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Research article

Leaching behaviour of copper slag, construction and demolition waste and crushed rock used in a full-scale road construction

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A B S T R A C T

The leaching behaviour of a road construction with fayalitic copper slag, recycled concrete and crushed rock as sub-base materials was monitored over ten years. All studied materials used in the road construction, including crushed rock, contained concentrations of several elements exceeding the guideline values recommended by the Swedish EPA for total element concentrations for waste materials used in constructions. Despite that, leaching from the road construction under field conditions in general was relatively low. The leachates from the recycled materials contained higher concentrations of several constituents than the leachates from the reference section with crushed rock. The leaching of the elements of interest (Cr, Mo, Ni, Zn) reached peak concentrations during the second and fourth (Cu) years and decreased over the observation period to levels below the Swedish recommended values. Carbonation of the concrete aggregates caused a substantial but short-term increase in the leaching of oxyanions such as chromate. The environmental risks related to element leaching are highest at the beginning of the road life. Ageing of materials or pre-treatment through leaching is needed prior to their use in construction to avoid peak concentrations. Also, the design of road constructions should be adjusted so that recycled materials are covered with low-permeability covers, which would minimize the exposure to atmospheric precipitation and weathering.

1. Introduction

The majority of granular materials (aggregates) used in construction are obtained from natural bedrock, sand and gravel resources. Across Europe, an estimated 3 Bt aggregates are produced each year, of which primary aggregates constitute over 90% (UEPG, 2006). Concerns about the depletion of natural resources and increased costs due to taxing of virgin materials as well as increasing landfilling fees have focussed attention on the potential use of alternative aggregates, especially for road construction (OECD, 1997). Available alternative aggregates include recycled concrete from construction and demolition waste, incineration ash, tyre shreds, metallurgical slags such as blast-furnace, steel and nonferrous slags, and mine waste rock. Many of these, e.g. blast-furnace slag and recycled concrete from sorted demolition waste, have physical properties that make them suitable as unbound road materials (Sherwood, 1995; Arm, 2003). The main barrier restricting these materials from being used as aggregates is the potential leachability of substances that could contaminate adjacent soil and water systems.

Not only measurements of total chemical content, but also leachability, are important factors in any environmental assessment of materials considered for recycling. However, feedback from experience with field applications is scarce and constitutes a major drawback to understanding and verifying the leaching behaviour of the materials under field conditions. For example, copper slag and blast-furnace slag have been used extensively in road construction in Sweden for over 30 years, but until the 1990s not much attention was paid to environmental issues. Based on laboratory testing, Tossavainen and Forssberg (2000) concluded that copper slag could be used without any risk of excessive trace element leaching since the high concentrations of metals in the slag are efficiently immobilised in a glass phase. Since laboratory leaching tests are commonly used to support decision-making on the management (e.g. recycling as road aggregate) of recycled materials, improved knowledge of the material leaching behaviour under long term field conditions is crucial for the development of accurate methods

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for environmental impact assessments.

In this study, the leaching behaviour of copper slag, recycled concrete and crushed rock used as aggregates in test sections of a full-scale road construction is evaluated. The test sections were built and monitored for leachate emissions during four years by the Swedish Road Administration (SRA, 2002). Later, supplementary samples were collected to create a ten-year long time series of field leachate data.

The aims of this work were to (i) assess the extent of element leaching from the field test sections containing recycled materials over time and (ii) to discuss the potential risks of using these materials in the road construction.

2. Material and methods

2.1. Description of the field site

Three separate 100 m sections with either copper slag, recycled concrete or crushed rock (reference) in the sub-base were built outside the city of Luleå in Northern Sweden during rehabilitation of a public country road in 1997 (SRA, 2002). The road had an annual average daily traffic (ADT) of 800 vehicles (~5% heavy vehicles). The sub-base was built on a subgrade containing sulphide soil (silty clay to clay). The groundwater surface lay 1–2 m below the road surface.

The road was asphalted with open road slopes. Lysimeters of low density polyethylene (LDPE) plastic sheets were installed below the sub-base in each test section in order to collect the percolating water (Fig. 1). The thickness of the sub-base was decided based on the geotechnical properties of the materials. Each lysimeter covered a 4.4 m × 6.8 m area from the middle of the road to about 1 m outside the asphalted surface. The collected water was transported by gravity to 80 L polypropene (PP) sampling wells on the side of the road.

2.2. Description of the tested materials

The copper slag consists of fayalite slag (FS) from copper production at Boliden Rönnskär's smelter in Skellefteå, Sweden. The slag is produced in the electrical smelting furnace and converters as silica sand is added and reacts with the iron bound in the copper minerals. During slag fuming and subsequent settling, the slag is stripped from zinc, lead, copper and precious metals. The cleaned slag is rapidly cooled by water granulation, which results in an almost completely amorphous (glassy) material (Mooseberg et al., 2003) with a particle size of 0–3 mm (95% < 2 mm). Fe and Si are major elements in the slag (Table 1), which has a chemical composition similar to that of fayalite (Fe_2SiO_4).

The construction and demolition waste (C&DW) consists of sorted building demolition waste crushed to a particle size of 0–100 mm (50% < 8 mm). Yet, pieces of e.g. wood, gypsum boards and plastics were identified during filling. The crushed rock (CR) is composed of biotite gneiss-granite crushed to a particle size of 0–30 mm (50% < 8 mm). Major elements in the C&DW were Si, Ca and Al and in the CR were Si, Al and Fe (Table 1).

Table 1
Loss on ignition and the total chemical composition of the fayalite slag (FS), construction and demolition waste (C&DW) and crushed rock (CR), along with the Swedish guideline values (GV) for "waste used in constructions" (SEPA, 2010).

	FS [a]	C&DW [b]	CR [b]	GV
LOI (%)	0	82	16	
Al (g (kg TS)$^{-1}$)	26	60	77	
Ca (g (kg TS)$^{-1}$)	15	110	21	
Fe (g (kg TS)$^{-1}$)	370	33	51	
K (g (kg TS)$^{-1}$)	5	20	30	
Mg (g (kg TS)$^{-1}$)	8	17	19	
Mn (g (kg TS)$^{-1}$)	3	1	0.7	
Na (g (kg TS)$^{-1}$)	6	19	20	
S (g (kg TS)$^{-1}$)	6	n.a.	n.a.	
Si (g (kg TS)$^{-1}$)	180	230	290	
Ti (g (kg TS)$^{-1}$)	1	5	6	
As (mg (kg TS)$^{-1}$)	17	5	0.6	10
Ba (mg (kg TS)$^{-1}$)	3100	730	670	
Cd (mg (kg TS)$^{-1}$)	<1	0.07	0.1	0.2
Cr (mg (kg TS)$^{-1}$)	1600	65	120	40
Cu (mg (kg TS)$^{-1}$)	4800	11	31	40
Hg (mg (kg TS)$^{-1}$)	0.7	<0.04	<0.04	0.1
Mo (mg (kg TS)$^{-1}$)	2800	<6	<6	
Ni (mg (kg TS)$^{-1}$)	130	12	31	35
Pb (mg (kg TS)$^{-1}$)	140	17	10	20
Sb (mg (kg TS)$^{-1}$)	90 [c]	n.a.	n.a.	
Se (mg (kg TS)$^{-1}$)	<5 [c]	n.a.	n.a.	
V (mg (kg TS)$^{-1}$)	55	130	110	
Zn (mg (kg TS)$^{-1}$)	13200	72	99	120

n.a. – data not available.
[a] Fällman and Carling (1998), n = 2.
[b] Jacobsson and Mácsik (1997), n = 1.
[c] SP (2003), n = 1.

2.3. Sampling and sample handling

From August 1998 to October 2002, water in the wells was sampled twice every autumn with two-months time between the samplings (SRA, 2002). Two weeks prior to each sampling, the wells were emptied and cleaned. From October 2006 to August 2007, samples were taken on 6 occasions, twice every autumn and spring. These samples were taken directly from the outlet of the collection pipe to minimize the contact with air and the risk of contamination by road runoff or rain water seeping through the lid of the well. All samples collected had a volume of at least 1 L and were collected in acid-washed polyethylene bottles. Separate aliquots were collected to determine pH, electrical conductivity (EC), alkalinity and anions. The bottles were filled up to their maximum

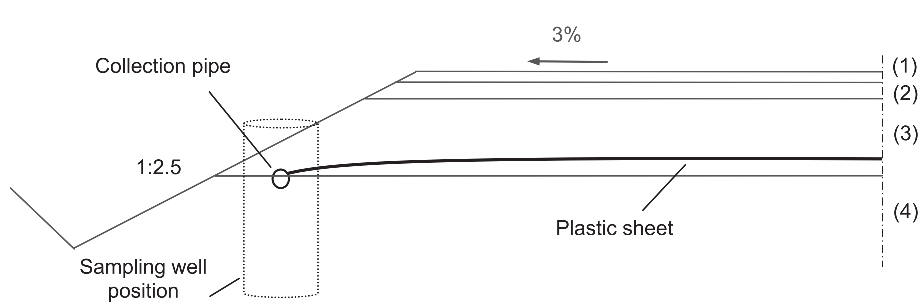

Fig. 1. Cross section of the test road with leachate collection devices: (1) Wearing course: 70 mm asphalt; (2) base: 80 mm crushed rock; (3) sub-base: 500 mm fayalite slag, 420 mm recycled concrete or 420 mm crushed rock aggregates; (4) subgrade: silty clay-clay.