FYDP Mid Defence Document

TITLE

THE MECHENICAL PROPERTIES OF LIGHT WEIGHT SUSTAINABLE ENGINEERED CEMENTITIUOS COMPOSITE (ECC)

Final Year Design Project Report

Names

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INTRODUCTION

The excellent mechanical properties and durability of Engineered Cementitious Composites (ECC) are well known. However, it is prone to cracking, which can seriously affect the safety and life of structures. Solutions to enhance crack resistance and toughness have been explored by engineering experts, and more new materials are being utilized in ECC to achieve this. (Cheng et al., 2023)

The type of fibre used in ECC really matters. Whether we're building something new or fixing up existing structures, the spot where the fibre meets the concrete is crucial. If this part isn't strong, it can cause problems for the whole structure. Making sure the fibre sticks well to the concrete is a must for safety, practicality, and how long the structure lasts.

Fibre makes the cement tougher and helps it stick better to the interface. They do this by reducing how much the cement shrinks. Especially when the outer layer is thin, fibres help stop the interface from cracking because of this shrinkage. When the structure gets stressed, the fibres also prevent tiny cracks from forming in the cement. This is a big deal as it reduces stress around the main crack, making the structure last longer and changing how it deals with damage. (Zhang et al., 2023)

Climate change is being seriously impacted by the extensive use of natural sand. Ways to produce concrete without harming the environment are being sought after by many researchers. Fibre reinforced concrete is being increasingly used for various purposes. Consideration is now being given to using waste plastic in concrete to dispose of plastic waste and aid the environment simultaneously. The amount of sand required in concrete can be reduced, and the natural resource footprint in the construction industry can be minimized by utilizing waste materials like waste rubber and plastic. (Nkomo et al., 2022)

PROBLEM STATEMENT

Engineering cementitious composite (ECC) is widely being used in construction industry, because of its strain capacity (usually >3%) which is greater than that of conventional concrete, and according to micromechanical design theory ECC is an ultrahigh toughness cementitious composite material. (Feng et al., 2022)

In construction industry manmade fibres are being incorporated in ECC. Nowadays, polyester (PET) has rapidly increased its production capacity in the textile industry, resulting in a greater production of waste fibres, with an annual output of 22.67 billion tons. The characteristic of PET is that it has a tensile strength of 5%, but the elongation decreases as it is loaded (Kartikeya Sharma et al., 2020).

ECC uses 50% of natural sand. The annual average extraction of river sand worldwide ranges from 10,000m^3/year to 230 million m^3/year. Environmental impact of excessive excavation of natural sand from riverbeds leads to destabilization of channels, lowering of riverbeds, and a decrease in the water table in nearby regions, thereby threatening the availability of water for local people, agriculture, and other activities. (Srivastava & Singh, 2020)

All over the world, millions of tires are discarded or buried every year, posing a serious threat to the ecology. Around 1000 million tires reach the end of their service life each year and 50% of the tires are being sent to landfills or disposed of as garbage. On the regular basis this continues, there will be 5000 million discarded tires by the year of 2030 (Thomas & Gupta, 2016).

Moreover, From the previous research, it is observed that the elastic modulus of ECC is relatively lower than that of conventional concrete, ranging from 30% to 50% due to the absence of course aggregate. Since the two critical factors are compressive strength and modulus of ECC, both of which should be improved simultaneously while retaining proper ductility. (Liu et al., 2023). Therefore, in this research, the sand will be replaced with rubber powder, and the ECC will be reinforced with a hybrid fibre that will address issues such as the depletion of natural resources, the disposal of waste tire rubber, and the lower elastic modulus of ECC.

PROPERTIES OF FIBRE AND RUBBER

Rubber

Crumb rubber powder mesh number 30 – 40 were used in this project, with replacement of sand, ratio of cement and sand For ECC was 1:1 adopted farther crumb rubber powder in three percentages were used for the project they were 10, 20 and 30 percentage.

Fig. powdered rubber #40 mesh

With every batch at first for dry mix material was prepared and rubber was taken by volume for mix first cement and sand was mixed for 2mins and then crumb rubber powder was added and again mixer was started till the color of mix gets uninform after that water was added.

Fibres

Hybrid Fibres in this project were used to control the cracks and enhance the strength, which is being compromised by the rubber, dosage of the fibre was 2% of the cement, reinforced fibre jute for the mix was used and length was 54mm taken. Other fibre was polyester textile waste and is manmade fibre, length was adopted 51mm.

Fig. jute and polyester fibre

Six batches were made for the project by changing the fibres accordingly as jute 1.5% and polyester 0.5% and 2nd percentage was divided as jute 1% and polyester 1% by keeping crumb rubber powder content same for 2 batches and changing fibre percentages.

With each batch dry mix material was collected and prepared accordingly, firstly cement and sand was mixed for 2mins and then crumb rubber powder was added and again mixer was started till the color of mix gets uninform after that water was added wet mix was prepared after that fibres were added.

LITERATURE REVIEW

Author	Material	Conclusion
Mengjun et al (2023)	• calcined clay limestone cement (LC3) Recycled crumb rubber (CR) • The ratio of span/depth was 3.3 and the bending test was conducted under the displacement control rate of 0.02 mm/min.	Results in reduction in cost and environmental impact but remains comparable with ordinary cement. Reduce the embodied energy and carbon footprint of concrete/ECC and improve long-term mechanical properties, durability and lower cracking stress and crack opening in terms of the stress-crack opening (σ-δ) relation.
Wenmei Zhou et al.	• Silica fume (SF). • P.O. 42.5 ordinary Portland cement (OPC). • Natural river sand (particle size 0-4.75mm) • Waste Rubber Powder (size 80 mesh). • Polycarboxylate superplasticizer (SP). • Poly propylene (PP). (Size 12mm length and diameter 48µm) • Water to binder ratio =>0.36 • WRP apparent density 1.05kg/m3. • PP dosage is 1% of cementitious material.	Researchers like Zhou improved concrete toughness and damping by using waste rubber powder as sand aggregate. Siddique found strength reductions of 50% and 85% with complete coarse aggregate replacement. Abbasi observed a shift from brittle to ductile behavior and increased energy absorption in rubberized concrete with higher WRP volume.
Zhuojun Feng et al.	• Ordinary Portland cement OPC. • Ground Granulated blast furnace slag GGBFS. • Limestone powder LP. • Silica fume SF. • 70-120 mesh silica quartz sand. • Polycarboxylate based high range water reducing admixture HRWRA.	This paper aims to create a cost-effective, high-performance hybrid fibre ECC (HF-ECC) by blending PE and PP fibres. It explores various volume ratios to balance strength, crack resistance, and cost. The study delves into macroscopic and microscopic aspects, including strength, viscosity, fibre bonding, diffusion, and porosity, using techniques like ESEM and MIP for detailed analysis
Mao et al. (2022)	• Ordinary Portland cement 52.5 (OPC), • Limestone powder (LP) • Silica fume (SF).	Excellent strain-hardening behavior and multiple micro-cracks with self-controlled width endow ECC with superior energy

	• Fine silica sand with a maximum grain size of 300 µm and an average particle size of 135 µm. • Polycarboxylate-based high range water reducer (HRWR) • The ratio of sand to binder (s/b) was adjusted from 0.42 to 0.72. • PE fibres were added along to a volume content 2%	absorption capability, as well as fatigue resistance and durability.
Ye et al.	• coarse aggregate • Water/Binder ratio was 0.25. • The Aggregate/Binder ratio is 0.36. • The Fly Ash/Cement ratio was 1.2, 2, 3, 4. • Density of ECC (1.8 kg/L), crumb rubber(1.2 kg/L) and silica sand(2.6 kg/L).	Relatively low s/b ratio and elimination of coarse aggregate results in high cement content per unit volume in ECC which is the origin of shrinkage. Although ECC can relief part of the shrinkage stress by forming multiple microcracks, the volume stability of ECC is worthy of further research to assure the strength performance, strain-hardening behavior, and durability.
Sahroni et al. (2014)	• Silicon carbide (Keating & Nesic). • Rice husk as reinforced materials. • Silicon carbide (SiC, carborundum). • Tin Sn (Sn is very ductile material which has a maximum value of only 18MPa tensile strength and maximum melting point of only 232). • 20kg of rice husk (low bulk density 90-150kg/m3).	A novel method using manual mixing blends natural fibres like SiC and rice husk with tin-lead alloy to enhance composite materials for engineering. It boosts bending and hardness properties significantly but doesn't notably improve tensile strength, which remains lower than pure tin-lead alloys (60-40).
Shabbir et al. (2022)	• Hooked steel fibres • Potable water. • Well-graded aggregates blend having 80% and 20% with 20 mm passing and 9.5 mm passing coarse aggregates (crushed). • Chopped carbon fibres. • Natural sand finer than 4.75 mm.	This study investigated concrete types for controlling early-age cracking. Compared to plain concrete (PCC), SFRC and CFRC showed 28.2% and 5.6% higher compressive strength, while SFRC and CFRC had 39% and 30.1% higher splitting tensile strength, and their rupture strength increased by 35.7% and 42.6%, respectively.

	• Steel fibre reinforced concrete (SFRC). • Carbon fibre reinforced concrete (CFRC). • Ordinary Portland cement (OPC). • Cement: sand: crush) is 1:1.5:3 • Water to cement ratio of 0.45–0.5. • Relative density (%) 90.	
Wei-Hao Mao et al. (2022)	micro-mechanics and fracture mechanics	Excellent strain-hardening behavior and multiple micro-cracks with self-controlled width endow ECC with superior energy absorption capability, as well as fatigue resistance and durability
He et al. (2023)	Rubber concrete	Rubberized concrete (RC) demonstrates enhanced characteristics such, as sensitivity to strain rate effective energy dissipation and improved ductility even though its static properties may be weakened. When the rubber volume fraction in RC is, than 30% it not improves mechanical performance but also enhances fire resistance, permeability and freeze thaw behavior.
Tiezhi Zhang et al (2019)	Jute fibres	Incorporating jute fibres into cement slurry improves its grip and cohesion. Tests indicate that this leads to enhanced splitting strength, decreased porosity, and prevention of cracks. The ideal conditions, for achieving these benefits are a water cement ratio of 0.30 jute fibres, with a length of 16 ± 2 mm and a fibre content of 3.0 kg/m3.
Muhammad Affan et al (2022)	Effect of jute fibre under freeze thaw condition	The concrete incorporates jute fibres at a proportion of 5%, to the mass of cement (to 0.8% by volume of the concrete) with a length of 50 mm and undergoes freeze thaw cycles for less, than 10, 20 and 30 times.

Ahmad et al. (2022)	• Natura fibres (Jute fibres)	After the addition of jute fibres several changes were observed in the mix. The fluidity or workability decreased, while the compressive strength increased. Additionally, there was an increase, in tensile strength and flexural strength. These improvements were observed for fibre additions, up to 0.10%.
Subodh Kumar et al,.(2023)	• Portland Pozzolana cement • Fly ash (FA). Finer particles were used. • River sand (sieve size of 1.18 mm) • Water • Low-cost polyester fibres (dosage of 3%), length 12mm. • Polycarboxylate-based high-range water-reducing admixture (HRWRA).	In this article, 28 days sample of 2% polyester Fibres, gives the tensile strength of 2.5 MPa and ductility of 0.3%. In the comparison of 2% PVA Fibre sample resulted greater tensile strength between 4.5 to 5MPa, ductility between 0.3% and 0.45%.
N. Banthia et al (2013)	• Hybrid reinforced concrete • Micro-cellulose fibre • Macro-steel fibres • Double Deformed fibre • Hooked-End fibre	The Hooked-End fibre (HE) was significantly better in shear than the Double Deformed fibre The cellulose fibre did not impart toughness under either mode of loading. There was a positive Synergy between steel and cellulose fibres in all instances. Under direct shear, Synergy was not uniformly positive across all fibre types and combinations.

CONTRIBUTION

In this innovative research initiative, we aim to revolutionize construction practices by developing a sustainable variant of Engineered Cementitious Composite (ECC). By strategically replacing sand with recycled rubber powder and incorporating a novel hybrid fibre, our project addresses critical challenges such as sand resource depletion and waste tire management. Our comprehensive approach seeks to not only enhance the elastic modulus and compressive strength of ECC but also contribute to the circular economy by repurposing waste materials. Throughout the process, we will conduct a thorough literature review, characterize materials, design optimal ECC mixes, and rigorously test and evaluate mechanical and durability properties. Stakeholders and potential customers, including construction industries, manufacturers, and environmental regulatory bodies, are integral to the success of this initiative. By disseminating our findings through conferences, journals, and direct engagements, we aim to facilitate the widespread adoption of this sustainable ECC variant, ushering in a new era of environmentally conscious construction practices.

Our research on the sustainable variant of Engineered Cementitious Composite (ECC) involves key stakeholders critical to its success. Construction industries stand to gain a unique opportunity by adopting our eco-friendly ECC, aligning with corporate social responsibility and sustainable building practices. Manufacturers in the construction materials sector are positioned to benefit from the potential market demand for the novel hybrid fibres and recycled rubber powder integral to our ECC development, fostering a more sustainable supply chain. Collaboration with environmental regulatory bodies ensures that our ECC variant meets stringent standards, encouraging widespread acceptance and adherence to sustainable construction practices. Meanwhile, potential customers, including infrastructure developers engaged in large-scale projects, architects and designers seeking green building solutions, and government agencies responsible for construction initiatives, can leverage our ECC variant to achieve sustainability goals, reduce environmental impact, and set a precedent for sustainable infrastructure development. Throughout this process, collaboration and engagement with these stakeholders are integral to ensuring the successful adoption and implementation of our sustainable ECC variant on a broader scale. By disseminating our findings through conferences, journals, and direct engagements, we aim to facilitate the widespread adoption of this eco-friendly ECC, ushering in a new era of environmentally conscious construction practices.

RELEVANT PROGRAM LEARNING OUTCOMES (PLOs)

The course is designed so that students will achieve the following PLOs:

1 Engineering Knowledge:	☑	7 Environment and Sustainability:	☑
2 Problem Analysis:	☑	8 Ethics:	☑
3 Design/Development of Solutions:	☑	9 Individual and Teamwork:	☑
4 Investigation:	☑	10 Communication:	☑
5 Modern Tool Usage:	☑	11 Project Management:	☑
6 The Engineer and Society:	☑	12 Lifelong Learning:	☑

COMPLEX ENGINEERING PROBLEM

The range of complex problem solving is defined as follows:

No.	**Attribute**	**Complex problems** have characteristic WP1 and some or all WP2 to WP7:	**Project based**
WP1	Depth of Knowledge Required	Cannot be resolved without in-depth engineering knowledge at the level of one or more of WK3, WK4, WK5, WK6 or WK8 which allows a fundamental-based, first principles analytical approach.	√
WP2	Range of conflicting requirements	Involve wide-ranging or conflicting technical, engineering, and other issues.	√

WP3	Depth of analysis required	Have no obvious solution and require abstract thinking, originality in analysis to formulate suitable models.	√
WP4	Familiarity of issues	Involve infrequently encountered issues.	
WP5	Extent of applicable codes	Are outside problems encompassed by standards and codes of practice for professional engineering.	√
WP6	Extent of stakeholder involvement and level of conflicting requirements	Involve diverse groups of stakeholders with widely varying needs.	
WP7	Interdependence	Are high level problems including many component parts or sub- problems.	√

COMPLEX ENGINEERING ACTIVITIES

The range of complex engineering activities is defined as follows:

No.	Attribute	**Complex activities** mean (engineering) activities or projects that have some or all of the following characteristics:	Project based
EA1	Range of resources	Involve the use of diverse resources (and for this purpose resources includes people, money, equipment, materials, information and technologies).	√
EA2	Level of interactions	Require resolution of significant problems arising from interactions between wide ranging or conflicting technical, engineering, or other issues.	
EA3	Innovation	Involve creative use of engineering principles and research-based knowledge in novel	√
EA4	Consequences to society and the Environment	Have significant consequences in a range of contexts, characterized by difficulty of prediction and mitigation.	
EA5	Familiarity	Can extend beyond previous experiences by applying principles-based approaches.	√

SUSTAINABILITY DEVELOPMENT GOALS

- SDG 9: Industry, Innovation, and Infrastructure
- SDG 12: Responsible Consumption and Production
- SDG 13: Climate Action

PROJECT DEVELOPMENT METHODLOGY / ARCHITECTURE

Methodology for testing will be adopted according to ASTM standards.

PHASE 1

In phase one material properties will be investigated by the tests for example sieve analysis, specific gravity, and water absorption test.

- Sieve analysis: Sieve analysis is performed to identify the gradation curve.
- Specific gravity and absorption: By the standard ASTM-C128, procedure to find specific gravity of fine aggregate was adopted.

PHASE 2

In phase two mechanical properties will be investigated by the adopting standard test procedures.

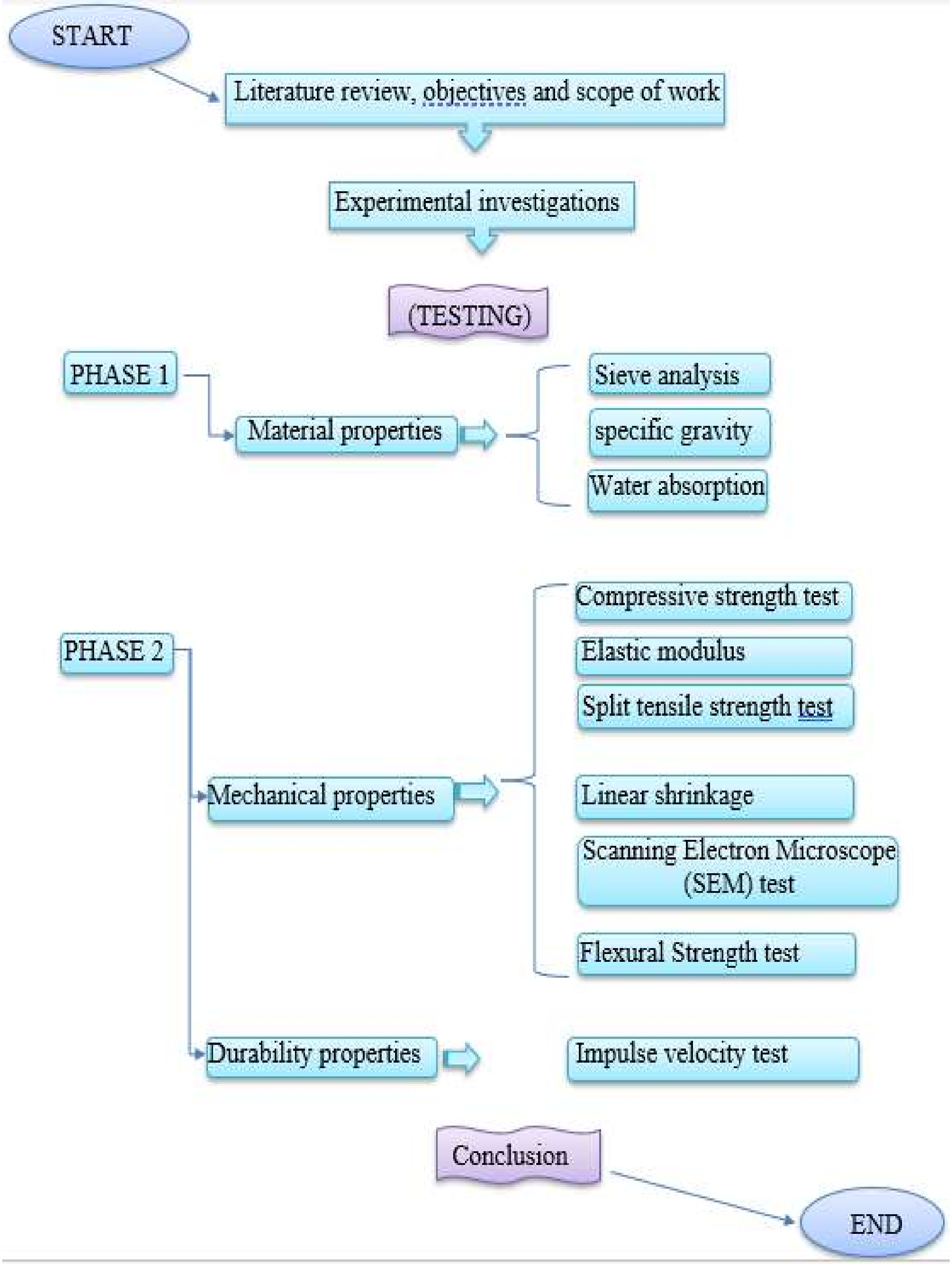
Mechanical Properties

- Cylindrical compressive test: This test will be performed on universal compression test machine and sample will be placed vertically, by which we will get ultimate strength, modulus of elasticity and poison ratio.
- Split tensile strength: This test will be performed on universal compression test machine and sample will be placed horizontally, by which we will get tensile strength.
- Flexural test: This test is adopted to find flexural strength of the sample and linear shrinkage.
- Scanning electronic microscope test: Checking the distribution of fibres and bonding.

Durability

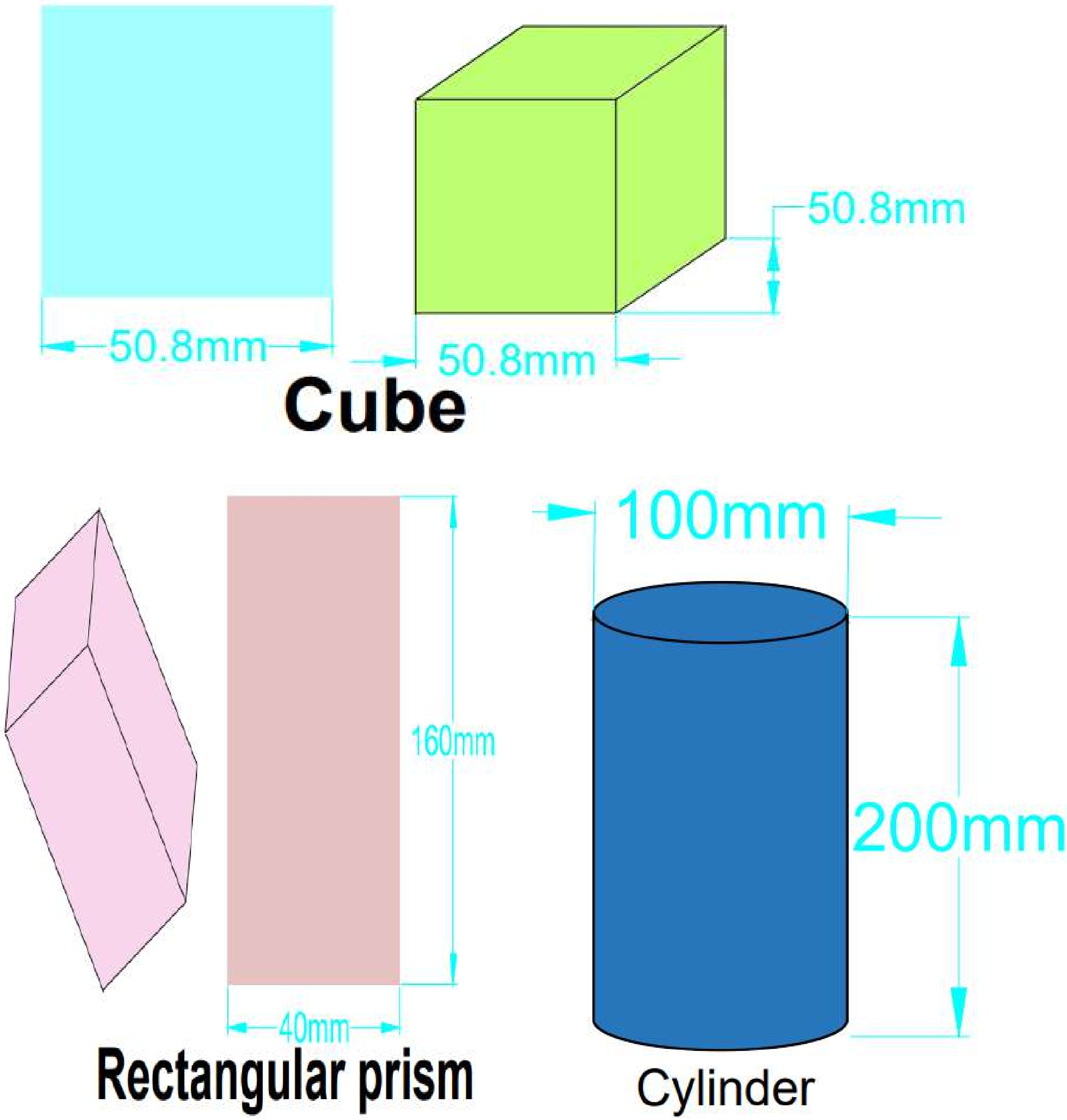
- Ultra sonic impulse test: This is a non-destructive test and is used to find the quality of sample for example voids and distribution of fibres.

EXPERIMENTAL TESTING					
PROPERTIES	TEST NAME	STANDARD	CURING	SPECIMEN SIZE	NO OF SAMPLES
PHYSICAL AND CHEMICAL PROPERTIES	S.G	C128	.	.	.
	Density	C128	.	.	.
	sieve analysis	C136	.	.	.
MECHANICAL PROPERTIES	compressive strength	C109/C 109M-02	28DAYS	50mm x 50mm x 50mm	3
	tensile strength	C496	28 DAYS	100mm x 200mm	3
	M.O.E	C469	28 DAYS	100mm x 200mm	3
	flexural strength	C348	28 DAYS	40mmx40mmx160mm	3
	Impulse velocity	C597	28 DAYS	40mmx40mmx40mm	3


START
Literature review, objectives and scope of work
Experimental investigations
(TESTING)
PHASE 1
Material properties
Sieve analysis
specific gravity
Water absorption
PHASE 2
Mechanical properties
Compressive strength test
Elastic modulus
Split tensile strength test
Linear shrinkage
Scanning Electron Microscope (SEM) test
Flexural Strength test
Durability properties
Impulse velocity test
Conclusion
END

DATA ANALYSIS:

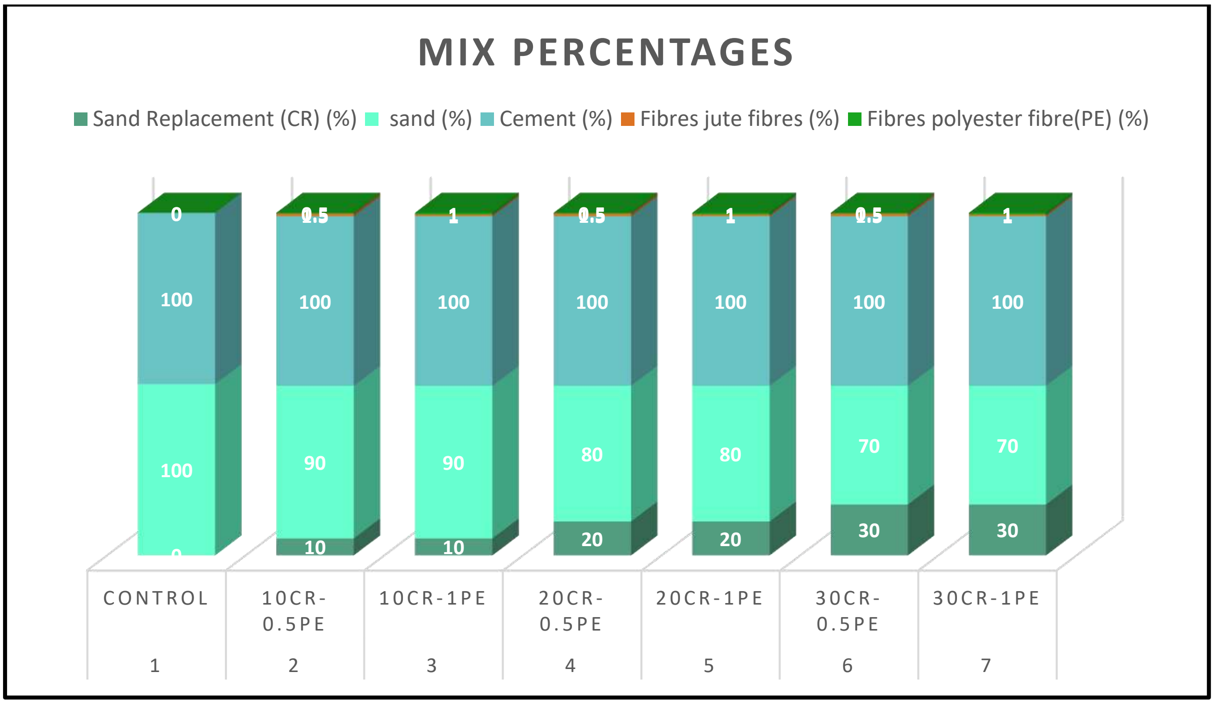
MOULD SIZE DIAGRAMS



MIX CALCULATION

ECC						
		Sand Replacement			Fibres	
No. of mix	Mix Name	(CR) (%)	Silica sand (%)	Cement (%)	jute fibres (%)	polyester fibre(PE) (%)
1	Control	0	100	100	0	0
2	10CR-0.5PE	10	90	100	1.5	0.5
3	10CR-1PE	10	90	100	1	1
4	20CR-0.5PE	20	80	100	1.5	0.5
5	20CR-1PE	20	80	100	1	1
6	30CR-0.5PE	30	70	100	1.5	0.5
7	30CR-1PE	30	70	100	1	1

Mix design ratio				
Cement	Silica sand	w/b	fibres	Density (Kg/m3)
1	1	0.42	2% of cement	1500



COMPLETE PROCEDURE OF THE PROJECT

TEST STANDARDS

EXPERIMENTAL TESTING					
PROPERTIES	TEST NAME	STANDARD	CURING	SPECIMEN SIZE	NO OF SAMPLES
PHYSICAL AND CHEMICAL PROPERTIES	S.G	C128	:	:	:
	Density	C128	:	:	:
	sieve analysis	C136	:	:	:
MECHANICAL PROPERTIES	compressive strength	C109/C 109M-02	28DAYS	50mm x 50mm x 50mm	3
	tensile strength	C496	28 DAYS	100mm x 200mm	3
	M.O.E	C469	28 DAYS	100mm x 200mm	3
	flexural strength	C348	28 DAYS	40mmx40mmx160mm	3
DURABILITY TEST	Ultra sonic impulse velocity	C597	28DAYS	50mm x 50mm x 50mm	3

1. PHASE - 1 (Initial testing)

1.1. Standard Test Method for Sieve Analysis of Fine and Coarse Aggregates

Designation: ASTM C 136 – 01

1.1.1. Apparatus

a) Balances: The readability and accuracy of balances or scales used to test fine and coarse aggregate must meet the following requirements:

i. For fine aggregate, readable to 0.1 g and accurate at any point within the usage range to 0.1 g or 0.1% of the test load, whichever is higher.

ii. For coarse aggregate, or combinations of fine and coarse aggregate, readable and accurate at any point within the usage range to within 0.5 g or 0.1% of the test load, whichever is higher.

b) Sieves: The cloth used in the sieve must be fixed to sturdy frames that are built to minimise material loss during the sifting process.

c) A mechanical sieve shaker, must generate motion in sieves to induce particle bouncing, tumbling, or turning, presenting varied orientations to sieve surfaces. The sieving action should meet specified adequacy criteria within a reasonable time frame, ensuring efficient particle separation based on size.

d) A suitably sized oven should consistently sustain a steady temperature of 110 ± 5°C (230 ± 9°F).

1.1.2. Sample preparation

a) The minimum size for the test sample of fine aggregate, after drying, is 300 g.

b) Coarse aggregate test sample sizes must adhere to the specified requirements.

c) When dealing with mixtures of coarse and fine aggregate, the test sample size should match that for coarse aggregate in section 7.4.

d) For samples of large-size coarse aggregate (50-mm nominal maximum size or larger), the sample size should be sufficient for testing, considering the challenges of sample reduction without large mechanical splitters and sieve shakers. Alternatively, if such equipment is unavailable, perform sieve analysis on multiple roughly equal sample increments, ensuring the total mass tested meets the requirements of section 7.4.

e) When determining material finer than the 75-µm (No. 200) sieve by Test Method C 117, follow these steps:

i. For aggregates with a nominal maximum size of 12.5 mm (1/2 in.) or less, use the same test sample for both Test Method C 117 and this method. Complete Test Method C 117, including the final drying operation, followed by dry sieving as outlined in 8.2-8.7 of this method.
ii. For aggregates with a nominal maximum size greater than 12.5 mm (1⁄2 in.), choose between using a single test sample as described in 7.7.1 or using separate test samples for Test Method C 117 and this method.
iii. If specifications necessitate determining the total amount of material finer than the 75-µm sieve by washing and dry sieving, follow the procedure outlined in 7.7.1.

1.1.3 Procedure

a) Dry the sample at 110 ± 5°C (230 ± 9°F) until a constant mass is achieved.

b) Choose sieves with appropriate openings to meet specification requirements. Use additional sieves as needed for supplementary information or to control material distribution. Arrange sieves in descending order of opening size, placing the sample on the top sieve. Agitate manually or mechanically for a duration determined by trial or measured on the actual sample to meet the sieving adequacy criterion (1.1.3 d).

c) Restrict the material quantity on each sieve to ensure multiple passages through openings during sieving. For sieves smaller than 4.75-mm (No. 4), the retained quantity should not exceed 7 kg/m2 of sieve surface area. For sieves 4.75 mm (No. 4) and larger, the retained quantity in kg should not surpass the product of 2.5 times the cube of the sieve opening (mm) and the effective sieving area (m2)

i) Avoid overloading an individual sieve using one of the following methods:

i.1) Introduce an extra sieve with an opening size between the sieve at risk of overloading and the sieve immediately above it in the original set.
i.2) Divide the sample into multiple portions and sieve each portion separately. Combine the masses of portions retained on a specific sieve before calculating the percentage of the sample on the sieve.
i.3) Opt for sieves with a larger frame size, offering more sieving area.

d) Sieve the material for a sufficient duration, ensuring that no more than 1% of the material on any sieve passes through during 1 minute of continuous hand sieving. Conduct the hand sieving by striking the sieve against the heel of the hand at a rate of about 150 times per minute. Turn the sieve about one sixth of a revolution at intervals of about 25 strokes. For sizes larger than the 4.75-mm (No. 4) sieve, limit the material on the sieve to a single layer. If the sieving motion is impractical, use 203-mm (8 in.) diameter sieves for verification.

e) In mixtures of coarse and fine aggregate, distribute the portion finer than the 4.75-mm (No. 4) sieve among multiple sets of sieves to avoid overloading.

i) Alternatively, reduce the portion finer than the 4.75-mm (No. 4) sieve using a mechanical splitter as per Practice C 702. If following this procedure, calculate the mass of each size increment of the original sample accordingly.

$$A = \frac{W_1}{W_2} \times B$$

where:

- A = mass of size increment on total sample basis,
- W1 = mass of fraction finer than 4.75-mm (No. 4) sieve in total sample,
- W2 = mass of reduced portion of material finer than 4.75-mm (No. 4) sieve
- B = mass of size increment in reduced portion sieved.

f) When not using a mechanical sieve shaker, manually sieve particles larger than 75 mm (3 in.) by identifying the smallest sieve opening through which each particle can pass. Begin the test with the smallest required sieve. Rotate particles, if necessary, to check their passage through a specific opening, avoiding any forced entry.

g) Weigh each size increment using a scale or balance meeting the specifications in 5.1, rounding to the nearest 0.1% of the total original dry sample mass. Ensure that the total mass after sieving closely matches the original sample mass placed on the sieves. If the difference exceeds 0.3% based on the original dry sample mass, refrain from using the results for acceptance purposes.

h) If the sample underwent prior testing using Test Method C 117, add the mass finer than the 75-µm (No. 200) sieve, as determined by that method, to the mass passing the 75-µm (No. 200) sieve through dry sieving in this method.

1.2. Standard Test Method for Density, Relative Density (Specific Gravity), and Absorption of Fine Aggregate

Designation: ASTM C 128 – 07a

1.2.1. Apparatus

a) Balance: Any balance or scale that can hold one kilogramme or more, is sensitive to one milligramme or less, and is accurate to within 0.1% of the test load at any point within the test method's usable range. The accuracy of any discrepancy between readings must be within 0.1 grammes within a 100-g test load range.

b) Pycnometer (for Use with Gravimetric Procedure): This is a flask or other appropriate container that may be used to easily enter the fine aggregate test sample and replicate the volume content within 6 0.1 cm3. The capacity of the filled container must be at least 50% larger than the amount of space needed to hold the test sample. A 500-cm3 size volumetric flask or a fruit jar sufficient for a 500-g test sample of the majority of fine aggregates when equipped with a pycnometer top.

c) Flask (for Use with Volumetric Procedure): For a test sample of around 55 g, a Le Chatelier flask according to Test Method C 188 is adequate.

d) Mould and Tamper for Surface Moisture Test: The metal mould must have a minimum thickness of 0.8 mm and be shaped like a frustum of a cone with the following dimensions: 40 ± 3 mm in the top, 90± 3 mm in the bottom, and 75 ± 3 mm in height. The metal tamper will weigh 340 ± 15 g and feature a 25 ± 3 mm diameter flat circular tamping face.

e) Oven: An oven big enough to keep the temperature constant at 110±5°C (230 ± 9^0F)

1.2.2. Sample preparation

a) Sample the aggregate using Practice D 75 guidelines. Mix the material well and decrease it using the appropriate methods outlined in Practice C 702 to produce a test specimen weighing about 1 kg.

1.2.3. Procedure

a) Conduct the test using the volumetric method in 9.3 or the gravimetric method in 9.2. Determine the mass of each object to 0.1 g.

b) Pycnometer (gravimetric) Method:

i) Pour some water into the pycnometer. Pour 500 ± 10 g of saturated surface-dry fine aggregate—prepared according to Section 8—into the pycnometer. Then, fill it up to about 90% of the way with water. As indicated in 9.2.1.1 (manually) or 9.2.1.2 (mechanically), agitate the pycnometer.

i.1) To get rid of any apparent air bubbles, manually roll, invert, or shake the pycnometer (or do a mix of these).

i.2) Use external vibration to mechanically shake the pycnometer in a way that doesn't harm the sample. Agitation at a level that just moves individual particles is enough to encourage de-airing without causing deterioration.

ii) After removing all air bubbles, raise the water level in the pycnometer to its calibrated capacity and, if needed, regulate the temperature of the pycnometer and its contents to 23.0 ± 2.0 °C by partial immersion in flowing water. Calculate the whole mass of the pycnometer, specimen, and water.

iii) Remove the fine aggregate from the pycnometer, dry in the oven to constant mass at a temperature of 110 ± 5 °C (230 ± 9 °F), cool in air at room temperature for 1 ± 1⁄2 h, and determine the mass.

iv) Determine the mass of the pycnometer filled to its calibrated capacity with water at 23.0 ± 2.0 °C.

c) Volumetric (Le Chatelier Flask) Procedure:

i) First, fill the flask with water up to the point where the 0 and 1-mL marks are located on the stem. Take a measurement at this starting temperature when the flask and its contents are between 23.0 ± 2.0 °C. In the saturated surface-dry state, add 55 ± 5 g of fine aggregate (or another specified quantity as necessary). Once all of the fine aggregate has been added, insert the stopper into the flask and roll it up or gently spin it in a horizontal circle to release any trapped air. Repeat until no more bubbles appear on the surface (Note 4). When the flask and its contents are within 1 °C of the starting temperature, take one last reading.


(i)


(ii)

Fig. (i) Specific gravity of sand (ii) moisture content of crumb rubber

2. MIXING PROCEDURES

Mixing Engineered Cementitious Composites (ECC), jute fibre, and polyester while replacing sand with crumb rubber involves a series of steps to ensure a homogeneous and well-blended composite material. Here's a general procedure for the process:

Materials:

1. ECC mix (cement, fine aggregates, water.)
2. Jute fibre
3. Polyester fibres
4. Crumb rubber (30-40 mesh)

Procedure:

The outlined procedure constitutes a thorough analysis aligned with the ASTM C270 and ASTM C94/C94M standards, which govern the production and testing of mortar and ready-mixed concrete, respectively. Incorporating the principles of ASTM C270, which outlines mortar specifications for masonry construction, and ASTM C94/C94M, providing guidelines for ready-mixed concrete, ensures adherence to industry standards. This comprehensive approach guarantees the quality, consistency, and performance of construction materials, supporting high standards of quality control for enhanced structural integrity and durability in diverse construction projects.

1. Weight and measure the required amount of cement, fine aggregates, and water based on the ECC mix design. Following specified ratios for cement, fine aggregates, and water to ensure compliance with ASTM C270 requirements.
2. Weigh the designated amount of jute fibres based on ASTM C1116 for fibre content in ECC mortar.
3. Weigh the required amount of polyester fibres according to ASTM C1116.
4. Calculate the crumb rubber quantity based on ASTM C136 for sieve analysis and ASTM D5644 for particle size distribution.
5. Adjust mixing parameters based on ASTM C143/C143M for slump testing to achieve desired workability.
6. Following the given standards for mixing the ECC materials.
    - ECC mix (without fibres or crumb rubber): 3-5 minutes
    - Jute Fibre: Additional 2-3 minutes
    - Polyester Fibres: Additional 2-3 minutes
    - Crumb Rubber (30-40 Mesh): Additional 2-3 minutes

MIXING PROCEDURE.

1. Mix the dry components (cement and fine aggregates) thoroughly to ensure a uniform blend. Sequentially introduce cement and fine aggregates, and mix for 3-5 minutes until a uniform consistency is achieved.
2. Gradually introduce crumb rubber to the mix while maintaining mixing for an additional 2-3 minutes, ensuring proper incorporation.
3. Gradually add water while mixing to achieve the desired consistency.

4. Gradually introduce jute fibres and Polyester Fibre into the mixer while continuing to mix. Mix for an additional 2-3 minutes to ensure even fibre dispersion.
5. Pour the material in the molds before the setting time starts.
6. Conduct quality control tests following ASTM standards, including compressive strength (**ASTM C109**) and flexural strength (**ASTM C348**).

Fig. dry mix of the constituent without fibre

3. CASTING

3.1. Casting in cylindrical molds

Before curing fresh mix was prepared according to mix design and cylinders (100mm diameter and 200mm height) were clean and checked the nuts were tight or not if not tight them so that mix or water

cannot comes out from the cylinders after that cylinders were lubricated so that when mix is dried easily can be taken out from the mold. The wet mix was poured at temperature of 22 C^{o} in molds in two layers with 25 blows with rod and kept at the room temperature and not directly to the sunlight as guided in ASTM C31. After 24-hour samples were taken out from the molds and weighed as weight before curing and naming of sample was done and kept in curing tank partially filled with water for 28 days for curing period by ASTM C31 to get 99% of mix strength. After curing period, samples were taken out from curing tank and weighed.

fig.3.1. (a) Casting of cylindrical and cubic mods

(i) (ii) (iii) (iv)

Fig 3.1 (b) after removing from moulds and taking their weights. (i)no crumb rubber, (ii) 10% crumb rubber (iii) 20% crumb rubber (iv) 30% crumb rubber

3.2. Casting in Cube and Prism

Designation: ASTM C 348 – 08

The mold for a prism test object measuring 40 x 40 x 160 mm must be a triple mold and must be designed so that the test object will be cast with the longitudinal axis in a horizontal position. The mold must be made of hard metal, not coated with cement mortar, and with a Rockwell hardness of not less than HRB 55.

Temperature

The air temperature around the mixing plate, dry ingredients, mold, support plate, and mixing bowl should be maintained at 73.5 ± 5.5 °F or [23.0 ± 3.0 °C]. Mixing water, wet toilet or wet room and storage tank water temperatures should be set to 73.5 6 3.5°F or [23 6 2°C].

Test Specimen

Make two or three samples from a batch of mortar for each period of testing or trial age.

TABLE 1 Permissible Variations of Specimen Molds

Parameter	2-in. Cube Molds		[50-mm] Cube Molds	
	New	In Use	New	In Use
Planeness of sides	<0.001 in.	<0.002 in.	[<0.025 mm]	[<0.05 mm]
Distance between opposite sides	2 in. ± 0.005	2 in. ± 0.02	[50 mm ± 0.13 mm]	[50 mm ± 0.50 mm]
Height of each compartment	2 in. + 0.01 in. to − 0.005 in.	2 in. + 0.01 in. to − 0.015 in.	[50 mm + 0.25 mm to − 0.13 mm]	[50 mm + 0.25 mm to − 0.38 mm]
Angle between adjacent faces[A]	90 ± 0.5°	90 ± 0.5°	90 ± 0.5°	90 ± 0.5°

[A] Measured at points slightly removed from the intersection. Measured separately for each compartment between all the interior faces and the adjacent face and between interior faces and top and bottom planes of the mold.

SOURCE (Table 1 from ASTM C 109/C 109M – 02)

Procedure:

Before curing, fresh mix was prepared according to mix design and cubes molds (50mm x 50mm) were cleaned and the tightness of nuts were checked, if not tightened tight them so that mix or water cannot comes out from the cube after that apply a thin layer of release agent to the non-absorbent inner surfaces of the mold and base plate. Apply oil and grease using an impregnated cloth or other suitable material. Wipe the mold and base plate surfaces with a cloth as necessary to remove excess release agent and to obtain a thin, even coating on the inner surfaces. When using aerosol lubricant, spray the release agent directly onto the surface of the mold and base plate from 6 to 8 inches or [150 to 200 mm] to achieve complete coverage. After spraying, wipe the surface with a cloth as necessary to remove any remaining aerosol lubricant. The layer of residue should be sufficient to allow fingerprints to remain after light finger pressure.

(i) (ii)

(iii) (iv)

Fig. 3.2. weighing samples after removing from moulds. (i) cube with 20% crumb rubber, (ii) cube with 30% crumb rubber, (iii) prism with 30% crumb rubber, (iv) prism with 20% crumb rubber.

The wet mix was poured at temperature of 22 C° in molds in two layers with the compaction pressure must be sufficient to ensure uniform mold filling. 4 rounds of tamping (32 strokes) of mortar must be completed in one cube before moving on to the next cube. When compaction of the first layer in all compartments of the cube has been completed, fill the compartments with the remaining mortar and then compact as specified for the first layer ASTM C 109/C 109M – 02. During compaction of the second layer, insert the forced-out mortar into the top of the mold after each round of compaction using gloved fingers and tamper after completing each round and before starting the next round of compaction. Once compaction is complete, the top of all cubes should extend slightly above the top of the mold. Insert the forced mortar into the top of the mold with a trowel and level the cubes by drawing the flat side of the trowel (with the front edge slightly raised) once across the top of each cube at a right angle to the length of the mold. Then, to even out the mortar and make the mortar protruding above the top of the mold a more uniform thickness, draw the flat side of the trowel (with the front edge slightly raised) ever so slightly along the mold. Cut the mortar until the surface is flush with the top of the mold by drawing the straight edge of the trowel (held almost perpendicular to the mold) with a sawing motion along the length of the mold.

After Samples were prepared and kept for casting at the room temperature and not directly to the sunlight as guided in ASTM C31. After 24-hour samples were taken out from the molds and weighed as weight before curing and naming of sample was done and kept in curing tank partially filled with water for 28 days for curing period suggested by ASTM C31 to get 99% of mix strength. After curing period samples were taken out from curing tank and weighed that was weight after curing.

Fig. 3. Prepared samples

4. CURING

4.1. Standard curing procedures

During initial curing, cylinders should be stored at 60-80 degrees F (15-26 Co) in an environment that prevents moisture loss for 48 hours. If the design strength of the concrete is 6,000 psi or higher, the initial curing temperature should be between 68- and 78-degrees Fahrenheit. Samples should be protected from direct sunlight or radiant heating devices, if used. A minimum-maximum thermometer should record the temperature during the initial curing period and then record it when the cylinders are removed.

For final curing, cylinders or beams must be placed in curing storage no later than 30 minutes after removal from the molds. The surface of the cylinders must always be kept free of water and the temperature must be maintained at a constant temperature of 73.5 degrees Fahrenheit +/- 3.5 degrees Fahrenheit. Cylinders and beams can be placed in wet areas or in water storage tanks, but beams must be moved into water-saturated areas. with calcium hydroxide at the same temperature at least 20 hours before testing. Do not allow the surfaces of the beams to dry out between removal of the water storage tank and testing.

5. PHASE - 2 (Final testing)

5.1. Mechanical Properties Testing

5.1.1. Compressive Strength Test

Designation: ASTM C 109

Appratus:

Compressive testing matchine

Procedure:

a) Clean the apparatus with the dry cloth and ensure that the room temperature for conducting this test should be 27 ± 2°C
b) The specimen must be kept in water for 3 or 7 or 28 days and for every 7 days for curing.
c) Testing specimens (mortar cubes) are placed in the space between bearing surfaces of the Compressive strength machine.
d) Care must be taken to prevent the existence of any loose material or grit on the metal plates of machine or specimen block.
e) The loading must be applied axially on specimen without any shock and increased at the rate of 35 N/mm^2/min. till the specimen collapse.
f) Due to the constant application of load on the face of the cube, the mortar cube starts cracking and fails at a point.
    a. Note down the reading from Compressive testing machine where the specimen starts failing.

Fig. 5.1.1. compression testing.

5.1.2. <u>Split Tensile Strength</u>

Designation ASTM C-496.

Apparatus:

Compression Testing Machine.

Procedure:

a) The cured sample is taken out and prepared to be tested.
b) Two bearings strips of nominal strength should be provided above and below the specimen.
c) Place the bearing strips between the specimen and both upper and lower bearing blocks of the testing machine or between the specimen and the supplemental bars or plates.
d) Draw diametric lines at each end of the specimen using a suitable device that will ensure that they are in the same axial plane.
e) Place the specimen between the bearing plates and apply the load at a constant rate until failure occurs.
f) Record the maximum applied load indicated by the testing machine at failure. Note the type of failure and appearance of fracture.

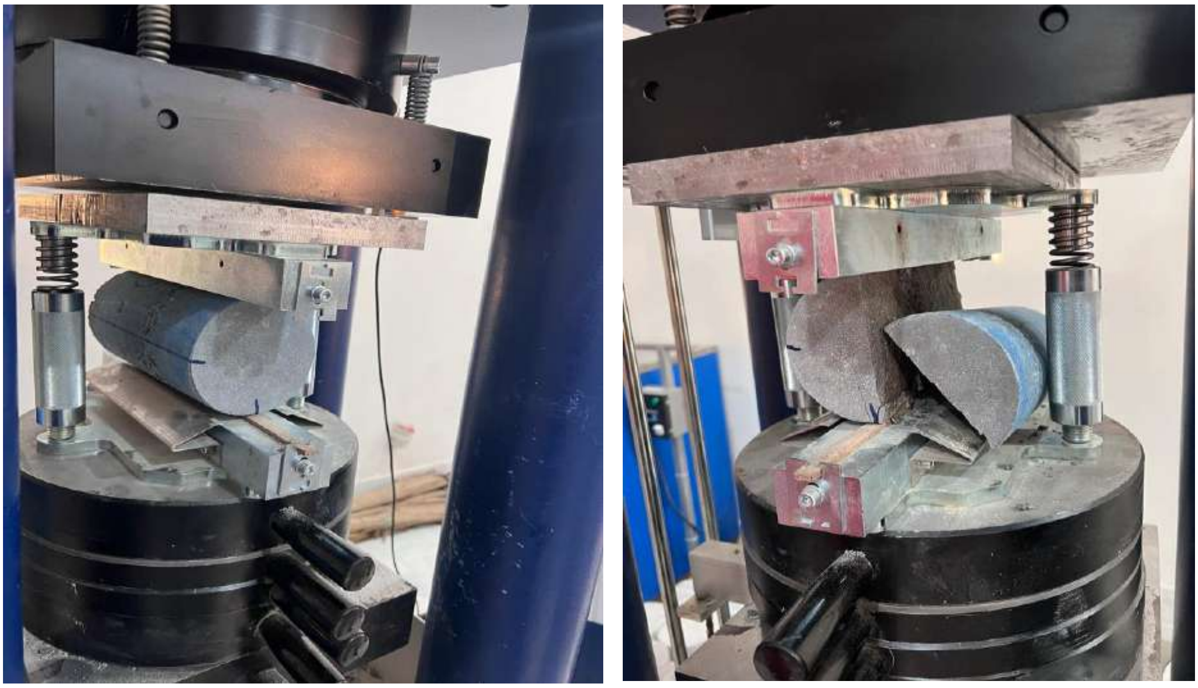


Fig. 5.1.2. split tensile testing.

5.1.3. Flexural Strength Test

Designation: ASTM C 348

Procedure:

a) As soon as the specimens are taken out of the storage water for all other specimens, or the damp closet for 24-hour specimens, test them. For a given test age, every test specimen must be broken within the allowed tolerance.

b) Test the prisms early enough such that the modified cubes are likewise broken within the specified tolerances when the parts of the prisms are tested as modified cubes in compliance with Test Method C 349. Cover the specimens with waterproof plastic until the test time if more than one is taken out of the wet closet at once for the 24-hour test. When removing many older specimens at once from the storage water for testing, make sure the water is deep enough to submerge each specimen fully and is at a temperature of 23 ± 2.0 °C until the test is scheduled.

c) Every prism should be cleaned until it is surface-dry, and any loose sand or incrustations should be removed from the faces that will come into contact with the bearing surfaces of the load application and support points. Examine these faces with a straightedge. Grind the face or faces to planar surfaces if there is noticeable curvature, or throw away the item. The cloths used to wipe 24-hour specimens should only be slightly moist.

d) Position the bearing plate and support edge assembly on the pedestal after centering it on the machine's base plate just below the top spherical head's centre. Fit the spherical head with the center-loading device. Place the specimen on the testing device's supports after turning it so that it is facing the opposite direction from how it was moulded. The specimen's longitudinal centre line must be positioned exactly above the middle of both supports. Make that the bearing edge of the center-point loading device is precisely at right angles to the length of the prism and parallel to its top face as positioned, with the bearing edge's centre exactly above the prism's centre line and at the span length's centre. When applying the load, be sure that there is continuous contact between the specimen and the loading edge. Apply the load at a rate of 2640 6 110 N, which will be shown on a dial graded in increments of no more than 44 N with a precision of 61%. Calculate the maximum load overall to the nearest 22 N.

5.1.4. Scanning Electron Microscope (SEM)

Designation: ASTM C 348

There are no standardized procedures for the SEM analysis of concrete. SEM supplements techniques of light microscopy, which are described in Practice C856/C856M, and, when applicable, techniques described in Practice C856/C856M should be consulted for SEM analysis.

Apparatus:

Scanning Electron Microscope (SEM).

Procedure:

a) An internal sample piece subjected to compression or split tensile testing is selected for examination through Scanning Electron Microscopy (SEM).
b) The surface of the specimen is polished to obtain a smooth surface.
c) The polished surface is then glued to a microscopic slide using epoxy, and the specimen is also impregnated with epoxy.
d) The sample is kept undisturbed at 65°C ‡ 2°C temperature, and the epoxy is allowed to dry.
e) The dried specimens are then cut in such a manner that only a thin layer of aggregate measuring approximately 40 pm is left attached to the microscopic slide.
f) The top surface of the specimen is then ground with silicon carbide abrasive paper to obtain a very thin section of approximately 30 um
g) It is then finally polished using chromium oxide, diamond paste, and alumina powder of Grade 2, respectively.
h) The polished surface is then sputter-coated with a thin film of carbon and tested using the scanning electron microscope.
i) Carbon coating is crucial to prevent the accumulation of static electric charge during SEM analysis

5.2. Durability Properties Testing

5.2.1. Ultrasonic Pulse Velocity Test on Concrete

Designation: ASTM C 597

Direct and semi direct approaches are used.

Apparatus:

a) Electric pulse generator
b) Pair of transducers
c) Standard calibration bar
d) Amplifier
e) Electronic timing device
f) Vaseline

Procedure:

a) The transducer is held in contact with one surface of concrete, and it traverses a known path length Q in the concrete.

b) An electrical signal passed the second transducer held in contact with the other surface of the concrete member.
c) The transit time (T) of the pulse to be measured.
d) The pulse velocity (V) is given by:
e) $V = L / T$
f) Once the path is discovered by the transducer the pulse velocity is transmitted at a right angle to the surface of the concrete to get the best result.
g) It is essential that pulse velocity propagated or transmission by the transducer is detected by receiving transducer. To ensure that they keep sufficient coupling between the concrete and the face of each transducer. Generally, copulates are petroleum jelly, grease, liquid soap, and kaolin glycerol paste.
h) In case, if there is a very rough concrete surface it is essential to smoothen it for placing the transducer.

Fig. 5.2.1. UPV testing.

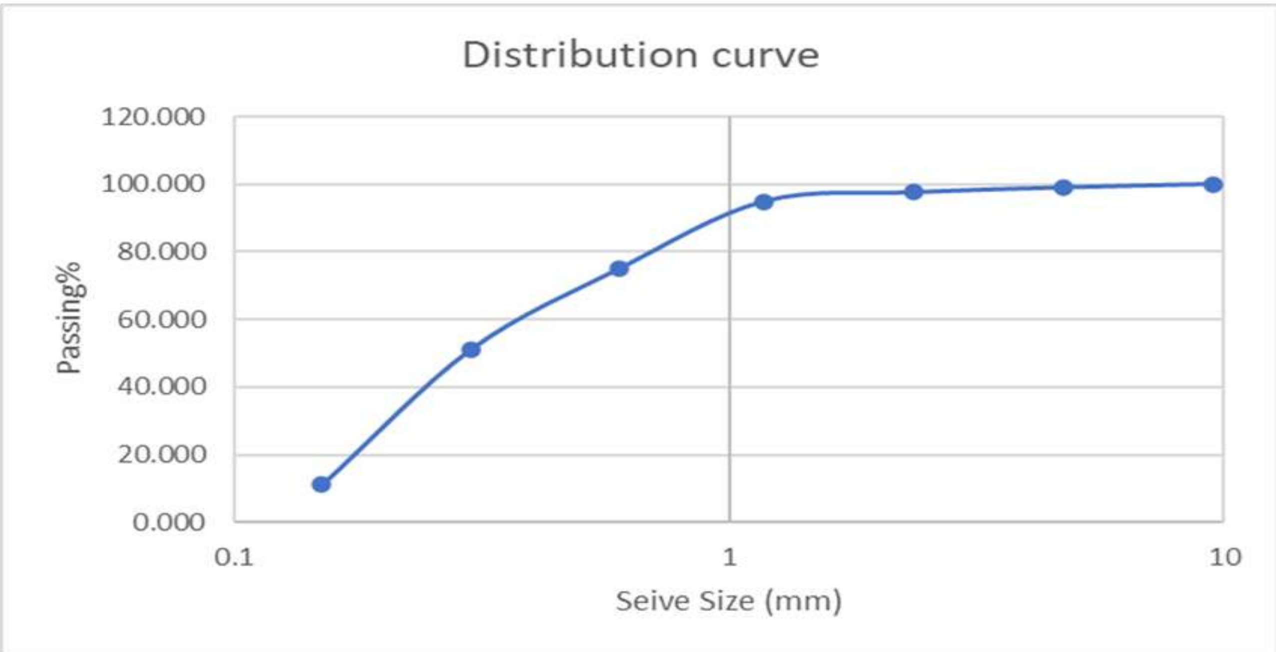
INITIAL RESULTS

INITIAL TESTING RESULTS

1. SEIVE ANALYSIS

Physical test astm c136

ASTM	C136	wt retained (g)	comulative wt retained	%comulative	passing
seive size					
3/8"	9.5	0	0	0.000	100.000
#4	4.75	5	5	1.004	98.996
#8	2.36	7	12	2.410	97.590
#16	1.18	13	25	5.020	94.980
#30	0.6	99	124	24.900	75.100
#50	0.3	119	243	48.795	51.205
#100	0.15	199	442	88.755	11.245
pan		56	498	100	0
		498		170.884	



2. SPECIFIC GRAVITY

Physical test astm c128

A (dry mass)	495
B(water+picnometer)	998
C(water+picno+sand)	1229
SSD	500

Gs A/(B+S-C)	1.840
Gs(SSD) S/(B+S-C)	1.859
W.A 100[(S-A)/A]	1.010%

3. DENSITIES OF SAMPLES BEFORE AND AFTER CURING

BATCH # 1

Densities Before curing

Control sample				
Before curing				
Cylinders	weight (kg)	Diameter (mm)	Height (mm)	Density
Control sample 1	3.462	100	200	2204.042655
Control sample 2	3.459	100	200	2202.132739
Control sample 3	3.432	100	200	2184.943498
Control sample 4	3.452	100	200	2197.676269
Control sample 5	3.484	100	200	2218.048703
Control sample 6	3.46	100	200	2202.769378

CUBES (kg)	weight (kg)	Length (mm)	Width (mm)	Height (mm)	Density(kg/m3)
Control sample 1	0.268	50	50	50	2144
Control sample 2	0.274	50	50	50	2192
Control sample 3	0.281	50	50	50	2248

Densities after curing

To be done after the completion of the curing time.

BATCH # 2

Densities Before curing

10 C R- 0.5-PE				
Before curing				
Cylinders	weight (kg)	Diameter (mm)	Height (mm)	Density (kg/m3)
CJ-1.5(1)	3.198	100	200	2035.970078
CJ-1.5(2)	3.215	100	200	2046.792933
CJ-1.5(3)	3.188	100	200	2029.603693
CJ-1.5(4)	3.252	100	200	2070.34856
CJ-1.5(5)	3.229	100	199	2066.036053
CJ-1.5(6)	3.209	100	200	2042.973102

CUBES (kg)	Weight (kg)	Length (mm)	Width (mm)	Height (mm)	Density(kg/m3)
CJ-1.5(1)	0.241	50	50	50	1928
CJ-1.5(2)	0.245	50	50	50	1960
CJ-1.5(3)	0.252	50	50	50	2016
CJ-1.5(4)	0.242	50	50	50	1936
CJ-1.5(5)	0.248	50	50	50	1984

Densities after curing

10 CR 0.5-PE				
After curing				
Cylinders	weight (kg)	Diameter (mm)	Height (mm)	Density (kg/m3)
CJ-1.5(1)	3.262	100	200	2076.714945
CJ-1.5(2)	3.276	100	200	2085.627885
CJ-1.5(3)	3.349	100	199	2132.102499
CJ-1.5(4)	3.314	100	200	2109.82015
CJ-1.5(5)	3.29	100	199	2094.540824
CJ-1.5(6)	3.268	100	200	2080.534776

CUBES (kg)	Weight (kg)	Length (mm)	Width (mm)	Height (mm)	Density(kg/m3)
CJ-1.5(1)	0.254	50	50	50	2032
CJ-1.5(2)	0.251	50	50	50	2008
CJ-1.5(3)	0.254	50	50	50	2032
CJ-1.5(4)	0.244	50	50	50	1952
CJ-1.5(5)	0.251	50	50	50	2008

BATCH # 3

Densities Before curing

20-CR, 1-PE				
Before curing				
Cylinders	weight (kg)	Diameter (mm)	Height (mm)	Density
20-CR, 1-PE 1	3.17	100	200	2018.144199
20-CR, 1-PE 2	3.243	100	200	2064.618813
20-CR, 1-PE 3	3.214	100	200	2046.156295
20-CR, 1-PE 4	3.167	100	200	2016.234283
20-CR, 1-PE 5	3.163	100	200	2013.687729
20-CR, 1-PE 6	3.16	100	200	2011.777813

CUBES (kg)	Weight (kg)	Length (mm)	Width (mm)	Height (mm)	Density(kg/m3)
20-CR, 1-PE(1)	0.2414	50	50	50	1931.2
20-CR, 1-PE(2)	0.2468	50	50	50	1974.4
20-CR, 1-PE(3)	0.2484	50	50	50	1987.2

Prisim	weight (kg)	Length (mm)	Width (mm)	Height (mm)	Density(kg/m3)
20-CR, 1-PE(1)	0.529	160	40	40	2066.40625
20-CR, 1-PE(2)	0.4943	160	40	40	1930.859375

Densities after curing

To be done after the completion of the curing time.

BATCH # 4

Densities Before curing

30-CR, 0.5-PE				
Before curing				
Cylinders	weight (kg)	Diameter (mm)	Height (mm)	Density
30-CR, 0.5-PE 1	3.024	100	200	1925.194971
30-CR, 0.5-PE 2	3.122	100	200	1987.585548
30-CR, 0.5-PE 3	3.076	100	200	1958.300175
30-CR, 0.5-PE 4	3.113	100	200	1981.855801
30-CR, 0.5-PE 5	3.084	100	200	1963.393283
30-CR, 0.5-PE 6	3.049	100	200	1941.110934

CUBES (kg)	Weight (kg)	Length (mm)	Width (mm)	Height (mm)	Density(kg/m3)
30-CR, 0.5-PE 1	0.232	50	50	50	1856
30-CR, 0.5-PE 2	0.224	50	50	50	1792
30-CR, 0.5-PE 3	0.227	50	50	50	1816

Densities after curing

To be done after the completion of the curing time.

BATCH # 5

Densities before curing

30-CR, 1-PE				
Before curing				
Cylinders	weight (kg)	Diameter (mm)	Height (mm)	Density
30-CR, 1-PE 1	3.151	100	200	2006.048066
30-CR, 1-PE 2	3.219	100	200	2049.339488
30-CR, 1-PE 3	3.123	100	200	1988.222187
30-CR, 1-PE 4	3.143	100	200	2000.954958
30-CR, 1-PE 5	3.146	100	200	2002.864873
30-CR, 1-PE 6	3.186	100	200	2028.330415

CUBES (kg)	weight (kg)	Length (mm)	Width (mm)	Height (mm)	Density(kg/m3)
30-CR, 1-PE 1	0.255	50	50	50	2040
30-CR, 1-PE 2	0.244	50	50	50	1952
30-CR, 1-PE 3	0.227	50	50	50	1816

Prisim	weight (kg)	Length (mm)	Width (mm)	Height (mm)	Density(kg/m3)
30-CR, 1-PE 1	0.509	160	40	40	1988.28125
30-CR, 1-PE 2	0.509	160	40	40	1988.28125

Densities after curing

To be done after the completion of the curing time.

BATCH # 6

Densities before curing

10-CR, 1-PE				
Before curing				
Cylinders	weight (kg)	Diameter (mm)	Height (mm)	Density
10-CR, 1-PE 1		100	200	0
10-CR, 1-PE 2	3.4119	100	200	2172.147064
10-CR, 1-PE 3	3.326	100	200	2117.459812
10-CR, 1-PE 4	3.378	100	200	2150.565017
10-CR, 1-PE 5	3.334	100	200	2122.552921
10-CR, 1-PE 6	3.323	100	200	2115.549897

CUBES	weight (kg)	Length (mm)	Width (mm)	Height (mm)	Density(kg/m3)
10-CR, 1-PE 1	0.2622	50	50	50	2097.6
10-CR, 1-PE 2	0.2635	50	50	50	2108

Densities after curing

To be done after the completion of the curing time.

4. ULTRAASONIC IMPULSE VELOCITY TESTING RESULTS

BATCH # 1

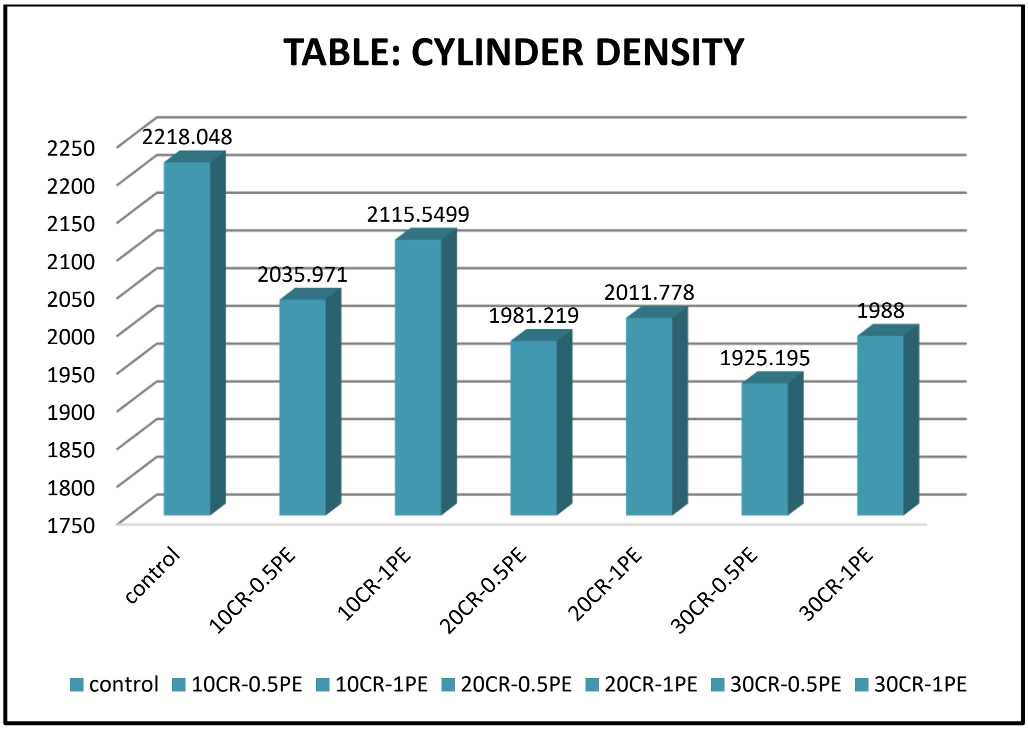
10cr-0.5pe		
direct test		
time (s)	distance(m)	velocity(m/s)
0.0000145	0.0508	3503.448276
semi direct		
time (s)	distance(m)	velocity(m/s)
0.0000064	0.03556	5556.25

BATCH # 2

20cr - 0.5pe		
direct test		
time (s)	distance(m)	velocity(m/s)
0.0000216	0.0508	2351.851852
semi direct		
time (s)	distance(m)	velocity(m/s)
0.0000076	0.03556	4678.947368

COMPARING DENSITY

Cylinders	weight (kg)	Diameter (mm)	Height (mm)	Density (kg/m3)
control	3.484	100	200	2218.05
10CR-0.5PE	3.198	100	200	2035.97
10CR-1PE	3.323	100	200	2115.55
20CR-0.5PE	3.112	100	200	1981.22
20CR-1PE	3.16	100	200	2011.78
30CR-0.5PE	3.024	100	199	1925.2
30CR-1PE	3.123	100	200	1988



FINAL TESING

1. COMPRESSIVE STRENGHT TEST RESULT

1.1. TRAIL BATCH COMPRESSIVE TEST (CYLINDER)

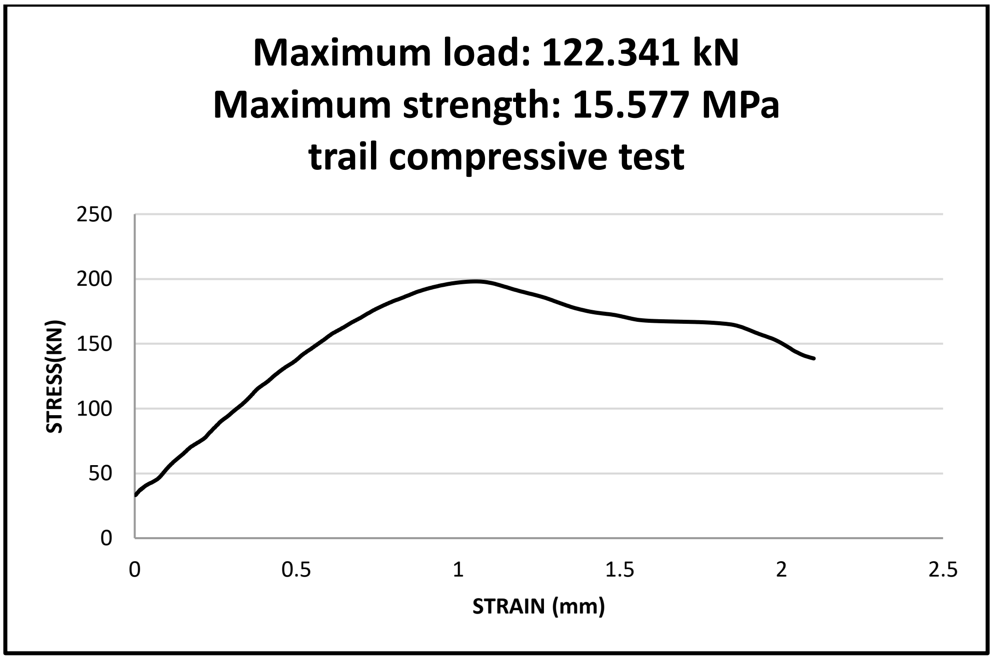


Fig control sample compressive result

1.2. CUBE RUSULT

Batch # 1

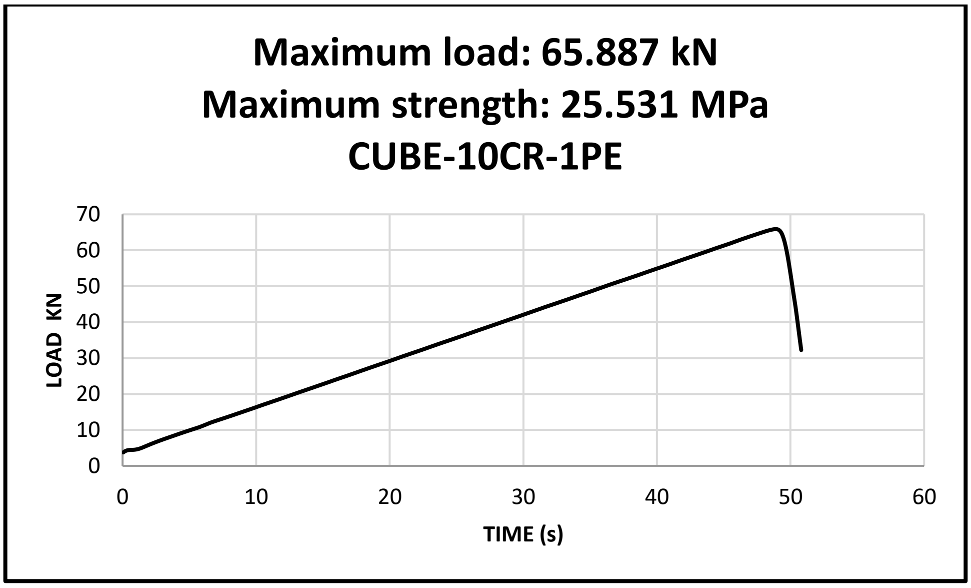


Fig 1.1. Cube 10CR-1PE TEST

Batch # 2

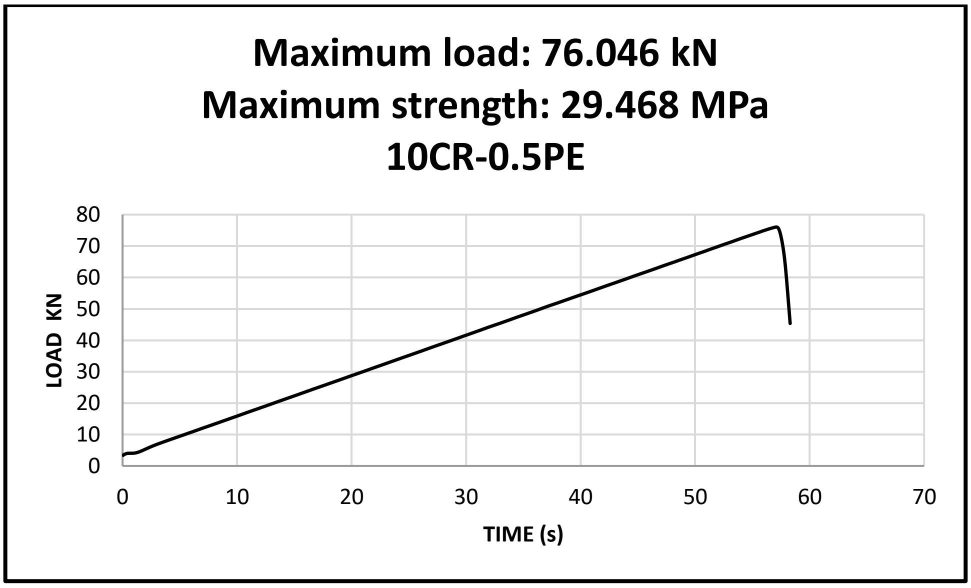


Fig 1.2. Cube 10CR-0.5PE TEST

1.3. CYLINDER RESULT

Batch # 1

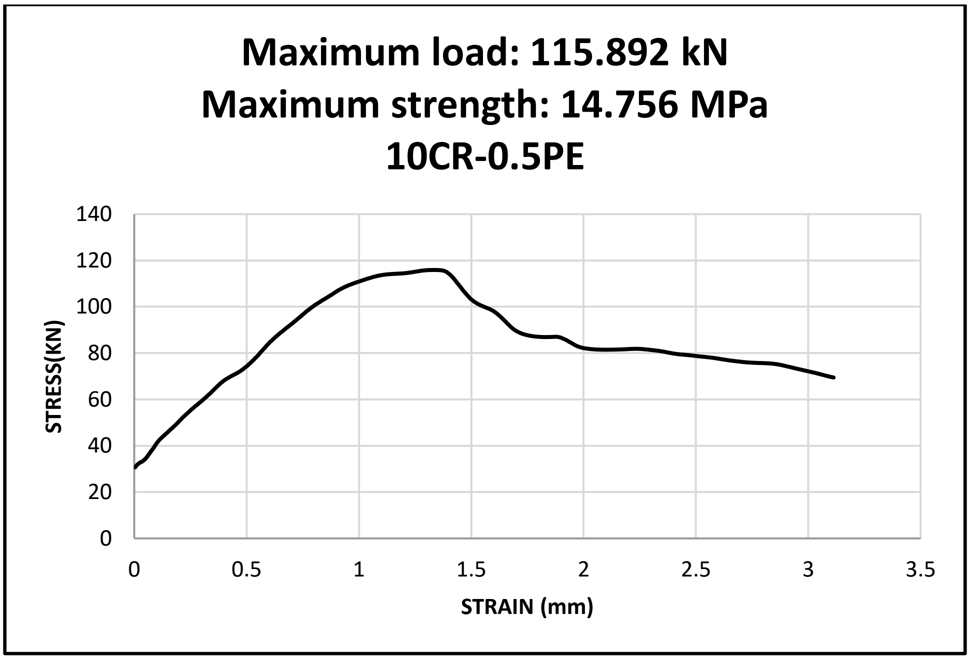


Fig 1.3 10CR-0.5PE

Batch # 2

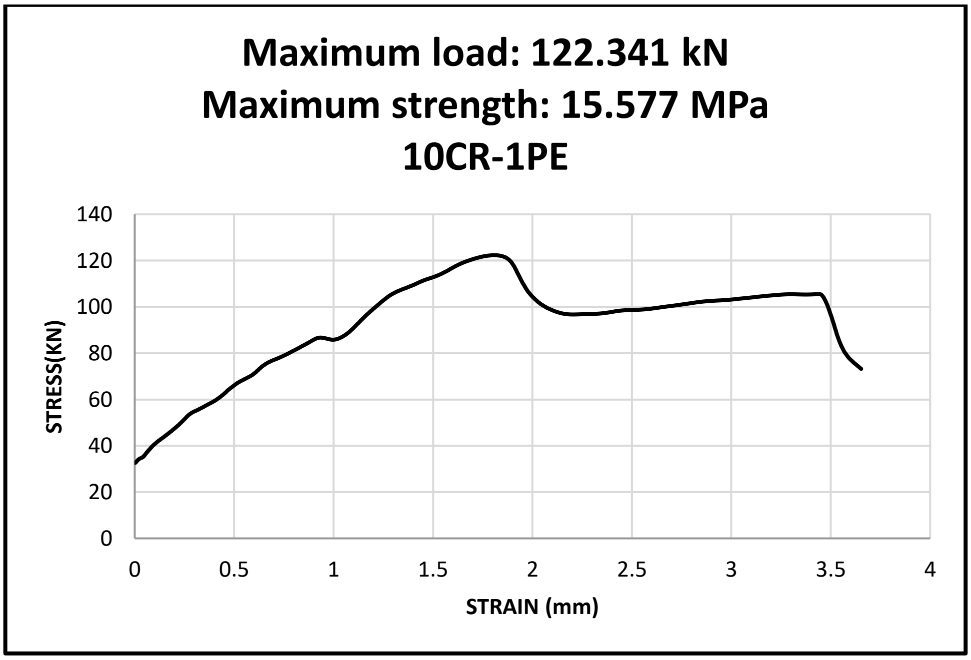


Fig 1.4 10CR-1PE

2. SPLIT TENSILE TEST RESULT

TRAIL BATCH

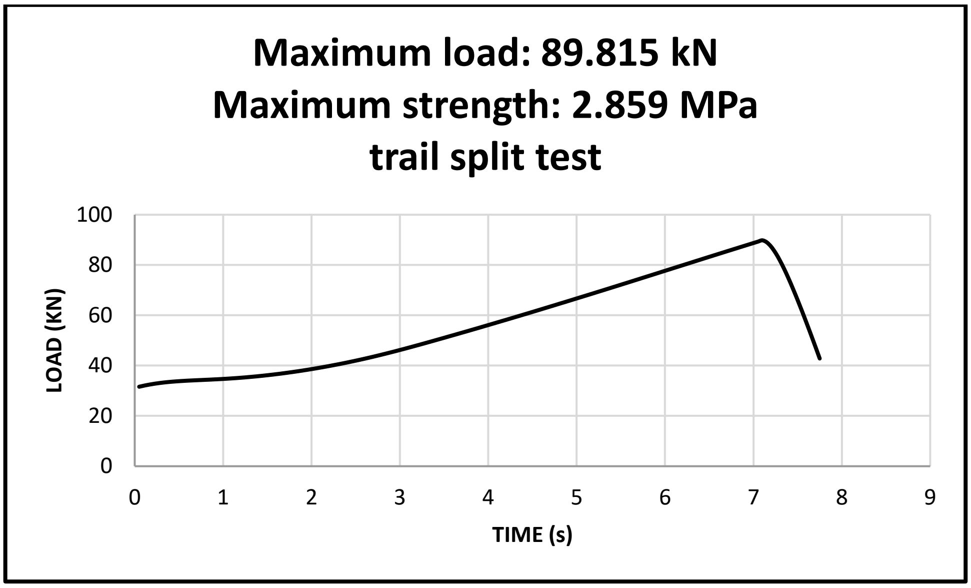
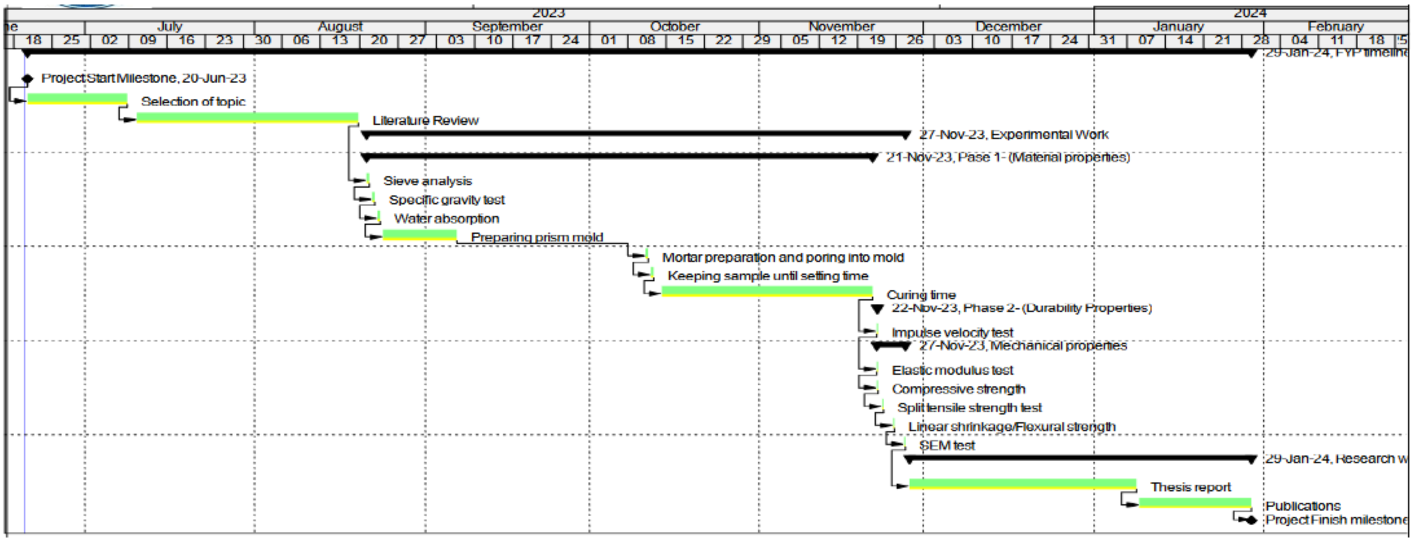
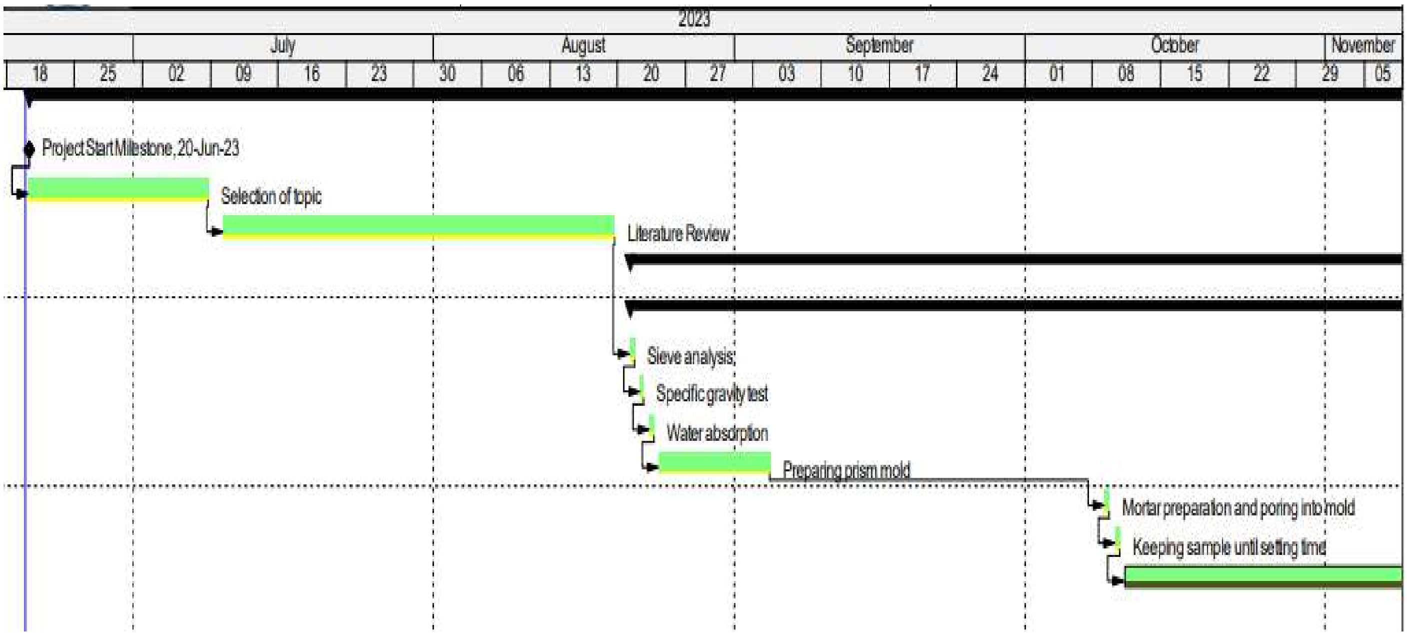


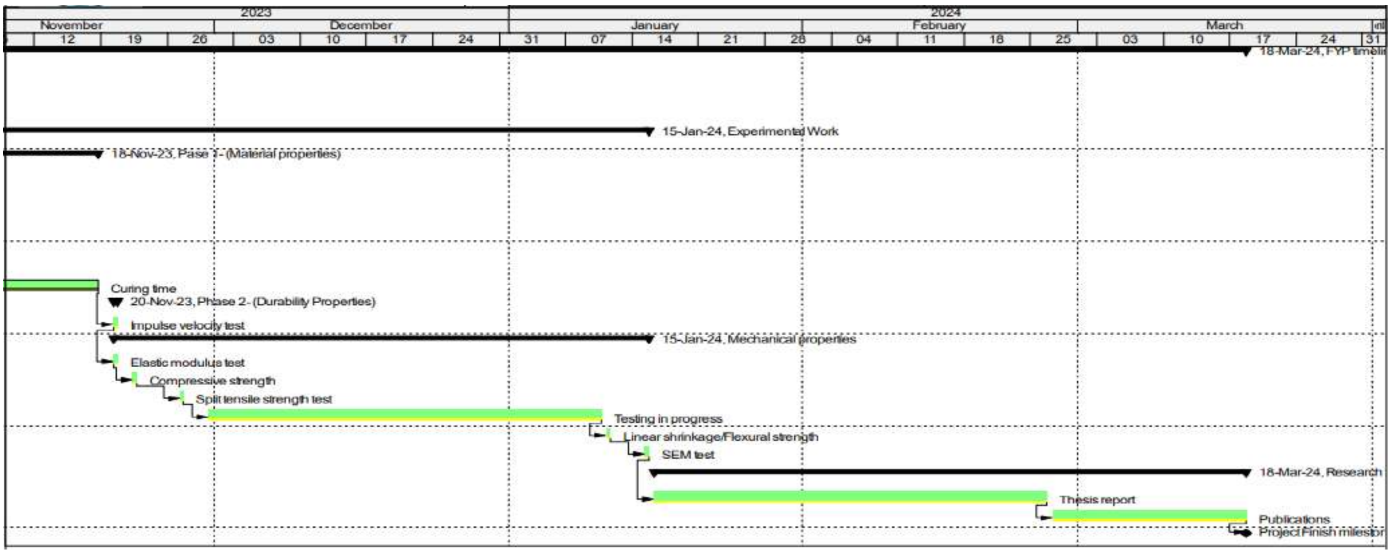
Fig control sample tensile result

PROJECT MILESTONES AND DELIVERABLES (PLANNED)



(INPROGRESS)





WORK DIVISION

Lab Work
Material quantity calculation = Malika Bulideh
Sample preparation = Sohaib Bashir, Mubeen, Ahmadyar Gola, Malika
Sample testing = Sohaib Bashir, Mubeen, Ahmadyar Gola, Malika
Report Work
Abstract = Ahmadyar Gola
Introduction = Ahmadyar Gola
Problem Statement = Malika
Literature = Sohaib, Malika, Mubeen.
Calculation/mix = Malika
Methodology/ Testing = Mubeen/ Ahmadyar Gola
Contribution = Sohaib Bashir
Data analysis = Sohaib Bashir/ Malika/ Mubeen ahmad
Initial Result = Sohaib Bashir
Discussion = Sohaib Bashir/ malika
Conclusion =Mubeen
References = Sohaib Bashir

COSTING

Materials

Sand	500		
Waste rubber	1500		
Cement	1600		
Textile fibre	300	Total Cost	3900

CONCLUSION

The waste products such as rubber replacing the sand and fibres like jute and polyester as reinforcement will be used to achieve the sustainable eco-friendly and durable ECC. As a result, the lightweight concrete will be achieved having more significance in a region prone to earthquakes such as Quetta. Moreover, our FYP addresses crucial challenges in the construction industry by proposing an innovative approach to enhance Engineered Cementitious Composites (ECC). The study focuses on improving ECC's mechanical properties, particularly crack resistance and toughness, by replacing sand with waste rubber powder and reinforcing it with a hybrid combination of jute and polyester fibres. This dual strategy aims to not only enhance the elastic modulus of ECC but also address environmental concerns associated with sand extraction and waste rubber disposal and will also make the concrete lightweighted. The findings underscore the importance of considering both mechanical performance and environmental sustainability in construction material choices. By integrating waste materials and hybrid fibres, the research provides a promising solution for creating resilient and eco-friendly structures, aligning with the global push for sustainable construction practices.

The comprehensive testing procedures outlined in Phase 1 of the project aimed to assess the physical and mechanical properties of the engineered cementitious composites (ECC) containing jute fibre, polyester fibres, and crumb rubber. The initial testing phase included sieve analysis (ASTM C 136–01), density (ASTM C 128 – 07a), relative density (specific gravity), and absorption of fine aggregate, followed by the mixing procedures to prepare the ECC. The casting phase involved the preparation and casting of samples in various molds, such as cylindrical molds, cube, and prism molds, adhering to ASTM standards i.e(ASTM C 348 – 08).

The tests conducted during Phase 1 were crucial in characterizing the constituents of ECC and ensuring that the mix design met ASTM standards. Sieve analysis provided information on particle size distribution, while density and relative density tests ensured the proper proportioning of fine aggregates. The mixing procedures, guided by ASTM C270 and ASTM C94/C94M standards, emphasized the importance of maintaining high-quality standards in the production of ECC. The subsequent casting phase allowed for the formation of test specimens in various molds, setting the stage for the evaluation of mechanical and durability properties in Phase 2.

Moving into Phase 2, the final testing encompassed a series of mechanical and durability tests to assess the performance of ECC. Compressive strength, split tensile strength, and flexural strength tests, conducted according to ASTM standards i.e. (ASTM C 109), (ASTM C-496), (ASTM C 348), Respectively, provided insights into the material's ability to withstand loads and deformations. Additionally, the Scanning Electron Microscope (SEM) analysis (ASTM C 348) offered a microscopic view of the ECC's internal structure. The durability properties were evaluated through the Ultrasonic Pulse Velocity Test (ASTM C 597) on Concrete, providing information on the material's resistance to internal flaws and potential durability concerns. However, the velocities decrease by increasing the percentage of crumb rubber.

Moreover, the densities decrease by the increase in percentages of rubber as the tables of densities show that the average density of Control sample is 2201 kg/m^3 while the other batches have lower densities i.e. 10 CR- 0.5-PE has an average density of 2048 kg/m^3 similarly 20 CR- 1-PE has an average density of 2028 kg/m^3.

Overall, the systematic testing approach outlined in both Phase 1 and Phase 2 of the project ensures a thorough understanding of the ECC's characteristics, performance, and potential areas for improvement. The results obtained from these tests contribute valuable insights for the development and optimization of ECC for various construction applications.

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- https://www.sicerts.com/aci/making-curing-concrete-test-specimens

THE MECHENICAL PROPERTIES OF LIGHT WEIGHT SUSTAINABLE ENGINEERED CEMENTITIOUS COMPOSITE (ECC)

Project/Thesis ID. 2023: 111

Session: BECE. Spring 224

Project Supervisor: Dr. Muhammad Tahir

Submitted By

Muhammad Sohaib Bashir (GL)
Malika Bulideh
Mubeen Ahmad
Muhammad Ahmadyar Gola

Civil Engineering

National University of Sciences and Technology, Baluchistan Campus (NBC)

Certification

This is to certify that **Muhammad Sohaib Bashir**, **343817**, **Malika Bulideh**, **349540, Mubeen Ahmad, 352001** and **Muhammad Ahmadyar Gola, 337406,** have successfully completed the final project **The Mechanical Properties Of Light Weight Sustainable Engineered Cementitious Composite (ECC),** at the **National University of Sciences and Technology, Baluchistan Campus (NBC)**, to fulfill the partial requirement of the degree **Civil Engineering.**

External Examiner

[Name of Examiner]

[Designation]

Project Supervisor

Dr. Muhammad Tahir

Assistant professor

Chairman

Department of Civil Engineering, NBC

Project Title (mention project title here)

Sustainable Development Goals

(Please tick the relevant SDG(s) linked with FYDP)

SDG No	Description of SDG	SDG No	Description of SDG
SDG 1	No Poverty	SDG 9	Industry, Innovation, and Infrastructure ✓
SDG 2	Zero Hunger	SDG 10	Reduced Inequalities
SDG 3	Good Health and Well Being	SDG 11	Sustainable Cities and Communities
SDG 4	Quality Education	SDG 12	Responsible Consumption and Production ✓
SDG 5	Gender Equality	SDG 13	Climate Change ✓
SDG 6	Clean Water and Sanitation	SDG 14	Life Below Water
SDG 7	Affordable and Clean Energy	SDG 15	Life on Land
SDG 8	Decent Work and Economic Growth	SDG 16	Peace, Justice and Strong Institutions
		SDG 17	Partnerships for the Goals

Range of Complex Problem Solving			
	Attribute	**Complex Problem**	
1	Range of conflicting requirements	Involve wide-ranging or conflicting technical, engineering and other issues.	✓
2	Depth of analysis required	Have no obvious solution and require abstract thinking, originality in analysis to formulate suitable models.	✓
3	Depth of knowledge required	Requires research-based knowledge much of which is at, or informed by, the forefront of the professional discipline and which allows a fundamentals-based, first principles analytical approach.	✓
4	Familiarity of issues	Involve infrequently encountered issues	
5	Extent of applicable codes	Are outside problems encompassed by standards and codes of practice for professional engineering.	✓
6	Extent of stakeholder involvement and level of conflicting requirements	Involve diverse groups of stakeholders with widely varying needs.	
7	Consequences	Have significant consequences in a range of contexts.	✓
8	Interdependence	Are high level problems including many component parts or sub-problems	✓
Range of Complex Problem Activities			
	Attribute	**Complex Activities**	
1	Range of resources	Involve the use of diverse resources (and for this purpose, resources include people, money, equipment, materials, information and technologies).	✓
2	Level of interaction	Require resolution of significant problems arising from interactions between wide ranging and conflicting technical, engineering or other issues.	
3	Innovation	Involve creative use of engineering principles and research-based knowledge in novel ways.	✓
4	Consequences to society and the environment	Have significant consequences in a range of contexts, characterized by difficulty of prediction and mitigation.	
5	Familiarity	Can extend beyond previous experiences by applying principles-based approaches.	✓

Abstract

Engineered Cementitious Composites (ECC) had been widely acclaimed in the construction industry for their exceptional attributes, including high strength, remarkable ductility, and low permeability, setting them apart from conventional concrete. However, the extensive utilization of natural sand in ECC production has raised concerns about the depletion of this finite resource. On the other hand, the expanding issue of waste rubber disposal posed a significant environmental challenge. Incorporating waste rubber into ECC could address this concern but often came at the cost of reduced material strength.

In that research endeavor, a novel approach was proposed to enhance ECC sustainability and maintain its structural integrity. The conventional sand component of ECC was replaced with waste rubber powder by 10%, 20%, and 30%, while textile waste fibers dosage of 2% was introduced to enhance its mechanical properties. Comprehensive testing, encompassing measurements of compressive, splitting tensile, and flexural strengths, as well as SEM, was conducted using varying percentages of waste rubber and textile fibers.

Through this innovative methodology, the development of a new ECC variant that not only aligned with the strength characteristics of traditional ECC but also contributed to sustainable construction practices by mitigating sand resource depletion and recycling waste rubber materials was anticipated.

Keywords: structural integrity, waste rubber powder, textile waste fibers, varying percentages, sustainable construction, resource depletion.

Undertaking

I certify that the project **The Mechanical Properties Of Light Weight Sustainable Engineered Cementitious Composite (ECC)** is our own work. The work has not, in whole or in part, been presented elsewhere for assessment. Where material has been used from other sources it has been properly acknowledged/ referred.

Muhammad Sohaib Bashir

343817

Malika Bulideh

349540

Mubeen Ahmad

352001

Muhammad Ahmadyar Gola

337406

Acknowledgement

We truly acknowledge the cooperation and help make by **Dr. Muhammad Tahir, Designation** of **Assistant Professor.** He has been a constant source of guidance throughout the course of this project. We would also like to thank **Mr. Taimoor Shahzad,** Lecturer from **Department Civil Engineering** for his help and guidance throughout this project.

We are also thankful to our friends and families whose silent support led us to complete our project.

Table of Contents

List of Tables

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List of Acronyms

AWS	Amazon Web Services
S3	Simple Storage System
GCP	Google Cloud Platform

List of Equations

Chapter 1

1.1 Introduction

The excellent mechanical properties and durability of Engineered Cementitious Composites (ECC) are well known. However, it is prone to cracking, which can seriously affect the safety and life of structures. Solutions to enhance crack resistance and toughness have been explored by engineering experts, and more new materials are being utilized in ECC to achieve this. (Cheng et al., 2023)

The type of fibre used in ECC really matters. Whether we're building something new or fixing up existing structures, the spot where the fibre meets the concrete is crucial. If this part isn't strong, it can cause problems for the whole structure. Making sure the fibre sticks well to the concrete is a must for safety, practicality, and how long the structure lasts.

Fibre makes the cement tougher and helps it stick better to the interface. They do this by reducing how much the cement shrinks. Especially when the outer layer is thin, fibres help stop the interface from cracking because of this shrinkage. When the structure gets stressed, the fibres also prevent tiny cracks from forming in the cement. This is a big deal as it reduces stress around the main crack, making the structure last longer and changing how it deals with damage. (Zhang et al., 2023)

Climate change is being seriously impacted by the extensive use of natural sand. Ways to produce concrete without harming the environment are being sought after by many researchers. Fibre reinforced concrete is being increasingly used for various purposes. Consideration is now being given to using waste plastic in concrete to dispose of plastic waste and aid the environment simultaneously. The amount of sand required in concrete can be reduced, and the natural resource footprint in the construction industry can be minimized by utilizing waste materials like waste rubber and plastic. (Nkomo et al., 2022)

1.2 Statement of the problem

Engineering cementitious composite (ECC) is widely being used in construction industry, because of its strain capacity (usually >3%) which is greater than that of conventional concrete, and according to micromechanical design theory ECC is an ultrahigh toughness cementitious composite material. (Feng et al., 2022)

In construction industry manmade fibres are being incorporated in ECC. Nowadays, polyester (PET) has rapidly increased its production capacity in the textile industry, resulting in a greater production of waste fibres, with an annual output of 22.67 billion tons. The characteristic of PET is that it has a tensile strength of 5%, but the elongation decreases as it is loaded (Kartikeya Sharma et al., 2020).

ECC uses 50% of natural sand. The annual average extraction of river sand worldwide ranges from 10,000m^3/year to 230 million m^3/year. Environmental impact of excessive excavation of natural sand from riverbeds leads to destabilization of channels, lowering of riverbeds, and a decrease in the water table in nearby regions, thereby threatening the availability of water for local people, agriculture, and other activities. (Srivastava & Singh, 2020)

All over the world, millions of tires are discarded or buried every year, posing a serious threat to the ecology. Around 1000 million tires reach the end of their service life each year and 50% of the tires are being sent to landfills or disposed of as garbage. On the regular basis this continues, there will be 5000 million discarded tires by the year of 2030 (Thomas & Gupta, 2016).

Moreover, From the previous research, it is observed that the elastic modulus of ECC is relatively lower than that of conventional concrete, ranging from 30% to 50% due to the absence of course aggregate. Since the two critical factors are compressive strength and modulus of ECC, both of which should be improved simultaneously while retaining proper ductility. (Liu et al., 2023). Therefore, in this research, the sand will be replaced with rubber powder, and the ECC will be reinforced with a hybrid fibre that will address issues such as the depletion of natural resources, the disposal of waste tire rubber, and the lower elastic modulus of ECC.

1.3 Goals/Aims & Objectives

The development of a new ECC variant that not only aligns with the strength characteristics of traditional ECC but also contributes to sustainable construction practices by mitigating sand resource depletion and recycling waste rubber materials is anticipated.

1.4 Motivation

1.5 Assumption and Dependencies

In this innovative research initiative, we aim to revolutionize construction practices by developing a sustainable variant of Engineered Cementitious Composite (ECC). By strategically replacing sand with recycled rubber powder and incorporating a novel hybrid fibre, our project addresses critical challenges such as sand resource depletion and waste tire management. Our comprehensive approach seeks to not only enhance the elastic modulus and compressive strength of ECC but also contribute to the circular economy by repurposing waste materials. Throughout the process, we will conduct a thorough literature review, characterize materials, design optimal ECC mixes, and rigorously test and evaluate mechanical and durability properties. Stakeholders and potential customers, including construction industries, manufacturers, and environmental regulatory bodies, are integral to the success of this initiative. By disseminating our findings through conferences, journals, and direct engagements, we aim to facilitate the widespread adoption of this sustainable ECC variant, ushering in a new era of environmentally conscious construction practices.

Our research on the sustainable variant of Engineered Cementitious Composite (ECC) involves key stakeholders critical to its success. Construction industries stand to gain a unique opportunity by adopting our eco-friendly ECC, aligning with corporate social responsibility and sustainable building practices. Manufacturers in the construction materials sector are positioned to benefit from the potential market demand for the novel hybrid fibres and recycled rubber powder integral to our ECC development, fostering a more sustainable supply chain. Collaboration with environmental regulatory bodies ensures that our ECC variant meets stringent standards, encouraging widespread acceptance and adherence to sustainable construction practices. Meanwhile, potential customers, including infrastructure developers engaged in large-scale projects, architects and designers seeking green building solutions, and government agencies responsible for construction initiatives, can leverage our ECC variant to achieve sustainability goals, reduce environmental impact, and set a precedent for sustainable infrastructure development. Throughout this process, collaboration and engagement with these stakeholders are integral to ensuring the successful adoption and implementation of our sustainable ECC variant on a broader scale. By disseminating our findings through conferences, journals, and direct engagements, we aim to facilitate the widespread adoption of this eco-friendly ECC, ushering in a new era of environmentally conscious construction practices.

1.6 Methods

1.7 Report Overview

Chapter 2

2.1 Heading

Headings and subheadings provide structure to a document. They signal what each section is about and allow for easy navigation of the document. Use a hierarchical structure for headings and sub headings.

Figure 1: Computer System

1. **2.1.1 Heading**

2. **2.1.2 Heading**

Chapter 3

3.1 Heading

3. 3.1.1 Mathematical Equation

$$(1+x)^n = 1 + \frac{nx}{1!} + \frac{n(n-1)x^2}{2!} + \cdots$$

Equation 1: Expansion of sum

4. 3.1.2 Heading

Figure 2: Computer System

Chapter 4

2. 4.1 Proposed Solution/Results & Discussion

Your proposed solution should relate the current situation to a desired result and describe the benefits that will accrue when the desired result is achieved. So, begin your proposed solution by briefly describing this desired result.

Activity	Optimistic (a)	Most Likely (m)	Pessimistic (b)	Expected (Te)
A	21	23	25	23
B	0.5	1	1.5	1
B	0.5	1	1.5	1

Table 1: PERT Activity Time estimate table

Chapter 5

3. 6.1 Summary and Future work

A summary of a thesis/project is like an abstract of a research paper. Basically, the purpose of the summary is to give the reader an overview of the main points of your thesis/project. Generally, the summary is about 200-350 words. The summary should include the following points:

1. What is the thesis about?
2. What is the purpose of the project/thesis?
3. What were the methods used to research the information?
4. What are the results, conclusions, and recommendations that the thesis presents?

The future work section is a place for you to explain to your readers where you think the results can lead you. What do you think are the next steps to take? What other questions do your results raise? Do you think certain paths seem to be more promising than others?

Chapter 6

7.1 Conclusion & Recommendation

The waste products such as rubber replacing the sand and fibres like jute and polyester as reinforcement will be used to achieve the sustainable eco-friendly and durable ECC. As a result, the lightweight concrete will be achieved having more significance in a region prone to earthquakes such as Quetta. Moreover, our FYP addresses crucial challenges in the construction industry by proposing an innovative approach to enhance Engineered Cementitious Composites (ECC). The study focuses on improving ECC's mechanical properties, particularly crack resistance and toughness, by replacing sand with waste rubber powder and reinforcing it with a hybrid combination of jute and polyester fibres. This dual strategy aims to not only enhance the elastic modulus of ECC but also address environmental concerns associated with sand extraction and waste rubber disposal and will also make the concrete lightweighted. The findings underscore the importance of considering both mechanical performance and environmental sustainability in construction material choices. By integrating waste materials and hybrid fibres, the research provides a promising solution for creating resilient and eco-friendly structures, aligning with the global push for sustainable construction practices.

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Moreover, the densities decrease by the increase in percentages of rubber as the tables of densities show that the average density of Control sample is 2201 kg/m^3 while the other batches have lower densities i.e. 10 CR- 0.5-PE has an average density of 2048 kg/m^3 similarly 20 CR- 1-PE has an average density of 2028 kg/m^3.

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References

References are to be placed in square brackets and interlaced in the text. For example, "A comprehensive detail of how to prevent accidents and losses caused by technology can be found in the literature [1]. A project report / thesis cannot be accepted without proper references. The references shall be quoted in the following format:

The articles from journals, books, and magazines are written as:

[1] Abe, M., S. Nakamura, K. Shikano, and H. Kuwabara. Voice conversion through vector quantization. Journal of the Acoustical Society of Japan, April 1990, E-11 pp 71-76.

[2] Hermansky, H. Perceptual linear predictive (PLP) analysis for speech. Journal of the Acoustical Society of America, January 1990, pp 1738-1752.

The books are written as:

[1] Nancy G. Leveson, Safeware System Safety and Computers, A guide to preventing accidents and losses caused by technology, Addison-Wesley Publishing Company, Inc. America, 1995.

[2] Richard R. Brooks, S. S. Iyengar, Multi-Sensor FusionFundamentals and Applications with Software, The Prentice-Hall Inc. London, 1998.

The Internet links shall be complete URLs to the final article.

[1] http://www.pu.edu.pk/ucit/projects/seminars.html

Annexure

Annexure (if any) should be placed at the end of the project report.

General Guidelines for Writing Project's Thesis

For convenient upload on PEC's e-Library

Page Setup

Page Size:	A4
Top margin:	1.00 inch or 2.54 cm
Bottom margin:	1.00 inch or 2.54 cm
Left margin:	1.00 inch or 2.54 cm
Right margin:	1.00 inch or 2.54 cm

Fonts and Styles:

Use a standard font such as Times New Roman, Arial, or Calibri

Font size should be 12 points for the main text.

Use consistent font sizes and styles (bold, italics) for headings, subheadings, and content.

Footer: Each page shall have a footnote "Page number, right align".

Header: Each page shall have a header "Project/Thesis Title".

Chapter Startup: Each chapter shall be numbered as Chapter 1, Chapter 2, etc.

Paragraph Formatting:

Single-spaced, Line entered paragraph, left align or justified.

Line Spacing:

1.5 spacing is required for the text. Only footnotes, long quotations, bibliography entries (double space between entries), table captions, and similar special material may be single spaced.

Maintain consistent spacing between paragraphs

Images, Figures, Hyperlink:

Ensure that images, figures, and hyperlink are of high quality and are properly labeled.

Tables and Equations:

Format tables with clear column and row headings.

Provide captions for each Table.

Label equations and provide clear explanations.

Citations and References:

Follow a standardized citation style (e.g., APA, MLA, PEC etc.) for references.

Include a separate references section at the end of the document.

File Naming Convention:

Submitted files are named with a clear and concise title that reflects the content of the paper or thesis.