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Waste Materials in Construction: Putting Theory into Practice

ENVIRONMENTAL QUALITY ASSURANCE SYSTEM FOR USE OF CRUSHED MINERAL DEMOLITION WASTES IN EARTH CONSTRUCTIONS

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Abstract

Annually 1 million tons of mineral demolition wastes mainly consisting of concrete and bricks, is produced in Finland. The crushed materials have in field studies on test roads showed favourable geotechnical properties for use in road constructions. The test samples from two crushing plants were chemically characterised and the leaching behaviour was studied by using column, two-stage batch leaching and pH static tests. Only sulphate and chromium leaching from the crushed material was detected. There was a good agreement between column and batch leaching tests. The contents of harmful organic compounds were very low. Based on experience and the results of the experimental study, a practical sampling and testing strategy for an environmental quality assessment system was developed. A two-stage batch leaching test was chosen for the quality control of demolition waste. Preliminary target values for leaching of sulphate, Cr, Cd, Cu and Pb were set. Both geotechnical and environmental properties of the crushed material indicate that the use of demolition waste in road constructions is acceptable and can be recommended to replace landfilling of this material. However, a detailed demolition plan is most important in order to have an acceptable material for utilisation in earth constructions.

1. Introduction

Annually 1 million tons of mineral demolition wastes consisting mainly of concrete and bricks, is produced in Finland. According to current practice, most of mineral demolition waste is landfilled. A proper demolition plan is most important in order to have an acceptable material for utilisation in earth constructions. Selective demolition of buildings and constructions will in the future improve the quality of waste materials. Also due to introduction of taxes on landfilling of wastes, utilisation of mineral demolition wastes will be encouraged. Crushed demolition concrete can be recycled as an aggregate in concrete or used in road bases, the latter of which is of particular interest in Finland.

Contents of harmful compounds must be low and the leaching behaviour of trace metals must be acceptable in materials to be utilised in earth constructions. Potentially harmful materials should be identified and removed before demolition. Examples of potentially harmful materials are preserved wood, electronic equipment, plastics, adhesives, sealing materials, asbestos, fluorescent lamps, gypsum materials, and tarry material. A list of harmful compounds, which may be present in materials or equipment used in the construction industry, is presented in Table 1. The list does not include asbestos, because due to Finnish regulations asbestos always needs to be removed from the buildings before demolition.

The content of harmful materials in building wastes has been estimated in a Swedish report (Sigfrid 1993) to be about 1 % of total mass. The age and the use of the building to be demolished significantly influence the amount of harmful materials. Cadmium for example was used in PVC-plastics as stabiliser and colour pigment during the 1960's and 1970's. The amount of cadmium in plastised PVC was 0,03-0,06 weight-% and in hard PVC 0,012-0,36 weight-%. Another example is the use of sealing compounds for wall elements containing polysulphides. The PCB-contents in these compounds were at least 20 %.

Table 1. Harmful compounds in mineral demolition wastes.

Harmful compound	Application
Organic bound cadmium	Stabilisers in plastics
Metallic cadmium	Surface finishing agents
Metallic mercury	Indicators and switches in electrical installations
Metallic lead	Sealing in sewer drains
Organic lead	Additive in plastics
PCB-compounds	Sealing compounds, condensers and anti-slip floor covering
CFC-compounds	Freezing agents and polymeric insulating materials
Oil and PAH	Oil spills, e.g. from machines, in felt roof, tarry compounds
Chromium (molybdenum)	Concrete, mortar
Copper	Wires, copper water pipes
Phenolic compounds	Insulating materials, adhesives

2. Materials and methods

2.1 Materials

During 1995 the environmental impacts of two different types of demolition wastes were studied in a Finnish project. One of the demolition materials was hollow core slab waste, which had been abandoned due to manufacturing process requirements. In the actual production of hollow core slabs, moulds used are treated with a mixture containing mineral and plant oil before moulding. The oil content in the crushed hollow core slab was estimated from the oil consumption to be a maximum of 110 mg/kg. The other demolition material was mineral building demolition waste, mainly concrete and bricks, from several domestic buildings. In both cases the material of about 10.000 t was crushed to a grain size of less than 70 mm. In these cases the test samples obtained as the crushed material was falling from a conveyor belt to a storage heap. Three test samples about 70 kg each were taken with about one week interval. The grain size distribution of the samples is shown in Figure 1. The test samples were milled and divided by a riffle box to representative laboratory samples of grain sizes of 4 and 20 mm.

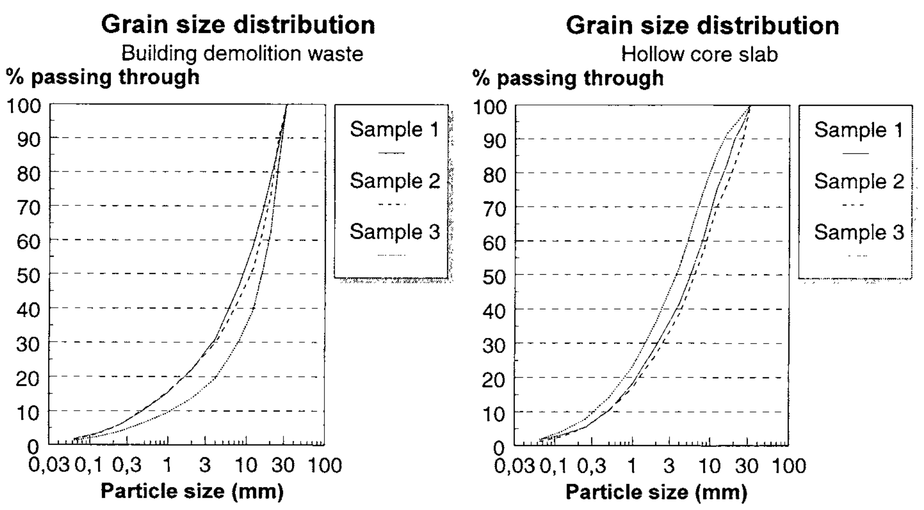

Fig. 1. Grain size distribution in test samples (the coarse fraction > 32 mm was excluded from the test samples).

The chemical analysis of the laboratory samples were performed as follows:

- content of metals was measured after aqua regia digestion by ICP- or AAS-technique.
- phenol-index was determined using 4-aminoantipyrine spectrometric method after distillation
- PAH-compounds were determined by SIM-technique with a gas chromatograph (GC) equipped with a mass selective detector. Three internal standards (d-pyrene, ββ-binapthyl- and indeno(1,2,3-cd)fluoranthene) were added. The sample extracts were cleaned with Silica® before analysis.
- PCB-compounds were determined with gaschromotograph techniques (GC-ECD) from the hexane extract. 2,4,6-tribromibiphenyl was used as an internal standard.

The results from the chemical analysis is presented in Table 2. As comparison also values from literature are shown.

During the summer 1996 additional quality controls of three other crushed demolition material were performed. The materials tested wastes were crushed railway sleeper waste, crushed bricks and crushed building demolition waste. These materials where not characterised chemically.

Table 2. Chemical composition of two demolition wastes and reference values from literature (all concentrations except loss of ignition in mg/kg).

	Building demolition waste	**Hollow core slab waste**	**Concrete granulates from demolition waste** (CROW 1994)		**Crushed concrete** (Kälvesten 1996)	
			Mean value	Range	Sample A	Sample B
Al	12900	14400	25300			
Cd	2,6	3,3	0,3	0,13-1	2,75 ± 0,14	0,137±0,002
Cr	20	29	104	30-160	87,9± 9,0	55,5±5,0
Cu	15	18	15/21	7-20	9,82 ± 0,37	7,63±0,15
Hg	<0,02	<0,02	0,10	0,10-0,10	<0,0433	<0,0438
Mo	<2	<2	2/3	2	<6,18	<6,18
Pb	11	10	25	11-50	6,36 ± 0,19	5,91±0,03
Zn	59	44	70	51-100	52,3± 0,7	41,8±1,1
Phenol-index	<0,2	<0,2				
PAH	0,042	0,96				
PCB Sample 1-3 Sample 1 Sample 3	 0,066 0,085 0,020	 <0,015 <0,015 <0,015				
Loss of ignition	2 %	2 %			3,8 %	3,3 %

2.2 Leaching tests

The leaching behaviour of the hollow core slab waste, demolition building waste and also railway sleeper waste were evaluated by column tests. To study the variation of leaching behaviour and correlation between column and batch leaching test, several batch leaching tests were performed. The batch leaching test is more suitable for quality control than column test. The results were interpreted on the basis of liquid (L) to solid (S) ratio achieved in the tests, in which assumptions about the percolation rate at the site and the geometrical dimensions of the construction were made. The column test to L/S 10 usually depicts the leaching behaviour on the site for hundreds of years.

Column tests were conducted with crushed materials (< 4 mm) according to the Nordtest method ENVIR 002 (similar to the Dutch standard NEN 7343) to L/S 10. The water flow rate was kept as low as possible to L/S 2, after which the flow rate was speeded up. Distilled water acidified to pH 4 with nitric acid was used as leachant. Leachant is pumped from the bottom up to the top of the column, where the eluate fractions are collected based on the L/S ratio. Batch leaching tests (CEN-test) were performed according to prEN 12457 with two leaching steps. During the test procedure the sample was mixed for 6 hours with water at L/S 2 and for 18 hours subsequently at L/S 8. The eluates collected from the column tests and batch leaching tests are analysed.

The pH environment may change with time, e.g. due to carbonation. pH static tests were carried out to characterise the pH-dependent leaching behaviour for selected metals. The tests were performed with crushed material (< 4 mm) at L/S 5 under pH-controlled conditions using automated pH control equipment with nitric acid addition. The tests were carried out for 24 hours at pH-values from 4 to 12.

Leaching is usually dictated by diffusion in road constructions which are isolated with pavements. Therefore diffusion tests provide a more realistic information of the leaching in isolated road constructions. For diffusion tests performed according to the Dutch standard NEN 7345 demolition wastes were mixed with 2 % cement. A test specimen was immersed in water for 64 days and at certain time intervals the leachate was renewed and analysed.

3. Technical properties

Lohja Rudus Environmental Technology Ltd has developed a processing system which enables the reuse of demolition waste in road construction. The concept is based on the self-hardening properties of crushed materials which contain unreacted cementious compounds. The crushed demolition waste, Betoroc, has a 2-3 times better bearing capacity than gravel or crushed rock allowing the reduction of the road base thickness. However, the improved bearing capacity cannot be fully utilised in the Finnish climate because of the frost periods.

Crushed demolition wastes have been used in about ten road constructions since 1994. The bearing capacities measured have been in accordance with planned values or have exceeded them. The E-modulus of crushed demolition waste have varied between 600-1500 MN/m^2, whereas the corresponding reference value for gravel is 280 MN/m^2. The hardening properties of the crushed demolition waste is checked by preliminary tests. Test specimen are prepared using an ICT Gyratory compator, which simulates the action of a roller generating vertical and horizontal shear deformation in the material, after which the E-modulus of the crushed concrete waste is estimated. Also the optimal water content and maximum dry density are measured for construction design.

The handling techniques, transportation, spreading and levelling, resemble those used for gravel. However, the compaction is more demanding, as at least five compactions with a vibrating roller of 10 tons are needed. The water demand is clearly higher, the optimum water content is in the range of 8-10 %. The crushed concrete needs also to be watered one month after construction or until paving.

The design of a construction with railway sleepers and hollow core slabs is shown in Fig 2. The bearing capacity of the construction was in accordance with planned capacity. The E-modulus of the crushed demolition waste was 1000 MN/m^2, while the optimum water content was 9 % and the maximum dry density was 1950 kg/m^3. The compression strength of test specimen after 28 days of hardening was 2 MN/m^2. On sites without risks for frost periods the construction layer could have been reduced with 20 cm compared to the alternative construction with gravel. The total cost of the construction was identical to the ordinary construction with gravel, but the technical properties, especially the bearing capacity, were much better.

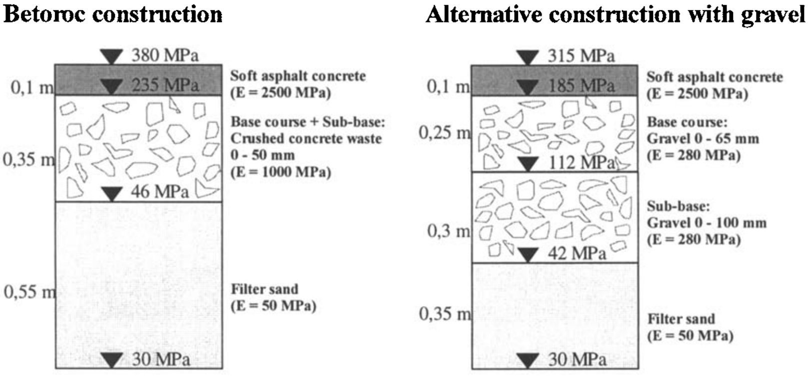

Fig 2. Design of a construction with crushed railway sleepers and hollow core slabs compared to ai alternative construction with gravel.

4. Results

4.1 Batch leaching test and column test

The pH-values of the eluates collected in column tests and CEN batch leaching test were all alkalin usually the pH-values were near 12,5. The high pH-value of the eluates indicate that the pH-valu were mostly dictated by the leaching of CaO which in water solutions gives pH-value of 12 Concrete contains free lime which is liberated during crushing. Furthermore the eluates from t batch leaching tests with coarse materials (< 20 mm) resulted in high pH-values.

The leached amounts from the demolition wastes were low, only sulphate and chromium were leach (Tables 3 and 4). The leaching of sulphate was much higher from building demolition waste than frc hollow core slab waste and railway sleeper waste. The leaching of sulphate from the buildi demolition waste was significantly high in the first eluates of the column test. This indicates a was off effect of sulphate. As expected leaching of metals from crushed hollow core slab waste was low than from building demolition waste, because the origin of the hollow core slab waste. The colur test and CEN-batch leaching test results were comparable. In this case the maximum grain size did r influence the leaching behaviour, probably due to small difference in pH-values of the eluates and d to a very low leaching generally. Both results were also comparable to refence values (see Table 5).

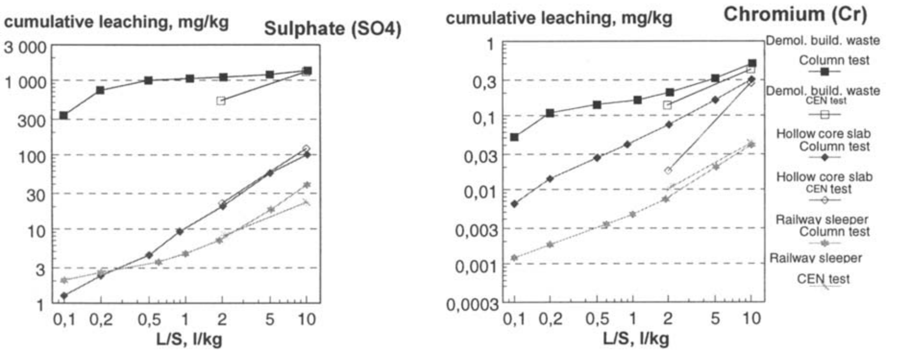

Fig. 3. Leaching of sulphate and chromium from three different types of demolition wastes.

Table 3. Accumulated leaching of metals and sulphate in batch leaching tests and column tests at L/S 2 and L/S 10 (concentrations in mg/kg).

	Building demolition waste, Sample 3B < 4 mm (1995)				**Hollow core slab waste,** Sample 1B, < 4 mm (1995)				**Railway sleeper waste, < 4 mm** (1996)			
	Column test		Batch test		Column test		Batch test		Column test		Batch test	
L/S	2	10	2	10	2	10	2	10	2	10	2	10
SO_4^{2-}	1100	1300	530	1300	20	100	22	120	7	39	8	23
Cl^-	33	44	24	58	8	44	9	58				
Al	2,4	17	2,4	13	7,2	39	4,5	29				
Cd	<0,002	<0,004	<0,02	<0,02	<0,002	<0,002	<0,02	<0,02	<0,0002	<0,0002	<0,0002	<0,0002
Cr	0,20	0,50	0,14	0,42	0,07	0,30	0,02	0,27	0,007	0,04	0,01	0,04
Cu	0,14	0,24	0,11	0,27	0,02	0,05	0,02	0,06			<0,05	<0,05
Zn	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1				

Table 4. Accumulated leaching of metals and sulphate in batch leaching tests at L/S 10 (concentrations in mg/kg).

	Building demolition waste (1995)					**Hollow core slab waste (1995)**					**Demolition waste (1996)**	**Crushed bricks (1996)**	**Railway sleeper waste (1996)**
	Sample 1 < 4mm	Sample 2 < 4mm	Sample 3A < 4mm	Sample 3B < 4mm	Sample 3B < 20mm	Sample 1A < 4mm	Sample 1B < 4mm	Sample 1B < 20mm	Sample 2 < 4mm	Sample 3 < 20mm	< 4mm	< 4mm	< 4 mm
SO_4^{2-}	185	181	230	1300	2700	43	120	42	42	30	250	480	23
Al	11	7	8	13	10	23	29	47	39	31			
Cd	<0,001	<0,005	<0,005	<0,02	<0,001	<0,005	<0,001	0,001	<0,005	<0,005	<0,001	<0,001	<0,001
Cr	0,35	0,40	0,36	0,42	0,35	0,22	0,27	0,34	0,29	0,29	0,12	0,07	0,04
Cu	0,10	0,11	0,13	0,27	0,08	0,05	0,06	0,09	0,08	0,03	0,16	0,05	
Zn	0,04	<0,5	0,5	<0,1	0,04	<0,1	<0,1	0,1	<0,5	<0,5			<0,05
Pb	<0,02	<0,05	0,05	0,05		<0,02			<0,03	<0,02	0,02	<0,04	<0,02
Mo													0,01
V													<0,05

Table 5. Accumulated leached amounts from crushed concrete and building demolition wastes presented in literature (concentrations in mg/kg)

	Crushed concrete (Kälvesten 1996)					**Demolition waste from a building** (Johansson *et al* 1996)		**Concrete granulate from demolition** (CROW 1994)	**Concrete destruction debris** (Mulder 1991)
	Column test	CEN-batch leaching test (2 steps)				CEN-batch leaching		Column test	Lysimeter [1)]
	L/S 2	L/S 2		L/S 10		L/S 2	L/S 10	L/S 10	L/S 5
	Sample A	Sample A	Sample B	Sample A	Sample B				
Cd	<0,0002	<0,0002	<0,0002	<0,001	<0,001	0,01	0,01	0,002	
Cr	0,046	0,0269	0,0294	0,148	0,157	0,16	1,71	0,11	0,039
Cu	0,0084	<0,002	0,004	<0,01	0,0121	0,07	0,12	<0,12	
Ni	<0,07	<0,04	<0,04	<0,02	0,36	0,02	0,06	<0,1	
Pb	<0,002	0,003	0,002	0,011	0,010	0,04	0,05	<0,04	
Zn	0,043	0,01	0,01	0,01	0,05	0,31	0,31	<0,5	0,16

1) pilot-scale research carried out in test bins which were placed outside under normal weather conditions

4.2 Diffusion test

The diffusion test results are shown in Table 6. The eluates were alkaline due to the calcium compounds. The leaching of sulphate and metals were low. The leached amounts were comparable to other cement solidified products reported in literature.

Table 6. Leaching of test specimen prepared from demolition waste containing 2 % cement in the diffusion test (cumulative leached amounts expressed as mg/m² /64 d).

	Specimen from building demolition waste	**Specimen from hollow core slab waste**	**Concrete road stone** (CROW 1994)
SO_4^{2-}	1700	490	2085
Cl^-	58	32	<17
Cr	0,8	1,0	<3
Cu	0,6	0,08	<1,5
Al	450	500	

4.3 pH static tests

The influence of pH changes on the leachability of metals and the buffer capacity of the test materials were studied using pH static test. The results for hollow core slab waste are presented in Fig. 4. The nitric acid consumption to achieve pH 10 was 0,6 mol/kg.

The leaching of cadmium and lead was very low at all studied pH-values. Also the leaching of chromium from building demolition waste was very low. In the case of hollow core slab the decrease of pH influenced the increasing leaching of sulphate, copper, chromium and lead. The leaching of metals and sulphate was lowest at pH-values near 12. The leaching of metals was at no studied pH-value over 1 mg/kg.

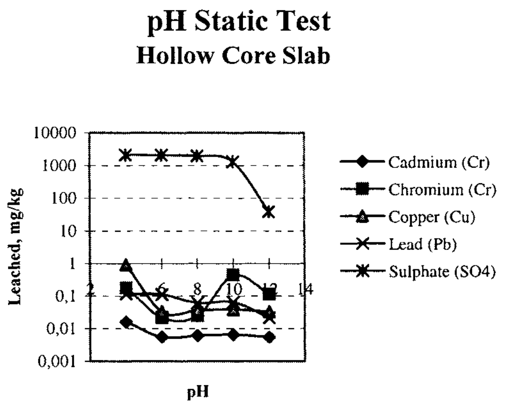

Fig. 4. Leaching from hollow core slab waste in pH-static tests.

5. EVALUATION OF THE ENVIRONMENTAL IMPACTS OF DEMOLITION WASTES

The results from the leaching tests can be compared to

- airborne emissions in wet depositions (e.g. sulphate)
- reference materials normally accepted as construction materials
- trigger values for estimation of contaminated soil (especially the content of organic compounds)
- background concentrations in different environmental surroundings (e.g. risk assessment based on the calculation of metal transport by water in typical utilisation sites).

The correlation between column tests and batch leaching test was very good. The leached amounts from the demolition wastes were low, only sulphate and chromium were leached. The leaching of metals from the demolition wastes studied was most cases in the range of variations observed for non-contaminated concrete (see Tables 4- 6). The influence of pH change on the leachability was estimated as low. Only in the case of hollow core slab waste an increase of leaching of chromium was observed at pH 10. However, the neutralisation capacity of the mineral demolition wastes is high. The environmental impacts of leaching of metals is estimated to be very small for the studied materials especially in isolated road constructions.

The airborne emissions of sulphate in Finnish wet depositions varied in the year 1994 on the range of 146-539 mg/m^2. Assuming that the water flow through an isolated road construction of demolition waste from buildings is 10 mm/year and the thickness of a layer would be around 0,5 m and the density of 2 t/m^3 , it can be roughly calculated that L/S 0,1 might be achieved in about hundred years. According to column test results the total accumulated release of sulphate from building demolition waste after the first 100 years is around 0,3 kg/m^2. The assumed release of sulphate is of course higher than the contribution to soil from wet deposition, but the leaching of sulphate is not regarded as significant. The results from column tests can also be compared to concentrations in natural water. According to diffusion test results the leaching of sulphate was lower than from concrete road stone.

The content of PAH and PCB analysed from the demolition wastes can be compared to Finnish trigger values for evaluation of contaminated soil (Ministry of the Environment 1994):

	Phenols	PAH	PCB
no restriction for use, (mg/kg)	10	20	0,05
only restricted use accepted (e.g. non-residential areas)	40	200	0,5

Despite the used trigger values currently being under examination and possible changed in the future, these values can be used for comparative purposes in order to get an indication of the degree of contamination in the demolition waste. The PAH and PCB contents in the hollow core slab waste material were far below the values for unrestricted use for soils. The PCB content in the building demolition waste was approximately equal to the lower value for unrestricted use, but far below the value for use of soils in non-residential areas.

The demolition waste is quite alkaline due to the liberation of CaO during crushing. The upper layer of the demolition waste is anticipated to be carbonated with time. The alkalinity is also typical for concrete constructions and no restrictions of use of concrete constructions are known. However, on sensitive water areas where the water flows are not mixed with big water volumes, risk assessment of the alkaline waters on aquatic life might be necessary .

Quality requirements for mineral demolition wastes were recommended for the leaching of some metals and for the total content of PCB and PAH. The content of PCB and PAH should not exceed Finnish trigger values for unrestricted or restricted use depending on the site. The target values for the leaching of the sulphate and some metals in the CEN-test with two steps are given in Table 7. The chosen metals are the most common metals which might be present in building wastes. The target values were estimated to be achievable for non-contaminated demolition wastes. Moreover, the values are also in agreement with the proposed Dutch values for maximum leaching in column test which have been calculated based on an acceptable immission of leached compounds from secondary raw materials which are used in earth constructions (Aalbers *et al* 1993). The target value for sulphate is the same as given in the Netherlands for mineral demolition waste for unrestricted use.

Table 7. Proposed target values for leaching from mineral demolition waste at L/S 10. Proposed test method is CEN-batch leaching test with two leaching steps.

Element	**Target value (mg/kg)**
Sulphate	750
Cadmium	0,02
Chromium	0,5
Copper	0,5
Lead	1,0

The conclusion of the study on the demolition wastes studied were following:

- Crushed hollow core slab wastes may be used without restriction, but for use in the vicinity of sensitive ground water areas special considerations on environmental effects are needed.
- The building demolition wastes are not recommended to be used on ground water areas. Building demolition waste are also recommended to be isolated with a water impermeable layer for example asphalt in order to avoid any risks with organic compounds from improper demolition of building.

6. A RECOMMENDATION FOR A QUALITY ASSURANCE SYSTEM FOR DEMOLITION WASTE FROM BUILDINGS

These recommendations are developed for mineral demolition wastes arising from a selective demolition of buildings and constructions. A proper demolition plan of buildings is the most important. Mineral demolition wastes should not be recovered from constructions contaminated by industrial activity or spills. Crushed demolition wastes are recommended to be used outside sensitive areas, e.g. ground water areas. The material shall be isolated with a water impermeable layer, such as asphalt.

In this work it was concluded after several discussions with experts (also including environmental authorities) that the quality assurance system of the crushed material can only be a spot control and therefore a simple sampling strategy was chosen. If crushed demolition wastes is used without any restrictions a more extensive test protocol needs to be created for quality control.

The proposed recommendations for the quality assurance system are as follows:
- the test samples are taken after crushing, preferably from a falling stream
- the samples are collected in a vessel with dimension preventing particles to jump out of the vessel and with a width exceeding the conveyor belt. The vessel is to be only half full.
- three separate test samples are taken at the same time and of these three samples one is randomly chosen for analysis. The two remaining samples are stored until the examined test sample is proved to be acceptable. If the examined test sample fails the quality requirements, the both other test samples are examined.
- the weight of each test sample is about 50 kg.
- at least 500 t materials shall be crushed between two subsequent sampling moments
- the sampling frequency is the following:

Amount of crushed material on the crushing site	Sampling frequency
< 10.000 t/year	1 sampling/for every starting 2500 t of crushed material
> 10.000 t/year	1 sampling/for every starting 2500 t until 10.000 t and after this 1 sampling/for every starting 5000 t of crushed material

- the particle size of the sample is reduced to less than 4 mm, after which the sample is divided into a laboratory sample (1 kg) e.g. using a riffle box
- the laboratory sample is studied using the CEN-test with two leaching steps (target values presented in Table 7)

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