



EARTH SCIENCES

Evaluation of Trace Elements from Used Industrial Waste in Soil improvement

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Abstract: The use of industrial waste as an additive in soil improvement has many advantages, including recycling of waste, reducing the need for waste storage, and obtaining an economical material. With the use of these wastes, desired positive results are obtained in some geotechnical properties of soil. However, the wastes can create trace element contamination in soil and groundwater. In this study, trace elements originating from industrial wastes contaminating groundwater are investigated. The industrial wastes were mixed at different proportions with the soil. These mixtures were compacted into a permeameter cells, and a seepage tests were performed. The leachates obtained from seepage tests were analyzed with inductively coupled plasma mass spectrometry (ICP-MS) to determine trace elements. The measured trace element quantities were compared with the allowable values in the relevant standards (EPA 822, WHO, TS266). The results reveal that quantitative values of the trace elements from the leachates were within the allowable limits, except for arsenic and chromium. Furthermore, when fly ash is used As and Cr can be combined with ettringite and be immobilized. Boron and silica fume are hazardous substances caused by trace elements. However, considering its long-term effect, they can be used with fly ash.

Key words; trace element, soil improvement, marble dust, fly ash, Boron wastes, silica fume.

INTRODUCTION

The amount of industrial waste generated continues to surge as a result of increased production of commodities, with this surge directly proportional to population growth. Due to a lack of storage facilities, the continuous generation of waste poses environmental threats if it is not converted into resourceful materials. To decrease this problem, industrial wastes are reused in many areas, including for soil improvement. These wastes are mixed with soil as an additive material to improve soil properties. The additive material increases the unconfined compression strength and durability of soil and decreases grain loss in the freeze-thaw

cycle and swelling potential. Industrial wastes such as fly ash, marble dust, silica fume, and boron waste were used as additive materials. Using industrial wastes to stabilize soil increases its geotechnical properties, including strength, resilient modulus, swelling potential, and durability, according to studies by Kalkan (2009, 2011, 2013), Fauzi et al. (2013), Zorluer & Demirbas (2013), Zorluer et al. (2013), Zorluer & Gucek (2014, 2017a, b), Kang et al.(2015), Geodarzi et al. (2016), Firat et al. (2017), Keshavan et al. (2017).

On the other hand, the use of industrial wastes in soil improvement has an environmental dimension. The associated risk is the potential of trace element in waste to contaminate

groundwater and soil. These contaminants in soil and groundwater as a result of using industrial waste as a stabilizer has been investigated by researchers as this could pose risks for movable water in communities. Heebink & Hasset (2001) demonstrated the environmental and engineering performance of fly ash in soil improvement. They mixed 12 different soils with fly ash in 12-14% ratio. Seepage test were performed with these mixtures to obtain leachates. Trace elements were analyzed in the leachates. Their study highlights that fly ash is not a hazard to the environment when used for improvement Goswami & Mahanta (2007) investigated leach concentration from lateritic soils stabilized by fly ash and lime. Test results exhibit that the high pH induced by lime treatment of mixes helps keep most of metals within the stabilized soil matrix.

Cetin et al. (2012a) conducted leach tests to investigate the leaching potential of six metals, Al, Cr, Fe, Mn, Sb, and V from the fly ash and lime kiln dust stabilized soils. The addition lime kiln dust caused a decrease in concentrations of Fe, Sb, V, and Mn, separately. Addition of fly ash caused an increase in concentration of Sb, V, Cr, Al, and Mn. Cetin et al. (2012b) evaluated leaching potential of road materials and evaluated ground water impacts of Ba, B, Cu, and Zn leaching. The results showed that an increase in fly ash and lime content has significant effects on leaching behavior of trace metals.

Cetin & Aydilek (2013) investigated leaching potential of B, Mn, Mo, and Se from high carbon fly ash stabilized highway embankment. Unburned carbon content of fly ash did not have a direct effect on metal leaching. Leelarungroj et al. (2018) performed to observe the influences of pH and leachates on leaching mechanisms of trace element from cement and fly ash stabilized soils. The mixture of fly ash and soil helped reduce the leaching of some trace elements

significantly. In alkaline conditions, an arsenic compound can be incorporated with ettringite and can be immobilized.

Trace elements (or heavy metals) are classified as essential and non-essential according to their degree of participation in biological processes. Essential elements in low concentrations must be consumed by organisms as part of their diet. In contrast, non-essential elements can cause health problems even at very low concentrations, and they show toxic effects when they exceed concentration limits.

Lead (Pb) from trace elements is a second-class carcinogen according to World Health Organization (WHO). Because of its neurotoxin properties, it causes a decrease in transmission in the nervous system and causes abnormalities in brain and nervous system functions. The lead accumulated in the bones dissolves with time (half-life of approximately 20 years) and causes harms to the kidneys. Acute intoxication is known to occur with food intake. Cadmium (Cd) is the most water-soluble element compared to other trace elements and thus the rate of diffusion in nature is high. Cd causes lung and prostate cancer. Chromium (Cr) can cause damage to the kidneys and liver and can destroy the circulatory system and nerve tissues. Mercury (Hg) causes heavy brain and kidney damage. It can also lead to increased blood pressure and heart attack. Arsenic (As) is found in more than 200 mineral species. It is widespread in nature and can be found in groundwater. Soluble arsenic compounds are potent poison, and high doses of As cause digestive, cardiovascular, and nervous system dysfunction. Long-term interaction with As carries with it very high risks of skin, lung, and kidney cancer (Kahvecioglu et al. 2015, Kartal et al. 2015, Guven et al. 2015).

When trace elements are discharged into the environment as waste, infiltration into the groundwater occurs and they end up in human

body system. Since these trace elements cannot be prevented from infiltrating into groundwater, it is imperative not to exceed the permitted values. These values are determined by WHO (2011) and vary by law in each country.

In this study, the possible infiltration of trace elements caused by industrial waste when used in soil improvement is investigated. The used industrial wastes were marble dust, fly ash, silica fume, and boron waste. The analyzed elements were selected from the top 10 toxic elements in references of Kahvecioglu et al. (2015), Kartal et al. (2015), Guven et al. (2015). These elements were Be, Cr, Co, Ni, Cu, Zn, As, Cd, Hg, and Pb. A seepage test was conducted on samples prepared in various ratios used for soil improvement. At the end of seepage tests, leachates were collected and analyzed with ICP-MS. The amount of trace elements seeping into the groundwater table was measured.

MATERIALS AND METHODS

Soil

The soil sample used for this study is a granular soil obtained from Afyonkarahisar municipality, Turkey. This material is used in road construction as a base layer. It contains 28% soil particles passing through US No. 10 sieve size (<2mm), and 8% soil particles passing through US No. 200 sieve size (<0.075 mm). The study soil is classified as a well-graded gravel (GW) according

to the Unified Soil Classification System (USCS) and A-1 according to the American Association of State Highway and Transportation Officials (AASHTO).

Industrial Wastes

The industrial wastes investigated in this study are used as a stabilizer and were obtained from various factories in Turkey. The marble dust (MD) was collected from a marble processing plant in Afyonkarahisar, Turkey. It was dried and sieved with a No.40 (425 µm) sieve. Ninety-five percent of the marble dust was finer than 0.075 mm (No.200 sieve). The fly ash (FA) was obtained from Soma B power plant in Manisa, Turkey. Approximately 80% of the particles were finer than 0.075 mm. The boron waste (BW) used in this study is waste slime boron and was obtained from a boron processing plant in Eskisehir, Turkey. The boron waste was dried and sieved with a No.40 (425 µm) sieve, resulting in boron grains that are smaller than 425 µm. The silica fume (SF) was obtained from an electrometallurgical (ferrochrome) plant in Antalya, Turkey. The silica fume, an industrial by-product consisting of very fine spherical particles containing high amounts of amorphous silicon dioxide, is a pozzolanic substance. The chemical characteristics of the soils and industrial wastes used in this study are summarized in Table I.

Table I. Chemical characteristics of soil and industrial wastes (%).

	SiO ₂	Fe ₂ O ₃	Al ₂ O ₃	CaO	MgO	SO ₃	P ₂ O ₅	Ti ₂ O ₂	Na ₂ O	B ₂ O ₂	LOI
SG (Soil)	0,24	0,06	0,16	36,05	16,99	-	-0,01	0,01	-	-	46,40
MD (Marble Dust)	0,20	0,11	0,07	54,50	0,3	0,08	0,02	-	0,01	-	44,52
FA (Fly Ash)	48,28	7,19	27,72	10,51	2,51	3,16	0,27	1,28	-	-	-
BW (Boron Waste)	21,64	0,19	0,75	-	9,40	-	-	16,77	7,88	7,75	35,38
SF (Silica Fume)	94,94	0,60	0,70	0,83	0,71	0,21	-	-	-	-	-

LOI: Loss of ignition.

Sample preparation

The mixing ratios of the samples were taken from previous studies (Zorluer & Demirbas 2013, Zorluer et al. 2013, Zorluer & Gucek 2014, 2017a, b, Firat et al. 2017, Thirumalai et al. 2017). The dried soil and waste materials were mixed at varying proportions on the basis of dry weight, as summarized in Table II. A compaction test was conducted for the mixtures with an appropriate amount of distilled water using a Standard Proctor mold. The mold was made steel and were

inner diameter 105.0 mm and length 115.5 mm. The compaction tests were carried out according to TS 1900-1 (2006). Compaction parameters (optimum moisture content- W_{opt} - and maximum dry unit weight- γ_{dmax} -) were shown in table II. The determined optimum water content was used for sample preparation for a seepage test. The mixtures were compacted into permeameter cells which are sized inner diameter 99.5 mm and length 105.0 mm. Permeameter cells were made aluminum. The wastes were mixed with binary

Table II. The mixture ratios and compaction parameters of samples.

Sample Name	Granular Soil (%)	Marble Dust (%)	Boron Waste (%)	Silica Fume (%)	Fly Ash (%)	γ_{dmax} (kN/m ³)	W_{opt} (%)
SG	100	-	-	-	-	21,48	6,00
SG-20MD	100	20	-	-	-	21,27	9,25
SG-20FA	100	-	-	-	20	20,03	10,50
SG-5MD-10FA	100	5	-	-	10	21,09	7,10
SG-10MD-10FA	100	10	-	-	10	20,70	9,20
SG-10MD-20FA	100	10	-	-	20	20,40	7,80
SG-15MD-30FA	100	15	-	-	30	19,72	10,00
SG-20MD-20FA	100	20	-	-	20	19,33	11,6
SG-20BW	100	-	20	-	-	20,35	10,60
SG-5BW-10FA	100	-	5	-	10	20,50	8,20
SG-10BW-20FA	100	-	10	-	20	19,62	9,90
SG-15BW-30FA	100	-	15	-	30	18,83	10,50
SG-5MD-5SF	100	-	-	5	5	21,58	8,90
SG-10MD-10SF	100	-	-	10	10	21,78	7,80
SG-20MD-20SF	100	-	-	20	20	22,17	8,00

The mixture ratios are based on the dry weight of the granular soil.

combinations. In other words, the two wastes are used together in different proportions. Sample names and mixtures proportions were summarized in Table II.

Seepage test

The prepared samples were placed in the experimental system seen in Figure 1. The samples were allowed to saturate at a constant water level of $\Delta h=160$ cm. Distilled water was used to saturate the samples. Immediately after saturation, an average of 250-300 mL of filtrated water was collected from each prepared sample during an approximately 24-hour period. Although flow rate affects the amount of trace elements in concentrations of seepage fluid, flow rate of filtrated water was not determined because of first flush phenomenon. Because, the first flush phenomenon is the most contaminated leachate (Goswami & Mahanta 2007). The pH, electrical conductivity (EC), and temperature values of 100-mL filtrates from each prepared specimen were measured and recorded using a portable pH meter (see Table III). pH meter is measured pH in between 1-14,

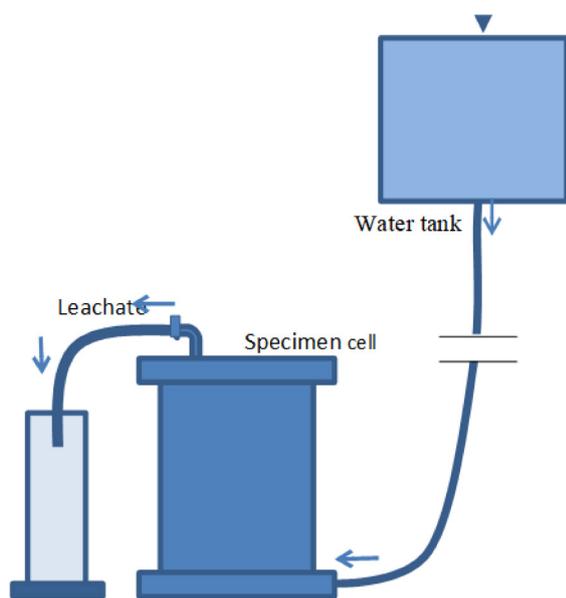


Figure 1. Seepage test system.

electrical conductivity in 0-500 mS/cm. Probe of pH meter is plunged into leachate and values are read from the display in a few seconds.

Determination of trace element concentrations

Inductively coupled plasma mass spectrometry (ICP-MS) was used to determine the amounts of trace elements that seeped through the prepared specimens. It was mentioned before that these elements were the 10 toxic elements. The quantities of trace elements in the filtrates obtained from the specimens are given in Table IV. The analyses were performed using an ICP-MS technique that includes the ionization of a sample by argon plasma at a temperature of 10,000°K via technical electromagnetic induction. This also involves the separation of ionized elements by mass spectrometry and the measurement of elemental concentrations by electron multiplexing detector.

RESULTS AND DISCUSSION

In the most of the mixtures, the leachate concentrations increase with an increase in waste additive rates (see Table IV). Because many ions pass into the water during leakage, this affects the pH values (see Table III). The pH-value of the unstabilized soil specimen was 7.22. Whereas, the specimens containing MD and BW had pH values of 7.12 - 8.09 respectively. Furthermore, the specimens containing MD and SF had pH values within the range of 8.28 - 8.87, respectively. However, the specimens containing FA had pH values beyond 12 on the pH probe meter. This confirms that FA increases the alkaline property of leachates. In the previous studies (Goswami & Mahanta, 2007, Cetin et al, 2012a, b, Cetin & Aydilek 2013) similar results were obtained, the increases in fly ash increased the pH values of the soil fly ash mixtures.

Table III. pH and EC values of samples.

Sample Name	pH	EC (mS/cm)	°C
SG	7.22	1.74	18.3°
SG-20MD	7.12	2.21	19.6°
SG-20FA	12.52	8.48	18.5°
SG-5MD-10FA	12.54	9.03	18.4°
SG-10MD-10FA	12.38	8.72	19.6°
SG-10MD-20FA	12.51	9.89	18.5°
SG-15MD-30FA	12.51	3.79	19.6°
SG-20MD-20FA	12.48	7.32	18.4°
SG-20BW	8.09	2.61	19.6°
SG-5BW-10FA	12.14	13.70	18.3°
SG-10BW-20FA	12.86	7.61	18.3°
SG-15BW-30FA	12.78	9.15	19.6°
SG-5MD-5SF	8.28	1.34	18.5°
SG-10MD-10SF	8.49	1.03	18.3°
SG-20MD-20SF	8.87	10.30	19.6°

Looking at Table III again, the EC values of specimens increased with addition of industrial waste, except SG-5MD-5SF and SG-10MD-30SF specimens. The EC values of SG-5MD-5SF and SG-10MD-30SF specimens were 1.34 -1.03 mS/cm respectively, whereas the EC value of the unstabilized soil specimen (SG) was 1.74 mS/cm. On the other hand, the specimens containing MD and BW had EC values of 2.21 - 2.61 mS/cm respectively. The EC values of specimens containing FA are between 7.32 -13.7 mS/cm, except SG-15MD-30FA specimen. These values showed that the EC values was higher in leachates containing FA, providing evidence that FA increases both pH and EC values.

Table V shows the allowable values for trace elements in drinking water according to Turkish Standard (TS) 266 (2005), WHO (2011), the Environmental Protection Agency (2018), and Council of the European Union (1998).

Trace elements concentrations above the standards are shown in bold in Table IV. The bold values are higher than the smallest value of all standards. In other words, these values are over the standard limit. According to ICP-MS analysis results from all the leachates failed to detect trace elements that include Be and Cd. Zn was detected from BW-FA specimens and not in other specimens. The trace of Zn in the leachate was the result of the Zn detected in BW and FA. However, Zn values were below specified limit for the EPA standard.

The amounts of Hg detected on MD were very low, but this element could trigger serious health issues in humans and animals if it contaminates the groundwater table. The amounts detected were far below the allowable values. In the MD-FA specimens, Pb was significantly detected although the values were 10 times lower than the allowable values specified in the standards.

The leachates from BW-FA specimens contain the highest amount of Copper (Cu) compared to the leachates from the rest of the specimens. Thus, Cu values are far below the allowable values specified in the standard. In addition, levels of nickel (Ni) were detected to be slightly above the recommended TS and WHO standard value, especially in unstabilized soil leachate. Furthermore, leachates from the stabilized specimens contained Ni values that were below the allowable standard values.

Arsenic (As) is a strong poison and levels of this element were detected to be approximately five times higher (> 5) than the standard allowable value, particularly in leachates that contained SF and no FA content. The soil (SG) and SG-20MD mixed specimen contained high

Table IV. The measured trace elements from leachates by ICP-MS.

Sample Name	Be	Cr	Co	Ni	Cu	Zn	As	Cd	Hg	Pb
	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
SG	0,00	0,002	0,0002	0,0355	0,00	0,00	0,0499	0,00	0,00	0,00
SG-20MD	0,00	0,019	0,002	0,0041	0,0139	0,00	0,0454	0,00	0,00	0,00
SG-20FA	0,00	0,632	0,001	0,0031	0,00	0,00	0,0012	0,00	0,0001	0,0018
SG-5MD-10FA	0,00	0,314	0,003	0,0132	0,0074	0,00	0,0020	0,00	0,0001	0,0001
SG-10MD-10FA	0,00	0,334	0,001	0,0051	0,0062	0,00	0,0020	0,00	0,0001	0,0015
SG-10MD-20FA	0,00	0,489	0,001	0,0065	0,0080	0,00	0,0017	0,00	0,0001	0,0021
SG-15MD-30FA	0,00	0,649	0,0006	0,0027	0,0097	0,00	0,0018	0,00	0,0001	0,0018
SG-20MD-20FA	0,00	0,242	0,0006	0,0012	0,00	0,00	0,0005	0,00	0,00	0,0017
SG-20BW	0,00	0,009	0,0004	0,0022	0,00	0,00	3,8189	0,00	0,0001	0,00
SG-5BW-10FA	0,00	0,073	0,0057	0,0100	0,3105	1,432	0,0994	0,00	0,0001	0,0001
SG-10BW-20FA	0,00	0,023	0,0041	0,0112	0,0947	1,563	0,2998	0,00	0,00	0,0001
SG-15BW-30FA	0,00	0,010	0,0007	0,0044	0,0289	0,080	0,1777	0,00	0,00	0,0004
SG-5MD-5SF	0,00	20,281	0,0001	0,0049	0,00	0,00	0,0422	0,00	0,0001	0,00
SG-10MD-10SF	0,00	13,947	0,0004	0,00	0,00	0,00	0,0996	0,00	0,0001	0,0001
SG-20MD-20SF	0,00	94,845	0,00	0,0050	0,00	0,00	0,0345	0,00	0,00	0,0001

Bold numbers are values above the standard limit.

amounts of arsenic. When specimens with BW and FA contained high As values about twenty or thirty times, SG-20BW specimen contained As at a level of 3.8 mg/L, which is 380 times higher than the permitted level. This value shows that As in the leachates come from BW. Consequently, when BW and FA were used together, AS concentrations values in the specimens decreased. The effect of FA can be seen this result. However, although the As values of leachate from BW-FA specimens are significantly lower, these values are still above the standard allowable value. But, since amount of wastes will not increase over time, As values will not increase.

Moreover leachates form MD and FA mixed specimens were detected to have lower As values, which could be attributed to the chemical reaction between FA and MD. As a result of this chemical reaction, as seen in figures 2 a, and c with red circle, ettringite structures are formed. Ettringite forms needle-shaped crystals and its distribution is not uniform in mixtures structure. It had been showed in previous studies (Heebink & Hasset 2001, Goswami & Mahanta 2007, Leelarunroj et al. 2018) that if fly ash and water combine under alkaline conditions with pH-12, ettringite forms as a hydration product. Looking at the Table III pH values of MD-FA specimens are above 12. Also, it is seen from figure 2 b, d, e, and f that there are not ettringite needles in

Table V. Trace element limit values according to standards (mg / L).

	TS 266	WHO 2011	EPA 2018	EURO 1998
Be	-	-	0,004	-
Cr	0,05	0,05	0,10	0,05
Co	-	-	-	-
Ni	0,02	0,02	0,10	-
Cu	2,0	2,0	1,00	2,0
Zn	-	3,0	2,00	-
As	0,01	0,01	0,01	-
Cd	0,005	0,003	0,005	0,005
Hg	0,001	0,001	0,002	0,001
Pb	0,01	0,01	0,015	0,01

specimens without FA. Some studies suggest that a pozzolanic compound and the formation of ettringite can inhibit arsenic (Chrysochoou & Dermatas 2006, Hasset et al. 2005, Zhang & Reardon 2003). However, it is suggested that FA-CaO hydration is the main mechanism to control arsenic immobilization (Moon & Dermatas 2007, Leelarungroj et al. 2018). This indicates that FA has a high capacity to significantly reduce As content in stabilized soil with MD. In the table IV, it has seen that measured As values remained below the standard allowable value in specimens with MD-FA.

Leachates for most of specimens were found to contain high values of Chromium (Cr) although leachates from the specimens containing FA and SF yielded higher values of Cr. Leachates from SG-20MD-20SF specimens had Cr values of 95 mg/L on average. Cr increased along with an increase in SF for the leachate specimens containing SF. This result is in agreement with the results published by Heebink & Hasset (2001), who found the value of the Cr element to be above the standard limit. It is logical there would be high Cr levels in the specimens containing SF,

due to the chemical constituents of SF, which is a waste generated from ferrochrome factories. According to the other results of this study, Cr was found to below the limit in leachates with BW content except SG-5BW-10FA mixture. Actually in the SG-5BW-10FA, Cr concentration was lower than EPA limit. Therefore, it can be said that Cr had not dangerous dimensions in the specimens with BW content. Also Cr concentration was lower than standard limits for SG. Cr is a serious danger for human health according to World Health Organization (WHO), and Cr levels are commonly found to be higher than the allowable values in the leachates containing FA, as FA contains some traces of Cr (Donahoe et al. 2007, Topal et al. 2011, Belviso et al. 2015). An increase in the initial Cr metal concentrations occurs with increasing fly ash content. This level of increase is probably due to the large amounts of Cr concentrations in the fly ash itself (Cetin et al. 2012a).

Cobalt (Co) was found in low levels in all leachates. Co has limited solubility in water and contains more airborne particles when it is present in water. Breathing in this element can

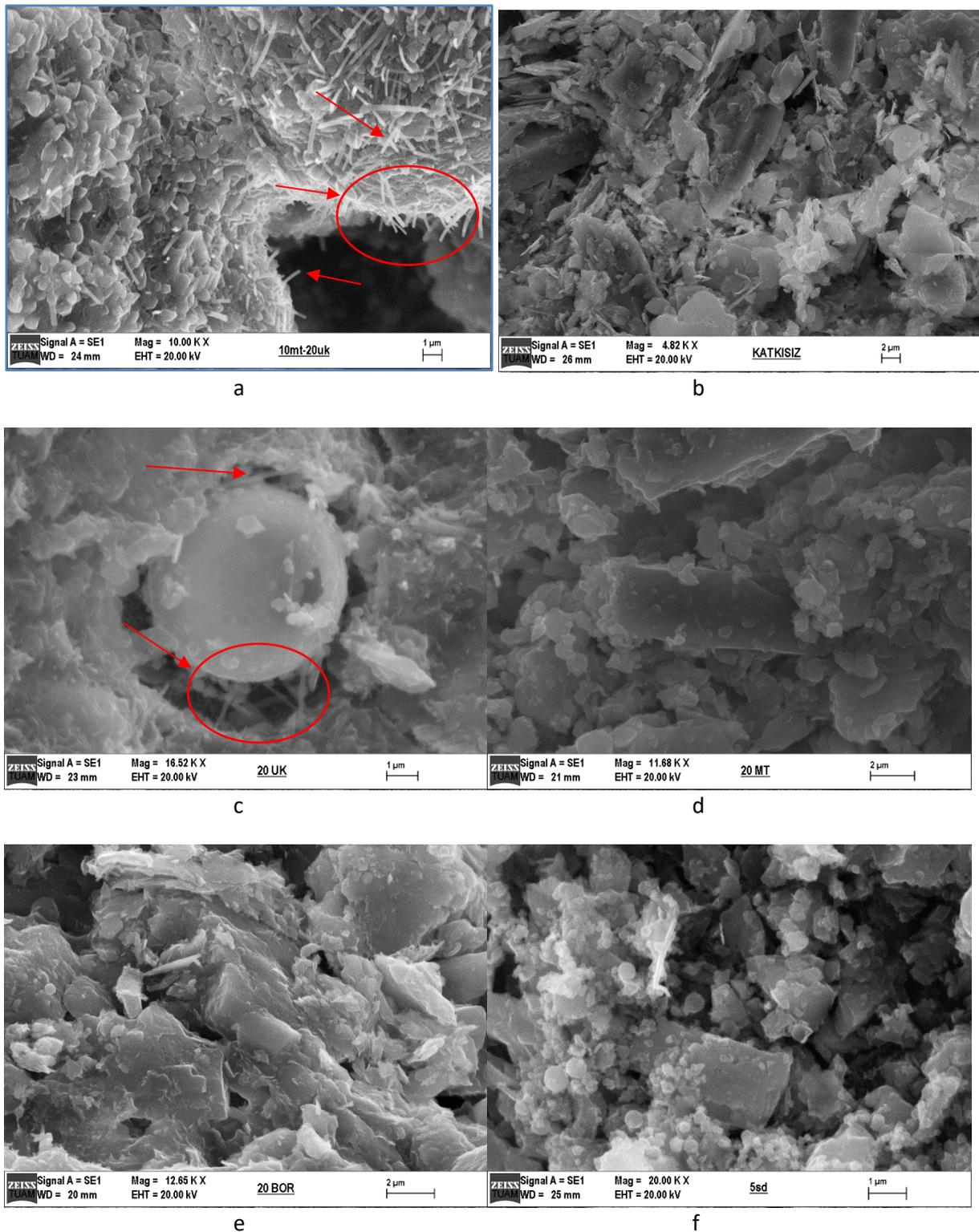


Figure 2. Scanning Electron Microscopy (SEM) images of specimens, -a Ettringite formation in 10MD-20FA specimen. -b No ettringite in SG specimen, -c Ettringite formation in 20FA specimen, -d No ettringite in MD specimen, -e No ettringite in 20BW specimen, -f No ettringite in 5SF specimen.

affect human health, but relevant standards do not include allowable values for Co (Barceloux & Barceloux 1999).

Levels of trace elements such as Cu, Ni, and As values were reduced in mixtures in which FA was used. This result is detailed in Table IV. This indicates that FA contains a pollution-reducing compound. Studies by numerous researcher (Nhan et al. 1996, Prashanth et al. 2001, Chrysochoou & Dermatas 2006, Moon & Dermatas 2006, 2007, Ahmaruzzaman 2010, Liu et al. 2018) have emphasized that FA can be used as a barrier to reduce pollution by solid waste, such as in landfills. On the other hand, FA increased values of some trace elements such as Cr, Pb and Hg. But during the formation of ettringite, several trace elements, including As, Cr, B, gHg can be fixed into crystalline structure. Since the formation of ettringite and fly ash hydration can take from days to months (Leelarungraj et al. 2018). Further, the concentration of trace elements decreases over time, since there will be no increase in waste material use in soil improvement. In addition, as mentioned in previous studies (Heebink & Hasset 2001, Zorluer & Demirbas 2013, Zorluer & Gucek 2017a, b, Firat et al. 2017) the reaction between soil and wastes develops very slowly. As a result of this reaction, the wastes and soil grains are bonded together, permeability and voids decrease, and strength increases.

From this study, it is seen that trace elements pass into the groundwater during the first leakage from industrial wastes. This situation is not suitable for human health and environment. Especially BW and SF are hazardous wastes for environment. However, when BW was used together with fly ash, it was observed that some trace element concentrations decrease in the leachates. This is promising and shows that fly ash is a suitable material. On the other hand, trace element concentrations in leachates

should be measured over the long term and the change determined. Because there will be no increase in the amount of waste used in soil improvement, trace element concentrations are expected to decrease. As a result, it can be stated that the use of industrial wastes in soil improvement is not negative for the environment and ground water.

CONCLUSIONS

This study investigated trace element pollution of groundwater from the use of industrial wastes in soil improvement. According to the obtained results, the following conclusion can be drawn:

The results from all the analyzed leachates failed to detect trace elements that include Be and Cd. However, trace elements that include Zn, Hg, Pb, Cu, and Ni were detected at levels below the allowable values specified by European standards. The level of Cr in the leachates from the most of the specimens was detected to be above the allowable value specified by standards. The toxic effects of Cr were not reduced to a reasonable level even when FA was introduced. In the specimens with BW and SF, As was detected at levels above the allowable values and was reduced drastically when FA was introduced at different ratios. This allows it to retain trace elements and reduce their toxicity.

This study has showed that the use of industrial wastes is not negative in soil improvement in point of environmental effects. The most of trace elements from specimens' leachates were below the allowable values according to various standards. Several elements, As and Cr, were above the standard limits. But, when industrial wastes were used together with fly ash, some element concentrations decreased in the leachates. Therefore fly ash is a suitable material for soil improvement. However trace

element concentrations in leachates should be measured over the long term and the change determined, because concentrations in the field decrease with time and distance due to dispersion in soil.

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