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.

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).

Table 1 - TBM material used

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

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 (f_c (28 d)) is dependent on the water-cement ratio (w/c) and the air void content (a), according to the following formula:

$$f_c (28 d) = 100 - 110 w/c - (a - 1.5) \times 2 \text{ [N/mm}^2\text{]}$$
 (valid for CEM I 32.5)

Fig. 3 – TBM material Polmengo.

Fig. 2 – Transportation of concrete via pump.

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.

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.

2.4 Discussion of results

All 54 tests produced well workable concrete suitable for building site use. However, the strength category 30/20 was not quite reached on test number IV.

The emptying of the TBM chips from the silos required considerable manual work.

The modulus of elasticity was only approximately 40...57% of the value which could be expected when using aggregate from the Swiss midland.

The larger percentage of cement paste and the lower modulus of elasticity produced a considerably greater shrinkage deformation than with "conventional" concrete.

The effect of the air entraining agent and the stability of

Table 2 - Concrete composition and fresh concrete properties

Material	Test				
	I Exploration tunnel Polmengo (biotite muscovite gneiss)	II Area Kandertal (calcareous shale)	III Exploration tunnel Polmengo (biotite gneiss from Lucomagno zone)	IV Exploration tunnel Frutigen (calcareous shale)	V Exploration tunnel Frutigen (silicious limestone)
A Concrete mixture:					
Aggregate					
TBM material					
O...32 / 40 kg/m ³	1680	1660	1630	1610	1680
Cement kg/m ³	380	380	385	390	380
Water kg/m ³	239	230	235	250	228
w/c ratio	0.63	0.61	0.61	0.64	0.60
Water reducing agent					
in mass % of Cement	1.5	1.2	1.5	1.4	1.2
Air entraining agent					
in mass % of Cement	0.2	0.4	0.25	0.3	0.2
B Fresh concrete:					
Bulk density kg/m ³	2219	2252	2312	2239	2271
Air voids content Vol. %	4.8	3.3	2.4	3.8	4.4
Degree of compatibility	1.26	1.13	1.14	1.25	1.08
Degree of segregability	1.16	1.04	2.27	1.04	
Flow diameter AM	360	390	340	370	360
Water content kg/m ³	240	249	235	260	245
w/c ratio	0.63	0.66	0.61	0.67	0.65

Remark: For tests I, II and IV the concrete was taken before the pump and for V after the pump, for test III (not pumped) during the placing of the concrete.

Table 3 - Hardened concrete on determined cores

Test value	Test				
	I Exploration tunnel Polmengo (biotite muscovite-gneiss)	II Area Kandertal (calcareous shale)	III Exploration tunnel Polmengo (biotite gneiss from Lucomagno zone)	IV Exploration tunnel Frutigen (calcareous shale)	V ³⁾ Exploration tunnel Frutigen (silicious limestone)
Compressive strength f_c					
Age 28 days [N/mm ²]	30.5	34.4	37.1	23.9	32.4
Modulus of elasticity					
Age 28 days [N/mm ²]	13'500	19'700	17'800	11'800	27'300
$E / \sqrt{f_c}$	2444	3359	2922	2414	4716
Water conductivity					
qw [g/m ² h]	19	23	17	25	10
Shrinkage value¹⁾					
after 28 days [%]	0.47	0.52	0.24	0.90	0.36
Air voids content^a					
- Outer layer [Vol. %]	5.71	1.80	2.41	4.28	1.47
Freeze-thaw resistance					
- Outer layer					
$a / n - U_{kr} = FS$	1.5...1.7	0.5...1.1	1.1...1.2	1.2...1.5	1.2
Assessment	high	low...medium	medium	medium..high	medium
Deicing salt resistance					
Δm_{30} [g/m ²]	700...4400	14'500	8'400	9100 ²⁾	1400
Assessment	medium...low	low	low	low	medium

1) At 20 °C / 70% r.h. 2) After 20 freeze-thaw cycles. 3) Determined on specimens made from the laboratory mix during the preliminary investigations.

the air void system apparently depend to a great extent on the type of aggregate used. In addition, the freeze-thaw resistance of the outer layer was greatly overestimated on the basis of the porosity values.

Fig. 4 – Pump with pipeline for the concrete.

3. FUTURE PROSPECTS

Even using untreated TBM chips, it is possible to produce concrete suitable for building site use. But with calcareous shale, the limit of application as concrete aggregate seems to be reached.

Nevertheless, the processes still need some improvement before being introduced, so that even untreated TBM chips can be used on a large scale as a substitute for gravel. For instance, it can be assumed that silos are a fairly unsuitable method to store this material which shows widely scattering characteristics as well as a tendency to clog. With modifications in storage, the conveyance method to the mixer would also change, and in addition there are other and more measurements on the aggregate necessary for the production control than are currently carried out.

Therefore, new ideas are requested and investment required in the production of concrete – an effort which seems hardly worthwhile by looking at the result: out of all these efforts we get anything else but a “high performance concrete”.

However, considering the fact that the majority of concrete is used in standard building construction and that high grade aggregate is getting scarce and expensive, it is clear that this new source of aggregate, currently graded low, could become a decisive factor for the future

of concrete construction. It will be increasingly necessary to make the most of the materials in order to save high grade material for high grade projects.

In a sense, the concrete produced in these large-scale tests is still a kind of “high performance concrete”, the maximum which could have been achieved by using raw TBM chips when considering the prevailing conditions. We are convinced that such concrete with “matched efficiency”, resulting from the necessarily growing use of alternative materials, will be the greatest challenge for concrete manufacturers, specialists and testers.

Fig. 5 – Completed 'wing wall' at location.

Fig. 6 – Determining flow diameters.

REFERENCES

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