Behaviour of Rubberized Concrete Beams in Shear

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Abstract. The shear strength of concrete beams manufactured from a mix including fine pieces of waste tire rubber (rubberised concrete) have been studied in several experimental programmes, with results showing a reduction in shear strength when using rubberised concrete instead of conventional concrete. In much of the recent research in this area, the main goal of the current investigation was thus to determine the extent of such reduction and to find ways to compensate for this reduction by the addition of steel fibre. A total of eight rubberised concrete beams of (140 mm width, 240 mm height, and 1240 mm length) were tested experimentally with replacement ratios by volume fraction of coarse and fine aggregate volume with fine tire waste of 0%, 25%, and 50% investigated. Additions of, 0%, 0.5% and 1.5% steel fibre content were also made to the rubberised concretes, in an attempt to test improvements in the resulting shear strength. A four-points load testing configuration was used for testing the specimens. The compressive strength of the rubberised concrete, volume fraction of steel fibres, longitudinal reinforcement ratio, replacement ratio of conventional aggregate by fine waste rubber, and shear span to depth ratio were the variables considered in this investigation, with the load-deformation behaviour and ultimate load investigated through experimental work. The test results showed that an increase in replacement ratio from 25% to 50% reduced the shear strength by 3.4%, while adding 0.5% steel fibre to the rubberised concrete increased the shear strength by 7.4% as compared with that of conventional strength concrete specimens without steel fibre. Overall, the shear modes of failure in rubberised concrete were similar to those of conventional concrete.

Keywords: Concrete beams, Modes of failure, Rubberised material, Shear strength, Steel fibre.

1. Introduction
Ongoing development in the transportation industry has led to serious problems with waste tires in many countries [1]. Every year, millions of tires are discarded as a waste, and landfill is no longer an acceptable option due to a lack of available sites for waste disposal [2]. One solution is to reuse the waste tires in concrete, creating “rubberised concrete” by replacing conventional aggregate with a fine crumb made of waste tires. Such rubberised concrete offers several potential benefits, especially in terms of dynamic behaviours, based on improved energy dissipation [3].

The shear strength of a concrete beam is reduced when conventional aggregate is replaced by fine waste tire, however, and many studies have already dealt with the effect of crumb rubber aggregate on the dynamic, mechanical behaviour and fatigue performance of concrete members [1-4]. Ahmed et al. [5] studied the shear strength of rubberised concrete beams reinforced with steel fibres. The size of crumb rubber ranged from 2 to 3 mm, and the replacement ratios of coarse aggregate were 5, 10, 15, and 20% by weight. Steel fibre was added in a volume fraction of 1%, and four-points load tests were used to show that the addition of steel fibre improved the performance and toughness of the mixtures with replacement ratios over 10%.
The reduction in shear strength of rubberised concrete can thus clearly be reduced through adding steel fibre to the concrete mixture. The main objectives of this study were thus to:

- Determine the exact shear strength reduction of rubberised concrete beams at different replacement ratios and steel fibre inclusion rates.
- Study the effects of shear span to depth ratio, replacement ratio, volume fraction of steel fibre, and longitudinal reinforcement ratio on the shear strength of rubberised concrete beams.
- Study the modes of failure of rubberised concrete beams under shear action.

2. Materials and Mix Proportions
The rubberised concrete mix proportions adopted in this investigation were taken from Bompa et al. [6]. The replacement ratios of coarse and fine aggregate by crumb fine rubber thus investigated were 25% and 50%, with maximum crumb size of 10 mm in each case. Silica fume, superplasticiser, and fly ash were used to improve the concrete strength and workability. Table 1 presents the mix design for the normal and rubberised concretes, and figure (1) shows a sample of the crumbed fine rubber.

The procedure used for constructing the rubberised concrete was as follows: all coarse and fine aggregates were mixed for two minutes, then the fine rubber, microsilica, fly ash, and cement were added and the product mixed for three minutes. Finally, superplasticiser and water were added, and the compound was mixed for four further minutes. Steel fibres of 15 mm length, and 0.2 mm diameter and maximum tensile strength of 1,250 MPa were added where required.

A reinforcement of 12 mm was used in the construction of the concrete beams. The target compressive strength in NSC is 25 MPa, with 25 to 35 MPa expected for rubberised concrete at 28 days of age. The beams were demoulded one day after pouring, and a process of curing was applied for 28 days.

| Table 1: Mix proportions |
|-------------------------|
| **fc** (MPa) | 25 | 25 | 25 | 35 |
| Type of concrete | Normal | Rubberised | Rubberised | Rubberised |
| Replacement ratio (%) | 0 | 25 | 50 | 50 |
| Microsilica | - | 44 | 44 | 44 |
| Fly ash | - | 43.4 | 43.5 | 42.5 |
| Fine rubber (kg/m³) | 0 | 112 | 220 | 220 |
| Cement (kg/m³) | 365 | 342 | 340 | 410 |
| Sand (kg/m³) | 778 | 548 | 492 | 611 |
| Gravel (kg/m³) | 1084 | 656 | 600 | 772 |
| Superplasticiser (kg/m³) | - | 7.7 | 7.6 | 7.6 |
| Water (kg/m³) | 187 | 148 | 149 | 149 |
| W/C | 0.51 | 0.43 | 0.43 | 0.36 |
Figure 1: Sample of fine rubber crumb

3. Specimens
The dimensions of each tested beam were 140 mm width, 240 mm height, and 1,240 mm length, as shown in Figure 2. According to ACI 318-14 [7], the R1-Rep50\% control beam is designed to fail in shear. Specimens were constructed from normal strength concrete (NSC), rubberised concrete with a crumb replacement ratio of 25\% (R1-Rep25) and rubberised concrete with a crumb replacement ratio of 50\% (R1-Rep50).

Figure 2: Test specimen dimensions

4. Experimental Work
A total of eight concrete beams were tested under four-point loading in laboratory of the civil engineering department, University of Technology, Iraq. The variables considered included the effect of replacement ratio of conventional aggregate by fine rubber on the shear strength of rubberised concrete, which was studied using three specimens (R1-Rep50, R2-Rep25\%, R3-Rep0); the effect of volume fraction of steel fibre on the shear strength of rubberised concrete, investigated in three specimens (R1-Rep50, R4-fib1.0 and R5-fib1.5); the compressive strength effect, was studied in two specimens (R1-Rep50 and R6-fc35); the effect of shear span to depth ratio, investigated in two specimens (R1-Rep50 and R7-a/d1.0); and finally, the longitudinal reinforcement ratio effect, studied in two specimens (R1-Rep50 and R8-\rho1.5). Table 2 lists the characteristics of the tested specimens.
### Table 2: Characteristics of tested specimens

| Specimens | Replacement ratio | f<sub>c</sub> (MPa) | Shear span/depth ratio (a/d) | Reinforcement ratio (%) | Volume fraction of steel fibre (%) |
|-----------|-------------------|-----------------|-----------------------------|------------------------|-----------------------------------|
| R1-Rep50  | 50%               | 25.2            | 1.6                         | 0.77                   | 0.5                               |
| R2-Rep25  | 25%               | 25.5            | 1.6                         | 0.77                   | 0.5                               |
| R3-Rep0   | 0%                | 25.7            | 1.6                         | 0.77                   | 0                                 |
| R4-fib1.0 | 50%               | 27.1            | 1.6                         | 0.77                   | 1.0                               |
| R5-fib1.5 | 50%               | 28              | 1.6                         | 0.77                   | 1.5                               |
| R6-fc35   | 50%               | 35.3            | 1.6                         | 0.77                   | 0.5                               |
| R7-a/d1.0 | 50%               | 25.2            | 1.0                         | 0.77                   | 0.5                               |
| R8-ρ1.5   | 50%               | 25.2            | 1.6                         | 1.50                   | 0.5                               |

5. Test Setup

Four-point loading was applied at the one-third span between the supports to test the specimens. The beams each had a simple span of 1,040 mm, with a shear span to depth ratio of 1.6. A dial gauge was used to measure vertical displacement at the mid span of the beam, with load increments of 0.2 kN/s applied to the beam through the steel I-section. Figure 3 shows the test setup.

![Figure 3: Test setup](image)

6. Experimental Results

6.1. Effects of Variables on the Shear Strength of Rubberised Concrete

The ultimate load at failure in each case is summarised in Table 3. It can thus be noted that:

- The increase the replacement ratio from 25% (R2-Rep25) to 50% (R1-Rep50) reduced the shear strength of rubberised concrete by 3.7%, due to conventional aggregate interlock effects on the shear strength of concrete.
- In rubberised concrete, adding 0.5% of steel fibre (R1-Rep50) increased the shear strength by 7.4% as compared with the NSC specimen without steel fibre (R3-Rep0). This confirms the influence of steel fibre in increasing the shear strength of rubberised concrete as compared with the aggregate interlock in conventional concrete.
• The shear strength of rubberised concrete increased by 6.3% when the compressive strength increased from 25 (R1-Rep50) to 35 MPa (R6-fc35), due to the significant role of compressive strength.

• The shear strength of rubberised concrete increased by 8.6% when the shear span to depth ratio decreased from 1.6 (R1-Rep50) to 1.0 (R7-a/d1.0). This was expected due to the reduction in the distance between the support and the applied load, which increases the applied shear.

• An increase of 6.2% in shear strength was observed when the reinforcement ratio of rubberised concrete increased from 0.77% (R1-Rep50) to 1.5% (R8-ρ1.5), due to reinforcement dowel action.

• The shear strength of rubberised concrete increased by 24.4% when the steel fibre content increased from 0.5% (R1-Rep50) to 1.5% (R5-fib1.5), due to the bridging effect in diagonal tension.

| Specimens | Ultimate load (kN) |
|-----------|--------------------|
| R1-Rep50  | 43.20              |
| R2-Rep25  | 41.73              |
| R3-Rep0   | 40.20              |
| R4-fib1.0 | 48.88              |
| R5-fib1.5 | 53.77              |
| R6-fc35   | 45.95              |
| R7-a/d1.0 | 46.93              |
| R8-ρ1.5   | 45.88              |

6.2. Load-deformation Behaviour
The applied load vs. deflection at mid-span for each variable as compared with the reference specimen (R1-Rep50) is depicted in Figure 4. This clearly shows that the specimens display approximately linearly behaviour to failure, which confirms the brittle nature of shear failure in these specimens. Increases in the compressive strength, volume fraction of steel fibre, and reinforcement ratio increase the stiffness of the load-deflection relationship, which decreases with increases in shear span to depth ratio.
6.3. Modes of Failure
As shown in Figure 5, the shear failure of rubberised concrete beams is similar to that of conventional concrete. The shear failure starts with hair-width flexural cracks in the area of constant flexural moment, while shear cracks begin in the area of constant shear force and near the support at the tension zone. As the load increases, these cracks propagate and move in an inclined plane toward the applied load, causing shear failure. It should also be noted that:

• Increases in the replacement ratio of conventional aggregate by waste rubber from 25% to 50% accelerate the appearance of shear cracks.
• Decreases in the shear span to depth ratio from 1.6 to 1.0 in rubberised concrete increase the brittleness behaviour of specimens at failure.
• Increases in the steel fibre content, decrease the compressive strength, while the longitudinal reinforcement seen in rubberised concrete results in transferring the mode of failure from brittle to ductile.
Figure 5: Modes of failure

7. Conclusions
This study produced the following findings with regard to the shear strength of rubberised concrete beams:

• Increases in the replacement ratio from 25% to 50% reduce the shear strength by 3.4%.
• In rubberised concrete, adding 0.5% steel fibre to the concrete increases the shear strength by 7.4% as compared with an NSC specimen without steel fibre.
• The shear strength of rubberised concrete increases by 6.3% when the compressive strength increases from 25 to 35 MPa.
• The shear strength of rubberised concrete increases by 8.6% when the shear span to depth ratio decreases from 1.6 to 1.0.
• An increase of 6.2% in shear strength is observed when the reinforcement ratio of rubberised concrete increases from 0.77% to 1.5%.
• The shear strength of rubberised concrete increases by 24.4% when the steel fibre content increases from 0.5% to 1.5%.
• The shear modes of failure in rubberised concrete are similar to those of normal strength concrete.

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