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Assessing the Influence of Waste Tire Rubber on Concrete Properties

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ABSTRACT

According to the Tire Industry Project's report for the World Business Council for Sustainable Development, around 1 billion end-of-life automobile and truck tires are generated annually. This substantial amount of non-biodegradable waste not only occupies large areas but also poses significant environmental hazards. Meanwhile, concrete is the second most consumed material in the world after water and the most widely used building material. Incorporating recycled waste tire rubber (WTR) into concrete offers an environmentally friendly solution, provided its effects on the concrete's mechanical properties are acceptable. This research examines the impact of adding different amounts of powdered WTR to both unreinforced and steel-fiber reinforced concrete, focusing on mechanical properties such as compressive and flexural strengths. Test results showed that replacing sand with up to 20 percent powdered WTR may reduce compressive strength by up to 50 percent, indicating that WTR dosages should be carefully controlled. This research aimed to advance recycling efforts, conserve resources, and support sustainable environmental practices by exploring viable methods to mitigate the ecological effects of waste materials.

1. INTRODUCTION

According to the Tire Industry Project's report for the World Business Council for Sustainable Development, approximately 1 billion end-of-life automobile and truck tires are generated annually. For instance, California reported 51.1 million end-of-life tires in 2018 alone (*California State CalRecycle*). This vast amount of non-biodegradable waste occupies large areas and poses significant environmental hazards (Siddika et al. 2019). Meanwhile, concrete is the second most consumed material in the world after water and is the most widely used building material. Incorporating recycled waste tire rubber (WTR) into concrete offers an environmentally friendly solution, provided its effects on the concrete's mechanical properties are acceptable (Formela 2021).

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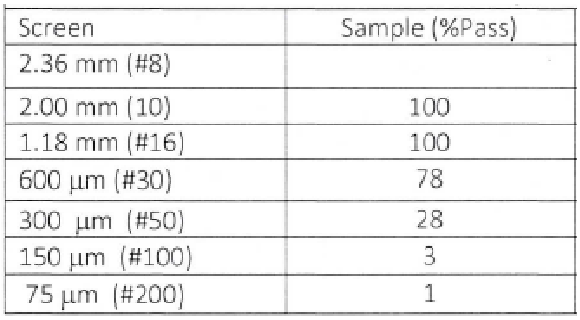
Numerous researchers have conducted experimental studies to evaluate the effect of using recycled rubber powder as a fine aggregate in concrete mixes. Gerges et al. (2018) evaluated the properties of rubberized concrete mixes, including compressive strength, split-tensile strength, and impact load capacity, by incorporating 5 to 20% rubber. They concluded that rubberized concrete can be efficiently used in certain structural applications. Siddika et al. (2019) found that the inclusion of recycled rubber aggregate can increase fatigue life, toughness, and enhance dynamic properties. They stated that concrete with recycled rubber aggregate performs well in both hot and cold weather. Hameed et al. (2016), Xiao et al. (2009), and Li et al. (2018) found that rubberized concrete can increase ductility, fatigue resistance, and impact resistance. Senin et al. (2017) suggest not including more than 20% rubber content in concrete. This paper discusses the influence of WTR on the mechanical properties of concrete, particularly compressive and flexural strengths. It presents the laboratory testing of concrete cylinders and beams to address the effect of WTR.

2. Laboratory Testing

2.1 Mix Design

Various concrete mixes were prepared using different dosages of powdered WTR. The 30 minus mesh crumb rubber was sourced from a local supplier and produced from on-road scrap tires. Table 1 details the screen parameters of the WTR. Tables 2 to 4 and Table 5 present the mix designs for 3 in. x 6 in. cylinders and 4 in. x 4 in. x 12 in. beams, respectively. Three groups of mixes were created: a baseline group without gravel or steel fibers, a group with gravel, and a group with steel fibers. Each mix group included multiple mixes with WTR contents varying from 0 to 22% of the sand weight. Three cylinders were tested for each mix.



Screen	Sample (%Pass)
2.36 mm (#8)	
2.00 mm (10)	100
1.18 mm (#16)	100
600 µm (#30)	78
300 µm (#50)	28
150 µm (#100)	3
75 µm (#200)	1

Table 1. Screen parameters of the WTR

Mix Design		**Rubber %**
Material	Weight (lbs.)	0
Cement	4.3	
Fine Aggregate-Sand	4.1	
Rubber Fiber	0	
Water	1.6	
Material	Weight (lbs.)	4
Cement	4.3	
Fine Aggregate-Sand	3.9	
Rubber Fiber	0.2	
Water	1.6	
Material	Weight (lbs.)	9
Cement	4.3	
Fine Aggregate-Sand	3.7	
Rubber Fiber	0.4	
Water	1.6	
Material	Weight (lbs.)	13
Cement	4.3	
Fine Aggregate-Sand	3.5	
Rubber Fiber	0.6	
Water	1.6	
Material	Weight (lbs.)	17
Cement	4.3	
Fine Aggregate-Sand	3.3	
Rubber Fiber	0.8	
Water	1.6	

Table 2. Baseline mix for 3”x6” cylinders

Mix Design		**Rubber %**
Material	Weight (lbs.)	**0**
Cement	2.4	
Fine Aggregate-Sand	2.3	
Coarse Aggregate-Gravel	4.8	
Rubber Fiber	0	
Water	0.9	
Material	Weight (lbs.)	**4**
Cement	2.4	
Fine Aggregate-Sand	2.2	
Coarse Aggregate-Gravel	4.8	
Rubber Fiber	0.1	
Water	0.9	
Material	Weight (lbs.)	**8**
Cement	2.4	
Fine Aggregate-Sand	2	
Coarse Aggregate-Gravel	4.8	
Rubber Fiber	0.3	
Water	0.9	
Material	Weight (lbs.)	**12**
Cement	2.4	
Fine Aggregate-Sand	1.9	
Coarse Aggregate-Gravel	4.8	
Rubber Fiber	0.4	
Water	0.9	
Material	Weight (lbs.)	**16**
Cement	2.4	
Fine Aggregate-Sand	1.9	
Coarse Aggregate-Gravel	4.8	
Rubber Fiber	0.4	
Water	0.9	
Material	Weight (lbs.)	**20**
Cement	2.4	
Fine Aggregate-Sand	1.8	
Coarse Aggregate-Gravel	4.8	
Rubber Fiber	0.5	
Water	0.9	

Table 3. Mix with gravel for 3”x6” cylinders

Mix Design		**Rubber %**
Material	Weight (lbs.)	0
Cement	4.3	
Fine Aggregate-Sand	4.1	
Rubber Fiber	0	
Water	1.6	
Steel Fiber	0.72	
Material	Weight (lbs.)	4
Cement	4.3	
Fine Aggregate-Sand	3.9	
Rubber Fiber	0.2	
Steel Fiber	0.72	
Water	1.6	
Material	Weight (lbs.)	9
Cement	4.3	
Fine Aggregate-Sand	3.7	
Rubber Fiber	0.4	
Steel Fiber	0.72	
Water	1.6	
Material	Weight (lbs.)	13
Cement	4.3	
Fine Aggregate-Sand	3.5	
Rubber Fiber	0.6	
Steel Fiber	0.72	
Water	1.6	
Material	Weight (lbs.)	17
Cement	4.3	
Fine Aggregate-Sand	3.3	
Rubber Fiber	0.8	
Steel Fiber	0.72	
Water	1.6	

Table 4. Mix with steel fiber for 3”x6” cylinders

Mix Design		**Rubber %**
Material	Weight (lbs.)	0
Cement	6.02	
Fine Aggregate-Sand	5.74	
Rubber Fiber	0	
Water	2.24	
Material	Weight (lbs.)	9
Cement	6.02	
Fine Aggregate-Sand	5.18	
Rubber Fiber	0.56	
Water	2.24	
Material	Weight (lbs.)	22
Cement	6.02	
Fine Aggregate-Sand	4.62	
Rubber Fiber	1.12	
Water	2.24	

Table 5. Mix for 4” x 4” x 12” beams

2.2 Compression Tests

The concrete cylinders were tested using a Gilson MC-300 PR concrete compression machine after 28 days. Figs. 1 to 3 show the compressive strengths of various cylinders with different WTR contents. Fig. 1 illustrates the baseline mix, which included no gravel or steel fibers. As WTR content increased from 0 to 17 percent, the compressive strength decreased from 8,458 to 3,851 psi. Fig. 2 shows the mix with gravel; compressive strength dropped from 7,016 to 3,052 psi as WTR content increased from 4 to 20 percent. A similar trend of compressive strength reduction with increased WTR content was observed when steel fibers were added (Fig. 3). At approximately 20 percent WTR content, all three mixes exhibited up to a 50 percent reduction in compressive strength, which is substantial. These findings align with those of other researchers, such as Gerges et al. (2018). Comparing Figs. 1 and 2 reveals that adding gravel increased compressive strength for the comparable WTR percentage. With the addition of steel fibers, compressive strengths further increased, as shown in Fig. 4.

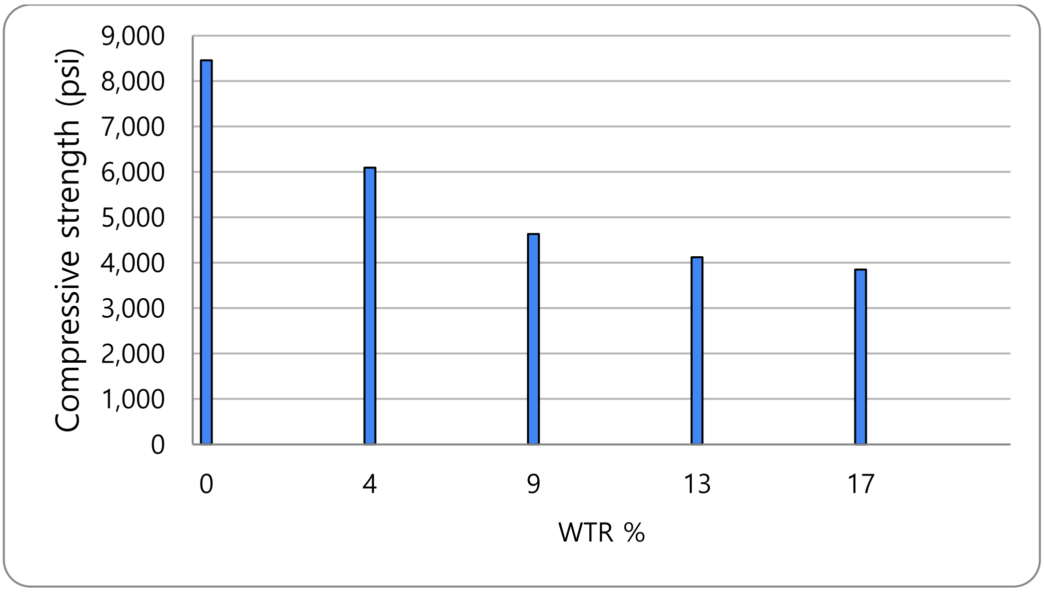


Fig. 1 Compressive strengths vs. WTR contents – baseline mix group

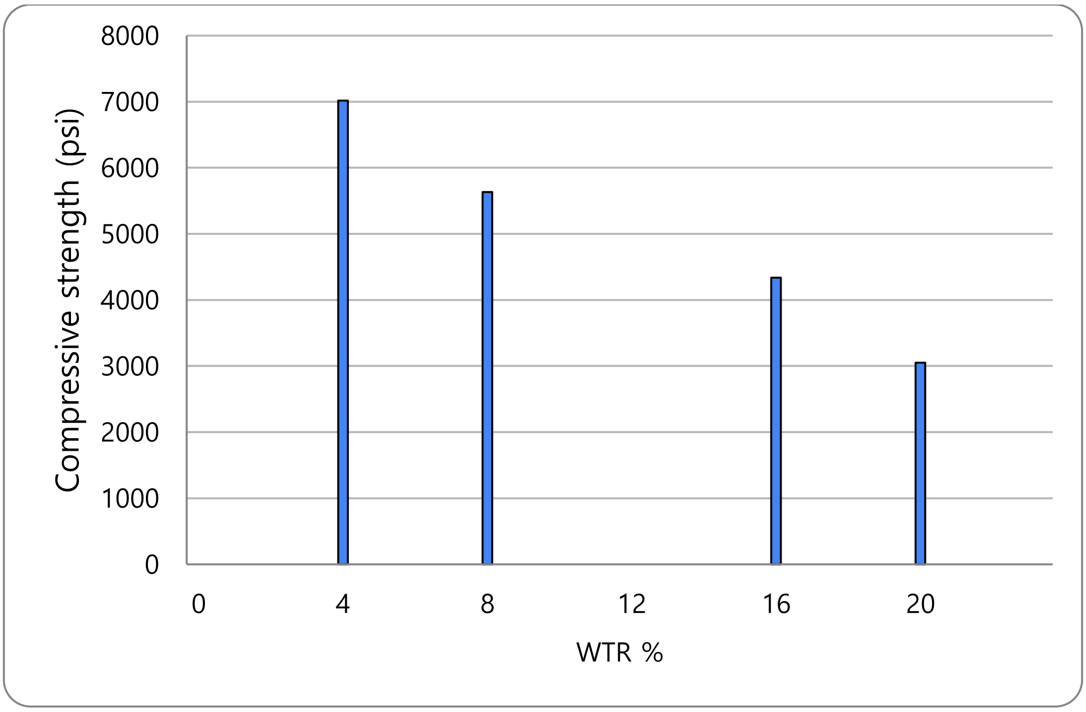


Fig. 2 Compressive strengths vs. WTR contents – mix group with gravel

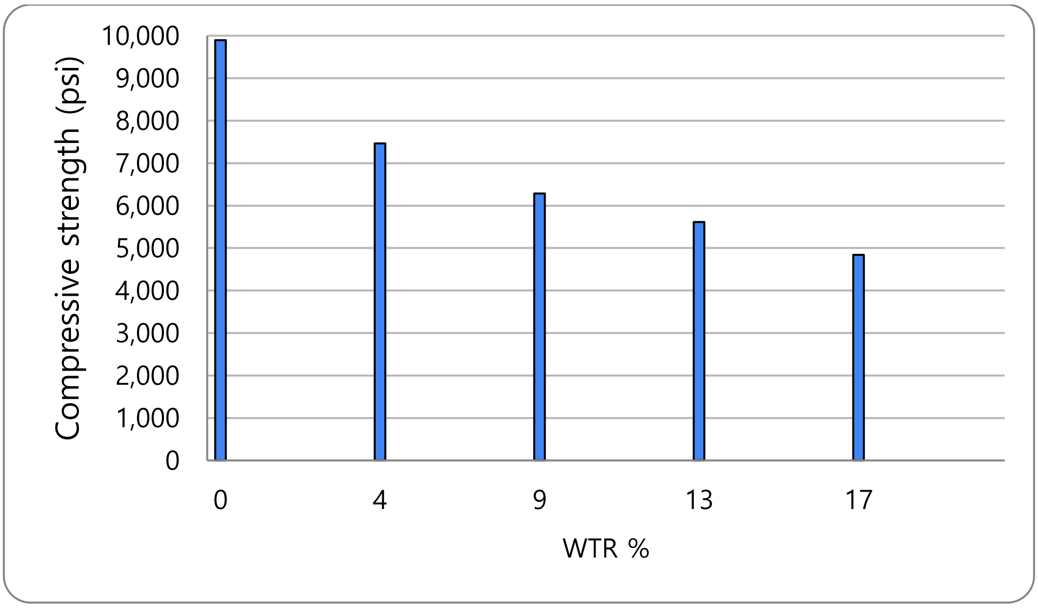


Fig. 3 Compressive strengths vs. WTR contents – mix group with steel fiber

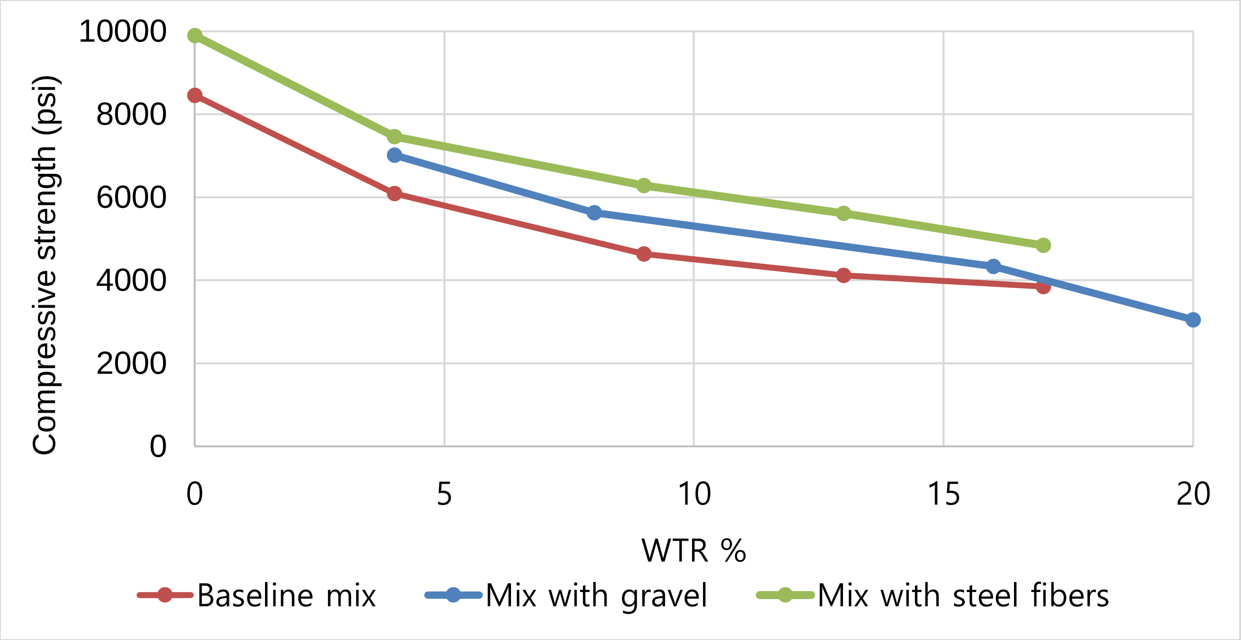


Fig. 4 Compressive strengths vs. WTR contents – all mix groups

2.3 Beam Flexural Tests

The 4 in. x 4 in. x 12 in. beams were tested to determine their flexural strengths. The beams were loaded at their mid-lengths until failure. Figs. 5 and 6 show the beam test setup and failed beam, respectively. Fig. 7 shows the peak forces applied for 9 and 22 percent WTR contents. The peak load decreased from 3,120 lbs to 1,930 lbs as the

WTR content increased from 9 to 22 percent, indicating approximately a 38 percent drop in peak load.

Fig. 5 Beam test setup

Fig. 6 Failed beam

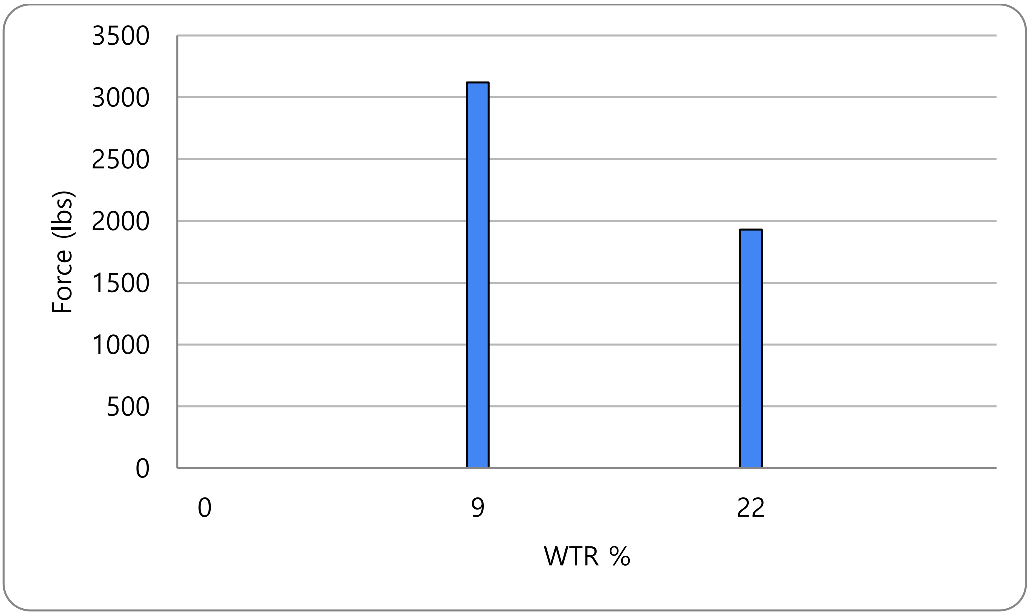


Fig. 7 Peak forces vs. WTR contents in beam tests

3. CONCLUSIONS

This paper discusses the effect of adding powdered WTR to concrete on mechanical properties, focusing on compressive and flexural strengths. Based on the cylinder and beam tests, it was found that adding WTR could reduce the strengths considerably. Replacing 20 percent of sand weight with WTR significantly impacts concrete’s compressive and flexural strengths. If the strength reduction is acceptable for certain structural applications, adding WTR could be a feasible solution for managing waste tires without causing environmental hazards. Controlling WTR content below 20 percent can minimize strength reduction. Future research on the effects of WTR on other properties, such as dynamic performance, fatigue life, and toughness, will further justify its inclusion in concrete structures.

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