International Journal of Research Publication and Reviews

Journal homepage: www.ijrpr.com ISSN 2582-7421

Study on Flexural Performance of RC Beam with Precious Slag Balls as Fine Aggregate Replacement

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DOI: https://doi.org/10.55248/gengpi.5.0524.1236

A B S T R A C T

Now a days industrial waste materials are difficult to transport and disposal. In the current era of sustainability in the construction industry, substituting natural fine aggregates with industrial by-products such as precious slag balls, it offers a number of benefits, including technical and environmental. Precious slag balls is a byproducts that are created when metals are melted or refined, particularly when steel is being made. Typically, these balls are made up of non-metallic materials and impurities that have been separated from the molten metal. This experimental study investigates the effects of substituting precious slag balls for traditional aggregates in standard concrete (M30 grade) to increase the material's strength and durability. After finding the optimum percentage of precious slag balls in concrete then the flexural behavior of concrete is also conducted. To find optimum percentage, number of extensive tests, such as split tensile strength, flexural strength, and compressive strength tests are carried out. The primary objective of this research work is the feasibility of using precious slag balls to produce high-quality concrete. From the experimental investigation, it is found that precious slag balls can be used as partial replacement for the fine aggregate in this concrete. The optimum value of precious balls replacement by replacing natural fine aggregate is 40%. The optimum mix and conventional beams are analyzed using ANSYS software. The flexural performance of control and optimum percentage mix beams in both experimental and analytical are compared.

Keywords: Precious slag balls, Sustainability, Standard concrete, feasible.

1. Introduction

In recent trends industrial waste materials are difficult to transport and disposal. In the current era of sustainability in the construction industry, substituting natural fine aggregates with industrial by-products such as precious slag balls, it offers a number of benefits, including technical and environmental. Basically river sand produces good quality concrete. But over exploitation of sand in river brings scarcity of sand in river in india.. Made from industrial waste materials, concrete lessens the quantity of garbage thrown in landfills, promoting environmental sustainability. It helps replenish groundwater reserves by allowing water to seep through. By 2030, the yearly output of steel slag waste from Indian steel mills is expected to rise from 19 million metric tons to 12 million tons. PS balls, or precious slag balls, are a novel material that can be produced by quickly cooling the slag produced in the Slag Atomizing Technology (SAT) steel-making process. PS Ball is an environmentally friendly substance, the Environment Ministry says. In order to reduce waste and the environmental impact of using a variable proportion of valuable slag balls in place of fine aggregate, this project work focuses on the experimental evaluation of partially substituted concrete materials. Next, the experimented-upon flexural behavior of the RC beam is compared to the analytical outcomes seen in the ANSYS software. Analysis helps in RC beam design so that applied loads can be properly supported while upholding safety requirements and structural integrity. It ensures that the beams will withstand expected forces and deformations without failing. By analyzing the behavior of RC beams under varied stress conditions and geometric arrangements, engineers can make design improvements that minimize material usage and costs while upholding performance requirements. By examining RC beams, one can be sure that safety standards are followed. It helps identify potential failure modes and gives engineers the ability to implement appropriate design controls to lower risks. By performing analysis, engineers may verify the quality of construction and identify any discrepancies between the structure's planned behavior and actual performance.

1.1 Objectives

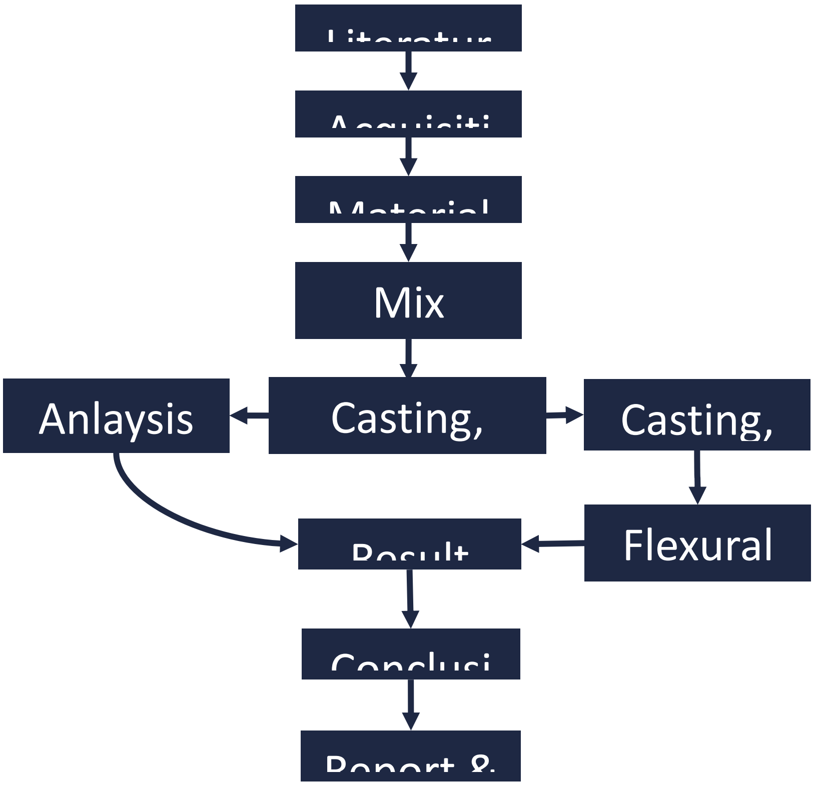
- First point To design the mix for M30 grade concrete.
- To find the optimum percentage of Precious slag balls in M30 grade concrete (10%, 20%, 30%, 40%, 50%).
- To design and fabricate the RC beam specimens (Control and optimum percentage mix).
- To analyze the RC beams using ANSYS software.

- To test the flexural behaviour of RC beams.
- To compare the flexural performance of control and optimum percentage mix beams in both experimental and analytical.

1.2 Scope

- To increase the quality and mechanical properties of the concrete.
- To replace the fine aggregate using waste materials.

1.3 Methodology



2. Literature review

S. Sharath investigated that is it feasible to produce high-quality concrete utilizing PS balls, to pinpoint any potential advantages of doing so, and to offer suggestions for boosting the balls' use in concrete applications. The purpose of the study is to determine how PS balls, used in various percentages (20%, 40%, 60%, 80%, and 100%) can substitute fine particles and affect the mechanical properties of concrete, including its flexural strength, splitting tensile strength, and compressive strength. The best mixture was discovered to be 40% PS ball replacement, resulting in a maximum strength of 62.89 MPa after 28 days of curing. When the permeability of the concrete was tested, replacing the fine particles with PS balls at 40% and 100% produced a concrete that was more durable.

Jagadish Mallick investigated that the influence of different amounts of recycled fine aggregates obtained from the steelmaking industry. In the present study, the effects of replacing sand by different percentages of PS Balls on compressive strength properties of concrete have been investigated. Replacement percentages were 9, 12, 15, 18, 27 and 36% by weight of used fine aggregate. Properties of fresh and hardened concrete were experimentally investigated. All the results of the performed tests indicate a better performance of mixtures containing this PS Balls compared with plain cement reference concrete in terms of mechanical properties and durability indicators.

Avinash H Talkeri investigated that the impacts of different percentages of recycled fine aggregates from the steel industry are investigated in this study. The current study looked at how different percentages of PS Balls substituted for sand affected the characteristics of concrete's compressive strength. In terms of weight of used fine aggregate, the replacement percentages were 12, 15, 18, 27, and 36%. Both fresh and hardened concrete's characteristics were investigated experimentally. All of the test results indicate that mixtures including these PS Balls perform better than reference concrete produced of regular cement in terms of mechanical properties and durability indicators.

Ashish Milind Wahane The study's findings indicate that the concrete's workability rose as the proportion of Steel Slag replacement dropped. Slump values increased for replacement percentages of 5% and 20% of Steel Slag, respectively, from 110mm to 120mm. The test findings suggest that Steel Slag can be used to replace 15% of the cement in a concrete mix to improve workability, compressive strength, and split tensile strength more successfully than conventional concrete.

3. Materials and methods

Cement, fine and coarse aggregate, precious slag balls, and SP430 are among the materials whose qualities have been documented. Regarding the mechanical, and flexural performance of the specimens, the test results are contrasted with the plain concrete control batch. Concrete with a grade of M30 was employed in the investigation for this project.

Table 1 – Material details

Materials	**Details**
Cement	Ultratech 53grade, OrdinaryPortland, Cement
Fine aggregate	Locally available M-sand ZONE-II
Coarse aggregate	Locally available well graded crushed granite.
Water	Available locally portable water
Precious slag balls	Collected from KEDIA MINERALS, Jaipur
Admixtures	SP430 collected from college

Fig. 1 – Precious slag balls

3.1 Preliminary tests

The basic tests like specific gravity test and sieve analysis test are carried out for manufactured sand, coarse aggregate and precious slag balls.

Table 2 - Preliminary test results

Material	**Bulk density (kg/m^3)**	**Specific gravity**	**Fineness modulus**
Coarse aggregate	1376	2.7	7.23
Fine aggregate	1690	2.65	3.65

Table 3 - Chemical composition of precious slag balls

Elementss	**IN %**
SiO2	19.5%
Al2O3	4.25%
Fe2O3	43.5%
MgO	2.72%
CaO	30%

3.2 Mix proportions

It is the crucial and important part in construction industry. For instance, in the context of concrete, "mix proportion" refers to the exact ratio of cement to aggregates, water, and admixtures in order to obtain the required strength, durability, and workability. Comparably, in manufacturing processes, the ratios of raw materials to produce ideal formulations are determined by mix proportion.

Table 4 - Mix proportion of M30 grade of concrete

Water	Cement	Fine aggregate	Coarse aggregate
0.4	1	1.8	3.47

Table 5 - Mix design values used in this investigation

Specimen Designation	Cement (kg/m^3)	M sand (kg/m^3)	PS balls (kg/m^3)	Coarse aggregate (kg/m^3)	SP430 (kg/m^3)	Water
RP0	370	663.6	0	1281	3.7	148
RP10	370	597.2	66.4	1281	3.7	148
RP20	370	530.8	132.8	1281	3.7	148
RP30	370	464.5	199.1	1281	3.7	148
RP40	370	398.1	265.5	1281	3.7	148
RP50	370	331.8	331.8	1281	3.7	148

Table 6 - Casting works

Specimen	No. of samples
Cube	3
Cylinder	3
Prism	3
Beam	1

4. Experimental investigations for optimum percentage

Here both fresh concrete (workability test) and hardened concrete tests (Compressive strength test, split tensile test, flexural strength test and flexural behavior test) carried out.

4.1 Slump cone test

Workability of the concrete is determined using the slump cone at the fresh stage of concrete and it is given below in the table 7 and figure 2. The Slump is carried out in compliance with Indian Standard IS 1199-1959 procedures.

Table 7 - Slump cone test values

Specimen Designation	Slump Value (mm)
RP0	**7676**767**76**
RP10	80
RP20	87
RP30	95

RP40	95
RP50	97

Fig. 2 – Slump cone test result graph

4.2 Density of concrete

The density of standard strength concrete cube specimen according to the IS standard is tested for 28 days of curing and it is given below in the table 8 and figure 3.

Table 8 - Density values of the concrete

Specimen Designation	**Average Weight of cubes (kg)**	**Volume of the cubes (m^3)**	**Density of the cubes (kg/m^3)**
RP0	8.74	0.003375	2589.78
RP10	8.76	0.003375	2594.7
RP20	8.8	0.003375	2607.5
RP30	8.97	0.003375	2656.67
RP40	9.1	0.003375	2692.32
RP50	9.15	0.003375	2710.21

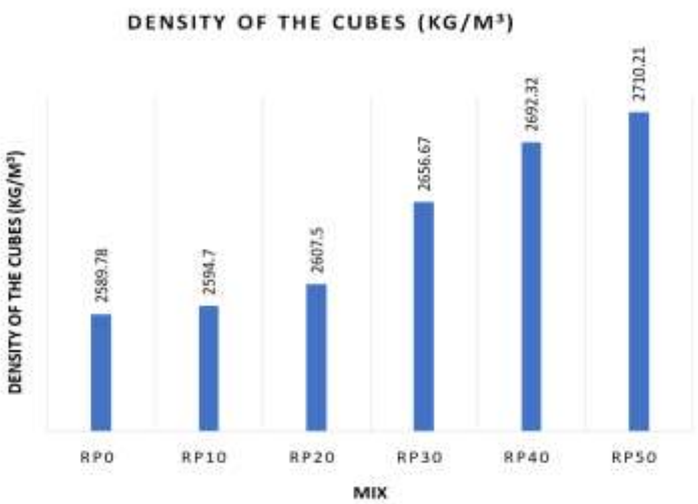


Fig. 3 – Density of concrete test result graph

4.3 Compressive strength test

The compressive strength of standard strength concrete cube specimen according to the IS standard is tested for 14 days, 28 days of curing and it is given below in the table 9, 10 and figure 4.

Table 9 - Concrete compressive strength at 14 days

MIX	Sample 1 Strength (N/mm^2)	Sample 2 Strength (N/mm^2)	Sample 3 Strength (N/mm^2)	Avg Strength (N/mm^2)
RP0	29.5	29.45	30.2	29.7
RP10	30.9	31.4	30.8	31.03
RP20	32.3	32.5	32.1	32.3
RP30	32.7	32.55	32.75	32.67
RP40	32.9	33.45	32.7	33.01
RP50	32.02	31.95	31.67	31.88

Table 10 - Concrete compressive strength at 28 days

MIX	Sample 1 Strength (N/mm^2)	Sample 2 Strength (N/mm^2)	Sample 3 Strength (N/mm^2)	Avg Strength (N/mm^2)
RP0	32.42	32.12	32.15	32.23
RP10	33.64	33.67	33.7	33.67
RP20	35.21	35.17	35.16	35.18
RP30	35.48	35.53	35.52	35.51
RP40	36.21	35.98	35.84	36.01
RP50	34.77	34.69	34.79	34.75

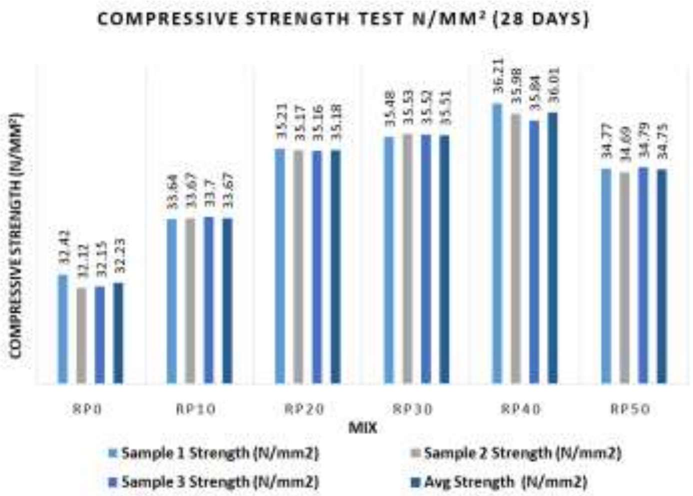


Fig. 4 – Concrete compressive strength after 28 days graph

4.4 Split tensile strength test result

The split tensile strength of standard strength concrete cylinder specimen as per IS standard is tested for 14 days, 28 days and comparison of test is given below in the table 11, 12 and figure 5.

Table 11 - Tensile strength of concrete at 14 days

MIX	Sample 1 Strength (N/mm^2)	Sample 2 Strength (N/mm^2)	Sample 3 Strength (N/mm^2)	Avg Strength (N/mm^2)
RP0	3.18	3.21	3.15	3.18
RP10	3.29	3.33	3.28	3.3
RP20	3.38	3.41	3.38	3.39
RP30	3.44	3.4	3.42	3.42
RP40	3.48	3.45	3.45	3.46
RP50	3.4	3.38	3.39	3.39

Table 12 - Tensile strength of concrete at 28 days

MIX	Sample 1 Strength (N/mm^2)	Sample 2 Strength (N/mm^2)	Sample 3 Strength (N/mm^2)	Avg Strength (N/mm^2)
RP0	3.69	3.675	3.693	3.69
RP10	3.7	3.72	3.713	3.71
RP20	3.729	3.73	3.731	3.73
RP30	3.732	3.74	3.738	3.737
RP40	3.74	3.75	3.73	3.75
RP50	3.72	3.71	3.728	3.72

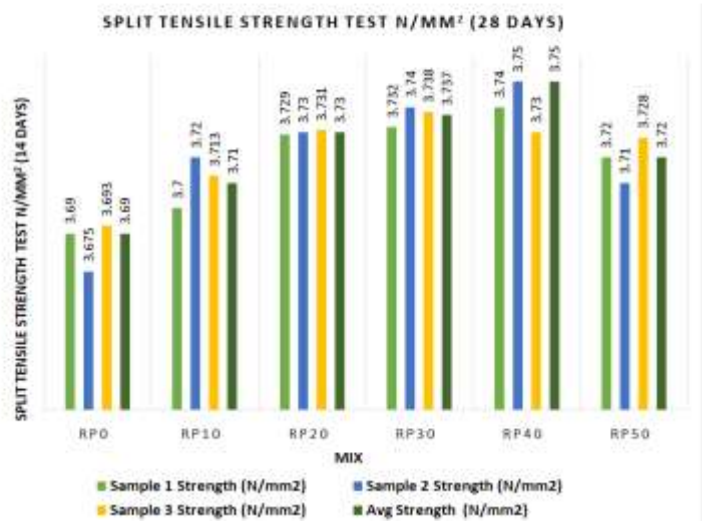


Fig. 5 – Split tensile strength after 28 days graph

4.5 Flexural strength test

The Flexural strength of standard strength concrete prism specimen according to the IS standard is tested for 14 days, 28 days and it is given below in the table 13, 14 and figure 6.

Table 13- Flexural strength of concrete at 14 days

MIX	Sample 1 Strength (N/mm^2)	Sample 2 Strength (N/mm^2)	Sample 3 Strength (N/mm^2)	Avg Strength (N/mm^2)
RP0	3.17	3.15	3.166	3.162
RP10	3.25	3.32	3.23	3.27
RP20	3.48	3.4	3.52	3.47
RP30	3.6	3.67	3.58	3.62
RP40	4.625	4.5	4.71	4.62
RP50	4.03	4.18	3.98	4.06

Table 14- Flexural strength of concrete at 28 days

MIX	Sample 1 Strength (N/mm^2)	Sample 2 Strength (N/mm^2)	Sample 3 Strength (N/mm^2)	Avg Strength (N/mm^2)
RP0	4.21	4.27	4.21	4.23
RP10	4.36	4.33	4.36	4.35
RP20	4.73	4.69	4.71	4.71
RP30	4.78	4.8	4.82	4.8
RP40	5.23	5.26	5.26	5.25
RP50	4.98	5.2	5.27	5.15

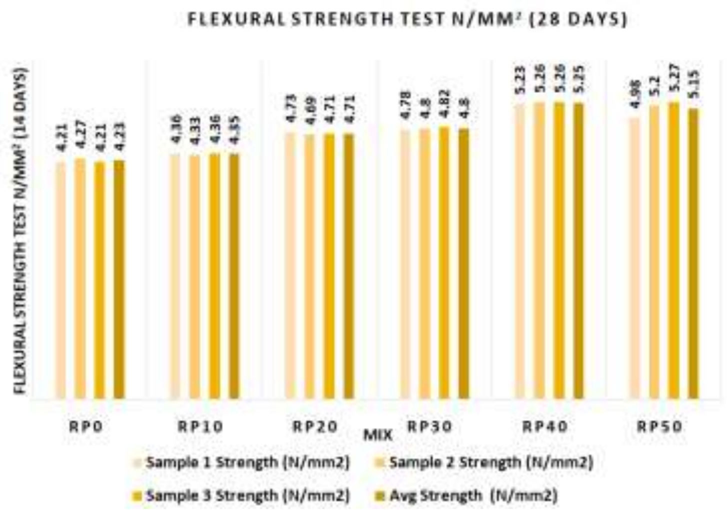


Fig. 6 – Flexural strength after 28 days graph

4.6 Youngs modulus test

Here modulus of elasticity of concrete determined by testing the cylinder specimen using UTM machine.

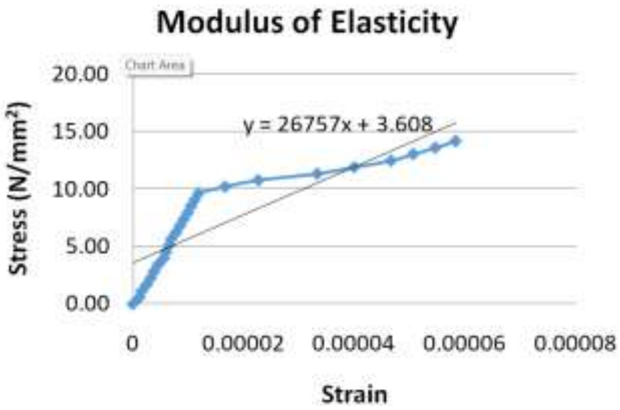


Fig. 7 – Modulus of elasticity graph

5. Experimental investigations of beams

The beam was manually designed using the provisions from IS 456:2000 for M30 grade of concrete and Fe550D grade of steel as follows. Fig 8 represents the reinforcement details of the beam.

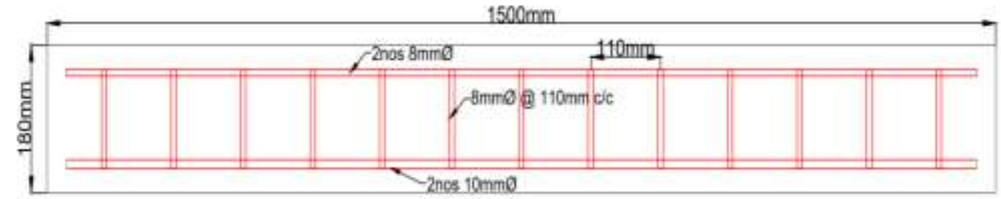


Fig. 8 – Detailing of beam

5.1 Casting of beam

Conventional concrete beam (CC) and optimum percentage concrete beam (K40) with 40% of precious slag balls as fine aggregate replacement were casted as shown in figures 9. They were allowed to cure for 28 days. 2 nos of 10mm dia bars were provided at the tension zone and 2 nos of 8mm dia bars were provided at the compression zone. 2 legged 8mm dia stirrups were provided at 110mm c/c spacing.

Fig. 9 – Casting of beam

5.2 Flexural behavior test results

The setup, which was only supported, was where the beam was positioned. On both sides of the beam, a 100mm support distance marker was placed. The load cell was adjusted and set up after a steel I section was positioned on the beam. In order to evenly distribute the load on the beam, a two-point loading configuration was created.

Fig. 10 – Experimental setup of the RC beam in loading frane

Table 15 - Final observations for conventional beam

Parameters	**Values**
Initial load	4.90 KN (0.5 tonnes)
Initial deflection	0.22 mm (L/2)
First crack load	68.65 KN (7 tonnes)
Deflection at first crack	3.14 mm (L/2)
Yield load at L/2	73.6 KN (7.5 tonnes)
Yield load deflection at L/2	3.43 mm
Yield load at L/3	112.78 KN (11.5 tonnes)
Yield load deflection at L/3	6
Ultimate load	139.25 KN (14.2 tonnes)
Deflection at ultimate load	10.78 mm (L/2)

Table 16 - Final observations for optimum mix beam

Parameters	**Values**
Initial load	4903.33 N (0.5 tonnes)
Initial deflection	0.11 mm (L/2)
First crack load	88.26 N (9 tonnes)
Deflection at first crack	2.5 mm (L/2)
Yield load at L/2	132.39 KN (13.45 tonnes)
Yield load deflection at L/2	5.8 mm
Yield load at L/3	127.49 KN (13 tonnes)
Yield load deflection at L/3	4.15 mm
Ultimate load	139254.43 N (14.2 tonnes)
Deflection at ultimate load	10.78 mm (L/2)

Fig. 11 – Load vs deflection curve (L/2)

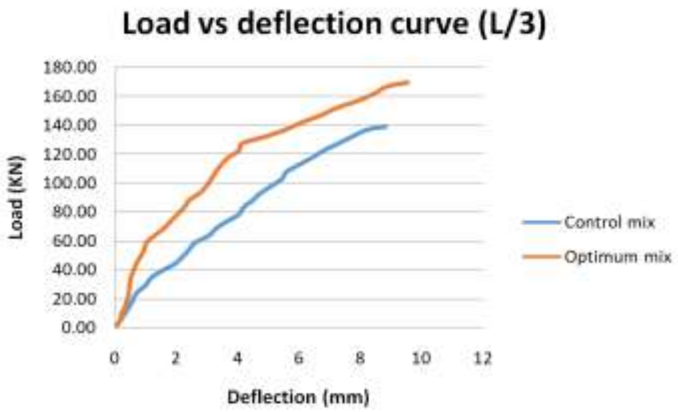
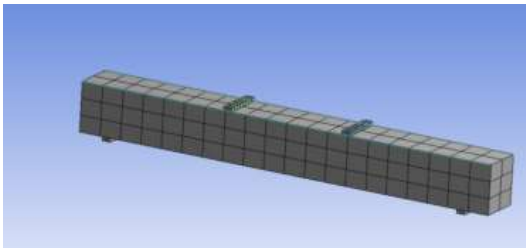


Fig. 12 – Load vs deflection curve (L/3)

6. Analytical investigations of beams

After finding experimental test results, we have analyzed RC beam in both conventional (CC beam) and optimum mix (K40 beam) using ANSYS software. Comparison of experimental and analytical values brings the efficiency of te research work.



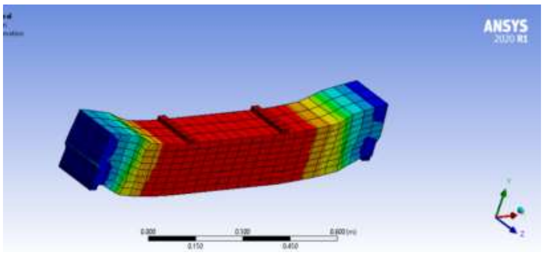


Fig. 13 – Meshing of beam, Total deformation of beam

Table 17 - Analytical test results

Specimen	Max deflection (mm)	Ultimate load (KN)
Conventional beam	8.01	132.98
Optimum mix beam	10.23	158.54

7. Results and discussion

The main results drawn based on the test results obtained in this research study are following:

- It was observed that the slump value of concrete increases as the PS Ball content increases at the same Water/Binder (W/B) ratio. Increased PS balls increased the density of hardened concrete due to higher specific gravity of PS Balls compared to manufactured sand.
- In comparison to the control mixes, the concrete mixes containing PS balls exhibited a greater compressive strength. With respect to the control mix, the compressive strength variation percentages for RP10, RP10, RP30, RP40, and RP50 were 4.47%, 9.15%, 10.18%, 11.73%, and 7.82%, respectively.
- In comparison to the control mixes, the concrete mixes containing PS balls exhibited a greater splitting tensile strength. The brittle failure of the concrete specimens containing PS balls was comparable to that of the reference concrete. With respect to the control mix, the split tensile strength variation percentages for RP10, RP20, RP30, RP40, and RP50 were 0.54%, 1.08%, 1.27%, 1.63%, and 0.82%, respectively.
- In comparison to the control mixes, the concrete mixes containing PS balls exhibited a greater flexural strength.. With respect to the control mix, the flexural strength variation percentages for RP10, RP20, RP30, RP40, and RP50 were 2.84%, 11.35%, 13.48%, 24% and 21.7% respectively.
- In experimental test results, the optimum mix beam (K40) withstands 21.58% higher load than conventional beam (CC). Also K40 beam resists 47.6% deflection than CC beam.
- In analytical test results, the optimum mix beam (K40) withstands 19.2% higher load than conventional beam (CC). Also K40 resists 27.7% deflection than CC beam.

8. Conclusion

The following are the main conclusions drawn based on the test results obtained in this research study:

- As the percentage of PS balls replacement increases, the workability of the concrete increased.
- The density of the concrete increases by the increase of PS balls linearly.
- The maximum compressive strength of concrete is observed when manufactured sand replacement is about 40% replaced with PS balls; when the replacement is greater than 40%, a slight decrease in compressive strength is observed.
- The maximum split tensile strength of concrete is observed when manufactured sand replacement is about 40% replaced with PS balls; when the replacement is greater than 40%, a slight decrease in compressive strength is observed.
- The maximum flexural strength of concrete is observed when manufactured sand replacement is about 40% replaced with PS balls; when the replacement is greater than 40%, a slight decrease in compressive strength is observed.
- The K40 beam gives better results in terms of the flexural behaviour when compared to CC beam in the experimental test. In other words, K40 beam has higher load bearing capacity than CC beam.
- Optimum mix beam withstands more load and restricts deflection than conventional beam in analytical test.
- Experimental test gives better results than analytical test.
- Hence, we can conclude that replacing 40% of fine aggregate in concrete by precious slag balls gives high quality concrete.

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