. Properties of Rubberized Concretes Containing Silica Fume Cement and Concrete Research 34 (12) 2004: pp. 2309 – 2317.
18. Bignozzi, M. C., Sandrolini, F. Tyre Rubber Waste Recycling in Self-compacting Concrete Cement and Concrete Research 36 (4) 2006: pp. 735 – 739.
19. Anison, M. An Investigation into a Hypothetical Deformation and Failure Mechanism for Concrete Magazine of Concrete Research 6 (47) 1964: pp. 73 – 82.