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Leachability of heavy metals from stabilized/ solidified mine tailing in Russia

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ABSTRACT

Mining activities are usually producing significant volume of solid waste, which is commonly known as tailing. In most of the cases, tailing contains hazardous pollutants like heavy metals that are posing risks for environment and public health. Therefore, proper management of tailing to minimize their risks is of great importance. In this study, the leachability of metals (Cd, Pb, Zn, Ni, Cu, Co, Fe, and Mn) from mine tailings was investigated. The mine tailings used for this study have been accumulated for several years at two abandoned Urupsky and Elbrosky tailing dumps in North Caucasus, Russia. The mineralogical composition and metals concentration in the tailing were determined using X-Ray diffraction (XRD) and chemical extraction analysis. Solidification of the tailing from Urupsky and Elbrosky sites was performed using ordinary Portland cement in a ratio of 1:3 cement to tailing. The solidified masses were cured in water for different periods of time (0, 14, 21, and 28 days) after which they were subjected to dynamic batch leaching test. Regardless of the initial pH value at the beginning of the leaching test, due to the alkaline nature of cement, the leachate pH has been increased immediately to alkaline range (above 11) for all leachates. The study revealed that immobility percentage (IP) of the metals ranged from as low as 2% for the Manganese in Elbrosky tailing to as high as 95.8% for Cadmium from Urupsky tailing. Despite this, all heavy metals concentrations in the leachate generated at the end of curing period of 28 days were either complying with Russian or USEPA Standards for fresh surface water. This indicates that solidification of tailing using cement is an efficient technology for decreasing the mobility of the studied heavy metals from both tailing sites.

Keywords: Heavy metals; immobility percentage; leaching test; North Caucuses; Portland cement; Russia; stabilization and solidification; tailing.

INTRODUCTION

Mining and milling industry to extract metals from mineral resources is usually associated with the production of large amount of waste in the form mine tailing. Due to the fact that there are several contaminants in tailing including heavy metals, tailings are classified as a hazardous waste (Manjunatha and Sunil 2013). Leaching of heavy metals from abandoned tailings is a main source of pollution that leads to adverse impacts on the quality of water bodies and water supplies and consequently poses a risk to human health (USEPA 2004). According to an inventory that was concluded in 2012, in France there are 2100 tailings, which were identified as a source of potential risks to ground water, surface water, soil, and public health (Bellenfant, 2013). In the United States, there are 20,000 – 50,000 abandoned mines, which have approximately 3 million cubic meters of tailings per mine that are adversely impacting about 23,000 kilometers of streams and rivers (Matlock et al. 2002). In Russia, there are many mining dump sites (tailings) spreading all over different regions of the country that contain about 80 Billion tons of mine waste (Litvintsev, 2015).

Stabilization and solidification are physicochemical processes that are widely used in managing hazardous and industrial wastes including tailing. They have been applied in the treatment of such wastes in order to minimize the rate of pollutant release from the waste masses into the environment by encapsulation and containment of the pollutants into solidified mass (Alpaslan and Yukselen 2001, Manjunatha and Sunil 2013). The reduction of contaminant mobility is usually achieved by using additives (binders) that improve the physical properties and ease the handling of the waste and minimizing the surface area through which the contaminant is released (LaGrega et al, 2001). US EPA has recommended solidification stabilization as being the best proved available technology for 57 hazardous wastes listed by Resources Conservation and Recovery Act (USEPA, 1993).

Portland cement has been widely used as a binder for stabilization/solidification (S/S) treatment of contaminated soils and it has been applied in the treatment of many types of hazardous wastes than any other material (Kogbara 2014, Yang et al, 2014). This is due to the fact that cement has a well established history of use. Furthermore, its durability and its relatively low cost render it suitable to be used in such processes (Glasser, 1997, Shawabkeh 2005, Tarik and Yanful 2013). In the US superfund sites the most widely used binder in site remediation is cement (USEPA, 2001).

Stabilization and solidification are usually leading to increase in the strength of the solidified masses and decrease in the leachability, compressibility, and hydraulic conductivity of the treated waste. Decreasing the leachability of contaminants is the most significant result of solidification (Kobgara, 2014), which leads to safe transportation, storage, and disposal of the solidified waste in landfills (Napia et al, 2012).

Many investigators tested various additive sand binders to solidify and stabilize hazardous waste including tailing of mining industry. By testing different additives (cement, lime, zeolite, activated carbon, clay, and sand) for immobilization of lead from artificially contaminated soil and based on the results of the EPA leaching test, Alpaslan and Yukselen (2001) concluded that lime and cement are very useful binders in Pb immobility with 88% efficiency at 1:21 lime: soil ratio and 99% efficiency at 1:15 cement: soil ratio, respectively. Manjunatha and Sunil 2013 utilized industrial byproducts, like lime and fly ash along with the partial addition of ordinary Portland cement in the Stabilization/solidification of iron ore mine tailings. The researchers found that solidified samples of mixing ratio with tailing materials ranging from 50% to 90% and 10% cement have shown success in decreasing the metals mobility; furthermore, the unconfined compression strength and hydraulic conductivity were found to comply with the USEPA regulatory standards.

Mohamed et al. (2002) studied the impact of using different additives like lime, fly ash, and aluminum on the hydro-mechanical properties of solidified tailing. Adding 5% of lime, with 10% of fly ash with 110 ppm of aluminum has resulted in the production of solidified mass with an unconfined compressive strength of 1000 kpa and hydraulic conductivity value of 1.96×10^{-6} cm s^{-1}, which renders such solidified mass reusable as it is complying with most standards for reusing solidified/stabilized masses.

Kim and Jung (2011) examined the solidification of Arsenic and heavy metals containing tailing using cement and blast furnace slag. The investigation reviled a relatively high strength of the solidified samples that were subjected to curing period of 28 days with 20% water content and mixing ratio of 7:3 tailing and 1:1 mixture of Portland cement and blast furnace slag. The researchers concluded that solidification is one of the best processes for the remediation of arsenic and heavy metals in tailings and other contaminated materials.

Among many alternative management options being tested, reuse and recycling of mine tailing in building materials were considered (Lottermoser, 2011). Many investigators studied the feasibility of utilizing the mine tailings as full or partial substitute for building materials in concrete, mortar, floor tiles, bricks, and other building materials. For example, Onuaguluchi and Eren (2012) investigated the use of copper tailings as an additive in cement mortar. Zhang and Ahmari (2012) studied the possibility of utilizing copper mine tailing in producing eco-friendly bricks through geopolymerization. The produced bricks were found to comply with ASTM requirements. Pyo et al. (2016) tested four types of mine tailings to produce low cost environmentally-friendly high performance concrete. Kundu et al. (2016) studied the utilization of copper mine tailing as partial substitute for cement in concrete.

The main objective of this study is to assess the solidification process of heavy metals containing tailing using ordinary Portland cement as a binder by testing the leachability of metals from such masses. To achieve that, samples from two abandoned tailing sites in North Caucasus (Russia) were collected and subjected to solidification and tested for mobility of heavy metals from the solidified masses at different initial pH values.

Based on the discussions with local authorities, and up to the authors' knowledge from the reviewed literature, no studies have been conducted to investigate the efficiency of the stabilization/solidification process in limiting the mobility of metals from the two abandoned tailings sites (Urupsky and Elbrosky). Therefore, the present study is the first of its type in the region, which will help in assessing the role that solidification/stabilization can play in limiting the mobility of heavy metals into the environment and will provide a tool for the concerned authorities to deal with the pollutants from the two tailing sites.

MATERIALS AND METHODS

Preparation of solidified matrices

Ordinary Portland cement M 500 according to Russian Standards was mixed with tailing from the two abandoned tailing sites of Urupsky and Elbrosky to prepare solidified cementitious mortar that conforms to Russian Standards GOST 310.4. The mixing ratio of cement to tailing adopted was 1:3 with a water to cement ratio of 0.5. Mortar cubes of 50 x 50 x 50 mm were prepared and subjected to curing for various durations (0, 14, 21, and 28 days).

Metals concentration in tailing

Soil samples from both Urupsky and Elbrosky tailing sites were collected with a special soil sampler "BUR-2". Composite samples of soil from the tailing sites were collected at different depths down to 0.5 m. To identify the mineralogical components and to determine the metals available in the tailing and their concentration, tailing samples were subjected to X-Ray diffraction as well as to chemical extraction analysis.

X-Ray Diffraction

To determine the mineralogical composition of the tailing, X-ray diffraction (XRD) analysis was carried out. Patterns of tailing samples of Urupsky and Elbrosky tailing sites were obtained by using a Rigaku Ultima IV 185 mm, computer automated diffractometer. The XRD analysis was conducted with X ray of 40 kV and 40 mA using a diffracted beam with a count time of 0.02 seconds per step and wave length is Cu k-alpha radiation 1, 0.154056 nm and scanning mode 2θ ranged from 7 to 90°. In order to quantify the presence of the crystalline mineral phases, the XRD patterns were qualitatively analyzed using the diffractometer library.

Metals Concentration in Tailing

To determine the total heavy metals concentration in the tailing soil, one gram of tailing was subjected to ashing at 650 ˚C in a muffle furnace after initially being dried at a temperature of 105 ° C to a constant weight. The remaining ash then digested in a 10 mL of concentrated 1 M nitric acid and 1 ml of hydrogen peroxide in microwave mineralizer "Minotaur 2". Filtration of the digested mass through 10 micrometer filter was carried out after which the filtrate diluted with distilled water of high purity. The total concentration of Cd, Pb, Zn, Cu, Ni, Co, Fe, and Mn in the filtrate was then determined using atomic absorption spectrometry with atomization in flame iCE 3300 (Thermo Scientific, USA) that was calibrated using certified standard samples.

Leaching Procedure

To simulate the behavior of heavy metals mobility from the solidified matrix, batch leaching tests were conducted by using mortar cubes of 50 x 50 x 50 mm prepared by mixing tailing with Portland cement in a ratio of 1:3. The cubes were subjected to curing in water for 0, 14, 21, and 28 days at a temperature of 20 ± 2 ° C. After curing, the cubes were allowed to be dried at the room temperature, and then they were crushed and ground. Particles with size of 3 mm were isolated from the ground mass in order to be subjected for the leaching process.

Leaching of the heavy metal was performed using shake extraction tests. From each fraction of the sieved tailing particle 5 grams were added to 125 ml of the extraction solution. To simulate the extreme conditions that the solidified matrix could be subjected to in the nature, each fraction of the isolated particles from the ground cubes has been subjected to extraction test under both acidic (pH 4.5 and 5.0) and alkaline (pH = 10) conditions. Crushed materials were contacted with either nitric acid or sodium hydroxide with different concentrations to get the initial pH value needed.

Extraction was performed according to the Russian Environmental Regulatory Document on the Federal Level (PNDFT 14.1:2:3:4.11-04 16.1:2.3:3.8-04) by using Environmental Shaker-Incubator ES-20/60 shaker (Latvia), at a temperature of 26.5 ± 0.5 ° C, for a duration of 18 ± 2 hours at a rotation speed of 120-130 rpm.

To determine the concentration of heavy metals leached from the solidified tailing, the extraction fluids from the leaching experiment were subjected to filtration after which the filtrate diluted with distilled water of high purity. The total concentration of Cd, Pb, Zn, Cu, Ni, Co, Fe, and Mn in the filtrate was then determined using atomic absorption spectrometry with atomization in flame iCE 3300 (Thermo Scientific, USA) that was calibrated using certified standard samples. All measurements were carried out in triplicate, where the average concentration and standard error values were reported to ensure reproducibility of the data.

RESULTS AND DISCUSSION

Mineralogy

XRD analyses were conducted to assess the mineralogical composition of the tailing. Figure 1 shows the patterns of XRD for both Urupsky and Elbrosky tailing samples, while Table 1 presents compounds detected in each tailing. It can be observed that the tailing in both Urupsky and Elbrosky sites contains quartz (SiO_2) material. Urupsky tailing contains Pseudo-eucryptite, Barium Bismuth, Copper Nitride, Lead Barium, Nantokite, Phosgenite, Westerveldite, Iron Zirconium, and Ordonezite, which is usual in such copper mine tailing (Wang et al. 2014). On the other hand, less minerals were detected in Elbrosky tailing, which include Dolomite, Albite, cadmium cyanide, zirconium hydride, Fraipontite, and Polylithionite. This is may be attributed to the fact that Elbrosky tailing has been abandoned long time ago in 1970s, while Urupsky was abandoned in 1990S. In addition, since the tailing is located directly on the right bank or Kuban River, it has been subjected to frequent flooding that may have washed out the minerals into the river water.

Other minerals associated with the detected minerals are most likely present in the tailings but in amounts below the detection limit of the XRD diffractometer. Moreover, the peaks of the more crystalline minerals (i.e., quartz) that present in both Urupsky and Elbrosky tailing samples could have masked the peaks of the other minerals.

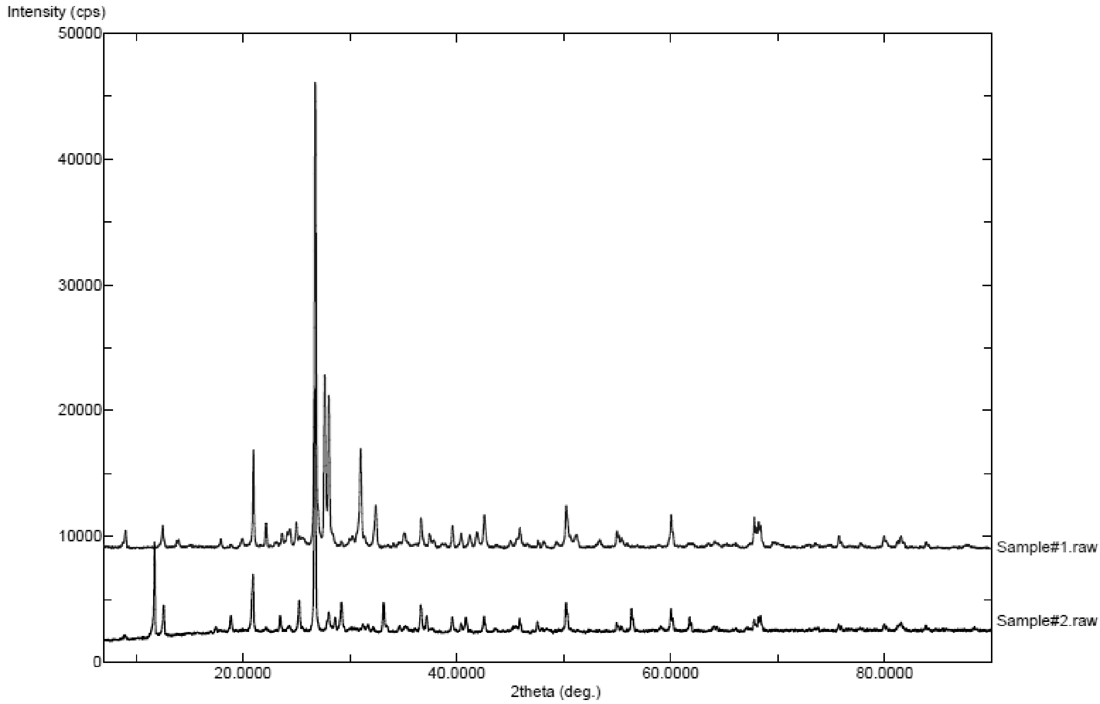

Fig. 1. XRD patterns of both Urupsky (sample 1) and Elbrosky (sample 2) tailings.

Table 1. Mineralogical composition of tailing identified by XRD.

No.	**Urupsky Tailing**	**Elbrosky Tailing**
1	Quartz	Quartz
2	Pseudo-eucryptite	Dolomite
3	Barium Bismuth	Cadmium Cyanide
4	Copper Nitride	Fraipontite
5	Lead Barium	Zirconium Hydride
6	Nantokite	Polylithionite
7	Phosgenite	Albite low
8	Westerveldite	
9	Iron Zirconium	
10	Ordonezite	

Metals Content

To determine the concentration of the metals that exist in the tailing and to find the materials that could not be detected by the XRD, chemical extraction process was performed. Table 2 shows the concentration of the metals detected in tailings of both Urupsky and Elbrosky sites. It can be observed that both sites contain Iron, Zinc, Copper, Lead, Cobalt, Manganese, and Nickel, with the concentration of Iron being the highest, while concentration of Nickel being the lowest on both tailing sites.

Table 2. Metal content of the tailing of both Urupsky and Elbrosky sites.

Element	Concentration in Urupsky Tailing (mg/kg)	Concentration in Elbrosky Tailing (mg/kg)
Iron (Fe)	29650 ± 8302	9363 ± 2621
Zinc (Zn)	1943 ± 544	942 ± 236
Copper (Cu)	1159 ± 334	8520 ± 238
Lead (Pb)	768 ± 215	1410 ± 395
Manganese (Mn)	352 ± 98	325 ± 91
Cobalt (Co)	27 ± 7	5 ± 1
Nickel (Ni)	24 ± 6	35 ± 9
Cadmium (Cd)	9 ± 3	55 ± 15

Leaching of Metals from Solidified matrices

Characterization of the leaching behavior of wastes is an important step in the environmental assessment for the purpose of reuse or disposal scenarios (Sanchez et al. 2002). This is especially true in the case of tailing stabilization and solidification, where it is necessary to minimize the leaching of various metals from the solidified tailing masses.

Therefore, in order to determine the effectiveness of the stabilization/solidification process, the tailings from both sites were subjected to a leaching test under different initial pH conditions. Elemental concentrations of leachate were plotted as a function of cubes curing time and compared with regulatory concentration requirements of both Russian and US EPA standard for discharge into surface fresh water.

Figure 2 shows the release of cadmium in leachate from the solidified cubes of tailing from both Urupsky and Elbrosky tailing sites. It can be observed that cadmium leaching from Urupsky sample without any curing is approximately 5 times greater than that of Elbrosky sample; however, despite the difference in concentration of cadmium in both tailing, after 14 days of curing the leachate concentration of both samples decreased to the same level of about 0.004 mg/l and continued at the same level until the end of the curing period (28 days). It can be also noted that, starting from day 14 of curing, the cadmium concentration in the leachate is complying with the Russian fresh water standard (Russian Standard for the Protection of Surface Water Bodies GOST 17.1.3.13-86) value of 0.005 mg/l, while it does not meet the USEPA fresh water standard value of 0.002 mg/l, which is more stringent than the Russian standard with respect to cadmium. This suggests that using Portland cement as a binder is efficient in immobilizing the cadmium from the solidified matrix of both sites. This is in agreement with Cartledge et al. (1990) who reported that, in a cement based solidified system when Cd is available, insoluble hydroxide salt is readily formed and consequently leads to lower mobility of Cd as a result of encapsulation within the cement crystals that formed.

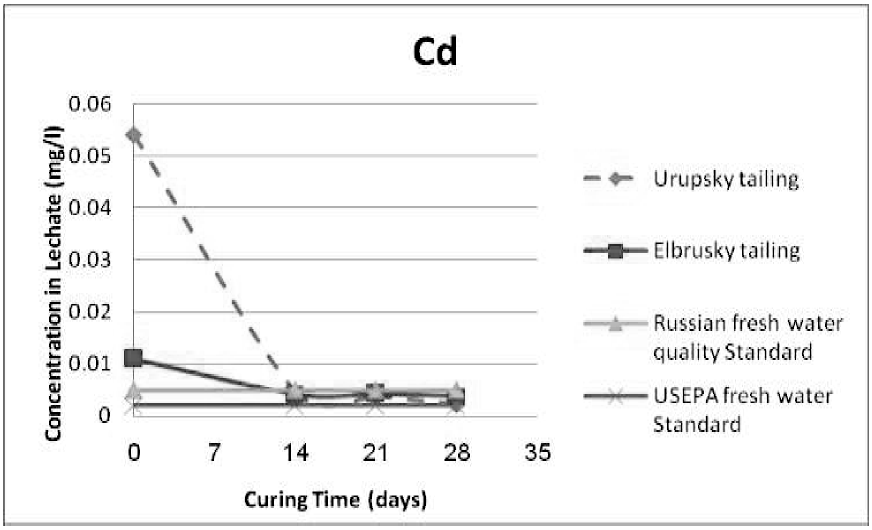

Fig. 2. Cadmium concentration in leachate from Urupsky and Elbrosky tailings as compared to Russian and USEPA standards.

Lead is another heavy metal that is available in the soil of Urupsky and Elbrosky tailings with a concentration of 768 and 1410 mg/kg, respectively. Figure 3 shows the leaching behavior of the lead from the tailings of both sites as a function of curing time. From the figure, it is shown that, as the case with Cadmium, the Lead leaching from Urupsky tailing for the sample without curing is 8 times greater than that of Elbrosky tailing. With the advancement of the curing process, the difference in leachate concentration of the lead from both tailings is becoming lower, where in Urupsky tailing it reaches twice of that in Elbrosky. The concentration of the leached lead from tailings of both sites is meeting the regulatory requirements of USEPA standard, while it is slightly above the Russian regulatory requirement. It should be noted here that with respect to Cadmium USEPA Standard is more stringent than the Russian standard, while for Lead, the Russian are more stringent than the USEPA Standards. Thevenin and Pera (1999) stated that, with Portland cement as a binder, Pb is stabilized by three mechanisms, namely, chemisorption, substitution, and precipitation.

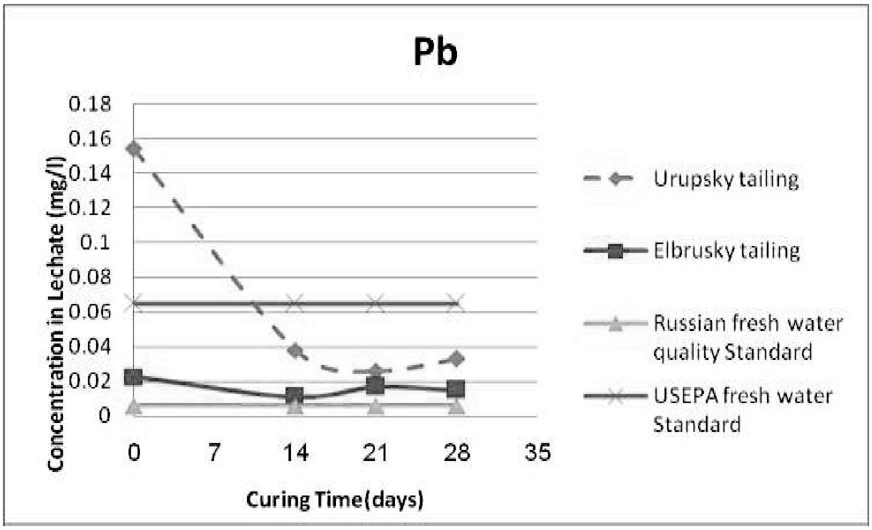

Fig. 3. Lead concentration in leachate from solidified Urupsky and Elbrosky tailings as compared to Russian and USEPA standards.

The same applies to Zinc as the case with Cadmium and Lead, where the concentration of Zinc in the leachate from samples without curing is higher for Urupsky than that of Elbrosky and at the end of the curing period the difference in concentration is decreasing to minimum. Zinc concentration in the leachate is meeting the regulatory requirement of the USEPA standard, while it is not meeting that of the Russian standard, which is also more stringent for the Zinc. Similar leaching trends of cement solidified Pb and Zn were reported by Yang et al. (2014), who indicated a sharp decrease in the concentration of both Pb and Zn in the leachate with the progress in curing time. Kogbara et al. (2012) reached a similar conclusion where a lower mobility of Zn from the monolithic solidified mass was found at pH value higher than 9.8. This may be explained by the entrapment of the metal within the crystalline structure of the solidified cementitious matrix.

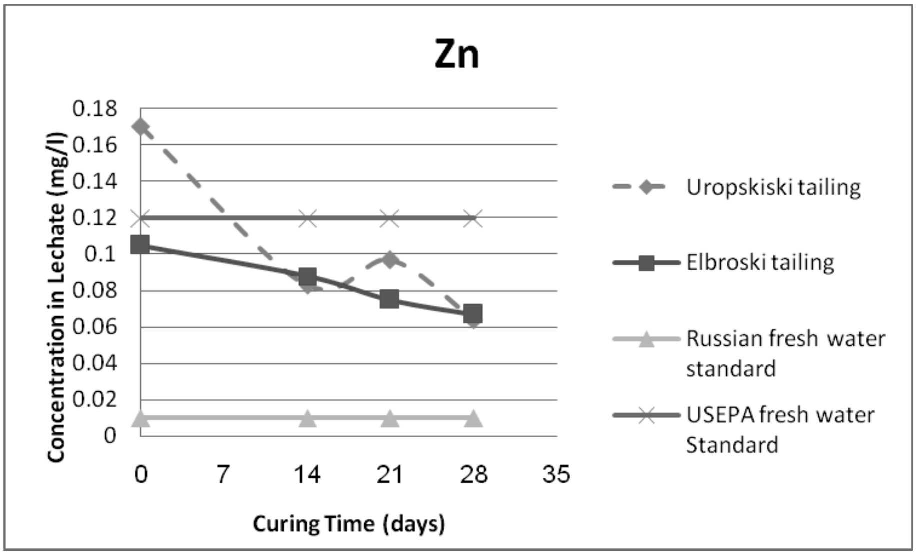

Fig. 4. Zinc concentration in leachate from solidified Urupsky and Elbrosky tailings as compared to Russian and USEPA standards.

Figure 5 shows the leaching behavior of Nickel and its concentration in the leachate with the progress of curing. Contrary to other heavy metals, the leaching behavior of the Nickel followed a different trend. The concentration of Nickel in the leachate for both Urupsky and Elbrosky from the first beginning of curing was less than the regulatory limit of the USEPA Standard and higher from that required by the Russian Standard. Furthermore, the concentration of Nickel leached from both Urupsky and Elbrosky tailing remained constant regardless of the curing period. Nickel is available for leaching below pH of 5; however, Nickel leaching at pH from 8-12 is 3-4 orders of magnitude lower than that in acidic conditions (Roy and Stegman, 2017). In the case of solidified matrix leaching test of both Urupsky and Elbrosky tailing, the pH values during all the test were immediately raised to alkaline level and ranged from 11.7 to 12.2, regardless of the initial pH value of the leaching test.

Figures 6-8 show the variation in pH value of the leachate from different leaching experiments of the tailing for different curing time and different initial pH values of 4.5, 5, and 10. It is obvious that, even for low initial pH values, all the values of leachate pH are in alkaline range. The increase of leachate pH is mainly attributed to the cement that is used in the solidification process as a binder, which created a highly alkaline environment with a pH greater than 11, and is considered as a primary reason for heavy metals immobilization (Roy and Stegman, 2017). Because of the high pH, the metals are encapsulated in the form of insoluble hydroxide or carbonate salts within the solidified mass, which provided an explanation to the leaching behavior of the heavy metals from the treated samples.

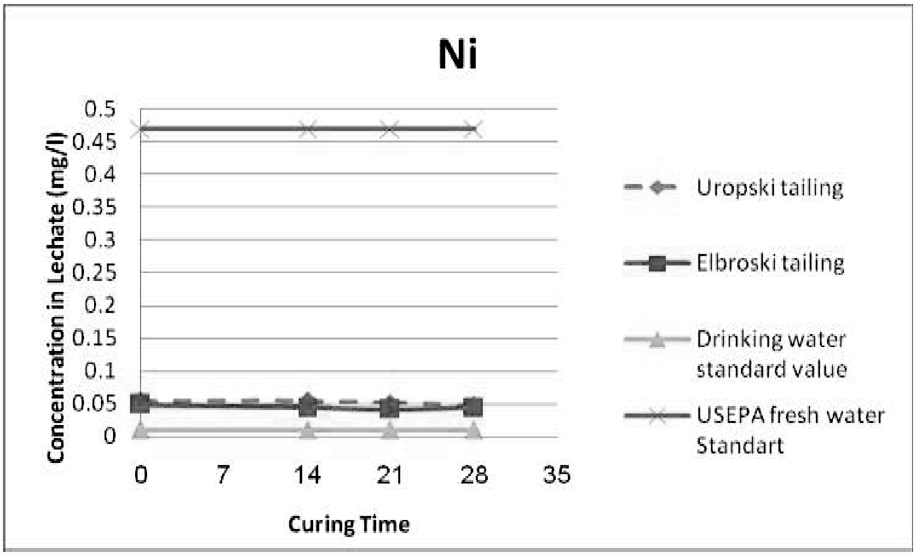

Fig. 5. Nickel concentration in leachate from solidified Urupsky and Elbrosky tailings as compared to Russian and USEPA Standards.

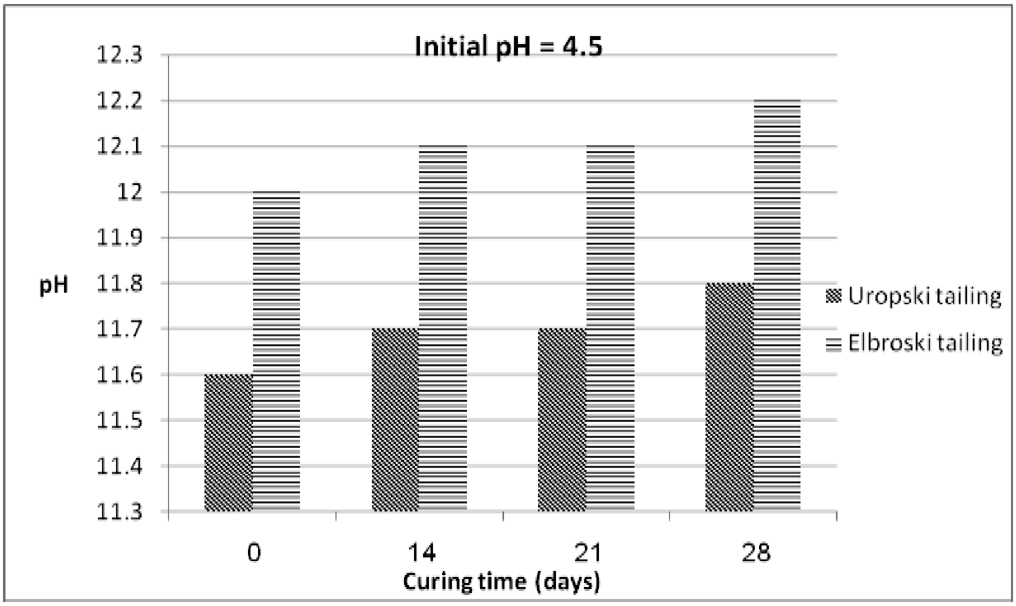

Fig. 6. Change of leachate pH value with curing time for samples with initial pH of 4.5.

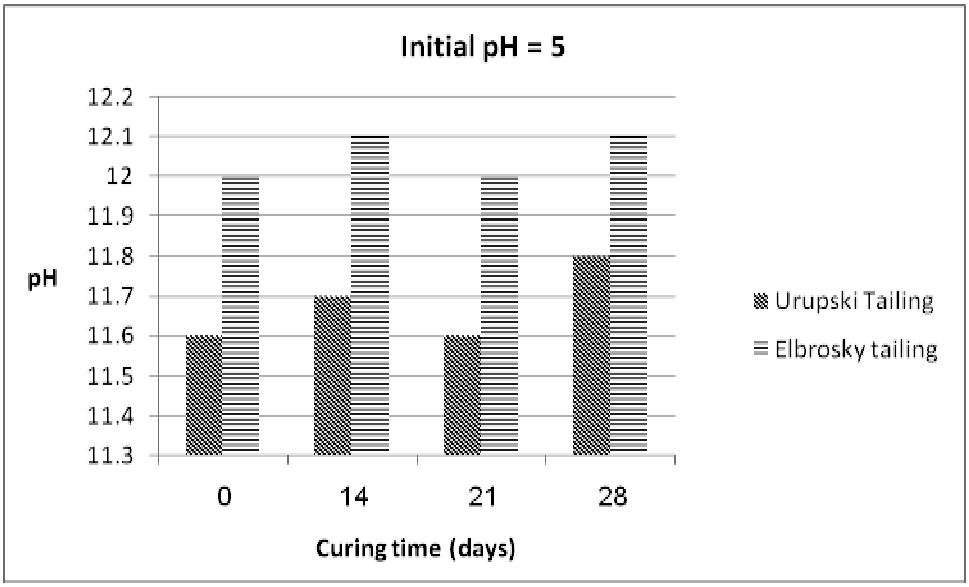

Fig. 7. Change of leachate pH value with curing time for samples with initial pH of 5.

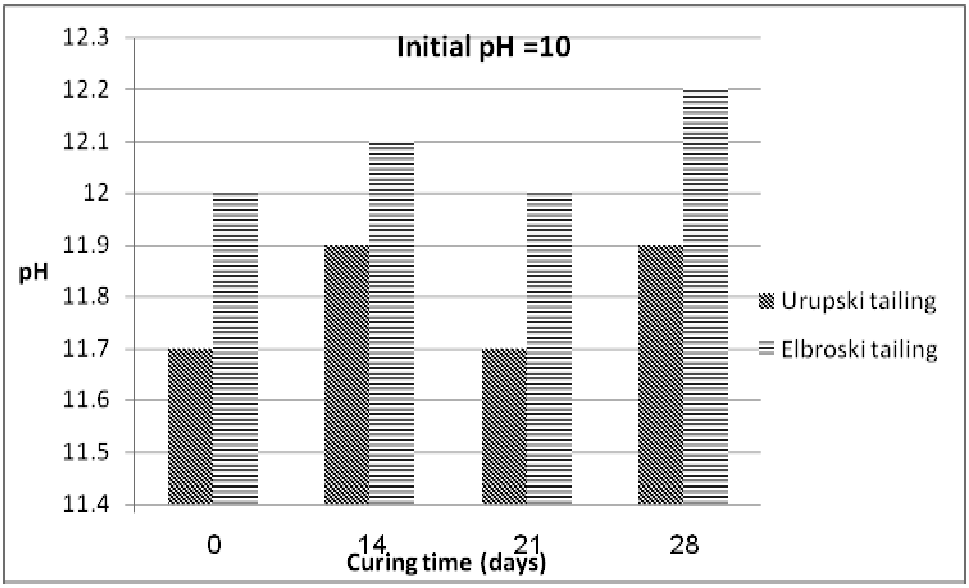

Fig. 8. Change of leachate pH value with curing time for samples with initial pH of 10.

The leachability trend for other metals (Co, Fe, and Mn) analyzed in the study is following the same pattern as the above analyzed metals. To assess the effectiveness of the cement-based solidification/stabilization process of the metals, the parameter immobilization percentage (IP) was introduced, which can be calculated by equation 1.

$$IP = (C_0 - C_1)/C_0 \quad (1)$$

where C_0 refers to the concentration of the metal in the leachate from the solidified matrix before curing (0 day curing); C_1 refers to the concentration of metal in the leachate of solidified matrix after the curing for a standard time of 28 days.

Table 3 shows IP values for all metals detected in both Urupsky and Elbrosky tailings. It can be seen that, among all the metals studied, Cadmium has the highest immobility percentage of 95.9 and 65.5 for Urupsky and Elbrosky tailings, respectively. Except for Cobalt, the immobility of all elements for Urupsky is higher than that for Elbrosky. This may be explained by the fact that Urupsky tailing contains clay amount more than Elbrosky, where the clay will contribute to the adsorption of the metals and contribute to increased immobility that is originally coming from the impact of the alkaline environment created by the cement. Despite the low immobility of certain metals like Nickel, Cobalt, and Manganese, all proved to comply with either Russian or USEPA standards of fresh water, which suggests that cement is an efficient binder that prevents leaching of the studied metals.

Table 3. Values of Immobility percent of all metals for both Urupsky and Elbrosky tailing sites.

Metal	Urupsky Tailing			Elbrosky Tailing		
	Concentration in leachate at zero days curing (mg/l)	Concentration in leachate after 28 days curing (mg/l)	Immobility % (IP)	Concentration in leachate at zero days curing (mg/l)	Concentration in leachate after 28 days curing (mg/l)	Immobility % (IP)
Cd	0.054	0.002	95.9	0.011	0.004	65.5
Pb	0.154	0.033	78.5	0.023	0.015	34.2
Ni	0.055	0.047	14.1	0.049	0.044	10.2
Zn	0.17	0.064	62.3	0.105	0.067	56.7
Co	0.032	0.027	13.9	0.030	0.021	28.0
Fe	0.87	0.30	65.4	0.44	0.26	41.8
Mn	0.023	0.017	25.9	0.017	0.016	2.0

CONCLUSIONS

Mine tailing is posing environmental and public health risks by leaching heavy metals to the environment. Stabilization and Solidification technology is one of the best available technologies to treat heavy metal release from tailing. In this study stabilization and solidification of mine tailing from two abandoned tailing sites in North Caucasus, Russia, were investigated. Using ordinary Portland cement as a binder, metal leachability of heavy metals from the solidified mass cured for different periods was evaluated from a regulatory perspective. The leached metal concentration values were compared to both Russian and US EPA standard values for fresh surface waters. It was concluded that Cadmium concentration in the leachate of both Urupsky and Elbrosky sites complies with the USEPA standard, while it is slightly higher than the Russian standard value. On the other hand, the concentration of other metals (Pb, Zn, Ni, Co, Fe, and Mn) complied with USEPA standard but not with the Russian Standards, which are more stringent than USEPA for such metals. Calculation of the immobility percent (IP) value revealed a wide range of immobility. The lowest IP value was 2% for Manganese from Elbrosky tailing, while the highest was for Cadmium from Urupsky tailing that reached 95.9%. Due to the alkaline environment created by cement addition, the pH values of all leachate studied were above 11, regardless of the initial pH of the test.

Overall, the study results indicated that leached metal concentration decreased steadily with the curing time of the solidified matrices and complied either with the Russian or USEPA Standards, which suggest that cement is an efficient binder for all the metals covered in the current research. Further studies should consider long term leachability of the metals from the solidified masses and the mechanical properties of such masses.

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انفصال المعادن الثقيلة من الكتل المتصلدة لمخلفات مناجم التعدين في روسيا

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الخلاصة

عادة ما تتسبب عمليات التعدين في المناجم بإنتاج كميات كبيرة من المخلفات التي تحتوي على مكونات ضارة، كالمعادن الثقيلة والتي لها مخاطر على البيئة والصحة العامة. ولذلك فإنه من الضروري اتخاذ التدابير اللازمة من أجل تخفيف المخاطر الناجمة عن هذه المخلفات. يهدف هذا البحث إلى دراسة عملية انفصال المعادن (كادميوم، رصاص، خارصين، نيكل، نحاس، كوبلت، حديد ومنغنيز) من مخلفات مناجم التعدين بعد إخضاع هذه المخلفات لعملية التثبيت والتصلد بواسطة الاسمنت البورتلاندي العادي. حيث تم إحضار عينات المخلفات المستخدمة في هذه الدراسة من موقعين مهملين ومغلقين للتخلص من مخلفات المناجم في شمال القفقاس في روسيا وبالتحديد من موقعي أوروبسكي والبروسكي. أُخضعت عينات المخلفات في البداية إلى التحليل بواسطة استعمال جهاز الحيود بالأشعة السينية وذلك بغرض تحديد المركبات المعدنية فيها بشكل عام، ومن ثم أُخضعت عملية فصل العينات لعملية الفصل الكيميائي لتحديد ماهية العناصر المعدنية الموجودة فيها ومقدار تراكيزها. تم تثبيت وتصليد عينات المخلفات من كلا الموقعين بإضافة وخلط الاسمنت البورتلاندي العادي مع المخلفات بنسبة 1 أسمنت إلى 3 مخلفات وعمل مكعبات إسمنتية ذات أبعاد 50 x 50 x 50 ملم ووضعها في الماء لتتصلب لفترات مختلفة (صفر، 14، 21، 28 يوم) ومن ثم تم طحن هذه المكعبات وإخضاعها إلى تجربة انفصال المعادن تحت درجات حموضة ابتدائية مختلفة (4.5، 5، 10). تبين من الدراسة أن الأسمنت عند إضافته إلى الخليط يعمل على خلق بيئة قلوية عالية تصل فيها درجة الحموضة أعلى من 11 حتى في التجارب التي فيها درجة الحموضة الابتدائية أقل من 5. وبناءً على تراكيز المعادن في العينات قبل وبعد عملية الفصل الكيميائي تم حساب نسبة تثبيت المعادن بواسطة عملية التصلد والتي تراوحت من 2% للمنغنيز في مخلفات موقع البروسكي إلى 95.8% للكادميوم في مخلفات موقع أوروبسكي، وعلى الرغم من انخفاض نسبة التثبيت لبعض المعادن إلا أن تراكيز جميع المعادن الثقيلة في السائل بعد الانفصال من العينات المتصلدة كانت ضمن القيم المحددة إما بالمواصفات الروسية أو بمواصفات الوكالة الأمريكية لحماية البيئة والخاصة بالمياه العذبة السطحية، الأمر الذي يشير الى أن عملية التثبيت والتصلد باستخدام الاسمنت كانت فاعلة في الحد من إنفصال وانتقال المعادن الثقيلة من الكتل المتصلده إلى البيئة المحيطة.