Application and Testing of Shotcrete According to the Austrian Guideline on Sprayed Concrete

By Wolfgang Kusterle

In 1989, the Austrian Concrete Society published a Guideline on Shotcrete that subsequently served as a reference work and a contractual basis for shotcrete works in tunnel construction in Austria and abroad. Other standards, such as DIN 18551, focused more strongly on shotcrete for concrete repair works. At the end of 1998, after several revisions, a new edition of the Austrian Guideline was published that also considers recent developments in the field of shotcrete technology. Dealing with a whole range of issues, from base materials for sprayed concrete production to contractual aspects, the 80-page guideline will retain its value as a document of topical importance, even after publication of a European Standard (Working Group TC 104/ WG 10). The text of the guideline is also available in English.[1]

Table 1

	Dry-mix shotcrete			Wet-mix shotcrete
Water content of aggregates	W < 0.2% by mass	Standard W = 2.0 to 4.0% Scatter 1.5 to 5.0% by mass		W < 8.0% by mass
Designation	dry-mix	moist-mix storable	moist-mix for immediate placing	wet-mix (pumped concrete)
Designation, abbr.	**TM**	**FM-L**	**FM-S**	**NM**
Binder	Tunnel cement TZ and accelerator or SBM-T, FT	Tunnel cement TZ and accelerator	SBM-FT	Tunnel cement TZ and accelerator
Addition of EB-AF	If necessary in mixing plant	During working	(If necessary during working)	During working
Production	Plant or site mixing	Plant or site mixing	Continuous mixing during working	Plant or site mixing
Storage	Closed (for example, bin, bag)	Sheltered	—	Sheltered
Availability	Unlimited	Limited	Unlimited	Limited
Storage time (without long-term retarder)	Storage according to requirements	Produced in advance, to be used within storage time (maximum 1.5 h)	Produced for immediate use	Produced in advance, to be used within storage time (maximum 1.5 h)

Shotcrete mixture classification, abbreviations:

- TM: dry-mix for the dry-mix process with oven-dry aggregates
- FM-L: moist-mix, storable, for the use in dry-mix process (conventional dry-mix process)
- FM-S: moist-mix, for immediate application in dry-mix process (for use with spray cement)
- NM: mixture for the wet-mix process
- TZ: tunnel cement, portland cement particularly suited for tunnelling
- SBM: spray cement — general term used to designate fast-setting binders that ensure the required rate of setting and strength development in fresh sprayed concrete without addition of accelerator
- SBM-T: spray cement for sprayed concrete with dry aggregates
- SBM-FT: spray cement for sprayed concrete with moist aggregates (short contact time)
- EB-AF: non-alkaline accelerator

Mixture

The mixture is the base product for dry-mix and wet-mix sprayed concrete. Depending on the procedure applied, three types of mixture can be used for dry-mix sprayed concrete (Table 1). Due to environmental considerations and efforts to increase shotcrete quality, only non-alkaline accelerators or special binders, called spray cements, with short setting time are now used in tunnelling. Dry-mix is still frequently used in central Europe as many tunnels are constructed in poor rock conditions.

In dry-mix production, the risk of segregation during material transport should be kept in mind; a maximum temperature of 40 C (104 F) must not be exceeded. Moist-mix for immediate placing is produced in a continuous mixing plant upstream of the spraying machine. Accurate dosages, a uniform moisture content of the aggregate, and a short working time are important. Both moist-mix and wet-mix have to be used within no more than 1.5 h of mixing.

Spraying Procedures

"The Guideline on Sprayed Concrete" provides a reliable basis for every construction site to select and apply

*Table 2: Indicative values for mix composition for SpB II and SpB III.**

	Dry-mix shotcrete	Wet-mix shotcrete
Cement additives (for example, fly ash)	310 to 360 kg/m³ ** 30 to 50 kg/m³	360 to 380 kg/m³ 50 to 80 kg/m³
Binder dose (TZ, SMB and additives)	340 to 380 kg/m³ †	400 to 450 kg/m³
Water-binder ratio	≤ 0.50 for strength requirements J2 and/or J3	
Consistence (spreading index)	—	48 to 55 cm
Aggregates	GK 8, GK 11	GK 8, max. GK 11
Fine-grained content (binder and aggregate), fines < 0.25 mm	min. 470 kg/m³ incl. cement	min. 550 kg/m³ incl. cement

*SpB = sprayed concrete; GK = maximum grain size; I,II,III = sprayed concrete classes; II being normally used for rock support uses, III, for example, for repair works).
† With binder doses of less than 340 kg/m³, adhesion of the sprayed concrete to the substrate is noticeably diminished.
**10 kg/m³ is approximately equal to 17 lb/y³ (16.86 lb/y³).

the most suitable spraying method. The advantages and disadvantages of non-alkaline sprayed concrete technologies are summarized in Table 3. Descriptions of the individual procedures are accompanied by instructions for proper application. These are quite similar to North American guidelines, so there is no need to go into detail. It should only be mentioned that special emphasis is laid on the proper metering of the accelerator. There is also experience in spraying shotcrete onto frozen substrates, requiring an increase in the sprayed concrete layer thickness of 20 to 30 mm (0.8 to 1.2 in.), and using a mixture with a minimum temperature of 13C (55.4 F).

Unfortunately, the guideline does not give any detailed specifications on nozzleman training or qualification.

Requirements to be Met by Sprayed Concrete

Depending on the application and the structural functions to be fulfilled, sprayed concrete is classified as follows: sprayed concrete without structural functions (Class SpB I), sprayed concrete with structural functions (Class SpB II), and sprayed concrete with special structural functions (Class SpB III).

*Table 3: Comparison of non-alkaline sprayed concrete technologies.**

	Dry-mix procedure		**Wet-mix procedure**
Mixture	TM	FM-S	NM
Binder	Spray cement T	Spray cement FT	Tunnel cement
Accelerator	—	—	Non-alkaline
Advantages	Requires little space in tunnel, high mobility, high reliability, excellent early strength, no problems in winter, conveying distance up to 300 m (985ft).	Low material costs, available any time, no residual quantities, several mix formulas, conveying distance up to 200 m (655 ft).	High output, little rebound and dust mobile, low compressed air requirement, accelerator dose adjustable to requirements.
Disadvantages	Drying costs, segregation, high temperatures, dust and rebound, low output.	Space requirement, heavy and immobile equipment, low output.	Low early strength, high material costs, transport logistics, limited pumping distance, difficult cleaning, prehydration, residual quantities, roadway to working face required.

*The moist-mix procedure using a non-alkaline accelerator has not been included (this table is not part of the guideline).

This classification also determines the frequency of testing for quality control purposes. Furthermore, fresh sprayed concrete is classified on the basis of early strength classes, J_2 being the regular requirement for tunnelling with about 200 mm (8 in.) layer thickness, J_3 being necessary only under very difficult ground conditions or strong water ingress.

The strength requirements and other properties are based on the provisions of the existing concrete standards.

Special Procedures

Special procedures dealt with in the Guideline include sprayed concrete under compressed air (unchanged from 1st edition), and steel-fiber sprayed concrete. In Austria, steel-fiber concrete is not yet used very widely; hence, the requirements have been used from other countries. An evaluation of the results obtained in the bending-beam test according to R. Morgan has been included in the Guideline.

By means of this method, the strength of sprayed concrete can be evaluated even at an early age, which is essential for the use of sprayed concrete for support in difficult rock conditions.

Figure 1: Hand application of dry-mix shotcrete without keeping nozzle within correct distance to substrate.

Testing

A large part of the Guideline deals with testing and testing requirements. The tests referred to are shown in Table 4.

Tests are to be performed in individual steps, starting with base materials, up to and including inspection of mixing and metering equipment. Non-compliance with the quality criteria to be met by hardened sprayed concrete is to be avoided through systematic establishment of important parameters before and during production.

Table 11 of the Guideline contains a clear overview and a binding list of the testing requirements to be met. The individual tables only refer to the relevant requirements for each spraying method. In regards to the testing of base materials, the tables refer to preliminary testing, self-inspection and internal inspection on the construc-

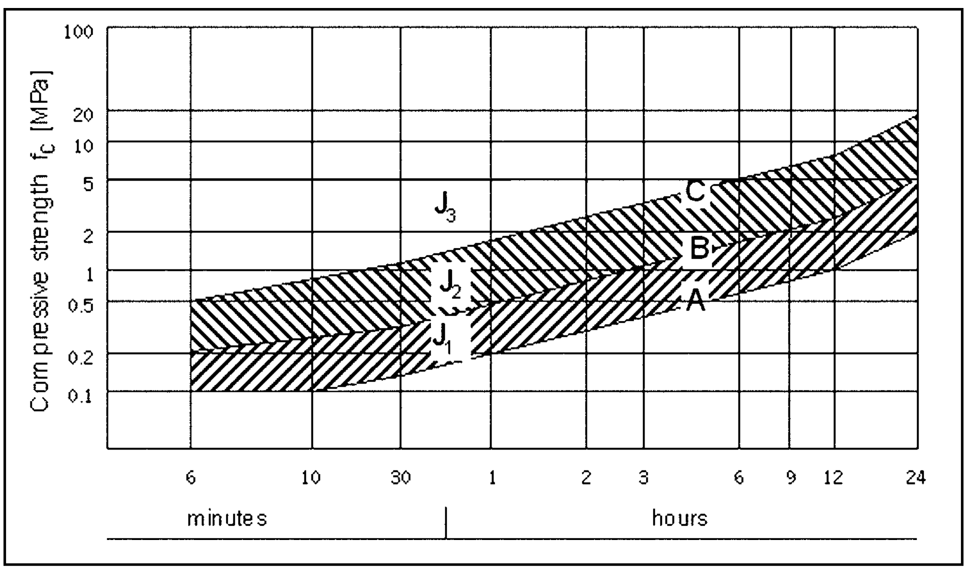

Figure 2: Early strength requirements to be met by fresh sprayed concrete (between A and B: class J_1, between B and C: class J_2, above C: class J_3).

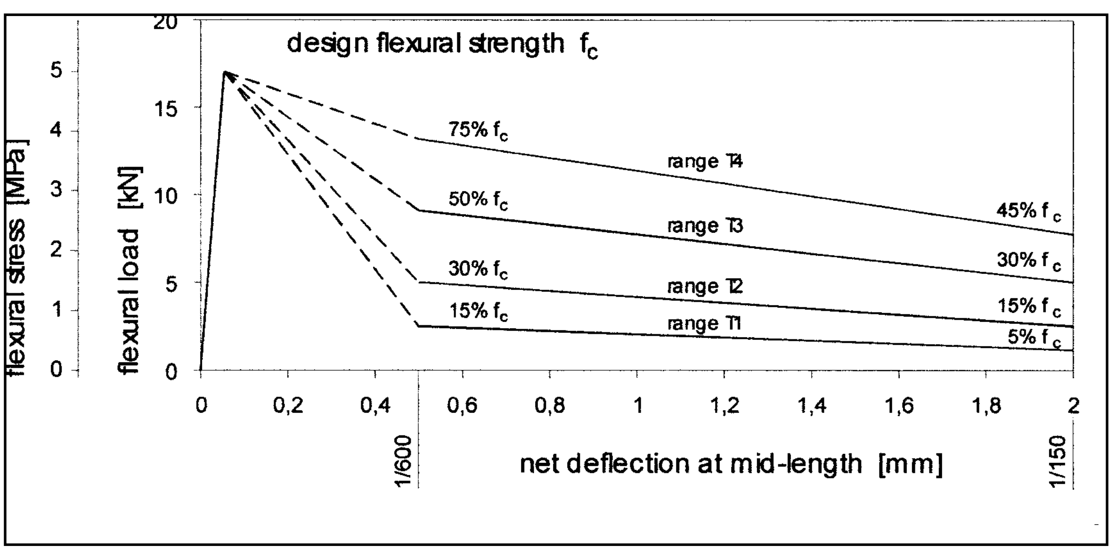

Figure 3: Boundaries of flexural toughness ranges for fiber-reinforced sprayed concrete (example).

Table 4: Reference to testing in the guideline

Testing of base materials
Testing of mixture
Testing of fresh sprayed concrete (< 24 hours)
Testing of sprayed concrete (hardened concrete)
Testing of production conditions
Testing of mixing and metering equipment

tion site. Information on preconstruction testing, production testing, and structural testing is provided (Table 5).

Testing Procedures

Many test procedures for base materials follow the national specifications, but it is very important to provide a reliable indication of the interaction of cement and accelerator on the behaviour of spray cement. This testing is done using a modified Vicat test and tests on small cylinders or prisms [40 x 40 x 160 mm (1.6 x 1.6 x 6.3 in.)].

Special instructions are given to ensure fast mixing and placing of the samples. Moreover, an identification test of the accelerator, including chemical properties, is obligatory.

Testing of base materials for concrete production, though a meaningful approach, will never be able to simulate the spraying procedure completely. Hence, testing of the reference sprayed concrete, in addition to laboratory testing as specified above, is provided for. A reference formula for sprayed concrete for small laboratory spraying equipment is specified.

Following a tradition established in the first edition, the Guideline devotes considerable attention to the testing of fresh sprayed concrete. It specifies the needle penetration test for a strength of up to 1.2 MPa (174 psi), and the stud-driving method for the range of strength from 1.0 to 16 MPa (145 to 2320 psi) (Fig. 4). The penetration needle is used to measure the force required to push a needle of 3 mm (0.12 in.) diameter and a tip with a taper angle of 60 degrees to penetrate into the shotcrete to a depth of 15 mm (0.6 in.). The instrument indicates the resisting force through compression of a spring, from which an estimated compressive strength can be derived from a conversion curve (Fig. 5).

For the stud-driving method, a threaded stud is driven into the shotcrete and the depth of penetration is determined. Then, the stud is extracted and the pullout force measured. The ratio of pullout force to penetration depth (or for low-strength, only penetration depth) can be used to obtain an estimated strength from conversion curves for different maximum aggregate grain size (Fig. 6).

The stud-driving method has been extended to cover the entire range of strength development. However, values above 16 MPa (2320 psi) can only be estimated. For aggregates other than those normally used in central Europe, mixture calibration is recommended, which can be performed quickly in any testing laboratory.

Testing of sprayed concrete after 28 days is performed on test cores according to the concrete standards. Special tests for sulfate resistance and leaching of sprayed concrete are referred to. Sulfate attack is more common in the Alps than alkali aggregate reactivity. Leaching may be a problem when using alkali aluminates or silicates as accelerators. During sprayed concrete production, inspections of dosages (cement content, accelerator dosage), rebound, fine-dust concentration, thickness of the sprayed concrete layer, and fiber content are essential. Fine-dust concentration is

Table 5: Overview of Table 11 in the Guideline: Testing of base materials, mix and sprayed concrete, inspection of mixing and metering equipment

Test	Manufacturer			Construction site		
of	Preliminary test	Self-inspection	External inspection	Preconstruction Test	Production Test	Structural test
Constituent materials	√	√	√	√	√	—
Basic mixture + sprayed concrete	In case of dry-mix with external inspection			Fresh-sprayed concrete only	Reduced scope	If required
	Production according to ÖNORM B 3307 (ready-mix concrete)			√	√	
Mixing and metering equipment	Acceptance test by inspection body			Self-inspection		—

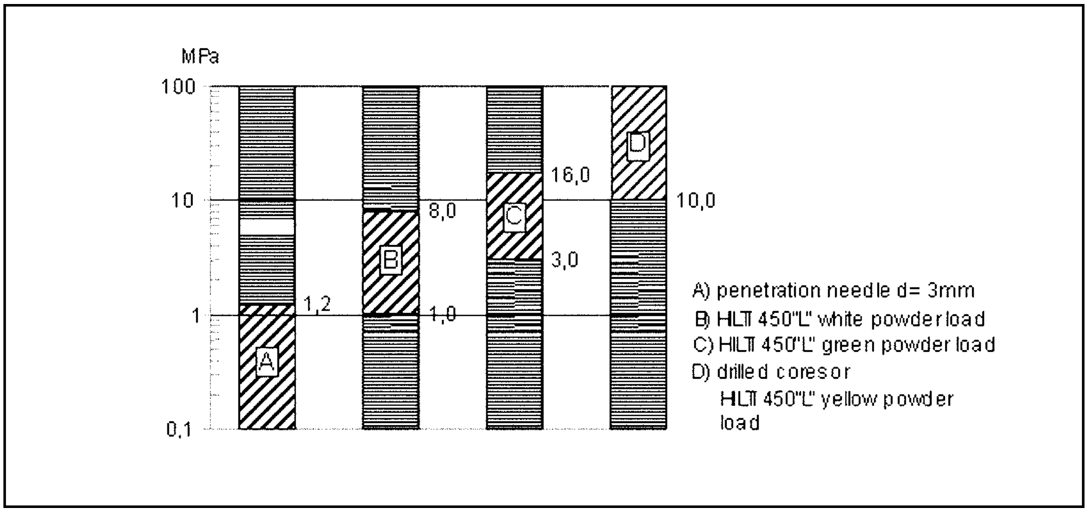

Figure 4 : Measuring procedures for the testing of fresh-sprayed concrete (Hilti 450"L" being the stud-setting unit used).

measured by light-scattering instruments. Conversion of the relative dust concentration into fine-dust concentrations obtained by gravity-based samplers can be done by conversion factors ranging from 1.1 to1.5.

References

1. Austrian Concrete Society, "Guideline on Sprayed Concrete," Vienna 3/99, e-mail: beton@netway.at.

Wolfgang Kusterle received his diploma in civil engineering at the University of Innsbruck in 1980. He then worked for 2 years with a consulting engineer designing bridges and other reinforced concrete structures. In 1983, he started working on his doctoral thesis at the University of Innsbruck, which he finished in 1984 with a PhD in civil engineering. He stayed at the Institute for Building Materials and Building Physics as assistant professor and later as associate professor. His main research areas are sprayed concrete and concrete repair. He is involved in national and international research programs and has published more than 60 papers. Consulting in concrete technology, product development, and the organization of conferences are some of his other areas of work.

Figure 5: Penetration needle in use.

Figure 6: Testing equipment for stud-driving method.