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ORIGINAL ARTICLE

Effect of Tyre Waste on Ground Granulated Blast Furnace Slag (GGBFS) Based Concrete Blocks

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Abstract

Objectives: To determine the effect of tyre waste on its addition to Ground granulated blast furnace slag (GGBFS) based Concrete Blocks in respect to compressive strength. **Methods:** Cube specimens of size 150 x 150 x 150 mm were casted with 45% replacement of cement by GGBS and tyre waste in different proportions 45%, 40%, 35%, 30% and 0%, 5%, 10%, 15% respectively. Cube specimens were kept in ambient conditions, so as to protect it from heat and cold, thus avoiding surface evaporation. After proper curing, compressive strengths were determined at 1, 3, 7, 14 and 28 days respectively. **Findings:** This research determined the exact quantity of tyre waste and GGBFS which can be used as a cement replacement in Concrete mix. It was found that maximum compressive strength was achieved at 45% GGBFS content and 0% Tyre waste content. Although tyre waste can be introduced up to 15% in the concrete mix and compressive strength is more than only OPC based concrete mix. **Novelty:** According to the findings of the comprehensive study, use of tyre waste at 15% and GGBFS at 30% in concrete mix reduces the requirement of cement, which finally plays a major role in reduction of construction cost by use of cheap tyre waste and less cement. It encourages us to use tyre waste on a larger scale in construction, along with the protection of environment.

Keywords: Ground granulated blast furnace slag; compressive strength; tyre waste; Ordinary Portland Cement; Environment friendly

1 Introduction

Waste tires occupy a lot of landfill space due to its durability and non-biodegradable nature [1].

Rubber pollution is caused due to mismanagement of tires. Record stockpiles of 1 billion scrap tires were found in United States in 1990. In 2015, a stockpile of 67 million tires were only left [2]. From 1994 to 2010, it was observed that European Union increased the amount of tires recycled from 25% to 95% obtained annually, with 50% of tires utilized in cement manufacturing industries [3,4]. This research paper focused on determination of optimum percentage replacement of Ordinary Portland Cement (OPC) by GGBFS, thus finding the maximum compressive strength. Here, M40 concrete grade was used, in which OPC replacement by GGBS in percentages of 40, 50, and 60 was carried out. Results helped in determining maximum replacement of cement by GGBS, thus reducing the usage of cement and the cost of construction [5].

It was finalized that there was a reduction in early age strength of concrete on increasing the proportion of GGBFS [6]. He discussed the optimum use of GGBFS in concrete for achieving maximum compressive strength. As a result, it was found that, maximum compressive strength is attained at 55–59% replacement of binder content by GGBFS [7].

Studied on rubber waste based concrete has shown that it is best suited for structures that lie in high risk earthquake seismic zones and also for applications susceptible to dynamic actions such in case of railway sleepers. Also rubber waste concrete can be used for non-load-bearing purposes, for example in noise reduction barriers. Research so far concludes that tyre waste concrete strength is very much dependent on the type and quantity of waste aggregates used [8].

In tyre waste concrete mixtures, it was observed that it showed good workability and lower unit weight when compared to plain concrete. Use of tyre waste in concrete as coarse aggregate in place of fine aggregate led to a greater reduction in mechanical properties of concrete when tested for flexural and compressive strength. By the use of rubber shreds in place of coarse aggregate in concrete, positive improvement was seen in post-cracking behavior such as ductility indexes and energy absorption of fibrous concrete [9].

1.1 The objective of the study

The aim of the current research is to analyze the performance of GGBFS and tyre waste in concrete blocks. GGBFS generated in the steel plants is been used. Though some quantity of GGBFS is used by cement manufacturing industries, major portion of it remains unutilized, causing several environmental problems. The current research uses GGBFS procured from Own dust India. Tyre waste was used in percentage of 5, 10, 15 by weight of cementitious material content. Compressive strength tests were determined at 1, 3,7,14 and 28 days respectively.

1.2 Materials Used

1.2.1 Ground granulated blast furnace slag (GGBFS)

Iron Slag (molten state) which is a byproduct of steel, iron industries obtained from metallurgical furnace is quenched in water or steam, to produce grainy, glassy product, finally dried and grounded in fine powder, to obtain Ground-granulated blast-furnace slag [10]. It has been observed that addition of GGBS led to an increase in workability and also provided good surface finish. It was procured from Own Dust India.

Generally, it has been observed that increase in lime content of GGBS, increases the basicity of GGBS along with its compressive strength. Also increase in Al_2O_3 and MgO content upto 14% and 12% respectively causes an increase in slag basicity and compressive strength; beyond this specified limit no changes are observed. Hydraulic activity demonstrated as binder compressive strength was correlated with slag composition, with the use of Hydraulic indices or various compositional ratios.

Table 1. Mineral composition of GGBFS and Portland Cement

Mineral	GGBFS	Portland Cement
CaO	30-50%	55-66%
SiO_2	28-40%	20-24%
Al_2O_3	8-24%	0-8%
MgO	1-18%	5%

1.2.2 Ordinary Portland cement

Portland cement chemical composition is mentioned in Table 2. Bogue compounds are formed due to chemical reaction between the constituents responsible for raw material formation, which occurs during burning, fusion and finally forms this compound [11]. In addition of water, maximum heat is produced by Tricalcium aluminate and minimum heat is produced by dicalcium silicate. As a result, Tricalcium aluminate is formed. Bogue compound proportions vary in different type of Portland cements. Dicalcium silicate and tricalcium silicates are responsible for imparting long term strength to cement. Tricalcium aluminate is responsible for initial setting of cement. Tricalcium silicate is responsible for early strength of cement, as it hydrates fast. Dicalcium silicate effect in cement is seen after 7 days and might continue upto 1 year. As we know Tricalcium aluminate produces more heat, hydrates rapidly and is responsible for small involvement in terms of strength in 1 day. Fourth bogue compound Tetracalcium alumino-ferrite has shown inactiveness. Here OPC 43 was used.

Table 2. Chemical Composition of Ordinary Portland Cement

Compound	Amount
Lime (CaO)	60-67%
Silica (SiO_2)	17-25%
Alumina (Al_2O_3)	3-8%
Iron Oxide (Fe_2O_3)	0.5-6.00%
Magnesia (MgO)	0.102-4.00%
Sulphur Trioxide (SO_3)	1.00-3.00%
Soda and/or Potash ($Na_2O + K_2O$)	0.50-1.30%

1.2.3 Tyre Waste

Tyre is basically a continuous pneumatic covering which is built up of either synthetic rubber, natural rubber or a mixture of both surrounding a wheel. Wheels could be old, new or recycled[(12)]. Classifications of tyre based on their use are tryck tyres, off the road tyre and passenger car tyres. Truck tyres majorly differ from other classes of tyre in terms of its ingredient composition such as presence of high metal material content and lack of textile fibres in truck tyre comparatively to other tyre class[(13)]. It was procured from local market situated in Gorakhpur, Uttar Pradesh.

1.2.4 Fine aggregate

Sand is used as a fine aggregate in mix design for M40.

1.2.5 Coarse aggregate

An aggregate of nominal size 20mm has been used in the mix design of M40.

1.2.6 Water

For concrete mix, tap water is found to be suitable. Hence, tap water has been used in the study for curing and mixing purpose.

2 Methodology

2.1 Preparation of Concrete Cube specimens

1. We calculated the required quantity of source material GGBFS, tyre waste and ordinary Portland cement 33 grade.
2. Cement content remains fixed at 55% of cementitious material content in all the specimens, with variation in GGBFS and tyre waste in proportion 45%, 40%, 35%, 30% and 0%, 5%, 10%, 15% respectively.
3. Mix the cement, GGBFS, tyre waste as shown in figure and place it in mould of 150*150*150mm cubes.
4. Proper compaction is done with the help of vibrator as shown in figure.
5. Cube specimens were tested for compressive strength at 1, 3, 7, 14 and 28 days respectively.

GGBFS, tyre waste and cement will be added in required proportion by weight of cementitious material content, determined from mix design as demonstrated in the flow chart. After proper mixing of the material in required proportion, cubes of 150 x 150 x 150 mm were casted under proper compaction, so as to determine the compressive strength. Cube specimens were kept in ambient conditions, so as to protect it from heat and cold, thus avoiding surface evaporation. After 1 day cubes were cured in water. Tests for compressive strength were carried out at 1, 3, 7, 14 and 28 days.

2.1 Tests conducted on specimen

2.1.1 Compressive strength

Digital compressive testing machine is used for compressive strength test of cube specimens at 1, 3, 7, 14, 28 days respectively

2.2.1.1 Procedure as per IS 516 – Methods of tests for strength of concrete.

1. Specimen to be tested is placed centrally on lower plate of testing machine, with small gap left between top of specimen and upper plate of testing machine.
2. Pressure release valve is closed.
3. Digital testing machine is set to zero by adjustment of zero knobs.
4. Display is set to “Peak hold” mode for obtaining maximum load reading.
5. Load is applied at specified pace by adjustment of fast slow knob.
6. Pace rate on lower side displays yellow color and red color is displayed if pace rate is on higher side.
7. Pace rate when becomes equal to set rate displays green color.
8. After the failure of sample, pressure is released by opening of valve.
9. Maximum load reading at which sample has failed will be displayed on digital screen. Pattern of failure is noted down and compressive strength is calculated in kg/cm^2 or N/mm^2.
10. Lower plate is cleaned, digital display is brought to Zero position by pressing the Reset Switch. Afterwards another test is conducted.

3 Results and discussion

3.1 Results

Table 3. Compressive Strength of 1 Day GGBFS and Tyre waste Mix

	GGBFS=45% T.W=0%	GGBFS=40% T.W=5%	GGBFS=35% T.W=10%	GGBFS=30% T.W=15%
Day 1	193	180	176	160
Day 1	194	179	176.1	160.2
Day 1	194.9	180.3	175	160.4
Average Load(KN)	193.95	179.78	175.72	160.20
Strength (MPa)	8.62	7.99	7.81	7.12

Table 4. Compressive Strength of 3 Day GGBFS and Tyre waste Mix

	GGBFS=45% T.W=0%	GGBFS=40% T.W=5%	GGBFS=35% T.W=10%	GGBFS=30% T.W=15%
Day 3	484	468	423	366
Day 3	485.3	466	421	368
Day 3	485.3	467.9	421.6	364
Average Load(KN)	484.87	467.33	421.86	366
Strength (MPa)	21.55	20.77	18.75	16.27

Table 5. Compressive Strength of 7 Day GGBFS and Tyre waste Mix

	GGBFS=45% T.W=0%	GGBFS=40% T.W=5%	GGBFS=35% T.W=10%	GGBFS=30% T.W=15%
Day 7	618	575	540	504
Day 7	619	576	539	503
Day 7	618	575	539	505
Average Load(KN)	618.33	575.33	539.33	504.00
Strength (MPa)	27.48	25.57	23.97	22.40

It was observed that maximum compressive strength was achieved at cement replacement by GGBFS at 45% with 0% tyre waste in concrete cube specimens and is 11.68% more than Ordinary Portland cement concrete cube specimens. According to values obtained after testing, it can be concluded that compressive strength values decreased on addition of tyre waste, although decrement was slight on further increment in tyre waste content.

Table 6. Compressive Strength of 14 Day GGBFS and Tyre waste Mix

	GGBFS=45% T.W=0%	GGBFS=40% T.W=5%	GGBFS=35% T.W=10%	GGBFS=30% T.W=15%
Day 14	902	901	885	882.3
Day 14	902	901	884	880
Day 14	903	902	886.3	881
Average Load(KN)	902.33	901.33	885.10	881.1
Strength (MPa)	40.10	40.06	39.34	39.16

Table 7. Compressive Strength of 28 Day GGBFS and Tyre waste Mix

	GGBFS=45% T.W=0%	GGBFS=40% T.W=5%	GGBFS=35% T.W=10%	GGBFS=30% T.W=15%
Day 28	1212	1199	1173	1144
Day 28	1212	1200	1172	1145
Day 28	1214	1198	1173	1144
Average Load(KN)	1212.66	1199.00	1172.66	1144.33
Strength (MPa)	53.89	53.28	52.11	50.86

It can be concluded that compressive strength of GGBFS based concrete cube specimens with 0% tyre waste at 28 days was 111.68% as of OPC concrete cube specimens. Also compressive strength of GGBFS concrete cube specimens with 5% tyre waste at 28 days was 110.4% as of OPC concrete cube specimens. Also compressive strength of GGBFS concrete cube specimens with 10% tyre waste at 28 days was 108% as of OPC concrete cube specimens. Also compressive strength of GGBFS concrete cube specimens with 15% tyre waste at 28 days was 105.4% as of OPC concrete cube specimens.

Also compressive strength of GGBFS based concrete cube specimens at 14 days with 0%, 5%, 10%, 15% tyre waste content was 74.4%, 75.1%, 75.4% and 77% respectively. Compressive strength of GGBFS based concrete cube specimens at 7 days with 0%, 5%, 10%, 15% tyre waste content was 51%, 48%, 46% and 44% respectively. Compressive strength of GGBFS based concrete cube specimens at 3 days with 0%, 5%, 10%, 15% tyre waste content was 40%, 38.9%, 35.6% and 32% respectively. Compressive strength of GGBFS based concrete cube specimens at 1 days with 0%, 5%, 10%, 15% tyre waste content was 16%, 15%, 14.9% and 14% respectively.

4 Discussions

In previous research studies as mentioned in the literature review, no one used tyre waste with variation of 5% in the concrete mix starting from 0% to 15%. Also in none of the studies held before GGBFS was used with variation of 5% in the concrete mix ranging from 30% to 45%. Here GGBFS and tyre waste was simultaneously mixed with cement in the concrete mix and tested for compressive strength at 1, 3,7,14 and 28 days. Finally, it was found that maximum compressive strength was found at 45% GGBFS in the concrete mix without any tyre waste content. It can be said that if someone wishes to only use GGBFS as a cement replacement in concrete mix, then also 45% cement cost can be saved, and compressive strength of GGBFS based concrete blocks will be more than normal concrete blocks consisting of Cement only as a binder material. And if someone wishes to use both tyre waste and GGBFS as a cement replacement in the concrete mix, then one can take GGBFS at 30% and Tyre waste at 15%. In this case also, it was found that compressive strength of specimens was better than normal OPC based concrete blocks. Tyre waste because of cheap in nature in comparison to GGBFS and cement can be used to save 15% cement cost. And use of GGBFS will save 30% cement cost. According to availability of raw material such as GGBFS and tyre waste, required proportions can be selected for the best results in respect to compressive strength. Thus this experiment provides us with new proportions of GGBFS and tyre waste in the concrete mix and has not been performed before. This study outperforms existing methods and proportions of admixture to be used as cement replacement in concrete mix, reduces construction cost and promotes use of waste material such as GGBFS and tyre waste on a large scale.

5 Conclusion

In absence of tyre waste content, compressive strength is maximum in test cube specimens of concrete for cement replacement by GGBS up to 45%. GGBFS and tyre waste-based concrete showed better compressive strength in comparison to OPC based concrete. Also it was observed that in comparison to OPC concrete, good mechanical properties was demonstrated by GGBFS.

GGBFS and tyre waste mix showed low early age strength.

The studies evaluated in the present work allow concluding that use of GGBFS and grounded tyre waste as a cement replacement in concrete blocks gives more compressive strength in comparison to plain OPC based concrete. Also, compressive strength of mix decreases on addition of tyre waste. But tyre waste can be added up to 15% of cementitious material content, as it gives required strength necessary for obtaining target strength. Use of GGBFS can be encouraged for its use on large scale in order to have proper utilization of it, thus reducing the use of cement. Also, there will be less production of CO_2 released in formation of cement, thus will be ecofriendly too. Use of tyre waste is very much beneficial from environment point of view and economically in concrete mix. Tyre waste are non-biodegradable waste material, if disposed in open landfills can pollute the environment and degrade the fertility of soil there.

6 Future scope of the research

Majorly, there are two ways in which GGBFS can be used in cement such as: 1) as an admixture along with aggregates, water and Ordinary Portland cement (OPC) in concrete mix. 2) In pozzolona Portland cement production itself. GGBFS generation and cement production occurs on a large scale in India, China and tops the world. It has been analyzed that GGBFS utilization vs GGBFS generation percentage in cement production and concrete is more in China (42%) in comparison to India (26.62%). Also, it has been analyzed that GGBFS utilization in cement manufacturing is more in India (18.44%) in comparison to China (10.72%). In cement sector alone, GGBFS utilization is approximately 25% when 70% PPC share is considered. It can be said that cement manufacture in future will be governed by factors such as how materials can be conserved, how energy can be saved, consideration of various environmental and economic issues. Tyre waste can be used on a large scale in near future in construction industry.

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