"Enhancing Concrete Performance through Polymer Blends"

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Abstract

The aim of this study is to develop a novel concrete composite using a mixture of low-cost rubber, Kevlar fibers, lightweight expanded polystyrene (EPS) and fire resistant nylon fibres. The goal is to create concrete that is stronger, lighter, fire-resistant and has insulating properties. A number of concrete blends were formulated using different percentages of the selected polymers. These blends were tested for compressive strength, split tensile strength, and density. Based on the findings, it can be concluded that incorporating those polymers would drastically improve the mechanical properties of concrete while reducing its weight. Some blend ratios achieved ensured optimal mechanical performance of the various polymer composite concrete and proved the feasibility of designing low-weight, resource-efficient concrete composites with varying applications in construction.

1 Introduction

1.1 Background: Like different types of concrete, polymer concrete is created from aggregates and a binder. However, it differs from traditional concrete in that it uses a polymer binder. This type of concrete exhibits many advantages over traditional concrete including greater tensile strength, adhesion, reduced permeability, and resistance to sever chemical attack. Polymers can be engineered for different functions, therefore concrete can also be designed for certain uses. This enables engineers to develop high performance concrete which is more durable, easily sustained, and stronger than conventional concrete.

1.2 Problem Statement: This research attempts to create advanced concrete composites using economical rubber, EPS, Kevlar fibres, and fire-resistant polyamides. The objective is to improve concrete's properties for new and sustainable construction methods.

1.3 Objectives:

1) Develop an optimized concrete blend by integrating rubber, Kevlar, EPS, and polyamides.
2) Enhance mechanical strength, fire resistance, and insulation through the custom polymer composite.

1.4 The aim: this research looks at the development and improvement of a concrete composite based on the synergistic effect of these four polymers to make it more versatile and sustainable as a construction material. With the economic advantages of rubber, the strength of Kevlar, the lightweight nature of EPS, and nylon's fire resistance, this study attempts to solve the problem of concrete lacking advanced attributes required for modern construction. This research analyses the impact of different ratios of these polymers on the mechanical properties, density, and fire resistance of concrete, so as to optimize the design for performance, sustainability, cost, and overall value.

1.5 Literature Review:

1.5.1 Rubberized Concrete: Rubberized Concrete: The application of recycled tire-derived rubber aggregates in concrete construction has become a notable sustainable and economical practice. Due to its improved elasticity combined with superior impact resistance and energy absorption properties rubberized concrete proves effective in scenarios where vibration damping and crack prevention are essential. Research indicates that concrete performance in flexural strength [2] , impact resistance, and freeze-thaw durability benefits from rubber aggregate addition. The amount of rubber content needs careful optimization because too much can reduce the compressive strength of the material. [3] [4]

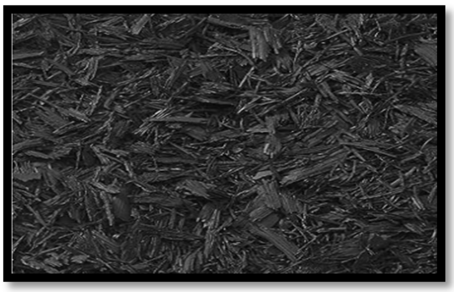

Image 1. Shredded rubber

1.5.2. Kevlar Fibre Reinforced Concrete: The exceptional tensile strength and stiffness of Kevlar fibres make them an emerging choice for concrete reinforcement material. The use of Kevlar fibres as concrete reinforcement results in major enhancements to structural strength and toughness, plus better crack resistance. Research studies [7],[8] have shown an increase in flexural strength along with impact resistance and energy absorption capacity when concrete is reinforced with Kevlar fibers. The advanced modulus of elasticity found in Kevlar fibres helps minimize deformation and cracking when concrete is subjected to load. [9]

Image 2. Kevlar fibres

1.5.3. EPS Lightweight Concrete: The use of Expanded Polystyrene (EPS) beads as an aggregate have been used commonly in concrete formulation in order to decrease its weight and enhance its thermal insulation capability.[10] The use of EPS in concrete gives benefits such us, lower dead weight, better energy performance, and enhanced resistance to fire damage.[11] The use of EPS beads can also enhance the workability and pumping ability of concrete. However, the compressive strength[12] and the adequate structural performance level of the designed mix tend to needs attention alongside effective mix designs to ensure proper structural performance. [12]

Image 3. EPS

1.5.4. Nylon Fibre and Fire Resistance: Synthetic polymers known as nylon fibres or polyamides display superior fire resistance along with outstanding insulation characteristics. Nylon fibres added to concrete materials improve their fire resistance along with thermal insulation and durability. Research shows that concrete reinforced with nylon fibres demonstrates better resistance to wearing while reducing explosive damage and improving mechanical properties after fire exposure. In fire-prone areas and structures which need strong thermal insulation properties nylon fibres offer significant benefits to concrete structures [14]

Image 4. Nylon fibers

2. Methodology

2.1 Mix design

IS code method used for design M20 grade concrete, and further for find optimal content of all 4 polymers with number of iterations. Mix design for Base mix as**. 1 : 1.242 : 2.644** This mix design excluding the replacement of materials.

Image 5. Casting of cubes

Image 6. Mixing of all four types of polymer material as per mix design

2.1.1 Determination of Specific gravity of polymer material

Material	Specific gravity
G rubber	0.96
G Kevlar	1.43
G nylon	1.14
G EPS	0.02

Table-1 Specific Gravity of Polymer filler materials

2.1.2 Experimental Iterations

literature review's past and modern trends suggest the upper and lower values of each polymer in concrete mix to obtain acceptable results are taken account for iterations as per below table.

The experimental investigation involved several iterations to analyze the effects of varying polymer proportions on the properties of concrete.

First Iteration: The initial series, named Mix 1 to Mix 10, explored a range of polymer contents, with the upper and lower bounds of each polymer being increased linearly across the mixes. This series involved the testing of 90 concrete cubes.

Mix name	**Kevlar (%)**	**EPS (%)**	**Nylon (%)**	**Rubber (%)**	Total % Replacement
Base mix	0	0	0	0	0
Mix 1	0.2	10	0.5	5	15.7
Mix 2	0.6	12	0.7	7	20.3
Mix 3	1	14	0.9	9	24.9
Mix 4	1.4	16	1.1	11	29.5
Mix 5	1.8	18	1.3	13	34.1
Mix 6	2.2	20	1.5	15	38.7
Mix 7	2.6	22	1.7	17	43.3
Mix 8	3	24	1.9	19	47.9
Mix 9	3.4	26	2.1	21	52.5
Mix10	3.6	30	2.3	23	58.9

Table-2 First Iteration: The initial series

Subsequent Iterations: Further sets of iterations were conducted to investigate the effects of maximizing the content of each polymer individually.

Mix k1 to Mix k10: Kevlar content was maximized at 3.6%, while the other polymer contents were linearly increased across the mixes. This series involved testing 81 cubes.

Mix E1 to Mix E10: EPS content was maximized at 30%, with 81 cubes tested. Mix N1 to Mix N10: Nylon content was maximized at 2.3%, with 81 cubes tested. Mix R1 to Mix R10: Rubber content was maximized at 23%, with 81 cubes tested.

These iterations allowed for a comprehensive analysis of the individual and combined effects of the polymers on the mechanical properties and density of the concrete.

2.1.3 Compressive test

Compressive test conducted for all iterations as per IS 516-2021 (part-1). The results are compiled and analysed.

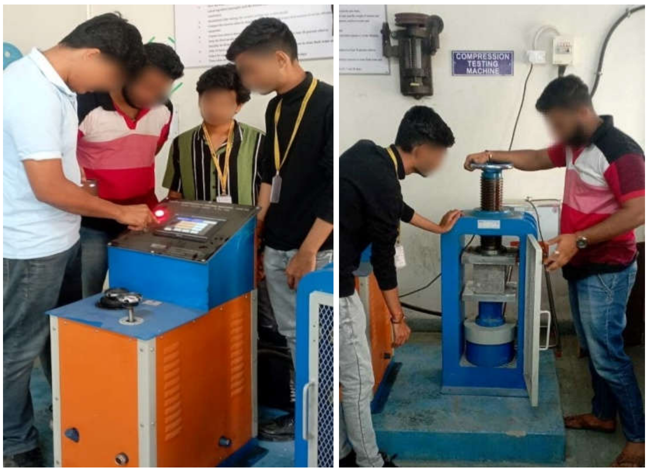

Image 7. Conducting compressive test on digital CTM

2.1.4 Split tensile test

Split tensile test conducted for all iterations as per IS 5816-1999. The results are compiled and analysed. Split tensile test will give better insights because polymer concrete excels in tensile strength.

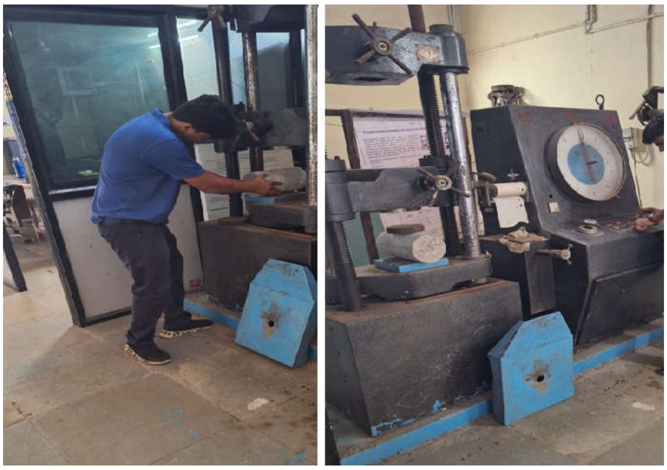

Image 8. Conducting Split tensile test on UTM

3 Results

3.1 Results of Compressive test and split tensile test.

3.1.1 Mix 1 to mix 10 test results

Mix name	28th day Strength (MPa)	Split tensile fsp (MPa)
Base mix	26.92	11.28
Mix 1	30.90	12.78
Mix 2	30.56	12.20
Mix 3	29.76	13.18
Mix 4	29.17	13.71
Mix 5	28.30	13.93
Mix 6	27.43	11.62
Mix 7	26.57	11.04
Mix 8	25.70	10.84
Mix 9	24.83	10.20
Mix 10	23.97	10.33

Table-3 Mix 1 to mix 10 Compressive tests and Split tensile strength results

3.1.2 Mix k1 to mix k10 test results

Mix name	28th day Strength (MPa)	Split tensile fsp (MPa)
mix k1	32.12	24.71
mix k2	31.66	24.35
mix k3	30.74	23.65
mix k4	30.03	23.10
mix k5	29.09	22.38
mix k6	28.16	21.66
mix k7	27.24	20.95
mix k8	26.31	20.24
mix k9	25.38	19.52
mix k10	23.97	18.43

Table-4 Mix k1 to mix k10 Compressive tests and Split tensile strength results

3.1.3 Mix E1 to mix E10 test results

Mix name	28th day Strength (MPa)	Split tensile fsp (MPa)
mix E1	32.88	14.30
mix E2	32.20	14.00
mix E3	31.25	13.59
mix E4	30.40	13.22
mix E5	29.51	12.83
mix E6	28.64	12.45
mix E7	27.77	12.07
mix E8	26.90	11.69
mix E9	26.02	11.31
mix E10	23.97	10.33

Table-5 Mix E1 to mix E10 Compressive tests and Split tensile strength results

3.1.3 Mix N1 to mix N10 test results

Mix name	28th day Stregnth (MPa)	Split tensile fsp (MPa)
mix N1	31.13	16.39
mix N2	30.69	16.15
mix N3	29.98	15.78
mix N4	29.37	15.46
mix N5	28.62	15.06
mix N6	27.87	14.67
mix N7	27.12	14.27
mix N8	26.37	13.88
mix N9	25.61	13.48
mix N10	23.97	10.33

Table-6 Mix N1 to mix N10 Compressive tests and Split tensile strength results

3.1.5 Mix R1 to mix R10 test results

Mix name	28th day Stregnth (MPa)	Split tensile fsp (MPa)
mix R1	33.18	14.43
mix R2	32.50	14.13
mix R3	31.55	13.72
mix R4	30.70	13.35
mix R5	29.81	12.96
mix R6	28.94	12.58
mix R7	28.07	12.20
mix R8	27.20	11.82
mix R9	26.32	11.45
mix R10	23.97	10.33

Table-7 Mix R1 to mix R10 Compressive tests and Split tensile strength results

3.2 Empirical Formula For Relationship Between Fc And Fsp

$$f_{sp} = a * fc + b \qquad \text{Eq (i)}$$

Where a and b are constants determined by the regression analysis. the analysis of the relationship between compressive strength and split tensile strength based on the data of experiments

3.2.1 Empirical formula for Liner incremental mix

After test results and interpretations of co passive tastings and split tensile test results below few empirical formulas are derived.

$$fsp = 0.4390 * fc - 0.2623 \qquad \text{Eq (1)}$$

3.2.2 For incremental liner proportions Maximum Kevlar.

$$fsp = 0.9559 * fc - 5.9170 \qquad \text{Eq (2)}$$

3.2.3 For incremental liner proportions Maximum EPS.

$$fsp = 0.4321 * fc + 0.1062 \qquad \text{Eq (3)}$$

3.2.4 For incremental liner proportions Maximum Nylon.

$$fsp = 0.7197 * fc - 5.6571 \qquad \text{Eq (4)}$$

3.2.5 For incremental liner proportions Maximum Rubber.

$$fsp = 0.4757 * fc - 1.3432 \qquad \text{Eq (5)}$$

4 Conclusion

Strength increases with more new materials, up to a point. Mix 3 is strongest (29.5 MPa, +10.4% over base).

Lighter concrete: Mix 4 is lightest (5.90 kg) and strongest. The split tensile strength for larger amount of replacement gives higher value even decreased of compressive strength.

Kevlar mixes upto mix K6 gives significant split tensile strength. They are strong candidate to be use in blast resisting walls.

Future research sessions will focus on comprehensive testing, including soundproofing, thermal resistance, and acid resistance. This conclusion is preliminary and only addresses the strongest and lightest concrete mixes. Other mixes also demonstrated promising and usable results. The potential applications of the qualified mixes, particularly their roles as lightweight and blast-resistant concrete, will be determined after further detailed testing. The next phase of research will aim to increase the strength of a new mix to meet M40 concrete standards, making it suitable for Pavement Quality Concrete (PQC).

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2. "Polymer-Modified Concrete: Properties and Applications" by Eshmaiel Ganjian and Adel Abdelhady.
3. "Polymer Concrete: A Versatile Material for Rehabilitation and Repair" by Joaquim Barros and Felix Lopez.
4. "Polymer Concrete Handbook: Properties and Applications" by Wilfried Kurth and Robert Cerny.
5. "Polymer Concrete and Polymer Mortars: Properties, Applications and Testing" by L.H. Sell and G. Coates.

Standards

- IS 516: Methods of Tests for Strength of Concrete
- IS 14858: Requirements for compression testing machine used for testing of concrete and mortar
- IS 2386 (Part 3): Methods of Test for Aggregates for Concrete: Part 3 Specific Gravity, Density, Voids, Absorption and Bulking
- IS 5816: Splitting Tensile Strength of Concrete - Method of Test
- IS 10262: Concrete Mix Proportioning - Guidelines
- IS 456: Plain and Reinforced Concrete - Code of Practice