Strength and durability studies of waste nylon cable ties concrete

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Abstract. Of late, concrete technology is changing at a fast phase. Concrete is a flexible material and several attempts are being made to incorporate different material specially industrial wastes as substitutes to the existing ingredients to enhance the quality of concrete. On the other hand environmentally sustainable concrete is in great demand. As plastic waste disposal has become a major problem for the modern day society, concrete has played a vital role as a dumping material. Plastic can either be used in concrete either as a partial substitute for fine aggregate or as an additive. Plastic wastes are present in different forms. This study focuses on use of waste Nylon Cable Ties (NCT) as a partial replacement of fine aggregates (1%, 2%, 4%) and as addition (0.5%, 1%, 1.5%) for M40 grade of concrete. Different tests like flexural, split tension, compression, effects of temperature and permeability test are being carried out. It was observed that 2% replacement of M-sand by waste NCT gives better results compared to 1% and 4% replacement of waste NCT. Addition of 1% NCT gives maximum compression, split tensile strength and flexural strength in concrete. When compared to replacement of fine aggregates by waste NCT, addition of waste NCT is found to give better strength. The permeability of the specimens was reduced for both replacement and addition of NCT ties. However permeability was found to be lesser for addition of NCT ties. But the performance of these specimens was not very satisfactory for either replacement or addition of NCT ties.

Keywords: Strength, Durability, Impact test, Nylon Cable Ties

1. Introduction

Plastic is one of the most commonly used wonder material worldwide. This has become boon to the people and bane to the environment in terms of quantum of non-biodegradable waste generation. According to newspaper article India is generating 9.46 Mtonnes of plastic waste annually and in that 43% remains uncollected [1]. Also, about 60% of global plastic produced dumped in landfills or in other natural environment causing further damage [1]. One of the areas where the plastic waste can be utilized effectively is its use in concrete. Concrete is the most important man-made construction material widely used all over the world. It proves to be an excellent waste disposal means for fly ash, ground granulated blast furnace slag, silica fume, powdered marble, plastic wastes like PET bottles, rubber tire, electronic waste which are not easily recycled and reused for different purposes by partial and complete replacement of aggregates and also as addition of materials.

Use of plastic waste in concrete is not new. Different types of plastic waste are used in different forms in concrete to enhance its properties. One of commonly used plastic waste used in concrete is use of PET waste [2,3,4]. With addition of rubber tire mix is beneficial for improving thermal It was
beneficial for improving thermal properties of concrete [2,3]. Also, the pellets made from PET or other forms of plastic can be used beneficially as partial replacement of fine aggregates [5] and coarse aggregates [6,7] or as shredded ties [4,8]. When replaced as a fine aggregate, up to 2% replacement, the compressive strength, split tensile and flexural strength increases [5]. When replaced as coarse aggregates, 20% replacement showed acceptable strength [7]. Slump of fresh concrete increases with addition of pellet shaped PET aggregates and decreases with flakier plastic aggregates. With the addition of plasticizers, the workability increases by 10% to 15% and compressive strength by 5% [9].

In this study, waste nylon cable ties, a form of plastic wastes are being used. Nylon cable ties are generally used for wrapping and tight packing of plastic bags in malls, aerospace, automotive, in electronics systems and military applications. Nylon Cable Ties (NCT) is a class of polymeric materials which are also known as polyamides i.e. Nylon 6/6. NCT is light weight, possesses high tensile strength and is more sustainable.

In this study, replacement of fine aggregates and addition of waste NCT both are studied. fine aggregates (M-Sand) are replaced with 1%, 2%, and 4% of waste NCT by weight and the waste NCT is added by 0.5%, 1%, 1.5% of total weight of fine aggregates in concrete. The grade of concrete considered in the study is M40.

2. Materials & Methodologies

2.1 Materials used

Ordinary Portland cement of 53 grade was used for this study. The results of the basic tests conducted on cement like normal consistency, initial and final setting times, and specific gravity are tabulated in Table 1. Aggregates smaller than 4.75mm and up to 0.075mm are considered as fine aggregate. M-Sand conforming to Zone-II was used as fine aggregate. Various tests were conducted to ascertain the basic properties of the materials such as cement and aggregates. The results are tabulated in Tables 1 and 2. Aggregates greater than 4.75 mm are considered as coarse aggregates. 20mm and 10mm size aggregates were used in the ratio of 3:2. Nylon cable ties were used in varying lengths of 0.3mm-50mm and 2.5mm thickness.

2.2 Methodology

The main aim of conducting this study is to find the effectiveness of waste nylon plastic ties both as a replacement and addition to concrete in place of fine aggregate. The experimental investigation is planned as follows:

1. To evaluate the relevant properties of the materials such as cement, sand, coarse aggregate
2. To obtain mix proportions of OPC concrete for M40 using IS Code:10262-2009. The waste NCT are used for replacement of fine aggregates (M-Sand) in varying percentages 1%, 2%, and 4% of waste NCT by weight. Also calculate the mix proportion with waste NCT in concrete for addition by 0.5%, 1%, 1.5% of total weight of fine aggregates.
3. To prepare the concrete specimens such as cubes for compressive strength, cylinders for split tensile test, prisms for flexural strength and also cubes for durability studies in laboratory.
4. To evaluate the mechanical properties of concrete such as compressive strength, split tensile test and the flexural strength.
5. To conduct the durability studies such as water permeability, porosity and water absorption on the specimens.
6. To compare the results for addition and replacement.
2.3 Mix design
The mix design for M40 grade of concrete was carried out as per IS 10262:2009. The proportions of the materials used in the present study are given in Table 3.

Table 1. Results of tests conducted on Cement

| Sl. No. | Characteristics     | Results Obtained |
|---------|---------------------|------------------|
| 1       | Specific gravity    | 3.12             |
| 2       | Normal Consistency  | 29%              |
| 3       | Initial setting time| 45 minutes       |
| 4       | Final setting time  | 480 minutes      |
| 5       | Fineness            | 4%               |

Table 2. Results of tests conducted on Fine and Coarse aggregates

| Sl. No. | Characteristics     | Results obtained |
|---------|---------------------|------------------|
|         |                     | Fine aggregates  |
|         |                     | Coarse aggregates|
|         |                     | 20 mm             | 10 mm             |
| 1       | Specific gravity    | 2.60             | 2.72              | 2.70              |
| 2       | Water absorption (%)| 6                | 0.5               | 0.5               |
| 3       | Fineness modulus    | 2.6 (Zone-II)    | 5.23              | 3.77              |

Figure 1. Cement used in the study

Figure 2. Waste NCT used

Figure 3. Fine Aggregates used

Figure 4. Coarse aggregates (20 mm) used

Figure 5. Coarse aggregates (10 mm) used

The cement and waste NCT used for the study are shown in Figures 1 and 2. The fine aggregates used for the study are presented in Figure 3. 20mm and 10mm and down size coarse aggregates used are presented in the Figures 4 and 5. In this study, the mix proportions of waste NCT is carried out both for partial replacement of fine aggregate by its weight and also for the addition by the total weight of the fine aggregates. The various proportions of the components used for carrying out the experimental studies has been tabulated in Table 3.
3. Results and Discussion

3.1 Test Results of Hardened Concrete

The tests conducted on hardened concrete were compression, flexure and split-tension. Figures 6 to 8 indicate the compression, split tension and flexure tests on specimen. The graphs for the test results related to compressive, split tensile and flexural strengths for varying percentages of waste NCT dosages are shown in Figures 9 to 14 for both addition and replacement. The results of compressive, split tensile and flexural strength for varying percentages of waste NCT ties for replacement of M-sand are as given in Table 4 and for addition are given in Table 5.

3.1.1 Compressive Strength

Cube specimens of 150 mm x150 mm x150mm size were casted and tested on a digital compression-testing machine in accordance with IS 516-1959 for the compressive strength. The compressive strengths of cubes were varied from 39.52MPa to 40.52 MPa for waste NCT ties varying from 0% to 4% replacement of fine aggregates and the peak strength of 43.65 MPa was obtained at 2% replacement. In case of addition of waste NCT ties, the compressive strengths were varied from 39.52 MPa to 40.86 MPa and the maximum strength of 46.43 MPa was obtained at 1% addition. When compared with the results of replacement and addition, better results were obtained for 1% addition of waste NCT ties.

Table 3. Proportion of NCT by replacement of fine aggregate and addition for one m³ of concrete

| Material/Component | Quantity 1 | Quantity 2 | Quantity 3 |
|--------------------|------------|------------|------------|
| Nylon cable ties (For replacement) | 1% | 2% | 4% |
| Cement (kg/m³) | 400 | 400 | 400 |
| Fine aggregate (kg/m³) (For replacement) | 663.34 | 656.63 | 643.24 |
| Nylon cable ties (For addition) | 0.5% | 1% | 1.5% |
| Fine aggregate (kg/m³) (For addition) | 670.04 | 670.04 | 670.04 |
| Coarse aggregate (kg/m³) | 1134.95 | 1134.95 | 1134.95 |
| GGBS (kg/m³) | 20 | 19.2 | 19.2 |
| Water (kg/m³) | 160 | 160 | 160 |

Table 4. Compressive, split tensile and flexural strength test results for replacement of fine aggregate by NCT

| Test specimen | Compressive strength (MPa) | Split tensile strength (MPa) | Flexural strength (MPa) |
|---------------|---------------------------|----------------------------|------------------------|
| NCTR 0%       | 39.52                     | 4.25                       | 7.5                    |
| NCTR 1%       | 43.03                     | 4.99                       | 10.35                  |
| NCTR 2%       | 43.65                     | 5.08                       | 11.5                   |
| NCTR 4%       | 40.52                     | 4.82                       | 7.92                   |

Note: NCTR 1% indicates replacement of fine aggregates by 1% with waste nylon ties.
Table 5. Compressive, split tensile and flexural strength test results for addition of NCT

| Test specimen | Compressive strength (MPa) | Split tensile strength (MPa) | Flexural strength (MPa) |
|---------------|---------------------------|-----------------------------|------------------------|
| NCTA 0%       | 39.52                     | 4.25                        | 7.5                    |
| NCTA 0.5%     | 45.77                     | 5.21                        | 8.83                   |
| NCTA 1.0%     | 46.43                     | 5.84                        | 10.95                  |
| NCTA 1.5%     | 40.86                     | 5.56                        | 10.50                  |

Note: NCTA 1% indicates addition of waste nylon ties by 1% by weight of fine aggregates.

3.1.2. Split-Tensile Strength
Cylindrical specimens 200mm long and 100mm in diameter were casted and tested for tensile strength on a digital compression testing machine in accordance with IS 516-1959. The split tensile strength of the cylinders increased from 4.25MPa for control specimens to 4.82MPa and a peak strength of 5.08 MPa was obtained for a replacement of 2% waste NCT ties. In case of addition of waste NCT ties, the strength increased from 4.25MPa and peaked to 5.84MPa at 1% addition and decreased further. When the test results of replacement and addition were compared, better results were obtained for 1% addition of waste NCT ties.

3.1.3 Flexural Strength
Beam specimens of dimension 100 mm x100 mm x500mm were casted and tested on a flexural testing machine in accordance with IS 516-1959. The flexural strength of the beams increased from 7.5 MPa to 7.92 MPa for waste NCT ties varying from 0% to 4% replacement of fine aggregates. The maximum flexural strength of 11.5 MPa was obtained for 2% of replacement of waste NCT ties. In case of addition of waste NCT ties, the strength increased from 7.5MPa and peaked to 10.95MPa at 1.5% . When the test results of replacement and addition of waste NCT were compared, better results were obtained for 1.5% addition of waste NCT ties.

The percentage increase in mechanical strength properties of concrete specimens for replacement and addition of waste NCT are presented in Table 6.
Table 6. Percentage increase in compressive, split tensile and flexural strengths for replacement and addition of waste NCT

| Sl. No. | Substitution                  | Percentage of replacement/Addition | % Increase in strength for M40 Grade of Concrete (28 days) | Compressive strength | Tensile Strength | Flexural Strength |
|---------|--------------------------------|------------------------------------|----------------------------------------------------------|----------------------|------------------|------------------|
| 1       | Replacement of M-Sand by NCT   | 1%                                 |                                                          | 8.8%                 | 14.8%            | 36.67%           |
|         |                                | 2%                                 |                                                          | 10.45%               | 19.52%           | 60%              |
|         |                                | 4%                                 |                                                          | 2.5%                 | 13.41%           | 18.67%           |
|         |                                | 0.5%                               |                                                          | 15.81%               | 22.58%           | 17.73%           |
| 2       | Addition of NCT                | 1.0%                               |                                                          |                      | 17.48%           | 46.0%            |
|         |                                | 1.5%                               |                                                          |                      | 3.39%            | 44%              |

3.2. Durability Tests
Durability of concrete is a major concern in the life cycle of concrete. Concrete is structurally strong enough to sustain the external loads but concrete structures may fail due to external environmental effects. Durable concrete will be always retain its original form, stability, quality serviceability when exposed to environment. Therefore, it necessary to conduct durability tests on concrete to test its sustainability. In this study different durability tests like water permeability and effect of temperature on cube specimens of size 150mm x150mm x150 mm after 28days of curing were carried out.

Figure 9. Compressive strength for varying percentages of waste NCT for replacement

Figure 10. Compressive strength for varying percentages of waste NCT for addition
3.2.1. Water Permeability

Water permeability test is conducted for to understand the ability of concrete to allow the movement of water or fluids. Cylindrical specimens of 150mm height and diameter were casted to carry out the tests as per IS 3085:1965. An air pressure of 10 kg/cm$^2$ was applied. The test results of permeability obtained for 7, 14, 28, 56 and 90 days are presented in Table 7.

Table 7. Permeability test results for both replacement and addition of NCT

| Test specimen | Permeability in $10^{-11}$m per sec |
|---------------|-----------------------------------|
|               | 7 days   | 14 days  | 28 days  | 56 days  | 90 days |
| NCTR 0%       | 6.36     | 5.83     | 5.28     | 4.88     | 4       |
| NCTR 1%       | 5.53     | 4.56     | 4.56     | 3.35     | 2.79    |
| NCTR 2%       | 4.26     | 3.26     | 3.26     | 2.52     | 1.4     |
| NCTR 4%       | 3.67     | 2.23     | 2.13     | 1.52     | 0.93    |
| NCTA 0%       | 6.3      | 5.78     | 5.2      | 4.78     | 3.94    |
| NCTA 0.5%     | 5.43     | 4.5      | 4.45     | 3.3      | 2.69    |
| NCTA 1%       | 4.28     | 3.2      | 3.19     | 2.45     | 1.33    |
| NCTA 1.5%     | 3.55     | 2.4      | 2.08     | 1.48     | 0.87    |
Figures 16 and 17 depict the variation of permeability for replacement and addition of NCT ties in concrete. It is observed that permeability goes on reducing with the increase in the proportions of waste NCT ties.

3.2.2. Temperature Test:
The test was conducted to determine the effect of temperature on strength of concrete. Cube specimens of dimensions 150mm x 150mm x 150mm were used to find out the compressive strength affected by temperature. After demoulding the cubes from moulds, it was cured for 28 days. After curing, the cubes were kept in oven for a period of one hour at 100°C maintaining a constant temperature as shown in Figure 15. After one hour the cubes were taken out from the oven, and allowed to be cooled. The compressive strength was tested and value was recorded [10].
The reduction in the compressive strengths of the specimens after conducting the temperature test are presented in Table 8. As observed from the test results there is a reduction of compressive strength for both replacement and addition of waste NCT ties. The reduction in compressive strength is more in case of replacement of NCT ties. Figures 18 and 19 depict the reduction in compressive strengths in the temperature test.

Table 8. Compressive strength results for both replacement and addition of NCT from Temperature test

| Sl. No. | NCT as addition | Compressive strength (N/mm²) | Percentage decrease in compressive strength(%) | NCT as replacement of fine aggregate | Compressive strength (N/mm²) | Percentage decrease in compressive strength(%) |
|---------|-----------------|-----------------------------|-----------------------------------------------|-------------------------------------|-----------------------------|-----------------------------------------------|
|         |                 | 28 Days (Normal curing) | 28 Days Oven Dried                          |                                     | 28 Days (Oven dried)       |                                     |
| 1       | 0%              | 39.52                       | 34.6                                          | 12.45                               | 0%                          | 34.6                                          | 12.45                                        |
| 2       | 0.50%           | 44.85                       | 39.1                                          | 12.82                               | 1%                          | 38                                            | 15.27                                        |
| 3       | 1%              | 45.76                       | 39.76                                         | 13.11                               | 2%                          | 38.38                                         | 16.13                                        |
| 4       | 1.50%           | 40.86                       | 35.45                                         | 13.24                               | 4%                          | 34                                            | 16.79                                        |

Figure 16. Permeability test results for varying percentages of waste NCT for replacement

Figure 17. Permeability test results for varying percentages of waste NCT for addition
4. Conclusions

1. It was observed that maximum compressive strength, split-tensile strength and flexural strength are obtained at 2% replacement of waste NCT.
2. For addition of waste NCT, the maximum compressive strength, split-tensile strength and flexural strength are obtained at 1% addition of waste NCT ties.
3. From the studies, it is observed that the compressive strength, split-tensile strength and flexural strength increase by 10.45%, 19.52% and 60% respectively at replacement of 2% fine aggregate by waste NCT.
4. Compressive strength, split-tensile strength are increases by 17.48%, 37.41% and 46% respectively at addition of 1% waste NCT into the concrete.
5. Least permeability is obtained at 4% replacement and at 1.5% addition of waste NCT.
6. It shows that concrete becomes less permeable with increase in waste NCT proportion in the concrete both for replacement and addition.
7. Average reduction of compressive strength after conducting temperature test is 12.09% for replacement of fine aggregates by waste NCT and 15.16% for addition of waste NCT.
8. When compared the test results of replacement and addition of waste NCT, better results are obtained for 1% addition of waste NCT ties.
9. Overall use of waste NCT in concrete is beneficial green alternative when used in right proportion.

5. References

[1] PTI New Delhi 2019 India generates 9.46 mn tonnes of plastic waste annually The Hindu BusinessLine 30 Aug Available at https://www.thehindubusinessline.com/news/science/india-generates-946-mn-tonnes-of-plastic-waste-annually/article29299108.ece
[2] Yesilata B, Isiker Y and Turgut P 2009 Thermal insulation enhancement in concrete by adding waste PET and rubber pieces Elsevier Construction and Building Materials 23 1878-1882
[3] Pacheco-Torgal F, Ding Y and Jalali S 2012 Properties and durability of concrete containing polymeric wastes tire rubber and PET bottles: An Overview Elsevier Construction and Building Materials 30 712-724
[4] Vali M N and Asada S S 2017 PET bottle waste as a supplement to concrete fine aggregate International Journal of Civil Engineering and Technology 8 (1) 558–568
[5] Ramadevi K and Manju R 2012 Experimental Investigation on the properties of Concrete with Plastic PET (Bottle) Fibers as Fine Aggregate International Journal of Emerging Technology and Advanced Engineering 2(6) 42-46
[6] Saikia N and de Brito J 2012 Use of plastic waste as aggregate in cement mortar and concrete preparation: A review Elsevier Construction and Building Materials 34 385-401
[7] Subramani T and Pugal V K 2015 Experimental study on plastic waste as a coarse aggregate for structural concrete International Journal of Application or Innovation in Engineering & Management (IJAIELM) 4(5) 144-152
[8] Saikia N and de Brito J 2014 Mechanical properties and abrasion behaviour of concrete containing shredded PET bottle waste as a partial substitution of natural aggregate Elsevier Construction and Building Materials 52 236–244.
[9] Rai B and Rushad S T, Bhavesh Kr and Duggal S K 2012 Study of waste plastic mix concrete with plasticizer International Scholarly Research Network (ISRN) Civil Engineering 2012 1-5
[10] Pathan M A and Jamnu M A 2012 Compressive Strength of Conventional Concrete and High Strength Concrete with Temperature Effect International Journal of Advanced Engineering Research and Studies IJAERS 1(3) 101-102.