Use of TBM chips as concrete aggregate

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1. INTRODUCTION

It has been known for some considerable time that available reserves of high-grade alluvial gravel in Switzerland will be practically exhausted in the foreseeable future [1] and that importing it from neighbouring states is hardly a permanent solution to the problem.

It can therefore be described as fortunate that in the near future a large number of tunnels are planned for construction and this will produce an enormous amount of tunnel excavation material.

For obvious reasons, there is more of this “waste product” than is needed for the tunnel construction itself. In addition, it is produced in a form that is very similar to gravel, especially when the excavation is carried out using tunnel boring machines (TBM).

Treated tunnel excavation material does not differ a great deal from crushed rock, stone chips and ballast. The technique for using this material to make concrete is well known and the fact that it is a full value substitute for alluvial gravel was recently shown dramatically on oil platforms in Norway. Of course, there are more problems associated with the production of concrete using TBM chips than with alluvial gravel. This production demands the application of state-of-the-art concrete technology and knowledge.

The processing of tunnel excavation material is very costly and results inevitably in a material loss which is not desirable for ecological reasons. For these reasons, laboratory investigations were carried out within the framework of the dissertation by Thalmann [2] with the aim of producing concrete using unprocessed tunnel excavation material. These investigations showed that this principle is possible and, under defined conditions, also economically interesting [3].

In order to determine whether these results are applicable in practice, five large scale trials were carried out which are briefly described in the following sections.

2. LARGE-SCALE TRIALS

2.1 Organisation

As determined by the general aims, the large-scale tests had to be carried out under building site conditions, which meant cooperation with concrete works and building contractors. The fifth test was carried out within the framework of a semester at the Institute of Technology State of Berne, Burgdorf.

During these tests, considerable good-will was required from all partners, as the material was rather unusual and because each had to bear the costs of the work carried out. We would therefore like to take this opportunity of thanking all those involved for their efforts, and we hope that it will pay off in the not too distant future.

<table>
<thead>
<tr>
<th>Table 1 – TBM material used</th>
<th>Designation</th>
<th>Source</th>
<th>Porosity vol.</th>
<th>Percentage of non-cubical grains (8/16)</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>Leventina Gneiss biotite muscovite gneiss</td>
<td>exploration tunnel Polmengo tunnel metre: 387...390</td>
<td>36.6</td>
<td>74</td>
</tr>
<tr>
<td>II</td>
<td>Calcareous shale</td>
<td>Kandertal area</td>
<td>42.1</td>
<td>76</td>
</tr>
<tr>
<td>III</td>
<td>Biotite gneiss from Lucomagno zone, shaley and slightly porphyritic</td>
<td>exploration tunnel Polmengo tunnel metre: 4600</td>
<td>37.2</td>
<td>77</td>
</tr>
<tr>
<td>IV</td>
<td>Calcareous shale</td>
<td>exploration tunnel Frutigen section 100...1500 m</td>
<td>42.3</td>
<td>65</td>
</tr>
<tr>
<td>V</td>
<td>Silicious limestone</td>
<td>exploration tunnel Frutigen tunnel metre: 6500</td>
<td>41.8</td>
<td>89</td>
</tr>
<tr>
<td>O</td>
<td>Alluvial gravel</td>
<td>Swiss midland</td>
<td>26.0</td>
<td>24</td>
</tr>
</tbody>
</table>

2.2 Determining the concrete composition

During preparation work for NEAT (New Railway Alpine Transversal) and underground construction work in the Kandertal area of Switzerland, a large amount of TBM excavation material was produced. The aim of the internal EMPA tests was to determine whether this excavation material (see Table 1) could be used as concrete aggregate. The specific target was to produce an easily pumpable concrete with an average cube compressive strength of 35 N/mm² after 28 days (strength class 30/20).
Fig. 1 - Particle size distribution of the 5 TBM materials (shaded area within SIA standard 162, art. 5, 14, 24; Fuller).

Apparently the particle size distribution, the porosity and the percentage of unfavourably formed particles differed widely from that commonly associated with alluvial gravel. For this reason, laboratory tests had to be carried out in order to determine the concrete composition. These tests were based on two simple technical principles for concrete:

- Concrete is only easily processed if the volume of the cement paste (cement + water + air) is at least as large as the voids in a unit volume of aggregate.
- The compressive strength (fc (28 d)) is dependent on the water-cement ratio (w/c) and the air void content (a), according to the following formula:

\[ f_c (28 \text{ d}) = 100 - 110 \frac{w}{c} - (a - 1.5) \times 2 \text{ [N/mm}^2\text{]} \]

(valid for CEM I 32.5)

This resulted in the concrete compositions quoted in Table 2 (see next page). It should be noted that a considerably higher amount of cement and admixtures was required than when alluvial gravel is used, although the targeted strength class was only 30/20. The air entraining agent was actually selected in order to achieve a high freeze-thaw resistance, but this proved to be advantageous, for less cement was needed.

Fig. 2 - Transportation of concrete via pump.

Fig. 3 - TBM material Polmengo.

2.3 Test procedure

The actual large-scale tests carried out in collaboration with a concrete works or a building contractor proceeded according to the following principles:

- 6...8 m³ concrete was produced at a concrete factory and loaded onto a mixer truck.
- Before the truck left, approx. 100 litre of concrete was removed from the mixer in order to make a fresh concrete control (including the production of test specimens).
- The mixer truck transported the concrete (journey duration approximately 15 minutes).
- Another fresh concrete control was made.
- The concrete was pumped into the concrete mould (with the exception of the test with biotite gneiss).
- A third control was made on pumped fresh concrete.
- 2 to 3 days after, the mould was removed and cores were taken from the hardened concrete.

The results of the fresh concrete checks and the investigations on hardened concrete are summarised in Tables 2 and 3.