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A Comparative Evaluation of Plain, Polypropylene Fiber, and Jute Fiber Reinforced Shotcrete

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***Abstract:** This study intends to establish the mechanical properties of plain , jute & polypropylene fiber reinforced shotcrete (PFRS) in terms of compressive, energy and flexural strengths, in accordance with IS-516/EN-14488/ ASTMC1609/C1609M-12. The mechanical properties identified the influence of polypropylene fiber content on the PFRS strength. In addition, the fiber rebounding rate and PFRS performance in tunneling application were evaluated based on a tunnel application in Indian Railway. Therefore, PFRS applied to a tunnel exhibited stability and constructability.*

I. INTRODUCTION

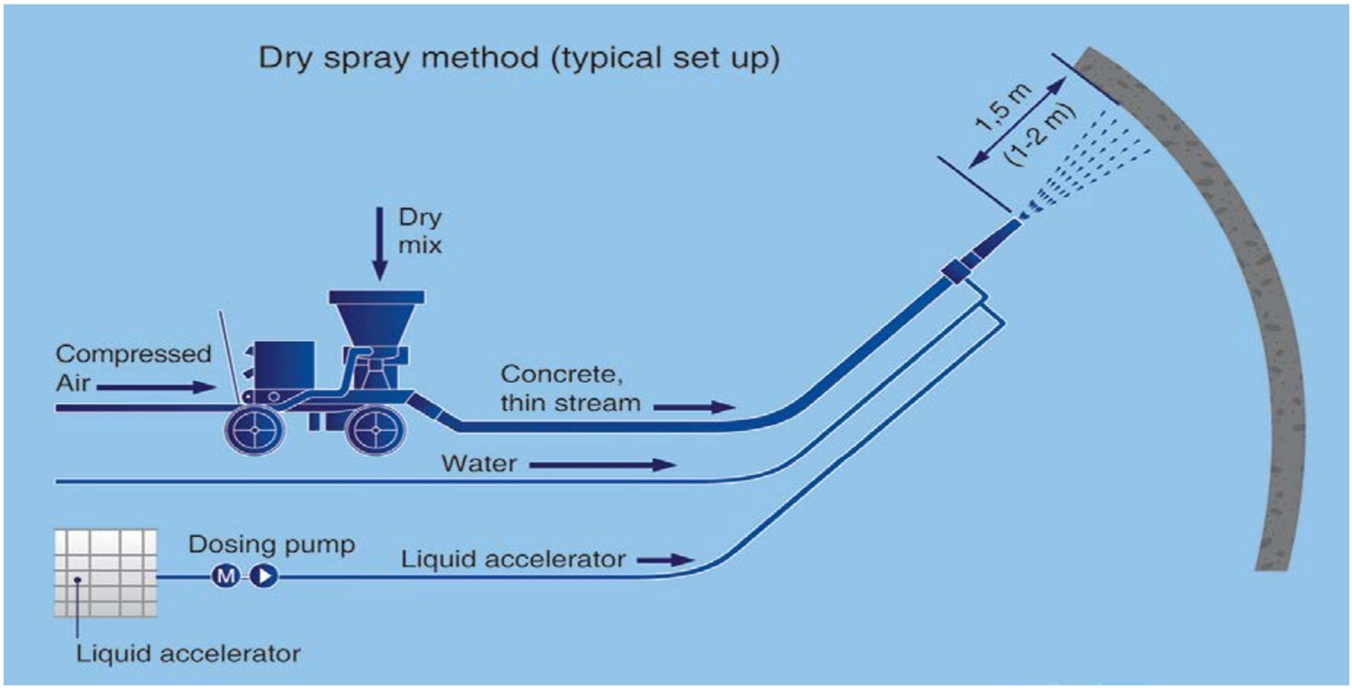
In modern era all over the world and also in India many construction projects are going on to develop infrastructure. Now a days everyone looks such type of technique or material which is not adversely affect the environment & same time not delaying the construction progress . Here we also evaluate such type of material which is not only ecofriendly but also enhance engineering properties of concrete/shotcrete mix. Shotcreting is a method by which we establish the slope or underground excavation quickly and it gives better support to ground as early as we apply.

A. Methods Of Shotcreting

Shotcrete is a construction technique where concrete or mortar is sprayed through a hose and projected at high velocity onto a surface using compressed air.

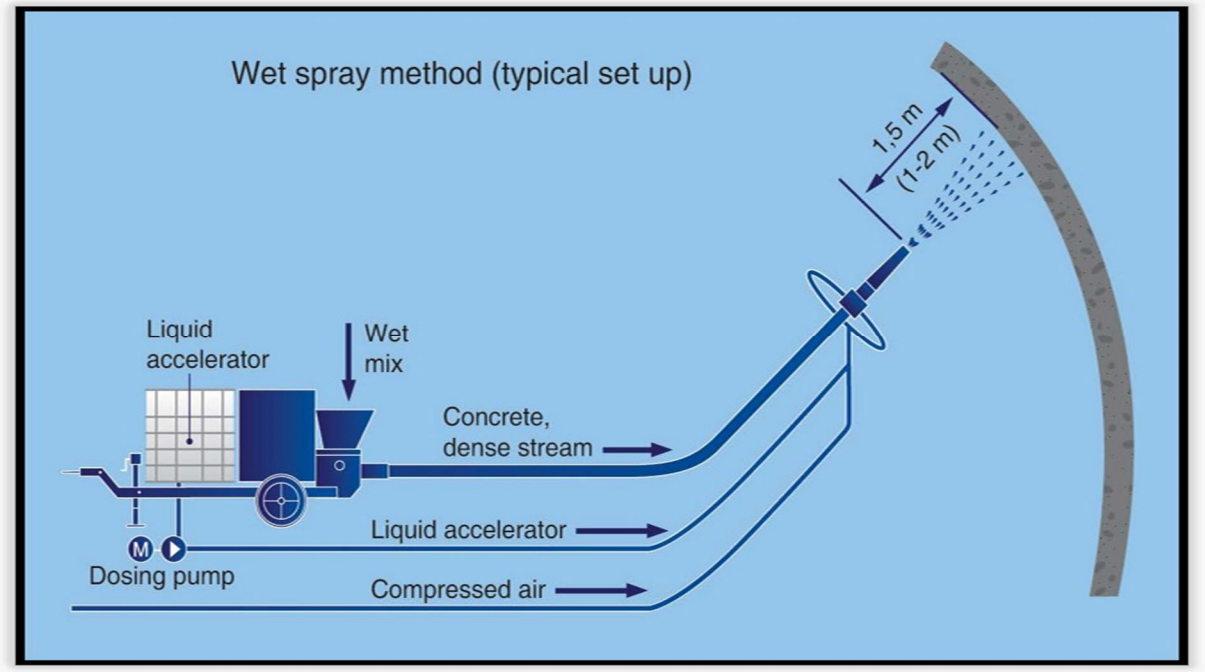
The Two Main Methods

1) Dry-Mix Method (Gunite): Dry cement and aggregates are mixed, fed into a machine, and pushed by air through a hose. Water is added under pressure right at the nozzle by the operator just before it hits the wall. It offers high flexibility for repairs.



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2) Wet-Mix Method: All ingredients, including water and admixtures, are completely mixed beforehand like regular concrete. It is pumped through a hose, and compressed air is added only at the nozzle to blast it onto the target. It creates uniform quality with less dust and waste



B. Objective

Major objective of this analysis is introducing natural fiber (jute fiber) in spraying concrete i.e. “shotcrete” and verifying its quality & mechanical properties with general fiber (polypropylene) or without fiber shotcrete. here we are using wet shotcrete method because of its better quality control and smooth spraying operation. In our case we are introducing jute fiber for enhancing the tensile property and bonding ability of shotcrete, so for adding jute fiber during wet mixing is more suitable as compared to dry mix method. When material in dry state ,jute fiber distribute evenly on whole mix then adding water and again mixing mechanically .Due to such process we get a homogeneous shotcrete mix. It is also our objective to produce this mix at very low cost, which satisfies

- Essential for future construction methodology
- Use of natural product gives solution over petroleum product (Polypropelene)
- Cost effective
- Environmental friendly
- Reducing rebound loss because of its better bonding ability.
- Easy to handle & feeding due to its lightweight from steel and other fiber.
- Saving of fuel consumption as compare to synthetic fiber production industry.
- Reduce wear & tear cost of equipments which are use in production & spraying of Jute fiber shotcrete,
- Increase rupture of modulus i.e flexural strength of mix.
- Enhance Energy absorption ability as compare to without fiber shotcrete.

II. LITERATURE REVIEW

Wire mesh, poly fibers, and steel fibers are all effective methods for slope stabilization, often used in conjunction with shotcrete or soil-mixing techniques to improve soil properties and prevent erosion. A review of the literature shows that while wire mesh provides a traditional and robust solution, dispersed fibers offer several advantages, including reduced labour and material costs, better crack resistance, and enhanced ductility in the soil matrix.

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1) KyongKu Yun [a], Mohammad Shakhawat Hossain [a], Seungyeon Han [b], Choi Seunghak [a]

Rheological, mechanical properties, and statistical significance analysis of shotcrete with various natural fibers and mixing ratios

The yield stress is determined by each physical characteristic of natural fiber incorporating with concrete, according to the length and weight of the natural fiber. Based on the type of natural fiber used, the amount of mixed water absorbed by the specimen differs significantly, and the adhesion of the fibers to the concrete differs as well.

- According to previous studies, natural fibers can effectively reduce cracks, but have a negligible effect on compressive strength.
- although natural fibers are less effective than steel fibers, which significantly enhance flexural strength, they improve flexural strength to some extent.

In natural fiber-reinforced concrete, the natural fibers act as a "tunnel" through which ionized chloride ions can travel. Consequently, all the specimens exhibited a high grade of chloride ion penetration. However, based on existing research, the chloride penetration can be reduced from a 'high' grade to a 'low' grade by adding pozzolanic materials to the natural fiber-reinforced concrete. Therefore, natural fiber-reinforced concrete has poor chloride resistance, which can be improved by adding pozzolanic materials.

2) Mohammad Mohsin[1], Tamim Ahmed[2], Rehnuma Raheem[3], Emad Ahmed[4]

JUTE FIBER OPTIMIZATION FOR ENHANCING CONCRETE PROPERTIES: A REVIEW (7th International Conference on Advances in Civil Engineering (ICACE))

12-14 December 2024, CUET, Chattogram, Bangladesh

This study conducted an in-depth analysis to maximize the overall performance of concrete by optimizing JTF length and content. The behavior of concrete is influenced by several crucial elements. Some of the most important factors affecting the behavior of concrete are as follows:1. When JTF content increases, the slump value of concrete decreases, which means the concrete requires a greater amount of water. Water-reducing admixtures are suggested, especially when working with high fiber content.

2. The optimal fiber length was found to be in the range of 10-20 mm. For 10 mm fibers, a replacement level of approximately 0.45% showed the best overall result. For 20 mm fibers, a 0.3% replacement was optimal. Fiber content between 0.3% and 0.45% provided the best performance in terms of compressive and tensile strengths.

3. The JTF considerably improved the concrete's split tensile strength. The incorporation of 0.5% JTF resulted in the greatest increase in split tensile strength.

3) Tarikul Islam, Faruk Patowary, Debasish Sen, Sharmin Reza Chowdhury*

Effect of Jute Fiber Content on Compressive and Split Tensile Strength of Concrete Utilizing Stone Chips as Coarse Aggregates

The optimal content of jute fibers is crucial for achieving a balance between enhancing mechanical properties and maintaining workability in concrete. The study underscores the importance of carefully determining fiber content in concrete mixtures to attain desired performance characteristics. Based on the experimental analysis, the following findings can be addressed.

•The introduction of jute fibers led to a noticeable reduction in workability, evident in decreased slump values (i.e., 31 ~ 70% reduction with 0.1~1.2% JF content). This decline is attributed to challenges in achieving uniform fiber distribution due to agglomeration and water absorption, a characteristic of the hydrophilic nature of jute fiber. As workability decreased, difficulties arose in ensuring proper fiber dispersion and concrete compaction, aligning with findings from previous studies.

•The compressive strength of concrete exhibited an increase with an increase in jute fiber content up to an optimal level of 0.4%, resulting in a remarkable strength increment compared to control concrete. The fibers played a role in bridging micropores and filling voids. However, beyond this optimal percentage, compressive strength experienced a decline, reaching a lower level at a 1.2% fiber addition. This decrease beyond the optimum was attributed to higher porosity resulting from poor compaction, decreased workability, and fiber aggregation, consistent with observations in previous studies on fiber-reinforced concrete.

•The inclusion of jute fibers demonstrated an enhancement in splitting tensile strength up to 0.4% fiber content. Incremental additions of 0.4% and 0.8% jute fiber- resulted in remarkable increases, whereas a 1.2% addition led to a comparatively smaller increase. The improved splitting tensile strength is linked to the suppressed brittle behavior in concrete and the prevention of microcrack spreading through physical and chemical connections between jute fibers and the matrix. Conversely, higher fiber percentages caused issues such as a balling effect, fiber aggregation, and improper bonding, contributing to reduced splitting tensile strength.

4) Pramodini Sahu, Chhabirani Tudu Effect of Jute Fibre Orientation and Percentage on Strength of Jute Fibre Reinforced Concrete

From this analysis, compression test results of cubes and cylinders, it is seen that with jute fibre the compressive strength value more or less changed with respect to plane cement concrete. With addition of jute fibre modulus of rapture (MR) value is increased. In case of beam with addition of 0.25% continuous jute fibre the MR value enhanced by 15% and in slab with addition of 0.25% continuous fibre the MR value is enhanced by 49% than plane cement concrete. It is clearly seen that addition of jute fibre enhances the flexural strength and hence the tensile strength. So this jute fibre reinforced concrete can be used as partition walls, door and window panels, inclined roofs etc.

From the above analysis it is found that the modulus of rapture is lower at 0.15% and 0.35% of jute fibre. So the value is maximum when the percentage of jute fibre is in between 0.15% and 0.35%. to know the accurate percentage of jute fibre experiments can be conducted in future for lesser fraction values of fibre. More keen analysis is required to know better application of jute as fibre for other works, behavior of fibres, durability, chemical affinity etc. Analysis can be carried out with respect to different aspect ratio of fibres.

III. MATERIALS TO BE USED

5) Jute Fiber

Natural fibers (plant based , mineral based , animal based) .
For our study we use natural fibers (jute)
which are mainly plant based fiber **.**
These fibers are reusable, abundant, and
less expensive than synthetic fibers,
making them ideal for the production of
environmentally friendly concrete that meets
the growing need for sustainable construction.
Fiber Length – 50mm



6) Polypropylene (synthetic) fibers

Polypropylene (PP) fiber is a
widely used synthetic additive
that significantly improves the performance,
durability, and safety of sprayed concrete (shotcrete).
It is heavily utilized in tunnel linings, mining,
and slope stabilization.
Fiber Length – 55mm



7) Cement

Generally ordinary Portland cement is used for shotcrete purpose to achieve early strength of shotcrete. The grade of the cement is OPC-53 , confirming as per IS 269 2015 . At site we received cement in 2 different ways 1st is cement bulker that is loose cement store in silos at site and 2nd is packed cement bags of 50kg .



8) Aggregates (10mm)

Particles larger than 4.75 mm,
usually crushed stone or gravel.
They give structures their compressive strength and bulk.



9) Sand (natural sand)

Particles smaller than 4.75 mm, typically natural or manufactured sand.
They fill voids and provide workability to mixtures. For these shotcreting purpose we are using natural sand (narmada river) for smooth spraying operation.

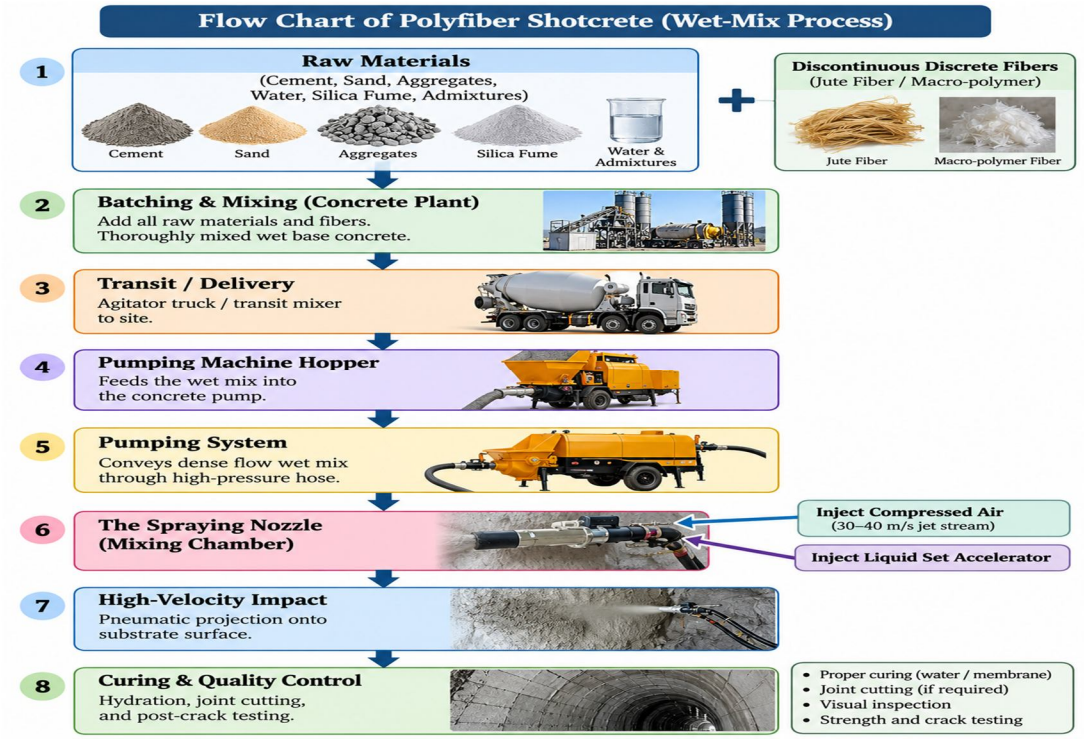


10) Accelerator / Admixture :-

Chemical accelerator (or accelerating admixture) is added to concrete mortar, to
shorten the setting time and increase the initial rate of early strength development



IV. METHODOLOGIES TO BE ADOPTED



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1) Methodology for Polypropylene Fiber in Tunnels

Step1: Mix Design Trials

- Conduct trial mixes to determine optimum fiber dosage for target workability & strength.
- Ensure uniform dispersion (avoid balling).

Step 2: Mixing Process

- Fibers added slowly into the mixer with cement and aggregates to ensure uniform distribution while mixing in batching plant .
- For transportation from batching plant to site used transit mixer .
- Use admixture to maintain workability.



Step 3: Application in Tunnels

- For Shotcrete: Fibers mixed with wet-mix shotcrete, pumped and sprayed onto excavation surface.
- For Cast-in-situ / Precast Segments: Fibers mixed at batching plant and poured into segment moulds.

Step 4: Curing & Quality Control

- Normal water curing; fiber ensures crack control during plastic shrinkage stage.
- Tests: Flexural strength, toughness index, residual strength.

Special Advantage: Poly fibers are highly effective in fire scenarios (tunnel fire spalling resistance due to melting of fibers creating vent channels for vapor escape).

2) Methodology for Jute Fiber in Tunnels

- Step 1: Material Selection
  - Choose type (natural plant based fibers commonly used).
  - Ensure aspect ratio (length/diameter) between 50–80.
- Step 2: Mix Proportioning
  - Fibers added slowly into the mixer with aggregates and cement to ensure uniform distribution.
  - Trial mixes for strength, ductility, and workability (slump loss expected).

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- Step 3: Mixing & Handling
  - Fibers fed gradually into mixer to avoid clumping.
  - Transit mixers preferred to transport the shotcrte mix from batching plant to site .
- Step 4: Application in Tunnels
  - Shotcrete (Primary Lining): Wet-mix jute fiber reinforced shotcrete applied directly onto the slopping face.
- Step 5: Testing & QA
  - Tests for compressive strength, flexural toughness, residual strength, and energy absorption capacity.

V. TEST TO BE PERFORM ON SHOTCRETE MIX

1) Workability And Temperature Verification At Site Before Spraying

Dampen the inside of the slump cone and place it firmly on a clean, level, non-absorbent base plate. Fill the cone in **three equal layers** (each roughly one-third of the height). Tamp each layer uniformly **25 times** with the tamping rod, ensuring the rod penetrates slightly into the layer below. Strike off the excess concrete flush with the top of the mold using the rod or a straight edge. Carefully lift the cone vertically straight up in a steady motion taking **5 to 10 seconds**, without twisting or jerking. Measure the distance from the original height of the mold down to the highest point of the slumped concrete



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Test Parameter	Result Obtained
Slump	-
Temperature	-

2) Shotcrete Panel Casting And Core Extraction At Site :-

When Shotcrete spraying at site the shotcrete panel casted for shotcrete core . The size of panel is generally taken as 750*750*125mm. Panel not transported before 18 hours from the spraying . size of the panel should be sufficient to take 16 numbers of core . After 18 hours of casting panel transported to the field lab for core extraction work . Total 16 number of cores were extracted from the panel for compressive strength load test .



Shotcrete panel Casted At Site



Shotcrete Core Extraction From Shotcrete Panel

3) Determination of the compressive strength of shotcrete cube and cylindrical core

The cores of 100 mm in length and 94 mm in diameter were extracted (along the casting direction) from the shotcrete panel . The ends of a core were cut using a diamond rotary saw to meet the tolerances of IS 516 (Part 4): 2018. Before the testing, the cores were soaked in water at 27± 3 ^{o}C for 44 ± 4 hours. Each core was subjected to axial compression in a compression testing machine of 2000 kN capacity, as shown in Figure . As per IS 516 (Part 4): 2018, necessary correction factors were applied to cater to the deviation in length to diameter ratio while calculating the compressive strength.



Figure 2. Test setup for the determination of compressive strength of shotcrete core

Sr No.	Age (Days)	Testing Length of Core L (mm)	Dia (D)mm	L/D Ratio	Weight (Kg)	Density (Kg/m3)	Load (KN)	Compressive Str.N/mm²	Correction Factor if L/D <2	Corrected Core Strength(Mpa)	Average Corrected Core Strength(Mpa)	Equivalent 150 mm Cube Strength (Mpa)
1	1	-	-	-	-	-	-	-	-	-	-	-
2	1	-	-	-	-	-	-	-	-	-		
3	1	-	-	-	-	-	-	-	-	-		
4	1	-	-	-	-	-	-	-	-	-		
5	3	-	-	-	-	-	-	-	-	-	-	-
6	3	-	-	-	-	-	-	-	-	-		
7	3	-	-	-	-	-	-	-	-	-		
8	3	-	-	-	-	-	-	-	-	-		
9	7	-	-	-	-	-	-	-	-	-	-	-
10	7	-	-	-	-	-	-	-	-	-		
11	7	-	-	-	-	-	-	-	-	-		
12	7	-	-	-	-	-	-	-	-	-		
13	28	-	-	-	-	-	-	-	-	-	-	-
14	28	-	-	-	-	-	-	-	-	-		
15	28	-	-	-	-	-	-	-	-	-		
16	28	-	-	-	-	-	-	-	-	-		

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4) Fiber Content Test

The volume of the sample (before fiber extraction) is determined by calculation (using actual dimensions) or by water displacement (reference method). The mass of the fiber is then determined by weighing, following extraction of the fiber from the fresh or hardened sample.



Figure 3. Shown the determination of Fiber Content in Shotcrete

Test Performed	Result Obtained
Fiber Content Test	- gram

5) Early Strength Test

Early Strength Test Performed on freshly spread shotcrete at site. According to EN-14488 part 2. The strength will be followed by J2 Curve as per EN- 14487 -1. Strength at different time interval mentioned in below

S. NO.	Time Interval	Strength according to J2 Curve	Result Obtained
1.	6 min	0.2 MPA	-
2.	10 min	0.25 MPA	-
3.	30 min	0.35 MPA	-
4.	60 min	0.5 MPA	-
Note :- Other age upto 24 hours as mentioned in J2 Curve .			



Figure 4. shown the determination of early strength of shotcrete

6) Energy Absorption Panel Casting & Testing

A square specimen shall be produced from a panel, sprayed and cured in a mould, in accordance with EN 14488-1, with dimensions of 600 mm x 600 mm and trimmed to a thickness of 100mm after spraying.

The prepared slab shall be cured under conditions according to EN 12390-2, for a minimum of 3 days immediately before testing and kept moist until testing. Testing shall normally be performed at 28 days. The specimens shall be examined and any abnormality observed shall be reported.

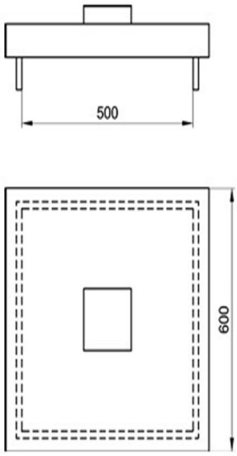


Figure 1 — Arrangement of loading of test specimen



Figure 4. shown the Panel Casting for Energy Absorption Tesr Of Shotcrete



Figure 5. shown the Energy Absorption Test Of Shotcrete in Field lab

Test Parameter	Result Obtained
Energy Absorption Test After 28 Days Of Casting	-

7) Determination of flexural strength :-

Prepare the test specimen by filling the concrete into the mould in 3 layers of approximately equal thickness. Tamp each layer 35 times using the tamping bar as specified above. Tamping should be distributed uniformly over the entire crossection of the beam mould and throughout the depth of each layer.

The specimen stored in water shall be tested immediately on removal from water; whilst they are still wet. The test specimen shall be placed in the machine correctly centered with the longitudinal axis of the specimen at right angles to the rollers. For moulded specimens, the mould filling direction shall be normal to the direction of loading.

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The load shall be applied at a rate of loading of 400 kg/min for the 15.0 cm specimens and at a rate of 180 kg/min for the 10.0 cm specimens.

Calculation

The Flexural Strength or modulus of rupture (fb) is given by

$$fb = pl/bd^2$$

(when a > 20.0cm for 15.0cm specimen or 13.0cm for 10cm specimen)

or

$$fb = 3pa/bd^2$$

(when a < 20.0cm but > 17.0 for 15.0cm specimen or < 13.3 cm but > 11.0cm for 10.0cm specimen.)

Where,

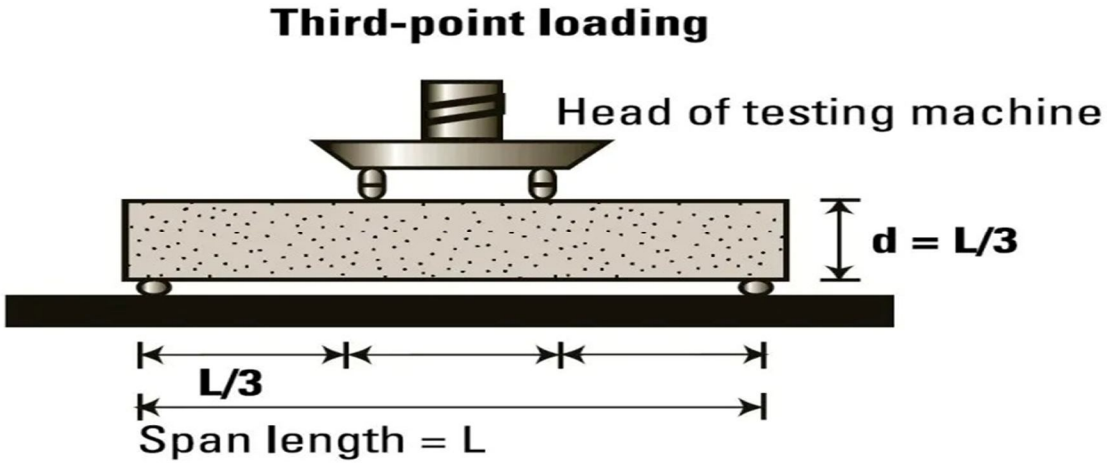
a = the distance between the line of fracture and the nearer support, measured on the center line of the tensile side of the specimen

b = width of specimen (cm)

d = failure point depth (cm)

l = supported length (cm)

p = max. Load (kg)





Flexural Strength Beam Casting In Field lab

Flexural Strength	Equation(a>200 mm)	Result
fb	= pl/bd^2 = _x1000x600/(150x150^2)	-

VI. APPLICATION

It is widely used in tunnel construction as a **primary or secondary support system**, particularly where rapid stabilization of excavated rock or soil is required.

A. Immediate tunnel-face and wall stabilization

After excavation, shotcrete is sprayed onto the exposed rock surface to provide rapid support and prevent loose rock pieces from falling.

B. Primary tunnel lining

Polyfiber shotcrete can form part of the primary support system in NATM/SEM tunnel construction. The fibers improve the post-cracking behavior of the shotcrete and help maintain load-carrying capacity after cracking.

C. Control of cracking

Polyfibers help control:

- Plastic shrinkage cracks
- Drying-shrinkage cracks
- Temperature-related cracking
- Crack propagation

D. Support of weak and fractured rock

It is particularly useful in areas containing:

- Jointed rock
- Highly fractured rock
- Weathered rock
- Loose or unstable strata

E. Around tunnel intersections

At locations such as cross-passages, caverns and junctions, additional support may be required. Fiber-reinforced shotcrete can provide distributed reinforcement over irregular surfaces.

F. Protection of rock bolts and reinforcement

Shotcrete is often applied over rock bolts, wire mesh and other reinforcement to create a composite support system.

- Jute Fiber Reinforced Shotcrete (JFRS) is shotcrete containing natural jute fibres to improve crack resistance, toughness, and post-cracking behaviour. It is particularly useful where a low-cost and more sustainable reinforcement is desired.
- Jute fiber shotcrete is mainly used in sloping area or outside tunnel with wiremesh where seepage occurs . It enhance the property of material and bonding between them . It reduces the accelerator dose because of rapid setting quality .
- While using jute fiber at site it reduces/ controls the shrinkage crack, and also gives the proper stabilization while primary lining work is done .
- Temporary construction support:- Can be used for temporary stabilization of excavated surfaces where moderate crack control is required.

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VII. FUTURE SCOPE

1) Eco-Friendly Construction: Jute is a renewable, biodegradable plant resource that lowers the carbon footprint and embodied carbon of cement composites.

2) Mechanical Enhancement: Optimal dosages (typically 0.1% to 0.25% by volume) improve tensile, flexural, and compressive strength while reducing micro-cracking through crack bridging.

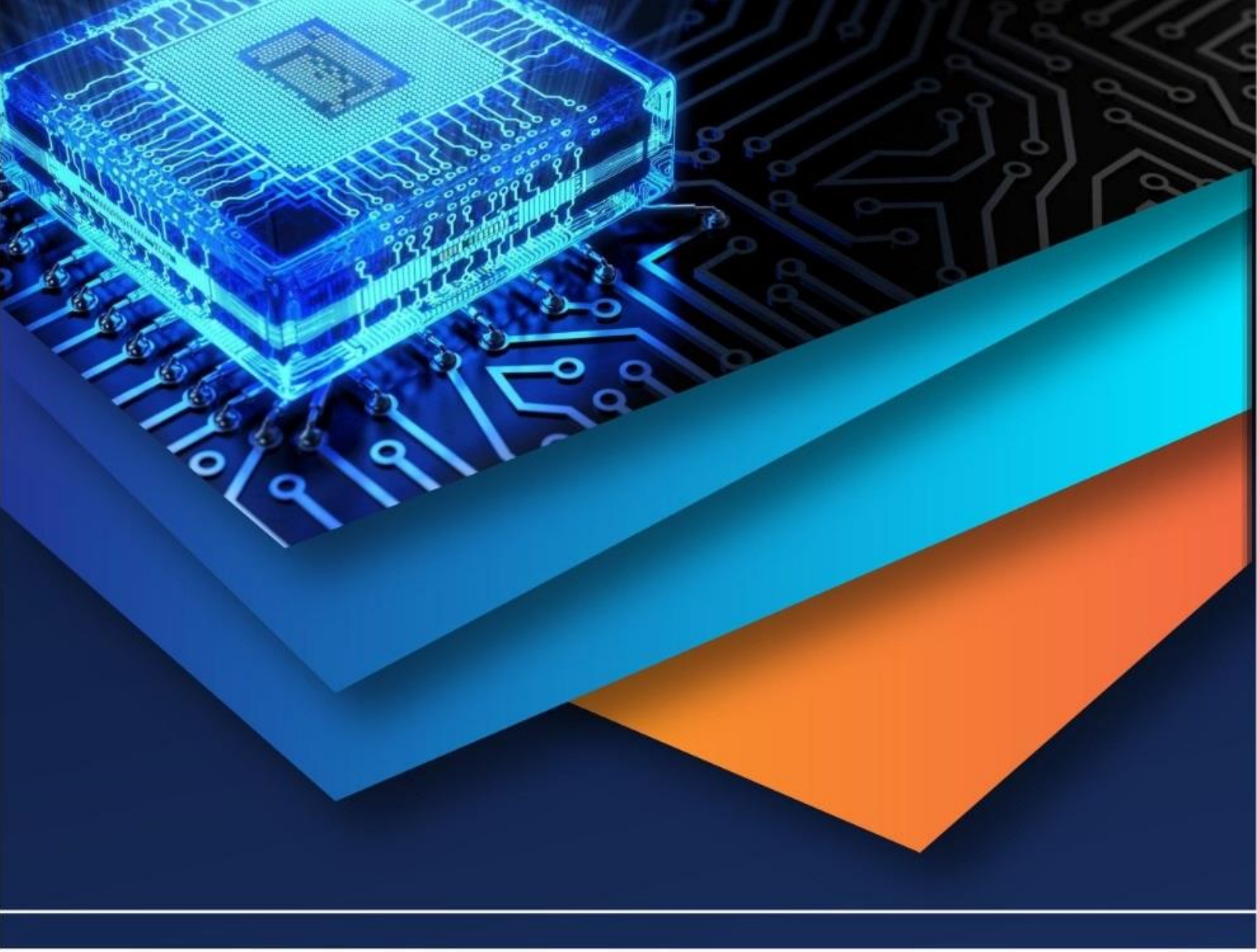
3) Target Applications: Primary future commercialization targets include low-cost residential housing, non-structural wall panels, ceiling boards, road pavements, and erosion control blocks.

4) Hybrid & Treated Composites: Ongoing researches focuses on alkali treatments (to improve bonding and remove moisture-attracting components) and nanotechnology (utilizing cellulose nano-fibers) to overcome jute's natural hydrophilic nature and degradation over time.

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