Research Square

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Sustainable Concrete Material Reinforced with Recycled Polypropylene Tarpaulin Fibers

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Abstract

Tarpaulin is a multipurpose textile product made from different coating formulation grades of polymer of which Polyethylene based tarpaulins are wildly used. It is water resistant and UV resistant, which makes it long lasting. However, after usage of for a season, it leads to the problem of disposal due to its non-degradable characteristics. This contribute to the growing problem of plastic waste in landfills, oceans, and other natural environments. Tarpaulins are not recyclable in conventional recycling methods. India generates a significant amount of plastic waste each year, with estimates suggesting that it produces around 9.46 million tons of plastic waste annually. While tarpaulins are just one type of plastic waste, they can contribute to the overall plastic waste problem in the country. As tarpaulin are of polymeric nature, it is proposed that this material also can turn into a value-added material by incorporating it into concrete mixture. In the current project, the attempt is made to develop a sustainable concrete material using shredded tarpaulin tapes of 3–5 cm in length. The volume of sand is replaced by these fibres in 5% concentrations. The concrete blocks with tarpaulin embedded in them showed marginal reductions in strength than the control blocks but this strength is acceptable by the ISO Standards. This project leads to sustainability and follows the principle of circular economy.

Introduction

Tarpaulin, a versatile material widely used in various industries, contributes significantly to the accumulation of plastic waste. According to a report by the Central Pollution Control Board (CPCB) of 2015, the daily plastic waste production of High-Density Polyethylene (HDPE) and Low-Density Polyethylene (LDPE) in 60 cities across India amounts to a staggering 2767 kg/day. It is assumed that tarpaulin waste accounts for approximately 30% of this total, contributing to around 830 kg/day. This substantial waste accumulation poses a significant challenge as conventional waste management practices, such as landfill disposal, have proven to be unsustainable [1]. The growing concern over plastic waste has prompted the need for innovative solutions to manage and reduce its environmental impact. The conventional methods of plastic waste disposal, including landfills, have raised concerns about space constraints, environmental pollution, and the long-term impact on ecosystems. The current waste management practices for tarpaulin waste are inadequate, with limited recycling efforts that are not a permanent solution. The consequence of these practices is the overcrowding of landfill sites, which necessitates urgent measures to minimize the materials delivered to landfills. Considering these challenges, alternative disposal methods focusing on the principles of reduce, reuse, recycle, and recovery become imperative [2]. By utilizing tarpaulin waste as a valuable resource in concrete mixtures, we can effectively mitigate the amount of plastic waste ending up in landfills. The use of high-density polyethylene plastic waste in concrete mixture as aggregate replacement. The study of this research paper gives limited solution towards the enormous amount of waste material and depletion of natural aggregates causing harm to environment and ecology. Products made of polymers like synthetic fibres, plastics, and rubber are petrochemical compounds and are not quickly biodegradable even over an extended period. In this experimental study, High Density Polyethylene (HDPE) waste is used as coarse aggregates in concrete with replacement rates of 10%, 20%, and 30% [3]. It is also being reported that the use of various synthetic fibre in the cementitious composites by testing uniaxial tension tests with different loadings of acrylic, polyester, and aramid fibres in both their initial state and after being aged in cement [4]. The incorporation of waste tarpaulin fibres in the concrete mixture offers several advantages. The workability of concrete with incorporated polymer fibre will be less workable and more viscous, according to earlier research, which has demonstrated this. The behaviour of compressive strength, it was observed that the value of compressive strength of concrete mixtures increased over time but decreased as more crushed polyvinyl tarpaulin was added. The percentage of crushed polyvinyl tarpaulin used in concrete mixes that 13 produced the highest compressive strength test result was 5%, and the percentage of crushed tarpaulin used in concrete mixes that produced the lowest strength result was 30%. This runs counter to earlier research, such as that conducted. Several recommendations were made in this paper that using of only finely crushed polyvinyl tarpaulin as an admixture, starting with a minimum of 1–10% of the cement weight [5]. Firstly, it provides a sustainable solution for waste management by diverting tarpaulin from landfills and reducing the overall carbon footprint. Secondly, we are trying to partially replace fine aggregate that is sand thus providing a solution to mitigate the use of natural resource sand in partial manner. Additionally, the potential cost savings associated with the use of waste tarpaulin fibres could make concrete construction more affordable, especially in resource-constrained regions. The M30 grade of concrete, known for its high strength and durability characteristics, is widely employed in various structural applications. However, the use of conventional reinforcement techniques, primarily steel bars, contributes significantly to the embodied energy and carbon emissions of concrete structures. Exploring alternative partial reinforcement options, such as waste tarpaulin fibres, can help reduce the environmental impact associated with concrete construction while maintaining structural integrity and performance [6]. The aim is to investigate the feasibility of incorporating waste tarpaulin as reinforcement in M30 grade concrete mixtures through a series of laboratory experiments. The key objectives of this project includes assessing the compressive strength of the tarpaulin-reinforced concrete, evaluating effect of fibres on density of block, and comparing the results with those of conventional concrete. The findings of this research will provide valuable insights and potential solutions for the construction industry [7], waste management authorities, and environmental organizations seeking to minimize the environmental impact of plastic waste.

Materials and Methods

The OPC grade cement, fine and coarse aggregate of 10 mm and 20 mm size was purchased from local market. The waste tarpaulin bags were collected from different locations and shredded for different cut length prior to use them in the concreate mixture. The aggregate testing was performed in the structural and civil engineering department and fiber processing and testing was performed in the department of textile engineering VJTI Mumbai. The experimental trials of concreate mix designs and its testing was performed in structural engineering department of VJTI Mumbai.

1.1 Sieve Analysis

To ascertain the aggregate material's particle size distribution, sieve analysis is an essential testing technique. The aggregate sample is put through a series of sieves with progressively smaller apertures, and the amount of material retained on each sieve is 16 measured afterward. The workability of the concrete is significantly affected by the particle size distribution. As a result, the mix design can be optimised to achieve desired workability, density, and strength of the product. For 10 and 20 mm aggregates, Sieves with sizes 40 mm, 20 mm, 10 mm, 4.75 mm, and finally a pan are arranged in that order, the detailed representation of sieves for 10 and 20 mm is shown in Fig. 1 (a) and Fig. 1 (b) Around 2000 gm of sample is taken at air dried condition and sieved. Each sieve is shaken separately over a clean tray until not more than a trace passes, but in any cases for a period of not less than two minutes. The shaking is done with a varied motion, backwards and forwards, left to right, circular clockwise and anti-clockwise, and with frequent jarring, so that the material is kept moving over the sieve surface in frequently changing directions. Material shall not be forced through the sieve by hand pressure, but on sieves coarser than 20 mm, placing of particles is permitted. On completion of sieving, the material retained on each sieve, together with any material cleaned from the mesh is weighed. The weights are compared against IS: 383 standards for suitability of selected aggregates.

1.2 Water Absorption for Aggregates:

The water absorption test of aggregates is an essential test conducted to determine the amount of water absorbed by the aggregates. The aggregates are submerged in water for a period and the increase in weight is measured after the immersion. A higher water absorption of aggregates results in higher demand of water in the concrete mixture. As a result, with the help of water absorption, adjustments can be made in the mix design to increase or decrease the amount of water required. For testing of water absorbency, initially 500 gm of aggregates are weighed and then aggregates are washed thoroughly to remove any dust particles and impurities. The aggregates are kept in water for 24 hours. After 24 hours the aggregates are removed from the water and placed on a dry cloth to surface dry them thoroughly. Finaly, the aggregates are weighed again and percentage water absorption is finally estimated using following formula,

Water Absorption % = $\frac{FinalWeight - InitialWeaght}{InitialWeight} \times 100$

1.3 Specific Gravity

Specific gravity of aggregate is defined as the ratio of the weight of aggregate to the weight of equal volume of water. It is an important parameter in the concrete mix design [8]. The specific gravity is helpful in calculating the volume of aggregates in the mix and adjusting the amount of water. To measure the specific gravity, initially 500 gm of aggregates are weighed and then kept in water for 24 hours. After 24 hours the aggregates are removed from the water and placed on a dry cloth to surface dry them thoroughly and then the weight is recorded. In later stage, the aggregates are placed in a pycnometer which is filled with distilled water. The pycnometer is dried from the outside and the weight of the aggregates with water in pycnometer is noted. In the last stage the water is removed from the pycnometer and the aggregates are kept in an oven for 24 hours at 110ºC. after 24 hours the aggregates are removed and allowed to cool. The the weight of oven dried aggregates is recorded. The specific gravity of the aggregates is calculated using following formula,

Specific Gravity = $\frac{D}{A-(B-C)}$

Where,

A is the Weight of surface dry sample

B is the Weight of pycnometer containing sample and filled with distilled water

C is the Weight of pycnometer filled with distilled water only

D is the Weight of oven dried sample

1.4. Concreate Mix Design

Mix design is the process of determining the proportion of the materials in a concrete mixture to achieve the desired properties and performance. The grade of concrete is the strength and quality of the concrete mixture. The grade of concrete is decided before starting to formulate the mix design. It is decided based on the strength requirement of the end product applications. The materials used are PPC Cement, coarse aggregates of 10 mm and 20 mm, crushed sand, water, chemical admixture (Mid PCE) and fibres. There is a replacement of 5% sand with waste tarpaulin fibres. The grade of concrete being used is M30. As a result, the characteristic strength is 30 MPa and the target strength is 38.25 MPa. For 38.25 MPa target strength, the water-cement ratio is 0.425. The water-cement ratio is necessary to calculate the amount of water and cement required. From the specific gravities of the aggregates their weights are calculated. The moisture content and water absorption are required to calculate the adjustments in water amount that is needed to be made. As we are replacing 5% fine aggregate by volume with tarpaulin fibres their weights change accordingly. The dimensions of the mould are 150 mm × 150 mm × 150 mm. Each test requires 3 samples, and the samples are tested for a period of 7, 14, 28 days of curing. As a result, we are required to make 9 samples of each batch i.e., one control batch and one batch containing fibres. So, the weights are calculated considering the volume of 9 samples. Wastages are also included. The detailed mix plan is reported in the Table 1.1.

Table 1.1
Concrete Mix Design Plan

Material	Quantity for 0% Sample	Quantity for 5% Sample
Cement	15.24 kg	15.24 kg
Water	7.6 kg	7.6 kg
Fine Aggregate	26.68 kg	23.99 kg
Coarse Aggregate	47.2 kg	47.2 kg
Fibres	0 kg	0.3263 kg
Chemical Admixture	0.1524 kg	0.1524 kg

1.5 Shredding of Fibers

The tarpaulin fibres are shredded manually with the help of scissors. The fibres are cut into lengths of 6–12 mm. However, a shredding machine can be used to obtain desired lengths.

1.6 Fiber Length and Denier Measurement

The shredded fibers are measured for its length and denier values using oil plate and cut weight method respectively. Both fiber length and denier values are important with respect to concreate mix and compressive strength. Total 50 measurements were performed in order to reduce the variability during measurement.

1.7 Workability Test

Workability refers to the ease with which a freshly mixed concrete can be handled, placed, and transported. A workability test or slump cone test is used to determine the workability of the concrete mixture. The workability test is essential to determine whether the concrete mixture is fit for use for or not. To measure the workability of mixed concrete, the concrete was initially poured in hollow cone of top diameter of 10 cm, bottom diameter of 20 cm, and a height of 30 cm. The internal surface of the cone is cleaned properly, and oil is applied. Then the cone is placed on a smooth horizontal non-absorbent surface [9]. The cone is filled with the concrete mixture in 3 layers. The excess concrete mixture is removed, and the cone is levelled properly. The mould is raised slowly and immediately in a vertical direction. The slump is measured as the difference between the height of the cone and the height of the concrete after the cone has been removed. There are four types of slumps viz. true slump, zero slump, collapsed slump, and shear slump. Of these four types of slumps only the true slump can be measured and is of significance. If any of the other three slumps is obtained, then the concrete mixture is said to be unfit for use.

1.8 Casting

Mould Preparation: The screws of the mould are tightened properly. The moulds are then cleaned thoroughly as any impurities may hamper the properties of the concrete block. The moulds are then oiled properly so that the concrete blocks are removed easily. The mould preparation of concrete blocks is shown in Fig. 1.2 (a) and (b) respectively.

1.9 Drying and Demoulding

The concrete mixture once vibrated and compacted is kept for 24 hours for drying and hardening of the block. Demoulding is the process of loosening the screws and releasing the concrete blocks from the moulds. Care must be taken to carefully demould the blocks to avoid any damages to the structural integrity of the concrete blocks. During demoulding, proper precautions must be taken to avoid any impact or shock that could cause cracking or damage to the concrete blocks. This can be done by using appropriate tools and equipment and avoiding striking the concrete block directly using an excessive force.

1.10 Curing of Samples

Curing is the process done to maintain favourable moisture and temperature conditions of the concrete blocks. It determines the strength, durability, and overall performance of the concrete blocks. As a result, it is important that the curing is done properly. Two types of curing are done. One is the initial curing which is done right after the surface of the concrete starts drying. This is done by covering the concrete surface with a damp burlap to avoid the rapid loss of moisture which may lead shrinkage cracks and reduced strength [9]. Another type of curing is the immersion curing where the concrete blocks are submerged in water for a period of 28 days.

1.11 Compressive Strength

Compressive strength is defined as the maximum compressive stress that a concrete block can bear before it falls under a uniaxial compressive load. It is an important mechanical property of concrete that determines the performance of the concrete. The compressive strength of tested and control samples is measured for 7, 14 and 28 days. The detailed representation of compressive strength of sample is shown in Fig. 3

Results and Discussion

2.1 Sieve Analysis

The detailed sieve analysis of selected aggregates was found to be in the range as per referred standards IS: 383. The detailed observations of fine and coarse aggregates are mentioned in Table 2.1, Table 2.2 and Table 2.3. The final fineness value of aggregates is shown in Table 2.4.

Table 2.1
Sieve Analysis Results of 20 mm Coarse Aggregates

IS Sieve (mm)	Retained Weight (g)	% of Retained Weight	% Cumulative Weight Retained	% Passing	Limit as IS:383
40 mm	0 g	0%	0%	100%	100
20 mm	316.5 g	15.825%	15.825%	84.175%	85–100
10 mm	1666.5 g	83.325%	99.15%	0.85%	0–20
4.75 mm	3.5 g	0.175%	99.325%	0.675%	0–5
PAN	13.5 g	0.675%	100%	-	-

Table 2.2
Sieve Analysis Results of 10 mm Coarse Aggregates

IS Sieve (mm)	Retained Weight (g)	% of Retained Weight	% Cumulative Weight Retained	% Passing	Limit as IS:383
12.5 mm	0 g	0%	0%	100%	100
10 mm	55 g	5.5%	5.5%	94.5%	85–100
4.75 mm	820 g	82%	87.5%	18.5%	0–20
2.36 mm	60 g	6%	93.5%	6.5%	0–5
PAN	65 g	6.5%	100%	-	-

During the analysis, it is found that all the values are satisfied according to IS:383, it can be said that the 10 mm coarse aggregates are suitable for use.

Table 2.3
Sieve Analysis Results of Fine Aggregates

IS Sieve (mm)	Retained Weight (g)	% of Retained Weight	% Cumulative Weight Retained	% Passing
4.75 mm	0 g	0%	0%	100%
2.36 mm	140.5 g	14.05%	14.05%	85.95%
1.18 mm	287.5 g	28.75%	42.8%	57.2%
600 μm	228.5 g	22.85%	65.65%	34.35%
300 μm	146.5 g	14.65%	80.3%	19.75%
150 μm	84.5 g	8.45%	88.75%	11.25%
PAN	112.5 g	11.25%	100%	
			∑F = 291.55 (excluding PAN)	

$$\textit{Fineness Modulus of Fine Aggregates} = \sum F/100$$

Table 2.4
Reference for determining the fineness of sand

Type of Sand	Range of Fineness Modulus
Fine Sand	2.2 to 2.6
Medium Sand	2.6 to 2.9
Coarse Sand	2.9 to 3.2

The Fineness Modulus of the Fine Aggregates is 2.91. As a result, the sand used is Coarse Sand. There is total 4 zones of sand and the sand used here satisfies maximum conditions for the Zone 2. It is observed that sand particles during sieve analysis is belonging to zone 2 as per referred standard.

2.2 Water Absorption Test

Water absorption test is important parameter which decides the mixing homogeneity, workability, and compressive strength for given grade of concrete. The results of water absorption test are listed in Table 2.5. The fine aggregates show high amount of water absorption because of high surface area to volume ration as compared to fine and coarse aggregates.

Table 2.5
Water Absorption Test Results

Type of Aggregate	Initial Weight (g)	Final Weight (g)	Water Absorption
Coarse Aggregates (20 mm)	1000 g	1010 g	1%
Coarse Aggregates (10 mm)	1000 g	1010 g	1%
Fine Aggregates	1000 g	1032 g	3.2%

2.3 Specific Gravity

Specific gravity of selected aggregates plays vital role in deciding overall density of concrete blocks. The observations of specific gravities of the aggregates is mentioned in the Table 2.6

Table 2.5
Specific Gravity Test

Material	Specific Gravity
Coarse Aggregates	2.74
Fine Aggregates	2.65
Cement	2.88
Chemical Admixture (Mid PCE)	1.1

2.3. Fiber length and Denier

The length and denier parameters of recycled tarpaulin polypropene fibers are listed in Table 2.6. The average length of fibers was found to be 3.2 cm and 65 denier with C.V % of 1.5.

Table 2.6
Fiber length and Denier

Sr. No	Fiber Parameter	Average Value
1	Length	3.2 cm
2	Denier	65 Denier

2.4 Workability of Concrete Samples

It is reported that, the workability of concrete sample is important parameter in concreate mix design. The addition of fibers as reinforcement may hamper the workability of given mix design. The workability of concrete in such cases can be improved by adding the certain dosages of admixtures. The workability of concrete mix is reported in Table 2.7. The slumps for both the mixtures i.e., the one without fibres and the one with fibres were true slumps.

Table 2.7
Slump Test Results

% of waste tarpaulin fibres	0%	5%
Workability test results	120 mm	100 mm

2.5 Compressive Strength

The target strength for the control sample was 38.25 MPa and the strength achieved is 36.73 MPa. As a result, there is not a significant difference. However, for the 5% fibre containing sample, the strength achieved is 31.2 MPa which is relatively low. But the strength achieved satisfies the characteristic strength of M30 grade concrete block. The results for the compressive strength test are shown in Table 2.8 and Table 2.9. The behavior of concrete after compression is shown in Fig. 2.1

Table 2.8
Compressive Strength Test Results

Amount of Tarpaulin Fibres	0%	5%
Age of Sample	**Average Compressive Strength (MPa)**	
7	25.32	22.62
14	33.06	25.36
28	36.73	31.2

Table 2.9
Comparative Study of Control and Specimen Sample

Days	Properties	Control Sample	Specimen Sample
7 days	Weight (kg)	8.85	8.83
	Density (kg/m3)	2622.12	2615.6
	Compressive Strength (MPa)	25.3	22.6
14 days	Weight (kg)	8.92	8.93
	Density (kg/m3)	2642.81	2645.23
	Compressive Strength (MPa)	33.06	25.36
28 days	Weight (kg)	8.78	8.86
	Density (kg/m3)	2623.6	2602.67
	Compressive Strength (MPa)	36.73	31.2

Conclusion

In the present work, experiments were conducted on specimens made of concrete, which contained 5% amounts of polymer fibre (Polyethylene) reinforcement. The control specimens contained no fibre reinforcement. The other specimens contained five percent (by volume) of waste polyethylene fibre reinforcement (PE) in the form of fibres extracted from waste tarpaulin. The preliminary test, slump test, compressive strength was performed on these specimens in accordance with appropriate ASTM and IS testing guidelines. Based on the test results and physical observations, it can be further concluded that,

all mixed concrete produces a medium slump value i.e. 120mm, which indicates that the concrete mix is medium in workability. The workability of concrete with incorporated polymer fibre was less workable and more viscous, with the value 100mm.The 5% replacement of sand in a concrete mixture with waste tarpaulin fibres results in slight reduction in strength of concrete mixture. However, the concrete mixture satisfies the characteristic strength for that grade of concrete i.e., 30 MPa. As a result, the concrete blocks with waste tarpaulin in it can be used in the applications where strength is not the primary requirement. In scenarios where high strength is not a critical factor, such as non-load-bearing walls, partition walls, or decorative elements, the use of concrete blocks incorporating waste tarpaulin fibres can be highly suitable. These applications often prioritize other properties such as thermal insulation, sound absorption or aesthetic appeal over sheer strength. Therefore, the slight reduction in strength associated with the replacement of sand with waste tarpaulin fibres may not be a significant concern. Tarpaulins, being non-degradable and difficult to dispose of naturally, contribute to environmental pollution and waste accumulation. By incorporating waste tarpaulin fibres as a replacement for sand, the research not only offers a sustainable solution for tarpaulin waste management but also contributes to waste reduction and environmental conservation. It is important to note that density is a critical parameter in assessing the quality and performance of solid blocks. Both samples of solid blocks achieved the desired density as per IS 2185 Part 1, indicating that the density requirements were met. However, it seems that there was no significant difference observed in the density between the two samples.

Declarations

Author Contribution

L. Salve, T.Ghate, D. Awatade, A.Varma contributed for experimental set up under the guidance of S.P.Borkar, S.S.Kole and S.Ranshur. The all the faculties have guided the students for result interpretation and drafting the manuscripts.

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