

# Possibilities of Assessment of Calibration Relationships for Various Methods of Production of Shotcrete

Adam Hubacek, Rudolf Hela

**Abstract**—The Shotcrete technology is beginning to apply in practical implementations especially in underground construction and the refurbishment and reconstruction of various types of concrete structures. They applied the new test standards and guidelines for the design, application and testing of sprayed concrete. Under these regulations are developed as well as individual calibration curves for assessing the increase in strength of young sprayed concrete. This increase in strength is mainly influenced by the dose of additives for accelerating hardening of cement and concrete. Currently, there is a method that would allow the possibility of the draft determination and prediction of strength of young sprayed concrete using commonly available laboratory equipment.

The aim of the paper is assessment of possibilities of shotcrete by means of common laboratory equipment. Concrete manufactured in traditional way is compared to shotcrete of identical composition. Influence of accelerating admixtures on development of strength of young shotcrete, strength of hardened concrete and other selected properties is observed.

**Keywords**—Shotcrete, compressive strength, early stage shotcrete

## I. INTRODUCTION

**S**HOTCRETE is predominantly applied in tunneling with the new Austrian tunneling method, where shotcrete is used as the main material of primary tunnel lining. Shotcrete can be used for temporary securing of excavation, it is sometimes used as construction material of final lining. Such applications demand higher quality and longer lifetime of shotcrete. Technology of shotcrete lies in transporting concrete by compressed air through a nozzle and sprayed onto base surface, creating dense and homogeneous layer. Shotcrete consists of basic concrete components (binder, aggregate, water, additives, admixtures); it can be either plain or reinforced (steel reinforcement, fibers). [6]

Shotcrete is described in the European standard CSN EN 14487-1 Shotcrete – Part 1: Definition, specification and compliance. Shotcrete is applicable mainly in special conditions, like absence of formwork, application in thin layers, fast setting and high initial strength or other special construction methods. More than 90% of shotcrete is applied in underground structures.

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## II. PROPERTY OF SHOTCRETE

It is necessary to realize that shotcrete differs from common compacted concrete mainly in the technology of application onto base layer. Composition of shotcrete is comparable to composition of common compacted concrete, however, after spraying, their properties are different. The difference is not only in strength, which is influenced mainly by accelerators, but also in water tightness, frost resistance and related durability of shotcrete. Spraying concrete onto base layer changes distribution of porous structure, certain part of shotcrete drops, and proportion of fine parts increases, which can cause shrinking. All these facts have to be taken into account in designing shotcrete structures.

It is also necessary to determine stability of base material (rock) for appropriate specification of shotcrete. Thin layers of concrete on hard rock preventing fall out of free stones have to show very good adhesive power. Tensile strength is marginal in such applications. However, if shotcrete should support bound circular ring, then compressive strength is the most important parameter and adhesive power is almost negligible.

### A. Young shotcrete

Shotcrete is considered young until the age of 24 hours after spraying. Strength of young shotcrete is one of the most important properties. Development of strength within first minutes after spraying is crucial for the volume of drop, in particular if thicker layers are sprayed or the base surface is overhang. Shotcrete in tunnel structures is usually sprayed in layers thicker than 10 cm, therefore initial strengths are very important. Weight of 10 cm thick layer is around 220 – 235 kg/m<sup>2</sup>. Strength of young shotcrete can be increased by adding accelerating admixtures at the nozzle of spraying apparatus. [7] Many parameters influencing initial development of strength are important at the stage of designing shotcrete. Therefore it is difficult to anticipate development of strength.

*The main parameters are following:*

- type and amount of accelerating admixture
- water cement ratio
- type and amount of cement
- temperature of fresh concrete and surrounding temperature
- retarding influence of some additions

As for development and requirements of strength, young shotcrete falls into ranges J1, J2 J3.

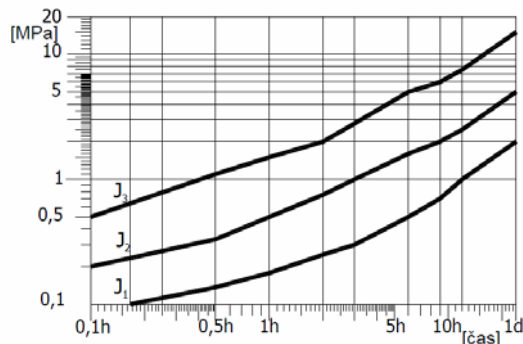


Fig. 1 Ranges of strength development of young shotcrete

Testing of young shotcrete is required mainly in the field of underground constructions. However, it is often impossible to take samples of shotcrete and transport it to laboratory; therefore methods of testing strength of young shotcrete from the point of application to reaching optimal strength for further layer are developed. (Morgan, D. E. R. 2008)

#### *B. Possibilities of Determination of Calibration Relationships to Assess Strength of Shotcrete*

The paper deals with the dominant physico-mechanical parameter of shotcrete – compressive strength. Because new standards describing design, application and testing shotcrete for repairs and renovation of structures, for new structures and reinforcement of land came into force in the Czech Republic in 2006 – 2007, it is necessary to assess physico-mechanical properties of shotcrete in accordance with the new regulations. Testing young shotcrete – determination of strength development within the first 24 hours from application – seems to be the most important step. These values are usually determined with a penetration needle and with the method of shooting nails into the layer of concrete. Recommended calibration curves are used to determine early compressive strength by means of individual methods in accordance with testing standards. However, these calibration relationships are rather general and do not take into account differences between basic properties of input materials. These properties usually vary considerably depending on origin of filler and raw materials used for production of cement.

At the same time, there is no method of manufacturing concrete mix for shotcrete in laboratory conditions without using spraying apparatus and predicting final properties of the material on the basis of tests. Methods of predicting properties of shotcrete in laboratory conditions without necessity of spraying concrete onto base surface are being examined. In this way, it would be possible to test various compositions and enhance properties of shotcrete. However, it is necessary to determine relationships between properties of shotcrete made by usual technology of spraying and concrete mixed in laboratory mixer, placed, and compacted in testing formwork. The aim is to propose manufacturing procedure and testing method for the two technologies, which seem to be

diametrically different. Based on the results, calibration relationships will be determined between these two technologies of manufacture and application of concrete.

The aim is to find and determine relationship between properties of shotcrete made in two different ways: concrete applied by spraying and concrete made in laboratory mixer, placed in testing formwork and compacted.

The aim of this paper is determining possibilities of testing properties of shotcrete – in particular compressive strength of young shotcrete – on testing specimens manufactured in common laboratory way. Concrete was always compacted by the same method – vibration with slight pressure; testing specimens with dimensions (500 x 500 x 150) mm were made to assess possibilities of testing shotcrete made in laboratory and predicting its properties after machine application. The main tested property was ability of concrete to compact even in case when testing specimens (boards) are made from concrete prepared in laboratory mixer and required dose accelerator of setting is added consequently. Concrete was manufactured, testing specimens made and properties tested as follows:

- Determination of compressive strength of “zero” shotcrete, i. e. concrete with no accelerator of setting added. Testing specimens in the shape of cylinders with diameter 100 mm were made.

- Determination of strength of young shotcrete by means of penetration needle at times 3, 6, 15, 30, 60, 90, 120 and 180 minutes. These tests were carried out in accordance with the procedure stated in CSN EN 14482-2.

- Determination of compressive strength of young shotcrete with the method of shooting nails at times 3, 6, 9 and 24 hours. These tests were also carried out in accordance with the procedure stated in CSN EN 14482-2.

The main goal is assessment of possibility of comparison properties of concrete of concrete applied by machine spraying and concrete made in common laboratory way. For this reason, two testing mix-designs were made with two different doses of accelerator ready for common machine application. Based on results, individual alternatives of preparation of shotcrete were compared and possible relationship between methods assessed with the aim of determination of calibration relationships for shotcrete made in above mentioned ways.

### III. EXPERIMENTAL PROGRAM

Tested concrete was made from Portland cement CEM I 42.5 R manufactured by CEMEX, Detmarovice plant, with superplasticizer Dynamon SX14 and accelerator of setting for shotcrete Mapequick FK 889. Dose of accelerator was between 3% and 7% by amount of cement used. Aggregate used: size fraction 0-4mm mined in Detmarovice quarry, coarse mined aggregate 4-8 mm from the same area.

Shotcrete was prepared and applied in two ways. To collect data for comparison of properties, the first four mix-designs were made in common way, i.e. by wet machine spraying.

This way of application enables exact control of mixing water in concrete. To determine properties of shotcrete made in common laboratory manner, “zero” concrete was prepared in laboratory mixer, i.e. concrete with no accelerator added. After determination of consistency, accelerator of setting was added. Then, concrete was mixed for another minute. Placing concrete into testing formwork and compacting was carried out as follows: testing formwork was placed on vibration table and concrete was intensely vibrated for two minutes after filling formwork. Slight pressure of ca 200 kg/m<sup>2</sup> was used during vibrating. Concrete prepared in above mentioned way was tested within the first 24 hours after application – compressive strength was determined by means of penetration needle and shooting nails. Compressive strength of hardened concrete was tested on drilled cores at the age of 7 and 28 days. Water absorbing capacity of concrete was also tested. Following tables and diagrams give test results.

TABLE I  
PROPERTIES OF ZERO CONCRETE

Lbl.	Slump [mm]	Compressive strength		Volume weight of concrete	
		7 days	28 days	7 days	28 days
		[MPa]	[MPa]	[kg.m <sup>-3</sup> ]	[kg.m <sup>-3</sup> ]
ZC	220	28,7	39,5	2250	2230

TABLE II  
PROPERTIES OF SHOTCRETE MADE IN LABORATORY WAY

Assessed property	Mix of shotcrete SCL			
	SCL1	SCL2	SCL3	SCL4
	3	5	7	9
Dose of accelerator				
PN - 1 min (MPa)	0,04	0,07	0,09	0,09
PN - 3 min (MPa)	0,11	0,15	0,15	0,17
PN - 6 min (MPa)	0,11	0,20	0,22	0,35
PN - 15 min (MPa)	0,15	0,25	0,29	0,43
PN - 30 min (MPa)	0,20	0,31	0,35	0,48
PN - 60 min (MPa)	0,25	0,36	0,52	0,66
PN - 90 min (MPa)	0,31	0,45	0,63	0,72
PN - 120 min (MPa)	0,39	0,50	0,78	0,91
MSN - 3 hrs (MPa)	0,55	0,84	1,4	1,8
MSN - 6 hrs (MPa)	0,85	1,5	2,1	2,4
MSN - 9 hrs (MPa)	2,9	5,1	7,0	7,2
MSN - 24 hrs (MPa)	13,1	12,8	11,9	13,5
CS - 7 days (MPa)	30,4	30,7	28,6	29,2
CS - 28 days (MPa)	36,7	35,2	33,9	34,6
WAC 28 days (%)	4,9	5,4	6,1	8,4

TABLE III  
PROPERTIES OF SHOTCRETE MADE IN COMMON WAY } MACHINE SPRAYING

Assessed property	Mix of shotcrete SC			
	SC1	SC2	SC3	SC4
	3	5	7	9
Dose of accelerator				
PN - 1 min (MPa)	0,06	0,06	0,09	0,06
PN - 3 min (MPa)	0,10	0,13	0,15	0,10
PN - 6 min (MPa)	0,11	0,22	0,25	0,11
PN - 15 min (MPa)	0,17	0,28	0,34	0,17
PN - 30 min (MPa)	0,22	0,36	0,41	0,22
PN - 60 min (MPa)	0,28	0,43	0,51	0,28
PN - 90 min (MPa)	0,35	0,48	0,60	0,35
PN - 120 min (MPa)	0,41	0,61	0,69	0,41
MSN - 3 hrs (MPa)	0,64	0,9	1,3	0,64
MSN - 6 hrs (MPa)	1,0	1,9	2,4	1,0
MSN - 9 hrs (MPa)	2,4	6,8	6,4	2,4
MSN - 24 hrs (MPa)	15,7	12,6	12,0	15,7
CS - 7 days (MPa)	32,8	31,3	30,8	32,8
CS - 28 days (MPa)	38,2	36,2	37,3	38,2
WAC 28 days (%)	4,9	5,2	6,6	7,4

Note: SCL – Shotcrete made in laboratory way  
SC – Shotcrete applied by spraying machine  
PN – Penetration needle  
MSN – Method of shooting nails  
WAC - Water absorbing capacity

#### IV. CONCLUSION

The paper deals with problems of determination of calibrating relationships to calculate strength of shotcrete. Tested concrete was made in laboratory mixer and compacted with slight pressure as well as applied by means of machine spraying. Test results imply that determined parameters of “laboratory concrete” are comparable with the values determined on mix-designs applied by machine spraying. So far, only mix-designs with 3%, 5% and 7% of accelerator were completely compared. However, above-mentioned values imply certain similarity between parameters of compressive strength. Values of water absorbing capacity differ; concrete prepared in laboratory showed lower values of water absorbing capacity. However, to determine calibration relationships, it is necessary to compare also other properties with considerable influence on strength parameters and shotcrete as such. It is necessary to compare effectiveness of laboratory compaction and common machine spraying. One of possibilities is comparison of compactness of concrete. To compare compactness of concrete, determination of volume weight in accordance with CSN EN 12390-7 has to be carried out: determination of volume weight with the method for regular shape objects and with the method of underwater weighing for irregular shape objects. The same values of density or volume weight would be an important basis for comparability of different methods of compaction. Based on measured values, calibration relationships will be determined to assess strengths of shotcrete applied in various methods.

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