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Experimental Study on Concrete by Partially Replacing Cement with Calcium BentoniteandFine Aggregate with Steel Slag

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Abstract: The growth of steel industry and increase of waste products are the major issues faced by humans. Large amount of carbon dioxide released in the environment during cement production which results in global warming. There is a need of alter the cement by some natural materials which having pozzolanic properties. Calcium Bentonite powder is a naturally available impure clay having pozzolanic properties able to replace cement partially. The technological trend towards waste utilization and cost reduction in industrial processing has attracted use of steel slag as an alternative material for aggregate in concrete. This work is a study of physical properties and strength behaviour of concrete by partially replacing cement with Calcium Bentonite powder and fine aggregate with steel slag. Concrete specimens prepared by partially replacing cement with different percentage of Calcium Bentonite (0% to 20%) and fine aggregate with 40% of steel slag. Workability, strength properties such as compressive strength, tensile strength, flexural strength and non-destructive test such as Ultra Sonic Pulse Velocity tests, durability test such as acid attack test were studied. The optimum level of replacement for strength and workability of concrete were done. The self-healing behaviour of concrete has been studied. The results indicate that the utilization of Calcium Bentonite powder as cement replacement and steel slag as fine aggregate replacement will improve the properties of concrete.

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I. INTRODUCTION

Concrete is prime material for structures and used for various other applications. It is a composite material consisting of cement, coarse aggregate, fine aggregate and water.Use of cement generate large amount of carbon dioxide which results in global warming and ozone layer depletion. Calcium Bentonite is the largest naturally available material whose production cost is very less compared to Ordinary Portland Cement (OPC). The composition of Calcium Bentonite is similar to Ordinary Portland Cement. The naturally available material can solve the environmental damages for certain extend. Sand is a major component of concrete. The properties of concrete depend mainly on type of sand used for construction. It can fill up the voids and pores in concrete, which contribute the strength characteristics. The growing demand of sand results in their non-availability especially in India. Due to industrialisation the waste products are tremendously increasing that cause ecological imbalance. Using the industrial wastes in concrete not only the method for solves the disposal problem of wastes but also reduces the cost of concrete. The waste products such as steel slag can be crushed and used effectively in the form of fine aggregate for concrete production.

II. MATERIAL AND METHODS

The materials for concrete mix are selected from conventional concrete industry. It includes ordinary Portland cement, fine aggregate, coarse aggregate and water. In addition Calcium Bentonite powder, steel slag and chemical admixture (super plasticizer) are incorporated in the mix.

Cement : Ordinary Portland cement of 53 Grade conforming to IS: 8112-1989 (Maha gold) was used for this study.

Table no 1 Material properties of cement

Sl.No	Property of cement	Observed values
1	Grade of cement	OPC 53 grade
2	Fineness of cement	1%
3	Specific gravity	3.15
4	Normal consistency	31%
5	Initial setting time	122min
6	Final setting time	329min

Coarse aggregate : The material properties were given in table no 2. The obtained values satisfied the results as per IS: 383-1970.

Table no 2 Material properties of coarse aggregate

Sl.No	Properties	Observed values
1	Specific gravity	3.1
2	Maximum size of aggregate	20mm
3	Fineness modulus	3.89

Fine aggregate : The material properties of M-sand were tested and results were given in table no 3. The obtained values satisfied the results as per IS: 383-1987.

Table no 3 Material properties of fine aggregate

Sl.No	Properties	Observed values
1	Specific gravity	2.8
2	Fineness modulus	2.861
3	Zone	Zone ii

Calcium Bentonite (CB) powder:used for this study was light yellow in colour (figure 1) and having a specific gravity of 2.42. The initial and final setting time is determined using vicat apparatus by replacing 0%, 5%, 10%, 15% and 20% of Cement by Calcium Bentonite powder. Normal consistency 0f 31% is kept same for each replacement and test was proceeded. The test result gives higher initial and final setting time of 139 minutes and 373 minutes respectively. For ordinary cement initial and final setting time found to be 122 minutes and 329 minutes respectively. The test results were shown in table no 4.

Figure 1 Calcium Bentonite powder

Table no 4 Initial and final setting time of cement and cement replaced by CB

	100% cement	95% cement and 5% CB	90% cement and 10% CB	85% cement and 15% CB	80% cement and 20% CB
Normal consistency	31%	31%	31%	31%	31%
Initial setting time	122 min	131	135	137	139
Final setting time	329 min	358	364	371	373

Steel slag (SS) : is the by-product of steel manufacturing. Slag of size similar to M-sand was used for the study, which passes through 4.75mm IS sieve as shown in figure 2. In this study 40% of fine aggregate replace partially by SS.[12]

Figure 2 Steel slag

The material properties of steel slag such as specific gravity and fineness modulus were determined using pycnometer and sieve analysis. The material properties of steel slag were given in table no 5.

Table no 5 Material properties of steel slag

Property	Observed value
Fineness modulus	3.29
Specific gravity	3.6

Chemical Admixture: To enhance the workability of concrete high performance super plasticizer Masterglenium SKY 8233 was used and its dosage level fixed as 500 ml to 1000 ml per 100Kg cement according to suppliers brochure.

Water : Water is the most important and least expensive ingredient of concrete as it actively participates in the chemical reaction with the cement. The pH value of curing water shall be more than 6.

Mix Design of M20 Grade Concrete : Mix design is performed as per IS 10262: 2009 for M20 grade concrete. The ratio of the mix is 1:1.84:3.33 with water-cement ratio of 0.50. Bentonite was added as partial replacement of cement at the concentrations of 0%, 5%, 10%, 15% and 20%. In each case the steel slag added as partial replacement of fine aggregate by 40% [12]. The mix design of M20 grade concrete is given in table no 6.

Table no 6 Mix design of M20 grade concrete

Water	Cement	Fine Aggregate	Coarse Aggregate
197L	394kg	726.544kg	1314.88kg
0.5	1	1.84	3.33

Experimental ProgrammeonConcrete : Experimental tests have been conducted on concrete to determine the workability of mix, strength and durability of concrete. Fresh concrete properties such as workability were determined using slump cone test. Strength test includes compressive strength test, split tensile strength and flexural strength test. Acid attack test is one of the durability test conducted to check the quality of concrete. Besides strength and durability tests non-destructive test such as UPV test was conducted.

Proportioning and Mixing of Concrete : The quantity of cement, fine aggregate, coarse aggregate Calcium Bentonite powder, Steel Slag and water for each batch is prepared based on mix design of M 20 grade concrete. Super plasticizer added along with water in each mix to make a workable concrete. Different batches are prepared and mixed by replacing 0%, 5%, 10%, 15% and 20% of cement with Calcium Bentonite powder and 40% of M-sand with steel slag. Potable water is used for curing.

Slump Cone Test : Figure 3 shows the slump cone. The slump test conducted on each mix by partially replacing cement with different percentage of CB and fine aggregate PCE admixture added in each mix to make a workable concrete.

Figure 3 Slump cone

Compressive Strength Test : Compressive strength is the most important property of concrete. Test conducted on a cube of size 150mmx150mmx150mm. Cube is placed on compressive strength testing machine. The test set up is as shown in figure 4.The load is applied is 140kg/Cm^2/minute and controlled by load rate control knob. The test is conducted on each mix by partially replacing cement with different percentage of CB (0% - 20%) and fine aggregate with 40% SS along with PCE admixture. The ultimate load obtained was tabulated and calculations are done as per IS: 516 – 1959.

Figure 4 Compressive strength test setup

Split Tensile Strength Test : Concrete is strong in compression and weak in tension. Concrete is not expected to take direct tension because of brittle nature and low tensile strength. Tensile strength is determined indirectly by conducting splitting test on cylinders. Cracking is a form of tension failure. The cylinder specimens of 150mm diameter and 300mm height were prepared for each mix by partially replacing cement with different percentage of CB (0% - 20%) and fine aggregate with 40% SS along with PCE admixture, and then placed in tensile strength testing machine. Figure 5 shows the test set up, cylinder after cracking and propagation of cracks.

Figure 5 Split tensile strength test setup, initiation and propagation of cracks in cylinders

Flexural Strength Test :In the flexural strength test the theoretical maximum tensile stress reached in the bottom of test beam is the modulus of rupture. The value of modulus of rupture depends on the dimension of beam and arrangement of loading. Figure 6 shows the test set up and cracked beam.

Figure 6 Flexural strength test setup and cracked beam

The test conducted on each mix by partially replacing cement with different percentage of CB (0% - 20%) and fine aggregate with 40% SS along with PCE admixture. Beam of size 100mm x 100mm x 500mm is used for testing. Test is performed under two point loading as per IS 516-1959. Loading is applied and cracking load is tabulated for each mix.

Durability Test on Concrete (Acid Attack Test) : Durability of concrete is important while considering the concrete properties. The Concrete cube of size 150mm x 150mm x 150 mm were prepared by adding different percentage of CB (0% - 20%), 40% SS along with PCE admixture. Figure 7 shows the cubes which were immersed in 5% H_2SO_4 solution for 60 days after taking the initial weight and the condition of cubes after 60 days of immersion in acid solution.

Figure 7 Cubes immersed in 5% H_2SO_4 solution for 60 days and after 60 days ready for acid attack test

Ultra Sonic Pulse Velocity (UPV) Test: Figure 8 shows the UPV test set up for velocity measurement of cubes.

Figure 8 UPV test set up to measuring velocity

III. RESULTAND DISCUSSION

Slump cone test results, strength test results, durability test results and UPV test results were discussed to evaluate the optimum percentage of replacement and check the quality of concrete.

Slump Cone Test: Concrete specimens were prepared with different percentage of Calcium Bentonite powder in concrete by partially replacing the cement (0% - 20% replacement). Table no 7 shows the slump cone test results of concrete.

Table no 7 Fresh characteristics of concrete

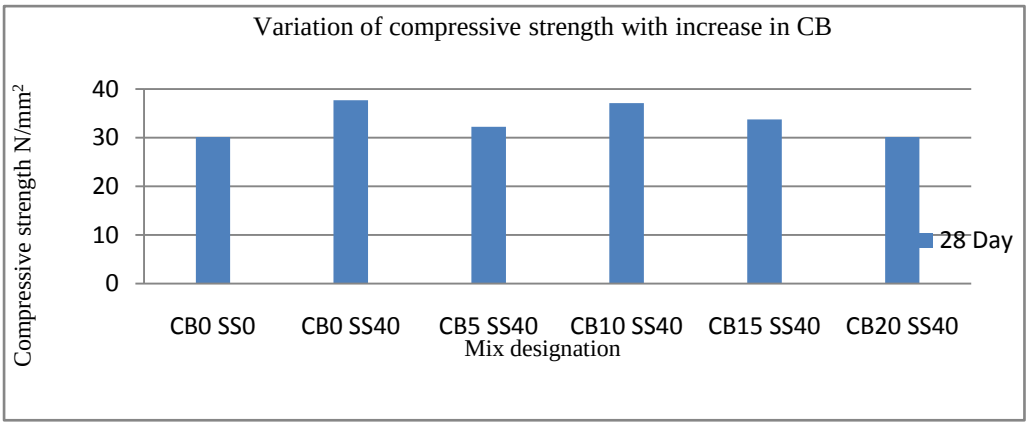
Mix designation	W/C ratio	Slump (mm)	Nature of collapse	Degree of workability
CB0 SS0	0.5	102	True slump	High workability
CB0 SS40	0.5	101	True slump	High workability
CB5 SS40	0.5	86	True slump	Medium workability
CB10 SS40	0.5	87	True slump	Medium workability
CB15 SS40	0.5	78	True slump	Medium workability
CB20 SS40	0.5	71	True slump	Medium workability

Workability test result shows that slump value is lower for concrete containing Calcium Bentonite and steel slag as compared to conventional concrete. The slump values are nearly in the same range. The slight variation is due to stiffness of mix. The super plasticizer keep the mix workable.A high slump value of 102 mm obtained for plain concrete, but the range is nearly same as that of mix containing 0% CB and 40% SS. The nature of collapse obtained was true slump and mix has medium workability in all cases of Bentonite addition. Hence the concrete is workable and used for construction purposes.

Compressive Strength Test : Compressive strength test was carried out to obtain the optimum percentage of Calcium Bentonite powder that can replace the cement. Compressive strength test was conducted on each cube. The compressive strength test results of 7^{th} day and 28^{th} day are given in table no 8. The graph indicates the variation of compressive strength with increase in percentage of Calcium Bentonitepowder at 28^{th} day of testing.

Table no 8 Compressive strength test results

Mix designation	Compressive Strength N/mm^2	
	At 7^{th} day	At 28^{th} day
CB0 SS0	20.04	30.10
CB0 SS40	25.80	37.72
CB5 SS40	22.66	32.24
CB10 SS40	24.14	37.11
CB15 SS40	23.36	33.78
CB20 SS40	20.00	30.11



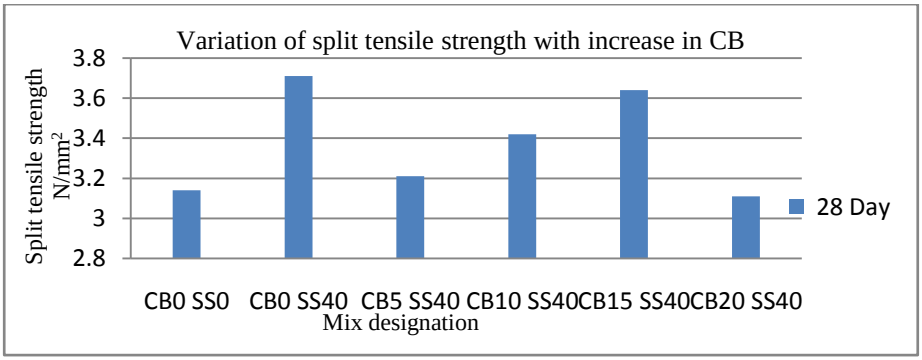
From compressive strength test results an increment of strength is observed for concrete with CB and SS than plain concrete. Test results shows that 10% replacement of cement withCB and 40 % replacement of M-sand with steel slag gave 20.46% and 23.29% higher compressive strength than conventional concrete on 7th and 28th day. This mix has 6.43% and 1.2% strength reduction on 7th and 28th day respectively. It indicates the later age strength of concrete with CB and SS. The strength gets reduced on further increment of CB in mix. The possible reason for the reduction in strength is weak interface of CB with coarse aggregate resulting in micro crack and failure under.

Split Tensile Strength Test : Split tensile strength of cylinders conducted on 7th day and 28th day. The test results are shown in table no 9.

Table no 9 Split tensile strength test results

Mix designation	Split tensile strength N/mm^2	
	At 7th day	At 28th day
CB0 SS0	2.08	3.14
CB0 SS40	2.59	3.71
CB5 SS40	2.12	3.21
CB10 SS40	2.35	3.42
CB15 SS40	2.47	3.64
CB20 SS40	1.99	3.11

A slight increase in split tensile strength was observed with 15% CB addition compared to plain concrete. Further increment in percentage of CB results in reduction of strength. Split tensile strength of concrete having 0% CB and 40% SS found to be higher than mixes with 5%, 10%, 15%, 20% CB and 40% SS. The mix with 15% CB and 40% SS shows only 1.89% strength reduction as compared with 0% CB and 40% SS on 28th day. The optimum percentage of replacement of CB observed as 15% on comparison with plain concrete.



The decrease in split tensile strength could be attributed to the same factors that reduce the compressive strength. 15% CB and 40% SS give good early age and later age tensile strength than plain concrete.

Flexural Strength Test : Flexural strength test conducted on beams on 28th day. The test results are shown in table no 10.

Table no 10 Flexural strength test results

Mix designation	Flexural strength N/mm^2
	28th day
CB0 SS0	5.5
CB0 SS40	6.55
CB5 SS40	6.2
CB10 SS40	6.5
CB15 SS40	6.15
CB20 SS40	5.85

An increase in flexural strength was observed with CB addition compared to plain concrete. The concrete having 0% CB and 40% SS shows high flexural strength of 6.55 N/mm^2. With the addition of 5% CB flexural strength reduced to 6.2 N/mm^2. The optimum percentage of CB replacement observed as 10% as compared with plain concrete. A flexural strength of 6.5 N/mm^2 obtained which is nearly in the same range of concrete having 40% SS. It indicates that less than 1% strength reduction occurred in concrete with 10% CB. Further addition of CB results in reduction of strength.

Acid Attack Test : Acid attack test conducted on cube specimens and test results were given in table no 11. The test results show that 10% CB and 40% SS in the mix makes the concrete more durable since the weight loss is found to be least for such mixes. Acid attack factor = 10/40 = 0.25.

Table no 11 Acid attack test results

Mix designation	Weight of Specimen after Immersion (g)	Weight of Specimen before Immersion (g)	Weight Loss (g)
CB0 SS0	8514	8899	385
CB0 SS40	8532	8910	378
CB5 SS40	7896	8161	265
CB10 SS40	7787	8011	224
CB15 SS40	7667	7903	236
CB20 SS40	7522	7763	241

In acid attack test the specimen with 10% Bentonite and 40% steel slag shows 17.96% lesser weight loss when compared with the plain concrete and 10.45% lesser weight loss when compared with the concrete having 0% CB and 40% SS. The reduction in weight loss is due to CB in the mix.

UPV Test :UPV test conducted on cube specimens with 0% CB and 40% SS, 10% CB and 40% SS and on plain concrete. Pulse velocity and time were measured. Test results of UPV for 7th day and 28th day are shown in table no 12 and table no 13.

Table no 12 7th Day UPV test results

Mix designation	Direct		Semi direct	
	Time (µs)	Velocity(m/s)	Time (µs)	Velocity(m/s)
CB0 SS0	28.5	4987	20.4	5154
CB0 SS40	28.7	4992	20.8	5193
CB10 SS40	31.1	4823	21.2	5036

Table no 1328th Day UPV test results

Mix designation	Direct		Semi direct	
	Time (µs)	Velocity(m/s)	Time (µs)	Velocity(m/s)
CB0 SS0	26.4	5345	16.4	5769

CB0 SS40	27.1	5421	16.8	5812
CB10 SS40	28.7	5226	16.9	5132

The quality of cube is given in table no 15 as per IS 13311-PART 1.

Table no 15 Pulse velocity and quality of cube

Pulse velocity (m/s)	Quality
> 4500	Excellent
3500 – 4500	Good
3000 – 3500	Medium
< 3000	Poor

From table it was found that Concrete with 10% CB and 40% SS have excellent quality. The concrete with 0% CB and 40% SS also have excellent quality but slightly lower than concrete with 10% CB. The excellent quality is due to the presence of CB in the mix.

IV. CONCLUSION

Based on the experimental research and behaviour study of concrete by partially replacing cement with Calcium Bentonite powder and fine aggregate with steel slag, the following conclusion have been drawn.

- Slump cone test was carried out and PCE admixture was used to make workable mix.
- Based on the Compression Strength test, 10 % replacement of cement with CB and 40% replacement of M-sand with steel slag gave higher compressive strength (23.29%) than plain concrete.
- Concrete with 10% CB and 40% SS shows 6.43% and 1.2% strength reduction on 7^{th} and 28^{th} day compared with 0% CB and 40% SS.
- Cement can be replaced by CB partially without affecting strength characteristics.
- Optimum tensile strength obtained for mix having 15% CB and 40% steel slag than plain concrete.
- The mix with 15% CB and 40% SS shows only 1.89% strength reduction as compared with 0% CB and 40% SS on 28^{th} day.
- Optimum flexural strength obtained for mix having 10% CB and 40% steel slag than plain concrete.
- The strength reduced less than 1% with 10% CB in the mix than the mix having 0% CB and 40% SS.
- In acid attack test the specimen with 10% CB and 40% steel slag shows 17.96% lesser weight loss when compared with the plain concrete and 10.45% lesser weight loss when compared with the concrete having 0% CB and 40% SS.
- UPV test shows that concrete with Calcium Bentonite and steel slag have good quality.
- Degree of damage is 26.17% for 10% replacement which reduces and solves crack problems.
- This experimental study has proved a better method or way to provide strong and durable concrete. It also gives solution to disposal problem of steel slag.

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