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Engineering Properties of Chromium Contaminated Soils

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ABSTRACT: Soil and groundwater contamination occurs with the industrial activities. Majority of such contaminated sites are in urban areas. With the recent interest by millennial generation or generation Y to live in urban areas, there is a tremendous demand for urban land. Hence some of those contaminated sites will be remediated for residential purposes while others will be developed as brownfield sites for retail purposes. For contaminated soil to be treated or contaminated sites to be used as brownfield sites, one should have a comprehensive understanding of engineering properties of contaminated soils. This manuscript describes such situation where engineering properties of chromium contaminated soils were used to evaluate the feasibility of such soils to be used as construction material or treated and used in brownfield sites. Chromium contaminated soils from nine contaminated sites in New Jersey were subjected to several physical and chemical tests to determine their engineering properties. In addition advanced instrumentation such as environmental scanning electron microscope (ESEM) and X-ray diffractometer (XRD) were used to evaluate the feasibility to use chromium contaminated soils as construction material or remediated and used in brownfield sites. The physical test results were compared with New Jersey Department of Transportation (NJDOT) and ASTM specifications for use as a construction material as well as to remediate the soil. The chemical test results and information obtained from advanced instrumentation were analyzed to determine the long-term impact of using chromium contaminated soils as construction material or remediated and used in brownfield sites. Based on test results it was found that chromium contaminated soils from nine sites are not suitable candidates for either entrapping the contaminants using cement or asphalt or to use as a construction material in brownfield sites.

Keywords: Engineering Properties, Chromium Contaminated Soils, Solidification and Stabilization, Construction Material, Brownfield Development.

1. INTRODUCTION

Chromium played a major role in the industrial development of New Jersey from 1905 to 1971, where the industrialized areas of Northern New Jersey imported chromium ore to process and make chromium. Imported chromite ore was processed at three major facilities, where chromite ore was first pulverized, then pulverized ore was mixed with Na_2CO_3 and CaO, and the mixture was heated to a temperature between $1100C^0$ and $1500C^0$ to produce sodium chromate (Na_2CrO_4), which is a highly water soluble salt (Katz and Salem, 1994). Resulting sodium chromate was reduced to extract metal Chromium. Calcium chromate has a less water solubility, which was considered a waste. Slowly dissolving chromate was found in the chromite ore processing residue ranged from 0.7 to 5% by weight (Burke et al. 1991).

The chromite ore processing residue was left on sides of the riverbanks, as most processing plants were located next to rivers. It is estimated that there are over 2 million tons of processed chromium ore residue in Hudson County, New Jersey, which was used as a fill material in the surrounding region. There are more than 150 confirmed sites in Hudson County, New Jersey, which have been classified as hazardous waste sites. The chromite ore processing residue from the above facilities was used as fill material for construction and development projects at residential, commercial, industrial, and recreational areas throughout Hudson County. The chromite ore processing residue was also used for backfilling of demolition sites, preparation for building foundations, construction of tank berms, roadway construction, filling of wetlands, and other construction and redevelopment activities. Chromate contamination was found among other places, on interior and exterior walls, on building floors, on the surfaces of driveways and parking lots, and in the surface and subsurface of unpaved areas throughout Hudson County (Qian, et al., 2014).

Chromium can be found in many forms in different chemicals solutions; however, there are two main stable forms of chromium in most chemicals and in nature, which are trivalent and hexavalent chromium. Trivalent chromium is not water-soluble. However, it has the sorption properties that will allow the chromium to adsorb onto soil particles. The trivalent chromium tends to precipitate as chromium hydroxide in slightly acidic and alkaline conditions. The hexavalent chromium is water soluble within the full pH range. Chromium in the ambient air occurs from natural sources, industrial and product uses, and burning of fossil fuels and wood. The most important industrial sources of chromium in the atmosphere originate from ferrochrome production. Compared with the relatively immobile Cr (III), Cr (VI) species is much more soluble and mobile. Of greater concern is that Cr (VI) is 100 times more toxic than Cr (III), and it has been added to the Class “A” Human Carcinogens list by the US Environmental Protection Agency (Richard and Bourg, 1991).

The state of New Jersey in consultation with the US Environmental Protection Agency embarked on a major site demonstration study back in 1995 to determine the best remediation options for 150 confirmed contamination sites in Hudson County, New Jersey. The study determined the most viable option would be vitrification of contaminated soils and use as construction aggregates. Hence a site demonstration was performed using cold top vitrification to evaluate the feasibility and also to determine the unit treatment costs (Meegoda et al., 1999, 2000a and 2000b; Kamolpornwijit et al., 2007). Meegoda et al., 1999, 2000a and 2000b showed the feasibility of remediation of chromium contaminated soils using cold top vitrification but the cost of remediation was in excess of $200 per ton of soils and hence no action was taken to remediate those contaminated sites. Subsequently the state of New Jersey investigated the feasibility of converting chromium-contaminated soils to stainless steel (Meegoda and Kamolpornwijit, 2011). However, this study also did not result in any actions for remediation of 150 confirmed contamination sites in Hudson County, New Jersey. Most of these contaminated sites are in urban areas with existing infrastructure such as water and sewer lines, electricity, roads and accessibility to public transportation.

On the other hand millennials are the social generation, both online and in-person. As the founders of the social media movement, and they live very close to their friends and family. They prefer to live in dense, diverse urban villages where there is social interaction. With the resurgence of cities as centers of economic energy and vitality, a majority of millennials are opting to live in urban areas over the suburbs or rural communities. Sixty-two percent of millennials indicated that they prefer to live in the type of mixed-use communities found in urban centers, where they can be close to shops, restaurants and offices. They are currently living in these urban areas at a higher rate than any other generation, and 40 percent say they would like to live in an urban area in the future. As a result, for the first time since the 1920s growth in U.S. cities outpaces growth outside of them. Hence there is a tremendous demand for urban land including those contaminated and abandoned industrial sites.

The necessity for the remediation and redevelopment of the contaminated sites continues to be a growing issue, where the urban sprawling (United Nations, 2014) increases the demand towards developable land neighboring industrialized zones (De Sousa, 2002). Hence brownfield restoration would reduce the development pressure on undeveloped land by encouraging redevelopment of contaminated land that has access to existing infrastructure and services. The U.S. Environmental Protection Agency (EPA) defines "brownfields" as "abandoned, idled, or under-used industrial and commercial facilities where expansion or redevelopment is complicated by real or perceived environmental contamination."

Converting the industrial sites to brownfield sites is considered as a major solution for the scarcity of land development. The lightly contaminated sites will be converted into reusable land through minimum remediation techniques. In economical perspective, most of the brownfield sites are located in industrialized locations with high demand for redevelopment. Main benefits of Brownfield sites are the locations, existing infrastructure such as water and sewer lines, electricity, roads and accessibility to public transportation. These approaches towards the brownfield sites have attracted environmental agencies to promote and invest on ventures to use brownfield sites as a part of developing the neighborhoods and spur the transformation of entire cities by attracting people into communities, where they expect to enhance the local community with local taxes, create more jobs and minimize the urban sprawling (Thornton et al., 2007, Pippin 2008). However, developing contaminated industrial zones such as brownfield sites have major challenges such as sustainability and health complications generated with the use of brownfield sites after the development (Ren et al., 2012).

Sites contaminated with chromium are major concern where the remediation technologies are expensive and duration for the remediation processes might take long time. The scarcity or expensive in-situ remediation technologies makes the process less viable. Due to these reasons treating those as brownfield sites, with minor remediation and redevelopment is considered as one of foremost answers. The New Jersey state government has many successive stories of brownfield sites in reuse throughout the state (NJDEP 2014). At those brownfield sites most common method of redevelopment would be to remove the topsoil and vegetation, and compact the contaminated soil with a cover of asphalt or cement concrete. Another attractive but more expensive option would be to mix the contaminated soil with either asphalt or cement to solidify and stabilize. However, the question of using brownfield sites with minimum remediation remains the same, with concerns about the movement of heavy metals such as chromium towards the surface of the site endangering the health of the community. To shed light on this question, this study focused on testing the engineering properties of the chromium-contaminated soil from nine major identified contaminated sites in New Jersey.

2. EXPERIMENTAL PROCEDURE

2.1 Sample Collection

Considering the history of heavy metal contamination in New Jersey, soil samples were taken from nine different chromium contaminated sites in Hudson County and were selected as sources for soil sampling and testing. The following are descriptions of nine sites. The Liberty State Park (LSP) site is near a monitoring well with no vegetation over the soil, where the soil was brown in color with a reddish tint. A total of 12 kg was taken from the surface of the site. The Colony dinner (CD) site had partial vegetation and the soil was dark brown with a distinct yellow-green fluorescent color. By digging a soil sample was collected. The Cavern Point Road (CPR) site was marshy and the soil was brown in color with a hint of reddish tint. The soil from the Hackensack River Road site (HRR) was obtained by boring on an access road leading to a bridge over the Hackensack River. The sampling point was 20 feet from the river. The Reed Mineral (RM) industrial site was one of the main chromium contaminated site considered in this study. This site was off Central Avenue, where complete site was paved to mitigate further contamination. The soil was dark brown in color with black crystals. The Roosevelt drive-in (RD) site was also considered a highly contaminated where the site was covered with a high-density polyethylene liner, followed by a two-inch gravel layer. The soil bored from the site had a brown color with reddish, yellow-green fluorescent color. The soil had magnetic properties and slag. The NJ Turnpike Bayview (TRP) site was located underneath a bridge on the New Jersey Turnpike. The soil collected from the site had reddish brown color and was a silty sand with magnetic properties. The Grafield Avenue (GA) site was covered with a high-density polyethylene liner, followed by a two-inch gravel layer. The initial screenings indicated low Cr^{6+} concentrations. Therefore, soil was taken from four locations and mixed at the site. The Diamond Shamrock (DS) site was one of the major polluted sites in Hudson Country. This site was capped with an asphalt concrete layer. The samples were taken by boring through the asphalt concrete cover. The soil was dark brown color with slag. Each sample was approximately 12kg in weight contained in a 5gallon bucket with a waterproof lid. All the samples were taken closer to the ground surface and not more than 15 cm bellow the ground surface level. The sample were collected close to the surface in order to mimic the use of the site as a Brownfield site. In certain locations the ground surface chromium levels were high due to the fluctuation of the groundwater table. Since all soil samples were contaminated, chain of custody forms were developed to keep track of soil usage.

2.2 Sample preparation and physical and chemical testing of soil

The experimental procedure consisted of laboratory testing of the sample collected from all sites. Prior to the testing, contaminated soils were homogenized by mixing. The laboratory testing comprised of analyzing the soil samples for the physical and chemical properties. First soil samples were subjected to Toxicity characteristic leaching procedure (TCLP) test to analyze the leachable chromium concentrations to identify the potential for environmental hazards. The physical tests performed included moisture content (ASTM D2216), liquid and plastic limit (ASTM D4318), grain size analysis (ASTM D421 and D422), and specific gravity (ASTM D854). The leftover soil after the specific gravity and hydrometer tests was air-dried. The chemical tests performed included total chromium analysis using both hydrofluoric and soft digestion (EPA SW-846) followed by induced couple plasma spectrometer (ICP) analysis.

The hexavalent chromium concentration was determined by alkaline digestion (EPA 3060A) followed by the colorimetric method (EPA 7196A). The pH was measured after mixing 5 grams of soil with 5 ml of deionized water. The laboratory tests for hexavalent chromium were performed within 48 hours of sample collection to ensure the maximum accuracy. Also X-ray diffractometer (XRD) analysis was performed to obtain mineralogy of nine soils. To further investigate and comment on engineering properties of chromium soils and to better understand soil constituents, soil samples obtained from the Colony Diner and Liberty State Park sites were tested under the environmental scanning electron microscope (ESEM) and subjected to detailed XRD analysis. Initial observation of the soil from eight sites indicated low silica contents in the contaminated soil indicating they are chromium ore processing residue.

3. TEST RESULTS

3.1 Physical Tests

The physical parameters tested for soil samples from nine different sites are presented in Table 1, where the main parameters presented are the specific gravity, moisture content and grain size corresponding to 10% passing (D_{10}), 30% passing (D_{30}), 60% passing (D_{60}), coefficient of uniformity (C_u) and coefficient of curvature (C_c). The tested contaminated soil indicated that it contained silty soil with no plasticity. The specific gravity of the contaminated soils ranged from 2.76 to 3.21, which was much higher than the typical 2.65 value for silty sands. There were high traces of iron slag in most of samples producing high specific gravity values. The grain size distribution showed that the maximum cumulative weight of the soil fraction finer than 0.15 mm was less than 30%. The moisture content varies from 6.1% to 56.2% where moisture content depended on the location of the original soil and weather condition on the sampling day.

The physical test results were compared with New Jersey Department of Transportation (NJDOT, 2014) and ASTM (ASTM 2014) specifications for use as a construction material as well as to remediate the soil. Based on the physical tests reported in Table 1, the chromium contaminated soil from each site was classified according to the Unified Soil Classification System (USCS). The percent passing 4.75 mm sieve opening (sieve No. 4) for soils from all nine contaminated sites was more than 50 indicating the granular nature. With low or no soil plasticity and wide grain size distributions all soils from nine sites were classified as Silty Sand (SM). Silty Sands are excellent candidates for compaction or solidification/stabilization with either asphalt or cement. Hence based on physical tests all nine sites are suitable candidates for brownfield redevelopment.

3.2 Chemical Tests

Table 2 indicates the results of the chemical tests from the nine sites. Colony Diner site had the highest hexavalent chromium content of 4800 mg/kg. The same site showed high concentration of leachate from TCLP test, a value of 68.58 mg/l. Roosevelt Drive-in had the second highest hexavalent chromium concentration of 4440 mg/kg and a leachate TCLP of 46.74 mg/l and the third highest was from Liberty State Park site with hexavalent chromium of 1240 mg/kg and leachate 32.41 mg/l. All the other 6 sites had low leachate values, which were less than 9 mg/l. All three sites with higher pH values had higher hexavalent concentrations or higher the pH value the higher the hexavalent chromium concentration. Because of the addition of lime before the processing of the ore, the high pH concentrations found in the three sites indicated the possibility of these soils have been used as fill material directly taken from the processed remains of chromium ore. Chromium (III) adsorption is generally influenced by pH and cation exchange capacity. When pH increases, negative surface charge of the soils increases, so there was an increased adsorption of Cr(III). However, the mobility of the chromium ions will be higher, as soil from all nine sites contained silty and coarse materials with low clay content with comparatively high permeability values. Griffin and Shimp (1978) showed that the relative mobility of metals in soils at pH 5, where Cr(III) was found to be the least mobile. With high pH values for all nine sites, mobility of chromium ion was high for it to move within the soil matrix with the fluctuation of the water table with different weather conditions. This would allow chromium to penetrate the soil fill or concrete over the contaminated soil if developed as brownfield sites.

Table 3 contains the major chemical composition of chromium-contaminated soil from all nine sites. The Hackensack River road site had the highest SiO_2 content and Table 1 shows the highest D_{10} vale of 0.15 mm indicating that at this site chromium ore-processing residue was blended with sand. The SiO_2 contents for nine sites varied from 2.5% to 32.1%. The CD, RM, DS and CPR sites had moderate silica contents that varied from 10.0% to 16.6%. The Fe_2O_3 content varies from 18.8 % to 43.5%. The RM, TRP, LSP and GA sites contained high concentrations of Fe_2O_3 ranging from 37.6% to 43.5%, where LSP site had the highest value of Fe_2O_3 (43.5%). The CaO concentrations ranged from 8.0% to 40.5%, where the DS, RD and CD sites had high concentrations. Correspondingly RD and CD sites had the highest soil pH values and highest TCLP Cr(VI) concentrations.

Natural chromite ores consist of two major parts: spinel fraction and gangue. The spinel fraction contains isomorphous mixture of mineral that constitutes a group crystallizing in the isometric system. The common chemical formula of mineral in spinel is $RO.R_2O_3$; i.e. $FeO.Cr_2O_3$, $MgO.Cr_2O_3$, and $FeO.Al_2O_3$.

Gangue is a minor portion consisting of mostly magnesium silicates. The natural chromite consists of 30 to 50 percent Cr_2O_3; 10 to 25 percent of FeO, Al_2O_3, and MgO; 2 to 10 percent of SiO_2, and less than 2 percent of CaO (Udy, 1956). The ideal chromite composition is $FeCr_2O_4$, where it would contain 68% Cr_2O_3 and 32% FeO. However, the highest grade of chromite ore contains 42-56% Cr_2O_3 and 10-26% FeO, with varying concentrations of impurities of Magnesia, Alumina and Silica.

3.3 ESEM and XRD Tests

The mobility and presence of heavy metals in soils depends on the nature of the interactions between solid constituents. Use of x-ray diffraction would allow identification of chemical constituents of soil by weight. Figure 1 shows results of XRD test for nine contaminated sites from Hudson County. It is observed that the soils from LSP, CPR, TPR, GA, and RM sites had intense spinel peaks. Table 3 shows soils from LSP, CPR, TRP, GA, and RM sites had the highest concentrations of Fe_2O_3 ranging from 29.8% to 43.5%, the other sites (CD, RD, DS and HRR) and contained SiO_2 and $CaCO_3$ peaks. Table 3 also showed high CaO concentrations ranged from 31.8% to 40.5% for soils from CD, RD and DS sites. The past chromite ore processing can be described as high lime (55% lime), low lime (15% lime) and no lime (NaOH) processes. Low lime process was introduced when the rotary kiln technology was available and therefore it was more efficient. It is convincing from Figure 1 that contaminated soils from different sites were subjected to those two different extraction processes. Above data suggests that chromium soil from CD, RD and DS sites used high lime process while LSP, CPR, TPR, GA, and RM used low lime process. With sand blending it was difficult to comment on the origin of soil from HRR site. Certain spinels, i.e. $MgO.Fe_2O_3$ and $FeO.Fe_2O_3$, possess magnetic properties, which may help to confirm the above.

Table 1: Physical properties of soil

Site	G_s	w (%)	D_{60} (mm)	D_{30} (mm)	D_{10} (mm)	C_u	C_c
Liberty State Park (LSP)	3.21	14.4	1.00	0.17	0.05	20	0.6
Colony dinner (CD)	2.72	29.6	0.60	0.21	0.06	10	1.2
Cavern Point Road (CPR)	3.12	25.4	0.84	0.16	0.04	21	0.8
Hackensack River Road (HRR)	3.02	14.7	3.15	0.22	0.15	21	0.1
Reed Mineral (RM)	2.90	6.1	2.00	0.51	0.08	25	1.6
Roosevelt drive-in (RD)	2.76	22.0	0.77	0.31	0.11	7	1.1
Turnpike Bayview (TRP)	2.76	32.5	0.40	0.075	0.01	40	0.01
Grafield Avenue (GA)	2.98	24.6	1.38	0.18	0.06	23	0.4
Diamond Shamrock (DS)	2.83	56.2	1.44	0.25	0.06	24	0.7

Table 2: Chromium concentrations and TCLP of Soils from the Bench scale tests

Site	Total Cr soft digestion (mg/kg)	Total Cr HF digestion (mg/kg)	Hexavalent Chromium (mg/kg)	TCLP Leachate (mg/l)	Soil pH	TCLP pH
Liberty State Park (LSP)	1544	16125	1240	32.41	10.18	7.24
Colony dinner (CD)	5294	25573	4800	68.58	11.25	7.88
Cavern Point Road (CPR)	1268	17738	29.2	5.81	8.95	6.37
Hackensack River Road (HRR)	587	2853	19.7	3.83	8.88	5.61
Reed Mineral (RM)	455	1936	-	4.62	9.25	4.41
Roosevelt drive-in (RD)	4600	20275	4440	46.74	12.22	9.80
Turnpike Bayview (TRP)	544	12228	29.2	2.09	9.71	7.11
Grafield Avenue (GA)	1821	11729	246	8.67	9.16	6.94
Diamond Shamrock (DS)	950	8086	61.7	1.65	8.99	5.48

Table 3: Major Chemical compositions of contaminated soil

Site	SiO_2 %	Al_2O_3 %	Fe_2O_3 %	MgO %	CaO %	TiO_2 %	ZnO %
Liberty State Park (LSP)	2.5	14.6	43.5	12.7	14.9	0.9	0.1
Colony dinner (CD)	12.9	17.6	19.5	7.8	31.2	0.9	0.3
Cavern Point Road (CPR)	10.0	14.1	29.8	16.0	17.6	0.9	0.2
Hackensack River Road (HRR)	32.1	19.5	18.8	11.5	8.1	1.3	0.1
Reed Mineral (RM)	16.6	21.7	38.1	6.7	8.0	1.3	0.1
Roosevelt drive-in (RD)	3.3	17.6	20.6	12.6	40.5	0.4	0.1
Turnpike Bayview (TRP)	6.7	9.5	37.6	19.2	14.9	0.9	0.1
Grafield Avenue (GA)	3.6	8.9	39.0	17.2	16.3	0.8	0.2
Diamond Shamrock (DS)	13.1	12.9	19.1	13.0	30.8	0.7	0.1

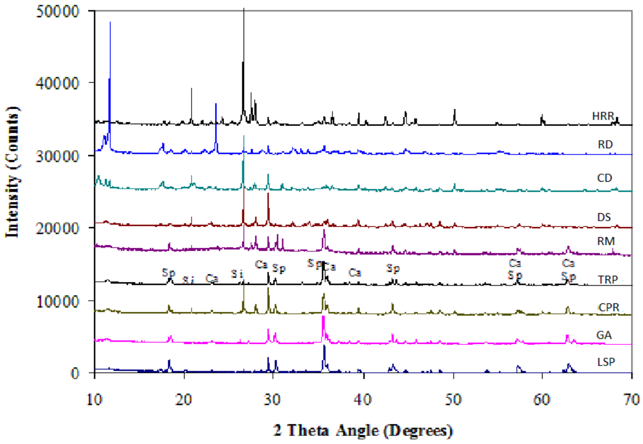


Figure 1 XRD results of Chromium Contaminated Soils from Nine Sites

As stated before, soil samples obtained from CD and LSP sites were tested using the environmental scanning electron microscope (ESEM) and were subjected to detailed XRD analysis. Figure 2 shows detailed XRD results for soils from CD site. Figure 2 indicates, that soil from CD site contains hydrates calcium aluminum chromite oxide ($Ca_4Al_{16}CrO_{16}$) and calcium chromite oxide ($CaCrO_4$), Silica (SiO_2), calcium carbonate ($CaCO_3$), anorthite ($CaAl_2Si_2O_8$), chromite ($FeCr_2O_4$), and magnetite (Fe_2O_3). The reddish brown color of the soil can be due to the presence of chromalite ($CaCr_2O_4$), which was not identified from XRD test. Figure 3 shows the ESEM image obtained for the contaminated soil from CD site showing the less angular and granular shaped soil with a wide range of size distributions. The particles are more rounded with variations in spherical shape.

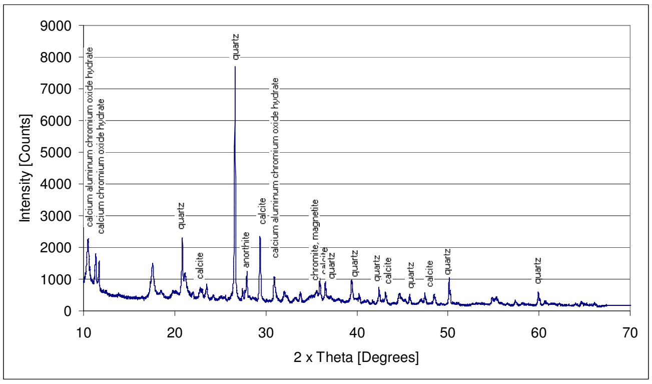


Figure 2 XRD Results of Chromium Contaminated Soil from CD Site

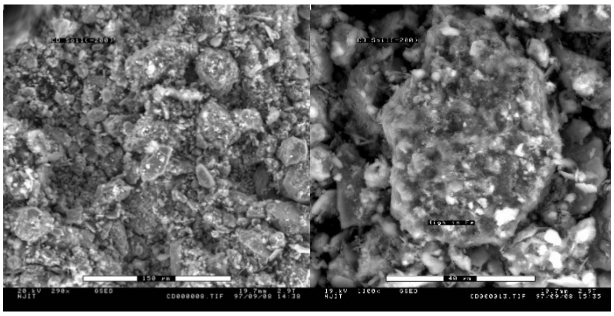


Figure 3 ESEM Images of Soil from CD Site

Figure 4 shows detailed XRD results for soils from LSP site. Figure 4 indicates that soil from LSP site contains calcite ($CaCO_3$), quartz (SiO_2), and spinel compounds, where the spinel compounds are chromite ($FeCr_2O_4$), magnesioferrite ($MgFe_2O_4$), manganese (Mn_2AlO_4), and magnetite (Fe_3O_4). Figure 5 shows the ESEM image obtained for the contaminated soil from LSP site again showing the less angular shaped soil with a wide range of size distributions. The particles are more rounded with variations in spherical shape.

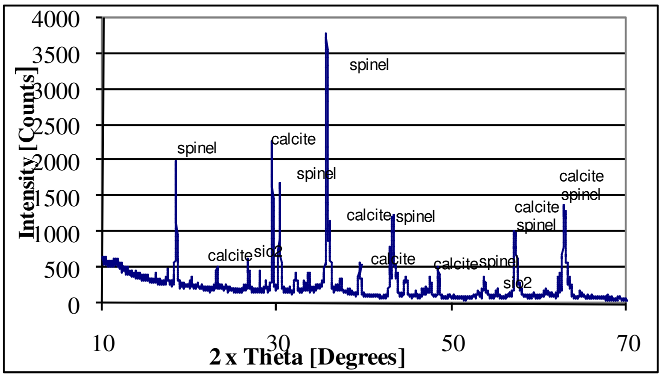


Figure 4 XRD Results of Chromium Contaminated Soil from LSP Site

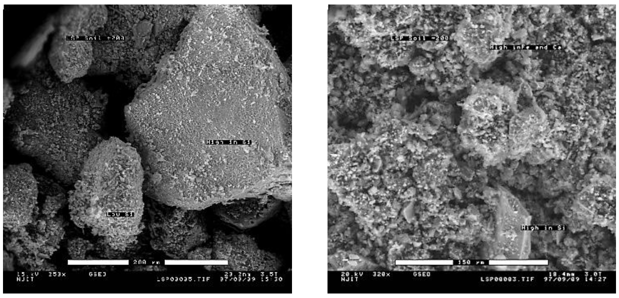
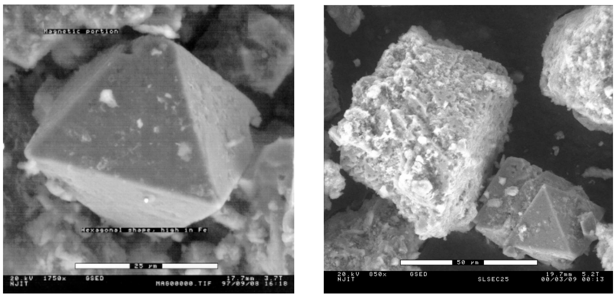


Figure 5 ESEM Images of Soil from LSP Site

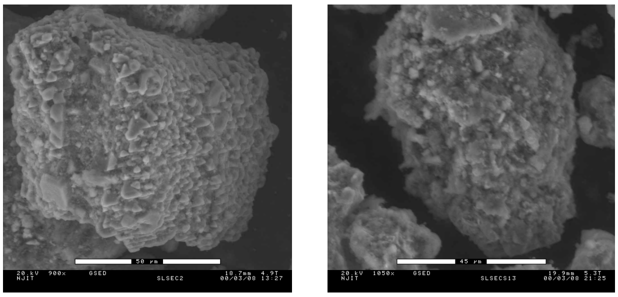
The ESEM images of soil from CD and LSP showed larger fraction of granular particles with low angular shapes. Soils structure also indicates very low clay content reducing the adsorption chromium onto soil particles. Presence of tracer manganese oxide in soils favors trivalent chromium oxidation, thus increasing the hazard of hexavalent chromium contamination of groundwater (Bartlett and James 1979). The sites indicated high water table fluctuation during a calendar year. Hence there is a strong possibility for the hexavalent chromium to move within the soil and even come in contact with humans. Also such mobility would indicate measured Cr(VI) values may not be representative. Such hexavalent chromium mobility was observed during subsequent soil sampling in springtime where the site looked like painted with yellow or commonly referred to as chromium blooming.

In order to further analyze the soil composition ESEM image from LSP soil was carefully scanned and identified different soil fractions. Figure 6 shows ESEM Images of different Soil fractions from LSP Site.

Based on Figure 6 soil from LSP site can be grouped into three categories based on the appearance and differences in physical and chemical characteristics. The first group is those particles having crystalline appearances similar to images shown in Figures 6a with average concentration of 39.1% Fe, 8.8% Cr, 6.1% Ca, 8.6% Mg, 3.5% Si, and 6.0% Al. Please note that if the octahedral crystal was pure chromite ($FeCr_2O_4$) and was analyzed one would have obtained 24% Fe and 46% Cr or 32% FeO and 68% Cr. The low Cr concentration was due to extraction of Cr from other particles shown in the image. The second group is those particles having appearance similar images shown in Figures 6b and 6c with average concentration of 24.7% Fe, 3.1% Cr, 14.5% Ca, 6.6% Mg, 4.9% Si, and 7.6% Al. The last group having appearance similar images shown in Figures 6d is those particle having appearance similar to regular aggregates with 7.4% Fe, 0.0% Cr, 6.2% Ca, 1.5% Mg, 23.3% Si, and 15.1% Al, which is essentially regular soil. During the chromate extraction process, calcium oxide reacted with chromite ore and subsequently formed calcium carbonate, which either separated from or deposited on the ore surface. The reaction proceeded inward and so did the formation of products. The observation of soil morphology and composition indicated that these three different types of particles represented un-oxidized ore, partially oxidized ore and fully oxidized and leached ores with impurities, respectively. Figure 6 attempts to demonstrate the progress of extraction of ores at different stages of extraction: intact crystals (6a), partially de-surfaced crystals (6b and 6c), and totally de-surfaced crystals (6d). Under normal environmental conditions soil fractions represented by Figures 6a and 6d are quite stable and would not cause detrimental effects. However, the soil fraction that is represented by Figure 6b and 6c seems to be unstable under high pH levels and the presence of tracer quantities of Manganese oxidation seems to proceed converting Cr(III) to Cr(VI) (Kamolpornwijit et al., 2007).



a) Intact Crystals b) Partially De-surfaced Crystals



c) Partially De-surfaced Crystal d) Completely De-surfaced

Figure 6 Assumed Deteriorating Process of Ores

4. DISCUSSION OF REUSE OR REMEDIATION OPTIONS

Well-graded silty sands with rounded texture are excellent construction material for subgrades as well as to support foundation loads. Tests on the physical properties of soils from nine contaminated sites showed that they are very good contenders as a construction material. Based on the physical properties, contaminated soils form nine sites, once they are properly compacted, can be used to support cement concrete or asphalt concrete pavements. In addition silty sands can also be blended or used directly with either cement or asphalt to stabilize and solidify (Meegoda et al., 2003). There are major trends to identify the possibility of using these types of contaminated soils in cement or asphalt concrete around the world considering the abundance and a method of entrapping contaminates as remediation technique (Andre´s et al., 2002, Zhang et al., 1997). In addition use of contaminated soil in manufacturing concrete blocks for the building industry is one of the well-pursued remediation method among researchers (Meegoda et al., 1994, Hago et al., 2007).

The entrapping the chromium in cement concrete structure by stabilization or covered with cement concrete as in brownfield type construction would theoretically stop oxidation of chromium. The extensive studies have been carried out and have reported that Cr (III) effectively can be immobilized in almost all the cement concrete matrices (Kindness et al., 1994). However, the study performed by Panda et al., (2013) present reliable evidence that even though Cr (III) can be successfully immobilized in concrete structure or covered by concrete, the presence of Cr (VI) will cause the change in the structure of the concrete and will cause high leachable chromium. In addition Palmer (2000) showed the mobility Cr (VI) in concrete, where the observations obtained in the study indicated that the reaction of Cr (VI) with concrete holding similarities to the sulfate attack in concrete. Palmar (2000) substantiates the possibility for the same consequences for contaminated soils from nine sites considered in the study with partially de-surfaced chromite crystals as shown in Figure 6b mixed with high pH cements.

Similar to the cement concrete, asphalt concrete has received a considerable attention as a waste encapsulation material due to its low cost, hydrophobic characteristics, and long-term chemical and biological stability (Phillips et al., 1984, Bednarik et al., 2005, Červinková et al., 2007). Moona et al., (2009) showed that high mobile of Cr(VI) making it unable to encapsulate Cr(VI) in asphalt concrete, especially if suction pressures exists due to unsaturated conditions. Based on the TCLP tests of soils, contaminated soils from nine sites tested had high to moderate leachable of chromium (see Table 2). Hence, the Cr(VI) leachate concentration from asphalt cement encapsulated soils form above sites would not be below 0.5 mg/L limit based on the universal treatment standards (UTS) (Title 40 of the US Code of Federal Regulations (CFR) Sec. 268.48). Hence with such partially oxidized ore none of the chromium contaminated sites can be redeveloped as brownfield sites as with time Cr(IV) will be released and will be in contact with the occupants of such sites.

5. SUMMARY AND CONCLUSIONS

A comprehensive literature search followed by a detailed experimental study was conducted to investigate the feasibility of utilizing chromium contaminated sites in NJ as brownfield sites. Chromium contaminated soils from nine contaminated sites in New Jersey were subjected to several physical and chemical tests to determine their physical and chemical properties. In addition advanced instrumentation tests such as environmental scanning electron microscope (ESEM) and XRD were used to evaluate the feasibility to use chromium contaminated soils as construction material or remediated and used in brownfield sites of with low or no soil plasticity and wide grain size distributions. All soils from nine sites were classified as Silty Sand (SM). Silty Sands are excellent candidates for compaction or solidification/stabilization with either asphalt or cement. The chemical tests indicated high chromium contents, with leachable Cr(VI) based on TCLP tests. The CaO concentrations ranged from 8.0% to 40.5%, with three sites having excessively high concentrations of over 30%. Two of those sites with high CaO concentration also had the highest soil pH values and highest TCLP Cr(VI) concentrations. The XRD data suggests that chromium soil from four sites used high lime extraction process and another four sites used low lime process. With sand blending it is difficult to comment on the origin of soil from the ninth site. The ESEM data suggested that soils from chromium contaminated soils contained three distinct fractions, the original chromite ore or un-oxidized ore, partially oxidized ore and fully oxidized and leached ores with impurities. The original chromite ore and fully degraded soil like chromium ore processing residue do not threaten the environment. However, partially oxidized ore is unstable and seems to produce mobile Cr(VI) with time. Hence with such partially oxidized ore none of the chromium contaminated sites can be redeveloped as brownfield sites as with time Cr(IV) will be released and will be in contact with the occupants of such sites.

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