Acceptance limits for the content of pollutants in recycled materials in road construction

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Abstract

The paper presents the acceptance limits for content of pollutants in recycling materials newly formulated by the “Norwegian Roads Recycling R&D program”, a 4-year research program of the Norwegian Public Roads Administration (NPRA). The paper explains how the limits have been calculated and how they are to be implemented as a quality requirement in the NPRA’s design codes.

The method used was a coupling of the European standard for characterization of waste, ENV 12920 (published as EN 12920 in April 2006), and the Norwegian national guidelines for risk assessment of contaminated soils, SFT 99:01. The coupled method was applied on a “standard road” scenario using recycled materials in their most usual fields of application, in an environment surrounded by sensitive recipients. Based on the acceptance criteria concerning drinking water, surface water and toxicity to humans, the limiting values of the content of pollutants were calculated and evaluated.

1. Introduction

Recycled materials have proved to be a valuable substitute of materials from natural resources, Norwegian full scale tests performed since the mid-90's confirm that experience[1]. In road construction, appropriately applied, these materials will in some cases exhibit even better technical performance than natural materials, e.g. bearing capacity of recycled concrete aggregate. However, a condition for their use, even in the technically simplest cases, is a full control of environmental impact.

In Norway, limits for hazardous waste and generic criteria for polluted soils in areas with sensitive land use are formulated. Between these extremes, maintaining clean environment is the responsibility of the construction authority, and the general requirement is case-to-case risk assessment. However, if the problem is limited to road structures with recycled materials and an environment typical for road structures, it is reasonable to assume that it is possible to determine a highest tolerable level of pollution of a recycled material. This set of values is called here acceptance limits for recycled materials in road construction. This paper is a short summary of the work that is reported in detail elsewhere[2,3,4,5,6].

2. Description of the approach and method applied

The chosen approach can be summarized as follows:

- A "standard road structure" is defined, where recycled materials are used in the most probable ways of application, as determined by their technical properties;
- A "standard scenario" is defined, as a combination of climate conditions, geology, ground water conditions, and land use;
- Environmental impact for the "standard road structure" is calculated. The material input values are given by composition or leaching properties. The criteria for evaluating the impact on the environment are described below.
- The calculation is then reversed and the input values adjusted in a way that the environmental impact remains with the acceptable levels. This is the basis for the formulation of acceptance limits for recycled materials (see Section 3).

The project has chosen to focus on recycled concrete aggregate, reclaimed asphalt, shredded tires, and granular foamed glass. The materials are chosen based on waste volume, their suitability as road building materials, and availability on the Norwegian market.

The method chosen in this project is based on a combination of two standardized procedures[7]:

- European standard for the characterization of waste, ENV 12920[8] (published as EN 12920, 2006), in this case applied for characterization of recycled materials, i.e. for quantitative description of leaching. The ENV 12920 method consists of 7 steps, see Figure 1.
- Norwegian guidelines for evaluating the impact of contaminated soil on health and ecosystem, SFT 99:01[9], in this case applied for the evaluation of environmental impact of recycled materials used in the road structure on the surrounding. Other calculation models than SFT 99:01 may also be applied. Risk assessment is added as step 8 to the method, see Figure 1.

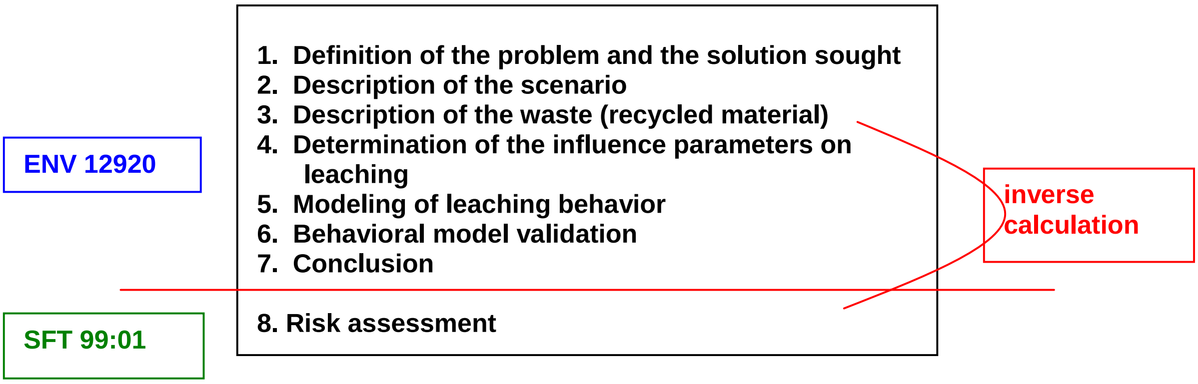

Fig. 1 Coupled method for description of waste material and risk assessment

The acceptance criteria for chemical concentration of different organic and inorganic compounds in water are taken from the following documentation:

- Norwegian Pollution Control Authority (SFT) "Guidelines for the Risk Assessment of Contaminated Sites" covers the risk contaminated site entails to humans and the environment[9].
- SFT guideline 97:04 covers environmental quality standards for fresh water, acceptance criteria for surface water correspond to "Good water quality" from this document. "Canadian Environmental Quality Standards" are used as parameters for fresh water where Norwegian values lack[10]
- Suitable environmental quality standards do not exist for antimony and phenols. Predicted No Effect Concentrations (PNEC) from European Union Risk Assessment Reports (EURAR) is therefore used as quality criteria. The reports are evaluating the following dianthimony trioxide (draft), bisphenol A, 4-t-octhylphenol (draft) and nonylphenol[11,12]. Other sources of information are selected Norwegian laws and regulations, EC directives and existing Danish quality guidelines for recycled materials[13].

3. Calculation procedure

3.1 Steps 1 – 2: Definition of the problem and description of the scenario

Steps 1-2 describe the road structure and the ways of application of the recycled materials. Figure 2 shows the "standard road" and the usual placement of the recycled materials, chosen as the problem for studies in this project. All parameters were chosen as realistic but conservative. Recycled concrete aggregate can be used in all part of the road structure, dependent on the type of road. Reclaimed asphalt can be found in the pavement and base layer. The most usual applications of granulated foamed glass and shredded tires and are in embankments or noise barriers. Foamed glass can also be used for insulation purposes in the sub-base layer.

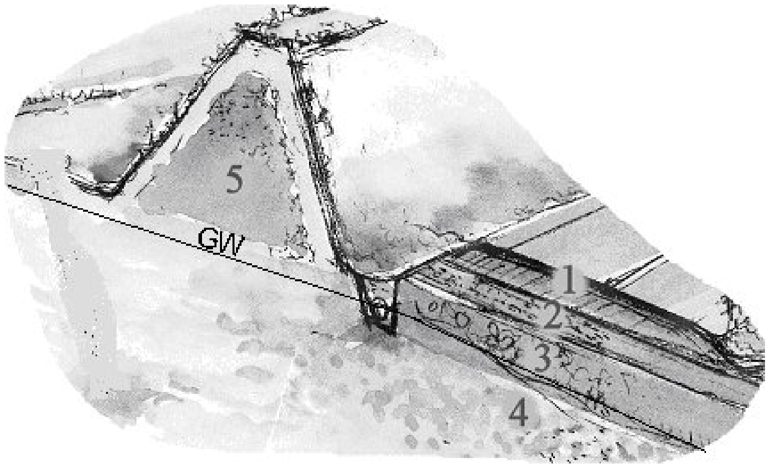

Fig. 2 "Standard road structure" and the most common applications of recycled materials: (1) pavement /road surface, (2) base, (3) & (4) sub-base above and below ground water table, respectively, (5) noise barrier.

4. 2 Step 3-7: Leaching characteristics of the recycled material, factors influencing leaching, modeling and validation

Steps 3-7 focus on each recycled material. In this project, chemical, physical, and mechanical properties of the materials, relevant for the scenario under consideration, were described. In addition, conditions enhancing or limiting the leaching of certain pollutants were studied and described, and the most relevant conditions chosen. Calculation models for leaching were applied. Finally, an evaluation of the collected data and its suitability for use as input for risk assessment was done. The path from here either leads back for improvements of the data set or continues to Step 8. Table 1 summarizes the work done in Steps 3 – 7.

Table 1. Summary of work performed in Steps 3 – 7 of the procedure for the calculation of acceptance limits.

Material	Recycled concrete aggregate[3]	Reclaimed asphalt[4]	Shredded tires[5]	Foamed glass[6]
Pollutants	Metals PCB PAH	Metals PAH	Metals PAH Phenols (4-t-octhyl and Bisphenol A)	Metals
Source of laboratory data	Characterization of concrete mixtures cast in laboratory (some including fly ash), crushed to RCA Characterization of RCA (real samples)	Leaching tests constant pH (metals) Composition (organic substances)	Total content analysis using extraction method. Total content calculations based on information from	Weekly composition analysis from production line (XRF). Annual random weekly samples

	originated from the Oslo area *Comments:* Organic compounds described as TOC, chem. properties described through pH dependent leaching properties and ANC.	Column leaching tests, eluate analyses	production. Laboratory leaching tests.	analyzed by ICP. Chem. properties described through pH dependent leaching properties and ANC.
Source of field data	Full scale field test [14]	Composition of field specimens of airfield and road pavements (PAH, PCB)	Lysimeter (10 m^2) placed under tires in noise barrier and light fill construction.	Full scale field test[14]
Factors assumed to have impact on leaching	pH and red ox conditions (affecting the constituent speciation at the solid surface and in the pore water), infiltration rate and volume (deciding diffusion, equilibrium or wash out/dissolution), exposed surface area and level of compression[14]	Infiltration rate, exposed surface area. pH and red ox conditions. Degradation of chemicals (bitumen).	Infiltration rate, exposed surface area. pH and red ox conditions. Degradation of chemicals (rubber).	Infiltration rate, exposed surface area. pH and red ox conditions.
Performed tests	Full pH dependent tests Determination of total composition in a number of different sample batches		EN 12457 L/S 2 & L/S 10 leaching tests on 5x5 cm chips.	Full pH-dependent tests. Column leaching test.
Leaching model applied	Calculation of pore water concentration (K_d) Geochemical speciation modeling, ORCHESTRA [15] Simplified model for cumulative release[16]	Calculation of pore water concentration (K_d)	Calculation of pore water concentration (K_d)	Calculation of pore water concentration (K_d)
Critical compound (and corres-ponding criterion)	As (exposure via fish) Cr (related to soil criteria - however due to the fact that only total Cr is measured)	Cd (surface water) PAH (ground water)	Cd (surface water, however metals cords are the probable source) Zn (surface water) PAH 16 (ground water) Phenols (ground water)	Cr (see comment for concrete) Pb (surface water, sets the min limit for pH at 5,5) Sb (surface water, however probably more relevant for other scenarios)

4. 3 Step 8: Environmental risk assessment with inverse calculation

Step 8 is the calculation of environmental risk based on SFT 99:01. In the first run, the calculation will determine if the environment *tolerates* the constituent release from the recycled material in the roads structure applied in the given way. The next run, and all further runs of this iterative calculation, are aimed at *adjusting* the material input properties in a way that the environmental impact is not greater than defined by the acceptance criteria.

An excerpt of the results from the previous steps was used as input in the calculation of environmental impact for the chosen structure and scenario. The procedure is constructed as a set of Excel spreadsheets. The main steps of the procedure are presented in Table 2.

Table 2 Procedure for risk assessment with inverse calculation of maximum content

Part A	Risk assessment following SFT 99:01	*Step I*	Comparison of composition values with soil criteria for sensitive land use (health risk).
		Step II	Scenario-specific risk assessment - the effect is calculated for soil in the specific "standard road" scenario (health risk)
		Step III	The actual leaching is determined by field measurements, monitoring or advanced calculations.
Part B	Inverse calculation		Adjustment of the input data to achieve risk level below the maximum acceptable. The result is a set of maximum values for recycled materials (independent on the material). Acceptance criteria for drinking water and surface water are applied.
Part C	Comparison of evaluations done in Part A and Part B		The aim is to take into account all relevant criteria and perform a qualified choice of limiting values – acceptance limits for recycled materials.

This procedure of risk assessment and inverse calculation was performed for each of the studied recycled materials. The iterative inverse calculation was carried out for one component at a time, increasing the content of the component in each step up to the point when the criteria for ground water or surface water were exceeded. These criteria represent effects on human health, flora and fauna. This calculation results in a set of values that present the maximum tolerable pore water concentration and are independent of the material. Due to limited space, this paper will show only a one set of results, those of recycled concrete aggregate, Table 3.

The maximum pore water concentration is the pollution limit of the pore water, as it represents the maximum tolerable *release* from a recycled material in the given scenario, i.e. maximum leachability. However, measuring leachability that reflects the given scenario in one single test is not possible. General acceptable leachability is therefore transferred to acceptable *maximum tolerable content* of pollutants for each material.

Table 3. Results of the calculation of the inverse calculation for recycled concrete aggregate

Parameter	Calculated max content [mg/kg]	Calculated leaching pore water [ug/l]	Calculated leaching ground water [ug/l]	Calculated leaching surface water [ug/l]	Documented total content [mg/kg]	[1]Documented leaching [µg/l]
Arsen	33	1091	4,2	1,5	0,4-6,4	< 2-4
Lead	873	873	3,4	1,2	0,9-185	< 1-3
Cadmium	2,2	73	0,28	0,1	<0,1-1,5	< 0,1-8
Copper	546	1091	4,2	1,5	2,2-224	26-172
Chrome total (III + VI)	55	1819	7,0	2,5	5-120	3-110
Mercury	0,7	4	0,01	0,005	<0,003-0,07	not meas.
Nickel	182	1818	7,0	2,5	2,2-107	2-242
Zinc	1455	14547	56,4	20	4,3-345	0,4-775
Naphtalen	6	284	1,1	0,4	not relevant	not relevant
Benso(a)pyren	24	2,58	0,01	0,0035	not relevant	not relevant
Pyrene	6,8	6	0,025	0,01	not relevant	not relevant
PAH totalt	236	26	0,10	0,04	0,74-19,8*	[2] -
PCB CAS1336-36-3	0,4	0,3	0,001	0,0004	0,013-0,14*	[2] -

[1] *From pH static test, EN 14429, values are from the pH range of 6,6-12,5*
[2] *Not determined by a relevant test method*

5. Formulation of the acceptance criteria

When the maximum tolerable leachability is transformed into maximum tolerable composition, the data set becomes material dependent. The way a certain pollutant is chemically bound in the material is crucial for the leaching mechanism and, therefore, for the knowledge on how the transformation from leachability to composition should be performed. Also, some additional criteria must be taken into consideration:
- some maximum values are far higher that ever documented in the specific material,
- the possibility of all compounds simultaneously reaching the extreme level is negligible,
- some compounds and their limitation are a “political” issue, which may have a stronger effect on the formulated acceptance limit than the calculated values (organic components).

Tables 4 and 5 summarize the acceptance limits for the four studied recycled materials.

Parameter	Documen-ted max content	Soil criteria sensitive land use	[1] Scenario specific acceptance criteria (Step II)	[2] Inverse calculation Criteria for ground /surface water maintained	Chosen acceptance limit	Comment - detrimental criterion for choice of acceptance limit
RECYCLED CONCRETE AGGREGATE [mg/kg]						
As	6,4	2	[3]20	33	[3]20	Step II
Pb	185	60	1400	873	200	max documented content
Cd	1,5	3	14	2,2	3	Step I - soil criteria
Cu	224	100	[8]< 10.000	546	250	max documented content
Cr tot	120	25	[8]< 10.000	[4]55	[5]110	inverse calc. - surface water
Hg	0,07	1	230	0,7	1	Step I - soil criteria
Ni	107	50	1700	182	110	max documented content
Zn	553	100	[8]< 10.000	1455	600	max doc. content
PAH total	< 2	2	116	1182	2	Step I - soil criteria
PCB	< 0,01	0,01	0,72	2,1	[6]0,01	Step I - soil criteria
RECLAIMED ASPHALT [mg/kg]						
As	0,3	2	[3]20	33	20	Step II
Pb	55	60	1400	873	100	inverse calc. - surface water
Cd	3	3	14	2,2	3	Step I - soil criteria
Cu	19	100	[8]< 10.000	546	100	Step I - soil criteria
Cr tot	74	25	[8]< 10.000	[4]55	[5]110	inverse calc. - surface water
Hg	0,1	1	230	0,7	1	Step I - soil criteria
Ni	139	50	1.700	182	150	inverse calc. - surface water
Zn	63	100	[8]< 10.000	1455	100	soil criteria + max.doc. x 1,5
PAH total	62	2	203	236	<100 100-1000	warm recycling – inhalation for cold recycling
B(a)P	4	0,1	13	24	10	inverse calc. - ground water
Naphtalene	1	0,8	2.703	6	5	inverse calc. - ground water
Pyrene	9	0,1	[8]< 10.000	7	5	inverse calc. - ground water
PCB	[7]0,004 - 0,01	0,01	0,14	0,4	[6]0,01	Step I - soil criteria

1. *Toxicity to humans or ecological impacts on flora and fauna*
2. *Calculated in relation to the criterion for ground and surface water quality*
3. *Based on recommendations from Norwegian Geological Survey (NGU 1999) concerning As in inorganic substances*
4. *Assumed to be Chrome VI*
5. *Acceptance limit for total Cr assuming max 50% Cr VI*
6. *A reasonable acceptance limit would have been 0,1, but 0,01 is chosen due to policy for extinguishing PCB from the environment*
7. *0,08 mg/kg documented in 1 of 36 specimens*
8. *No unacceptable exposure is expected for concentrations < 10.000 mg/kg*

Parameter	Documen-ted max content	Soil criteria sensitive land use	[1]Scenario specific acceptance criteria (Step II)	[2]Inverse calculation Criteria for ground /surface water maintained	Chosen acceptance limit	Comment - detrimental criterion for choice of acceptance limit
SHREDDED TIRES [mg/kg]						
As	4,1	2	[3]20	33	[3]20	Step II
Pb	52	60	1400	873	60	Step I - soil criteria
Cd	3,6	3	14	2,5	5	inverse calc. x 2 - field tests[9]
Cu	32	100	[8]< 10.000	546	100	Step I - soil criteria
Cr tot	3,3	25	[8]< 10.000	[4]55	25	Step I - soil criteria
Hg	0,1	1	230	0,7	1	Step I - soil criteria
Ni	3,3	50	1700	182	50	Step I - soil criteria
Zn	174	100	[8]< 10.000	1455	250	max doc x 1,5
PAH 16	114	2	116	1182	120	Step II
B(a)P	5	0,1	7,2	118	7	Step II
Naftalen	1	0,8	9.339	28	2	max doc. x 1,5 (approx.)
Pyrene	20	0,1	[8]< 10.000	34	30	max doc. x 1,50
PCB	-	0,01	0,72	2,1	0,01	Step I - soil criteria
4-T-oktylfenol	-	-	-	3,9	2	inv. calc. x 0,5 – ground water
Bisfenol A	-	-	-	8	4	inv. calc. x 0,5– ground water
FOAMED GLASS [mg/kg]						
As	30	2	[3]20	33	30	inverse calc. – surface water
Pb	1254	60	1400	873	[10]800	[7]for pH-levels > 5,5
Cd	<1	3	14	2,2	2	inverse calc. – surface water
Cu	150	100	[8]< 10.000	546	200	max documented content
Cr tot	354	25	[8]< 10.000	[4]55	[9]550	inverse calc. – surface water
Hg	0,09	1	230	0,7	1	Step I - soil criteria
Ni	40	50	1.700	182	50	Step I - soil criteria
Zn	126	100	[8]< 10.000	1455	200	max documented content
Sb	[11]30 - 52	-	-	197	150	Inverse calculation based on EURAR (chapter 3.2)

1. *Toxicity to humans or ecological impacts on flora and fauna*
2. *Calculated in relation to the criterion for ground and surface water quality*
3. *Based on recommendations from Norwegian Geological Survey (NGU 1999) concerning As in inorganic substance*
4. *Assumed to be Chrome VI*
8. *No unacceptable exposure is expected for concentrations < 10.000 mg/kg*
9. *Acceptance limit for total Cr assuming < 10% Cr VI in total Cr*
10. *The formulated acceptance limit of 800 mg/kg is regarded as safe for pH-levels above 5,5. For lower pH-levels (acid soil or ground water), extended characterization is recommended.*
11. *Only three test series available.*

6. Conclusions

The combination of EN 12920, Characterization of waste, and SFT 99:01, Norwegian guidelines for risk assessment of contaminated soils, has proved to be a useful framework for establishing a relation between properties of recycled materials and their environmental effect in a given scenario. This approach has been successfully used to adjust the input values of material properties in a way that the environmental impact in a scenario described as the "standard road" does not exceed the acceptable level. The formulated acceptance limits for recycling materials in road construction reflect the present level of knowledge and data available, and will necessarily be subject to adjustments.

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