Stahlfaserspritzbeton für Gebirgssicherung und Brandschutz

WET PROCESS STEEL FIBRE REINFORCED SHOTCRETE FOR ROCK SUPPORT AND FIRE PROTECTION, NORWEGIAN PRACTICE AND EXPERIENCES

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Der rasante Fortschritt auf dem Gebiet der Betontechnologie und die Entwicklung von Einrichtungen und Geräten hat in Norwegen zum Übergang vom händischen Trockenspritzverfahren zum mechanischen Naßspritzverfahren geführt. Spritzbeton mit einer Würfelfestigkeit von mehr als 100 MPa kann im Naßspritzverfahren hergestellt werden. Die entsprechenden Einrichtungen für dieses Verfahren können nun bis zu 20 m^3 pro Stunde herstellen. Geringer Rückprall (5 - 10 Prozent) und kein übermäßiger Rückprall von Stahlfasern sowie die hohe Kapazität machen diese Art der Gebirgssicherung umso wirtschaftlicher und effizienter. Die Beigabe von Stahlfasern bewirkt in erster Linie hohe Bruchenergie, d.h. verformbare Tunnelauskleidungen. Auch die Zugeigenschaften werden verbessert, besonders unter ungünstigen Nachbehandlungsbedingungen.

In jenen Fällen, in denen Frostbeständigkeit und Schutz vor Wasserzutritt erforderlich sind, z.B. Kavernen und Verkehrstunnel, haben sich Platten aus PE-Schaum als wirksam und wirtschaftlich erwiesen. Als Brandschutzmaßnahme wird eine 20 - 30 mm starke Schicht aus leichtem, mit Stahlfasern verstärktem Spritzbeton aufgebracht. Eine 20 mm starke Schicht dieses Materials entspricht den Anforderungen von Brandschutzklasse A 120. Das Material besitzt eine hohe Zugfestigkeit, ca. 30 Prozent der Druckfestigkeit.

Rapid development in concrete technology and development of equipment has led to a change from dry hand-operated to wet robot shotcreting in Norway. Shotcrete of more than 100 MPa cube strength can be achieved by the wet method. Wet process shotcreting equipment has been modified to produce shotcrete with a capacity up to 20 m^3/hour. Low rebound (5-10 %) and no excess rebound of steel fibre combined with the high production capacity, are important contributions to economy and efficiency in rock support. Incorporation of steel fibres first of all gives high fracture energy, i. e. ductile tunnel linings. Tensile properties are also improved, especially under adverse curing conditions.

Where frost insulation and sheltering from water leakages are needed, e. g. in caverns and traffic tunnels, sheets of polyethylene foam have proved both effective and economic. To provide fire protection, a special light-weight steel fibre reinforced cement mortar is shotcreted at a thickness of 20 - 30 mm. A 20 mm thick layer of this material satisfies fire class A 120, the material has a high tensile strength, approx 30 % of the compressive strength.

1. Introduction

Shotcrete is one of the most commonly used and well recognised methods of supporting rock tunnels and caverns, due to the flexibility, reliability and economy of the method.

During the early 1980s wet-process shotcreting completely replaced the dry method in Norway. In the same period steel fibre reinforcement also took over, instead of mesh reinforcement, which was used earlier.

The main advantages with the wet process are:

- higher capacity, up to 18 - 20 m^3/hour
- reduced rebound, typically 5 - 10 %
- improved working conditions
- no excess fibre rebound
- less variation in quality

The main advantages with steel fibre reinforcement are:

- considerable time saving, the time-consuming process of fixing the mesh is avoided
- far less labour costs
- safer working conditions
- less material consumption, profile and shape is maintained

Parallel to the development mentioned, robot-operated equipment replaced hand-held equipment. The technique of today is consequently a result of developments made in the fields of equipment, spraying technique and materials.

2. Qualities

Traditionally concrete C25 (25 MPa cube strength) has been specified. The quality levels have been improved mainly due to

- use of high-range water reducing admixtures
- use of silica fume
- use of steel fibres of higher qualities, longer fibres at higher dosages

The normal qualities of shotcrete for rock support is presently C35 and C40, C45 for subsea tunnels where the shotcrete is exposed to seawater. Production testing during a concrete repair job has confirmed that concrete quality C100 can be achieved in full-scale production.

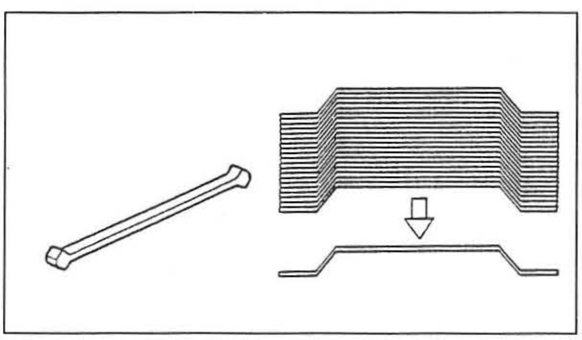

Fig. 1: EE-fibre (left) and Dramix fibre (right)

The most important characteristics of a shotcrete lining, however, is its bond to rock and a ductile behaviour. Bond is often jeopardized by the rock quality. The ductility of a lining is best described by the materials fracture energy, i. e. its ability to absorb energy during deformation.

It was early proved that different steel fibres showed quite different abilities to alter the brittle nature of concrete. The steel fibres mostly used to date are the 18 mm EE-fibres and the 30 mm Dramix ZC 30/.50 fibres, see **Fig. 1**.

The EE-fibres (EE-Enlarged Ends) were developed by Australian Wire Industry, and are now produced by Christiania Spigerverk in Oslo. The EE-fibres are now also manufactured 25 mm long. The EE-fibre is an easily workable "compromise fiber", which gives considerable improvement of the fracture energy without putting high demands on the shotcreting equipment. The Dramix ZC 30/.50 fibres more than double the fracture energy compared to the 18 mm EE-fibres, but call for certain demands on equipment to be used. See **Fig. 2**.

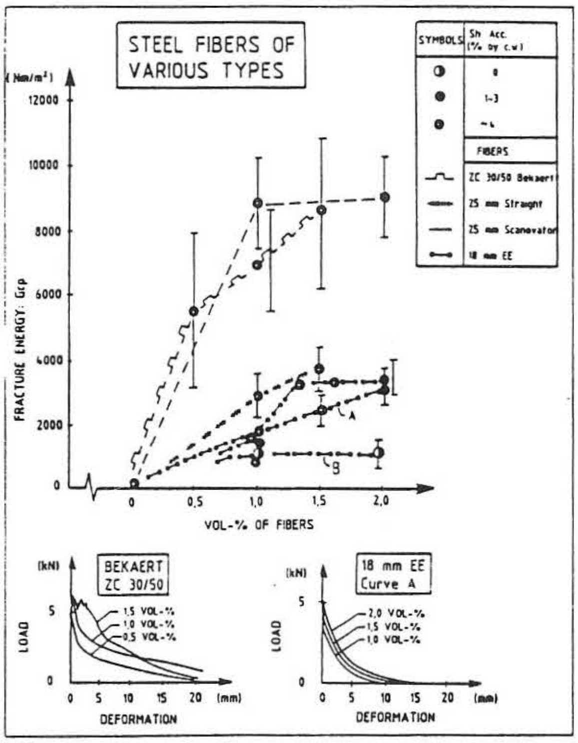

Fig. 2: Fracture energy of microsilica shotcrete with steel fibres of various types /1/

A comprehensive testing programme of shotcrete containing this Dramix ZC 30/.50 fibre carried out in cooperation between Aker Entreprenør A/S - Robocon, Norcem Cement A/S and Bekaert SA, the Belgian manufacturer of Dramix, showed that /2/:

- the fracture energy was increased 35 - 50 times by use of 1.0 vol-% (75 kg/m^3) Dramix ZC 30/.50 fibre

- the load capacities for large specimens were increased 85 % and 185 % respectively for 1.0 and 1.5 vol-% fibres (75 and 112.5 kg/m^3 of fibres)

- the ductility of the material was increased 18 - 22 and 27 - 37 times respectively for 1.0 and 1.5 vol-% fibres. See **Fig. 3.**

In this test a concrete of 50 MPa cube strength was used.

tests **/5/** where this fibre has been used have given very interesting results, see **Fig. 4 and 5**:

- compared to ZC 30/.50 the longer fiber ZCX 40/.60 doubles the fracture energy. The flexural strength is also improved considerably.
  Note: The definitions and the way of calculating fracture energy is different in **Fig. 4** and **Fig. 2.**

- at first crack shotcrete with ZCX 40/.60 does not show an instant reduction in load capacity, as other known types of fibre do. This indicates an improved bond between the fibres and the cement matrix, which in turn leads to better crack distribution for linings in service.

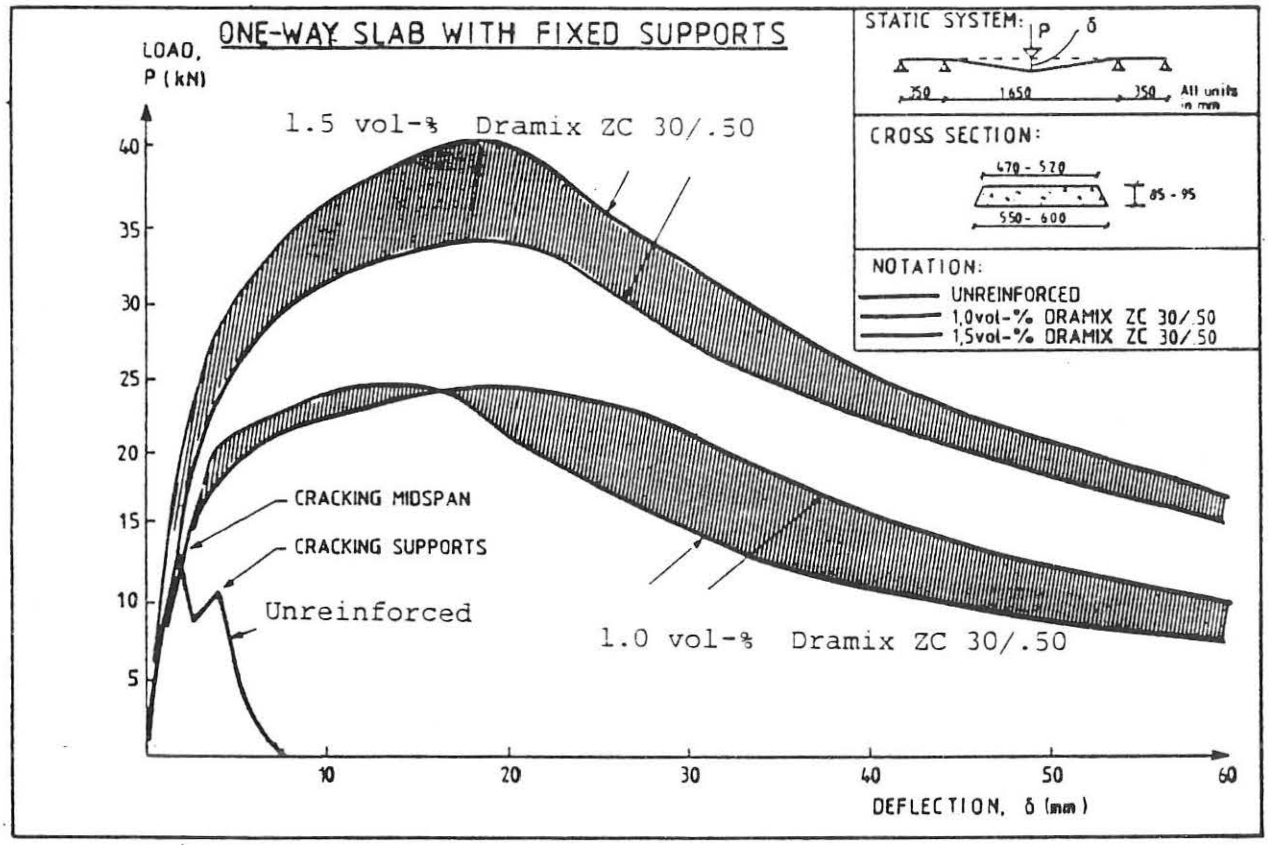

Fig. 3: Load deflection curves for one-way slabs. One curve corresponds to one sample. Hatchure is done between two samples of the same fibre dosage /2/

The latest step in the development process of steel-fiber reinforced shotcrete for rock support has been the use of even longer Dramix fibres, the 40 mm long Dramix ZCX 40/.60.

Especially for subsea traffic tunnels the risk of corrosion for the steel fibres has been questioned. Even though investigations of steel-fibre shotcrete in subsea tunnel **/3/** have shown that the risk of corrosion is rather modest, Robocon has developed the equipment further to handle the 40 mm long, glavanised steel fibre Dramix ZCX 40/.60. Job

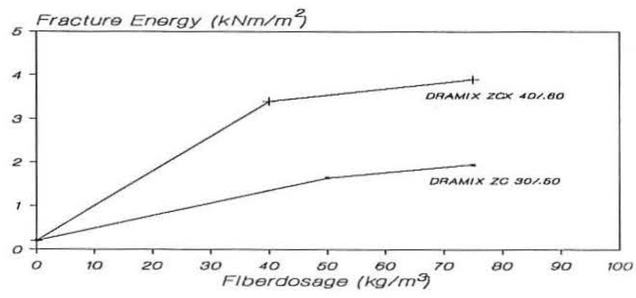

Fig. 4: Fracture energy of shotcrete depending on type and dosage of fibre /5/

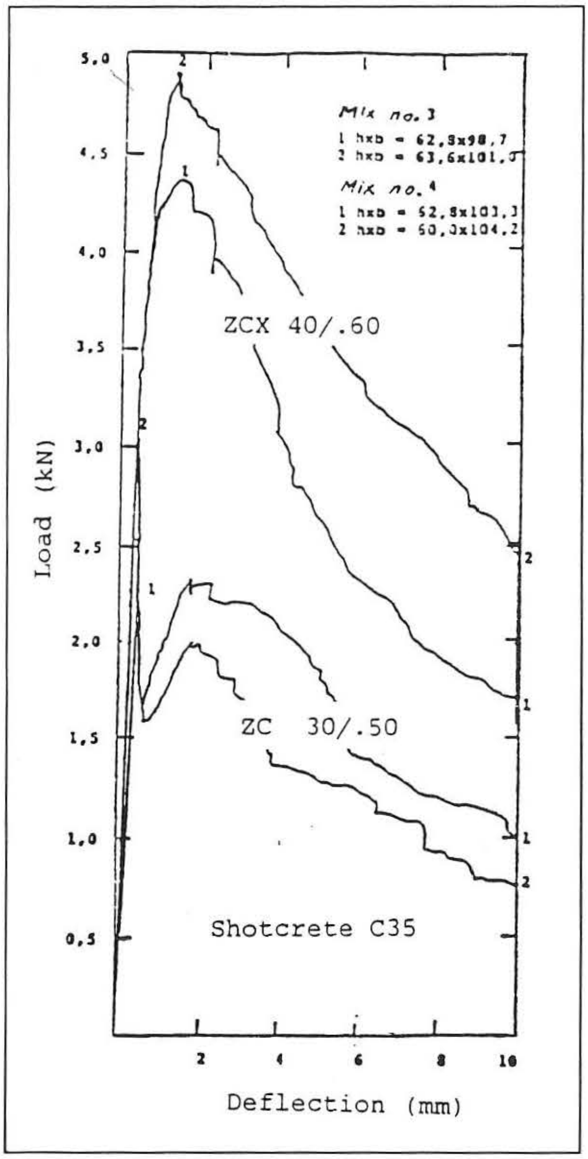

Fig. 5: Load/deflection curves for beams cut from shotcrete panels

3. Use of shotcrete for rock support

The present technology of wet-process robotised shotcreeting gives the possibilities to meet a very wide range of material specifications, both as strength and ductility are concerned. Use of high quality shotcrete with high dosages of the longer steel fibres opens for quicker and more economical strengthening in situations where traditionally cast concrete was considered the only alternative only a few years ago. Training and certification of shotcreting operators have also improved the reliability of shotcrete linings.

The following examples may be mentioned to illustrate the increased potential for use of shotcrete.

At Dokka Hydropower plant a 15 m long curved part of the overflow tunnel was strengthened with a 20 cm thick lining of shotcrete C40 with 115 kg/m^3 Dramix ZC 30/.50. The lining was strengthened by two shotcrete ribs of 1 m width, 20 cm thickness. The lining was anchored by 4 and 6 m long rockbolts systematically 1.5 x 1.5 m, plus an additional row of bolts in each rib. To begin with traditionally cast concrete was considered the only possible alternative. The cost of the chosen support was approximately half that of cast concrete, and the total completion time was only 3 - 4 days, compared with 2 - 3 weeks estimated for cast concrete.

At Tømmerneset road tunnel the entrances were shotcreted against a formwork shield. The quality was C35 with 75 kg/m^3 Dramix ZCX 40/.60. This project is considered a pioneer project which may lead to new possibilities for use of shotcrete.

4. Shotcrete for fire protection

Where frost insulation and sheltering from water leakages are needed, e. g. in caverns and traffic tunnels, sheets of polyethylene foam (PE-foam) have proved both effective and economic. This method has been used for several years in Norway. The sheets are fixed to the rock surface by short rockbolts and wires or steel rods.

At temperatures above 700 °C the sheets may catch fire, and consequently fire protection is needed where this material is used to cover large areas.

Fire protection is provided by a specially designed light-weight, steel fibre reinforced cement mortar sprayed on to the sheets at a thickness of 25 mm. The name of this proprietary mix is ROBOTIC 10.

The main requirements to the fire protection material are:

- sufficient fire protection, the temperature behind the insulation should not exceed 70 °C after exposure to a petrol fire for 22 minutes.

- high flexural strength and high ductility, in order to obtain sufficient static and dynamic load capacity. Especially in traffic tunnels the dynamic loads may be substantial.

- good bond to the PE-sheets.

- low dead weight, to avoid overloading of the short rockbolts.

The ROBOTIC 10 fire protection is based mainly on Portland cement, Perlite as light-weight aggregate and 18 mm EE-fibres as reinforcement. Some admixtures and modifications agents are also used.

5. Material properties

Tests performed at the Fire Laboratory of the Norwegian Institute of Technology have shown that a 20 mm layer of ROBOTIC 10 satisfies Fire Class A 120. Therefore the material is also very interesting for application in housing and industry etc.

The bond strength to the PE-sheets exceeds the tensile strength of PE-foam.

The compressive strength is typically 13 MPa (cube strength), and the flexural strength around 3.8 MPa, i. e. approximately 30 % of the compressive strength.

The ductility of the material is very high, both in compression and tension. Typical working diagrams for ROBOTIC 10 are shown in **Figs. 6 and 7**.

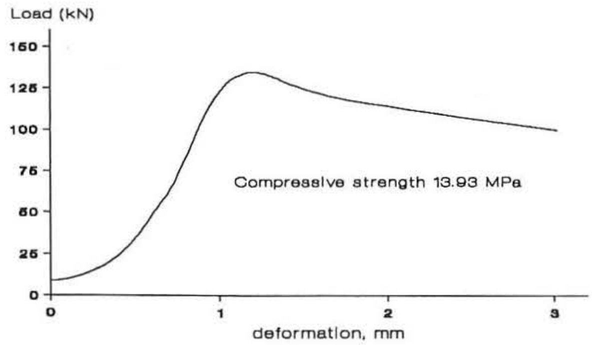

Fig. 6: Typical working diagram for ROBOTIC 10 in compression

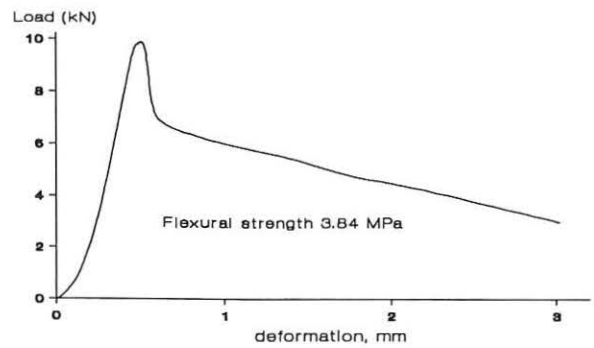

Fig. 7: Typical working diagram for ROBOTIC 10 in flexure

6. Projects carried out with ROBOTIC 10

So far only two tenders have been announced in this field in Norway, and both contracts were won based on the use of ROBOTIC 10:

1. The Ålesund tunnels, two subsea 3-lane tunnels 4176 m and 3481 m respectively, 100.000 m^2 of PE-foam. Because the tunnels were already open to traffic, shotcreting could take place only at night. The installation of the fire protection was completed in 9 weeks.

2. The Sønsterud tunnel, E68 between Oslo and Hønefoss, 25.000 m^2 of PE-foam.

Considering they were pioneer jobs, the execution of the work has been exceptionally unproblematic. As usual in wet process shotcreting, the mortar was mixed at a readymix plant (Hønefoss Ferdigbetong A/S), transported to the site and shotcreted with equipment specially suited for this type of job. An extremely low rebound was the only surprise encountered.

7. References

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