Environmental impacts of asphalt and cement composites with addition of EAF dust

Okoljski vplivi asfaltnih in cementnih kompozitov z dodatkom EOP-prahu

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Abstract: EAF dust can be used in civil engineering as an appropriate additive in asphalt and cement composites. Before its intended use it is necessary to estimate the environmental impacts. For this purpose leachability tests based on diffusion were performed in water and salt water for six months. Stable compact and ground asphalt composites with addition of 2 % of EAF dust and cement composites with addition of 1.5 % of EAF were studied. Data demonstrated that Cr was leached almost solely as Cr(VI). The results indicated that Cr(VI) was not leached from compact asphalt composites with addition of EAF dust. However, in ground asphalt composites with addition of EAF dust Cr(VI) was leached with water in concentrations up to 220 μg L^{-1} and with salt water up to 150 μg L^{-1}. In compact and ground cement composites with addition of EAF dust leaching of Cr(VI) with water was negligible, while Cr(VI) was leached with salt water in concentrations up to 100 μg L^{-1}. The leaching of Cr(VI) originated primarily from cement. Other metals investigated did not represent an environmental burden. Therefore, from the environmental aspects EAF dust can be safely used as a component in asphalt and cement mixtures.

Original scientific paper

Izvleček: V gradbeništvu lahko EOP-prah uporabimo kot primeren dodatek asfaltnim in cementnim kompozitom. Pred tovrstno uporabo pa je poleg fizikalno-mehanskih, potrebno preučiti tudi okoljske vplive. V ta namen smo šest mesecev sledili izluževanju kovin z izlužitvenimi preizkusi na osnovi difuzije v vodi in slani vodi. Pripravili smo kompaktne in zdrobljene asfaltne kompozite z dodatkom 2 % filtrskega prahu in kompaktne ter zdrobljene cementne kompozite z dodatkom 1,5 % filtrskega prahu. Ugotovili smo, da se je krom izluževal pretežno kot Cr(VI). Ta se ni izluževal iz kompaktnih asfaltnih kompozitov z dodatkom EOP-prahu, medtem ko so dosegle izlužene koncentracije iz zdrobljenih kompozitov vrednosti do 220 μg L^{-1} Cr(VI). Iz cementnih kompozitov z dodatkom EOP-prahu se je Cr(VI) izluževal le s slano vodo v koncentracijah do 100 μg L^{-1}. Izluževanje nekaterih drugih kovin je bilo zanemarljivo. S fizikalno-mehanskega in okoljskega vidika EOP-prah lahko uporabljamo kot dodatek asfaltnim in cementnim kompozitom za uporabo v gradbeništvu.

Key words: EAF dust, asphalt and cement composites with addition of EAF dust, leachability, Cr(VI)

Ključne besede: EOP-prah, asfaltni in cementni kompoziti z dodatkom EOP-prahu, izluževanje, Cr(VI)

Introduction

In the developed countries industrial by-products from steel making industry e.g. steel slag [1–6] and electric arc filter (EAF) dust [7, 8] are widely used in civil engineering. Waste products are increasingly used as alternative materials that successfully substitute natural raw materials. Re-use of industrial by-products leads to preservation of natural resources,[3] substantial reduction of landfills load and consequently to the protection of the terrestrial environment. The use of materials that contain industrial by-products is possible when such materials posses appropriate technical characteristics [3, 6] and are environmentally acceptable. [3–5, 9] Industrial by-products that can be potentially re-used may contain various inorganic and organic pollutants. Among pollutants in wastes from steel making industry, metals represent the potential environmental threat. It is well known that the toxicity and mobility of particular metal depends not only on the total concentration, but also on its chemical form. An example is chromium that is extremely toxic in its hexavalent form (carcinogenic, mutagenic, provoker of contact dermatitis), while trivalent chromium compounds (Cr(III)) are essential for glucose metabolism and are much less toxic than those of hexavalent chromium (Cr(VI)).[10] When waste materials and industrial by-products are re-used for road construction and in civil engineering, toxic substances may be successfully immobilised with asphalt [7] and cement.[8, 11, 12] However, before the use, the environmental risk due to the potential release of contaminants from alternative aggregates should be critically apprised.[4, 5, 7, 8, 13] Although it is important to predict the possible long-term effects of alternative aggregates to the environment, there are only few papers reported in the literature on such investigations. In order to estimate the long-term environmental impact, leaching tests based on diffusion were proposed in the Netherland's NEN 7345 standard [14] and applied in the leaching protocol developed for concrete.[15]

The aim of this work was to appraise the long-term environmental impacts of the re-use of EAF dust as additive to asphalt and cements. We report estimation of the results from the leachability tests based on diffusion that were performed in a time span of six months [7, 8] with particular emphasis to critically evaluate the concentrations of Cr(VI) in leachates. Finally, the conclusion was made on the environmental acceptability of the use of EAF dust in road construction and in other civil engineering applications.

Materials and methods

Filter dust generated at the steelwork Štore Steel steelworks, Slovenia was mixed with asphalt and/or cements into stable composites. It was found experimentally that the maximal amount of filter dust added to asphalt that ensured the optimal physico-mechanical characteristics was 2 % by mass of asphalt composite [7] and 1.5 % by mass of cement composite.[8]

In order to assess the long-term environmental impact of asphalt and cement composites with addition of filter dust, the leachability test was carried out in water and salt water (3.8 % NaCl). The salt water simulated the salting of roads during the winter time and the marine environment. Leachability was investigated in compact and ground composites. Ground composites simulated the long term environmental conditions when asphalt disintegrates with time.

To perform the leachability test, NEN standard (NEN 7345, 1995), based on diffusion [14] and the leaching protocol that was developed for concrete [15] were considered. Accordingly, the ratio between volume of a testing composite and the volume of added leaching solution was 1 : 5. In the leaching solutions pH and Cr(VI) concentrations were followed for six months. Concentrations of Cr(VI) were determined either by the spectrophotometry or by anion-exchange fast protein liquid chromatography – electrothermal atomic absorption spectrophotometry.[16] In the leaching solutions from the last samplings some selected metals were also determined by atomic absorption spectroscopy.

Results and discussion

Chemical characteristics of EAF dust

EAF dust is a material with a rather constant composition. The major components of filter dust represent Zn (23–24 %) and Fe (18–22 %), the minor components Pb (1.3–1.5 %), Ca (3.1–3.6 %), Mg (1.6–2.0 %) and Mn (3.5–3.9 %) while in lower concentrations Cr (0.3 %), Cu (0.2 %), K (0.4 %), Ba (0.2 %) and Al (0.2 %) are present.[7] The leachability of these metals in water is low. However, it should be taken into consideration that total leached chromium (0.8 mg kg^{-1}) is present exclusively in its toxic hexavalent form. Despite neutral pH of filter dust water extracts, leaching of Cr(VI) was significant (0.8 mg kg^{-1}), due to very high specific area of filter dust (particle size < 5 µm).[7] Therefore, when filter dust is re-used as additive in road construction and in civil engineering, long-term environmental impacts of new materials should be investigated.

Investigation of the environmental impact of asphalt composites with addition of EAF dust

In order to estimate the environmental impact of EAF dust used as additive to asphalts, four different asphalts were mixed with EAF dust (2 % by mass) so that stable composites with optimal physico-mechanical properties were formed.[7] To simulate the worst case scenario of salting of roads during the winter time and disintegration of asphalts with time, the leachability of chromium and Cr(VI) was investigated in a time span of six months in compact and ground composites using water and salt water as leaching agents. pH was determined in leachates throughout the experiment and was found to be 7.0 ± 0.1. The analytical data indicated that during the course of the experiment Cr(VI) was not leached with water and salt water from compact asphalt composites with addition of filter dust. However, in ground asphalt composites with addition of filter dust Cr(VI) was leached with water and salt water. The results are presented in Figure 1.

The data from Figure 1 indicate that leaching of Cr(VI) from water and salt water is similar for all four samples of asphalt composites with addition of EAF dust. From Figure 1 (A) it is further evident that leaching of Cr(VI) in water from ground asphalt composites with addition of filter dust

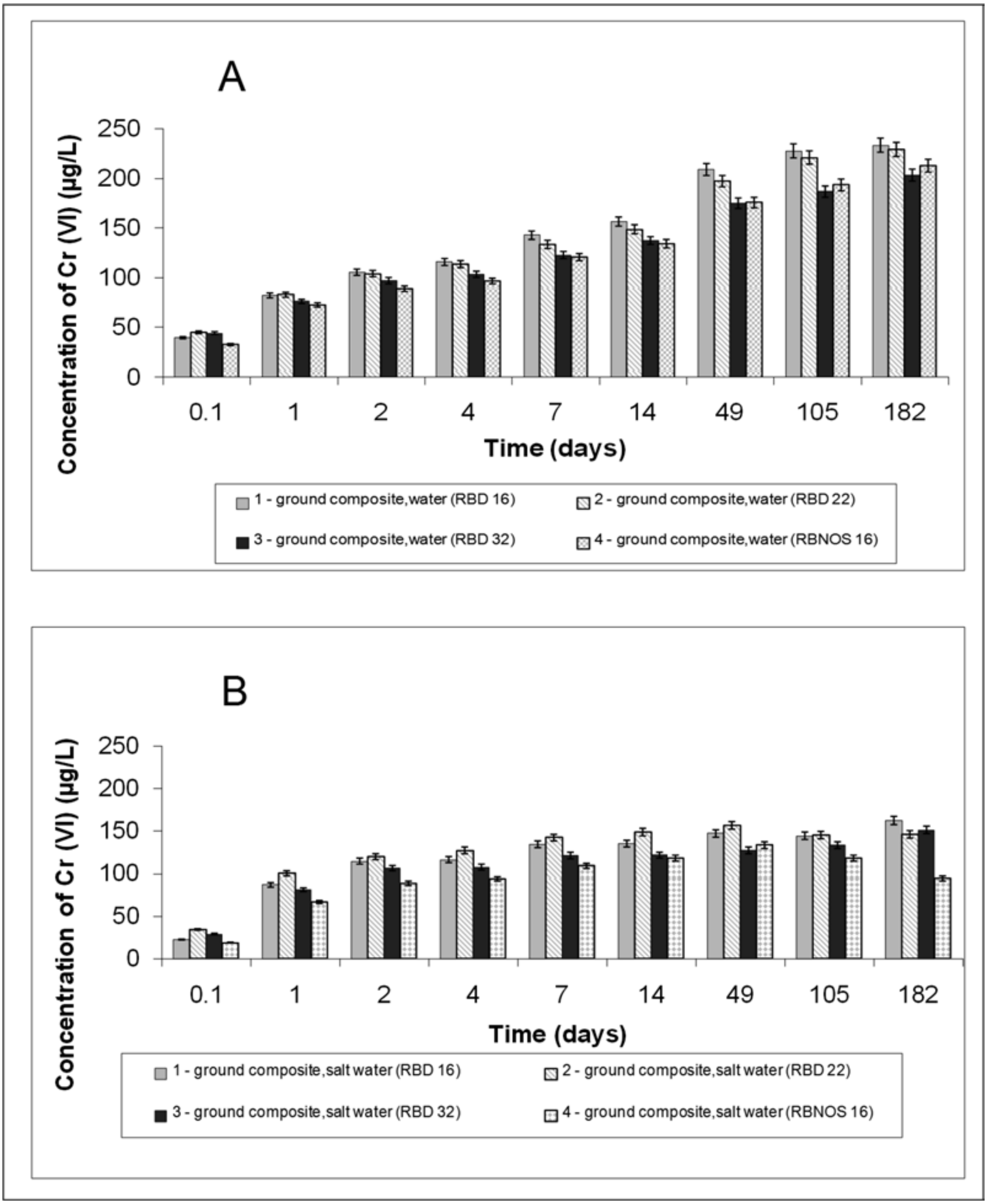

Figure 1. Leaching of Cr(VI) in water (A) and salt water (B) with time from ground asphalt composites with addition of 2 % of EAF dust by mass (resumed from reference 7).

gradually increases with time and reaches constant values (concentrations about 220 μg L^{-1} Cr(VI)) after approximately 100 d. In salt water (Figure 1 (B)) lower concentrations from ground composites with addition of filter dust are leached in comparison to leaching in water. The constant values (concentrations about 150 μg L^{-1} Cr(VI)) are reached faster, after 7 d. It was experimentally found the 90 % of total chromium was leached in its hexavalent form. The relatively low Cr(VI) concentrations that are leached from ground asphalt composites with addition of filter may possibly represent the environmental hazard only if the leachates reach the ground and/or drinking water reservoirs. However, due to the reducing characteristics of the bitumen and neutral pH of aggregate, it may be expected that concentration of Cr(VI) will be slowly decreased in the environment after decades. At more acidic environmental conditions, in the case of acid rain precipitations (pH about 4), Cr(VI) would be readily reduced in the presence of organic matter arising from bitumen. According to the Slovenian legislation [17] the maximal allowed Cr(VI) concentration in leachates from disposals of inert waste is 100 μg L^{-1}. Leaching of other metals: Pb, Ni, Cu, Cd and Zn in ground asphalt composites with addition of filter dust in water and salt water was negligible.

Investigation of the environmental impact of cement composites with addition of EAF dust

For estimation of environmental consequences of the use of EAF dust as an additive to cement, stable cement composites and cement composites with addition of 1.5 % of EAF dust by mass were investigated [8]. The leachability of total chromium and Cr(VI) was studied in compact and ground composites in water and salt water. The pH in leachates was not changed during the course of the experiment. high concentrations of water soluble calcium in the form of hydroxides regulated the pH of aqueous extracts and salt water leachates, which was highly alkaline. In aqueous and salt water leachates of cement composites and cement composites with addition of EAF dust the pH ranged between 11 and 13. In ground composites the pH was for one unit higher than in compact composites as a result of higher specific surface and consequently higher leachability of $CaCO_3$ and $Ca(OH)_2$. Due to higher ionic strength, the pH was for one unit higher in salt water composites. As a consequence of the high alkaline pH, the leachability of metals (with the exception of calcium) is generally very low. However, attention should be paid to soluble Cr(VI) concentrations.

Data of the leaching test indicated that during the course of the experiment the total chromium and Cr(VI) were not leached with water in compact cement composites and compact cement composites with addition of EAF dust, while in ground cement composites and ground cement composites with addition of EAF dust total chromium and Cr(VI) were leached with water, but in very low concentrations (below 5.5 μg L^{-1} of total chromium). The leaching was more pronounced in salt water. In Figure 2 leaching from compact composites and in Figure 3 leaching from ground composites in salt water are presented. The data from Figures 2 and 3 indicate that more than 90 % of chromium in leachates was present in its haxavalent form. Namely, the traces of dissolved trivalent chromium are almost completely oxidized to its hexavalent state due to the high alkaline pH and the presence of oxygen. The extent of leaching of Cr(VI) in salt water was higher than in water due to the higher ionic strenght of salt water as leaching solution that causes more efficient leaching of $Ca(OH)_2$ and $CaCO_3$ and consequently higher pH of the leachate. It is known that higher pH values favour the existence of Cr(VI). Data from Figures 2 and 3 further indicate that leaching of Cr(VI) in salt water from compact and ground cement composites and cement composites with addition of EAF dust gradually increased with time and reached constant values after three months. During the course of the experiment the concentrations of Cr(VI) in leachates from compact cement composites in salt water (Figure 2(A)) did not exceed 20 μg L^{-1} and in leachates from compact cement composites with addition of EAF dust 40 μg L^{-1} (Figure 2 (B)).The difference (20 μg L^{-1} of Cr(VI)) corresponded to the leachability of Cr(VI) from EAF dust added to cement composite. More intensive leaching in salt water is observed from ground cement composites (up to 80 μg L^{-1} of Cr(VI)) (Figure 3 (A)) and ground cement composites with addition of EAF dust (up to 100 μg L^{-1} of Cr(VI)) (Figure 3 (B)). Again, the difference (20 μg L^{-1} of Cr(VI)) corresponded to the leachability of Cr(VI) from EAF dust added to cement composite. Therefore, Cr(VI) that originates from cement, mainly contributed to the leachability from cement composites with addition of EAF dust. The highest Cr(VI) concentrations that were observed in salt water leachates from ground cement composite with addition of EAF dust did not exceed 100 μg L^{-1}, that is according to the Slovenian legislation [17] the maximal allowed Cr(VI) concentration in leachates from disposals of inert waste. Leaching of other metals: Ni, Cu, Zn, Fe, Mg, Mn, Mo, Co, V, Cd and Pb from compact and ground cement composites and cement composites with addition of EAF dust is negligible in water and salt water.

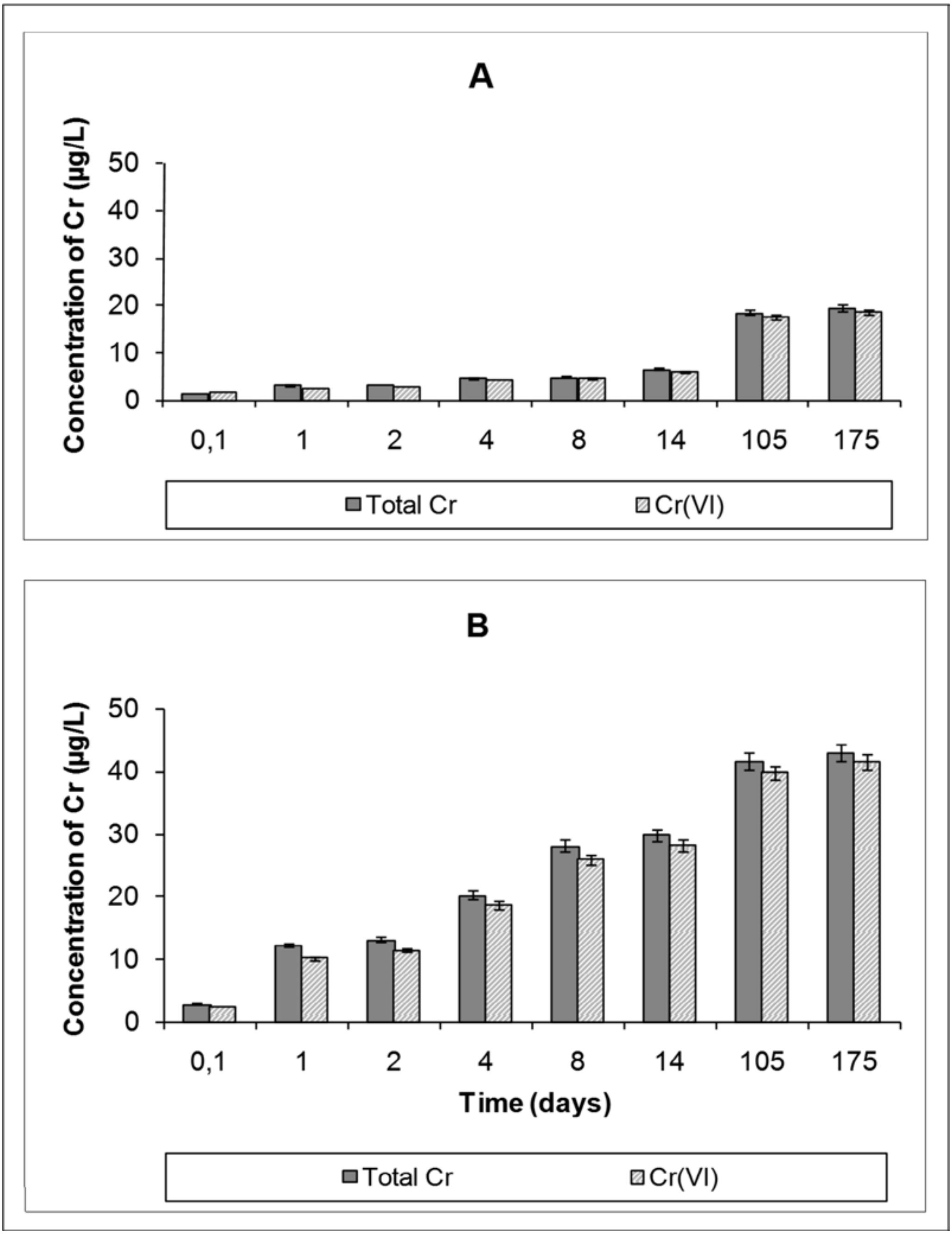

Figure 2. Leaching of total chromium and Cr(VI) in salt water with time from compact cement composite (A) and compact cement composite with addition of 1.5 % of EAF dust by mass (B) (resumed from reference 8).

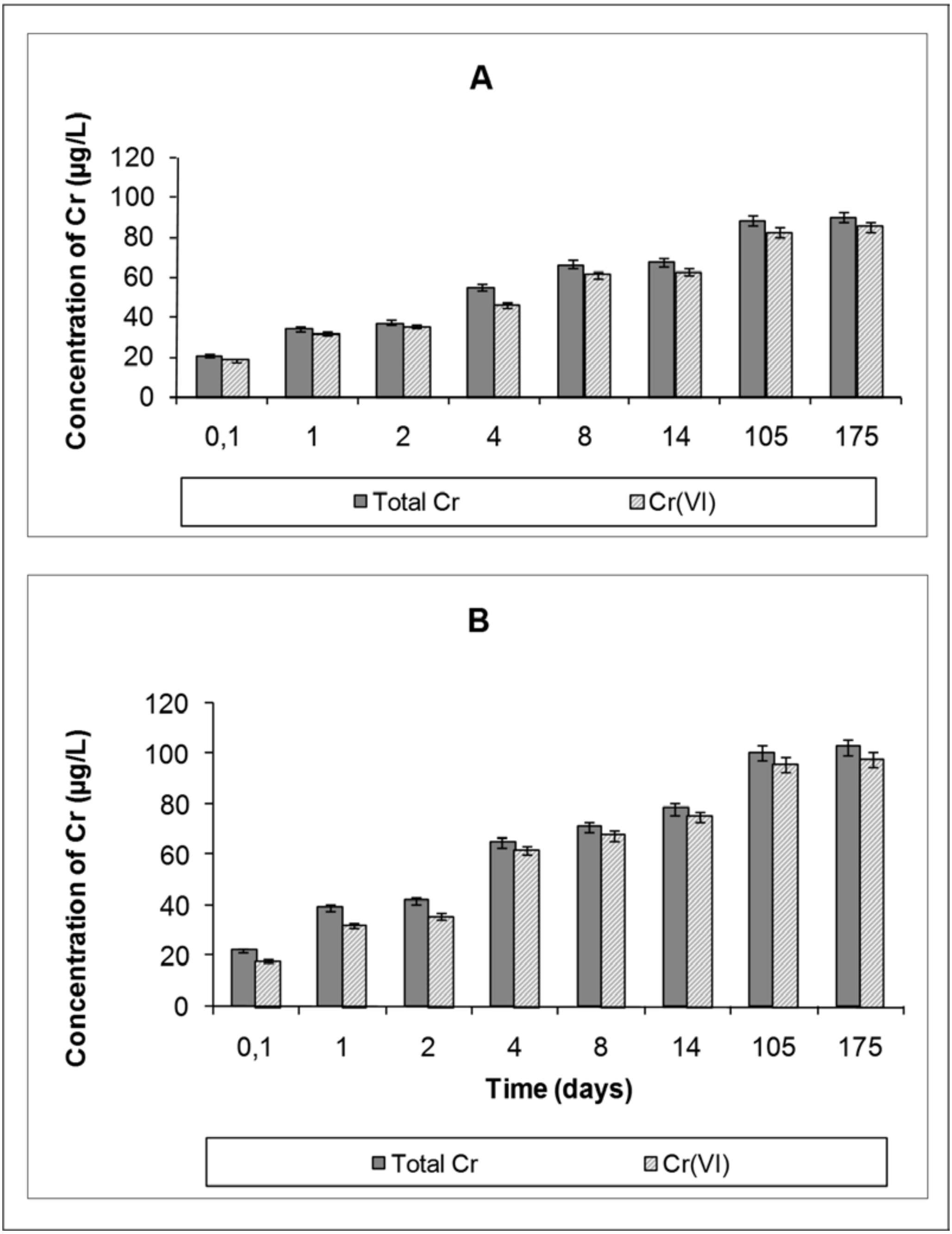

Figure 3. Leaching of total chromium and Cr(VI) in salt water with time from ground cement composite (A) and ground cement composite with addition of 1.5 % of EAF dust by mass (B) (resumed from reference 8).

Conclusions

In the present work long-term environmental impacts of asphalt and cement composites with addition of EAF dust were evaluated, on the basis of the literature data. Leachability tests based on diffusion were considered. The data demonstrated that leaching of metals from stable asphalt and cements with addition of EAF dust is negligible in water and in salt water. Salt water simulated the marine environment and salting of roads during the winter time. The only important metal species that was leached was Cr(VI). However, neither in ground asphalt and cement composites with addition of EAF dust, that simulated the worst case scenario when composites decomposes with time, nor when the salt water was used as leaching agent, concentrations of Cr(VI) that were leached did not represent an environmental hazard. Nevertheless, attention should be paid to ensure the conditions that prevent the leaching into the ground and/or drinking water reservoirs. From the environmental point of view, EAF dust in maximal addition of 2 % by mass can be used as an additive to asphalts for road construction and in civil engineering for all purposes, including applications in the external environment. Cement composites to which a maximum of 1.5 % by mass of EAF dust has been added can also be used in civil engineering for all purposes as well as for balances in washing machines. Such balances can be, at the end of their service life, safely disposed in landfills. It is also important to stress that the re-use of EAF dust disburdens the landfills and prevents the latent environmental threat due to the dusty nature of EAF dust that contains also toxic Cr(VI). The re-use of EAF dust in road construction and in civil engineering represents positive environmental aspects. Since the recycling of EAF dust and its disposal on landfills are expensive, the re-use of EAF dust has also positive economic aspects.

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