Effects of Partial Replacement of Coarse Aggregates with Reclaimed Rubber on the Mechanical Properties of Hardened Concrete

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Abstract: The replacement of conventional aggregates with alternate materials like Reclaimed Rubber (RR) results in reduction of self-weight and compressive strength of concrete. This reduction in self-weight further decreases the dead load which contributes towards contraction in size of concrete members and reinforcement requirements. This diminution in compressive strength is compensated by replacing cement with supplementary materials like Silica Fume, Fly Ash or GGBS. This research focuses on the effects of partial replacement of cement and coarse aggregates with Silica Fume (SF) and Reclaimed Rubber (RR) respectively in the concrete mix. Concrete mix was prepared for M20 grade by replacing cement and coarse aggregates with SF and RR respectively for cube and cylinder samples. A base study has been carried out through compression and split tension tests by partially replacing cement with SF in 3 percent increments up to 24 percent. Maximum compressive strength of 19.6N/mm², 24.2N/mm² and 32.5N/mm² was obtained at 12% replacement of cement with SF by weight while testing specimens after 7, 14 and 28 days of curing. Maximum strength of 2.4N/mm², 2.9N/mm² and 3.1N/mm² was obtained during split tension tests conducted after 7, 14 and 28 days of curing period. Further compression and tension tests were conducted replacing cement with 12%SF along with various proportions of RR replacing coarse aggregates after different curing periods. Experiments reveal that a combination of 12%SF and 9%RR replacement produces maximum compressive strength of 19.2N/mm², 23.1N/mm² and 29.4N/mm² after curing the samples for 7, 14 and 28 days respectively. The tensile strength decreases as the rubber content is increased in the concrete mix along with optimum SF when compared with normal mix.

Keywords: Compressive Strength; Concrete; Reclaimed Rubber; Silica Fume; Tensile Strength

1. Introduction

The demand for concrete as one of the most important element in a construction project, is increasing globally. Aggregates, which is one of the major ingredients of concrete, occupy nearly 60-75% of the volume of concrete. Coarse aggregates are becoming scarce day by day because they need to be extracted from natural resources for various reasons hence, there is a necessity to find a suitable material which can replace coarse aggregates in concrete. In the last two decades, significant research has been involved using chipped or crumb rubber as partial replacement for coarse and fine aggregate respectively. Partial replacement of coarse aggregate with reclaimed rubber affects the mechanical properties of concrete. The use of supplementary cementing materials like Silica Fume compensates the reduction in the mechanical properties of concrete. Reclaimed rubber is available in the form of sheets which is being obtained from vulcanized scrap rubber by passing it through a thermo-chemical process. In this research, compression and tension tests were carried out

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on cube and cylindrical samples with various proportions of SF to obtain the optimum replacement level. Tests were also carried out with a combination of optimum SF and different proportions of RR in concrete mix. The test results were analyzed and concluded.

One of these studies investigated the possibility of utilizing alternate materials to replace cement in the concrete mix since its cost was increasing constantly in the market. Cement was partially replaced with Silica fume and tests were carried out after curing the samples for 7, 14 and 28 days. Results show that 10%SF replaced concrete gave more strength when compared with normal mix and it is considered as optimum replacement level.[1]

Researchers’ exploration for an alternative to cement continues as the emission of carbon dioxide is harmful to the surrounding environment. Hence, in this research, Silica Fume (SF) and Fly Ash (FA) replace cement in the concrete mix. The compressive and split tensile strength reached its maximum value at 6%SF and 15%FA replacement. The compressive strength of composite concrete (Silica fume + fly ash) attains its optimum value at 15% when compared with the acid attack concrete (H2SO4 and NaCl) for 28 days.[2]

The increasing market demand of cement compels its production at large scale results in depletion of natural resources at one hand and rising prices on the other hand. An enhancement in compressive and flexural strength is obtained with 12% silica fume replacement in the concrete mix. During split tensile strength test the maximum strength is attained at 9% replacement of silica fume.[3]

The amount of waste automobile tire is increasing rapidly creating a major problem of disposal to the authorities globally. Compressive, split tensile and flexural strength of concrete were determined. An optimum value of 10%SF as cement replacement and 10% crumb rubber as fine aggregate replacement in concrete enhanced the mechanical and durability properties of concrete.[4]

Extensive mining of aggregates causes an ecological imbalance, hence alternate sources like recycled aggregates are used to replace conventional aggregates in concrete. The compressive and split tensile strength of silica fume concrete is found to be more than normal concrete at 7.5% replacement of SF. Addition of recycled aggregate shows a decrease in strength but up to 30% replacement of recycled aggregates show higher strength than control mix[5].

Discarded vehicle tires constitute important part of solid waste which is disposed into landfills. These tire rubber particles replace natural aggregates in the production of concrete. Test results showed that concrete with rubber aggregate contents higher than 10% by mass would be unacceptable for primary structural elements. Rubber aggregates can be used in non-primary structural applications of medium to low strength requirements[6].

The relative effect due to the nature of coarse aggregates on the compressive strength achieved by concrete mix has been investigated by using three different types of aggregates in this study. Concrete mix prepared with crushed granite performed best in compression than those samples mixed with natural and unwashed gravels of similar grading. Variation in concrete strength is due to factors like surface nature, cleanliness and internal structure of the aggregate materials.[7]

In order to reduce the environmental pollution due to the disposal of waste rubber tires, it is being reused in previous research works. From observations, it is noted that unit weight of beam and cylindrical specimens reduce due to the increase in percentage of chipped rubber in concrete. The split tensile and flexural strength decreases with an increase in rubber aggregate content.[8]

The production of cement has a negative impact on the environment hence silica fume is being used as an alternative material for cement. The optimum 7 and 28-day compressive strength has been obtained at 25% silica fume replacement level. Moreover, the split tensile strength of concrete is high when 25% of cement is replaced with silica fume[9].

The above contents show that silica fume and scrap rubber have been used individually and in combinations. Scrap tires in different forms namely shredded, crumb or recycled rubber were used to replace coarse aggregates in the concrete mix. No work has been carried out using reclaimed rubber as a partial replacement for conventional aggregates in concrete along with admixtures, hence this study has been done to find the combined effect of optimum SF and reclaimed rubber in concrete.
2. Material properties

The properties of certain materials like cement, silica fume and reclaimed rubber were obtained from the manufacturer and the physical property tests for fine and coarse aggregates were carried out in the material testing laboratory.

2.1 Cement

Ordinary Portland cement was used in this research work to prepare the concrete mix along with other ingredients. 53 grade cement was used in the concrete which indicates that the compressive strength of cement concrete after 28 days of curing is 53N/mm$^2$. It acts as a binding material filling voids in fine aggregate.

2.2 Aggregates

Aggregates having a size less than 4.75 mm were used as fine aggregate in the mix. Grading of aggregates is found using sieve analysis test. It is done by using a mechanical sieve shaker. A sample of 500g of sand was used in the sieve analysis test and carried out through standard test procedure and its fineness modulus was obtained using relevant formulae. Similarly, properties like relative density and water absorption were obtained using standard test procedure. Hard granite broken stones of 20mm size were used as coarse aggregates in the concrete mix. It is an ingredient of concrete which is being replaced partially by reclaimed rubber. Table 1 shows the properties of both fine and coarse aggregates.

Table 1 shows the source of materials, such as silica fume and reclaimed rubber which were tested in lab and obtained from the supplier.

2.3 Silica fume

Micro silica is a reactive and puzzalonic material due to its fine particle size and high purity of SiO$_2$ content. It makes the concrete durable to chemical attack, thereby increasing its compressive strength. High strength is obtained by adding SF which improves the bond between rubber and the mix. Moreover, addition of SF enhanced the hardened rubberized concrete properties$^{[10]}$. The physical properties of silica fume are given in Table 3.

| S.No | Name of test       | Fine Aggregate | Coarse Aggregate |
|------|--------------------|----------------|-----------------|
| 1    | Relative density   | 2.6            | 2.7             |
| 2    | Moisture absorption| 2.4%           | 0.5%            |
| 3    | Fineness modulus   | 3.5            | 3.5             |

Table 1. Properties of aggregates

| S. No | Name of Material | Source                          |
|-------|------------------|---------------------------------|
| 1     | Silica fume      | Astra Chemicals, Chennai        |
| 2     | Reclaimed rubber | Inter City Enterprises, Chennai |

Table 2. Source of materials

| S. No | Description | Nature / Results |
|-------|-------------|------------------|
| 1     | Physical state | Powder           |
| 2     | Smell        | Nil              |
| 3     | Physical appearance | White   |
| 4     | Density      | 0.76 gm/cc       |
| 5     | PH           | 6.9              |
| 6     | Specific gravity | 2.85            |
| 7     | Moisture content | 0.058%          |

Table 3. Physical features of micro silica
2.4 Reclaimed rubber

Replacing aggregates with reclaimed rubber reduces the density of concrete. Introduction of recycled rubber tires in concrete mix leads to decrease in slump. Addition of rubber aggregates results in a significant decrease in compressive strength compared to conventional concrete\cite{11}. Reclaimed rubber was cut in size which is approximately equal to the size of aggregates (Figure 1).

Table 4 shows the properties of reclaimed rubber. The gradation curve for tire chips and for normal aggregates was not possible to determine since they were elongated in shape from 10mm to 40mm. Specific gravity for crumb rubber and tire chips are 0.83 and 1.02 respectively\cite{12}.

3. Preparation of specimens

Based on the properties of fine and coarse aggregates M20 mix was designed as per IS code 10262:2009 and the mix proportion was found to be 1:1.85:3.13:0.5. Cube moulds of size 150mm x150mm x150mm and cylindrical moulds of 150mm diameter with 300mm height were used in this study. In the basic study, 81 cubes and 81 cylinder samples were cast using various ingredients of concrete along with silica fume which replaced cement at various proportions. Concrete was mixed in a standard concrete mixer machine by filling the mixer with the required quantities in order to prepare the conventional mix. Moreover, required quantity of reclaimed rubber and silica fume is weighed apart from the conventional materials and batched in the required proportion. To achieve the desired slump, it is essential to add water to the aggregate before mixing\cite{13}.

A concrete mixer machine having a production rate of 6.8m³ per hour was used to mix the various ingredients. Concrete is mixed continuously in the mixer machine until it achieves homogeneity and desired consistency. After mixing the concrete, cube and cylinder moulds of standard size are filled with concrete in three layers by compacting each layer 25 times in order to reduce voids in concrete mix. Cast samples are shown in Figure 2. The specimens were removed after 24 hours from their moulds and cured in water for 7, 14 and 28 days. The curing process is carried out in a curing tank at a temperature of 27-30°C. After the curing process the samples were removed, dried and taken for testing in the concrete testing laboratory. The indirect tension and compression tests were done to determine the optimum replacement of silica fume. Further study used reclaimed rubber to replace coarse aggregates by weight at 3 percent increments starting from 3 to 24 percent and mixed in concrete along with optimum SF. A similar set of samples (cubes and cylinders) were cast. It was also cured and tested in a UTM which has a capacity of 50 tons. Tests were conducted to find out the ultimate load.

![Figure 1. Reclaimed rubber used in concrete.](image)

| S. No | Type of test   | Results   |
|-------|----------------|-----------|
| 1     | Cinder         | 5.43%     |
| 2     | Bulk density   | 1.12g/cc  |
| 3     | Tensile strength | 17.7Kg/cm² |
| 4     | Specific gravity | 1.45      |
| 5     | Moisture       | 8.5%      |

Table 4. Properties of reclaimed rubber

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4. Test Results and discussions

The compression test results are calculated using the maximum force and the cross-sectional area of cubes. Table 5 shows the compressive strength values of concrete mix with partial replacement of cement with silica fume.

The following Figure 3 indicates a proportionate increase in strength as SF content is increased. Twelve percent SF substitution produces a compressive strength of 32.5N/mm² which is 53% higher than conventional mix value at 28 days of curing. Comparing the results of conventional mix with that of 12 percent fill-in of cement with SF the variation in strength is negligible in 7 and 14 days cured samples. Comparing the percentage increase in strength of 28 days cured samples, it is found that for every 3 percent increment of SF there is a considerable decrease in compressive strength. A similar pattern of decrease in strength is observed while comparing 7 and 14 days cured sample values. Minimum strength is obtained at 24% replacement of cement in concrete mix at all ages of curing. On the whole the optimum replacement level of silica fume is 12 percent irrespective of the age of concrete beyond which the strength decreases considerably since more replacement of cement with silica fume tends to decrease its filling effect in the concrete mix. Moreover, the compressive strength of 12% SF replacement is consistent with previous research work done by Joe Paulson, John Wesley and Angelin[14]. In this study, maximum compressive strength of 32.5N/mm² is achieved at 12% SF replacement whereas in the earlier research a maximum strength of 33.4N/mm² is obtained at 13% SF replacement since the initial replacement starts with 12% only and compression test result is observed for every 0.5% increment of SF in concrete mix such as 12.5%, 13% and 13.5%, and the variation between the present result and previous work is also negligible.

| SF (%) | Average Compressive Strength (N/mm²) |
|--------|--------------------------------------|
|        | 7 days | 14 days | 28 days |
| 0      | 13.9   | 17.4    | 21.2    |
| 3      | 15.8   | 19.7    | 25.4    |
| 6      | 17.5   | 21.9    | 28.1    |
| 9      | 18.2   | 22.5    | 30      |
| 12     | 19.6   | 24.2    | 32.5    |
| 15     | 14.7   | 20.5    | 26.6    |
| 18     | 12.1   | 16.4    | 22.3    |
| 21     | 10.5   | 14.2    | 19.4    |
| 24     | 8.8    | 11.6    | 15.2    |

Table 5. Compression test results of cubes.
Table 6 shows the outcome of tests conducted on M20 grade concrete cube samples which were cured for 7, 14 and 28 days.

The following Figure 4 indicates that strength increment is negligible for combined mix containing 3 percent RR and optimum SF compared to control mix for all samples irrespective of the concrete age. It can be observed that the maximum strength is attained with a combination of 12 percent SF and 9 percent RR for all ages of curing. Comparing the maximum strength with conventional mix values the percentage increase is 38, 33 and 39 after 7, 14 and 28 days of curing period respectively. Comparing the strength values of 3% and 6% replacement levels of RR combined with optimum SF the strength increases whereas it decreases while comparing the values of 6% and 9% replacement levels of RR with optimum SF which indicates that as the rubber content is increased the compressive strength decreases gradually. The effect of combined replacement of RR with optimum SF is negative while comparing the compressive strength of concrete replaced with SF alone for all the proportions and ages of concrete mix. A 10 percent decrease in strength is observed while estimating the difference between the optimum SF value with that of combined mix with optimum SF and optimum RR.
Comparing the test results of conventional mix with combination of optimum SF replacement and every 3 percent reclaimed rubber replacement the variation in strength is negligible after 7 and 14 days of curing. The following Table 7 shows the split tensile strength values of cylindrical specimens of M20 grade mix cast with different proportions of SF.

From the above Figure 5, the optimum replacement of SF is found to be 12 percent which is due to the adhesion of cement with SF which acts as a bonding agent in concrete. Moreover, the split tensile strength is within one eighth to one twelfth of the compressive strength for control and other mix with various proportions of silica fume irrespective of the age of concrete. The above figure also indicates that early age (7 & 14 days) strength gain at optimum replacement level is higher than the 28 days strength increment when compared with the respective control mix values. The split tension values of 9% and 15% replacement levels are almost same irrespective of the curing period. A similar pattern is seen while comparing the tensile strength values of 3% and 21% replacement levels.

Different researchers found similar results on partial replacement of SF and its influence on the tensile strength of M20 grade concrete. Similar to the results of the present study experiments carried out earlier found that 12.5% SF concrete produced 2.47N/mm² which is almost equal to the present value of 3.1N/mm² obtained at 12% SF replacement. In both the studies the tensile strength reduces beyond 12% replacement of SF which is clearly seen from their test results. By comparing the control mix values of both the studies, it can be seen that the variation in tensile strength is very less. Even though 12% replacement result is not seen in the previous research from the results, it can be presumed that after 12% replacement the strength would have reduced gradually in line with this research work. Table 8 shows the split tensile test results of previous study[15].

| SF (%) | Average Split Tensile Strength (N/mm²) |
|--------|--------------------------------------|
|        | 7 days  | 14 days | 28 days |
| 0      | 1.3     | 1.5     | 1.8     |
| 3      | 1.6     | 1.9     | 2.2     |
| 6      | 1.7     | 2.1     | 2.3     |
| 9      | 1.8     | 2.7     | 2.8     |
| 12     | 2.4     | 2.9     | 3.1     |
| 15     | 1.7     | 2.5     | 2.9     |
| 18     | 1.3     | 2.1     | 2.5     |
| 21     | 1.2     | 1.7     | 2.2     |
| 24     | 1.0     | 1.5     | 1.9     |

Table 7. Split tension test results of cylinders
Figure 5. Split tensile strength of cylinders at various proportions of SF.

| Type of Mix | M0% | M5% | M10% | M12.5% | M15% |
|-------------|-----|-----|------|--------|------|
| Split Tensile Strength (N/mm²) | 2.25 | 2.5 | 2.6 | 2.47 | 2.4 |

Table 8. Test results of tensile strength after 28 days of curing

| SF (%) | RR (%) | Average Split Tensile Strength (N/mm²) | 7 days | 14 days | 28 days |
|--------|--------|----------------------------------------|--------|---------|---------|
| 12     | 0      | 1.3                                    | 1.5    | 1.8     |         |
|        | 3      | 1.2                                    | 1.4    | 1.7     |         |
|        | 6      | 1.1                                    | 1.3    | 1.6     |         |
|        | 9      | 1.0                                    | 1.1    | 1.5     |         |
|        | 12     | 1.0                                    | 1.0    | 1.4     |         |
|        | 15     | 0.9                                    | 1.0    | 1.2     |         |
|        | 18     | 0.8                                    | 0.9    | 1.1     |         |
|        | 21     | 0.7                                    | 0.8    | 0.9     |         |
|        | 24     | 0.7                                    | 0.7    | 0.8     |         |

Table 9. Test results of cylinders

Table 9 shows the split tension test results of concrete cylindrical specimens cast with a combination of optimum silica fume and various proportions of reclaimed rubber.

It is observed from Figure 6 as the rubber content increases the split tension values tend to decrease for various curing periods. Comparing Figure 5 and Figure 6 it can be seen that the strength decreases to 50% while finding the percentage decrease between optimum SF value and combined mix of optimum SF and various proportions of RR for all ages of concrete. Moreover, the variation in tensile strength for every 3% increment can be neglected since the difference between each increment is very less. While comparing the control mix values with combined optimum SF and RR mix, it is observed that the strength decreases nearly 10% for every 3% increment of RR in 7, 14 and 28 days cured samples.
5. Conclusion

The following conclusions are drawn based on the above research:
1. Test results show that maximum compressive strength is attained at 12 percent replacement of cement with Silica Fume which is taken as optimum replacement.
2. The combined replacement mix with optimum SF and 9 percent replacement of coarse aggregates with RR produces compressive strength which is 39% higher than the strength of normal mix.
3. Maximum compressive strength reduction of 37% is observed at 24% replacement of Silica Fume while comparing strength of normal mix samples after 7 days of curing.
4. Silica fume seems to have a more pronounced effect on the compressive strength than split tensile strength.
5. Assimilating the strength of cube samples with optimum SF replacement and control mix a 40 percent increase is observed for 7 and 14 days cured samples.
6. By comparing the cube strength of samples replaced with 12 percent SF and control mix, an increase in the strength of concrete up to 50 percent is observed for 28 days cured samples.

6. Recommendations for future study

This study has investigated the utilization of reclaimed rubber and its effects on the mechanical properties of concrete along with silica fume replacement. The individual replacement of SF in concrete produced optimum compressive and split tensile strength were found to be 32.5N/mm² and 3.1N/mm² respectively. The combined replacement of optimum SF with various proportions of RR produced maximum compressive strength was 29.4 N/mm². The following recommendations are given for further research in this area:

- Apart from the above tests, flexural strength test can be done on beams of standard size in future studies for M20 grade concrete.
- Further research can be done using admixtures like fly ash and GGBS and their effects on the mechanical properties of concrete with various proportions may be investigated.
- The above study can be extended on standard and high strength concrete grades like M30, M40, M50 and M60.
- Influence of super plasticizers along with admixtures may be analyzed with tests like compression, split tension and flexural strength in future research works.
- Durability studies can be executed on cube and cylinder samples using RCPT and sorptivity testing methods respectively.
- The above tests can be conducted under different curing conditions with different proportions of silica fume and reclaimed rubber.

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