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Characteristics of selected concrete with tunnel excavation material

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HIGHLIGHTS

- The research investigates the mechanically characteristics of concrete using tunnel excavation materials.
- Determination of characteristics of concrete by using different cement types.
- The research incorporates experimental testing like compressive tests, bending tests and wedge splitting tests.
- The results provide basic as well as fracture mechanical parameters of concrete.

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ABSTRACT

Infrastructure tunnels are an important element in transportation. In the process of tunnel driving, a large amount of excavating material accumulates. Strategies to reuse this material have been growing in popularity during recent years as a result of economic and environmental considerations. It is therefore necessary to reassess the material management concept and identify possibilities to recycle the excavated rock material at the same time. The aim of the current paper is to investigate the mechanically relevant parameters of concrete using various tunnel excavation materials as aggregates and different cement types (e.g. composite cements) by experimental testing. Thereby, basic material parameters of freshly mixed as well as hardened concrete and fracture relevant quantities of hardened concrete are determined. Moreover, the properties of plain concrete and fibre reinforced concrete with aggregates of tunnel excavation material are compared with each other.

1. Introduction

In our time, concrete is the most commonly used building material worldwide. It is characterised by a very favourable ecological balance compared to other construction materials, such as clay bricks, steel or plastics [1–3]. Extensive research is being done to further improve its environmental performance and sustainability. One of the highest energy demands in the production of concrete and its components arises during the cement manufacturing process [4]. However, a further possibility to improve the ecological balance can be achieved by using recycled materials as aggregates for concrete. Such materials might be extracted from deconstruction sites, or they might accumulate in the process of tunnel excavation. Especially in the second case, the reuse strategy helps to reduce amount of material that needs to be deposited, which in turn improves the ecological balance. The use of special, low energy cement types, such as composite cement, supports the ecobalance even further.

A major task to achieve this is to verify if such excavated material is suitable for the production of concrete, as may not fulfil all criteria stated in the relevant standards. In addition, the mechanical behaviour of such concrete would be of high interest for design and assessment purposes of structural members made from concrete with excavated rock material. Therefore, in particular basic material parameters (e.g. compressive strength) are of high interest for elastic assessment purposes. Moreover, fracture mechanical parameters (e.g. fracture energy) are of high interest if also plastic material behaviour will be considered beyond the elastic material behaviour. Such parameters have to be determined by means of experimental tests [5–13].

The properties of numerous materials within the new code specifications have in most cases not yet found their way into the literature [14]. These properties are frequently derived from historical experiments, e.g. [15], and specific material development is typically disregarded [16]. For the characterisation of concrete by using excavated rock material, such methods are not feasible,

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as data can hardly be found in the literature and furthermore each rock type has specific properties. Nevertheless, the effective application and acceptance of performance based approaches as a module for design and development considerably depends on the accessibility of information about material properties [17–20].

This contribution focuses on the characterisation of the material behaviour of concrete by using a variety of excavated rock materials, admixtures and additives as well as steel- and polypropylene (PP) fibres. A number of different experimental tests were carried out.

2. Excavation material

Currently, a large number of tunnel structures in Europe are in their planning and construction stages. In the course of the expansion processes of traffic route engineering by the European Union to establish an efficient connection between northern and southern Europe, even more tunnel structures will be designed within the coming years. One such connection is the Brenner Base Tunnel as a main element of the new Brenner railway from Munich to Verona and the infrastructure section of the new high-capacity axis for the Berlin–Palermo railway line. Details on that project can be found e.g. in [21–23].

An existing prognosis of the possible recycling magnitude states that only around 6% of the excavated rock material can be reused as aggregates for concrete and ca. 15% are suitable as filling materials. This would imply that ca. 79% of the rock material has to be deposited. Further treatment of the excavated material might improve these numbers. The aim has to be a maximum of recycling by optimising the processing method and the material management concept [24,25]. In fact, the general aim is to find the optimal use for the excavated rock, e.g. as an aggregate for concrete. In this case, the rock material has to satisfy various requirements so that it can be easily processed and the operational feasibility and durability of the structure is guaranteed.

2.1. Properties of excavation material

The rock properties of excavation materials of the Brenner Base Tunnel were examined. Three types of lithology were considered: quartz phyllite (Innsbrucker Quarzphyllit), schist (Bündnerschiefer) and central gneiss (Zentralgneis). The investigations involved the evaluation of common rock properties. Consequently, standard concrete tests and fracture tests with respect to the tensile behaviour and fracture energy of various concrete mixtures were performed, using tunnel excavation material as aggregates for concrete. In addition, admixtures and additives as well as steel- and PP-fibres were used for the preparation of the different concrete mixtures (see Fig. 1).

For the characterisation of the tunnel excavation material, different tests were performed (see [26]). One key parameter in particular is the compressive strength. The determination of this parameter was carried out according to EN 1926 [27]. Table 1 shows an overview of the obtained values. Immediately apparent is the high scatter of compressive strength, which is primarily caused by the bedding of the rock.

2.2. Fracture mechanism of aggregates in concrete

Crucial for the concrete strength is the development of the bond zone between cement paste and aggregates [29]. This represents a weakness in the structure of the hydrated concrete. For conventional concrete production, mainly aggregates with a compact grain-shape are used. In general, these also have a higher strength and a higher modulus of elasticity than the cement stone. This fact implies that the stress trajectories are curved and tensile stresses occur at the side of the aggregates.

When using laminated aggregates with high phyllosilicate content and rather low grain strength, as it is the case for rocks of quartz phyllite and schist, the concept of aggregate failure the concrete, as shown in Fig. 2a, can be used in a limited way only. It is dependent on the orientation of the individual components. Firstly, the compressive strengths of the aggregates are in the range of those of the cement, and the moduli of elasticity of rocks are only slightly higher than that of the cement matrix. This means that the stress distribution within the concrete should be represented in a rather more homogeneous way. Therefore, the stress distribution is the cause for the development of the fracture zone between grain and cement stone.

As opposed to conventional concrete, where the grain-shape of the aggregates is compact and the grain orientation therefore is not relevant, grain orientation as well as the surface texture of the excavation material used as aggregate are of great importance and have a considerable impact on the concrete strength.

3. Experimental tests

In order to characterise concrete where tunnel excavation material is used instead of conventional aggregates, experimental tests on the freshly mixed concrete (density, slump value, air content) as well as on the hardened concrete (density, compressive strength, bending strength, fracture energy) were carried out.

3.1. Freshly mixed concrete

The density of the freshly mixed concrete was determined according to ONR 23303 [31]. To calculate the concrete density, cube moulds with side lengths of 150 mm were filled with freshly mixed concrete and compacted. The density was then determined by weighing.

The consistency describes the stiffness of the freshly mixed concrete. It is a measure of its processability. This property was determined by measuring the slump value of concrete according to ONR 23303.

(a) (b) (c)

Fig. 1. Investigated excavation materials: (a) quartz phyllite, (b) schist and (c) central gneiss; particle size 8/16 mm.