CSCE Annual Conference
Growing with youth – Croître avec les jeunes

Laval (Greater Montreal)
June 12 - 15, 2019

USING TDA TO PARTIALLY REPLACE COARSE AGGREGATES IN CONCRETE MIXTURES

El Naggar, A.[1,2], Sadeghian, P.[1], and El Naggar, H.[1]
[1] Department of Civil and Resource Engineering, Dalhousie University, Halifax, Canada
[2] abdelmoneim.elnaggar@dal.ca

Abstract: Applications utilizing rubberized concrete have grown substantially in the last decade as an answer for the scrape tires stockpiling problems and its associated environmental issues. Though rubberized concrete mixtures generally have a reduced compressive strength and stiffness that may limit their use in specific structural applications, they possess several desirable properties such as lower density, higher toughness, and better dampening ability resulting in an enhanced dynamic performance. The purpose of this study is to investigate the effect of using recycled Tire Derived Aggregates (TDA) to partially replace coarse aggregates in concrete mixtures. Natural coarse aggregates in the considered concrete mixtures was partially replaced by 10%, 20%, and 30% of TDA. The specimens were tested under uniaxial compression up to failure. The results showed a decrease in the compressive strength and the elastic modulus of the concrete as the replacement ratio increase. It was observed that increasing the content of TDA to 30% of the coarse aggregates by volume decreased the compressive strength and elastic modulus of the concrete by 36% and 17%, respectively. This is a research in progress and more results on higher content of TDA will be provided later.

1 INTRODUCTION

Serious environmental problems are rising from the stockpiling of scrap tires. The growth of the auto industry within our consumer society only adds to this problem. In the United States alone, about three billion waste tires have been accumulated in stockpiles and dumps, millions of them scattered illegally in forests, desserts, and other ecosystems (Thomas et al. 2015). These stockpiles serve as great harbor for insects, rats, and other organisms that could harm their surrounding environments if a balance is not maintained (Figure 1). Likewise, over 30 million waste tires are stockpiled per year in Canada (Tire and Rubber Association of Canada, 2016). Uncontrolled fires and harmful gases would eventually arise from the chemical reactions occurring within these stockpiles, further polluting the environment. Hence, stockpiling tire wastes is an unsustainable practice that has been proven harmful for the environment. Better recycling techniques must be devised to combat this rising dilemma, as stockpiling tire waste pollutes the environment and prevents useful development of the land used for stockpiling.

Research efforts has been made to investigate the potential applications Tire derived aggregates (TDA) could have in the civil engineering field. TDA has been used as lightweight fill material for highway embankments, which resulted in the overall unit weight reduction and, for mixtures containing sand or sandy silt, an increase in shear strength (El Naggar et al., 2016). Likewise, research on the feasibility of adding TDA to other lightweight materials like expanded shale/clay/slate or tufts and slag in rigid culverts construction to mitigate high earth loads and settlements have been conducted (Sparkes et al. 2019). The lightweight aggregates and TDA mixtures were evaluated for their shear strength, compressibility, and coefficient of earth pressure at rest using a large direct shear box, one-dimensional compression testing equipment, and a split-ring apparatus (Sparkes et al., 2019). Studies illustrated that using a layer of TDA backfill above pre-existing buried pipes is an excellent construction alternative to enhance the stress bridging mechanism under static loading conditions (Mahgoub and Elnaggar, 2019).

Figure 1: A hazardous stockpile of tires (photo credit: www.heraldsun.com.au)

Ordinary cement-based concrete lacks desirable dynamic loading resistance properties, like impact resistance, damping characteristics, and toughness. Rigidity and high compressive strength aren't always sought after when designing structures that will be subjected to seismic situations like traffic barriers and structures within areas that have a great risk of seismic activity. In fact, structures that aren't impact resistant could experience great damages and cracks when exposed to extreme sudden dynamic forces. TDA could be added to concrete mixes to add the desired damping abilities and seismic resistance properties. The rubber qualities of TDA within the concrete mix would improve the ductility of the overall concrete structure, allowing it to tolerate certain degrees of deformation without suffering serious damages.

Experimental efforts directed towards studying the behaviour of concrete mixed with tire derived aggregates allowed us to realize that the overall concrete strength decreases as the TDA content increases. The tire aggregates, however, give a great potential for applications in areas where impact resistance plastic deformation of concrete is needed (Siringi 2012). Most of the researched regarding mixing rubber with concrete used small rubber aggregate sizes replacing the fine aggregates of the concrete mixtures. Grinding the tires to become small rubber particles would require great energy, which would become inefficient and unsustainable. The aim of this research is to investigate the behaviour of concrete mixed with TDA too create an efficient and cost-effective mix that would have great applications within seismic or dynamic loading areas.

2 EXPERIMENTAL STUDY

2.1 Test Matrix

12 cylindrical concrete specimens (150 mm x 300 mm), with TDA content ranging from ordinary concrete to 30% TDA by volume of coarse aggregates were created with three specimens for each 10% increment. Three cylindrical specimens were created for each TDA content to ensure that the data tested yielded accurate and precise results, minimizing the effects of experimental error. The test matrix has been provided in Table 1, and the nomenclature follows the TDA content within the mix. For example, TDA-0

means that the mix is ordinary concrete (has 0% TDA) while TDA-10 means the mix contains 10 % by volume of coarse aggregates was replaced by TDA, and so on.

Table 1: Test matrix

Specimen ID	TDA content (%)	Number of specimens
TDA-0	0	3
TDA-10	10	3
TDA-20	20	3
TDA-30	30	3
Total	-	12

2.2 Material Properties

The concrete specimens were using Portland general use (type GU) cement. The coarse aggregate maximum size was 0.5 in gravel, while the fine aggregate was masonry sand used at saturated surface dry (SSD) condition. Likewise, the TDA aggregate sizes ranged from 4.75 mm to 19.05 mm (Figure 2a), any aggregate size exceeding this range was removed. A sieve analysis was conducted on the material used (Figure 2b). About 1.5 kg coarse aggregates, 0.5 kg fine aggregates, and 2 kg TDA were prepared for the analysis, using the ASTM C-136 method for sampling, which composed of dividing the batch into four sections, then removing the two diagonally opposite quarters, then continuing with the mixing and quartering technique until the desired size is obtained. Each aggregate type was then laid in the sieve vibrator and allowed to vibrate for 7 minutes to allow complete material passage. The fine aggregate size ranged from and 0.15 mm to 9.5 mm for the fine aggregates. Using the ASTM C29, the bulk densities of the aggregates were obtained. 25 strokes were evenly spread out to each new layer (comprising of a third of the cylindrical container containing the aggregates). The bulk density for coarse, fine, and TDA aggregates was 1601, 1817, and 557 kg/m^3, respectively.

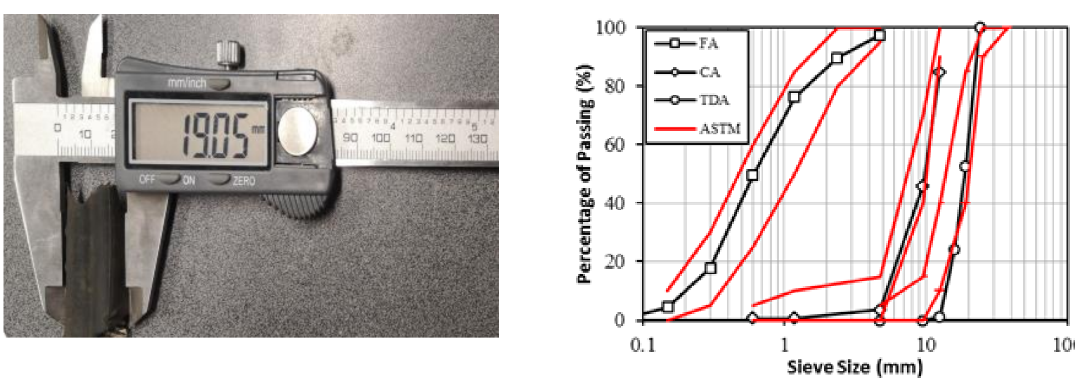

Figure 2: (a) Maximum TDA particle size; (b) Gradation curves for the used materials (Jafarian et al., 2018)

2.3 Specimen Preparation

Using the general use Portland cement (type GU) 12 concrete cylinders were produced, following the Portland Cement Association method. First the dry aggregates were mixed together using the concrete mixer. After that, cement and water were added to the mix and allowed to thoroughly mix with the rest of the ingredients for at least 5 minutes. The concrete design was based on a 100 mm slump, so a slump test was conducted on the concrete mix to make sure that the 100 mm slump criteria was satisfied, and to ensure the workability of the mixture. If the slump was found to be less than 100 mm, superplasticizer was added accordingly to allow the mix to reach the required slump height. After reaching the desired slump height, the concrete mix was poured into 150 mm x 300 mm cylindrical plastic molds. The cylindrical mold received 25 strikes using the tamping rod after each third was filled. The molds for left to harden for at least 24 hours, then the cylindrical concrete specimens were released into the moist curing room. After staying for 28 days in the curing room, the specimens were ready for testing. The cylindrical specimens were then capped using a sulfuric compound to ensure uniform loading distribution when subjected to a compression load via the Instron machine.

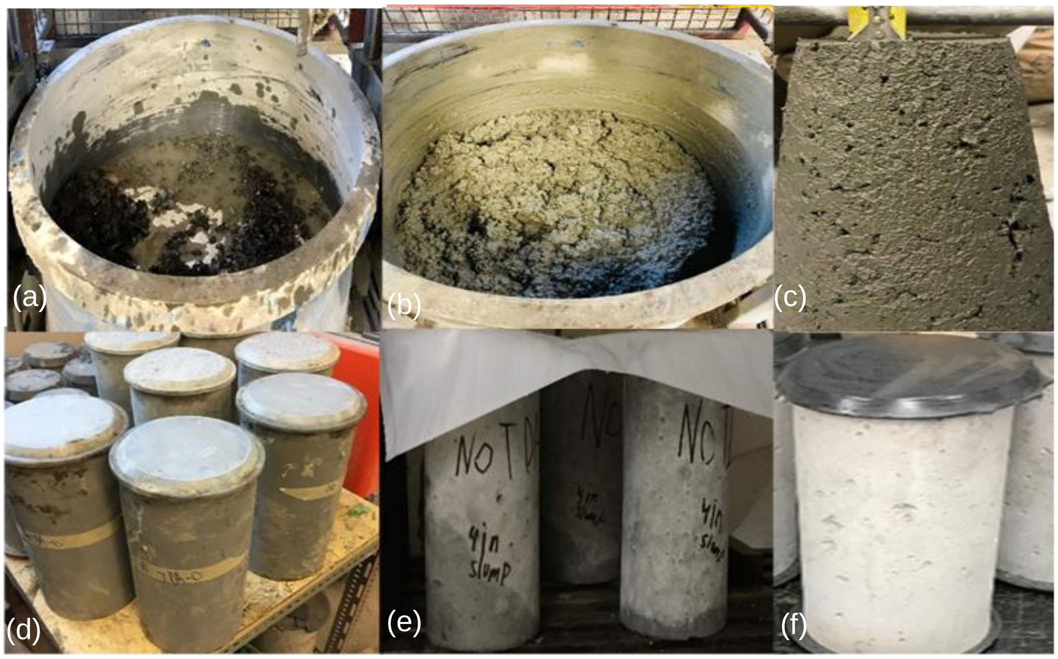

Figure 3: Preparation of concrete specimens: (a)TDA added; (b) mixing the concrete materials; (c) slump test; (d) fresh concrete poured in the cylindrical molds; (e) concrete specimens after curing; (f) capped specimens

2.4 Test Setup and Instrumentation

In this study, the uniaxial compression test was conducted by using a 2 MN universal testing machine using a displacement control approach with a rate of 0.5 mm/min. The loading was applied with a rate of 0.5 mm/min on the top and bottom steel plates, which transfer the pressure to the capping of specimens. Four linear potentiometers (LPs) displacement gauges were placed on a two-steel ring yoke setup around the concrete specimens to measure the lateral and horizontal displacements. LP#1 and LP#4, aligned towards the cylinder's center, recorded the horizontal displacements. The values obtained from these LPs helped find the lateral strain. LP#2 and LP#2, aligned on the same horizontal level with respect to each other and the cylindrical specimen, recorded the vertical displacements, and were used to find the axial strain of the cylindrical specimen undergoing the compressive testing. The displacements and corresponding loading were measured using a data acquisition system reading the data from LPs at 0.1 second time steps. Figure 4 shows a schematic illustration of the test set-up.

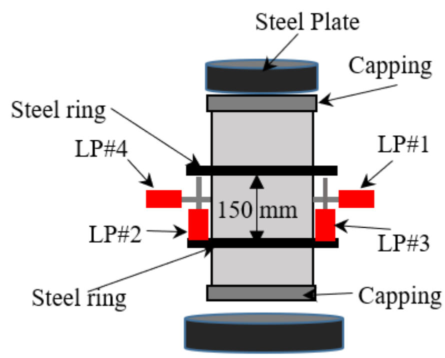

Figure 4: Schematic illustration of the test set-up

3 RESULTS AND DISCUSSION

3.1. Effect of TDA on Compressive Strength

Figure 5 shows the variation of compressive strength of concrete against TDA content. Each bar indicates the average compressive strength of three identical specimen. The top of the error bar show one standard deviation from the average and the bottom of the error bar shows one standard deviation below the average. The standard deviation varies in the range of 0.6 to 1,96 MPa, which shows low variability of test results from average. There is a drop of 29% with replacing 10% (by volume) of the coarse aggregates with TDA. After that, with 20 and 30% of TDA, the strength reduction rate decreases and stabilizes at 34% and 36% with respect to the control specimen, respectively.

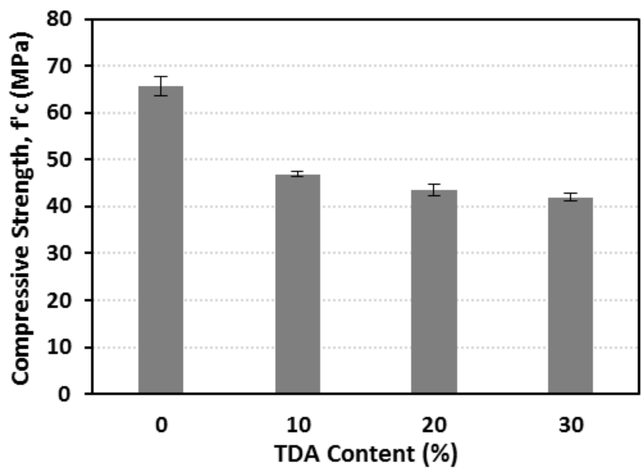

Figure 5. Effect of TDA on concrete compressive strength

3.2. Effect of TDA on Elastic Modulus

Figure 6 shows the variation of elastic modulus of concrete against TDA content. Overall as the TDA content increases, the elastic modulus of concrete decreases with a shallow gradual rate, which is different that the compressive strength. This indicates that the negative effect of TDA on elastic modulus is not as severe as that of on compressive strength of concrete. Overall, with increasing the TDA content to 10, 20, and 30%, the elastic modulus of concrete decreases 8, 11, and 17% with respect to elastic modulus of control specimen, respectively.

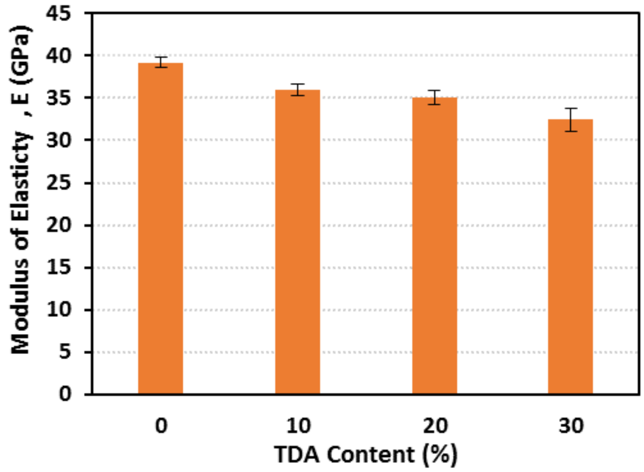

Figure 6. Effect of TDA on concrete elastic modulus

3.3. Effect of TDA on Strain

Figure 7 shows the variation of compressive strain of concrete at peak load against TDA content. The figure indicates that as the TDA content increases, the strain increases with a constant gradual rate. Overall, with increasing the TDA content to 10, 20, and 30%, the strain increases 12, 26, and 37% with respect to control specimen, respectively. These percentages are averagely more than two time of the reduction percentage of elastic modulus. The behavior indicates that the TDA increases the number of micro cracks after initial cracking. This is compatible with the reduction in strength of concrete. More results with higher TDA content is needed to provide a better understanding of the effect of TDA on the mechanical properties and failure mechanism of concrete in compression.

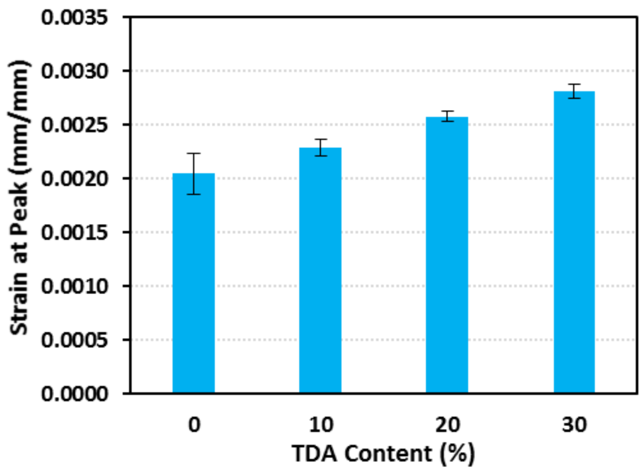

Figure 7. Effect of TDA on concrete elastic modulus

4. CONCLUSIONS

In this paper, 12 cylindrical 150×300 mm concrete specimens were prepared with the natural coarse aggregates component being partially replaced by 10%, 20%, and 30% of TDA by volume. The specimens were tested under uniaxial compression up to failure to determine the effect of adding TDA to the mixture on the mechanical properties of concrete. The results showed a decrease in the compressive strength and the elastic modulus of the concrete as the replacement ratio increase. It was observed that increasing the content of TDA to 30% of the coarse aggregates by volume decreased the compressive strength and elastic modulus of the concrete by 36% and 17%, respectively. It was also found that adding TDA to the mixture resulted in concrete that has ductile post-peak behavior compared to plain concrete. This is a research in progress and more results on higher content of TDA will be provided later.

5. Acknowledgements

The authors would like to thank Jordan Maerz, Jesse Keane, and Koosha Khorramian for their assistance in the lab. The funding provided by the Natural Sciences and Engineering Research Council of Canada (NSERC) for the last two authors is acknowledged. The authors are also grateful for the support and generosity of Halifax C&D Recycling Ltd. (HCD) for providing the used TDA.

6. References

ASTM C33 / C33M-13. 2013. Standard specification for concrete aggregates. ASTM International, West Conshohocken, PA, USA.

“Annual Report 2016.” (2016). https://www.catraonline.ca/, https://www.catraonline.ca/storage/files/shares/publications-en/catra-annualreport-final-03apr2017-pdf.pdf

El Naggar, H., Soleimani, P., and Fakhroo, A. (2016). “Strength and Stiffness Properties of Green Lightweight Fill Mixtures.” Geotechnical and Geological Engineering, 34(3), 867–876.

Mahgoub, A., and El Naggar, H. (2019). “Using TDA as an Engineered Stress-Reduction Fill over Pre-existing Buried Pipes.” ASCE, Journal of Pipeline Systems Engineering and Practice, 10(1), doi/10.1061/%28ASCE%29PS.1949-1204.0000362.

Siringi, G.M. 2012. Properties of Concrete with Tire Derived Aggregate and Crumb Rubber as A Lightweight Substitute for Mineral Aggregates in The Concrete Mix. Materials Science & Engineering, PhD dissertation, University of Texas at Arlington, Texas, USA.

Sparkes, J., El Naggar, H., and Valsangkar, A. (2019). “Compressibility and Shear Strength Properties of Tire-Derived Aggregate Mixed with Lightweight Aggregate.” ASCE, Journal of Pipeline Systems Engineering and Practice, 10(1), doi/10.1061/%28ASCE%29PS.1949-1204.0000354.

Thomas, B., Gupta, R., Mehra, P., Kumar, S. (2015). Performance of high strength rubberized concrete in aggressive environment. Construction and Building Materials. 83. P.P. 320-326.