# Comparative Study of the Mechanical Behavior of Concrete Railway Sleeper Mix Design, using Waste Rubber and Glass Materials

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*Abstract: Waste rubber tires and glass powders, are hazardous materials for the environment. One of the methods to consume them, is their application in railway engineering projects. Rubber and glass materials, in this research, are provided from waste tires and glass bottles. Therefore, a modification is conducted to the concrete railway sleeper mix design, incorporated with waste rubber (R) and glass powder (GP). Three mechanical tests, including compressive, flexural and tensile splitting, have been studied on rubber and glass powder concrete specimens. Three different percentages of 5%, 10% and 15% by cement weight, for GP and by fine aggregate volume for R, are investigated herein. The results show that GP concrete has a better performance over the rubber concrete (RC), but lower than Ref. specimens. 5%GP as the best mix design, has compressive, flexural and tensile strengths of 45.4 MPa, 7.5 MPa and 5.82 MPa, respectively. Moreover, these strengths, for compressive and flexural, of 5%GP are about 24% and 6% lower than the Ref. strengths, respectively, while, tensile splitting strength is almost 14% higher than Ref. strength.*

*Keywords: Concrete railway sleeper; waste rubber; waste glass; recycled materials*

## 1 Introduction

Railway sleepers are an important component of railway tracks, that help to disperse and reduce train loads from the rail foot to the underlying ballast bed and, as a result, to subgrade of the track [1]. Timber, concrete, and steel are used to make traditional sleepers [2]. The majority of railway tracks were made of wood sleepers, but due to their environmental problems, they were gradually replaced by other types of sleepers [3]. Steel sleepers were utilized instead of wooden sleepers to replace them [4]. When it comes to the performance of steel sleepers, there are concerns with high train speeds and corrosion [5]. In railway engineering, concrete sleepers are widely utilized [6]. Their performance on railway tracks results in lower maintenance costs, increased track stability, and extended track life cycles [7]. Mono-block concrete sleepers are one of the most common types of pre-stressed concrete sleepers used in railway tracks [8].

Jing et al. [2] assessed the combination of glass powder and steel fiber as a silica fume replacement in concrete railway sleeper mix design. Results showed that with the consideration of the performance and cost, the combination of 10% GP and 1.5% steel fiber is optimal mix design. Cementitious composites with glass powder were tested by Siad et al. [9] to test the concrete's mechanical behavior, glass powder was used instead of fly ash. GP improve the performance of concrete by 20%. In a study, Ramdani et al. [10] employed GP coupling with rubber fibers. They demonstrated that combining rubber fiber with GP can improve concrete's mechanical qualities. The performance of GP in concrete has been studied by a number of researchers. Generally, non-crystalline silica, sodium oxide, calcium oxide, and other components are ingredients of GP. As a result, the high silicon concentration of GP material makes it ideal for the concrete industry, making it acceptable for partial cement replacement [11-13]. Some investigations were conducted using UHPC's behavior with GP to better understand glass powder in microstructure [14-16]. The presence of GP decreases chloride penetrability and the corrosion risk of bars placed in concrete sleepers, according to Shayan and Xu [17], especially in high chloride content locations. Kou and Xing [18] founded out that GP content in concrete decreased 7 days compressive strength, however; the cement replacement by GP is very useful in case of rehology.

Rubber concrete (RC) has been widely used in a variety of applications, including the manufacture of sleepers. Jing et al. [6] studied manufacturing of a rubber concrete railway sleeper. In this study behavior of a rubber and conventional concrete railway sleepers are compared using digital image correlation (DIC). The results show that the rubber pre-stressed concrete sleeper has a resistance against crack initiation by 20% greater than that of the conventional pre-stressed concrete sleeper. Anilkumar et al. [19] demonstrated that rubber concrete sleepers with crumb rubber as fine aggregate have a higher deflection, especially when the rubber content is increased from 5% to 15%, and their impact absorption is higher than that of sleepers without rubber content. In another research, Hameed et al. [20] looked at the effects of rubber crumb as a fine aggregate on railway sleeper impact absorption. When compared to pre-stressed concrete sleepers, the impact strength of railway sleepers containing crumb rubber increased by 60%. Larger fracture widths and deflections result from RC's weaker mechanical qualities, including as compressive and flexural strengths [20-22]. Furthermore, their distinct bond behavior [23], which is primarily attributable to mechanical properties, necessitates assessing their fracture behavior in order to evaluate crack width. Rubber has been widely studied as an aggregate or fiber material in concrete [24-27]. Superior impact absorption [28, 29], stronger ductility [30, 31], better dynamic qualities including damping features [32-34] and higher resistance to the beginning of first cracks in the concrete [35, 36] are the four primary characteristics of rubber concrete which are significantly important for concrete railway sleepers.

None of the referenced papers have compared the behavior of waste rubber and glass materials, in concrete railway sleeper mix design. Consuming these materials can protect the environment and, moreover, can reduce the production cost of concrete railway sleepers, as well as, a reduction of deposits of waste materials. Therefore, in this research, attention to different admixtures, incorporated with waste rubber and glass, and the performance of the concrete railway mix design is studied.

# 2 Experimental Program

## 2.1 Materials and Mix Proportion

The materials of seven mixtures of rubber and glass concrete and Ref. concrete are introduced in the current section with 5%, 10% and 15% by cement weight for GP and by fine aggregate volume for R (Table 1). All the materials that are used in this research, excluding rubber and glass particles are the same as those are used by a concrete sleeper factory to produce conventional concrete sleeper. Ordinary Portland cement type (II) has been used for mixtures. The rubber used in this research obtained from waste tires. After gathering and omitting steel wires, they are changed to powder in a factory (Table 2). A poly-carboxylate superplasticizer is used for all the concrete mixtures. The gradation graphs of fine and coarse aggregates are presented in Figure 1. Sand is one of the expensive materials in concrete sleeper production. Considering the important role of sleepers in railway tracks, good quality of materials is expected. Sand is one of the expensive materials as most of the time they are produced using stone crushing machine. The Glass powder that is used in this research is obtained from waste glasses, which were purchased from a factory. After gathering the waste glass and washing them, they are changed to a powder for different purposes (Table 2). The glass powder (GP) material has a maximum particle size of 0.01 mm. To combine powder materials with concrete admixture and also avoid particle agglomeration, they are mixed before the water and a superplasticizer is added. First, the fine aggregates are mixed in the mixer followed by adding the powder materials and mixed for around 4 minutes. Then almost half of the 2% (by cement weight) superplasticizer is diluted in the admixture water and is gradually added within 2 minutes. The remaining superplasticizer are gradually added, during a next 4 minutes of mixing. The fresh concrete is cast in two kinds of molds, with dimensions of 100 * 100 * 400 mm prismatic and 100 mm cubical. The specimens without movement are covered with plastic sheets and are kept at ambient temperature for a day before demolding. After demolding, the samples are cured in with heat and vapor. The curing method is in this way that specimens are cured at 20 ℃ for 73 hours of curing time, then the heat is smoothly raised to 90 ℃. This heat is stable for 50 hours, afterwards, it is gradually reduced back to 20 ℃. For validity of test results, each mix of 3 specimens are manufactured and tested.

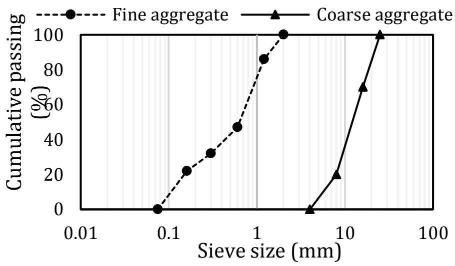


Figure 1
Gradation curve of concrete aggregates

Table 1
Concrete admixtures

| Mix ID | W/C | Cement | Glass powder | Rubber | Fine agg. | Coarse agg. |
|---|---|---|---|---|---|---|
| | | (kg/m$^3$) | | | | |
| Ref. | | 400 | - | - | 691 | 1229 |
| 5GP-0R | | 377 | 23 | | 691 | 1229 |
| 10GP-0R | | 354 | 46 | - | 691 | 1229 |
| 15GP-0R | 0.3 | 331 | 69 | | 691 | 1229 |
| 0GP-5R | | 400 | | 14.23 | 656.4 | 1229 |
| 0GP-10R | | 400 | - | 28.46 | 621.9 | 1229 |
| 0GP-15R | | 400 | | 42.69 | 587.3 | 1229 |

Table 2
Glass powder and waste rubber properties

| Type of Material use | Size | Density (g/cm$^3$) | Pictures |
|---|---|---|---|
| sand aggregate replacement | 0.28 mm | 1.085 |  |

| | | | |
|---|---|---|---|
| Cement replacement | 13μm | 2.1 |  |

## 2.2. Compressive Strength Test

Seven concrete specimens, including glass powder, rubber specimens and Ref. are tested in compressive strength test as shown in Figure 2. The results indicate that the presence of glass powder and rubber decrease concrete strengths. A 5% mix of glass powder, has the highest strength between glass powder and rubber specimens, however, it is 25% lower than Ref. strength. 5GP-0R is followed by 0GP-5R specimen with 43.5 MPa compressive strength. The Ref.'s compressive strength is about 60.5 MPa. Overall, increasing rubber and glass powder decreases concrete strengths. 5%, 10% and 15% glass powder by weight of cement specimens have strengths almost 25%, 30% and 40%, respectively, and 5%, 10% and 15% rubber by volume of fine aggregate have about 28%, 29% and 34% lower compressive strength, respectively, than Ref. with 60.5 MPa strength. Therefore, for the case of using waste materials glass powder in 5% of cement weight, shows better performance than other admixtures.

Figure 2
An overview of compressive strength test machine

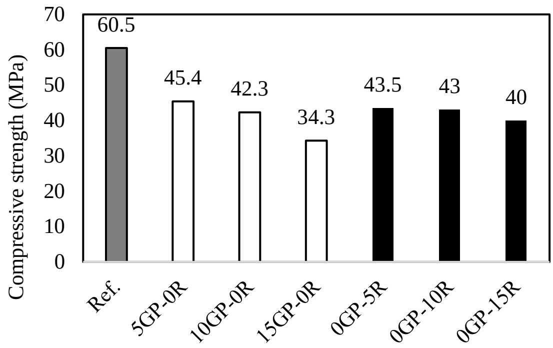


Figure 3
Compressive strength and flowability of concrete specimens

## 2.3. Flexural Strength Test

Flexural strengths of Ref. specimen decreases in presence of rubber and glass powder. Figure 4 shows an overview of flexural strength of specimens. Ref. specimen has 8 MPa strength almost 6%, 6% and 10% higher than 5GP-0R, 10GP-0R and 15GP-0R specimen's strengths, respectively. These difference percentages for rubber concrete specimens, including 0GP-5R, 0GP-10R and 0GP-15R are 6%, 8% and 10% respectively. Maximum flexural strength is identical between 5GP-0R and 0GP-5R as 7.5 MPa (Figure 5).

Figure 4
An overview of flexural test layout

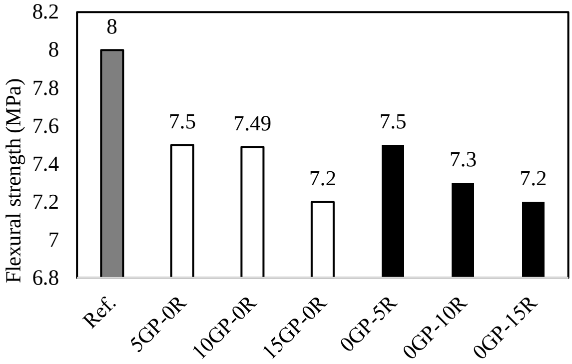


Figure 5
Flexural strength test results of concrete specimens

## 2.4 Splitting Tensile Strength

The splitting tensile strength of the different admixtures with glass powder and rubber are shown in Figure 6. Concrete has weakness in tension, therefore, splitting tensile strength test is one of the necessary tests to determine the concrete specimens in which load level may crack. The results indicate that the presence of fibers in admixture improves the concrete splitting tensile strength. The highest value of splitting tensile strength test is obtained by 5GP-0R as 5.82 followed by 0GP-5R and Ref. Presence of glass powder and rubber improve tensile strength of concrete. 10% and 15% glass powder and rubber have 10%, 14% and 8%, 10%, respectively, lower strengths than Ref. as shown in Figure 7.

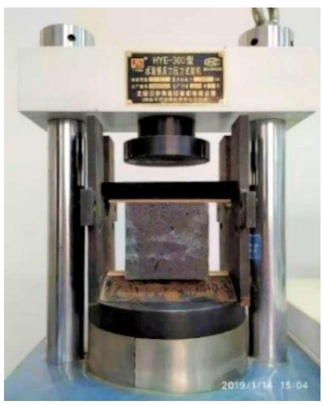


Figure 6
Splitting tensile test layout of concrete specimens

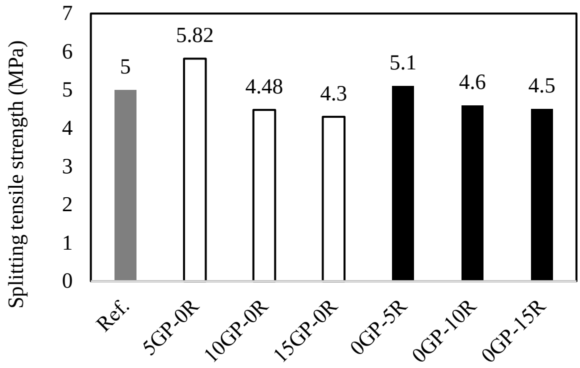


Figure 7
Splitting tensile strength of concrete specimens

# 3 Results and Discussion

This study aims to use environmentally troublesome waste materials in railway engineering projects. Therefore, three different percentages as 5%, 10% and 15% of glass powder by cement weight and rubber by fine aggregate volume are studied in comparison with a Ref. mix of concrete railway sleeper. Generally, the presence of waste materials reduces concrete strength, but considering cost and environmental issues, they still can be used in concrete railway sleepers production. Thus, concrete mixtures have been manufactured by adding glass powder and rubber as 5GP-0R, 10GP-0R, 15GP-0R, 0GP-5R, 0GP-10R and 0GP-15R. Mechanical properties of all mixtures were measured and compared with compressive, tensile and flexural strengths of concrete railway sleeper to determine the performance of railway concrete mix design as presented in Table 3. The test results show that the mechanical performance of admixture of 5GP-0R is the best among all other admixtures. However, splitting tensile strength of 5% glass powder shows better results than Ref., but generally, the mechanical behavior of concrete decreases. Considering the cost for 1 m$^3$ concrete manufactured, using recycled materials, it can be seen that a 5%GP, has an almost 10% cheaper price, followed by 10% and 15% of GP, with 18% and 27% less cost than the Ref. concrete, respectively. Rubber particles are even cheaper than GP as 5%R, has an 11% cheaper price. The percentages for 10% and 15% of rubber (R) are 20% and 29% cheaper than the Ref., respectively.

Table 3
Steel fibers properties

| Notation | Compressive strength | Flexural strength | Splitting tensile strength | Cost |
|---|---|---|---|---|
| | MPa | | | RMB |
| Ref. | 60.5 | 8 | 5 | 6766 |
| 5GP-0R | 45.4 | 7.5 | 5.82 | 6100 |
| 10GP-0R | 42.3 | 7.49 | 4.48 | 5500 |
| 15GP-0R | 34.3 | 7.2 | 4.3 | 4900 |
| 0GP-5R | 43.5 | 7.5 | 5.1 | 6050 |
| 0GP-10R | 43 | 7.3 | 4.6 | 5350 |
| 0GP-15R | 40 | 7.2 | 4.5 | 4820 |

## Conclusions

In this study, 7 admixtures are prepared to investigate the performance of waste materials, including waste glass and rubber, and their influence on concrete railway sleeper mix design mechanical properties. To study waste materials and compare their behavior, different glass powder and rubber, ratios are considered as (5%GP-0%R), (10%GP-0%R), (15%GP-0%R) and (0%GP-5%R), (0%GP-10%R), (0%GP-15%R). The following results are concluded from this study:

1) The 5%, 10% and 15% glass powder by weight of cement specimens have 25%, 30% and 40% lower compressive strengths than Ref., respectively. While, 5%, 10% and 15% rubber by volume of fine aggregate have 28%, 29% and 34% lower compressive strengths than Ref. with 60.5 MPa strength, respectively.

2) The Ref. specimen has 8 MPa strength almost 6%, 6% and 10% higher than 5GP-0R, 10GP-0R and 15GP-0R specimen's strengths, respectively. These difference percentages for rubber concrete specimens, including 0GP-5R, 0GP-10R and 0GP-15R are 6%, 8% and 10%, respectively.

3) 10% and 15% glass powder and rubber have 10%, 14% and 8%, 10%, respectively, lower strengths than Ref., while 5% GP and R have higher splitting tensile strengths by 16% and 2% than Ref., respectively.

4) A 5G-0R mix design shows the best performance in case of mechanical properties among other specimens contain waste materials and can be used for manufacturing a concrete railway sleeper.

5) Considering that sand is an expensive materials, in concrete sleeper manufacturing, using GP and R can reduce the finished concrete sleeper price by 10%, 18% and 27% for a 5%, 10% and 15% of glass powder, respectively, and 11%, 20% and 29% cheaper than the Ref. cost for rubber concrete, respectively.

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