Behaviour of Steel Fibre Reinforced Rubberized Continuous Deep Beams

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Abstract. Transfer girders and pier caps, which are in fact deep beams, are critical structural elements present in high-rise buildings and bridges respectively. During an earthquake, failure of lifeline structures like bridges and critical structural members like transfer girders will result in severe catastrophes. Ductility is the key factor that influences the resistance of any structural member against seismic action. Structural members cast using materials having higher ductility will possess higher seismic resistance. Previous research shows that concrete having rubber particles (rubcrete) possess better ductility and low density in comparison to ordinary concrete. The main hindrance to the use of rubcrete is the reduction in compressive and tensile strength of concrete due to the presence of rubber. If these undesirable properties of rubcrete can be controlled, a new cementitious composite with better ductility, seismic performance and economy can be developed. A combination of rubber particles and steel fibre has the potential to reduce the undesirable effect of rubcrete. In this paper, the effect of rubber particles and steel fibre in the behaviour of two-span continuous deep beams is studied experimentally. Based on the results, optimum proportions of steel fibre and rubber particles for getting good ductile behaviour with less reduction in collapse load is found out.

1. Introduction

The reports of National Disaster Management Authority of India reveal the fact that more than 60% of India is under the threat of moderate to severe earthquake. In the event of a disaster like an earthquake due consideration must be given for the protection of lifeline structures like bridges and critical load-carrying members of high rise building. The failure of these structures will intensify the resulting damage during these disasters. Deep beams are important structural members found in bridges and high rise building as pier caps and transfer girders respectively. Ductility is one of the most significant factors that influence the seismic resistance of any structure. Many studies were conducted to improve the properties of concrete by adding different materials. The results of some of these research show that the presence of crumb rubber in concrete led to improved ductility and energy absorption capacity [1]. Adding crumb rubber to concrete (as a partial replacement to fine aggregates) helps in reducing the density of concrete which also helps in improving the seismic resistance of the structure. Such a concrete having crumb rubber as partial replacement to its aggregate (fine/coarse) is termed as rubcrete. The major drawback of rubcrete was the reduction in compressive and tensile strength due to the presence of rubber particles. Khatib and Bayomy [2] found the lack of adhesion between the cement paste and rubber particles as the reason for the reduction in strength of rubcrete. Some researchers tried to modify the surface of rubber particles using chemicals like NaOH, Polyvinyl Alcohol, etc. for controlling the lack of bond between the cement paste and rubber particles. Chou et al [3] tried pre-treating rubber particles using NaOH for improving strength and stiffness of resulting concrete. They concluded better strength for the concrete mixes containing pre-treated rubber particles in comparison to ordinary rubcrete.
Another material which possesses the potential to improve the tensile strength and ductility of concrete is steel fibre. Steel fibre reinforced concrete (SFRC) is a cement based composite which is reinforced with randomly distributed steel fibres. Steel fibre reinforced concrete was systematically studied by Romualdi and Batson [4]. From this period, a lot of research was done to study the effect of steel fibres in concrete. As far as concrete is considered it is weak in carrying tensile stresses. As a result, its resistance to cracking is limited. Presence of discrete randomly distributed steel fibres in the concrete matrix will help in overcoming these limitations and improves many of its properties. The research done by Shah and Rangan [5] found an increase of 6 - 17% compressive strength, 18 - 47% split tensile strength, 22 - 63% flexural strength and 8 - 25% modulus of elasticity corresponding to the different percentage of fibre. Work carried out by Thomas and Ramasamy [6] also showed similar results for fibre content varying from 0 to 1.5%. Enhanced peak strain capacity of about 30% was noted as another significant benefit derived from the use of fibre. In comparison to ordinary concrete, SFRC usually has improved ductility, toughness and load carrying capacity.

Elavenil and Knight [7] studied the behaviour of steel fibre reinforced beams having different aspect ratio and fibre content. By varying the aspect ratio of steel fibre from 50 to 100 for a fixed fibre content of 1%, it was observed that the flexural strength had an improvement of 11 – 50%. It was also noted that the primary factor that influences the increase of flexural strength was the fibre content.

Noaman et al [8] studied the combined effect of crumb rubber and steel fibre on impact energy of concrete beams. Fine aggregate of ordinary concrete and steel fibre reinforced concrete were replaced partially with crumb rubber having a size between 1–2 mm. Their study showed that impact energy for specimens having a combination of rubber (20%) and steel fibre (0.5%) was 61% higher than that of SFRC specimen.

Based on the literature survey it was concluded that Rubcrete is a newly developing material which can contribute, improved ductility to concrete structures and side by side reduce a non-degradable waste material. The main drawback of rubcrete was the reduction in compressive strength and tensile strength due to the presence of rubber particles. Literatures relating to SFRC shows that the presence of steel fibre in concrete can enhance its tensile strength, which was one of the limitation found while using rubcrete. The results of available work on SFRC and the combined effect of crumb rubber and steel fibre reveals the potential of latter in controlling the undesirable effects of rubcrete. Most of the available work on steel fibre and crumb rubber combination is limited to small scale elements like cubes, cylinders, prisms, etc. Research work done on larger structures like beams, columns, deep beams, beam column junction, frames, etc. are limited. From the conducted literature survey, it was understood that most of the available work done on deep beams are on simply supported deep beams. But in many of the real life structures like transfer girders in high-rise buildings, bridges, etc. deep beams will be supported continuously. Hence, an attempt is made to study the behaviour of two span continuous concrete deep beams having crumb rubber and steel fibre in different proportions. Based on the results of the experimental work, the optimum content of crumb rubber and steel fibre for maximum load carrying capacity is also suggested.

2. Experimental Work

The objectives of the present investigation were to study the behaviour of two-span continuous deep beams cast using steel fibre reinforced rubberized concrete (SFRRC) and to find the optimum combination of crumb rubber and steel fibre content for SFRRC, that will result in better performance and ultimate load carrying capacity.

For this, sixteen two-span continuous concrete deep beams having an overall dimension of 1500mm × 350mm × 75mm were cast and tested. Crumb rubber was used to replace fine aggregate in two different proportion by volume (10% and 15%). Steel fibre was added to the concrete mix in three different proportions (0.50%, 0.75% and 1.00%) based on volume. Details of each of the specimen used in this investigation with their designation, content of crumb rubber and content of steel fibre are given in Table 1. For each of the concrete mix, two samples were tested and the average value of the results are reported.
## Table 1 Details of test specimens

| No | Designation of Specimen | Steel Fibre Content (%) | Rubber Content (%) |
|----|--------------------------|--------------------------|--------------------|
| 1  | RF                       | 0                        | 0                  |
| 2  | S1                       | 0.50                     | 0                  |
| 3  | S2                       | 0.75                     | 0                  |
| 4  | R1                       | 0                        | 10                 |
| 5  | R2                       | 0                        | 15                 |
| 6  | SR1                      | 0.50                     | 10                 |
| 7  | SR2                      | 0.75                     | 10                 |
| 8  | SR3                      | 1.00                     | 10                 |

RF – Reference Concrete Specimen, S – SFRC Specimen, R – Rubcrete Specimen and SR – SFRRC Specimen

### 2.1 Materials and Concrete Mix Proportions:

In the present investigation, concrete mix with a target strength of 30 MPa was prepared using Portland Pozzolana Cement (PPC) having specific gravity 3.15. The mix design was done based on IS 10262:2009. The fine aggregate used was natural river sand with specific gravity 2.54, and coarse aggregate was crushed stone having a maximum size of 12mm with specific gravity 2.77. The crumb rubber used for partial replacement of fine aggregate was having a specific gravity of 0.58. Initially, the crumb rubber was sieved to different fractions having a particular size and then proportioned so as to grade them to the zone of fine aggregate. Before adding the crumb rubber in concrete, they were kept in Poly Vinyl Alcohol (PVA) solution for improving the bond between the rubber surfaces and surrounding paste. Crimped steel fibre having aspect ratio 66 and diameter 0.45 mm was used for SFRC and SFRRC.

A total of eight concrete mixes consisting of ordinary concrete, rubcrete, SFRC and SFRRC were used for preparing the specimens. In each of this mix, the content of cement, coarse aggregate and water were kept constant. Varying parameters were the content of crumb rubber, steel fibre and fine aggregate. Since higher rubber content resulted in a significant reduction of ultimate load carrying capacity, for all the SFRRC specimen the rubber content was kept at a constant value of 10%. The details of each of these concrete mixes are shown in Table 2.

### Table 2 Mix proportions

| No | Mix | Cement (kg/m³) | Coarse Aggregate (kg/m³) | Fine Aggregate (kg/m³) | Steel Fibre (kg/m³) | Crumb Rubber (kg/m³) | Water (kg/m³) |
|----|-----|---------------|--------------------------|------------------------|---------------------|----------------------|--------------|
| 1  | RF  | 438.13        | 1158.23                  | 623.75                 | 0.00                | 0.00                 | 197.16       |
| 2  | R1  | 438.13        | 1158.23                  | 561.37                 | 0.00                | 62.38                | 197.16       |
| 3  | R2  | 438.13        | 1158.23                  | 529.73                 | 0.00                | 94.02                | 197.16       |
| 4  | S1  | 438.13        | 1158.23                  | 623.75                 | 39.25               | 0.00                 | 197.16       |
| 5  | S2  | 438.13        | 1158.23                  | 623.75                 | 58.88               | 0.00                 | 197.16       |
| 6  | SR1 | 438.13        | 1158.23                  | 561.37                 | 39.25               | 62.38                | 197.16       |
| 7  | SR2 | 438.13        | 1158.23                  | 561.37                 | 58.88               | 62.38                | 197.16       |
| 8  | SR3 | 438.13        | 1158.23                  | 561.37                 | 78.50               | 62.38                | 197.16       |

### 2.2 Testing Procedure:

All the deep beam specimens used in this investigation were designed to fail in shear. The typical reinforcement details of the deep beam and the test setup are shown in Fig 1 & 2 respectively. A compression and bending testing machine having 300T capacity was used for testing the beams. The specimens were tested by applying a concentrated load at the centre of each of the span. The load was increased from zero till failure at a constant rate of 2T per minute. A dial gauge was fixed at the centre of each of the span to record the deflection for each load increment.
3. Results and discussions

3.1 Behaviour of specimens: The loading was done at a constant rate starting from zero. The cracking of all the tested beams began with the formation of small flexural cracks near the mid-span. Upon further increase in the load, cracks initiated from the support towards the loading point. Towards the ultimate load, all the specimens failed by forming diagonal cracks. The addition of crumb rubber to concrete resulted in a reduction of load carrying capacity. SFRC specimens were able to carry more load in comparison to the remaining specimens. Before failure, a number of small cracks were observed in specimens containing steel fibre. It may be due to the bridging effect of steel fibres which inhibit the growth and widening of cracks in SFRC specimen. The SFRC deep beams also failed by forming diagonal cracks. It was also observed that in comparison to rubcrete specimen SFRRC specimen were able to carry a higher load. Typical crack pattern obtained for the tested specimens are shown in Figs 3-6.
3.2 Load-deflection behavior: The deflection corresponding to each load increment was recorded, and the variation of deflection on each load increment was plotted. A comparison of load deflection response obtained for each of the specimens is shown in Fig 7.

![Fig 7 Comparison of load deflection response for different specimens.](image)

The slope of load deflection response obtained for rubcrete and SFRRC specimen were less steep compared to reference beam. This indicates that the mix containing crumb rubber are less stiff in
comparison to standard concrete. The ultimate load carrying capacity for both rubcrete and SFRRRC specimen were reduced due to the presence of rubber particles. All the specimens containing crumb rubber presented a more ductile behaviour in comparison to the reference specimen. All SFRRC specimens were able to undergo higher deflection in comparison to reference and rubcrete specimen before failure.

3.3 First crack load and ultimate load carrying capacity: The load corresponding to the point at which the load deflection curve deviated from its initial linear behaviour was considered as the first crack load. The values obtained for first crack load and ultimate load for each of the specimen are tabulated in Table 3. For comparing the flexibility of different specimens, procedure adopted by Osama and Zaids (2016) was used by considering the deflection obtained for various specimens corresponding to 50% first crack load of the reference specimen. For all the specimens, deflection corresponding to first crack load (δ\(_{fc}\)) and the deflection corresponding to 50% first crack load of reference specimen (δ\(_{50}\)) were obtained and it was compared with corresponding deflection obtained for reference specimen. Ultimate load, deflection corresponding to 50% of first crack load obtained for reference specimen and maximum deflection obtained for each of the specimens are given in Table 3. The percentage increase or decrease of the compared values were studied, and the variation of the same with respect to reference specimen are also given in Table 3.

| Sl No | Designation | First crack load (kN) | Ultimate Load (kN), P\(_u\) | % Increase / Decrease in P\(_{fc}\) | Deflection at 50% First Crack load of reference specimen, δ\(_{50}\) | % Increase / Decrease in δ\(_{50}\) | Deflection at first crack load, δ\(_{fc}\) | % Increase / Decrease in δ\(_{fc}\) |
|-------|-------------|-----------------------|-------------------------|----------------------------------|---------------------------------|---------------------------------|-------------------------------|----------------------------------|
| 1     | RF          | 275                   | 600                     | -                                | 0.55                           | -                               | 1.06                           | -                               |
| 2     | S1          | 325                   | 615                     | 2.5                              | 0.51                           | -7.27                           | 1.35                           | 27.36                           |
| 3     | S2          | 400                   | 685                     | 14.17                            | 0.53                           | -3.64                           | 1.92                           | 81.13                           |
| 4     | R1          | 125                   | 400                     | -33.33                           | 0.59                           | 7.27                            | 0.59                           | -44.34                          |
| 5     | R2          | 120                   | 333                     | -44.50                           | 0.65                           | 18.18                           | 0.60                           | -43.40                          |
| 6     | SR1         | 225                   | 430                     | -28.33                           | 0.79                           | 43.64                           | 1.21                           | 14.15                           |
| 7     | SR2         | 250                   | 480                     | -20                              | 0.72                           | 30.91                           | 1.29                           | 21.70                           |
| 8     | SR3         | 200                   | 430                     | -28.33                           | 0.66                           | 20.00                           | 0.88                           | -16.98                          |

Ultimate load and maximum deflection obtained for each of the specimens was compared with the value obtained for reference specimen. The percentage increase or decrease of the compared values were studied, and the variation of the same with respect to failure load of the reference specimen is also tabulated in Table 3. It was observed that by replacing 10% and 15% fine aggregate with crumb rubber, the resulting ultimate load carrying capacity of the specimen was reduced by 33% and 45% in comparison to the ultimate load obtained for reference specimen. This reduction in strength may be due to the lower stiffness of crumb rubber as compared to aggregates. Another factor that can contribute to the lower load carrying capacity is the weak bond between crumb rubber and surrounding paste. Since the zone formed between crumb rubber and surrounding paste is weak, there are chances of cracks originating from these areas which can speed up the failure of the specimen. The replacement of fine aggregate by 15% rubber particles resulted in a reduction of 45% ultimate load carrying capacity. So the addition of rubber content above 10% is not suggested.

In order to enhance the strength of rubcrete, steel fibres in different percentage were added to rubcrete having 10% rubber particles. From the results, it can be seen that when 0.50% steel fibre was added to rubcrete the reduction in ultimate load carrying capacity was decreased to 28% in comparison to reference specimen. By further increasing the percentage of steel fibre content to 0.75% the reduction in ultimate load carrying capacity was again reduced to 20%. Since there was a continuous increase in
ultimate load carrying capacity for rubcrete specimen due to the addition of steel fibre, the steel fibre content was further increased to 1%. It was observed that further increase in steel fibre content did not resulted in decreasing the reduction in load carrying capacity. So based on the results of the present investigation 10% rubber particles and 0.75% steel fibre addition were found to be optimum for maximum load carrying capacity.

It was observed that the addition of rubber particles significantly increased the deflection ($\delta_{50}$) compared to the reference specimen. Even though the deflection at first crack load for steel fibre specimens are higher, it does not show an overall improvement of flexibility. The ultimate load obtained for SFRC specimen was much larger, which allowed the specimen to have a higher deflection. In the case of SFRRC specimen, the deflection at first crack load, as well as the deflection at 50% of the first crack load of reference specimen, was significantly improved. It can be observed from these results that the addition of rubber particles made the specimen more flexible.

4. Conclusions

In this paper details of experimental investigation on sixteen two-span continuous deep beams which were cast using ordinary concrete, rubcrete, SFRC and SFRRC are discussed. An attempt was made to find the optimum content of steel fibre and crumb rubber for SFRRC by studying the effect of crumb rubber, steel fibre and their combinations on the ultimate load carrying capacity and deflection of two-span continuous deep beams. Replacement of 15% fine aggregate with crumb rubber resulted in a reduction of 45% ultimate load carrying capacity of two-span continuous deep beams. So, replacing more than 10% fine aggregate using rubber particles is not recommended. For improving the strength of rubcrete specimen steel fibres were added to rubcrete mix containing 10% crumb rubber. The presence of steel fibre in rubcrete helped in decreasing the reduction in load carrying capacity by 15% and 40%, for a fibre content of 0.5% and 0.75% respectively. So, based on the results of the present investigation, the suggested optimum value of crumb rubber content and steel fibre for maximum performance of two-span continuous deep beam is 10% and 0.75% respectively.

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