ADING
ingredient of every structure

MATERIALS AND TECHNOLOGIES FOR TUNNEL CONSTRUCTION

LEVELING COMPAUNDS

DECORATIVE COATINGS AND MORTARS

JOINT SEALANTS

ADMIXTURES

FLOOR FINISHING PRODUCTS

GROUTING AND SEALING

ABOUT US...

ADING is a company for production of construction chemicals with more than 50 years of experience in the field and long-running presence on the markets in Europe, Asia and Africa. Since the establishment of the company back in 1969, more than 100 construction chemicals are being produced categorized in 12 product groups. In line with our marketing slogan, "Ingredient of every structure", these products are embedded everywhere around us and they are part of the most distinctive construction undertakings in the countries in which we are present in the past 50 years.

Apart from the standardized and certified products from our product range, our engineering teams have technologies available to them and acquired know-how in the fields of: tunnel construction, repair of reinforced concrete structures in building construction, hydraulic and industrial buildings, bridges, factory smokestacks and other specific engineering structures.

On the following 40-something pages, we share our concrete experience and knowledge of tunnel construction. Below you can see some of the most significant reference construction projects in this field in which we have participated and in which our knowledge and products are embedded:

NORTH MACEDONIA
- "Preseka" tunnel, "Demir Kapija" tunnel , "Kozjak" hydro-technical tunnel, "Sasa" hydro-technical tunnels, "Katlanovo" tunnel, "Kumanovo" railway tunnel, Deve Bair tunnel etc.

SERBIA
- "Brdjani" tunnel, "Golubac" tunnel, "Bancarevo" tunnel, "Shargan" tunnel, "Manajle" tunnel, "Predejane" tunnel, Pirot ringroad tunnels

MONTENEGRO
- "Klisura Kolashin" tunnel, "Carine i Ibarac" - Rozaje, tunnel,, "Njegusi" tunnel, "Budosh" tunnel, "Sozina" tunnel etc.

BOSNIA AND HERZEGOVINA
- "Stambolcic" tunnel, "Chemerno" tunnel, "Zenica" tunnel

CROATIA
- "Pecina Rijeka" tunnel, "Sv. Rok" tunnel, "Zmijarevic ploca" tunnel - Sibenik, "Umac" tunnel, "Mala Kapela" tunnel, "Tuhovik" tunnel

KAZAKHSTAN
- "Almaty" metro

ALBANIA, Pogradec
- Tunnel 1 and 2

BULGARIA
- "Zheleznica" tunnel

CONTENT

1 INTRODUCTION

TUNNEL – underground structure intended for vehicular road traffic or rail traffic, water courses or installations.

1.1 CATEGORISATION OF TUNNELS ACCORDING TO THEIR PURPOSE OF USE:

Road traffic tunnels and city traffic tunnels

Railway tunnels, including:

- metro stations
- underground railway stations
- mines

Hydro-technical tunnels:

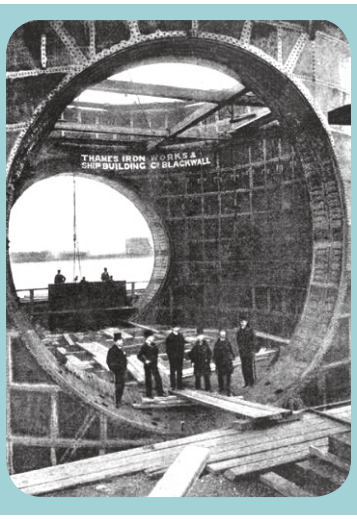
Intended for: water supply, overflow systems in hydro-technical facilities, as well as sewerage systems for drainage of waste water.

2 METHODOLOGY OF TUNNEL CONSTRUCTION

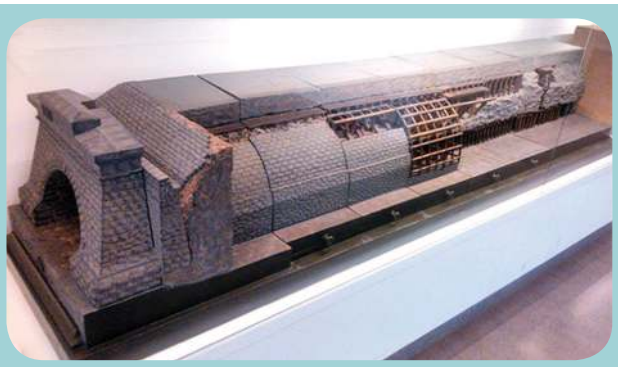
2.1 HISTORY

Depending on the available equipment, geology, hydrology, purpose and length of the tunnel, during history, different methodology for construction of tunnels had been used. Differences occur in all phases of the construction such as excavation, support, final lining, construction site organization and management, etc.

General differentiation of the methodology for tunnel construction is between "classical" and "contemporary" that is further divided depending on the geological and hydrological conditions.



Example: Blackwall tunnel – tunnel underneath the River Thames – created in 1897 as the longest underwater tunnel in the world at that time, measuring 1,900 meters in length.



Old Austrian Tunnelling Approach

The classical Austrian method is based on a construction of a rigid load-bearing structure and stone masonry.

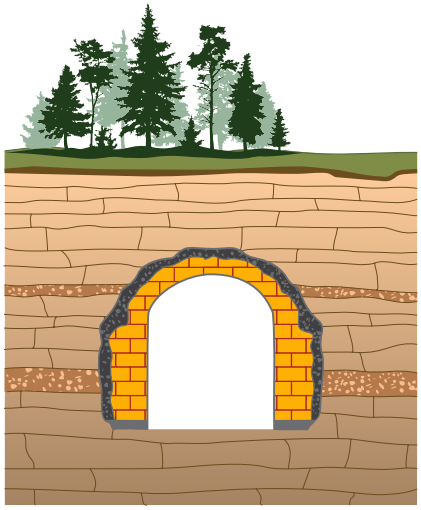
MASSIVE TIMBERWORK OF A TUNNEL

2.2. NEW AUSTRIAN TUNNELLING METHOD

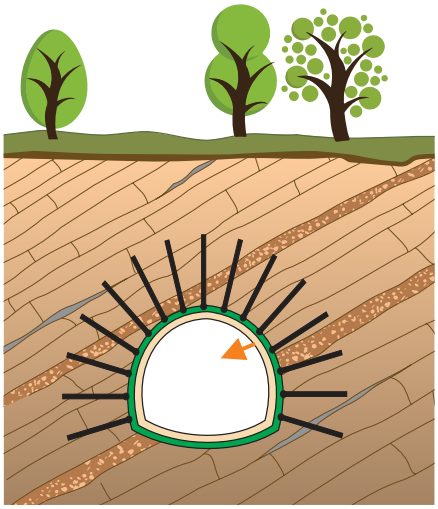
A new concept of tunnel construction was introduced in the '60. The development of the NATM has been conditioned by the development of the concrete technology and the introduction of admixtures for sprayed concrete. Developed for the first time in Austria by professor Rabcewicz, two decades earlier known also as "Neue Osterreichiche Tunnelbauweise" (New Austrian Tunnelling Method - NATM) or simply "Shot-Crete" method, NATM emphasises the significance of sprayed concrete in tunnel building.

This completely new philosophy of tunnel building is based on "mobilising" and making use of the load-bearing capacity of the rock mass itself as a backbone of the tunnel during the construction and use.

NATM is based on the construction of a flexible primary support made of sprayed concrete, tunnel rock bolts and lattice girders, which enable the rock mass to find its own state of balance.



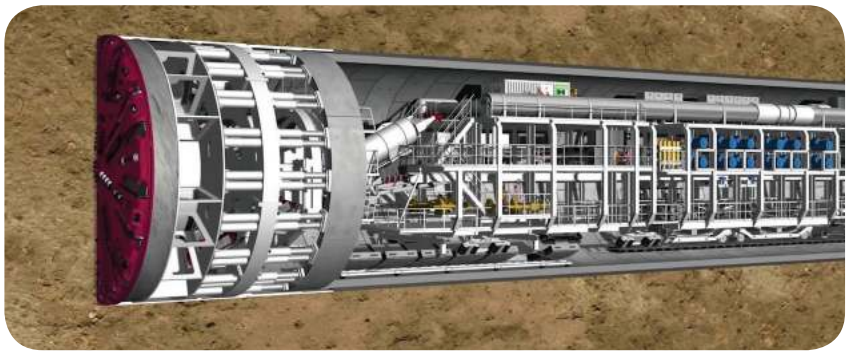
Classical massive lining



NAMT

2.3 CONSTRUCTION OF TUNNELS BY USING TBM – MACHINES (TUNNEL BORING MACHINE)

The TBM is used for excavating tunnels with a circular cross section through a variety of soil and rock strata. The diameter of the tunnel may range from 1 meter (made with a micro-TBM) up to almost 16 meters.



Precast concrete elements for lining

Part of the methodology for construction of tunnels with TBMs includes automated installation of precast concrete elements for lining of the tunnel. These types of elements are usually manufactured in plants (factories) and as ready-made products are transported to the tunnel. This type of plant production allows for high level of production quality control, and thus efficiency in the construction of tunnels. The TBM is usually equipped for automated installation of these concrete elements.

3 NEW AUSTRIAN TUNNELLING METHOD

3.1 GENERAL

The New Austrian Tunnelling Method – NATM, is an economical and safe method of tunnel construction which is based on the following principles:

1. The process of tunnelling envisages the construction of two tiers of support:

- Flexible primary lining
- Secondary lining

Jointly, the two linings form the so-called "load-bearing ring" – three-dimensional spherical shell in the interior of the rock mass.

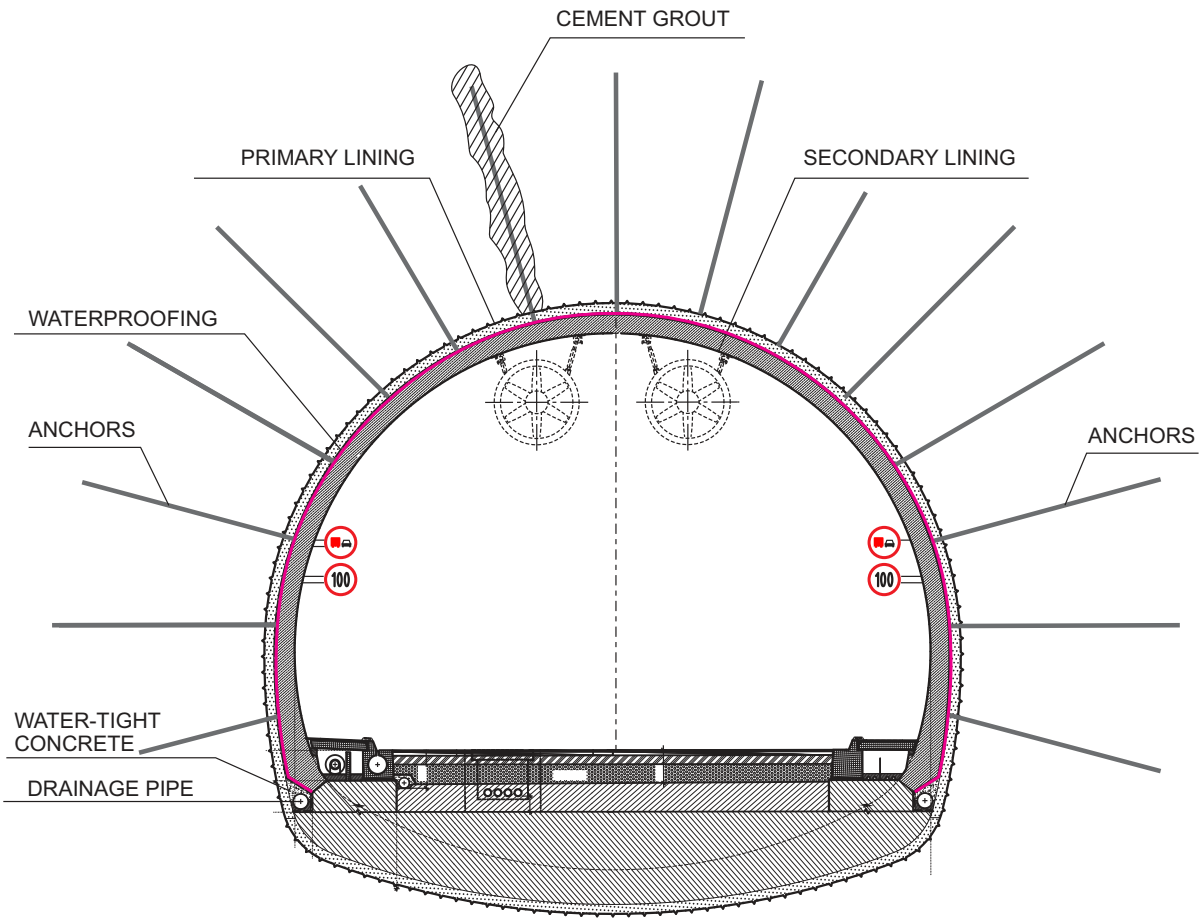
2. The basic load-bearing capacity of the tunnel is provided by the surrounding rock mass.
The primary tunnel lining must be flexible to allow for redistribution of the stress and strain in the interior of the rocks until a new state of balance is achieved.

Requirements for construction of the primary lining:

- The lining must not take over the weight and be the support of the tunnel. The NATM completely discards the classical massive tunnel support structures
- The profile of the tunnel must be rounded
- Preservation of the stability of the rock mass by careful excavation and installation of the primary lining as soon as possible
- Reinforcement of the primary lining is achieved not by increasing the thickness of the shotcrete, but rather by improving the anchoring to the surrounding rock mass
- It is necessary to perform constant monitoring of the situation during construction and use.

3.2 PRIMARY TUNNEL LINING

The primary tunnel lining in the NATM is a system of steel anchors fixed to the rock mass and connected to a flexible shell of sprayed concrete. In addition, depending on the category of the rock through which the tunnel is created, the shell of the lining may be provided with single or double reinforcement by embedding steel arches – lattice girders. The sprayed concrete is applied over this structure.
Alternatively, instead of a classical reinforcement, steel fibres can be used in the sprayed concrete.



3.2.1 SPRAYED CONCRETE

The sprayed concrete – Torkret, Shotcrete, Gunite – is a specially designed concrete intended to be applied by using spraying equipment under pressure.

It is used for the construction of support structures in tunnel building, mining, for stabilization of slopes, for concreting of structures with a complex form, etc.

In tunnel construction, sprayed concrete is primarily used for the construction of the primary lining when applying the NATM.

METHODS OF APPLICATION OF SPRAYED CONCRETE

There are two basic methods of applying sprayed concrete:

- "Dry" procedure (Gunite) whereby a dry mixture of cement and aggregate is applied (blown) through pressurized hose, and water is added at the release nozzle, immediately before application.
- "Wet" procedure (Shotcrete) whereby ready-mix concrete is transported and poured in the spraying (application) equipment.

CHARACTERISTICS OF A "DRY" AND "WET" METHOD OF APPLICATION OF SPRAYED CONCRETE	
"WET" METHOD	"DRY" METHOD
Application technology	
● The concrete mixture is transported as ready-mix concrete (in-transit mixers) and is poured into the equipment used for application ● Immediately before exiting from the hose, the thick concrete is dispersed by air current under high pressure ● Liquid admixture – at the release nozzle of the hose, set accelerating agent is added to the concrete	● The dry concrete mixture is poured into a machine for application ● By using current of compressed air, the dry cement mixture is transported to the exit of the hose ● Before coming out of the release nozzle, the necessary amount of water is added to the mixture ● Powdery set accelerator is added to the dry concrete mixture ● Liquid set accelerator is added together with the water at the release end of the hose used for application
Advantages	
● Much lower exposure of workers to harmful effects (dust, etc.) ● Better control of the concrete production process ● Higher speed of application ● Longer durability of the equipment	● Lower price of the equipment ● Easy application and maintenance of the equipment ● Low W/C ratio (no need for pumpable concrete)
Disadvantages	
● Higher price of the equipment ● Complex process of starting and cleaning of the equipment	● High exposure to dust ● Lesser control over the concrete during application ● Higher wear-and-tear of the equipment

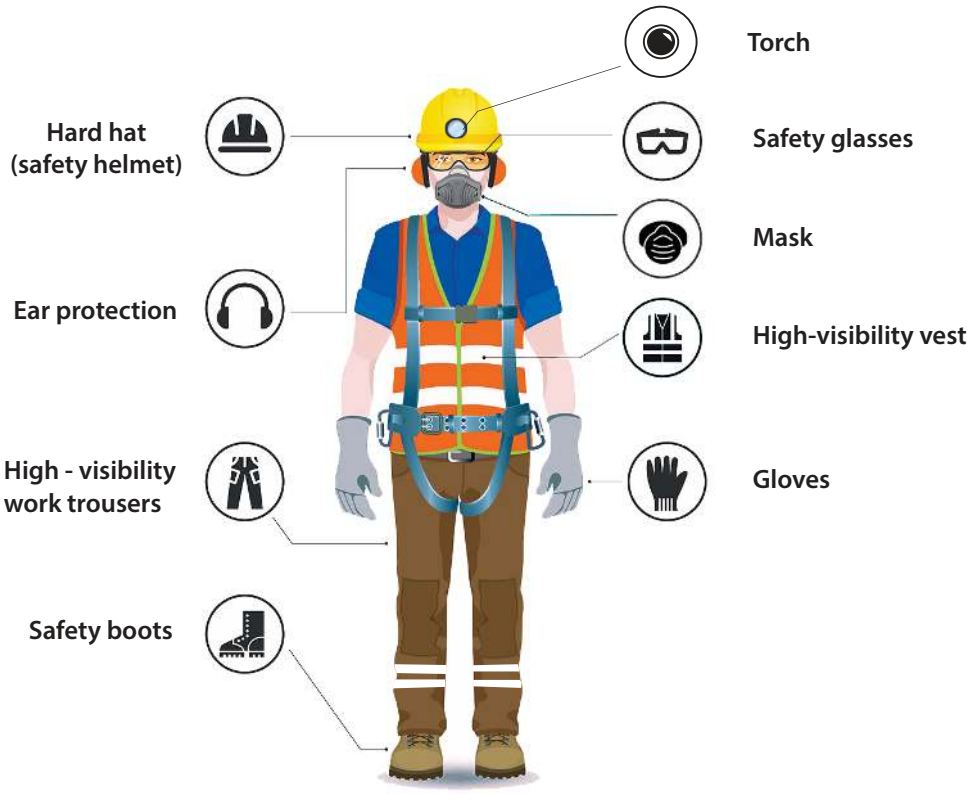
SPECIALISED EQUIPMENT FOR APPLICATION OF SPRAYED CONCRETE

In order to increase the efficiency and quality of the application of sprayed concrete, and at the same time to lower the risk and exposure of workers to negative effects, the application of sprayed concrete in tunnel construction is carried out by using specialized machines – „Robots".

They are equipped with a specialized "telescopic arm" to which the pipes for pumping and spraying the concrete are attached. Also, the "Robot" is equipped with automated pumps and dosing devices for admixtures – set accelerating agent.

The shotcrete application of the "Robot" is managed through a remote controller – which enables the operator of the machine to be at a safe distance from the place of application and away from the zone of increased risk of injury.

Despite this, wearing personal protective equipment during application of sprayed concrete is mandatory!

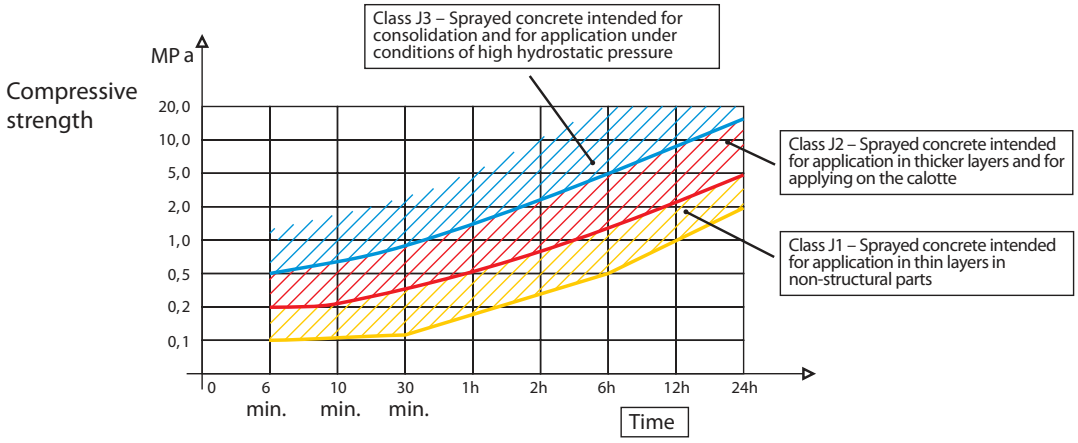


QUALITY REQUIREMENTS AND SPRAYED CONCRETE PERFORMANCES

Early strength properties

Early strengths are essential for proper application of the sprayed concrete. Achieving initial strength in the first several minutes allows for "over-head" spraying of the calotte, application of concrete in thicker layers and concrete spraying over surfaces with active water ingresses. Early strength is also a guarantee for safety at work.

Finally, quick setting of concrete reduces deflection of concrete during application, thus significantly improving the cost-effectiveness of the work. Usually, early strength of sprayed concrete is achieved in the period between the 6th and the 60th minute following application, whereby sprayed concrete is divided in three classes, J1-J3.



Class of sprayed concrete according to the strength properties in the first 24h

Strength class of sprayed concrete	Compressive strength at 6 minutes	Compressive strength at 60 minutes	Application
J1	0,1 - 0,2 MPa	0,2-0,5 MPa	Spraying in thinner layers, application on non-structural elements
J2	0,2-0,5 MPa	0,5-1,0 MPa	Spraying in thicker layers Application of calotte
J3	>0,5 MPa	>1,0 MPa	Stabilisation of the terrain, preventing active water ingresses

TESTING THE STRENGTH PROPERTIES OF SPRAYED CONCRETE

The strength properties of sprayed concrete in the first 24 hours are tested in compliance with the European Standard EN 14488-2 Testing sprayed concrete - Part 2: Compressive strength of young sprayed concrete. The testing is carried out in situ – at site by applying three methods:

Method A: Penetration needle

This method is used for indirect measuring of the strength needed to stick a needle of certain dimensions into the sprayed concrete to a depth of 15 mm +/- 2 mm. While doing this, the instrument – penetrometer – registers the strength of resistance to penetration. The compressive strength of the concrete is established through a conversion curve provided by the manufacturer of the equipment. This method is used for establishing the compressive strength of "young" sprayed concrete with strength of up to 1.5MPa.

Method B: Stud driving

Steel studs are pushed with a precisely determined strength through the fresh concrete that is set and the depth of penetration is then measured. Then the stud is pulled out and the pulling strength is registered. Concrete strength is determined by means of the registered pulling strength.

Testing is carried out on a sample of sprayed concrete that is produced at site during application by using the required shotcrete equipment. The sample of sprayed concrete should be at least 10 cm thick.

Method C: Cylindrical core, kern

After achieving concrete strength of over 5MPa, testing is carried out on a core taken out from the sample which is tested on a pressing machine.

DETERMINING THE STRENGTH PROPERTIES OF SPRAYED CONCRETE

METHOD A: PENETRATION NEEDLE

METHOD B: STUD DRIVING

METHOD C: CYLINDRICAL CORE, KERN

DESIGN AND TECHNOLOGY FOR PRODUCTION OF SPRAYED CONCRETE

In order to meet the requirements for performance and quality of ready-mix sprayed concrete, as well as to enable proper application of the concrete, it is necessary to develop an appropriate concrete mix design and concrete design appropriate to the available equipment and methodology of application.

Usually, the performance requirements of fresh sprayed concrete are: consistency (slump), viscosity without the occurrence of segregation, uniformity, content of entrapped air, possibility for application with the available equipment, substrate adhesion, setting time.

Performance requirements of hardened sprayed concrete are: early and final strength properties, compressive strength and tensile strength, water-tightness, resistance to frost, salts and carbonation.

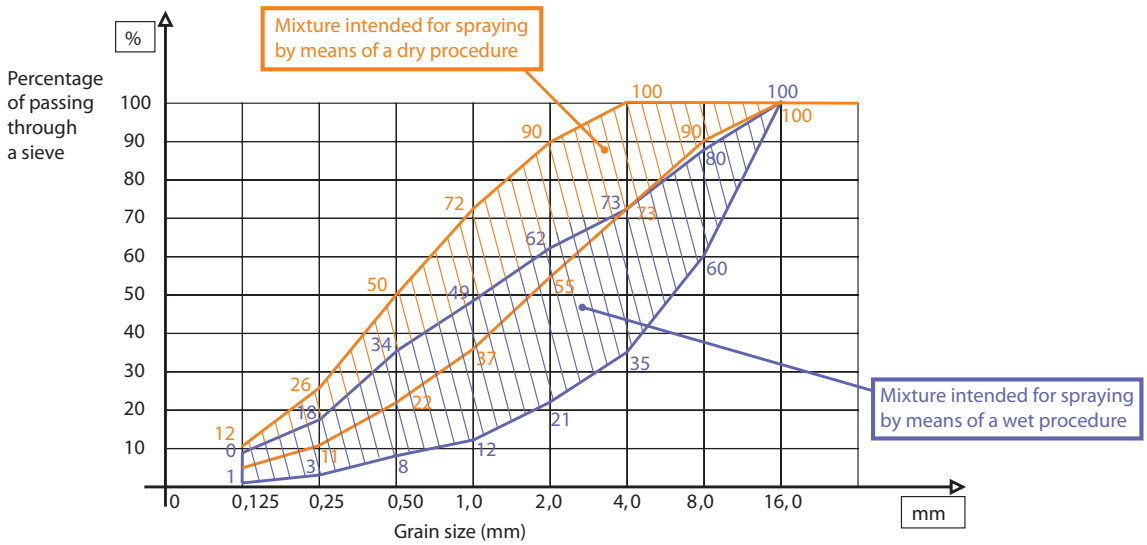
To meet the given requirements, it is necessary to perform previous lab and industrial tests, select materials and test the application equipment.

There are four basic components of sprayed concrete:

- Aggregate
- Cement
- Water
- Admixtures

AGGREGATE

Most commonly, for the production of sprayed concrete, aggregate fractions of (0-4) or (0-8) mm are used, and more rarely of (0-16) mm. The key factor for achieving the desired performance characteristics of concrete is the amount of tiny particles (<0.125mm). According to the recommendations of EFNARC /European Federation for Specialist Construction Chemicals and Concrete Systems/, below you can find the basic granulometric curves for sprayed concrete intended to be applied by means of dry and wet procedure:



CEMENT

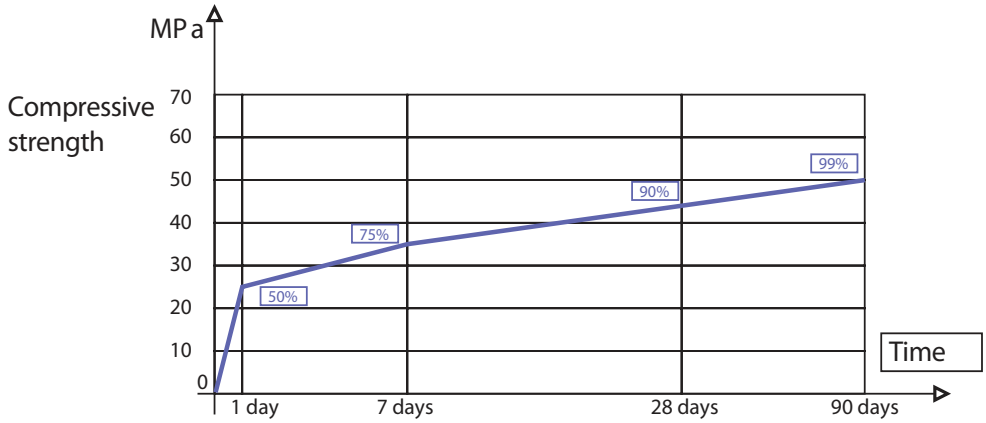
Recommended amounts of cement with different maximum size of aggregate are:

D max	Recommended amount of cement
(0-4) mm	450-600 kg/m^3
(0-8) mm	350-450 kg/m^3
(0-16) mm	300-400 kg/m^3

ADMIXTURES

Several different types of chemical and mineral admixtures are added to sprayed concrete in order to achieve certain properties:

- Superplasticisers – concrete admixtures which allow for workability of concrete with low W/C ratio, whereby his strength properties are significantly improved, as well as the possibility for quality placement of the concrete. Depending on the needs and weather conditions, superplasticisers may allow for extended maintenance of the consistency of fresh concrete for over 90 minutes.
- Set accelerating agents – Admixtures which allow for almost instant initiation of the process of concrete setting and which are the basis for production of sprayed concrete. Set accelerating agents are added automatically at the release nozzle of the shotcrete hose. The new generations of set accelerators do not contain alkali, which significantly reduces health risk for the workers and improves working conditions in tunnel building. At the same time, the new generations of set accelerators allow for continuous improvement of the strength properties of sprayed concrete.



Typical strength development in sprayed concrete
CEM 1R 42.5
W/C= 0.42

- Microsilica – powdery mineral concrete admixture which allows for the achievement of extremely high strength properties, concrete durability, resistance to frost, salts and carbonation, improved concrete placement and reduced occurrence of concrete segregation.

ADING – Admixtures for the production of sprayed concrete

As part of its product range, ADING company produces several types of admixtures intended for the production of sprayed concrete.

Their development over the years comes as a result of continuous monitoring of the needs of contractors, as well as a result of the latest trends in the development of concrete technology. In the past decades, Ading's admixtures have been successfully applied in the construction of many traffic and XTO tunnels in many countries on three different continents.

All admixtures are certified in compliance with the corresponding European standards for concrete admixtures EN934-2, EN934-5.

NAME OF THE ADMIXTURE	TYPE OF ADMIXTURE	CONFORMITY	Recommended dosage (in relation to the cement dosage)
SUPERPLASTICISERS			
SUPERFLUID	Superplasticiser for concrete	EN 934-2 T-3.1 & T-3.2	(1,0 – 1,2)%
SUPERFLUID M1	Superplasticiser/ set retarder for concrete	EN 934-2 T-11.1 & T-11.2	(1,0 – 1,2)%
SUPERFLUID M1M			
SUPERFLUID 21EKO	Polycarboxylate-based superplasticiser for concrete	EN 934-2 T-3.1 & T-3.2	(0,7 – 0,9)%
SUPERFLUID 21M EKO	Polycarboxylate-based superplasticiser/ set retarder	EN 934-2 T-11.1 & T-11.2	(0,7 – 0,9)%
SUPERFLUID 21M1M EKO			
SUPERFLUID 21MC EKO			
SUPERFLUID 21M1M			
SET ACCELERATING AGENTS			
INGUNIT T	Set accelerator for concrete	EN 934-5	2,0-6,0 %
INGUNIT T EKO	Alkali-free set accelerator for concrete	EN 934-5	3,0-9,0 %
INGUNITTC EKO	Alkali-free set accelerator for concrete	EN 934-5	3,0-9,0 %
INGUNIT P	Powdery set accelerator for concrete Intended to be applied by "dry" procedure	/	2,0-6,0 %

3.2.2 TUNNEL ANCHORS

The connection between the terrain – the rock mass – and the spherical shell of sprayed concrete is achieved by fixing geotechnical tunnel anchors. Usually, after installing the anchors, they are grouted-injected by using a cement mixture. In this way, cracks are additionally filled and the rock mass is consolidated.

Depending on the type of rock mass, the design of the anchors and the grouting equipment, the grout should meet several criteria in terms of strength properties, early strengths, viscosity, etc. At the same time, in cement based grouts it is necessary to prevent the occurrence of segregation, as well as to limit volume changes – shrinkage during use. Therefore, when preparing cement grouts, specialized superplasticising admixtures are used – they allow for flowability of the mixture with low W/C ratio (reduced water content), prevent the occurrence of segregation (separation of water), and compensate for cement shrinkage during hydration. Alternatively, cement-based or synthetic resin-based ready-mix grouts can be used.

As part of its product range, ADING company produces several types of admixtures and ready-mix grouts for anchor grouting.

NAME OF THE PRODUCT	PERFORMANCES
ADMIXTURES FOR PREPARING ANCHOR GROUTS	
INJEKTING K	Superplasticiser – allows for flowability of mixtures with low W/C ratio (reduced water content) Viscosity modifier – prevents the occurence of segregation Expanding agent – compensates for the shrinkage of cement Powdery form – added to the dry mixture together with the cement
INJEKTING K2	
READY-MIX ANCHOR GROUTS	
KOMPLEKSING AM	Ready-mix powdery material for grouting anchors in tunnel building Has high early and final strengths Has volume stability Thixotropic material – allows for application in vertical openings without leaking

EQUIPMENT FOR INSTALLATION OF TUNNEL ANCHORS

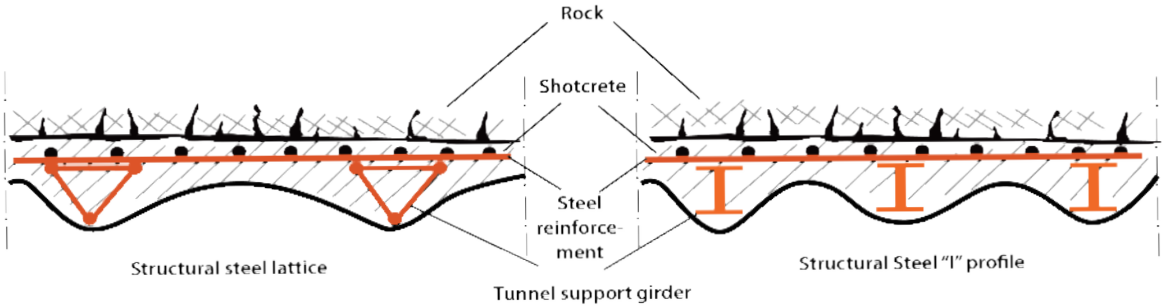
Depending on the design and needs, different types of anchors and equipment for their installation and grouting are used in tunnel construction. The anchors can be installed in boreholes that have been previously created or self-drilling anchors can be used where the drill bit is part of the anchor. Some anchors are produced in the form of a shallow pipe with embedded openings for grouting with the cement mixture.

REINFORCEMENT

In order to ensure appropriate load-bearing capacity and flexibility of the primary lining, depending on the class of the rock and the conditions of the tunnel, different types of primary lining structures are used, with different section thickness, which apart from the tunnel anchors includes the installation of a reinforcement in one or two layers and lattice girders. Alternatively, in addition to or a replacement of the steel reinforcement, it is possible to use steel or synthetic fibres.

TUNNEL SUPPORT GIRDER

As part of the primary support depending on the rock category support girders are installed. Function of these girders is to prevent falling of pieces of the rocks and soil, and to provide additional strengthening of the tunnel support system. Support girders can be steel lattice arcs, or structural steel profiles. Shotcrete need to be applied in layers that covers and structurally connects steel reinforcement and girders with the anchors.



3.2.3 TUNNEL WATERPROOFING

After the assessment of the water inflow from the surrounding rock, waterproofing membrane is applied partially or completely covering the tunnel. In case of partial waterproofing, inflowing water is collected in the drainage pipe system and carried out of the tunnel. In case of complete waterproofing, water is prevented from infiltration and circulated around the tunnel.

According to NATM waterproofing membrane is fixed between primarily and secondary tunnel lining. Waterproofing membrane is fixed to the primary lining and protected with geo-textile.

3.2.4 SECONDARY LINING

After installing the primary lining and applying the tunnel waterproofing, according to the NATM, a secondary lining should be placed. The secondary lining of the tunnel is made of doubly reinforced concrete shell which defines the final profile of the tunnel. Most often it is placed in situ – on site in the tunnel, by using a spherical formwork equipped with openings for placing concrete and formwork vibrators. The formwork is usually placed on rails and is moved from one tunnel liner to the next as the placement of concrete takes place. Transport of concrete in larger tunnels is carried out by using stationary concrete pumps and metal pipes for concrete transport.

In order to perform quality and proper placement of concrete when creating the secondary tunnel lining, the concrete should meet several criteria in terms of performance when fresh, as well as the quality requirements when hardened.

Usually, performance requirements of concrete for construction of the secondary tunnel lining are the following:

Concrete consistency (slump) – fresh concrete used for the construction of a reinforced concrete secondary structure is most commonly transported in in-transit mixers from the concrete plant to the tunnel, and then by using a concrete pump it is transported through a system of steel pipes to the formwork. This "pipeline" for transport of concrete may be even over 200m long, and it ends with rubber hoses which are fixed to the openings of the formwork. Fresh concrete should have a high class of consistency which will allow for smooth pumping of the concrete through the pipes and appropriate filling of the spherical formwork. At the same time, occurrence of concrete segregation is not allowed. Alternatively, instead of classical concrete and formwork vibrators, a self-consolidating (SCC) concrete can be used.

Strength properties of concrete – on the basis of a static analysis performed when designing the tunnel, the required concrete strength class is established. The commonly required strength class for construction of the secondary lining in tunnels according to the NATM is C30/37. A second criterion that determines the required strength of the secondary lining in tunnels is the exposure of the tunnel structure to aggressive impacts in the course of its use. The exposure class of the tunnel is defined in the European standard for concrete EN 206-1 and arises from the position and purpose of use of the tunnel.

*more information about the exposure classes of the tunnel reinforced concrete structure and the recommendations on concrete performance and protection systems can be found in the next chapter.

Early strength – in order to observe the dynamics for construction of the tunnel, it is usually necessary for the formwork used in creating the secondary lining to be moved on particular time intervals (usually from 12-24 hours). In order to be able to release the formwork at certain time period, it is necessary for the concrete to have certain strength in order to avoid any potential damage to the concrete structure (usually 50 - 70% depending on the required type of concrete).

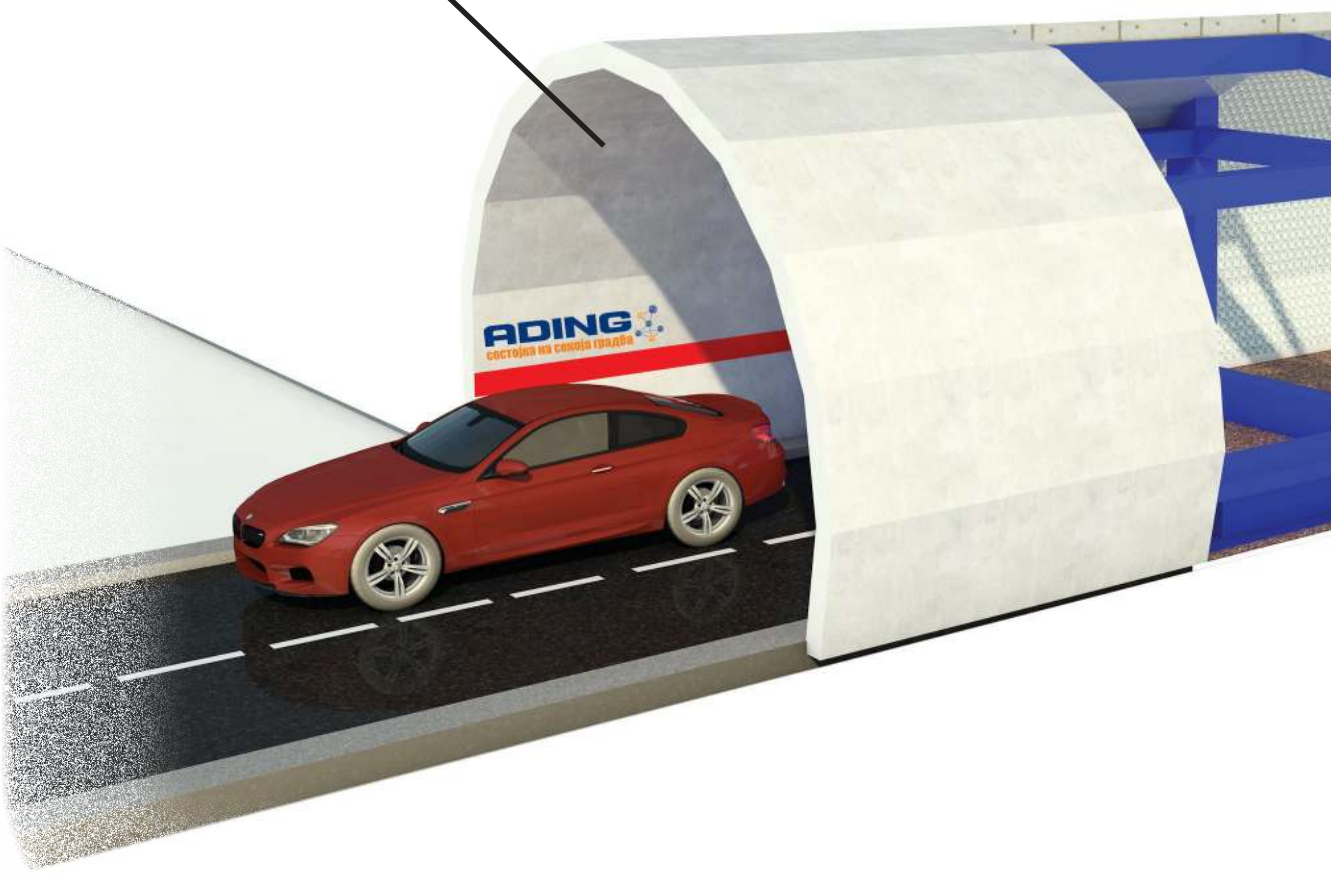
In order to meet the required criteria concerning consistency and strength of concrete, it is necessary to perform previous extensive testing and establish the concrete mix design. The consistency of fresh concrete should have the class of S4 or S5 in order to enable smooth pumping and placement of concrete. The granulometric composition of concrete

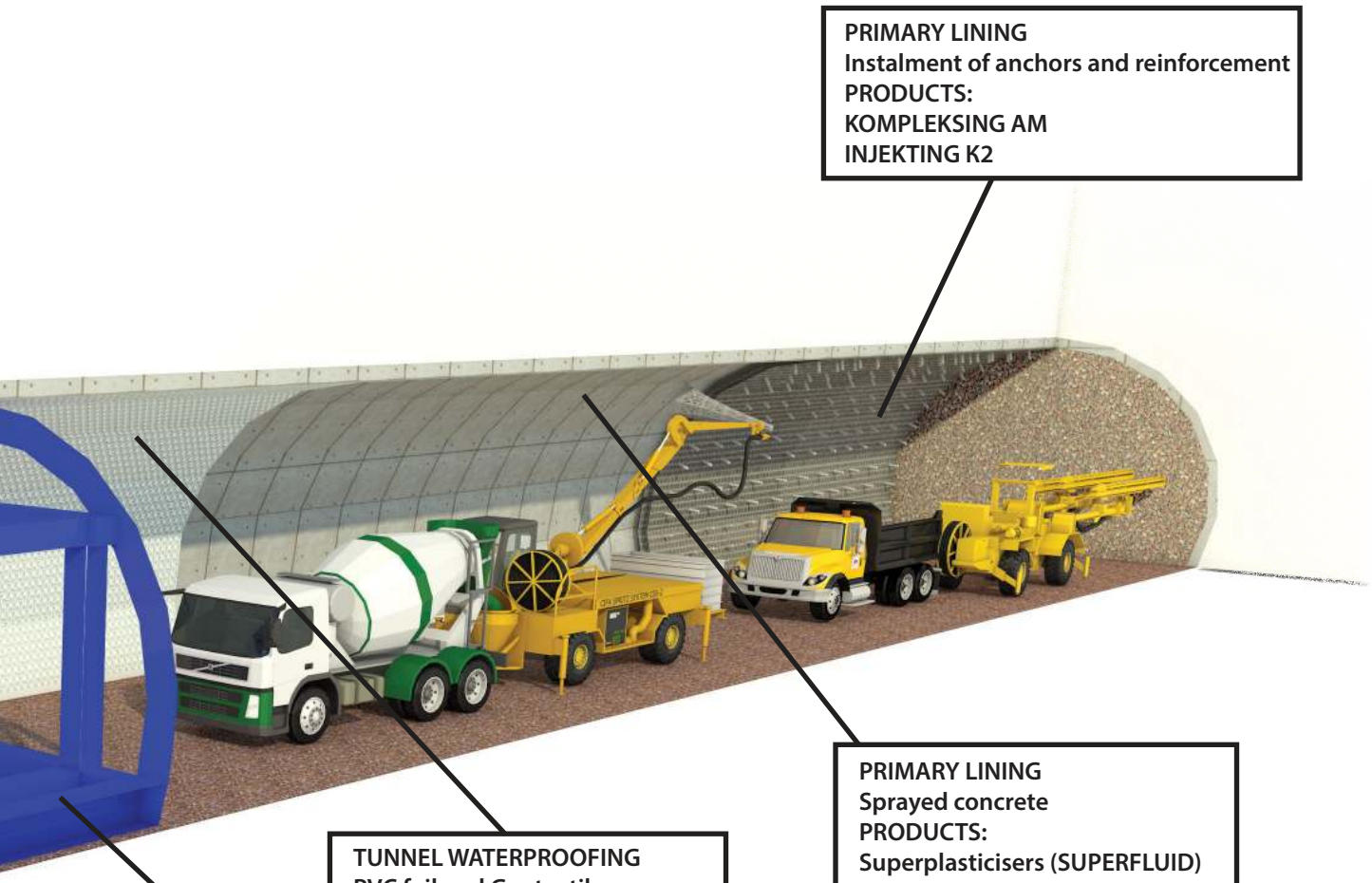
should also be appropriate for transport and placement without the occurrence of segregation. Most commonly, it is 3 or 4 – fraction concrete with maximum granulation Dmax = 16 or 32 mm. The amount of cement and the content of filler (particles <0.125m) in the composition of the concrete mixture are also a key factor which allows for proper pumping of concrete at long distances without the occurrence of segregation.

Concrete admixtures – for production of concrete intended for the construction of the secondary lining of the tunnel, admixtures from the group of superplasticisers are used, which allow for water to be reduced (to achieve low W/C ratio and high strength properties) and at the same time to ensure proper placement of concrete.

TUNNEL CONSTRUCTION STAGES ACCORDING TO THE NATM

PROTECTIVE FINISH OF THE CONCRETE STRUCTURE
PRODUCTS:
ANTIKOROZIN BB
FASIL V
ADINGPOKS AKVA 1B
ADINGPOKS AKVA




PRIMARY LINING
Instalment of anchors and reinforcement
PRODUCTS:
KOMPLEKSING AM
INJEKTING K2
PRIMARY LINING
Sprayed concrete
PRODUCTS:
Superplasticisers (SUPERFLUID)
Set accelerating agent (INGUNIT)
TUNNEL WATERPROOFING
PVC foil and Geotextile
SECONDARY LINING
Installation of formwork and placement of high-performance concrete
PRODUCTS:
SUPERFLUID 21M EKO
SUPERFLUID 21M1M EKO

4 PROTECTION OF THE TUNNEL STRUCTURE

4.1 GENERAL – EXPOSURE CLASSES OF CONCRETE STRUCTURES

Depending on the intended purpose of use of the tunnel (road or rail traffic, hydro-technical structure-tunnel, etc.), as well as its position (rock category, presence of underground water and aggressive agents), the reinforced concrete structure of the tunnel during its use may be exposed to different types of aggressive impact.

In order to perform graduation of the intensity of the destructive impact to which the structure is exposed, and at the same time to perform risk assessment for potential damages during its use, the European standard for concrete EN 206-1 Concrete: Specification, performance, production and conformity, defines the following exposure classes of concrete structures to corrosion and chemical aggression.

EXPOSURE CLASSES OF CONCRETE AND REINFORCED CONCRETE STRUCTURES	
X0 – NO RISK OF CORROSION AND ATTACK	
Concrete without reinforcement which is not exposed to frost, salts and chemical attack	Ex. Concrete elements inside buildings with low humidity
Reinforced concrete in a very dry and protected environment	
XC1 – XC4 CORROSION OF THE REINFORCEMENT INDUCED BY CARBONATION	
XC1 – Dry or permanently wet environment	Concrete permanently submerged in water, buildings with low air humidity
XC2 –Wet, rarely dry environment	Foundation structures
XC3 –Moderate humidity	External concrete surfaces sheltered from rain
XC4 –Cyclic wet and dry environment	
XD1 – XD3 CORROSION INDUCED BY CHLORIDES OTHER THAN FROM SEA WATER	
XD1 – Moderate humidity	Concrete surfaces exposed to airborne chlorides
XD2 –Wet, rarely dry environment	Swimming pools, reservoirs with chlorine. Water
XD3 –Cyclic wet and dry environment	Parts of bridges, pavements, car parks
XS1 – XS3 CORROSION INDUCED BY CHLORIDES FROM SEA WATER	
XS1 – structures that are not in direct contact with sea water	Structures near to or on the coast
XS2 –permanently submerged structures	
XS3 –cyclic exposure to sea water	Tidal, splash and spray zones
XF1 – XF4 FREEZE/THAW ATTACK WITH OR WITHOUT DE-ICING AGENTS	
XF1 – Moderate water saturation, without de-icing agent	Vertical concrete surfaces exposed to rain and freezing
XF2 –Moderate water saturation, with de-icing agent	Vertical concrete surfaces of road structures exposed to freezing and airborne de-icing agents
XF3 – High water saturation, without de-icing agent	Horizontal concrete surfaces exposed to rain and freezing
XF4 – High water saturation, with de-icing agent	Road and bridge decks exposed to direct spray containing de-icing agents, marine structures exposed to freezing
XA1 – XA3 EXPOSURE TO CHEMICAL ATTACK	
* Concrete exposed to chemical attack from ground water or sea water, with limiting values of concentration of contaminants given in the standard EN 206-1. For higher concentrations and other chemical attack, it is necessary to prepare an additional study.	

In addition, as part of the same standard EN 206-1, recommendations are given for preparation of concrete depending on the exposure class in which it is categorised. These recommendations define the minimum requirements of concrete design according to its exposure class, which include:

- **Minimum concrete strength**
- **Minimum amount of cement**
- **Maximum W/C ratio**
- **Type of cement**
- **Content of entrapped air**

RECOMMENDATIONS ON CONCRETE DESIGN AND PERFORMANCE DEPENDING ON THE EXPOSURE CLASS											
	No risk of corrosion	Carbonation				Corrosion induced by chlorides					
						Sea water			Chlorides not from sea water		
Concrete exposure class	X0	XC1	XC2	XC3	XC4	XS1	XS2	XS3	XD1	XD2	XD3
Max W/C	-	0,65	0,6	0,55	0,5	0,5	0,45	0,45	0,55	0,55	0,45
Min. strength class	C12/15	C20/25	C25/30	C30/37	C30/37	C30/37	C35/45	C35/45	C30/37	C30/37	C35/45
Min. amount of cement (kg/m^3)	-	260	280	280	300	300	320	340	300	300	320
Min. entrapped air (%)	-	-	-	-	-	-	-	-	-	-	-

RECOMMENDATIONS ON CONCRETE DESIGN AND PERFORMANCE DEPENDING ON THE EXPOSURE CLASS							
Max W/C	Freezing-thawing cycles				Chemically aggressive environment		
Concrete exposure class	XF1	XF2	XF3	XF4	XA1	XA2	XA3
Max W/C	0,55	0,55	0,50	0,45	0,55	0,50	0,45
Min. strength class	C30/37	C30/37	C30/37	C30/37	C30/37	C30/37	C35/45
Min. amount of cement (kg/m^3)	300	300	320	340	300	320	360
Min. entrapped air (%)	-	4,0[a]	4,0[a]	4,0[a]	-	-	-
Other requirements	Aggregate in compliance with EN12620 with satisfactory resistance to freezing/thawing					Sulphate resistant cement	

In order to ensure durability of the structure-tunnel during its use, when performing the construction works, it is necessary to use concrete that meets the given (minimum) requirements for appropriate exposure class.

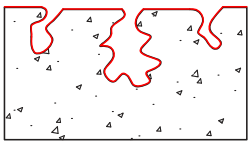
4.2 EUROPEAN STANDARD EN 1504 – PRODUCTS AND SYSTEMS FOR THE PROTECTION AND REPAIR OF CONCRETE STRUCTURES

Apart from meeting the required concrete performances, the surface of the tunnel that is directly exposed to mechanical and chemical impact should be protected by applying products and systems for surface protection of concrete. These materials have been defined in accordance with the European standard EN 1504-2 Products and systems for protection and repair of concrete structures – Part2: Surface protection materials. In accordance with EN 1504, by applying these systems, the following principles of protection of concrete are achieved:

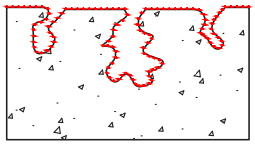
- Principle 1 – Protection against ingress
- Principle 2 – Moisture control
- Principle 5 – Increasing physical resistance
- Principle 6 – Chemical resistance
- Principle 8 – Increasing resistivity

There are three basic methods for surface protection of concrete structures:

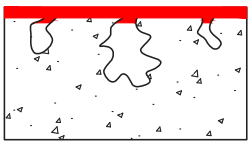
- Impregnation
- Hydrophobic impregnation
- Surface coating



Impregnation



Hydrophobic Impregnation



Coating

IMPREGNATION

Treatment for reducing permeability and improving the physical and mechanical characteristics of the substrate through partial or complete sealing of pores and forming an intermittent thin film on the surface.

HYDROPHOBIC IMPREGNATION

Treatment applied in order to obtain water-repellent and vapour-permeable surface, whereby the appearance of the surface is not changed at all.

SURFACE COATING

Forming a continuous uninterrupted layer on the concrete surface with thickness of to 5mm which protects concrete against moisture and aggressive agents, increases the physical and mechanical resistance of the substrate and the resistance against chemical aggression.

4.3 EXPOSURE AND PROTECTION OF TUNNEL STRUCTURES

4.3.1 EXPOSURE AND PROTECTION OF TRAFFIC TUNNELS

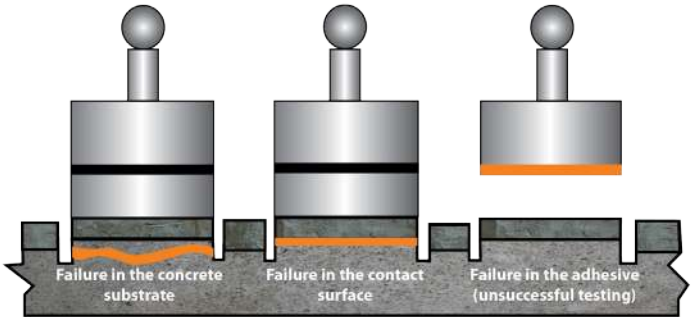
As a result of the intended use of traffic tunnels – road or rail traffic – the basic negative impact to which the structure of these tunnels is exposed to is the carbonation of concrete, as well as the impact of frost and salts (de-icing agents) in the first 100-200m at the entrance and exit of the tunnel. Also, the wall surface of the tunnel measuring up to approximately 3m has a significantly higher level of exposure in terms of the calotte because of water spraying and abrasion from sand falling from the tyres of vehicles, as well as mechanical impact from the cleaning of the tunnel (with water under pressure or rotating brushes). Accordingly, the protection applied at the entrance and on the lateral walls of the tunnel is usually different from the protection applied to the calotte.

During the past decades, Ading company has developed several materials and systems for protection of reinforced concrete structures of traffic tunnels, observing the requirements of the investors and contractors, as well as the highest standards in this area applied in Europe and the rest of the world.

When selecting materials for protection of the concrete structure, it is necessary to take into account several factors – the level of protection needed for the class of exposure of the structure, waterproofing of the material, vapour permeability, substrate adhesion, the possibility for application by means of mechanical spraying under pressure (airless), the setting time and the drying of the material.

From contractors' point of view, it is especially important that the used materials should be suitable for application on wet and water saturated concrete substrate, and at the same time, to achieve proper adhesion (usually adhesion strength of protective coatings exceeds the tensile strength properties of concrete, therefore, when performing the pull-off test, it is the concrete structure that breaks and not the contact with the coating).

Testing the adhesion of a protective coating with a pull-off method



The concrete structure breaks when exceeding the tensile strength properties of concrete.

To achieve durability of the established adhesion bond between the concrete and the protective coating during use, it is also important that the applied system enables free diffusion of vapour (to enable the construction to "breath"). In this way, the occurrence of negative pressure on the material is reduced, as well as the possibility for detachment. In this regard, it is much better to use water-based materials which have higher level of vapour permeability in comparison to solvent-based materials.

Having regard to the fact that the working space in the tunnel is closed, in order to reduce the health risk for workers, it is recommended that the materials used should not contain toxic substances which are released during application (for ex. solvents).

Taking into account all performance requirements, Ading as part of its product range offers several cement and polymer based systems which are water based (based on silane, acrylate resins and water epoxy resins). Depending on the level of exposure in the tunnel, they can be used either individually or as a system.

NAME OF THE PRODUCT/ PROTECTIVE SYSTEM	PERFORMANCES	CONFORMITY
FASIL V	Material (primer) for hydrophobic impregnation of concrete surfaces based on silane emulsion without solvents	Compliant to EN 1504-2:2004 / 1.1(H); 2.1 (H);8.1 (H)
ANTIKOROZIN BB	Acrylate-based coloured coating for protection of concrete surfaces against corrosion. Vapour permeability Class I,SD < 5 m Capillary absorption < 0.1 kg/(m^2·h0,5) Adhesion strength (bond) ≥ 1.5 Mpa Permeability of CO2 SD>50m Reaction to fire Euroclass "B"	Compliant to EN 1504-2, method 1.3(C) - surface protection against ingresses method 2.2(C) - moisture control, method 8.2 (C) - increased resistance
ANTIKOROZIN BR	Synthetic resin and solvent-based coloured coating for protection of concrete surfaces against corrosion Vapour permeability Class I,SD < 5 m Capillary absorption < 0.1 kg/(m^2·h0,5) Adhesion strength (bond) ≥ 2 Mpa Permeability of CO2 SD>50m	Compliant to: EN 1504-2 Method 1.3 (C) - surface protection against ingresses, method 2.2 (C) - moisture control, method 8.2(C) - increased resistance
ADINGPOKS AKVA 1B	Two component water-based epoxy coating for surface protection of concrete exposed to mechanical and chemical impact Vapour permeability Class I,SD < 5 m Capillary absorption < 0.1 kg/(m^2·h0,5) Adhesive strength (bond) ≥ 2 Mpa Permeability of CO2 SD>50m Reaction to fire Euroclass B Class "B" Abrasion resistance < 3000mg Resistance to strong chemical aggression class I Impact resistance class II ≥10Nm	Compliant to: EN 1504-2: 1.3(C); 2.2(C); 5.1(C); 6.1(C); 8.2(C)
ADINGPOKS 1B	Two-component epoxy coating for surface protection of concrete exposed to mechanical and chemical impact Vapour permeability class III Sd>50m Capillary absorption < 0.1 kg/(m^2·h0,5) Adhesive strength (bond) ≥ 2 Mpa Permeability of CO2 SD>50m Reaction to fire Euroclass B Class "C" Abrasion resistance < 3000mg Resistance to strong chemical aggression class II Impact resistance class I ≥4Nm	Compliant to: EN 1504-2:1.3(C); 2.2(C); 5.1(C); 6.1(C); 8.2(C)
ADINGPOKS AKVA	Epoxy-cement coating/mortar for repair and surface protection of concrete Vapour permeability Class II 5m≤SD≤50m Capillary absorption < 0.1 kg/(m^2·h0,5) Adhesive strength (bond) ≥ 2 Mpa Permeability of CO2 SD>50m Abrasion resistance < 3000mg Impact resistance Class III ≥20Nm Compressive strength ≥ 45N/mm^2 Bend strength ≥ 5N/mm^2	Compliant to: EN 1504-2, method 1.3(C), 2.2(C), 8.2(C), 5.1(C) and EN 1504-3, method 3.1 and 7.1

In order to achieve optimal protection and durability of the tunnel structure, as well as optimal methodology and dynamics of construction, and optimal cost-effectiveness of the protective system of the tunnel, the suggested materials are often applied as a system.

Apart from protection, the finishing should provide safety signage in tunnels which forms part of the road traffic infrastructure. They should be marked with signal colours and longitudinal lines and marks at the emergency exits, fire-fighting equipment, etc. All given materials meet the relevant standards for traffic safety in tunnels.

Below we present two systems for protection of a tunnel structure which forms part of the motorway infrastructure by applying materials from the product range of Ading.

PROTECTION SYSTEM 1

Applied protection system:

Adingpoks Akva (White) - 1 working procedure

Antikorozin BB (signal white colour) - 2 working procedure

Antikorozin BB (signal red and green colour) - Signage

PROTECTION SYSTEM 2

Applied protection system:

Fasil V - 1 working procedure

Adingpoks Akva – 1B (signal white colour) - 2 working procedure

Antikorozin BB (signal red and green colour) - Signage

4.3.2 EXPOSURE AND PROTECTION OF HYDRO-TECHNICAL TUNNELS

The hydro-technical tunnels are underground concrete structures intended for permanent or temporary conveyance of water. The hydro-technical tunnels form part of the water supply network for distribution of drinking water, the sewerage systems for drainage of waste water, the industrial plants – for drainage of industrial waste water, as part of the hydro-technical systems – dams for evacuation of overflow water, part of the small and large hydro-power plants, mines, tailings ponds, etc.

Due to its intended use, the hydro-technical tunnels are seriously exposed to damages due to the mechanic impact of the water that flows (erosion, cavitation and abrasion), as well as the chemical impact (chemical erosion of concrete and reinforcement due to the presence of chemical contaminants dissolved in the water). In some cases, even the clean "soft" drinking water may cause chemical erosion of concrete (partial dissolution of the aggregate of limestone origin in concrete).

Depending on the character and intended purpose of use of the hydro-technical tunnel, the speed and intensity of the water flow, as well as the content and aggressiveness of the water that is being conveyed, in order to protect this type of tunnels, different types of materials and systems based on cement and polymer and/or reactive resins are used.

Just like the case with traffic tunnels, the concrete used to construct them must be compliant in terms of ingredients and performance to the exposure class of the intended use. In the lower zone of water flow, the concrete must be additionally resistant to the abrasion from the water. One of the basic factors for achieving the required level of abrasion is also the use of a proper aggregate (usually of magmatic origin) which has high level of hardness and wear-and-tear resistance.

For this purpose, Ading company has developed ready-mix concrete with different grain sizes (4-8-16mm) intended for construction and repair of concrete channels in tunnels.

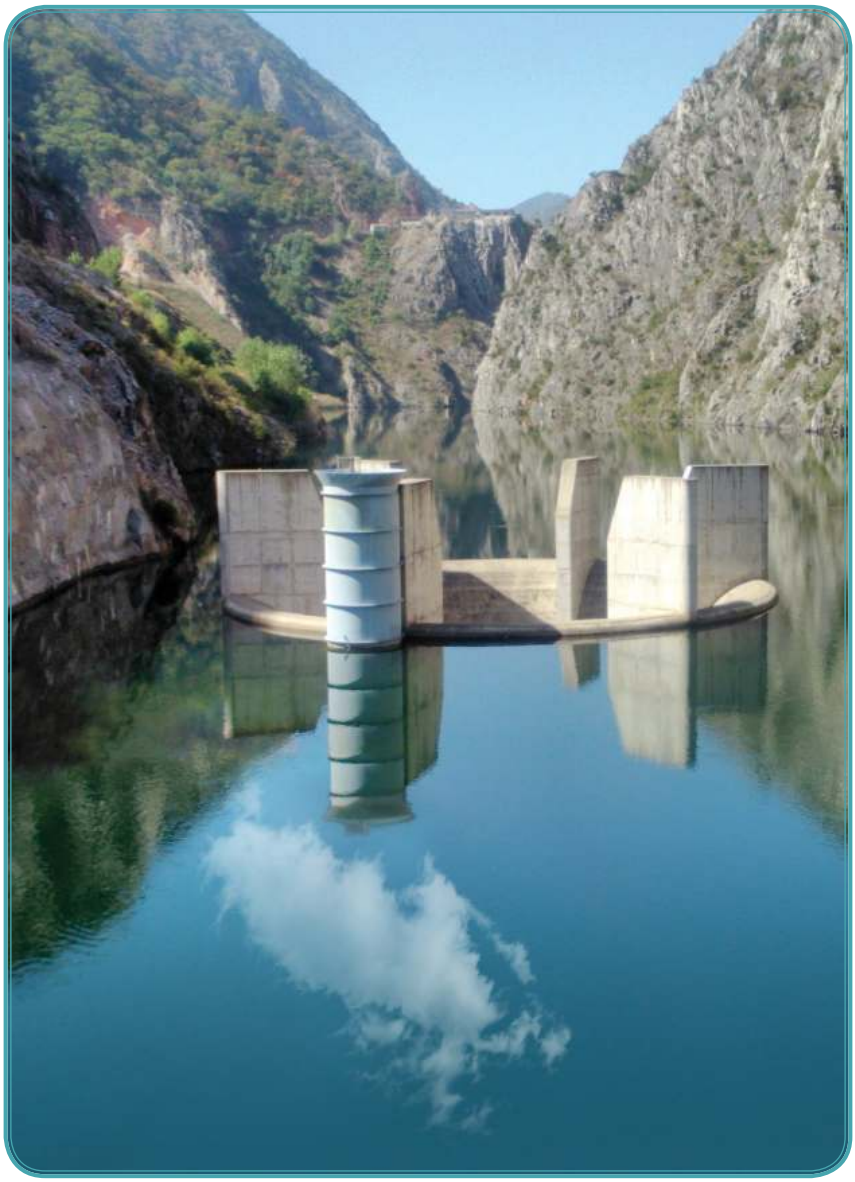
Damage - chemical and mechanical aggression

Floor remediation and shaping - Eksmal

In order to achieve additional surface resistance to mechanical impacts, as well as chemical resistance of the concrete structure, it is necessary to use materials and systems for protection of concrete in compliance with the European standard EN 1504.

Similar to traffic tunnels, depending on the type and intensity of the external impacts, in this case also we can use materials for hydrophobic impregnation or a protective coating. They can be based on cement and polymers. In view of the working conditions and conditions for construction of hydro-technical tunnels, the same performance requirements/recommendations apply (possibility for application on a wet substrate, water-tightness, vapour permeability, free of toxic substances).

NAME OF THE PRODUCT/ PROTECTION SYSTEM	PERFORMANCES	CONFORMITY
EKSMAL 4	Ready-mix, self-levelling, shrinkage-compensating mortar/concrete with maximum grain size of 4 mm High wear-and-tear resistance Vapour permeability Class I,SD < 5 m Capillary absorption < 0.5 kg/(m^2·h0,5) Adhesive strength (bond) ≥ 2 Mpa Compressive strength ≥ 55N/mm^2 Reaction to fire Euroclass "A"	Compliant to: EN 1504-3 Class R4
HIDROMAL	One-component, cement-based, rigid waterproofing Suitable for application in contact with drinking water Vapour permeability Class I,SD < 5 m Capillary absorption < 0.1 kg/(m^2·h0,5) Adhesive strength (bond) ≥ 1 Mpa Compressive strength ≥ 35N/mm^2 Reaction to fire Euroclass "A"	Compliant to: EN 1504-2:2.2(C); 8.2(C)
FASIL V	Silane-based, solvent-free primer for hydrophobic impregnation of concrete surfaces	Compliant to: EN 1504-2:2004 / 1.1(H); 2.1 (H);8.1 (H)
ADINGPOKS AKVA PRIMER	Water-based epoxy primer for impregnation of concrete surfaces	Compliant to: EN 1504-2
ADINGPOKS AKVA	Epoxy-cement coating/mortar for repair and surface protection of concrete	Compliant to EN 1504-2, method 1.3(C), 2.2(C), 8.2(C), 5.1(C) and EN 1504-3, method 3.1 and 7.1



EXPERIENCE AND CARE FOR THE PARTNERS

The proper selection of appropriate materials, as well as the advices and knowledge that our engineers share in the field, are key to the life cycle of the building. They are supported by the R&D Department, as well as by the accredited lab for concrete testing, who in combination with the engineers from the Technical Application and Sales Department, give an added value to your structures.

The products certified according to the European standard EN 1504, as well as according to the local regulations in other areas where we are present, guarantee our seriousness and dedication to our partners.

The goal is to ensure quick, cost-effective and efficient performance to our partners, to meet their demands as soon as possible and to offer solutions that will provide long-term use of the buildings even in the most extreme environments.

ADHESIVES

PROTECTIVE COATINGS

WATERPROOFING

FIRE PROTECTION

CONCRETE REPAIR

OTHER PRODUCTS
APPLIED IN CONSTRUCTION

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ingredient of every structure

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ADING AD SKOPJE, Novoselski pat (ul. 1409) br. 11, 1060 Skopje R. North Macedonia
tel: + 389 / 02 2034 840; e-mail: ading@ading.com.mk; www.ading.com.mk

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