Review of IS 9012:1978 recommended practice for shotcreting: Recommendations for inclusion and amendment

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***Abstract*—There has been a rapid advancement of shotcrete technology in international sector since the first Indian shotcrete code was published. Recommended practice for shotcreting (IS 9012) was first published in 1978 and reaffirmed in 2002. The provisions in certain clauses of this code are inadequate. Hence, this paper reviews and compares the codal provisions in IS 9012 with other international codes such as American Concrete Institute (ACI), European Standards (EN) and European Federation of National Associations Representing for Concrete (EFNARC). Also, the paper presents recommended provisions for inclusion and amendment in IS 9012. The paper emphasizes on aspects such as materials, strength, testing, durability and application of shotcrete.**

Keywords—Shotcrete; Sprayed concrete; Tunnels

I. INTRODUCTION

Shotcrete has been has been generally referred as sprayed concrete, spraycrete, gunite, pneumatically applied mortar or concrete, air-blown mortar or concrete and gunned concrete. Indian and American standards term this concrete as shotcrete, whereas European standards term as sprayed concrete. Shotcrete is defined by IS 9012 and ACI 506R as "mortar or concrete (conveyed through a hose) and pneumatically projected at high velocity onto a surface" [1,2]. As per BS EN 14487, sprayed concrete is defined as "concrete produced with basic mix and projected pneumatically from nozzle into place to produce a dense homogeneous mass by its own momentum" [3]. EFNARC states that "sprayed concrete is a mixture of cement, aggregate and water projected pneumatically from a nozzle into place to produce a dense homogeneous mass" [4].

Shotcrete technology has been broadly developed throughout the construction industry over the last century. The current Indian shotcrete code, IS 9012 is not adequate to fulfil the requirement of the present scenario of sprayed concrete construction. The details about the mix design, usage of fibers, long term durability and standard testing procedures for shotcrete are deficient. Also there is no minimum requirement clause for the strength properties such as flexural strength, bond strength and toughness, which aids in achieving shotcrete of controlled quality. Therefore, the current Indian code needs to be upgraded. The need to modify this code arises from factors like growth of knowledge and rapid developments in shotcrete technology worldwide.

Hence in this paper, an attempt has been made to review, compare, document and discuss the guidelines and recommendations of Indian standard and other international standards. The referred standards are ACI 506R-05 (Guide to Shotcrete), ACI 506.1R-08 (Guide to Fiber-Reinforced Shotcrete), ACI 506.5R-09 (Guide to Specifying Underground Shotcrete), BS EN 14487-1-2005 (Sprayed concrete - Definitions, specifications, and conformity) and EFNARC-1996 (European specification for sprayed concrete). The paper also recommends provisions for inclusion and amendment in IS 9012. It has to be noted that, in this paper the term shotcrete or sprayed concrete adheres to wet-mix shotcrete. Also unless otherwise specified the term Indian Standard refers to IS 9012, EN refers to BS EN 14487-1 and ACI refers to the American codes mentioned above.

II. MATERIALS

A. Indian codal provisions

IS 9012 mentions that all the materials for shotcrete shall be complied with the respective Indian standards for particular materials such as cement, aggregates, water, admixture and reinforcement.

B. Commentary and Recommendations

Usage of quality material is a precursor for a durable mix design of shotcrete. Indian standard lists only the codes to be referred for the relevant materials and thus user has to refer the respective codes. In contrast, International codes such as ACI, EN & EFNARC suggest elaborate guidelines for the usage of materials in shotcrete. Other than the properties of materials, these codes also specify the minimum and maximum proportion of shotcrete materials.

i. Cement content

Cement content has a direct impact on the strength of the shotcrete, its durability and impermeability. Too low a cement content may provide inadequate strength and durability. On the other hand, very high cement content can cause shotcrete to suffer from excessive shrinkage and thermal cracking by the heat of hydration. Indian standard remains silent on limits for the minimum and maximum cement content for shotcrete.

International standards have suggested cementitious/cement content for the shotcrete. ACI 506R suggests cementitious content range from 390 to 450 kg/m^3. European standards such as EFNARC and BS EN 14487-1 refer to EN 206 for minimum cement content. EN 206 recommends minimum cement content from 260 kg/m^3 to 360 kg/m^3 to meet the appropriate environmental exposure conditions. However, for sprayed concrete both EFNARC and EN limit the minimum content as 300 kg/m^3. It is inferred that the typical cementitious content specified in ACI includes the cement and pozzolona, whereas the minimum cement content mentioned in EN comprises cement and factored pozzolona (cement + k × additives). The k value varies with respect to type of pozzolana added [5].

As per IS 456-2000, the minimum cement content varies with respect to compressive strength and exposure conditions [6]. The limiting values for cement content related to exposure conditions as recommended in Table I can be incorporated in IS 9012.

TABLE I - MINIMUM CEMENT CONTENT

Exposure condition	Minimum Grade of Shotcrete	Minimum Cement Content (Kg/m^3)
Mild	M 20	340
Moderate	M 25	340
Severe	M 30	360
very Severe	M 35	380
Extreme	M 40	400

Note:

1) Exposure conditions are as defined in Table III of IS 456.
2) Cement content is irrespective of grade of cement and it is inclusive of pozzolana.
3) Minimum cement content prescribed in this table is for aggregate of 10mm nominal maximum size.
4) Cement content of plain shotcrete shall not be less than 300 Kg/m^3.

ii.Aggregate

Fine aggregate

The use of finer sand will generally result in greater drying shrinkage and coarser sand in more rebound. The Indian standard suggests that sand for shotcrete shall grade evenly from fine to coarse as per Zone II and Zone III grading of IS 383-1970 [7].

The fine aggregate grading limits specified by IS 9012 and ACI 506R are in similar lines. The grading zone for fine aggregate suggested by IS 9012 as per IS 383 can be adopted.

Coarse aggregate

Indian standard suggests that coarse aggregate shall conform to one of the grading with nominal maximum aggregate size of 10, 12.5 and 20 mm as illustrated in Table I of IS 9012.

ACI 506R suggests the combined aggregates (fine and coarse) conform to either grading #1 or grading #2 with maximum aggregate size of 4.75 or 10 mm respectively.

In practice, it has been observed that a coarse aggregate with maximum size of 10mm will promote an in-place shotcrete composition as close as possible to that of cast -in- place concrete [8]. ACI also specifies 10mm maximum aggregate size as discussed above. Thus 12.5mm and 20mm maximum aggregate size specified in IS 9012 can be omitted and the maximum aggregate size can be limited to 10mm.

Fine and coarse aggregate ratio

Coarse aggregate to fine aggregate ratio is obviously one of the most important parameters in shotcrete mix design and it is represented by aggregate packing density, which is an indicator of the amount of voids between the aggregate particles. The Indian standard does not include the proportioning of coarse and fine aggregate. ACI 506R specifies total aggregate will consists of 20% to 30% coarse aggregate and 70 to 80% fine aggregate. It is recommended to incorporate the values suggested as per ACI 506R in the Indian standard.

iii. Water Cementitious Ratio

The water cementitious (w/cm) ratio should be as low as possible to achieve high strength and durable shotcrete. The Indian standard specifies a maximum w/cm of 0.5.

ACI 506.5R specifies maximum w/cm of 0.45 [9]. Similarly, ACI 506R suggests a typical range for w/cm as 0.4 to 0.5 without admixture and also lower w/cm is possible with the use of water-reducing admixtures. EFNARC specifies maximum w/cm as 0.55. EN refers to EN 206 for maximum w/cm. EN 206 recommends maximum as 0.55.

A typical water cement ratio of 0.4 to 0.5 is recommended and it can be further reduced using appropriate admixture.

iv. Pozzolana

Pozzolana in shotcrete enhances the strength and durability properties through either purely physical effects or physico-chemical effects, which results in pore-size and grain-size reduction phenomena [10].

Indian standard suggests only the usage of Portland slag cement and Portland pozzolana cement with no mention of pozzolanic materials in shotcrete.

ACI 506.5R suggests a typical range from 7 to 10% (Max 15%) for the replacement of cement by silica fume. It also mentions that addition of fly ash and slag is acceptable only if all shotcrete performance requirements can be demonstrated during preconstruction testing. EFNARC has given max percentage of silica fume as 15% of Portland cement. It has also given that max percentage of fly ash and GGBS each as 30% of Portland cement. Thus it is proposed that the Indian standard should recommend an appropriate percentage of pozzolanic materials for the replacement of cement in shotcrete. Although slag, fly ash and silica fume are used for durability requirement and cost effectiveness, codes and literatures generally specify silica fume with shotcrete instead of fly ash and slag. This may be due to the fact that silica fume increases early compressive and flexural strength of shotcrete considerably than fly ash and slag. As noted earlier, even ACI has suggested the usage of fly ash and slag only after preconstruction testing. Thus, it is recommended to incorporate maximum percentage of silica fume as 15% of Portland cement. The dosage of fly ash and slag shall be as per the design requirement of the project but the maximum replacement shall not exceed 30%.

v.Reinforcement

Broad classification of reinforcement types used in shotcrete is illustrated in Fig. 1. Indian standard mentions reinforcing bars and welded wire fabric as reinforcement in shotcrete whereas fibers are extensively used in current practice. In underground and tunnel construction, it has become more common to use fiber reinforcement instead of steel-mesh reinforcement.

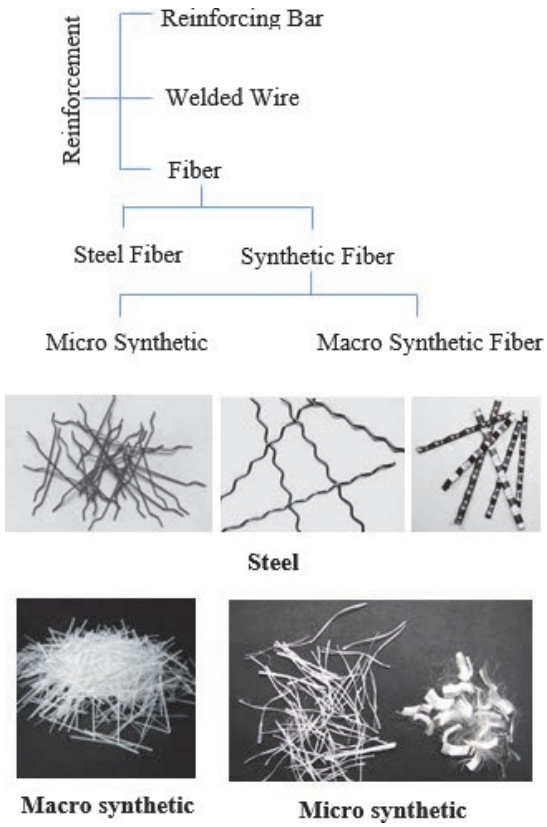

Fig 1 - Reinforcement in Shotcrete

. Fibers eliminate the need for conventional reinforcing steel and welded wire mesh by imparting toughness or energy absorption capability to hardened shotcrete. Additionally, fiber reinforced shotcrete has high ductility, provides homogeneous fibre reinforcement and strong bond to the surface [11].

Indian standard has not specified fibers for shotcrete reinforcement. Other international standards such as ACI apart from suggesting reinforcing bars and wire mesh have extensively dealt with fibers also.

Typical length and diameter for different types of fiber as per ACI is presented in Table. II. Both ACI and EN discuss the dimensions and tolerances of steel fibers. As per both the codes permissible deviation of the nominal/declared value from the specified value shall not more than 10% for length and diameter and 15% for aspect ratio respectively. In addition, EN also specifies deviation of the average value relative to the declared value.

A typical range of minimum and maximum dosages of different types of fiber used in shotcrete as per three ACI codes are depicted in Fig. 2. ACI reports specific dosages for both steel and synthetic fibers whereas, EN although elaborates extensively on fibres it has not included dosage for fibres. As seen from the graph there is a variation in dosage of steel fibers within ACI codes.

The dosage and type of fiber shall be selected based on the design requirement of the project.

TABLE II - FIBER DIMENSIONS

Code	Steel Fiber				Micro Synthetic Fiber				Macro Synthetic Fiber	
	Length (mm)		Diameter (mm)		Length (mm)		Diameter(mm)		Length(mm)	Dia (µm)
	Min	*Max*	*Min*	*Max*	*Min*	*Max*	*Min*	*Max*	*Max*	*Max*
ACI 506.1	19	35	0.4	0.8	40	50	0.4	0.8	12	33
ACI 506.5	25	35	Min aspect ratio - 40		45	55	-	0.8	12	32

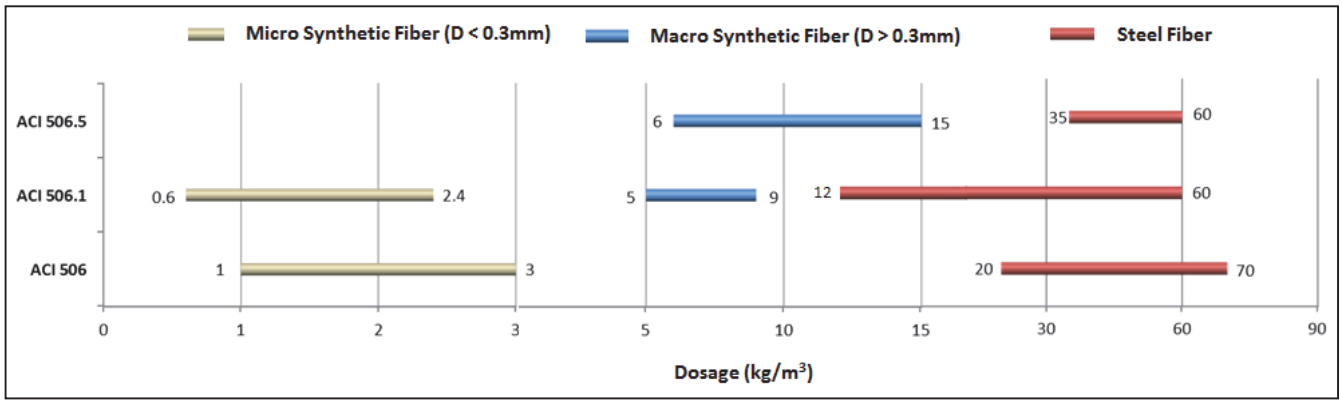

Fig 2 - Fiber Dosages

III. Strength Properties

A. Indian codal provisions

The physical properties of sound shotcrete in place are comparable to those of conventional mortar or concrete of the same composition. Most reported values for 28 days compressive strength are in the range of 20 to 50 N/mm^2. It is suggested that strength higher than 25 N/mm^2 be specified only for the most carefully executed shotcrete jobs.

B. Commentary and Recommendations

Indian standard does not mention minimum requirement for the strength properties such as flexural strength, bond strength and toughness of shotcrete to be achieved. Provisions mentioned in other International standards are elucidated below

i. Compressive strength

IS 9012 mentioned that the compressive strength of 28 days shotcrete are in the range of 20 to 50 MPa. Whereas, ACI 506R reports that the strength of wet mix shotcrete is generally between 30 to 50 MPa and strengths over 100 MPa have been reported. ACI 506.5R specifies the minimum compressive strength as 30 MPa whereas for some special application such as permanent tunnel lining, compressive strength of 40 MPa or more is specified.

EFNARC states that compressive strength classes of sprayed concrete vary from C24/30 to C48/60. The minimum compressive strength of C24/30 and C48/60 are 20.5 MPa and 41 MPa respectively as per the in-situ strength requirement. EN refers to EN 206-1 for the compressive strength classes of sprayed concrete. EN 206-1 lists compressive strength class from C8/10 to C 100/115.

Compressive strength of shotcrete depends on improving density of the material, maximizing hydration of cement and minimizing porosity. Modern specifications typically require compressive strengths of 20 MPa (for temporary sprayed concrete) to 40 MPa or higher (for permanent sprayed concrete) at 28 days [12]. Thus current minimum compressive strength of 20 MPa in IS 9012 should suffice for the Indian conditions.

ii. Flexural Strength

Flexural strength is usually specified for fiber reinforced shotcrete. Load deflection curve obtained by testing a simply supported beam under third-point loading is used for the evaluation of flexural strength. Minimum flexural strength as per ACI & EFNARC is presented in Table III.

TABLE III - MINIMUM FLEXURAL STRENGTH

Minimum Flexural Strength (MPa)			
ACI 506.5	EFNARC		
	C 24/30	*C 36/45*	*C 44/55*
4 to 4.5	3.4	4.2	4.6

It is a well-known fact that the flexural strength increases in accordance with compressive strength. Dosage of fiber also influences flexural strength of shotcrete. For a typical M40 grade shotcrete, flexural strength from 4 to 4.5 MPa is recommended, whereas up to 6 MPa can also be achieved.

iii. Bond strength

Strength developed between the substrate and shotcrete layer can be termed as bond strength. Inference from both ASTM and EN is if the failure occurs in the bond zone then it is reported as bond strength between the two materials whereas if the failure occurs in any individual material then it is reported as tensile strength of that material. Bond strength reported in ACI is illustrated in Fig. 3.

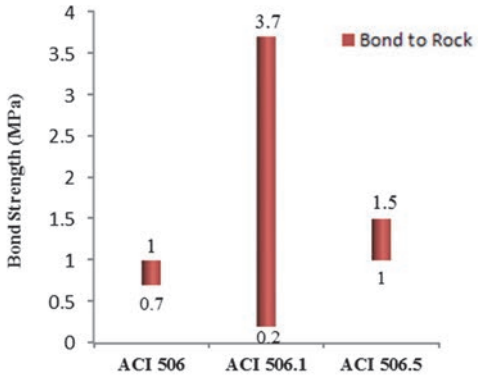

Fig 3 - Bond Strength (ACI)

Bond strength mentioned in ACI 506.1 & 506.5 is between shotcrete and rock whereas in ACI 506, it is not clearly mentioned. As depicted above there is a variation in the range of bond strength specified within ACI codes.

Minimum bond strength required as per EFNARC is demonstrated in Fig. 4.

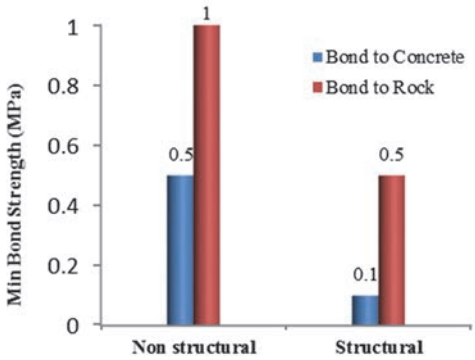

Fig 4 - Bond Strength (EFNARC)

Typical value of 0.5 to 1.5 MPa is recommended for bond strength between shotcrete and rock. These values might vary depending on the fiber content.

iv. Toughness

As per ACI 506.1R toughness energy is quoted as "ability of the shotcrete specimen to absorb energy before and after cracking" [13]. Energy absorption as per ACI & EFNARC is illustrated in below

The energy absorption of the shotcrete panel depends on centrally loaded round panel or square panel test method. Thus a minimum energy absorption value of 280 joule (Upto 40 mm deflection) and 500 joule (Upto 25 mm deflection) is

recommended for round panel and square panel test respectively.

TABLE IV – ENERGY ABSORPTION

Energy Absorption (Joule)			
ACI 506.5	**EFNARC & EN**		
for deflection upto 40mm	*for deflection upto 25mm*		
280	a	b	c
	500	700	1000

IV. DURABILITY PROPERTIES

A. *Indian codal provisions*

Indian standard specifies a drying shrinkage range of 0.06% to 0.1% for the shotcrete. As far as durability is concerned Indian standard has a brief mention that durability of shotcrete in laboratory tests and under field exposure has generally been good.

B. *Commentary and Recommendations*

Permeability and porosity are the two important factors for a durable shotcrete and they in turn affect the other parameters such as strength and ability to resist deterioration mechanism. Codal provisions pertaining to above discussed parameters in the other international standards have been elaborated below

i. *Absorption and volume of permeable voids*

Boiled Water Absorption (BWA) and Maximum Volume of Permeable voids (VPV) are related in the sense they both measure porosity due to capillary action in the sample, but express differently. BWA represents mass ratio whereas the VPV represents the volumetric ratio of water absorbed. ACI 506R recommends acceptable values of permeable void volume in the range of 14 to 17% and typical boiled absorption values in the range 6 to 9%. Similarly, ACI 506.5R specifies maximum volume of permeable voids at 7 days as 17% and maximum boiled absorption at 7 days as 8%.

Test method as per ASTM C642 can be incorporated in the Indian standard to find BWA and VPV. Morgan et al (1987) have published quality indicators based on ASTM C 642 results, as shown in the table below [14].

TABLE V – VPV AND BWA

Shotcrete quality	Permeable void volume (%)	Boiled water absorption (%)
Excellent	< 14	< 6
Good	14 to 17	6 to 8
Fair	17 to 19	8 to 9
Marginal	> 19	> 9

EFNARC and EN does not include the concept of BWA and VPV. Although table suggested by Morgan are being used as a quality indicator, further research is underway to establish clear relationship between BWA and compressive strength and also between BWA and durability of shotcrete.

ii. *Permeability*

EFNARC suggests a maximum value of water penetration in accordance with EN 7031 as 50mm and the mean average value shall be less than 20mm. Also it states that sprayed concrete is considered water-tight when the coefficient of water permeability is less than 10-12 m/s. Similarly EN suggests resistance to water penetration in accordance with EN 12390-8 as 50mm [15]. Latest test procedure as per EN can be incorporated in the Indian Standard to measure permeability.

iii. *Air content*

Air content (%) and spacing factor are related to the freezing and thawing resistance of shotcrete. The term "spacing factor" refers to the distance between air bubbles in hardened shotcrete. ACI 506R recommends an entrained air-void system with in place air content in the range of 4 to 6% with a maximum air void spacing factor of 0.3mm to resist freezing and thawing cycles. Further it states that total air content in concrete before shooting as 6 to 10%.

ACI 506.5R suggests air content as shot: 4 ± 1% and Air content immediately before the pump as 7 to 10%. Further it states a maximum spacing factor of 0.3mm for as shot. A minimum air content of 7 ± 1% before shooting and 4 ± 1% as shot is recommended where freezing and thawing resistance is of interest.

EFNARC and EN does not discuss the concept of air content. EN has noted that current available test methods for the measurement of air content do not give reliable data results for fresh sprayed concrete.

V. TESTING

A. *Indian codal provisions*

Indian standard focuses on the compressive strength from preconstruction testing. The code suggests that the cubes or cores shall be taken from the panel of size 75 x 75 cm with thickness same as in the structure but not less than 7.5cm. It also specifies the core shall have a minimum diameter of 7.5 cm and a length-diameter ratio of at least 1.

B. *Commentary and Recommendations*

Compressive, flexural and energy absorption tests are widely adopted to evaluate shotcrete quality. Similarly, bond strength is adopted to examine the strength developed between the shotcrete layer and substrate such as rock or concrete.

Brief description of the test method specifications mentioned in international standards has been discussed below. As the Indian standard does not include any of the below mentioned tests, it is recommended to incorporate these test methods.

i. *Flexural strength Test*

ACI refers ASTM C1609 for the testing of flexural strength of shotcrete. The code recommends Third-point loading test with deflection controlled machine. This test method utilizes two preferred specimen sizes of 100 x 100 x 350mm tested on a 300 mm span (or) 150 x 150 x 500 mm tested on a 450mm span as presented in Fig 5. ACI suggests an increase in rate of deflection as illustrated in Table VI.

TABLE VI – RATE OF INCREASE IN NET DEFLECTION

Beam Size (mm)	Rate of Increase in Deflection	
	Deflection upto L/900	*Deflection beyond L/900*
100 x 100 x 350	0.025 to 0.075 mm/min	0.05 to 0.2 mm/min
150 x 150 x 500	0.035 to 0.1 mm/min	0.05 to 0.3 mm/min

EFNARC and EN 14488-3 also suggest Third-point loading with deflection controlled machine [16]. Both specify the test specimen of size 125 x 75 x 600mm tested on a span of 450mm. The code mentions the deformation rate of the midspan of the beam shall be 0.25 ± 0.05mm per minute until a deflection of 0.5mm. After this point the rate of deflection can be increased to 1 mm/min.

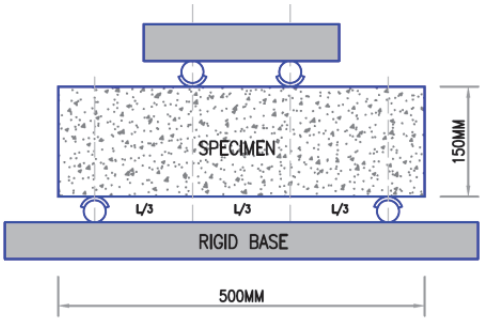

Fig 5 - Third Point Loading Test

A noteworthy point is third point loading of the beam is the standard test mentioned in all the codes for the flexural strength test and preferred choice is the deflection controlled machine. EN and EFNARC mention that the test shall be finished when the mid span deformation exceeds 4mm or the specimen fractures. But ACI does not specify the upper limit of deflection to finish the test.

ii. Energy absorption test

ACI refers ASTM C1550 for the testing of energy absorption or toughness of shotcrete. The code recommends centrally loaded round panel test with a deflection controlled testing machine. It specifies a specimen with diameter of 800 ± 10 mm and thickness of 75 -5/+15 mm as depicted in Fig 6. The code suggests that the loading shall be applied so that the piston advances at a constant rate of 4.0 ± 1.0 mm/min up to a central displacement of at least 45mm and the fixture supporting the panel during testing shall include three symmetrically arranged pivot points on a pitch circle diameter of 750mm. Further it states that the energy absorption capacity in joules is reported as the area under the load-deflection curve between 0 and 40 mm deflection.

EFNARC and EN 14488-5 suggest centrally loaded square plate test with a deflection controlled testing machine for the testing of energy absorption or toughness of shotcrete. Both specify a specimen of size 600 x 600 x 100 mm in illustrated in Fig 7. Further these codes state that the specimen shall be supported on its 4 edges and a center point load is applied through a contact surface of 100 x 100mm.

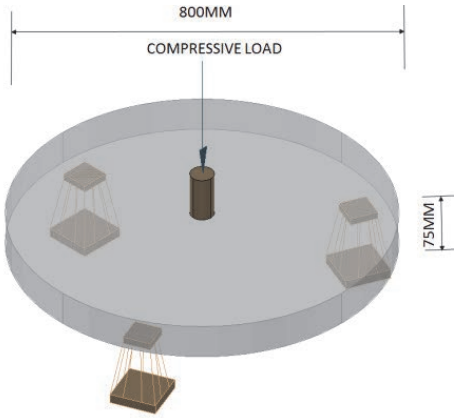

Fig 6 - Energy Absorption Test (ACI)

EFNARC suggests that the rate of deformation of the midpoint shall be 1.5mm per minute and the test shall continue until a deflection of 25mm is achieved at the center point of the slab. EN 14488-5 suggests that the loading shall be at a constant rate of 1 ± 0.1 mm/ min at the center of slab and the load-deflection shall be continuously recorded with the data logger until a deflection of at least 30mm is obtained. It specifies the energy absorption capacity in joules is reported as the area under the load-deflection curve between 0 and 25 mm deflection.

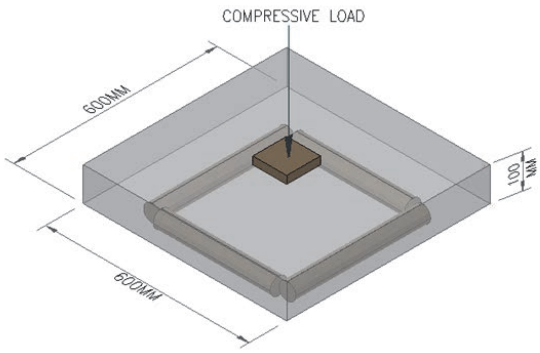

Fig 7 - Energy Absorption Test (EN & EFNARC)

The energy absorbed by a given mix in a square EN 14488-5 panel test at 25 mm central deflection is approximately 2.5 times the magnitude of energy absorbed by the same mix in the ASTM C-1550 at 40 mm central deflection [17].

iii. Bond strength test

ACI refers ASTM C1583 for the testing of bond strength of shotcrete and rock/concrete. The code suggests Direct tension (Pull-off method) test with tensile loading machine. In this test method, a test site of 1m x 1m is prepared and core of 50mm is drilled to at least 10mm below the concrete-overlay interface and tested without extracting the core as presented in Fig 8. It specifies a rate of loading of 0.035 ± 0.015 MPa per second.

EFNARC and EN 14488-4 also suggest Direct tension test for the testing of bond strength of shotcrete and rock/concrete. The core is drilled out and extracted from sprayed concrete layer

together with a portion of the substrate rock/concrete and then tested as depicted in Fig 9

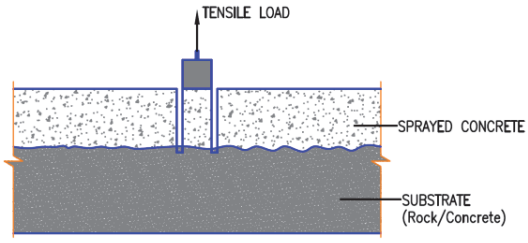

Fig 8 - Direct tension test (Pull-off method) – ACI

.EFNARC specifies a specimen with core diameter of 50 to 60 mm. The code suggests the rate of loading shall be 1 to 3 MPa per minute. EN specifies a specimen with core diameter of 50 to 100mm and length not less than 2d. The code suggests the rate of loading shall be 0.05 ± 0.01 MPa per second.

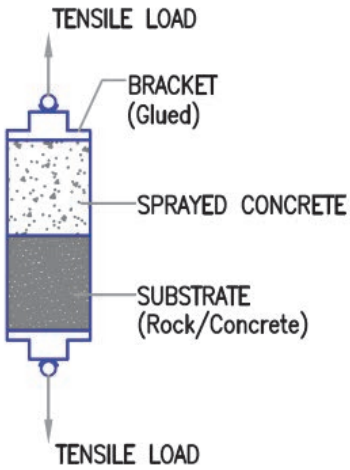

Fig 9 - Direct tension test (Pull-off method) – EN & EFNARC

VI. Application

A. *Indian codal provisions*

Indian code has suggested methods for reducing the rebound during application of shotcrete. Depending on the position of the work, the standard has specified the percentage of rebound as listed in Table VII.

B. *Commentary and Recommendations*

Optimum nozzle distance is a precursor to attain a properly compacted quality shotcrete. Minimum nozzle distances of 0.6 & 1m and maximum nozzle distances of 1.8 & 2m are recommended in ACI & EN. Adjustment of impact velocity of shotcrete is important at varying nozzle distance.

Rebound primarily depends on the expertise of the nozzle operator. Because of the relatively high impact velocity, the concrete and the fibers do not adhere completely onto the treated surface and generally a large quantity of rebound is observed [18]. Lesser rebound is an indicator of quality shotcrete and efficient application. The percentage of rebound values for different type of surfaces as per ACI 506R is depicted in Table 7.

Larger aggregates and fibers show a significant rebound in shotcrete. Lower aggregate density and the addition of fine particles reduce aggregate rebound. Synthetic fibers display lower rebound than steel fibers. Also advanced application techniques have evolved in recent times which reduce rebound. Hence aggregate size, fiber type and application technique plays a key role in the percentage of rebound in shotcrete. Considering the aforementioned factors and surface of application, the values for percentage of rebound is recommended as proposed in Table VII. EN and EFNARC have not included the criteria for percentage of rebound.

Table VII – Percentage of Rebound

Surface	% of Rebound		
	IS 9012	**ACI 506R**	**Proposed**
Floors or Slabs	5 to 15	0 to 10	0 to 5
Sloping & vertical walls	15 to 30	10 to 30	10 to 30
Overhead work	25 to 50	10 to 30	15 to 30

VII. Summary and Conclusion

As noted earlier there has been a tremendous improvement in the shotcrete technology. Newer concepts have evolved in quality of materials, design and the application technology. For instance, shotcrete robots have replaced nozzle men and fibers replaced the reinforcement bars. The Indian standard has addressed few issues but needs further improvement in some details. In this context, the current international codes for shotcrete such as ACI, EN and EFNARC have been referred and discussed. Also, recommendations have been suggested for updating Indian Standard.

- Major areas requiring improvement in the Indian standard for shotcrete are as below
- The provisions on cement, aggregate and pozzolana needs to be updated.
- Latest ACI and EN have a specific code for fiber reinforced shotcrete. Specifications and guidelines for the usage of fibers in shotcrete to be incorporated or specific code for fiber reinforced shotcrete has to be published.
- More elaborate detail pertaining to flexural strength, bond strength, energy absorption and their testing methodology should be included.
- The percentage of rebound of shotcrete requires to be modified.
- Important durability factors such as absorption, volume of permeable voids, permeability and air content have to be added.

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