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# Comparative Study on Poyfibre Reinforced Shotcrete To Be Used For Primary Support In Tunnes

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## Abstract

Shotcrete is a cement-based mixture pneumatically projected at high velocity onto a receiving surface. The material component of shotcrete is essentially concrete or sometimes mortar, but the process of shotcrete application is unique. This process allows a good compaction of concrete to be obtained without vibration. Compared to cast-in-place concrete, other important advantages of the shotcrete process are related to the reduction of the amount and time for formwork installation, removal, and associated labor costs, very good working safety and good environmental conditions. Nowadays, because of the significant advances that occurred mainly in the last few decades, shotcrete can be considered a proper repair material particularly suitable in different situations such as where formwork is not practical or can be reduced or eliminated, where access to the work area is difficult, where thin layers and/or variable thickness is required and where normal casting techniques cannot be employed.

**In this study**, a review of Shotcrete is presented. The work contains a brief introduction of shotcrete, materials used followed by typical shotcrete mix design .It has exactly the same basic ingredients as an ordinary concrete i.e. cement, aggregates and water, however, additives like fibers, accelerators, change its character and make it a unique material, usable in quite a different fashion than concrete.. Shotcrete is a useful material which could be applied in numerous situations where the use of conventional concrete is neither convenient nor economically feasible. A small update has also been given about the various applications of shotcrete.

# 1. Introduction

Shotcrete is a term used for concrete and mortar conveyed through a hose pipe and sprayed at high velocity on to a surface. Shotcrete undergoes placement and compaction at the same time due to the force with which it is projected from the nozzle. It can be blown onto any type or shape of surface, including vertical or overhead areas. Shotcrete can be produced by either dry mix or wet mix methods. Although, shotcrete is today a comprehensive term that presents spraying concrete or mortar by both dry and wet mix process. However, in USA the name shotcrete applies only to the one placed by the wet mix method. Whereas, gunite refers to the dry-mix process, in which the dry cementitious mixture is propelled through a hose to the nozzle, and the water is injected immediately prior to application (Engineering Manual, 1993). Apart from gunite and shotcrete, there are also other names for the same material like sprayed concrete, pneumatic concrete, and gun concrete etc.

## 1.1 Importance of proper application.

Properly applied shotcrete is a structurally sound and durable construction material which exhibits excellent bonding characteristics to existing concrete, rock, steel, and many other materials. It can have high strength, low absorption, good resistance to weathering, and resistance to some forms of chemical attack. Many of the physical properties of sound shotcrete are comparable or superior to those of conventional concrete or mortar having the same composition. Improperly applied shotcrete may create conditions much worse than the untreated condition.

## 1.2 Advantages of shotcrete.

Shotcrete is used in lieu of conventional concrete, in most instances, for reasons of cost or convenience. Shotcrete is advantageous in situations when formwork is cost prohibitive or impractical and where forms can be reduced or eliminated, access to the work area is difficult, thin layers or variable thicknesses are required, or normal casting techniques cannot be employed. Additional savings are possible because shotcrete requires only a small, portable plant for manufacture and placement. Shotcreting operations can often be accomplished in areas of limited access to make repairs to structures.

**1.3 Strength and bonding**. The excellent bonding of shotcrete to other materials is often an important design consideration. The force of the impact of this pneumatically propelled material on the surface causes compaction of the shotcrete paste matrix into the fine surface irregularities and results in good adhesion to the surface. Within limits, the material is capable of supporting itself in vertical or overhead applications. Applications The selection of shotcrete for a particular application should be based on knowledge, experience, and a careful study of required and achievable material performance. The success of the shotcrete for that application is contingent upon proper planning and supervision, skill and continuous attention provided by the shotcrete applicator. Repair. Shotcrete can be used to repair the damaged surface of concrete, wood, or steel structures provided there is access to the surface needing repair. The following examples indicate a few ways in which shotcrete can be used in repairs:

(1) Bridges. Shotcrete repair can be used for bridge deck rehabilitation, but it has generally been uneconomical for major full-thickness repairs. It is very useful, however, for beam repairs of variable depths, caps, columns, abutments, wingwalls, and underdecks from the standpoint of technique and cost.

(2) Buildings. In building repairs, shotcrete is commonly used for repair of fire and earthquake damage and deterioration, strengthening walls, and encasing structural steel for fireproofing. The

repair of structural members such as beams, columns, and connections is common for structures damaged by an earthquake.

(3) Marine structures. Damage to marine structures can result from deterioration of the concrete and of the reinforcement.

Damaging conditions are corrosion of the steel, freezing and thawing action, impact loading, structural distress, physical abrasion from the action of waves, sand, gravel, and floating ice, and chemical attack due to sulfates. These problems can occur in most marine structures such as bridge decks, piles, pile caps, beams, piers, navigation locks, guide walls, dams, powerhouses, and discharge tunnels. In many cases, shotcrete can be used to repair the deteriorated surfaces of these structures. (4) Spillway surfaces. Surfaces subject to high velocity flows may be damaged by cavitation erosion or abrasion erosion. Shotcrete repairs are advantageous because of the relatively short outage necessary to complete the repairs.

(4) Underground excavations. For the most part, shotcrete is used in underground excavations in rock; but on occasion, it has been successfully used in the advancement of tunnels through altered, cohesionless, and loose soils. Typical underground shotcrete applications range from supplementing or replacing conventional support materials such as lagging and steel sets, sealing rock surfaces, channeling water flows, and installing temporary support and permanent linings Slope and surface protection. Shotcrete is often used for temporary protection of exposed rock surfaces that will deteriorate when exposed to air. Shotcrete is also used to permanently cover slopes or cuts that may erode in time or otherwise deteriorate. Slope protection should be properly drained to prevent damage from excessive uplift pressure. Application of shotcrete to the surface of landfills and other waste areas is beneficial to prevent surface water infiltration.

(5) New structures. Shotcrete is not necessarily the fastest method of placing concrete on all jobs, but where thin sections and large areas are involved, shotcreting can be used effectively to save time. some of the applications involved with construction of new structures.

(a) Pools and tanks. Shotcrete has been used extensively to construct concrete swimming pools. More recently, large aquariums have been constructed using shotcrete.

(b) Shotcrete floors and walls. Shotcrete floors in tanks and pools on well compacted subbase or on undisturbed earth have generally given excellent service. Vertical and overhead construction for walls, slabs, columns, and other structural members has been frequently shotcreted.

(c) Shotcrete domes. Construction techniques using inflatable air-forming systems have made the construction of shotcrete shells or domes practical. These large structures have been used for residential housing, warehousing, bridge, and culvert applications

## 1.4 Shotcrete Processes

Shotcrete can be applied by two distinct application techniques, the dry-mix process and the wet-mix process.

### a) Dry-mix shotcrete.

The cementitious material and aggregate are thoroughly mixed and either bagged in a dry condition, or mixed and delivered directly to the gun. The mixture is normally fed to a pneumatically operated gun which delivers a continuous flow of material through the delivery hose to the nozzle. The interior of the nozzle is fitted with a water ring which uniformly injects water into the mixture as it is being discharged from the nozzle and propelled against the receiving surface.

### b) Wet-mix shotcrete

The cementitious material, aggregate, water, and admixtures are thoroughly mixed as would be done for conventional concrete. The mixed material is fed to the delivery equipment, such as a concrete pump, which propels the mixture through the delivery hose by positive displacement or by compressed air. Additional air is added at the nozzle to increase the nozzle discharge velocity.

### c) Comparison of dry-mix and wet-mix processes.

Shotcrete suitable for most requirements can be produced by either the dry-mix or wet-mix process. However, differences in the equipment cost, maintenance requirements, operational features, placement characteristics, and product quality may make one or the other more attractive for a particular application.

(1) Bond strengths of new shotcrete to existing materials are generally higher with dry-mix shotcrete than with wet-mix shotcrete. Both shotcrete mixtures often provide significantly higher bond strengths to existing materials than does conventional concrete.

(2) Typically, dry-mix shotcrete is applied at a much slower rate than wet-mix shotcrete. Dry-mix shotcrete is often applied at a rate of 1 or 2 cubic yards per hour compared to wet-mix shotcrete applied at a rate of up to 7 or 8 cubic yards per hour. Depending on the application, in-place production rate may be significantly lower because of obstacles, rebound, and other features which may cause delays.

(3) Rebound is the shotcrete material that "bounces" off the shooting surface. Rebound for conventional dry-mix shotcrete, in the best of conditions, can be expected to be at least 20 percent of the total material passed through the nozzle. Wet-mix shotcrete rebounds somewhat less than dry-mix shotcrete.

(4) The use of air-entraining admixtures (AEA) in shotcrete is practical only in wet-mix shotcrete. When batched properly, AEA forms an air-void system suitable for providing frost resistance to wet-mix shotcrete. The formation of an air-void system in dry-mix shotcrete is not possible. However, dry-mix shotcrete, when properly proportioned and applied, will have a compressive strength exceeding approximately 7,000 pounds per square inch (psi). It has performed well in moderate exposures to freezing and thawing.

## 1.5 Fiber reinforcement

Plain shotcrete, like plain conventional concrete possesses a very low tensile strength, limited ductility and little resistance to cracking (Shetty, 2005). The addition of fibers to the shotcrete mixture adds ductility to the material as well as energy absorption capacity and impact resistance. The composite material is capable of sustaining postcrack loadings and often displays increased ultimate strength, particularly tensile strength. Fibers used in shotcrete are available in many forms e.g. steel fibers, glass fibers, and other synthetic fibers

Unreinforced shotcrete, like unreinforced conventional concrete, is a brittle material that experiences cracking and displacement when subjected to tensile stresses or strains. The addition of fibers to the shotcrete mixture adds ductility to the material as well as energy absorption capacity and impact resistance. The composite material is capable of sustaining postcrack loadings and often displays increased ultimate strength, particularly tensile strength. Fibers used in shotcrete are available in three general forms: steel fibers, glass fibers, and other synthetic fibers

The use of steel fibers has evolved rapidly since its inception in the late 1950's. The present third generation steel fibers are greatly superior to the earlier fibers. Early mixing and handling problems which hampered uniform distribution of fibers in a mixture have been minimized by the manufacture of fibers with low aspect ratios (ratio of length to diameter), surface deformations, and improved shape.

The use of glass-fiber-reinforced shotcrete (GFRS) is an adaptation of the technology of using chopped glass fibers and a resin binder. The equipment and process to apply glass-fiber shotcrete is not a conventional shotcrete operation, but requires a special gun and delivery system. This process termed "spray-up" is used extensively in the construction of lightweight panels for building cladding and special architectural features and is usually applied in a plant production situation. A common onsite application is the construction of simulated rock structures for animal exhibits at zoos. The fibers are made from a special zirconium alkali-resistant (AR) glass to resist deterioration in the highly alkaline Portland cement environment.

Other synthetic fibers are composed of nylon, polypropylene, polyethylene, polyester, and rayon. The predominant fiber used for shotcrete has been of polypropylene produced in a collated fibrillated form. The primary benefit of synthetic fiber additions to shotcrete is to decrease width of shrinkage cracks in the material

## 1.6 Synthetic fibers

The synthetic fibers are important in projects where corrosion is a concern e.g. marine structure. Synthetic fibers are derived from organic polymers. The most common synthetic fibers are nylon, polypropylene, polyethylene, polyester etc. Among these fibers, polypropylene has the most successful commercial applications. Polypropylene has a low density and is also chemically inert. It has a hydrophobic surface which does not absorb mixing water (Ramakrishnan, 1987). Synthetic fibers are added to impart high post-crack energy absorption to shotcrete, to increase its durability after cracking, and to build strain hardening behavior under deformation thus their popularity is mainly attributed to their excellent post-crack performance (Clements et al., 2004). The major shortcomings of synthetic fibers are low modulus of elasticity, poor bond with cement matrix, and combustibility. The synthetic fibers have low melting point (150-200ºC) much lower than that of steel fibers. As fire takes place, these fibers melt, creating voids in the concrete. Similarly water present in concrete pores vaporizes. In case of concrete without plastic fibers, the water vapors will try to escape and if trapped, would exert pressure on surrounding concrete. This will create cracks and ultimately will lead to spalling of concrete. On the other hand, in fiber reinforced concrete, the voids created due to melting of plastic fibers would provide way for the water vapors to escape and hence the spalling of concrete is avoided.

Typical applications for fiber-reinforced shotcrete are for tunnel linings, surface coatings on rock and soil, slopes, structures, embankments, or other structures that may be subject to high deformations or where crack control is needed

## 2. Materials used in this study

1. Aggregate 10mm and crushing sand: Based on the individual fractions of 10mm and crushed sand percentage of aggregate has been finalized to achieve gradation requirement for grade aggregates as per BIS 363. Specific gravity of 10mm and crushed sand were 2.92 and 2.81 respectively.Water absorbtion of 10mm and crushed sand were 1.27% and 2% respectively.

| Grading 10mm IS 2386 PART 1 & IS 383 | | | | | |
|---|---|---|---|---|---|
| | Percentage Passing | | | | |
| IS Sieve size | sample 1 | sample 2 | sample 3 | Average | As per IS 383 |
| 12.5 | 100 | 100 | 100 | 100 | 100 |
| 10 | 95.60 | 95.76 | 95.62 | 95.66 | 85-100 |
| 4.75 | 13.24 | 13.4 | 12.10 | 12.91 | 0-20 |
| 2.36 | 2.60 | 2.76 | 2.62 | 2.66 | 0-5 |

| Grading of Crusher sand AS per IS 383 | | | | | |
|---|---|---|---|---|---|
| | Percentage Passing | | | | Limits as per IS 383 |
| IS Sieve size | sample 1 | sample 2 | sample 3 | Average | Zone II |
| 10 | 100 | 100 | 100 | 100 | 100 |
| 4.75 | 99.60 | 98.80 | 99.37 | 99.26 | 90-100 |
| 2.36 | 79.40 | 77.90 | 79.10 | 78.8 | 85-100 |
| 1.18 | 58.20 | 56.80 | 57.73 | 57.58 | 75-100 |
| 0.6 | 37.00 | 36.70 | 37.07 | 36.92 | 60-79 |
| 0.3 | 22.90 | 22.10 | 22.53 | 22.51 | 12.0-40 |
| 0.15 | 14.50 | 13.90 | 14.3 | 14.23 | 0-20 |

2. Poly fibre BG55 with specific gravity 0.91.
3. Cement ulltratech OPC 53 with specific gravity 3.14.
4. Admixture (Dynamon sx in) with specific gravity 1.05. Admixture confirming to IS 9103 were used in concrete for reduction of water. In this study 1% of admixture by weight of total cementitious was used.
5. Accelerator (Mapeiquick AF -70) .

# 3. Test Methodology

1. Casting of 9 cubes to observe 3 days, 7days and 28 days strength
2. Casting of 3 flexural beams to observe flexural strengthafter 28 days
3. Casting of panels at site for cylindrical cores to observe core compressive strength at 1,3,7,28 days at 7% accelerator by weight of cement.
4. Casting of 5 panels at site with 7% acceerator to observe energy absorbtion results.

# 4. Quantaties of Ingredients selected.

| Quantaties Of Ingredients selected | | |
|---|---|---|
| Ingredients | Materials selected for test | Materials required per cum of concrete |
| Cement(kg) | 13.50 | 450 |
| W/C ratio | 0.012 | 0.4 |
| Free water (lts) | 5.40 | 180 |
| 10mm aggregate(kg) | 21.69 | 723 |
| Crushed sand(kg) | 35.40 | 1180 |
| Admixture(kg) | 0.135 | 4.5 |
| Polyfibre(kg) | 0.12 | 4 |
| Density of fresh concrete(kg/cum) | | 2542 |

# 5. Test results

1. Cube compressive strength
   a) 3 days cube compressive strength

| Weight of cube(kg) | Load(KN) | Compressive Strength (N/mm2) |
|---|---|---|
| 8.600 | 587.2 | 26.10 |
| 8.650 | 611.3 | 27.17 |
| 8.692 | 616.9 | 27.42 |
| Avg Strength | 605.13 | 26.89 |

   b) 7 days cube compressive strength.

| Weight of cube(kg) | Load(KN) | Compressive Strength (N/mm2) |
|---|---|---|
| 8.692 | 844 | 37.51 |
| 8.684 | 849 | 37.73 |
| 8.690 | 868 | 38.58 |
| Avg Strength | 853.67 | 37.94 |

C) 28 days cube compressive strength

| Weight of cube(kg) | Load(KN) | Compressive Strength (N/mm2) |
|---|---|---|
| 8.690 | 1100.8 | 48.92 |
| 8.682 | 1064.4 | 47.31 |
| 8.688 | 1089.8 | 48.44 |
| Avg Strength | 1085.00 | 48.22 |

Fig 1 showing casted cubes

Fig 2 showing cune in compression testing machine

2. 28 days Flexural strength of beams

| Specimen No | Position of fracture(mm) | Weight of beam(Gms) | Load(KN) | Flexural Strength(N/mm2) | Avg. Flexural Strength (N/mm2) |
|---|---|---|---|---|---|
| 1 | 230 | 41650 | 35.84 | 6.37 | 6.50 |
| 2 | 270 | 41610 | 38.82 | 6.90 | |
| 3 | 284 | 41680 | 35.1 | 6.24 | |

Fig 3 showing beam in the flexural testing machine

3. Core compressive strength
   a) 1day core compressive strength
   b) 3days core compressive strength
   c) 7days core compressive strength
   d) 28days core compressive strength

| | |
|---|---|
| Avg. 1 day core compressive strength of shotcrete with 7% accelerator by weight of cement | 16.23 N/mm2 |
| Avg. 3 days core compressive strength of shotcrete with 7% accelerator by weight of cement | 22.69 N/mm2 |
| Avg. 7 days core compressive strength of shotcrete with 7% accelerator by weight of cement | 33.82N/mm2 |
| Avg. 28 days core compressive strength of shotcrete with 7% accelerator by weight of cement | 43.97N/mm2 |

Fig 4 showing casted cores

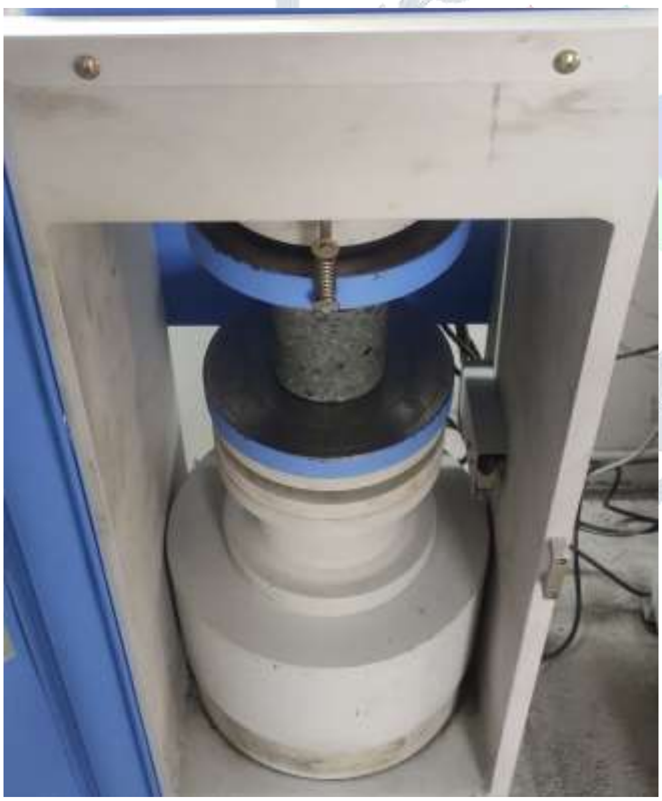

Fig 5 showing core in the compression testing machine

4. Energy absorbtion test results

| Panel no | Energy Absorption in( Joules) |
|---|---|
| 1 | 946.225 |
| 2 | 1047.061 |
| 3 | 965.004 |

Fig 6 showing tested pane

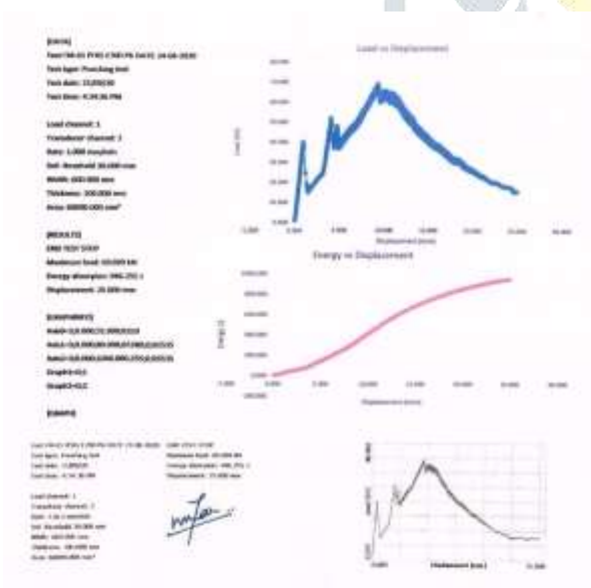

Fig 7 showing graphs of tested panel

## 6. Conclusion

1. The cube compressive strength of polyfibre reinforced shotcrete at 3days,7days and 28days was observed as 26.89N/mm2,37.94N/mm2 and 48.22N/mm2 respectivey.

2. The flexural strength after 28 days was observed as 6.50N/mm2.
3. The core compressive strength with 7% accelerator after 1day,3days,7days and 28 days was observed as 16.23N/mm2, 22.69N/mm2, 33.82N/mm2 and 43.97 respectivey.
4. Energy absorption results of the three panels was observed as 946.225,1047.061 and 965.004 joules respectively.

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