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Influencing parameters of the grout mix on the properties of annular gap grouts in mechanized tunneling

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ABSTRACT

In mechanized tunneling with segment lining the annular gap between segment lining and soil, caused by tunnel driving, must be backfilled instantaneously with an adequate grouting mortar, to avoid bulking of the surrounding soil, to embed the tunnel lining and to minimize settlements of the ground surface. The decisive requirements for such annular gap grouts are on the one hand optimal flow properties lasting for several hours and sufficient stability against segregation at same time, on the other hand a fast development in shear strength immediately after grouting within a few minutes. Latter is usually achieved by dewatering of the mortar into the surrounding soil. Thus, two contradictory requirements are demanded on annular gap grouts.

The main objective of this research study was to investigate the dewatering behavior of grouting mortars, which can be influenced by the constituents and the composition significantly. In systematic and extensive investigations the correlation of these properties has been studied fundamentally as well as the consistency.

For this purpose, a test setup was developed, simulating the conditions within annular gaps up to 20 cm in width. The amount of filterable water, including temporal effects, has been determined. Additionally, the development of shear strength, influenced by the dewatering effect, has been examined. In comparison, shear strengths were also determined at non-dewatered specimens, reflecting the worst case of non-dewatering. The investigations were based on grout compositions, which were primarily used in major traffic tunnels. These mixes have been modified by parameters such as fineness of the binder (cement, fly ash, inert additions) and types of aggregates.

From the experimental results, the main influencing parameters on the dewatering behavior and on the development of the required shear strength could be defined.

1. Introduction

The gap between segment lining and soil, caused by tunnel driving, must be backfilled instantaneously with an adequate grouting mortar, to avoid bulking of the surrounding soil and to stabilize the tunnel system. The construction of an annular gap is schematically illustrated in Fig. 1.

The decisive requirements for such grouts are on the one hand optimal flow properties lasting for several hours and sufficient stability against segregation during the processing and grouting phase. On the other hand the same grouting material has to develop its shear strength very fast soon after grouting within a few minutes, so that this property corresponds to that of the surrounding soil. This is usually achieved by dewatering of the mortar into the surrounding soil. Thus, two contradictory requirements are demanded nearly simultaneously on annular gap grouts.

Annular gap grouts have been almost exclusively defined on empirical basis. However, fundamental scientifically-based investigations on the influences of the grout compositions on the relevant material properties (consistency, dewatering, strength development) are still missing. Thus, the main aim of the studies reported here was close these gaps.

Based on these experiments, it should also be possible, to perform grouting materials in accordance with real design concepts and to ensure diagnosable and unerring annular gap grouting in practice.

2. General requirements on annular gap grouts

The gap between the segment lining and soil can be up to 20 cm in width (Thewes and Budach, 2009) and must be backfilled with

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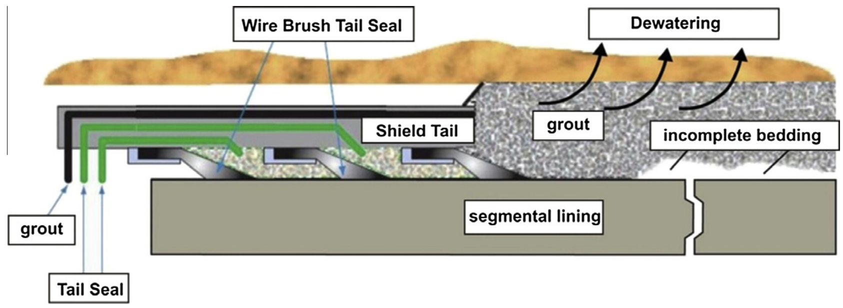

Fig. 1. Annular gap (Thewes and Budach, 2009).

an adequate grouting mortar through pipes in the shield tail soon after mounting of the segments to avoid bulking of the surrounding soil, to stabilize the tunnel lining and to minimize settlements at the ground surface (Babendererde et al., 2002; EFNARC, 2005; Girmscheid, 2001; Deutscher Ausschuss für Unterirdisches Bauen (DAUB), 2001). Besides these main tasks also

- sealing against ground water and leakage water (Astner, 2005; Maidl et al., 2001),
- protection of the segment lining against concrete-aggressive agents in water and soil (Astner, 2005; Maidl et al., 2001),
- high erosion stability in case of high flow velocities of water (Bäppler, 2006; Wittke et al., 2006) and
- high filter stability in case of very permeable soil (Bäppler, 2006; Wittke et al., 2006)

are expected from the final annular gap grout.

Against this background, the grout composition must be defined in consideration of the geological and hydrogeological situations as well as the project-specific boundary conditions.

Therefore, following requirements can be met for annular gap grouts:

- workability lasting for several hours, i.e. high flowability and sufficient stability against segregation for this period (Thewes and Budach, 2009),
- optimal pumpability for at least 12–24 h (Linger et al., 2008; Wittke et al., 2006),
- fast development of shear strength and stiffness modulus, corresponding to those of the surrounding soil soon after grouting (Babendererde et al., 2002; Bäppler, 2006).

Further demands on high compressive strengths are usually not necessary, so that cementitious constituents are not required at all or just in small amounts in the grout mix (Bäppler, 2006).

Annular gap grouts can differ in their binder content, proportion of stabilizing component (one- or two-component) and their maximum grain size of aggregates. Referring to the binder content annular gap grouts can be classified in three different types (EFNARC, 2005):

- Active grouts: hardening is mainly induced by hydration of the binder, generally based on Portland cement with an amount >200 kg/m^3.
- Semi-inert or reduced-active grouts: small content of cement between 50 kg/m^3 and 200 kg/m^3; rapid stiffness, followed by a very slow strength development.
- inert or inactive grouts: nearly no cement, at most 50 kg/m^3, cement is usually replaced by e.g. hydraulic lime or fly ash.

Active grouts achieve after 24 h compressive strengths $\geqslant$0.5 MPa and a stiffness modulus up to 10 MPa, which corresponds to a common soil in the scope of tunneling with segment lining (Thewes and Budach, 2009). The final strengths of these hydraulically setting grouts are usually in a range between 3 MPa and 7 MPa (Philipp, 1987; Schneider and Spiegl, 2008). Typical parameters for cementitious grout mixes are compiled in the following Table 1, mainly based on values from practical experiences.

Concerning the required workability and consistency, a flow diameter of about 20 cm immediately after mixing and about 15 cm at an age of 8 h are recommended when this property is tested according to DIN EN 1015-3. Referring the shear strength a value of more than 2 kPa is demanded to avoid deformations caused by buoyancy forces.

3. Parameters for the specification of grout mixes

The required properties of annular gap grouts can be specifically influenced by the constituents and the composition of the grout mix. Due to the fact, that the grouting mortar only has to reach relatively small values of shear strength and stiffness modulus, corresponding with the adequate values of the surrounding soil, hydraulic binders as cement are not necessary generally. The temporary flow properties can be achieved by using additives and other fine additions. Especially artificial pozzolana (fly ash)

Table 1
Typical parameters for cementitious grout compositions for annular gap grouting (Astner, 2005; Linger et al., 2008; Thewes and Budach, 2009).

Requirements	Parameters	Time after mixing	
Workability/consistency	Spread flow diameter SF according to EN 1015-3	(t = 0 h)	15 ± 5 cm
	Flow diameter a according to EN 1015-3	(t = 0 h)	20 ± 5 cm
	Flow diameter a according to EN 1015-3	(t = 8 h)	15 ± 5 cm
Strength development	Shear strength τ_y		$\geqslant$2 kPa, usually 5–10 kPa
	Compressive strength f_c	(t = 24 h)	$\geqslant$5 MPa
	Stiffness modulus E_s		5–10 MPa (corresponding to a common soil in mechanized tunneling with segment lining)