Report about

Sprayed Concrete

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Abstract:

Sprayed is a cement-based mixture pneumatically projected at high velocity onto a receiving surface. The material component of Sprayed is essentially concrete or sometimes mortar, but the process of Sprayed 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 Sprayed process are related to the reduction of the amount and time for formwork installation, removal, and associated labour costs, the very flexible logistics, very good working safety and good environmental conditions. Nowadays, because of the significant advances that occurred mainly in the last few decades, sprayed 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. the two different application techniques of Sprayed, namely the dry-mix process and the wet-mix process, and discusses their respective advantages and disadvantages. The drawbacks of conventional Sprayed (only based on cement and aggregate mixtures) are reviewed and high performance Sprayed are presented. These novel Sprayed materials are produced through the addition of new generations of chemical admixtures, supplementary cementitious materials and reinforcement fibres. Cases histories of a successful use of the Sprayed process in the rehabilitations of architecturally important historic buildings are described.

1. Introduction:

Sprayed is a term used for concrete and mortar conveyed through a hose pipe and sprayed at high velocity on to a surface. The unit weight of Sprayed is usually between 2230 to 2390 kg/m^3, about the same as conventional concrete. Sprayed 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.

Sprayed can be produced by either dry mix or wet mix methods. Although, Sprayed is today a comprehensive term that presents spraying concrete or mortar by both dry and wet mix process. However, in USA the name Sprayed 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 Sprayed, there are also other names for the same material like sprayed concrete, pneumatic concrete, and gun concrete etc.

Figure 1: hillside covered by sprayed concrete

2. Methodology:

2.1 Wet and dry mix methods: Comparison:

In dry-mix process, cement and aggregates are mixed and fed into a mechanical feeder or gun as shown in Figure 2. The mixture is then transferred at a known rate by a distributor into a stream of compressed air in a hose leading to the delivery nozzle. Inside the nozzle a perforated manifold is fitted, through which pressurized water is introduced for mixing with the other ingredients, before the mixture is projected at high velocity.

Wet-mix Sprayed involves pumping of a previously prepared concrete, typically ready-mixed concrete, to the nozzle. Compressed air is introduced at the nozzle to impel the mixture onto the receiving surface, as demonstrated in Figure 3.

Both the methods have their own advantages and disadvantages and any method can be selected for one or more specific reasons. Following is a brief comparison of the two methods.

1. Higher strengths of the order of 7000 psi are possible with dry mix method while strengths are much lower with the wet mix.
2. Except for accelerators, it is usually difficult to apply other admixtures in dry mix process.
3. Although both processes result in stronger bonding with the underlying surface than the conventional concrete. However, bond strength with dry method is generally more as compared to wet method.
4. Typically, dry mix Sprayed is applied at a rate of 1 to 2 cubic yards per hour much lower than the wet mix Sprayed which is applied at a rate of 7 to 8 cubic yards per hour.
5. The wet mix procedure generally produces less rebound, waste and dusts compared to the dry-mix procedure. Nearly 20-40 % Sprayed and 75% fibers (in case of a fiber reinforced Sprayed) are lost if dry mix method is carried out. In case of wet Sprayed, the waste is about 5 to 15%.
6. The equipment maintenance costs are normally higher in wet mix.

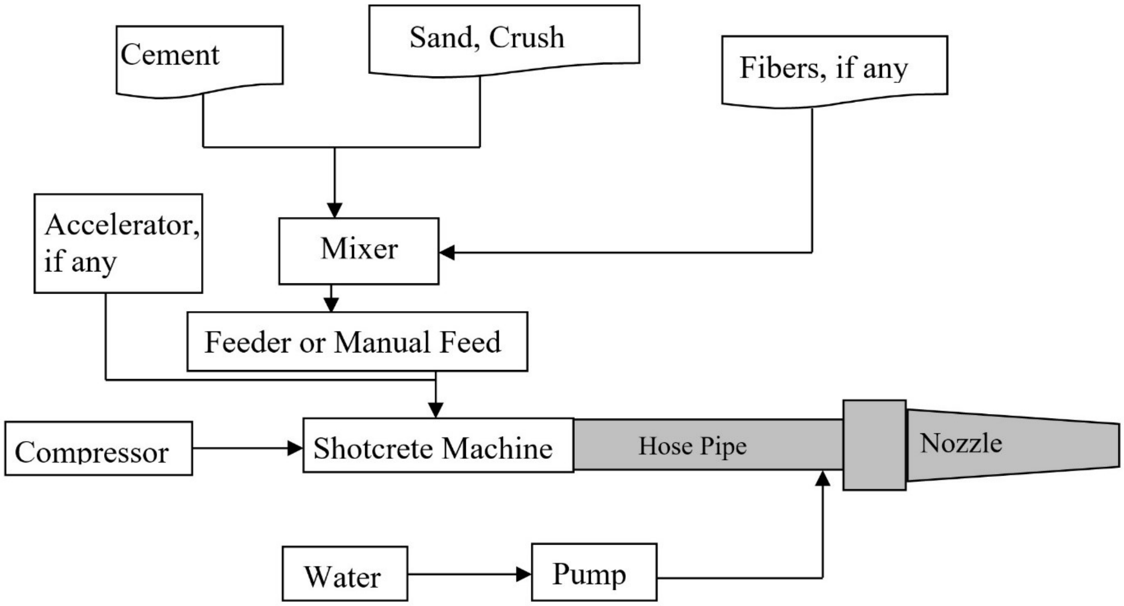

Figure 2: dry mix method sprayed concrete

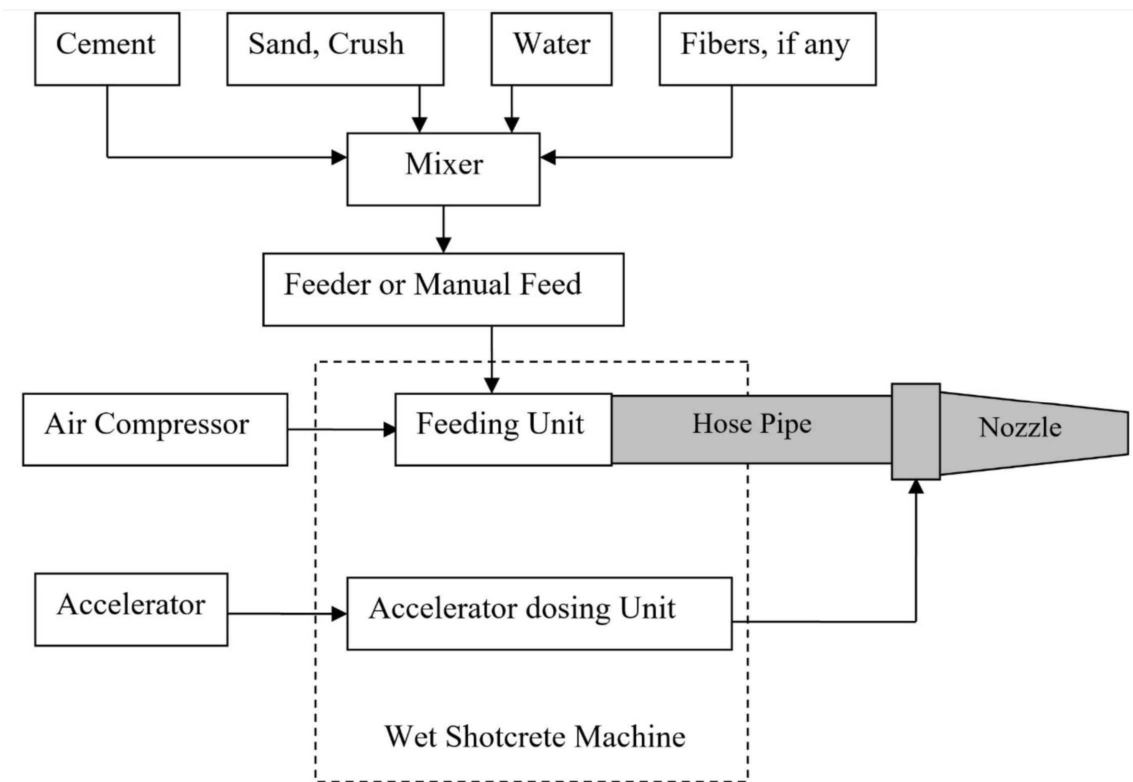

Figure 3: Wet mix method sprayed concrete

2.2 Sprayed Mix design:

Sprayed design for wet process can be designed like conventional concrete but these mixes contain higher volume of fine aggregates and cement. Sprayed process can be designed by absolute volume method or by weight. However, in the dry process, usually the water content is not included in the calculation.

Aggregate

Aggregates for Sprayed me contain river sand, crushed sand and crushed stone with particle sizes up to normally up to 10 mm. A typical and recommended gradation of combined aggregates for Sprayed is given the Table 1.

Table 1 Typical aggregate gradation for Sprayed

Sieve size, U.S. standard square mesh	*Percent by weight passing individual sieves*		
	Gradation No. 1	Gradation No. 2	*Gradation No. 3*
¾ in. (19 mm)	-	-	*100*
½ in. (12 mm)	-	100	*80-95*
3/8 in. (10 mm)	100	90-100	*70-90*
No. 4 (4.75 mm)	95-100	70-85	*50-70*
No. 8 (2.4 mm)	80-100	50-70	*35-55*
No. 16 (1.2 mm)	50-85	35-55	*20-40*
No. 30 (600 µm)	25-60	20-35	*10-30*
No. 50 (300 µm)	10-30	8-20	*5-17*
No. 100 (150 µm)	*2-10*	*2-10*	*2-10*

Water Cement Ratio

The water-cement ratio for wet Sprayed normally falls within a range of 0.40 to 0.55 for wet-mix Sprayed. Dry mix design shall only include water content enough for the hydration process of cement needed for strength development.

Cement Content

Typical and recommended cement content is given in the following Table 2.

Table 2 Typical Cement factors for Sprayed

Specified 28-day compressive strength		Cement content	
PSi	MPa	Lb/yd^3	Kg/m^3
3000	21	500-650	300-380
4000	28	550-700	325-425
5000	35	650-850	380-500

Additions

Accelerators are typically added at a rate of 3 to 10 percent by weight of cement. An increased amount can result in a decreased final strength. The fibres are added at a rate of 0.2 to 2% by volume of Sprayed.

Additives

Admixtures can add significant flexibility to wet-process sprayed concrete and overcome some of the potential shortcomings of the method (e.g. poor stop/start flexibility). A plasticiser will reduce the water/cement ratio (thereby increasing the strength and durability) whilst maintaining the required workability (and hence pump ability). Stabilisers prolong the workable life of the concrete whilst accelerators are added at the nozzle to initiate setting once the concrete has been sprayed. However, admixtures are an additional expense, can be caustic in nature and can be detrimental to some properties of the sprayed concrete (e.g. accelerators can reduce long-term strength). All admixtures are sophisticated chemicals and advice should always be sought from the manufacturer about dosage and application rates. Admixtures can alter their behaviour when added in combination, so care should be taken to ensure compatibility. Admixtures for sprayed concrete should comply with the requirements of EN 934-2 and EN 934-6 or BS 5075, Parts 1, 2 and 3 or EFNARC (1996)

Superplasticisers and water reducers:

Superplasticisers are high performance water-reducers which disperse the fines more effectively within a mix and therefore improve workability and cohesion. The two commonest types are sulphated melamine formaldehyde condensates (which form a lubricating film on the particle surfaces) and sulphated naphthalene formaldehyde condensates (which electrically charge the cement particles so that they repel each other although many hybrids now exist. Water reducers are commonly lignosulphonic acids or hydroxylase carboxylic acids and are utilised in a similar way to superplasticisers. The dosage of superplasticisers and water reducers depends on the mix specification, water/cement ratio, required workability, and cement and aggregate types.

Air entrainment

Air-entraining agents are added to wet-sprayed concretes to create a hardened concrete with small, well-distributed air pores which act can contain frozen water which has expanded, consequently improving freeze-thaw durability and de-icing chemical scaling resistance.

Polymers

Latex solutions (such as styrene-butadiene rubber (SBR)) are added to improve bleeding resistance, pump ability and adhesion. It is also claimed that they can improve the tensile and flexural strength, permeability, abrasion and chemical resistance of the hardened concrete

Accelerators

Accelerators are rarely required in low-volume applications but can be essential when rapid strength development is necessary. They are available in powdered form (mainly for dry spraying) or liquid form (generally added at the nozzle).

Retarders and stabilisers

Traditional retarders are not common in sprayed concrete work. However, stabilisers are often incorporated (in conjunction with an activator added at the nozzle) to control hydration where long periods of standing-time are expected in the spraying process, seen as in underground work where the concrete is batched above ground and then conveyed large distances to spraying pump.

Fiber reinforcement

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

Steel fibers

The use of steel fibers has evolved rapidly since its inception in the late 1950's. Early steel fibers used for concrete or Sprayed reinforcement were round and smooth. They were obtained by cutting or chopping wire. Today, smooth and straight fibers have been replaced by the ones which have rough surfaces, hooked ends and are undulated throughout their length. These characteristics increase fiber resistance to pull out from a cement matrix. The steel fibers range from 0.25 to 0.76 mm in diameter. Although steel fibers improve ductility, flexural strength and toughness, they result in poor workability (ease of placing and compacting of concrete) of mix due to clumping effect while mixing and casting. As steel is a corrodible material, corrosion damage and increased weight density are the other drawbacks of steel fibers.

Glass fibers

The use of glass-fiber-reinforced Sprayed (GFRS) is an adaptation of the technology of using chopped glass fibers and a resin binder. Commonly used glass fibers are round and straight and have diameters of 0.005 to 0.015 mm, but these fibers are bonded together to produce larger ones with diameters of 0.013 to 1.3 mm. A special gun and delivery system is used to apply GFRS. This process termed "spray-up" is used extensively in the construction of lightweight panels for building cladding and special architectural features. A major disadvantage of glass fiber is its reactivity in the alkaline cementitious environment (alkali-silica reaction). To overcome, the fibers are made from a special zirconium alkali-resistant (AR) glass. The strength of glass fiber is comparable to that of steel fiber, its density is lower, and its elastic modulus is about one third that of steel.

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. Synthetic fibers are added to impart high post-crack energy absorption to Sprayed, to increase its durability after cracking, and to build strain hardening behaviour under deformation thus their popularity is mainly attributed to their excellent post-crack performance. 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 vapours 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 vapours to escape and hence the spalling of concrete is avoided.

Carbon fibers

Carbon fibers are produced from petroleum pitches. These fibers are manufactured in strengths as high as steel fibers but have much low density, making the overall matrix light in weight. Carbon fibers are inert in aggressive environment, abrasion-resistant and stable at high temperature, with relatively high stiffness.

Reinforcement

Wire mesh is included to limit the development of cracks resulting from shrinkage, thermal movement and flexure. Sprayed concrete be reinforced with steel mesh when the total thickness exceeds 50 mm and that the reinforcement has the smallest possible diameter, with a minimum diameter of 3 mm. Reinforcement should comply with EN 10080 or BS 4466:1989.

Pozzolanic additions

Silica fume is a very fine noncrystalline material composed mostly of silica. It was first introduced in Sprayed during 1970s and now it has become viable as an underground mining support. Silica fume in Sprayed is used as a pozzolanic material i.e. as a partial replacement of cement. Silica fume is used in concrete and Sprayed to increase strength, decrease permeability, and enhance cohesion and adhesion. Specific advantages of silica fume in Sprayed are the improved bond strength of Sprayed to substrate surfaces, the improved cohesion of the Sprayed, and the resulting ability to apply thicker layers of Sprayed in a single pass to vertical and overhead surfaces. The material is more resistant to "washout," where fresh Sprayed is subject to the action of flowing water, and rebound is significantly reduced. Sprayed containing silica fume may have improved resistance to aggressive chemicals. Such Sprayed has higher silica fume contents.

In general, silica-fume Sprayed produces unhardened and hardened material properties which, among other uses, make it suitable as a substitute for polymer-modified Sprayed and accelerated Sprayed applications. Use of silica-fume Sprayed should be considered for many applications that presently use conventional Sprayed because of its bond and strength performance.

Silica-fume Sprayed has been widely used in tunnel construction often combined with fibers to control shrinkage cracking as well as for tunnel rehabilitation purposes (Parker et al., 2002). Because of inherent improvements in permeability, silica-fume Sprayed has been used to cap landfills and other waste areas to be sealed from surface water infiltration. Performance in high-strength applications is more easily accomplished with silica-fume Sprayed.

2.3 Applications:

Sprayed is frequently used due to better quality, high speed and more convenience than ordinary concrete. Sprayed can be applied in places where other methods of delivery are difficult or impossible such as elevated, and confined places. Sprayed can be used in a wide variety of applications including building new structures and reinforcing existing ones. Today Sprayed has gained great popularity due to its high strength, durability, low permeability, good bond, countless shape possibilities and easy handling in areas of difficult access. The following paragraphs discuss the use of Sprayed in several common applications.

2.3.1 Concrete restoration or retrofitting:

One of the strong points of Sprayed is its excellent bond with old concrete, rock face and even with metal. That is for this reason Sprayed can be used to repair the damaged surface of concrete, wood, or steel structures.

The following examples indicate a few ways in which Sprayed can be used in repairs:

1. Sprayed can be used for repair of bridge decks.
2. In building repairs, Sprayed is commonly used for repair of fire and earthquake damage and deterioration, strengthening walls, and encasing structural steel for fireproofing (Steel concrete composite structures). The repair of structural members such as beams, columns, and connections is common for structures damaged by an earthquake.
3. 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 sulphates. 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, Sprayed can be used to repair the deteriorated surfaces of these structures.
4. Surfaces subject to high velocity flows may be damaged by erosion. Sprayed repairs are advantageous because of the relatively short outage necessary to complete the repairs.

Figure 4: sprayed Concrete restoration

2.3.2 Underground excavations and rock reinforcement:

Sprayed is used in underground excavations in rocks as well as the advancement of tunnels through altered, cohesion less, and loose soils. As an application, Sprayed is seldom used in isolation, but is used instead in combination with other forms of support and reinforcement such as rock bolting, cable bolts, lattice girders, or steel sets. Sprayed functions as rock reinforcement in two distinct ways. Being applied to the rock at high pressures, it forces its way into the spaces between intact rock pieces. In this way, it effectively prevents falling of individual pieces, constraining the movements within the mass. Secondly, it gains strength rapidly quickly functioning as a membrane.

Figure 5: sprayed Concrete in tunnel

2.3.3 Slope stabilization:

Unstable slopes can be graded out if sufficient space is available and thus the need of supporting the slope by any material like Sprayed can be avoided. However, the situations may arise where space is limited, as is money, and steep slopes are unavoidable. In these situations, Sprayed might be very useful. Sprayed permanently covers 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 Sprayed to the surface of landfills and other waste areas is beneficial to prevent surface water infiltration. For mass support, the Sprayed may be used with rock bolts and wire mesh, or reinforced with fibers.

Figure 6: sprayed Concrete for slop

2.3.4 New structures:

Sprayed can be easily applied for thin and large sections, where ordinary concrete possesses a lot of problems both in convenience and time. The following paragraphs describe some of the applications involved with construction of new structures.

1. Sprayed can be used extensively for quick lining of canals and water courses for prevention of water seepage. This could prove to be very economical both in terms of money and and time.
2. Sprayed has been used extensively to construct swimming pools and large aquariums. Sprayed can be projected at the walls and slopes of the pool surface without the need

of forms or moulds. A skilled applicator can apply the Sprayed evenly and smoothly in a very short period of time.

3. Sprayed floors in water reservoirs on well compacted sub surface are common and have provided excellent service. Sprayed can be aimed and applied to surfaces at any angle, including overhead. Since Sprayed is applied through a hose and nozzle, it is possible for workers to move in tight spaces.
4. Construction techniques with air accommodating agents have made the construction of Sprayed shells or domes practical. These large structures have been used for residential housing, warehousing, bridge, and culvert applications.

Figure 7: sprayed Concrete new wall

3. Result:

mine personnel can measure early compressive strength development, bond strength, and flexural load capacity. Establishing and monitoring these strength characteristics can improve safety by insuring that the Sprayed used within the ground support system meets the ground support design specifications as shown in this report.

Properly applied Sprayed 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 Sprayed are comparable or superior to those of conventional concrete or mortar having the same composition. Improperly applied Sprayed may create conditions much worse than the untreated condition.

4. Conclusion:

Sprayed is a diverse material. It can be used in a number of situations. The material can be applied to stop the leakage of water in irrigation canals. It can also be used for the retrofitting and rehabilitation of structures damaged by the recent floods. It can be used in situations, where waterproofing is required. The performance of Sprayed can be even made better by incorporation of certain additives and admixtures like fibers, silica fumes etc.

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