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ENVIRONMENTAL OPTIMISATION OF SHOTCRETE APPLIED AT THE BRENNER BASE TUNNEL (BBT)

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Abstract

For the construction of the access tunnel "Wolf" of the Brenner Base Tunnel (BBT), ecologically optimized shotcrete is applied in order to reduce the environmental impacts of the tunnel. Therefore shotcrete mixtures with aggregates consisting of 100% processed tunnel spoil and cements with lower clinker content were developed considering all project requirements.

The following LCA (Life Cycle Assessment) study evaluates the environmental improvements achieved by the applied optimized shotcrete. Therefore, the study compares four recipes of shotcrete:

(i) with processed tunnel spoil (100 %) and Portland cement (CEM I)
(ii) with processed tunnel spoil (100 %), composite (CEM II/A-M) and Portland cement (CEM I) as well
(iii) with primary aggregates (100 %) and Portland cement (CEM I)
(iv) with primary aggregates (100 %) and composite cement (CEM II/A-M)

The environmental indicators applied for the LCA are Global Warming Potential (GWP), Acidification Potential (AP) and Non-renewable Cumulative Energy Demand (Nr-CED). The Mineral Resource Demand (MRD), which is part of the Swiss Ecological Scarcity Method, is used to describe the impact of tunnel spoil recycling.

The results of the study show that the application of optimized shotcrete at the BBT conserves a considerable amount of mineral resources (MRD) and furthermore reduces environmental pollution (GWP, AP, Nr-CED) although not at the same level as for mineral resources. These lower reductions can be explained by an increased content of fines in the processed aggregates grading curve, what demands higher water and consequently higher cement content. Furthermore, the study demonstrates that the production of raw materials is of significant importance for all four indicators. Raw material transport and concrete production (mixing) processes play a minor role regarding the LCA results.

Keywords:

LCA; shotcrete; Tunnel, Spoil; Bündner schist; Mineral resource demand; Global Warming Potential; Acidification Potential; Non-renewable Cumulative Energy Demand

1 INTRODUCTION

The Brenner Base Tunnel (BBT) is the heart of the Scandinavia-Mediterranean TEN Corridor from Helsinki (Finland) to La Valletta (Malta). The Tunnel is a straight, flat railway tunnel of 55 kilometres length, crossing the central Alps between Innsbruck (Austria) and Fortezza (Italy). Approximately 5 million cubic meters of different types of concrete will be required for this rail connection and 15.5 million cubic meters of spoil will be excavated. In order to dispose as little spoil as possible in landfills, a primary objective is the recycling of a great part of the spoil as filler,

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drainage gravel as well as solid and loose foundation layers. The main interest regarding the recycling of spoil is of course its re-use as aggregates for concrete production.

In this study the environmental improvements for shotcrete applied at the access tunnel of BBT-site "Wolf" (Austria) are presented, i.e. shotcrete with aggregates consisting of 100 % spoil and optimized cements with lower clinker content.

2 PROCESSED TUNNEL SPOIL

The tunnel alignment of the BBT crosses four main lithologies: Innsbruck quartz phyllite, Bündner schist, central gneiss and Brixen granite. Central gneiss and Brixen granite are advantageous lithologies for all kind of re-use. The Innsbruck quartz phyllite is poorly suitable for the reuse as processed aggregates [1]. For the Bündner schist feasibility studies [1,2] show the opportunity to process and reuse the tunnel spoil within shotcrete. Hence, in order to reduce the landfill volume and to increase the sustainability of the overall project a specific material management including concepts for material flows, processing and quality control was developed [3]. From an economic point of view it was determined that the reuse of the tunnel spoil is very beneficial for long tunnels. However, the necessary length of the tunnel to finally amortize the investment into spoil processing depends on the particular lithology.

For the access tunnel of the BBT-site Wolf the processing of tunnel spoil consisting mainly of Bündner schist lithology is carried out in several process steps. The spoil passes through a pre-crushing process with dry screening followed by the processing plant with two additional crushing units and wet screening before finally getting to a bucket-wheel sand washing plant. So far, after some adaptions of the processing plant at the beginning all applied concrete aggregates on the BBT-site Wolf have been processed out of tunnel spoil.

3 SHOTCRETE MIXTURE

The key materials in tunnel construction are shotcrete and concrete. According to the World Resources Institute [4] the worldwide cement industry accounts for 3.8 % of the total greenhouse gas emissions or around 5 % of the global CO_2 emissions. Most of the CO_2 emission during concrete production is caused by limestone decarbonation occurring during the clinkering process. Thus, the reduction of the clinker content within the concrete also reduces its environmental impacts. A clinker substitution is done by Portland composite cements (e.g. CEMII or CEM III) and to some extent by substitutions with less energy- and CO_2-intensive latent hydraulic additions.

At BBT-site Wolf different variants of cements and hardening accelerators were tested within the shotcrete mixtures. For two of these shotcretes mixtures (OSc1 and OSc2 – Table 1) , a Life Cycle Assessment (LCA) was carried out. The results were compared to the LCA results of two standard shotcrete recipes (SSc1 and SSc2 – Table 1).

	Standard shotcrete		*Optimized shotcrete*	
	SSc1	*SSc2*	*OSc1*	*OSc2*
	kg/m³	*kg/m³*	*kg/m³*	*kg/m³*
Cement				
CEM I 52,5 R	400		208	320
CEMII/A-M 42,5R		360	208	
Additives				
Latent Hydraulic Add.	20	60	49	100
Water	200	200	219	216
Aggregates				
Primary agg.	1650	1819		
Processed spoil			1607	1607
Admixtures				
Hardening acc.	24	21,6	24	24

Table 1: Investigated shotcrete mixtures.

Table 1 demonstrates the higher water demand caused by the higher content of fines in the processed aggregates grading curve compared to the standard grading curve.

4 LCA

The environmental improvements achieved by the optimized shotcrete used applied for the access tunnel of the BBT-site Wolf are analysed using the Life Cycle Assessment (LCA) method according ISO 14040 [5] and ISO 14044 [6] The LCA was carried out with nine indicators, four environmental indicators and five indicators for the consumption of resources. The results for the following four key indicators will be presented in this study:

(i) Global Warming Potential (GWP),
(ii) Acidification Potential (AP),
(iii) Non-renewable Cumulative Energy Demand (Nr-CED) and
(iv) Mineral Resource Demand (MRD) from the Swiss Ecological Scarcity Method.

The investigated shotcretes are similar in terms of strength and durability and are mixed on site. Thus, for all investigated shotcretes except from the disposal phase (C4) all life cycle phases after the mixing process (A4 – C3) can be defined as equal and not significant for the study. However, the fact that the reused spoil does not need to be landfilled (C4) for the optimized shotcretes is

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taken into account as burden for the standard shotcrete mixtures.

Thus in accordance with EN 15804 [7] the system boundaries for the LCA study were set as shown in Fig.1.

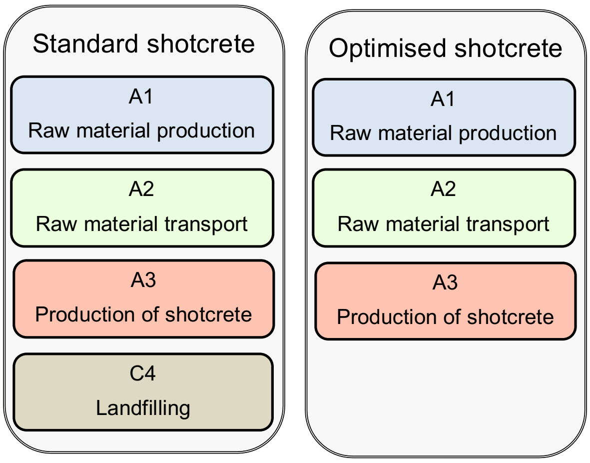


Fig. 1: System boundaries of the LCA study.

All the processes from the extraction of raw materials to the finished production of the shotcrete mixture are considered, i.e. a "from cradle to gate" LCA is carried out. Therefore, no analysis period respectively product lifetime is considered. The comparison is made for a functional unit of '1 m^3 of shotcrete used for the access tunnel support'.

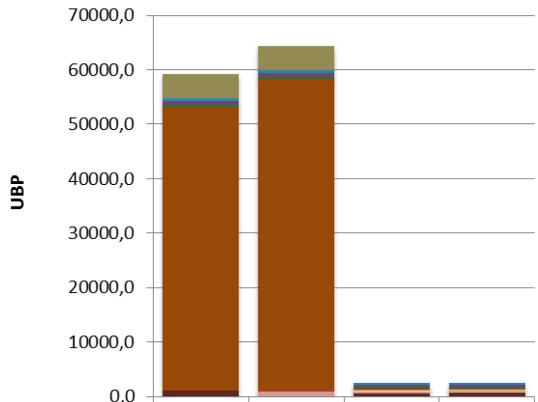
The life cycle inventory datasets were modelled with SimaPro using the database ecoinvent 2.2. For the raw material production (Fig. 1; A1) the required materials according to Table 1 are considered. In addition the influences of air-entraining agents, stabilizer and plasticizer are modelled, but however their impact is insignificant. Thus, their environmental impacts are summed up in the results as 'admixture other'.

For cement production, tap-water use, primary aggregates (gravel crushed), plasticizer and air-entraining agent the Swiss ecoinvent datasets were adopted according to the electricity mix for Austria.

The mixture of latent hydraulic additions is standardised within ÖN B 3309-1 [8]. For this study the secondary raw material within the latent hydraulic additions is considered by applying the economic allocation method.

5 RESULTS

Fig. 2 shows the results for the Mineral Resource Demand (MRD). The significant differences between the results for the shotcretes with and without primary aggregates underline the need of saving resources by reusing processed tunnel spoil.



	SSc1	SSc2	OSc1	OSc2
Deposit of spoil	4483,4	4483,4	0,0	0,0
Production	396,2	396,2	396,2	396,2
Transport	839,9	877,3	429,3	454,8
Accelerator	416,2	374,6	416,2	416,2
Admixture other	38,7	35,1	58,0	102,0
Water	2,8	2,8	3,0	3,0
Processing Spoil	0,0	0,0	272,4	272,4
Primary Aggregates	52013,3	57340,7	0,0	0,0
Latent Hydraulic A.	8,4	25,3	20,6	42,1
CEM II/A-M (S-L)	0,0	798,7	461,5	0,0
CEM I 52,5 R	977,7	0,0	508,4	782,1
Sum	59176,6	64334,0	2565,7	2468,9

Fig. 2: Comparison of mineral resources (EP).

Fig. 3 compares the GWP in kg CO_2 equivalents and shows the main influence of the cement and a minor influence of production and transport. The acidification potential in SO_2 equivalents is demonstrated in Fig. 4. The results generally correspond with the GWP-results, but with a lower influence from the cements and a higher influence from accelerator production, disposal of spoil and from transport processes. For the Non-renewable Cumulative Energy Demand an even higher influence from these three processes is recognised (Fig. 5).

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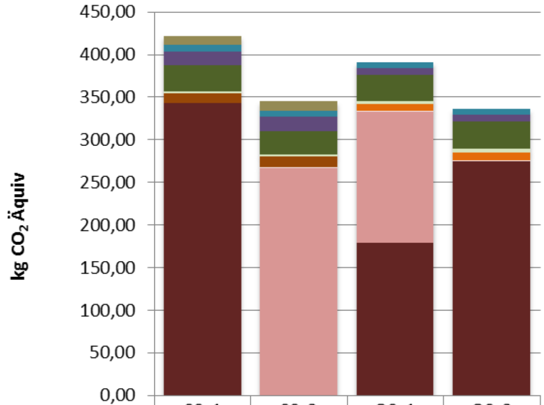
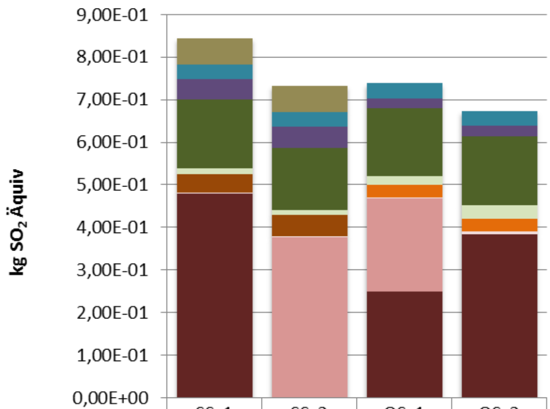


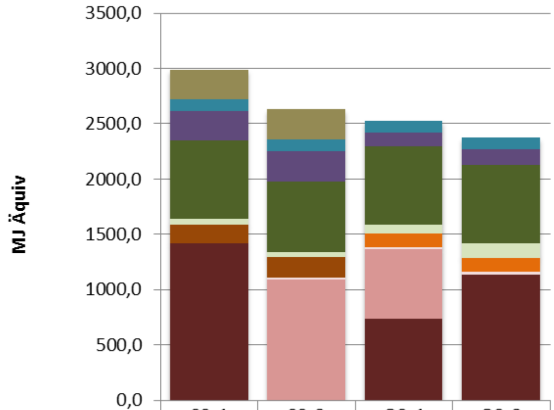
	SSc1	SSc2	OSc1	OSc2
Deposit of spoil	10,65	10,65	0,00	0,00
Production	7,22	7,22	7,22	7,22
Transport	15,82	16,67	7,29	8,01
Accelerator	31,46	28,31	31,46	31,46
Admixture other	1,7	1,5	2,5	4,5
Water	0,06	0,06	0,06	0,06
Processing Spoil	0,00	0,00	8,60	8,60
Primary Aggregates	11,26	12,41	0,00	0,00
Latent Hydraulic A.	0,33	1,00	0,82	1,67
CEM II/A-M (S-L)	0,00	267,07	154,30	0,00
CEM I 52,5 R	343,09	0,00	178,41	274,47
Sum	421,55	344,89	390,66	335,98

Fig. 3: Comparison of GWP (Global Warming Potential) [kg CO_2 eq].



	SSc1	SSc2	OSc1	OSc2
Deposit of spoil	6,19E-02	6,19E-02	0,00E+00	0,00E+00
Production	3,53E-02	3,53E-02	3,53E-02	3,53E-02
Transport	4,82E-02	5,07E-02	2,25E-02	2,46E-02
Accelerator	1,60E-01	1,44E-01	1,60E-01	1,60E-01
Admixture other	0,0	0,0	0,0	0,0
Water	1,45E-04	1,45E-04	1,59E-04	1,57E-04
Processing Spoil	0,00E+00	0,00E+00	2,97E-02	2,97E-02
Primary Aggregates	4,37E-02	4,81E-02	0,00E+00	0,00E+00
Latent Hydraulic A.	1,02E-03	3,06E-03	2,50E-03	5,10E-03
CEM II/A-M (S-L)	0,00E+00	3,76E-01	2,17E-01	0,00E+00
CEM I 52,5 R	4,79E-01	0,00E+00	2,49E-01	3,83E-01
Sum	8,44E-01	7,32E-01	7,38E-01	6,72E-01

Fig. 4: Comparison of the AP (Acidification Potential) [equivalent kg of SO_2 eq].



	SSc1	SSc2	OSc1	OSc2
Deposit of spoil	269,1	269,1	0,0	0,0
Production	107,7	107,7	107,7	107,7
Transport	263,7	277,5	122,6	134,2
Accelerator	708,8	637,9	708,8	708,8
Admixture other	49,2	44,6	74,2	132,9
Water	0,8	0,8	0,9	0,9
Processing Spoil	0,0	0,0	129,4	129,4
Primary Aggregates	167,2	184,4	0,0	0,0
Latent Hydraulic A.	5,0	14,9	12,2	24,8
CEM II/A-M (S-L)	0,0	1091,8	630,8	0,0
CEM I 52,5 R	1416,7	0,0	736,7	1133,4
Sum	2988,3	2628,7	2523,3	2372,1

Fig. 5: Comparison of the nr-CED (Non-renewable Cumulative Energy Demand) [equivalent MJ eq].

6 SUMMARY

The Ecological Scarcity Method is based on Swiss environmental policies in which conversation of mineral resources such as gravel and sand plays an important role.

This emphasizes the need for the construction sector and especially for large construction projects such as the Brenner Base Tunnel to apply recycling material wherever possible and reasonable, to save important resource and to reduce the disposal processes.

The use of tunnel spoil also has a positive effect on the results for the other main indicators, although not at the same level as for mineral resources. This can be explained by the higher cement demand for the shotcretes with tunnel spoil, which slightly diminishes the positive effect of spoil application.

The analysis also shows that the production of raw materials (especially clinker for cements) are extremely important for all four indicators and that transport and concrete production processes play a subordinate role.

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7 OUTLOOK

For the GWP, AP and Nr-CED indicators further reductions can be achieved by optimizing the cement respectively reducing its clinker content. This reduction is limited due to required concrete characteristics and the necessary early strength development (class J2).

8 ACKNOWLEDGMENTS

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