Proceedings of the 7th World Congress on Civil, Structural, and Environmental Engineering (CSEE'22)
~~Lisbon, Portugal~~ Virtual Conference – April 10 – 12, 2022
Paper No. ICSECT 131
DOI: 10.11159/icsect22.131

Effect of Incorporating Shredded and Crumbed Rubber in Pavement-Grade Concrete on Elasticity and Toughness Moduli

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Abstract **-** Used car tires are generally recycled at the end of their lifecycles to make useful products. However, the phenomenon of dumping used tires in Kuwait has reached significant levels, with a “tire graveyard” containing over 7 million tires being formed in a remote area of the country. This landfill is a major environmental hazard and poses a major risk to the public health that wouldn’t be allowed in other parts of the world. To mitigate the environmental impact, the tires must be recovered and recycled at a large scale. This study aims to quantify the impact of incorporating repurposed rubber products on the toughness and modulus of elasticity of concrete. The rubber products were incorporated into concrete individually and tested to examine their properties and effects on a benchmark mix before creating a hybrid mix that contains both materials. The concrete was tested for its slump, compressive strength, split tensile strength, modulus of elasticity, toughness, and stress-strain behaviour. The use of shredded and crumbed rubber had a detrimental impact on most concrete properties examined in this study; however, the crumbed rubber improved the toughness of the concrete. Additionally, the hybrid mix displayed similar behaviour to its constituent replacement materials, with the most notable observation being a sharp drop in the mix’s toughness. Overall, the rubberized concrete displays suitable properties (compressive strength, modulus of elasticity, and toughness) for use in paving structures. Further studies could evaluate the long-term effects of using this concrete in a hot weather climate.

Keywords**:** green concrete; pavements; modulus of elasticity; toughness; tire products; shredded rubber; crumbed rubber;

1. Introduction

The method of disposal of used tires in Kuwait is a significant environmental hazard [1]. Over 50 million used tires are deserted in a massive 1 km^2 “tire graveyard” in Kuwait, with an annual accumulation rate of 480,000 tonnes [2]. Due to an ever-increasing use of private transportation vehicles in Kuwait, the build-up of used tires poses a serious risk to the ecosystem, therefore recycling waste products is fundamental [3-6]. Researchers have found that recycling waste rubber tires has several environmental and economic advantages [7,8-10]. The recycled rubber products are considered suitable and useful materials in civil engineering applications [3,11-12]. Recovered rubber tires undergo a process of shredding, separation of components, and granulation to convert them into useful by-products [13]. Some useful by-products include shredded rubber (also known as chipped rubber), crumb rubber, and ground rubber [12,14]. A study to investigate the properties of several concrete mixtures concluded that the waste rubber tire can be used to make workable rubberized concrete, and also found a reduction in the unit weight of rubberized concrete mixtures compared to plain concrete [15].

Furthermore, studies have shown [2] that increasing the roughness of shredded rubber particle surfaces could improve the performance of concrete. Additionally, using rubber particles in concrete improved some properties such as porosity, ductility, and cracking resistance performance.

Other studies [16] found that the partial replacement of sand with crumb rubber up to 25% would result in satisfactory compressive strength for structural concrete. However, the increase in the rubber content above this threshold would reduce the compressive strength to a point where the mix would not be acceptable for structural or non-structural applications.

Despite the reduction in mechanical properties due to the increasing amount of rubber in the mix [7,11-12,17-18], it is still recommended to use rubber as a replacement material in civil engineering applications, especially in pavement projects [2,7,9,11,14,19-20].

The objective of this study is to investigate the effect of incorporating recycled rubber products sourced from waste tires on the modulus of elasticity and toughness of the concrete mix. Each tire byproduct was tested individually to observe its properties and effects on a benchmark mix before creating a ‘hybrid’ mix that contains a combination of the materials.

2. Materials and Methods Used

2.1. Benchmark Concrete Mix

A benchmark pavement-grade concrete mix with a 28-day compressive strength of 35 MPa has been proportioned and cast. Concrete pavements are preferred in Kuwait due to their ability to resist high temperatures without causing permanent damage to the pavement itself. However, concrete used in hot climates is subjected to high rates of evaporation, loss of moisture, and quick setting times [21]. As a result, concrete mixes used in hot weather climates need to have a slump value at the higher end of the recommended range for pavements. A superplasticizer was used to reach the required workability while maintaining the water/cement ratio at 0.55. The mix design proportions are shown in Table 1.

Table 1: Mix design propositions of benchmark concrete

Material	**Quantity**
Cement (kg/m^3)	327
Sand (kg/m^3)	663
Coarse aggregates – 9.5 mm (kg/m^3)	740
Coarse aggregates – 12.5 mm (kg/m^3)	442
Water (kg/m^3)	180
SIKAment®-500 OM Superplasticizer (% of binder weight)	2.00
Water/Cement ratio	0.55

2.2. Recycled Tire Products

Crumb rubber (CR) and shredded rubber (SR) were obtained by recycling used tires (Figure 1). The recovered rubber used in this study is varied in source but is believed to be a blend of natural and synthetic hydrophobic rubber optimized for automobile use. For this study, the recycled tire products were provided by the Green Rubber Tire Recycling Plant in Kuwait. CR and SR are used as a partial replacement for fine and coarse aggregates respectively.

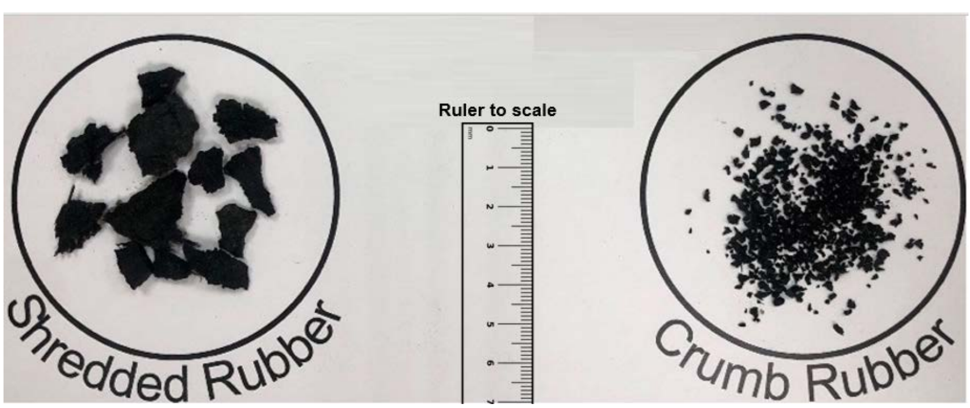
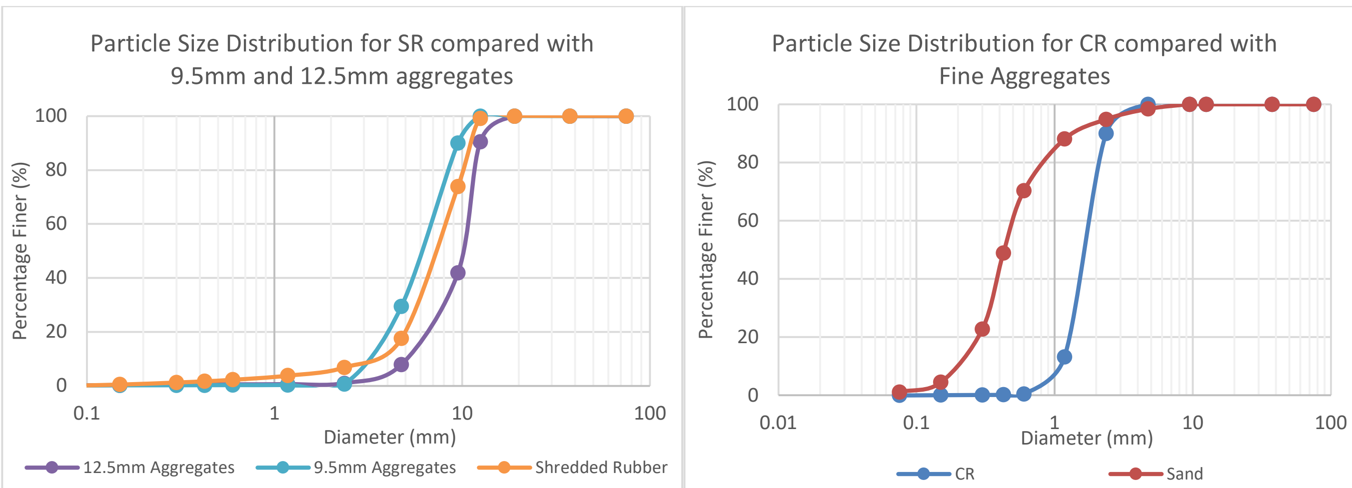


Fig. 1: Crumb rubber and shredded rubber obtained by recycling used tires

2.3. Rubber Properties

The density of SR used in this study is 566 kg/m3. In order to ensure that replacement occurred between similarly-sized sized particles, SR was sieved and only particles passing a 12.5 mm sieve were used. The size distribution of the SR, which which is compared with that of the coarse aggregates (9.5 mm and 12.5 mm), is shown in Figure 2. The particle size distribution for both sizes of coarse aggregate as well as the SR are well-distributed. Interestingly, the particle size distribution of SR fits between the distribution of the two sizes of coarse aggregates used in this study. Therefore, a direct replacement of both sizes of coarse aggregates with SR is used.

The density of CR used in this study is 552 kg/m3. The size distribution is also shown in Figure 2 and is compared with the size distribution of fine aggregate used in this project. Ideally, the CR would be introduced to replace a similarly-sized particle sizes; this is not feasible in real-life applications due to the discrepancy in particle size distribution of both materials. Therefore, a direct replacement of sand with CR is used.



(a) (b)

Fig. 2: Particle Size Distribution: (a) SR and coarse aggregates, (b) CR and fine aggregates

2.4. Description of Concrete Mixes and Sampling

A total of 6 concrete mixes were cast, including the benchmark. The mix codes and descriptions are shown in Table 2. SR and CR in the concrete mix codes show the presence of shredded rubber or crumb rubber in the concrete mix respectively. When a combination of SR and CR is used in a concrete mix, the code starts with an "H."

For each mix, 12 cylinders (100 mm diameter by 200 mm height) are cast and sulfur-capped as per ASTM C617 [22]. A minimum of 3 cylinders are tested to calculate the tensile strength at 28 days as per ASTM C496 [23]. Similarly, a minimum of 3 cylinders are used to calculate the compressive strength at 7 and 28 days as per ASTM C39 [24].

Table 2: Concrete Mixes and Descriptions

Code	% of coarse aggregate replaced with SR	% of fine aggregate replaced with CR
BM	0	0
SR-1	10	0
SR-2	20	0
CR-1	0	10
CR-2	0	20
H-1	10	10

3. Results and Discussion

3.1. Slump Test

Knowing that the slump for a pavement-grade concrete should be within 50 to 75 mm, the results of the slump test performed on the six families of concrete are shown in Figure 3. All samples except the two SR families displayed results within the recommended range; the SR results were very close to the lower bound of the recommended range. It is clear that introducing SR has a profound effect on the concrete's slump. It is interesting to note that the presence of CR had no effect on the slump, exhibiting identical results to the benchmark. The hybrid mix had an intermediate slump value falling between its two constituent materials.

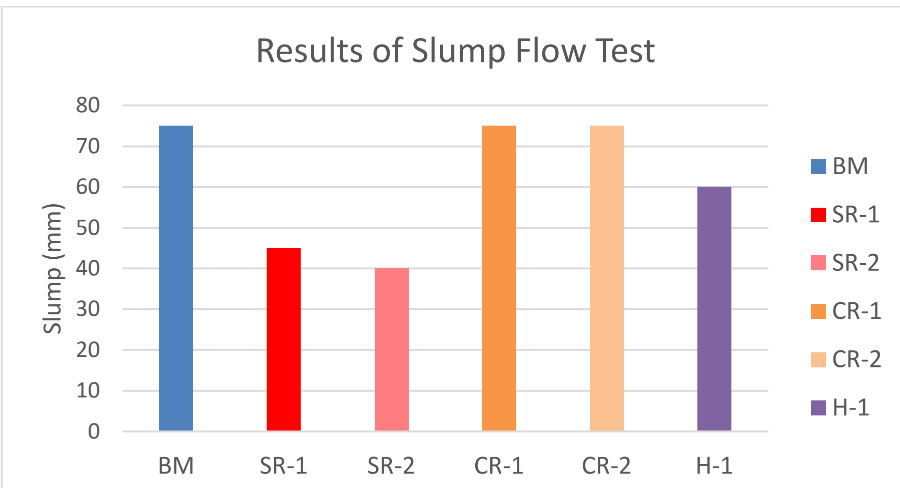


Fig. 3: Slump Test Results

3.2. Compressive Strength at 28 Days

The benchmark concrete mix was designed with a target compressive strength of 35 MPa at 28 days of age. Using the results of the benchmark concrete mix, the effects of introducing each replacement material is highlighted in Figure 4. Both replacement materials have a detrimental effect on the 7- and 28-day compressive strength, with SR samples showing a larger reduction overall compared to CR samples. It is interesting to note that the use of either replacement material does not have an effect on the rate of strength gain in the concrete. However, both the 28-day compressive strength and the rate of strength gain are impacted when a combination of both replacement materials are present in the concrete, as was the case in the hybrid mix.

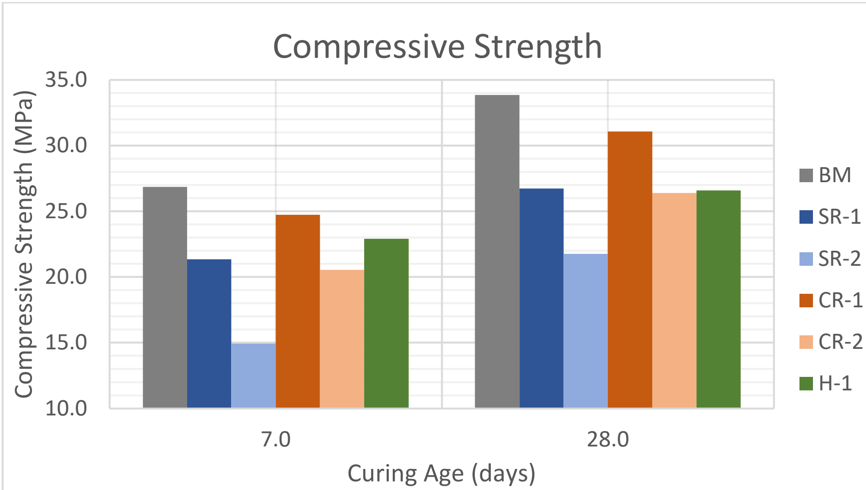


Fig. 4: Compressive Strength Test Results

3.3. Tensile Strength

The effects of introducing each replacement material on the split tensile strength is shown in Figure 5. Both replacement materials have a detrimental effect on the tensile strength, with SR samples showing a larger decrease overall compared to CR samples. Interestingly, increasing the dose of CR in a sample of concrete has a larger effect on the split tensile strength of concrete as compared to SR, which shows a smaller relative decrease in split tensile strength. The hybrid mix showed an improvement over SR-1 but fell short of reaching CR-1's split tensile strength.

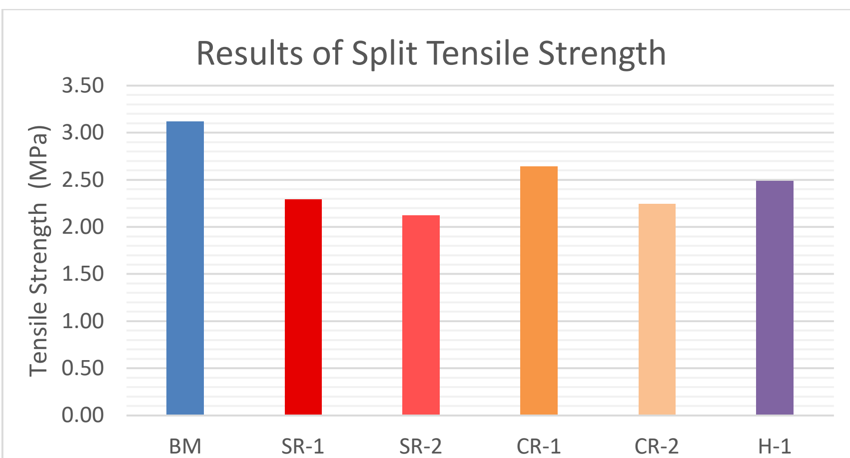
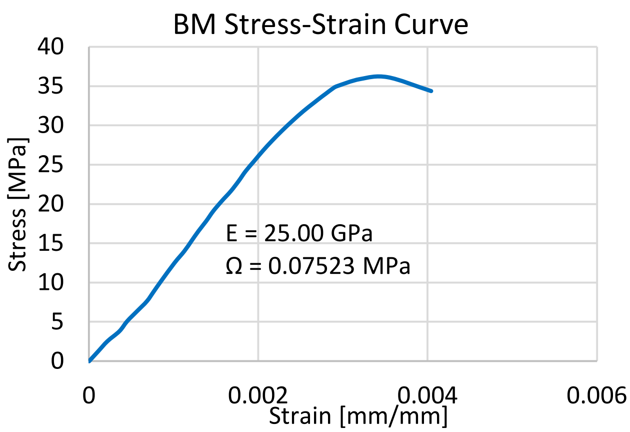


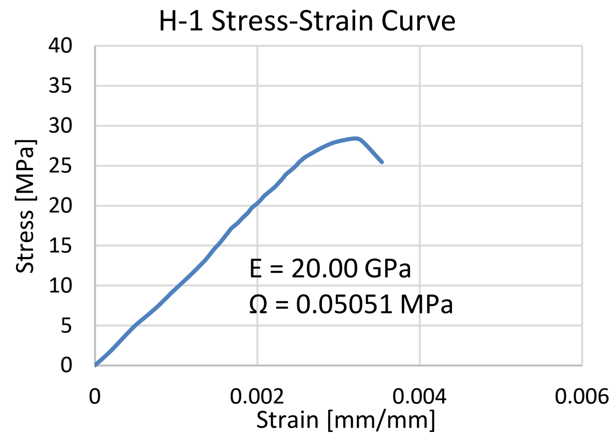
Fig. 5: Tensile Test Results

3.4. Elasticity and Toughness Moduli

Figure 6 shows the stress-strain behaviour for the 6 mixes. By examining the stress-strain relationship, the incorporation of SR leads to a well-defined peak in the diagram. On the other hand, the incorporation of CR shows a much smoother curve with not much of a defined peak. All samples containing replacement materials had a reduction in their modulus of elasticity (E) compared with the benchmark, with a maximum reduction of 20% in SR-1, CR-2, and H-1. However, it is worth mentioning that the incorporation of additional SR into the concrete mix could increase E, and vice versa for CR. Additionally, the combination of both materials into a single mix (as shown in H-1) shows no difference when compared to its constituents. As for the modulus of toughness (i.e., Ω, area under the stress-strain curve up to failure reported in MPa or N.mm per mm^3), we see that higher doses of SR lead to an increase compared to the benchmark. We also see that the introduction of CR at doses of 10% and 20% significantly improves the modulus of toughness (up to 20%). However, combining both replacement materials in a single mix significantly reduces the modulus of toughness by 33%.



(a)



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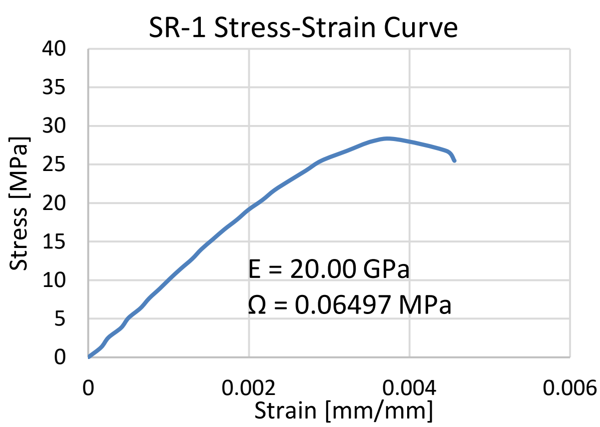
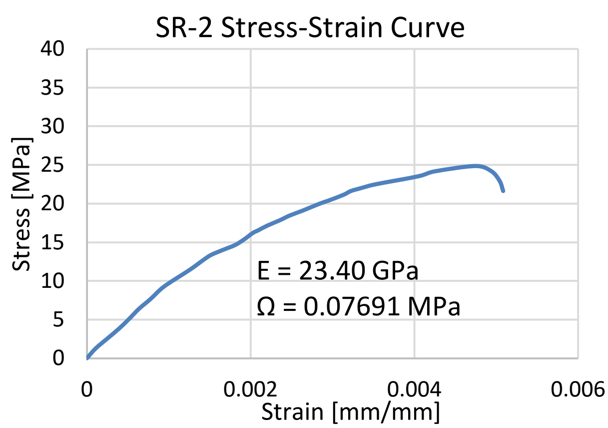


(c)



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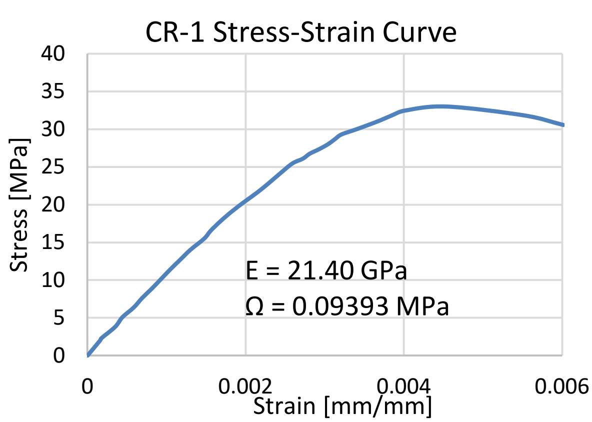
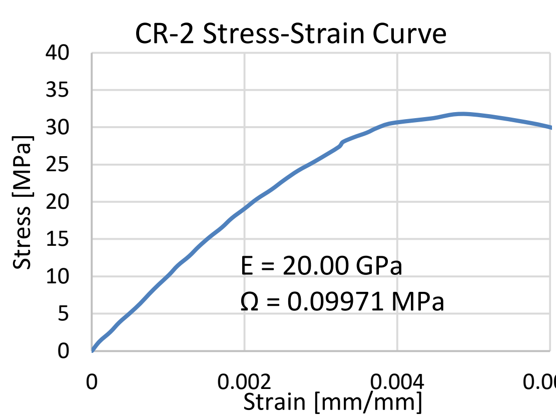


(e)



(f)

Fig. 6: Stress-Strain Curves for (a) Benchmark mix, (b) Hybrid mix, (c-d) SR family, and (e-f) CR family.

4. Conclusion

- **Slump:** As expected, the slump of concrete decreased due to the presence of SR but remained constant in the presence of CR. The hybrid mix showed a decrease in slump as well.
- **Compressive Strength:** Both materials caused the concrete to decrease in 28-day compressive strength, where SR had a much larger impact on compressive strength than CR. As expected, the compressive strength of the hybrid mix decreased as well.
- **Tensile Strength:** Both materials caused the concrete to decrease in split tensile strength, where SR had a larger impact on compressive strength than CR. As expected, the split tensile strength of the hybrid mix noticeably decreased as well.
- **Modulus of Elasticity:** Both materials exhibited a reduction of no more than 20% in modulus of elasticity.
- **Modulus of Toughness:** Both materials contributed to increasing the strain at failure by up to 25%. Samples containing SR were able to maintain the modulus of toughness of the benchmark at higher doses (20%). Samples containing CR exceeded the modulus of toughness of the benchmark at any dose. Using a combination of SR and CR severely decreases the modulus of toughness. Concrete containing CR exhibited a significant increase in the modulus of toughness, and its impact resistance, which is important in a pavement-grade concrete, will thus be improved.

Acknowledgements

This project was funded ‘partially’ by Kuwait Foundation for the Advancement of Sciences under code PR19-15EV-02.

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