Durability Studies on Normal Strength Concrete using Construction and Demolition waste as fine aggregates

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Abstract

Due to growth in the construction industry the use of natural resources has increased. Over exploitation of sand has led to its depletion and resulted in environmental issues and has also become uneconomical. Engineers and researchers all over the world have started working in the direction of a sustainable alternative material. Reuse of construction and demolition waste seems to be an alternative for concrete. Along with understanding the strength characteristics of these materials it is also necessary to observe their durability in various environments to which the concrete is likely to be exposed to. The objective of the investigation was to understand the behaviour of NSC with C&D waste as fine aggregates under various exposure conditions. Crushed concrete, mortar, granite, glass and ceramic waste combined in equal quantities were used as fine aggregates for replacement levels of 0, 30, 70 and 100%. The behaviour of these concrete specimens in 5% HCl, 5% $MgSO_4$ and 5% NaCl solutions, their resistance to fire at 300^{0}C and 600^{0}C, resistance to corrosion and extent of water absorption was analysed by observing the change in weight and compressive strength. It was observed that the concrete with C&D waste performed on par with control mix or better than the control mix especially for 30% replacement level. However as the replacement ratio increased the performance decreased. It was concluded from the limited experiments that replacement up to 30% can be carried out without any compromise on strength and durability.

Key Words: *Construction and Demolition Waste, Fine aggregate, Durability, Normal Strength Concrete*

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1. INTRODUCTION

The growth of the construction industry and major infrastructure projects has led to an unheralded increase in the use of resources thereby depleting natural resources at an alarming rate. Most of the natural resources presently used in the industry are not being recycled and thus effectively becoming non-renewable and imposing pressure on the supply to meet demand.
River sand is used as fine aggregate and constitutes a sizeable volume of concrete. Extensive mining has reduced the availability drastically thus driving up the prices and also providing a window for illegal construction activities. It adversely effects the environment degrading the river beds, erosion of banks and may even lead to imbalance in the aquatic ecosystem.
In this scenario it is even more important to find suitable alternatives to river sand. In this regard the river sand has been replaced by various construction and demolition (C&D) waste in equal percentages. This not only could be an alternative to river sand but also a solution to the problem of disposal of construction and demolition waste which again is a big nuisance to the society by wasting precious land as landfills. Also since the material is inert the processing and reuse of this material can result in an eco-friendly, economical and sustainable solution.

2. EXPERIMENTAL STUDY

2.1 Materials

Ordinary Portland cement of 43 grade conforming to IS: 8112-1989 was used. Tests on cement were conducted and the results are as follows.

Table-1:- Tests on cement

Details of the test	Results
Fineness	0.04
Specific Gravity	3.279

Standard Consistency	30.5%
Setting Time	
a)Initial Setting Time	80 minutes
b)Final Setting Time	390 minutes

Coarse aggregates of 20mm and downsize were used. Various tests on coarse aggregate were conducted and they had the following properties.

Table-2:- Tests on coarse aggregates

Details of Test	Results
Shape	Angular
Bulk Density	
a)Compact state	1617.8 kg/m^3
b)Loose state	1455 kg/m^3
Water Absorption	0.2%
Specific Gravity	2.606

Potable water was used while mixing and curing of the concrete.
River sand was used as the natural fine aggregate. Glass, ceramic, concrete, mortar and granite waste were mixed in equal proportions for the required replacement level and used as recycled fine aggregates. The recycled fine aggregates were subjected to various aggregate tests to determine their usability and those values were compared with the river sand.

Table-3:- Tests on fine aggregates

Property	C&D waste	Natural sand
Specific gravity	2.58	2.53
Bulk density (Kg/m^3)	1476	1605
Fineness modulus	2.81	2.35
Grain Size Distribution	Zone II	Zone II

2.2 Mix Proportions

In the present study the mix design for normal strength concrete was done according to IS:10262:2009. Then trial mixes were done and strength was checked. Final mix design was altered based in the results obtained from trial mixes as shown in Table-4.

Table-4:- Mix proportions of Concrete

Cement	348.33 Kg/m^3
Fine aggregate	697.6 Kg/m^3
Coarse aggregate (20mm downsize)	1145 Kg/m^3
Water	191.58 lit/m^3

The quantity of fine aggregate was calculated based on the replacement ratio and then each waste material was replaced in equal proportions. No other changes were made and all replacement levels were found to have the desired range of workability hence no additional water of superplasticizer was required.

2.3 Preparation of the specimens

Initially all the waste was collected and crushed manually and the tests on aggregates was conducted. Quantity of materials required was calculated and batched. Each part was fed into the mixer and after the constituents thoroughly mixed the concrete was transferred to the moulds in 3 layers with vibration after every layer. They were demoulded after 24 hours and cured for 28days to be used for the required tests.

2.4 Testing Methodology

Various experimental studies were carried out to assess the durability characteristics of the concrete. Also compressive strength tests were carried out at the age of 28 and 56 days and these were compared to strength values obtained from other tests.
Cubes of 150mm were immersed in 5% HCl solution, 5% $MgSO_4$ solution and 5% NaCl solution to determine the acid resistance, sulphate resistance and the chloride resistance of concrete for 56 days. Weights were taken every 5days and percentage weight loss was calculated. Also the compressive strength was found at 28 and 56 days and these values were compared with the actual strength values.
Saturated water absorption test was carried out on 150mm cubes according to ASTM 642 where the cubes were oven dried for 24 hours at 105^0 C and weighed until constant mass was attained. Then the specimens are immersed in water and weights taken at regular intervals until constant mass.
Specimens were cured for 56 days and then the surface dried specimens were kept in an electrical furnace for a period of 2 hours at 300^0 C and 600^0 C and then immediately quenched in water upon removal. They were kept in the water for a period of 24 hours and then tests for compressive strength was done.
For the accelerated corrosion tests prisms of 400mm length and 75mm square cross-section were used. The reinforcement used in these specimens were weighed initially before casting. Cured specimens were then immersed in 5% NaCl solution and connected with a constant DC voltage source. An ammeter was also connected to record the current. The current was passed for 2 hours after which the specimens were removed from solution and broken and the reinforcement weighed again and the loss in weight determined.

3. RESULTS AND DISCUSION

The various tests results obtained have been presented below. The compressive strength values obtained at the age of 28 days and 56 days is given below.

Table-5:- Compressive Strength at 28 and 56 days

Replacement Level	Average Compressive strength 28days(N/mm^2)	Average Compressive strength 56days(N/mm^2)
NSC-0%	42.67	46.89
NSC-30%	41.56	47.56
NSC-70%	40.89	45.11
NSC-100%	40.22	44.44

It was observed that even up to 100% replacement ratio the target strength has been attained. Highest 28 day strength was for 0% replacement and highest 56 day strength was for 30% replacement.
Time scale diagrams have been plotted to observe the reduction in weight as shown in Chart-1.

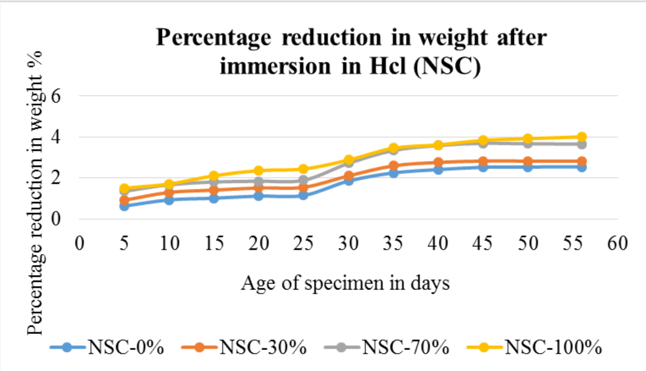

Chart-1:- Percentage reduction in weight v/s time after immersion in HCl

From Chart-1 it was observed that that 0% replacement level has the least weight loss and with the increase in replacement levels weight loss increased.

Table 6:- Compressive strength after 28 days and 56 days of immersion in 5% HCl solution

Replacement Level	28days (N/mm^2)	56 days (N/mm^2)
NSC-0%	31.33	40.29
NSC-30%	30.22	43.47
NSC-70%	28.89	43.35
NSC-100%	25.55	45.5

From the Table 6 it can be observed that at 28 days highest strength was obtained by 0% replacement and at 56 days highest strength was obtained by 30% replacement ratio. Graphs were plotted to obtain reduction in compressive strength after immersion in HCl as shown in Chart-2 and Chart-3.

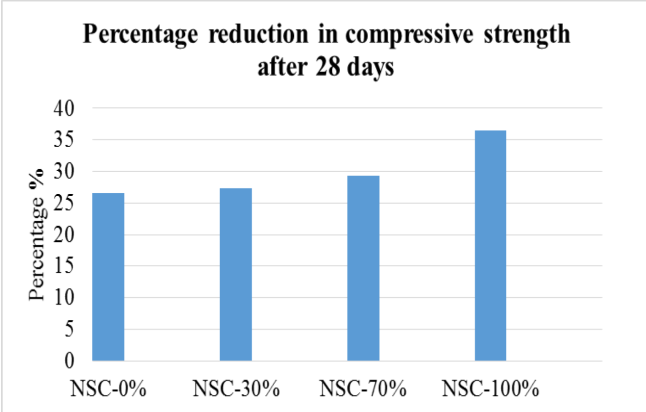

Chart-2:- Percentage reduction in compressive strength after 28 days in HCl

From the Chart-2 it was observed that highest reduction in strength was for 100% replacement ratio and least for 0% replacement level. As the replacement levels go up the reduction in strength increases. However 30% replacement level was comparable with the 0% replacement level.

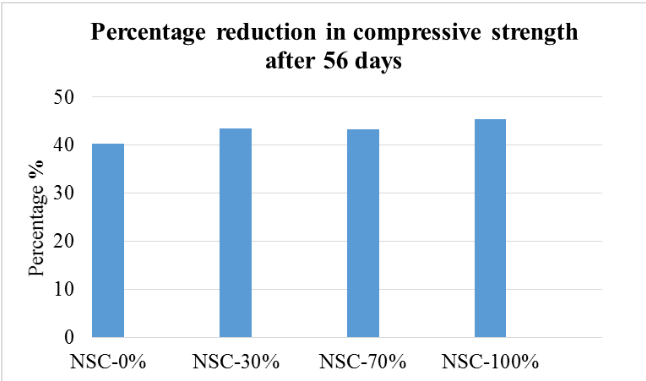

Chart-3:- Percentage reduction in compressive strength after 56 days in HCl

From the Chart-3 it was observed that a similar trend continues with increase in replacement levels leading to a higher reduction in strength.
Time scale diagrams have been plotted to observe change in weight after immersion in $MgSO_4$ as shown in Chart-4.

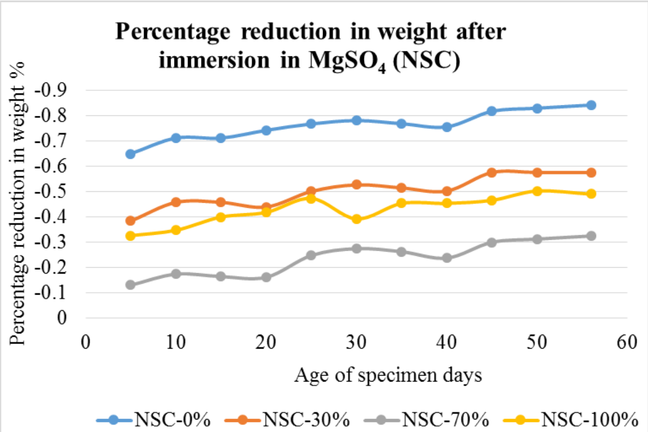

Chart-4:- Percentage reduction in weight v/s time after immersion in $MgSO_4$

It can be observed from Chart-4 that there was weight gain instead which can be attributed to the formation of ettringite and absorption of the magnesium sulphate solution. Least weight gain seen for 100% replacement level whereas the highest weight gain for 0% replacement level.

Table 7:- Compressive strength after 28 days and 56 days of immersion in 5% $MgSO_4$ solution

Replacement Level	28days (N/mm^2)	56 days (N/mm^2)
NSC-0%	48	48
NSC-30%	43.78	43.34
NSC-70%	44	44.89
NSC-100%	47.55	43.78

To get a proper understanding of sulphate resistance the compressive strength values and percentage change in compressive strength values must be co-related. Graphs were plotted to observe changes in compressive strength as shown in Chart-5 and Chart-6.

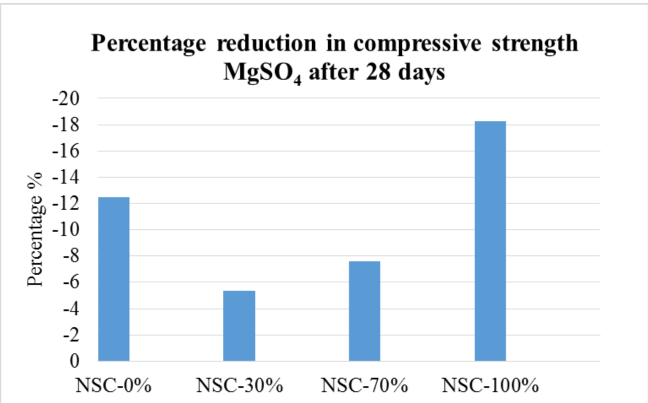

Chart-5:- Percentage reduction in compressive strength after 28 days in $MgSO_4$

The negative values indicate there was an increase in the strength. Higher compressive strength increase shows that the concrete reacts with sulphate much faster and hence the increase in compressive strength. It was observed from Chart-5 that highest increase in strength was for 100% which indicates that it's the most vulnerable to sulphate attack whereas the least was for 30% replacement level making it the least vulnerable. 30% replacement level showed better performance even when compared with the control replacement level.

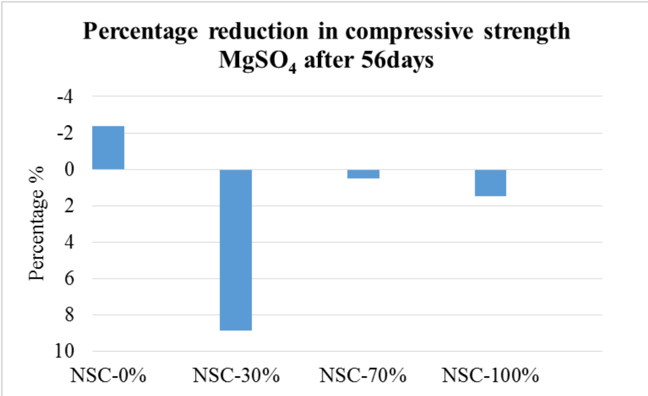

Chart-6:- Percentage reduction in compressive strength after 56 days in $MgSO_4$

Ettringite formation is an expansive reaction and hence leads to tensile stresses in concrete which ultimately causes cracking of the concrete. As the formation of ettringite increases at 56 days 0% replacement level showed better performance with no reduction in strength. All the recycled aggregates showed small reduction in strength with 30% replacement level showing the highest reduction. However the reduction in strength was not substantial. Time scale graphs were plotted to observe changes in weight over time as shown in Chart-7

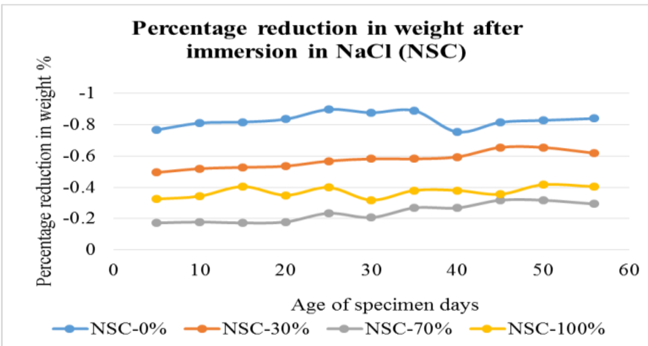

Chart-7:- Percentage reduction in weight v/s time after immersion in NaCl

In the chloride resistance test there was weight gain over 56 days. It indicates no deterioration of the concrete when subjected to chloride action. The weight gain was highest for 0% replacement level and 70% having the least.

Table 8:- Compressive strength after 28 days and 56 days of immersion in 5% NaCl solution

Replacement Level	28days (N/mm^2)	56 days (N/mm^2)
NSC-0%	43.44	47.34
NSC-30%	42.22	50
NSC-70%	43.78	45.56
NSC-100%	42.89	45.78

There was an increase in the compressive strength for all replacement levels. AT 28 days 70% replacement had the highest strength whereas at 56 days the 30% replacement ratio had the highest strength. Graphs were plotted to observe changes in compressive strength at 28 and 56 days as shown in Chart-8 and Chart-9.

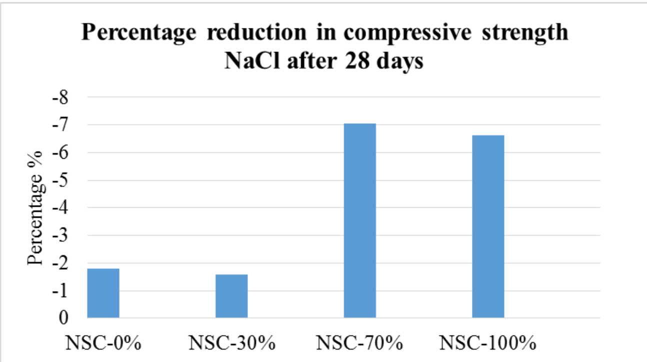

Chart-8:- Percentage reduction in compressive strength after 28 days in NaCl

It can be observed from the chart-8 that the strength gain was also very marginal for all the replacement levels and at 28 days and it can be said that chloride had no deteriorating effect on the concrete irrespective of replacement ratio of fine aggregate.

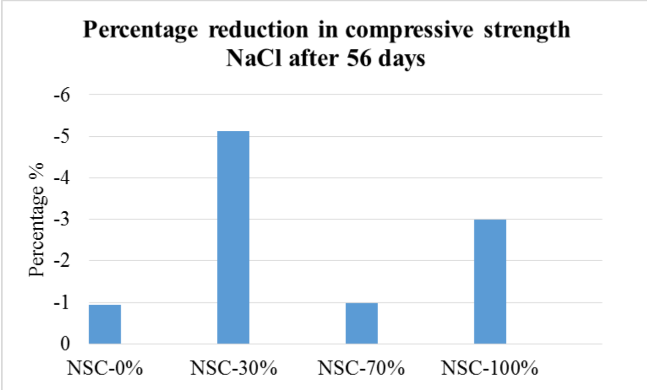

Chart-9:- Percentage reduction in compressive strength after 56 days in NaCl

It can be reiterated from the Chart-9 that even at 56 days that the chloride has not effected the concrete adversely with all the replacement levels showing slight increase in strength.

Table-9:- Saturated water absorption at 28 days

Replacement Level	Saturated water absorption (%)
NSC-0%	4.3
NSC-30%	4.66
NSC-70%	4.8
NSC-100%	5.06

It was observed from the Table-9 that as the replacement ratio increases the water absorption increases which can be explained by the higher water absorption capacity of the recycled aggregates when compared with natural aggregates. However it was less than the limiting value of 5% even up to 100% replacement ratio.

Table-10:- Compressive Strength and percentage reduction in compressive strength at 56 days after 2 hours at 300^0C

Replacement Level	Average Compressive strength (N/mm^2)	Percentage reduction in compressive strength (%)
NSC-0%	30.52	33.66
NSC-30%	25.04	46.5
NSC-70%	30.67	31.85
NSC-100%	26.67	40.03

It was observed from Table-10 that the highest compressive strength was for 70% replacement level and also has the least reduction in strength with 30% replacement level being the worst performing replacement level.

Table-11:- Compressive Strength and percentage reduction in compressive strength at 56 days after 2 hours at 600^{0}C

Replacement Level	Average Compressive strength (N/mm^2)	Percentage reduction in compressive strength (%)
NSC-0%	29.33	36.24
NSC-30%	24	48.72
NSC-70%	16.89	62.47
NSC-100%	16.44	63.03

At a higher temperature however it was observed that control mix performed better and as the replacement levels increased the performance deteriorated. The performance of 30% replacement level however was comparable to that of the control mix.

Table-12:- Average weight loss of reinforcement

Replacement Level	Average weight loss of reinforcement(grams)
NSC-0%	10
NSC-30%	6
NSC-70%	8
NSC-100%	9

It was observed from the Table-12 that the weight loss of reinforcement was comparable with that of the control mix and 30% replacement level and the least weight loss even lesser than the control mix. It can be concluded that the replacement of fine aggregates does not aid corrosion and the behaviour was comparable to the control mix.

4. CONCLUSIONS

From the experimental investigations conducted the following conclusions can be drawn.

- The characterisation of various aggregates was a very important parameter and they should conform to the required standards for fine aggregates.
- It was observed that that bulk density and specific gravity of the construction and demolition waste was less than the natural aggregates.
- It was possible to obtain the target strength even up to 100% replacement levels.
- The acid resistance of the control mix and that of 30% replacement level was comparable.
- The sulphate resistance of the control mix was better than concrete with replacement, however there was only marginal decrease in strength for other replacement levels and hence the performance can deemed satisfactory.
- The chloride resistance test indicated that irrespective of replacement ratio there was no deterioration of the concrete.
- Water absorption of concrete increased with increase in replacement levels however was within the stipulated limits for all replacement levels.
- At 300^{0}C 70% replacement level showed performance better than the control mix and showed the least decrease in strength. . However at 600^{0}C the control mix and 30% replacement level showed marginal difference whereas the other mixes lost strength rapidly.
- The weight loss of reinforcement for all replacement levels was similar to the control mix and hence the replacement level did not have any adverse effect which increased corrosion activity.

It can be finally concluded that an optimum of 30% replacement is feasible from all durability viewpoints. The higher replacement levels can even be adopted for specific purposes where they will not exposed to extreme environments. But 30% replacement level had performance comparable to or even better than the control mix in all parameters and hence can be concluded that it can be a suitable alternative to river sand.

5. SCOPE OF FURTHER INVESTIGATIONS

- Suitable methods need to be developed for proper characterisation and uniform crushing of all waste materials as they play an important role in the performance of concrete.
- Long term durability studies and studies for shrinkage and creep can be carried out to understand further the behaviour of the concrete.
- The proportion of waste materials can be optimised based on the availability of waste rather than in equal proportions.

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