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Dilation Characteristics of Rubberized Concrete

by

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Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
NUTC R342		

4. Title and Subtitle	5. Report Date
Dilation Characteristics of Rubberized Concrete	Date
	6. Performing Organization Code
7. Author/s Mohamed ElGawady	8. Performing Organization Report No. Project # 00042523
9. Performing Organization Name and Address Center for Transportation Infrastructure and Safety/NUTC program Missouri University of Science and Technology 220 Engineering Research Lab Rolla, MO 65409	10. Work Unit No. (TRAIS) 11. Contract or Grant No. DTRT06-G-0014
12. Sponsoring Organization Name and Address U.S. Department of Transportation Research and Innovative Technology Administration 1200 New Jersey Avenue, SE Washington, DC 20590	13. Type of Report and Period Covered Final 14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract
Green construction has been a very important aspect in the concrete production field in the last decade. One of the most problematic waste materials is scrap tires. The use of scrap tires in civil engineering is increasing. This article investigates the effect of the strain rate on the confined concrete mechanical properties. Self consolidating (SCC) control and rubberized concrete mixtures were designed and used during the course of this study to test the properties of concrete having 0%, 10%, and 20% volume replacement of sand with shredded rubber. The compressive strength of the concrete was reduced by the use of rubber. The confined compressive strength was also reduced for the FRP tubes by the use of rubber. The confinement of both conventional and rubberized concrete resulted in an increase in both the compressive strength and ductility. The increase in the strain rate by two and three orders of magnitude resulted in an increase in the compressive strength and ductility of the confined concrete in the FRP tubes.

17. Key Words	18. Distribution Statement
Accelerated bridge construction, rubberized concrete	No restrictions. This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161.

19. Security Classification (of this report)	20. Security Classification (of this page)	21. No. Of Pages	22. Price
unclassified	unclassified	20	

Form DOT F 1700.7 (8-72)

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SUMMARY

Green construction has been a very important aspect in the concrete production field in the last decade. One of the most problematic waste materials is scrap tires. The use of scrap tires in civil engineering is increasing. This article investigates the effect of the strain rate on the confined concrete mechanical properties. Self consolidating (SCC) control and rubberized concrete mixtures were designed and used during the course of this study to test the properties of concrete having 0%, 10%, and 20% volume replacement of sand with shredded rubber. The compressive strength of the concrete was reduced by the use of rubber. The confined compressive strength was also reduced for the FRP tubes by the use of rubber. The confinement of both conventional and rubberized concrete resulted in an increase in both the compressive strength and ductility. The increase in the strain rate by two and three orders of magnitude resulted in an increase in the compressive strength and ductility of the confined concrete in the FRP tubes.

Keywords: High strength concrete, rubberized concrete, scrap tires, damping ratio

1. Introduction

Green construction has been an important aspect in the concrete production field in the last decade or so. The use of waste products in concrete manufacturing is beneficial both economically by replacing some of the components with waste materials and environmentally by clean disposal of waste materials. One of the most problematic waste materials is scrap tires; if improperly handled, scrap tires can be a threat to environment. Exposed scrap tires can be a breeding space for mosquitoes that carry disease. Scrap tire piles can be easily set on fire which is difficult to put out, and produces heavy smoke and toxic run off to waterways [Rubber manufacturers association 2014].

The addition of shredded scrap tires to concrete provides some favorable characteristics for concrete and alters some of concrete properties. The ordinary cement-based concrete is generally brittle; however, the addition of rubber to concrete, producing what is called rubberized concrete, can increase its ductility and impact resistance [Eldin and Senouci (1993); Topcu (1995); Toutanji (1996)]. Rubberized concrete is used in many applications such as concrete pavements, sidewalks, and road barriers where concrete is subjected to dynamic loading from moving vehicles or people walking on sidewalks.

The mechanical properties of rubberized concrete have been extensively investigated [Khatib and Bayomy (1999); Khaloo et al. (2008); Güneyisi et al. (2004); and Segre and Joekes (2000)]. An extensive literature review for the mechanical properties of rubberized concrete can be found in Siddique and Naik (2004). Past research concluded that the addition of high percentage of shredded rubber to concrete reduces the compressive strength and workability of fresh concrete. However, these effects vary according to many factors such as the size and distribution of the rubber particles, the type of aggregate to be replaced (coarse aggregate or fine aggregate), and the percentage of rubber content in a rubberized concrete mixture.

Researchers have recently shown that confining conventional concrete using FRP increases its axial capacity and ductility [Lam et al. (2006)]. To date there has been very limited investigation of the behavior of rubberized concrete encased in FRP tubes. Youssf et al. (2014) investigated the FRP confinement effects on rubberized concrete. They concluded that confining both conventional concrete and rubberized with FRP layers resulted in significant overall increases in compressive strength of the confined specimens compared with unconfined ones, and the thicker the FRP the greater the increase in strength. The research demonstrated that confinement using FRP layers effectively negates the decrease in strength that occurs in rubberized concrete compared with conventional concrete and retains the advantages of increased ductility that arise from rubberized concrete. This has promising implications for the use of confined rubberized concrete in applications such as bridge columns in seismic zones.

Properties of the materials used in reinforced concrete structures are almost all strain-rate dependant [Bischoff and Perry (1991)]. Strength, stiffness and ductility can be affected by the loading rate but, in most cases, the difference becomes significant when the rate changes by more than one order of magnitude. A thorough knowledge of materials constitutive relationships and failure criteria is required, often over a wide range of strain rates. Figure 1 shows the range of strain rates expected for different loading cases.

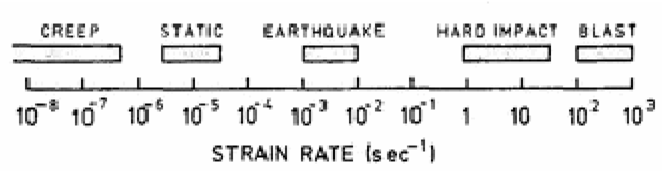


Figure 1. Magnitude of strain rates expected for different loading cases

The mechanical properties of confined concretes with scrap tires under different strain rates, to the best knowledge of the authors, have not been studied yet. In this report, the mechanical properties of confined concrete with and without scrap tire rubber as a substitution for fine gravel are studied. Different percentages of replacement of sand ranging from 0 to 20% by volume were investigated.

2. Experimental Investigation

2.1. Material characteristics

Self consolidating (SCC) control and rubberized concrete mixtures were designed and used during the course of this study to test the properties of concrete having 0%, 10%, and 20% volume replacement of sand with shredded rubber. Variable amounts of superplasticizer were used to maintain the same workability of the fresh concrete regardless of the rubber percentages. The materials used in this study are shown in tables 1.

The cement used in all mixtures is type I Portland cement meeting ASTM C150 specifications. Limestone washed coarse aggregate with nominal maximum size of 1 in was used. The sand used was Missouri river sand. The rubber used was ground rubber with three different sizes of 8-14, 14-30, and 30- where the first number represents the sieve number of the passing particles and the second number represents the sieve number of the retained particles. Different trial mixtures including different grading of the shredded rubber were prepared and the grading that had the best workability and consistency was selected for all mixtures. Figure 2 shows the grading of the sand, coarse aggregate and ground rubber used during the course of this research. Figure 3 shows the used ground rubber. The material characteristics of the sand, coarse aggregate and rubber are shown in table 2.

Table 1. Mixture proportions for the control concrete and for rubberized concrete

Materials (lb/ft^3)	Water	Cement	Fly Ash	Coarse aggregate	Super-Plasticizer	VMA	Sand	R(8-14)	R(14-30)	R(30-)
Normal Concrete	12.5	17.5	7.5	50.0	0.094	0.030	50.0	-	-	-
R 10	12.5	17.5	7.5	50.0	0.167	0.060	45.0	1.636	0.519	0.114
R 20	12.5	17.5	7.5	50.0	0.197	0.065	40.0	3.273	1.039	0.228

Table 2. Material characteristics

Material	Specific gravity	fineness	Unit weight (lb/ft^3)
Sand	2.61	2.86	90
Coarse Aggregate	2.69	N.A*	97
Rubber	1.16	N.A*	40

* N.A = Not available

<u>Concrete mixing</u>

The mixing procedure of the concrete was started by dry mixing the coarse aggregate, sand, and rubber for about 1 minute to insure distribution of the aggregates and then the cement and fly ash were added and the concrete was dry mixed for another minute. The superplasticizer was added to the water and the water was then added to the mixture along with the viscosity modifying admixture (VMA) and the concrete was mixed for 2 minutes and then let stand for 1 minute; then, mixed for another two to three minutes until consistency was observed. The slump test was performed after the mixing and superplasticizer was carefully added if the slump was not satisfied.

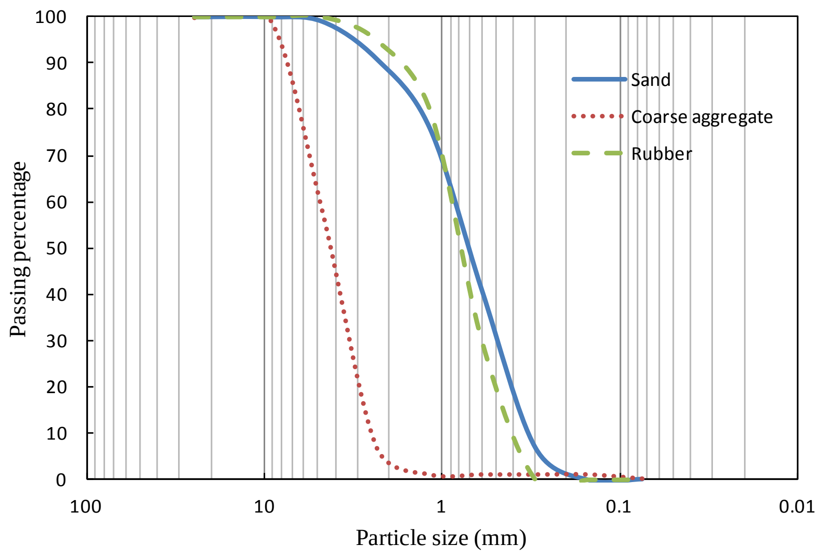


Figure 2 – Grading of used materials

Figure 3 – Used ground rubber

2.2. Test specimens

A total of eighteen FRP tubes with nominal diameter of 6.25 in and nominal height of 12 in were prepared and concrete was poured inside the types; six tubes for each percentage of rubber replacement, where 1 layer of glass fiber was used in three of these tubes and 3 layers of glass fiber were used in the other three tubes. Six 4 x 8 cylinders for each mixture were cast in the same day with the FRP tubes to determine the compressive strength of the concrete at 28 days. The cylinders were tested under axial cyclic loading at 28 days to determine the unconfined compressive strength of the different concrete mixtures. The cylinders were demolded after 24 hours and were moist cured in a controlled moisture room for 28 days. The FRP confined concrete tubes was tested under three different loading rates of 0.02, 2, and 20 in/min to simulate the loading rates associated with static loading, an earthquake, and a higher shock, respectively, as illustrated in Figure 1 above. The test matrix is shown in table 3.

Table 3. Test Matrix

FRP confined tube	Number of FRP layers	Loading Rate (in/min)
Normal Concrete	1	0.02
		2
		20
	3	0.02
		2
		20
R 10	1	0.02
		2
		20
	3	0.02
		2
		20
R 20	1	0.02
		2
		20
	3	0.02
		2
		20

2.3. Test setups

The compressive strengths of the 4x8 concrete cylinders were determined using an MTS machine. The cylinders were grounded to assure the leveling of the surface and the two surfaces are parallel to each other. To determine the average axial strain of the concrete, two string potentiometers were placed on two opposite sides of each cylinder at a gauge length of one-third of the cylinder height. The average axial strains along a full specimen height were also measured using a Linear Variable Displacement Transducer (LVDT). The test setup for the compressive strength is shown in Figure 4.

The cylinders were cyclically loaded using displacement control up to failure. The loading rate was 0.013 in/min to maintain the same strain rate for the cylinders and the FRP tubes in the static load range. The cyclic axial compressive loading, including loading/unloading cycles, was applied based on a prescribed pattern of progressively increasing levels of axial displacements until failure occurred. Three cycles of loading/unloading were applied at each axial displacement level.

Figure 4 -- Compression test setup

The FRP tubes were cyclically loaded using displacement control up to failure using the MTS machine with a capacity of 550 kips. The loading rates were 0.02, 2, and 20 in/min to simulate static loading, earthquake loading, and a stronger shock, respectively. The cyclic axial compressive loading, including loading/unloading cycles, was applied based on a prescribed pattern of progressively increasing levels of axial displacements until failure occurred. Three cycles of loading/unloading were applied at each axial displacement level. The test setup for the confined concrete with FRP tubes is shown in Figure 5.

Figure 5. Confined concrete test setup

3. Experimental results and discussion

3.1. Fresh concrete properties

The workability of the concrete was maintained the same by increasing the superplasticizer dosage in the mixtures containing scrap rubber. The slump of the rubberized concrete and control mixtures is shown in figure 6(b). The slump of the self consolidated concrete (SCC) is measured as the diameter of the resulting circle after removing the cone since it is not possible to measure the vertical slump, as shown in Figure 6(a).

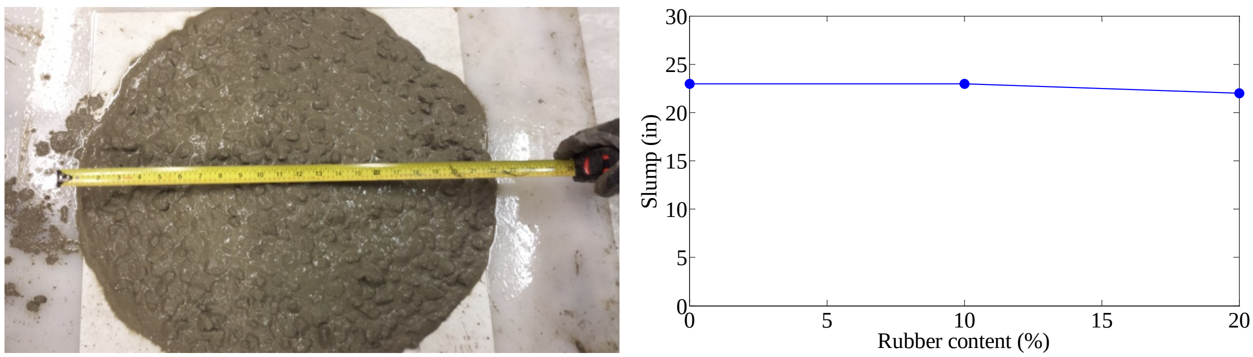


Figure 6. Slump of the rubberized concrete

3.2. Compressive strength

The compressive behavior of the control and rubberized concrete mixtures was determined at 28 days. Figure 7 shows the stress strain curves for the cyclic loading of the cylinders after 28 days of moist curing according to ASTM C192 (2013) and also a comparison between the different rubber contents using the envelope of the cyclic curves. The figure shows a compressive strength reduction for the rubberized concrete and an increase in the strain at the maximum stress.

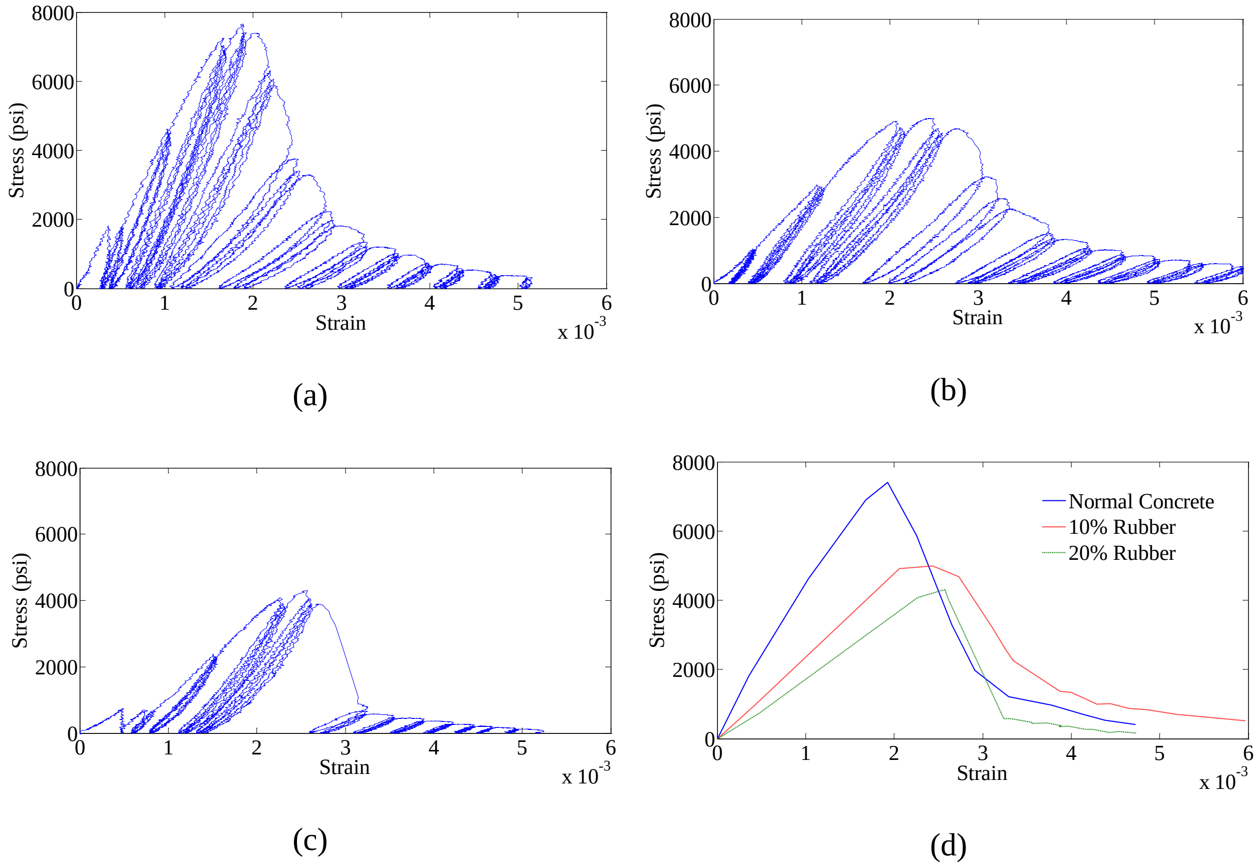


Figure 7. Stress strain curves for a) normal concrete, b) 10% rubber replacement, c) 20% rubber replacement, and d) envelope

3.3. Effect of rubber replacement on confined compressive behavior

The compressive behavior of the confined control and rubberized concrete mixtures was determined at 28 days. Figure 8 shows the stress strain curves for the cyclic loading of the FRP confined tubes after 28 days of moist curing according to ASTM C192 (2013) and also a comparison between the different rubber contents using the envelope of the cyclic curves. Similar to the unconfined concrete, the figure shows a compressive strength reduction for the rubberized concrete and an increase in the strain at the maximum stress.

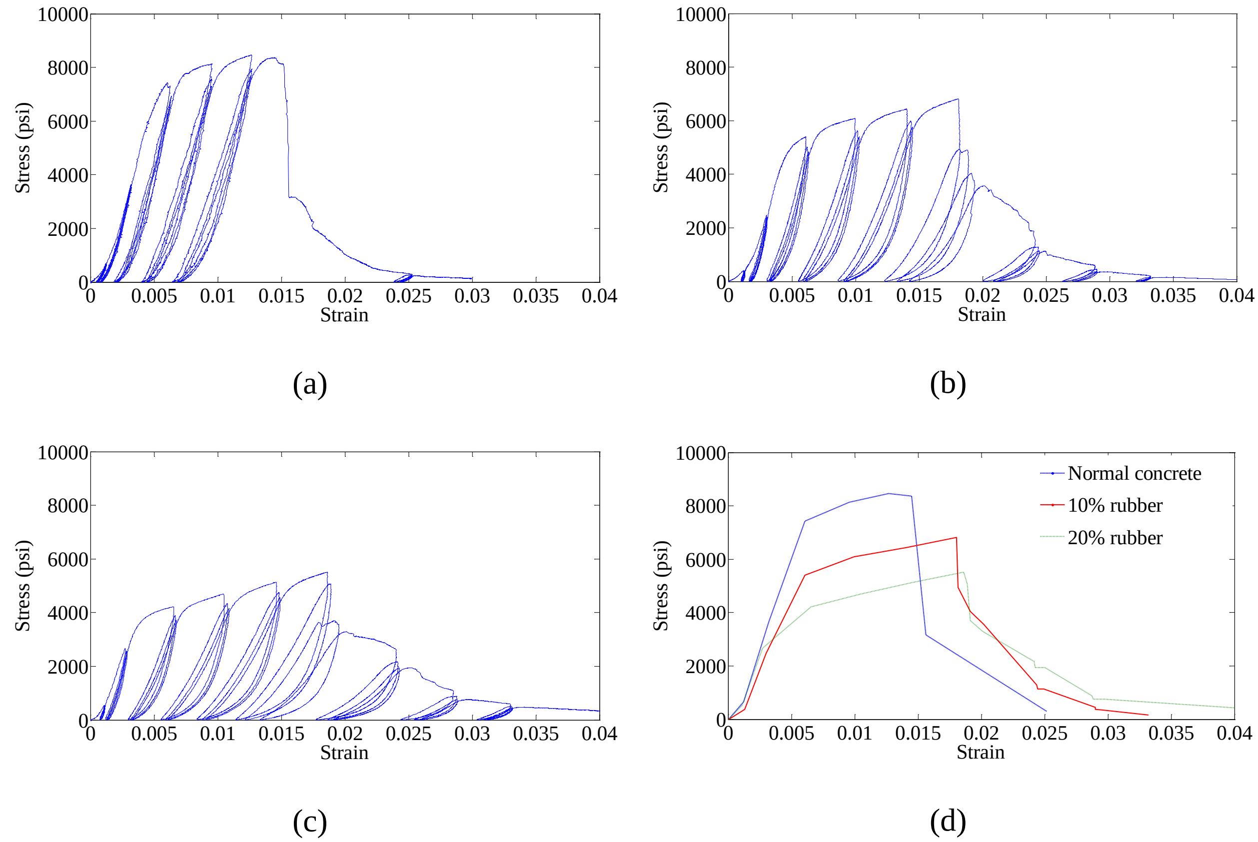


Figure 8. Stress strain curves for confined a) normal concrete, b) 10% rubber replacement, c) 20% rubber replacement, and d) envelope

3.4. Effect of confinement on confined compressive behavior

Figure 9 shows the effect of confining the concrete with one and three layers of glass FRP tubes for the normal concrete, 10% rubber replacement, and 20% rubber replacement. The use of 1 layer of glass FRP did not increase the compressive strength by much but increased the strain significantly. The use of 3 layers of glass FRP increased both the compressive strength and the ductility.

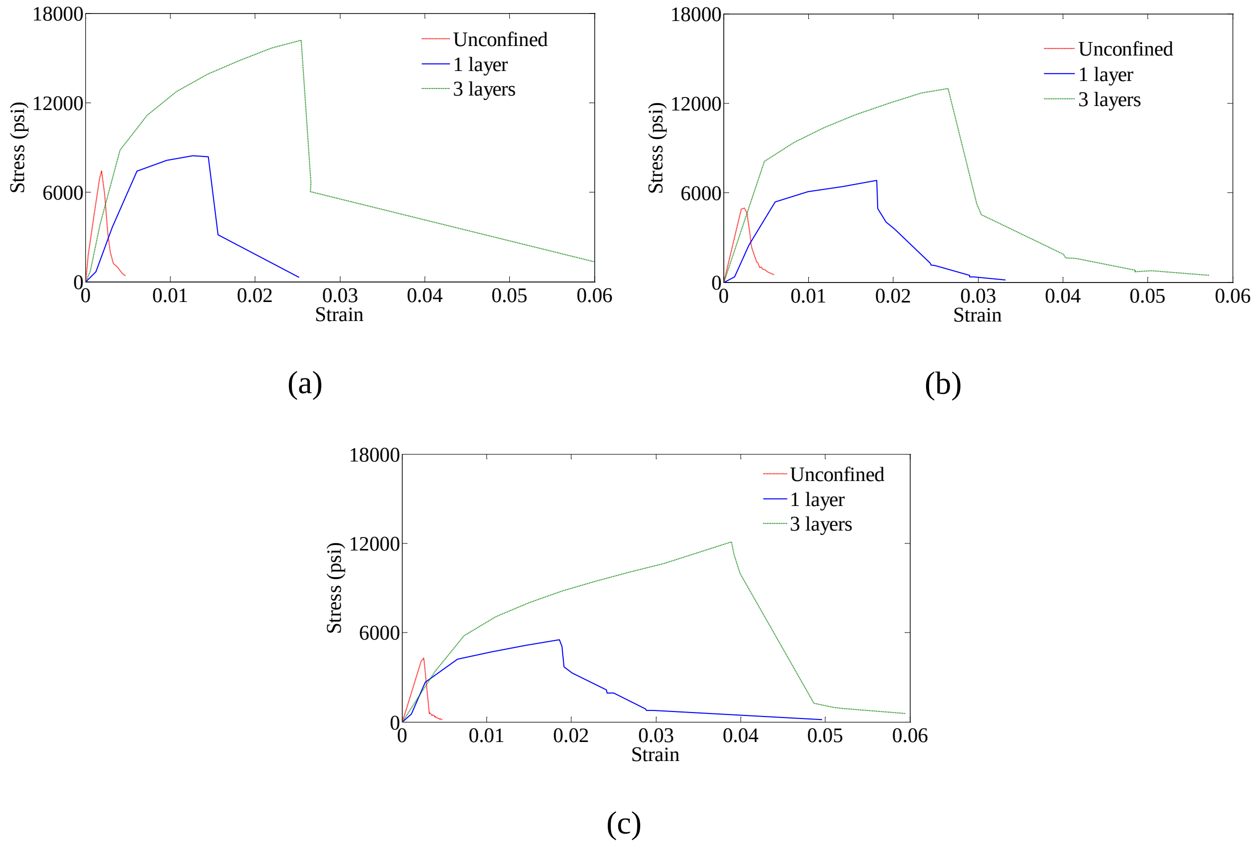


Figure 9. Effect of confinement on confined a) normal concrete, b) 10% rubber replacement, and c) 20% rubber replacement

3.5. Effect of strain rate on confined compressive behavior

Figure 10 shows the stress strain curves for the normal concrete under loading rates of 0.02, 2, and 20 in/min. The figure shows a slight increase in the compressive strength and ductility with the increase of the loading rate.

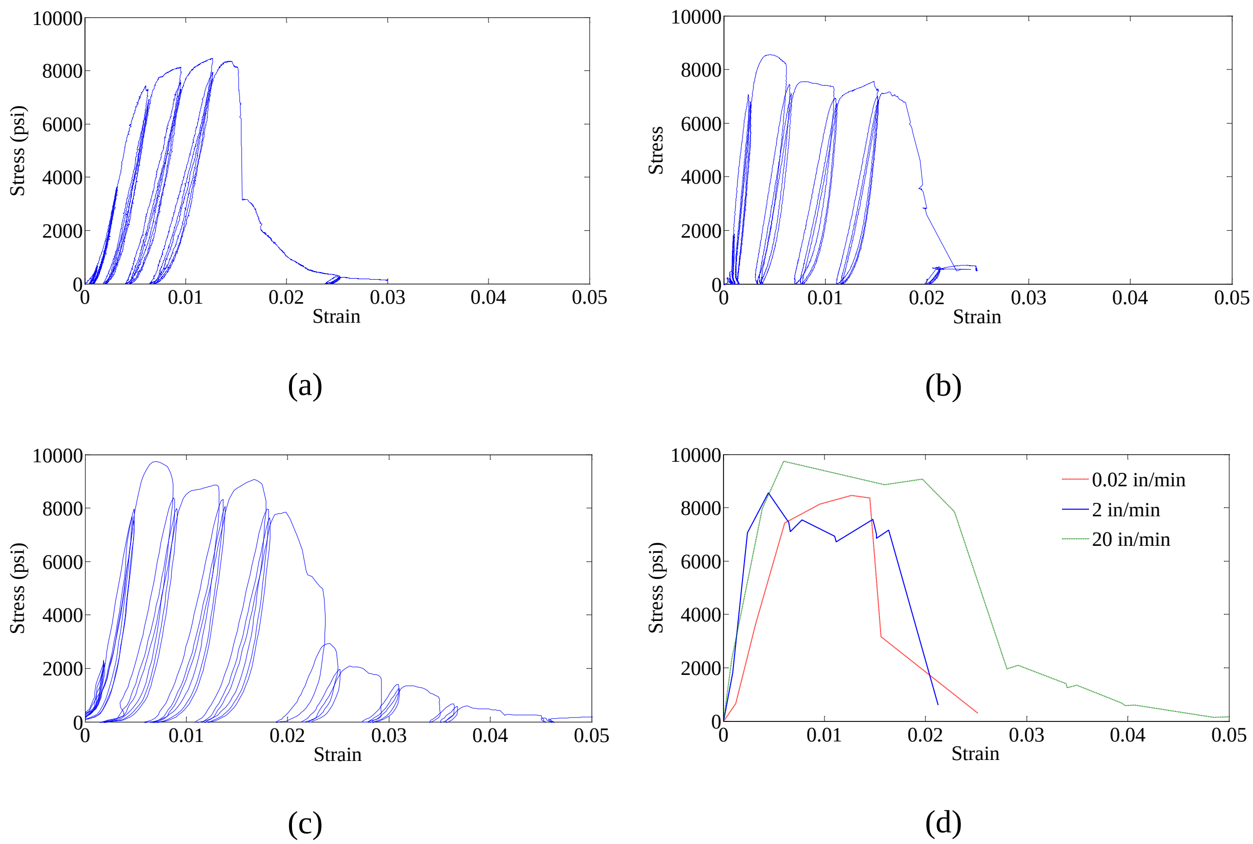
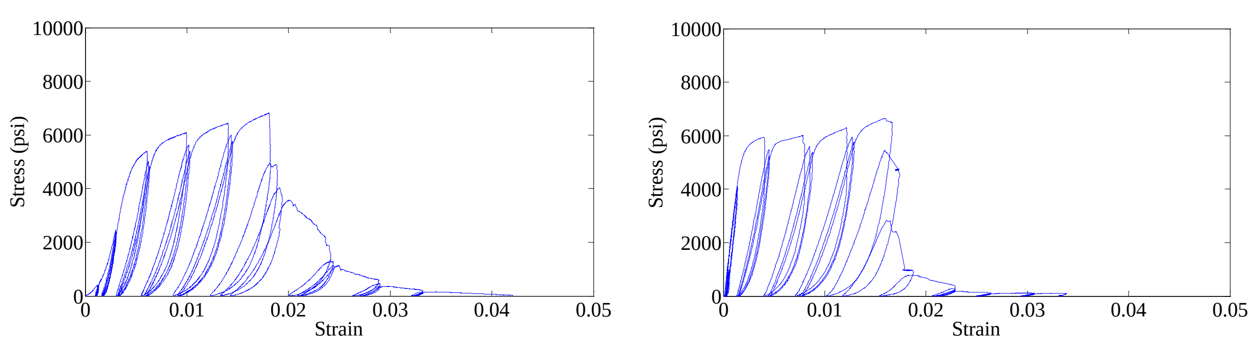
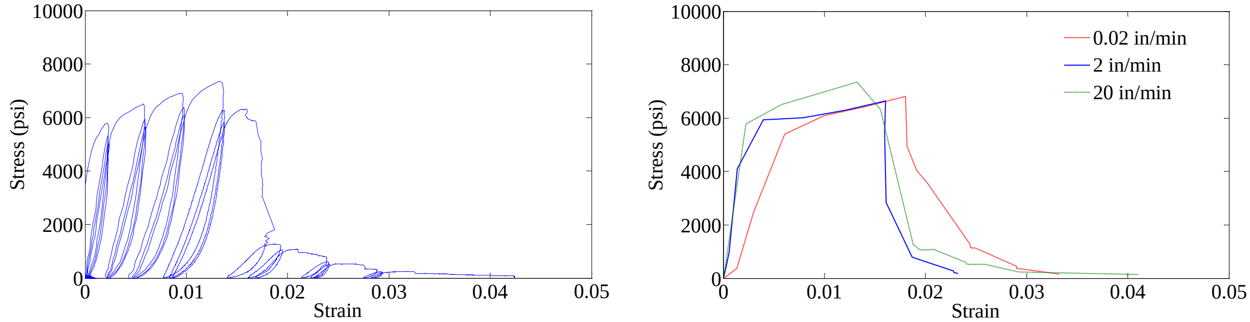


Figure 10. Stress strain curves for confined normal concrete with strain rates of a) 0.02 in/min, b) 2 in/min, c) 20 in/min, and d) envelope

Figure 11 shows the stress strain curves for the 10% replacement rubberized concrete under loading rates of 0.02, 2, and 20 in/min. The figure shows a slight increase in the compressive strength and similar ductility with the increase of the loading rate.



(a) (b)



(c) (d)

Figure 11. Stress strain curves for confined 10% replacement rubberized concrete with strain rates of a) 0.02 in/min, b) 2 in/min, c) 20 in/min, and d) envelope

Figure 12 shows the stress strain curves for the 20% replacement rubberized concrete under loading rates of 0.02, 2, and 20 in/min. The figure shows a slight increase in the compressive strength and ductility with the increase of the loading rate.

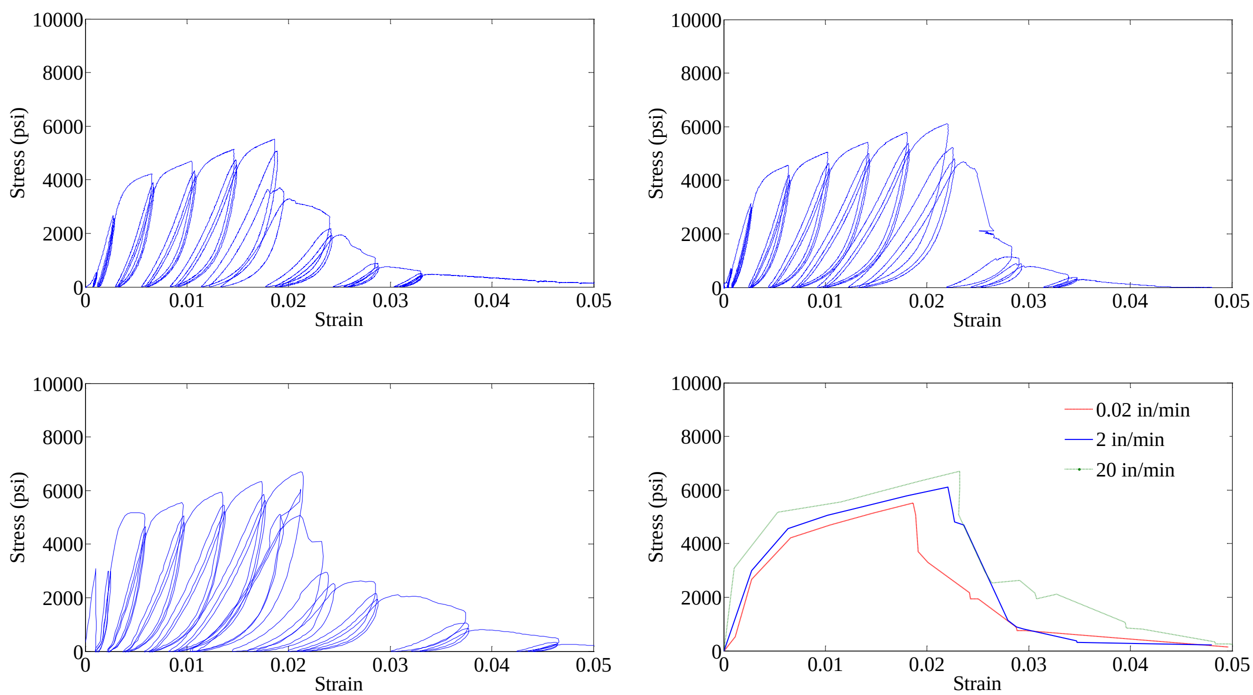


Figure 12. Stress strain curves for confined 20% replacement rubberized concrete with strain rates of a) 0.02 in/min, b) 2 in/min, c) 20 in/min, and d) envelope

4. Conclusions

This article investigates the effect of the strain rate on the confined concrete mechanical properties. Self consolidating (SCC) control and rubberized concrete mixtures were designed and used during the course of this study to test the properties of concrete having 0%, 10%, and 20% volume replacement of sand with shredded rubber. A total of eighteen FRP tubes with nominal diameter of 6.25 in and nominal height of 12 in were prepared and concrete was poured inside the types; six tubes for each percentage of rubber replacement, where 1 layer of glass fiber was used in three of these tubes and 3 layers of glass fiber were used in the other three tubes. Six 4 x 8 cylinders for each mixture were cast in the same day with the FRP tubes to determine the compressive strength of the concrete at 28 days. The cylinders were tested under axial cyclic loading at 28 days to determine the unconfined compressive strength of the different concrete mixtures. The cylinders were demolded after 24 hours and were moist cured in a controlled moisture room for 28 days. The FRP confined concrete tubes was tested under three different loading rates of 0.02, 2, and 20 in/min to simulate the loading rates associated with static loading, an earthquake, and a higher shock, respectively. The compressive strength of the concrete was reduced by the use of rubber. The confined compressive strength was also reduced for the FRP tubes by the use of rubber. The confinement of both conventional and rubberized concrete resulted in an increase in both the compressive strength and ductility. The increase in the strain rate by two and three orders of magnitude resulted in an increase in the compressive strength and ductility of the confined concrete in the FRP tubes.

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