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Immobilization of Heavy Metals from Paving Block Constructed with Cement and Sand-solid Waste Matrix

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ABSTRACT

The research focuses on the solidification/stabilization of heavy metal contaminated landfill Decomposed Solid Waste (DSW). DSW samples were collected from Matuail and Aminbazar landfill sites of Dhaka South City Corporation and Dhaka North City Corporation respectively. Ordinary Portland Cement (OPC) was used as stabilizing binder to investigate the feasibility of solidifying/stabilizing the waste. A series of trials were observed for optimum composition of OPC and fine aggregate in mortar mixture. Solid waste was mixed as the substitute of total volume of fine aggregate as big as 10-70%, with the range of 10% per composition. The study observed the strength development and immobilization of heavy metals like Fe, Cu and Ni of the final product. This study revealed that 30% of the total volume of the fine aggregate can be replaced by dry decomposed solid waste having a mix proportion 1:3 of stabilizing binder (i.e., OPC) and fine aggregate which obtained compressive strength 2494 psi at 28 days curing period that satisfy the Bangladesh standard for paving block. Immobilization of Fe, Cu and Ni were obtained ranges from 96.5-95.0, 88.16-72.64 and 93.05-89.28%, respectively for different composition of solidified matrix. The Outcome of this study gives the information of compressive strength development of solidified waste mortar block and immobilization (i.e., entrap) of heavy metals within the block to minimize the release into the environment.

Key words: Solid waste, ordinary portland cement, compressive strength, heavy metal, immobilization

INTRODUCTION

Landfilling of municipal solid waste is a common waste management practice and one of the cheapest methods for organized waste management in many parts of the world (Bhalla *et al*., 2012; Jhamnani and Singh, 2009; Longe and Balogun, 2010).

Landfills pose serious threat to the quality of the environment if incorrectly secured and improperly operated. The threat to surface and ground waters could be deleterious (Jhamnani and Singh, 2009; Longe and Balogun, 2010). In order to reduce the scale of pollution of waste at landfill sites, solidification and stabilization (S/S) techniques are used to prevent or minimize the release of hazardous compounds from contaminated waste into the environment by producing a solid mixture, improving handling characteristics, decreasing surface area for contaminant transport, reducing mobility of the contaminant transport and bonding the contaminate into a non-toxic form

(Omar *et al.*, 2008). Stabilization refers to techniques that chemically reduce the hazard potential of a waste by converting the contaminants into less soluble, mobile or toxic forms (USEPA, 1993). Solidification refers to techniques that encapsulate the waste, forming a solid material and does not necessarily involve a chemical interaction between the contaminants and the solidifying additives. S/S procedures usually involve mixing the waste with solid additive materials like fly ash, cement, lime, cement kiln dust, sulphur or combination of them (Omar *et al.*, 2008). Among various binders, portland cement is one of the most regular binders used for S/S matrix. This stabilization process relies on the formation of calcium silicate hydrate ($CaO \cdot SiO2 \cdot nH2O$, briefed as C-S-H), ettringite hydrate ($3CaO \cdot Al_2O_3 \cdot 3CaSO_4 \cdot 32H_2O$, abbreviated as AFt) and monosulphate ($3CaO \cdot Al_2O_3 \cdot CaSO_4 \cdot 12H_2O$, abbreviated as AFm) in the matrix, due to the hydration reaction of Portland cement and thus the heavy metals both chemically fixed in the lattice of hydration production and physically encapsulated in the matrix (Gupta and Surwade, 2010).

In this study it is therefore aimed to investigate the optimum composition of stabilizing binder (OPC) and fine aggregate (i.e., sand-solid waste) for compressive strength development of solidified waste mortar block that reduce the mobility of heavy metals from waste to prevent the release into the environment. Matuail and Aminbazar sanitary landfill sites were selected as sample collecting area for DSW.

MATERIALS AND METHODS

Sampling of waste: In this current study, decomposed solid waste was collected from five different locations of each landfill site. Waste samples were air dried at room temperature after collecting from landfill sites.

Properties of waste and sand: Air dried decomposed solid waste and sand samples were sieved as the requirements of each laboratory experiment. Physical parameters of both samples such as fineness modulus, Water Absorption Capacity (WAC), dry density, bulk density, specific gravity and moisture content were determined using the standard methods ASTM C136-95a, ASTM C 128-93, ASTM-D2937-00, ASTM 128-93 and ASTM D2216-80, respectively. These parameters were analysed to compare the value of waste and sand with quality parameters and also to measure the level of effectiveness and efficiency for using waste as construction material through solidification process (Primanda and Rahardyan, 2010). Each test of parameters was performed 3 times for confirming the reproducibility of experimental data.

Decomposed solid waste was digested for heavy metal concentration analysis using Aqua-Regia digestion method. Parameters related to heavy metals such as Fe, Cu and Ni were determined in this study. The concentration of Fe and Cu were analysed using flame emission Atomic Absorption Spectrophotometer (AAS) (Spectra AA Varian) and Ni was measured using Hach DR/4000 Spectrophotometer (Using method: 8037).

Properties of ordinary portland cement (OPC): In this study, OPC was purchased commercially. Physical parameters of OPC were also analysed to check the fitness of quality as a binding material for using in solidification of waste. Parameters such as normal consistency limit, initial setting time, final setting time, specific gravity and fineness of OPC were determined by using the standard methods ASTM C187, ASTM C150, IS -2720 and ASTM C184-94, respectively. OPC used for casting of waste mortar blocks, was type-I and 52.5 grade.

Table 1: Mixing composition of ingredients for Solidified Waste Mortar Block (SWMB)

		Fine aggregate (75%)	
Sample No.	Cement (25%)	Sand (%)	Waste (%)
S_1	25	90	10
S_2	25	80	20
S_3	25	70	30
S_4	25	60	40
S_5	25	50	50
S_6	25	40	60
S_7	25	30	70

Mixture preparation: Before performing the waste solidification/stabilization, a mixing composition was formed between the cement and fine aggregate on the basis of unit weight of cement mortar 2080 kg m^{-3} (CEP). The mixing ratio of cement and fine aggregate was used in this research is 1:3. This ratio is commonly used for the mixture of paving block (Primanda and Rahardyan, 2010). Table 1 shows the ingredients mixing composition for S_1-S_7 sample.

Compressive strength: The mixture was compacted, vibrated and molded in a cubical mold of dimensions 5×5×5 cm (Malviya and Chaudhary, 2006). The cubes were unmolded after 24 h and cured in distil water for 3, 7, 14, 21 and 28 days under the average humidity of 93±2% at 25±1°C in the laboratory room. At the curing period, pH of curing water was taken 7.0 constantly by using distil water. Compressive strength of samples were tested by using the method ASTM C109-93. Strength was determined by using the B-ELE, M-ADR 2000KN concrete compression machine. Strength was tested up to the failure point of mortar block.

Leaching test: American Nuclear Society (ANS) 16.1 leaching test was selected as heavy metal extraction procedure from solidified waste mortar block. Heavy metal leaching tests were performed for 28 days with leachate sampling on the 3, 7, 14, 21 and 28 days. The results of the metal leaching tests were recorded in terms of cumulative release in relation to the total availability of waste mass in the samples.

RESULTS AND DISCUSSIONS

Table 2 represents the physical parameters of decomposed solid waste (DSW) and sand samples. Fineness Modulus (FM) of DSW and sand samples were found 2.30 and 2.43, respectively which lies within the range 2.20-2.60 (Singh and Singh, 2008). Water absorption percentage of waste was observed high enough, 6.89% than sand which indicates that the higher water content, the less water is required in the mixing processes (Primanda and Rahardyan, 2010). But moisture content was too much high in waste than sand which was 16.2 and 2.96%, respectively. The specific gravity of grinding waste samples was found lower value than sand, 2.15 which was represented very low value as compared to gravel, sand, silt and clay soil (Bowels, 1997; Haque *et al*., 2013). In addition, dry and bulk density of DSW was observed values less than 1 g cm^{-3} indicating the presence of organics in waste samples (GCREC), whereas sand showed 1.53 g cm^{-3}.

The physical properties of OPC found from laboratory tests are shown in Table 3. OPC used for the laboratory experiments, satisfied the ASTM standard values that ensured as a stabilizing binding material for solidified waste mortar blocks.

Table 2: Physical parameters of decomposed solid waste and sand

	Experimental values (Average±SD)	
Parameter	Solid waste	Sand
Fineness modulus	2.30±0.05	2.43±0.03
Water absorption capacity (%)	6.89±0.75	2.87±0.41
Moisture content (%)	16.2±2.780	2.96±0.33
Specific gravity (%)	2.15±0.06	2.62+0.09
Dry density (g cm^{-3})	0.72±0.04	1.53±0.03
Bulk density (g cm^{-3})	0.83±0.04	1.43±0.74

Table 3: Physical parameters of ordinary portland cement

Parameter	Experimented values (Average±SD)	ASTM standard
Fineness (%)	95.6±0.85	not less than 90%
Consistency limit (%)	27.5±0.55	22-30% by cement weight
Initial setting time (min)	135±6.50	not less than 45 min
Final setting time (min)	265±7.35	not more than 375 min
Specific gravity	3.05±0.05	IS -2720 (3.15)

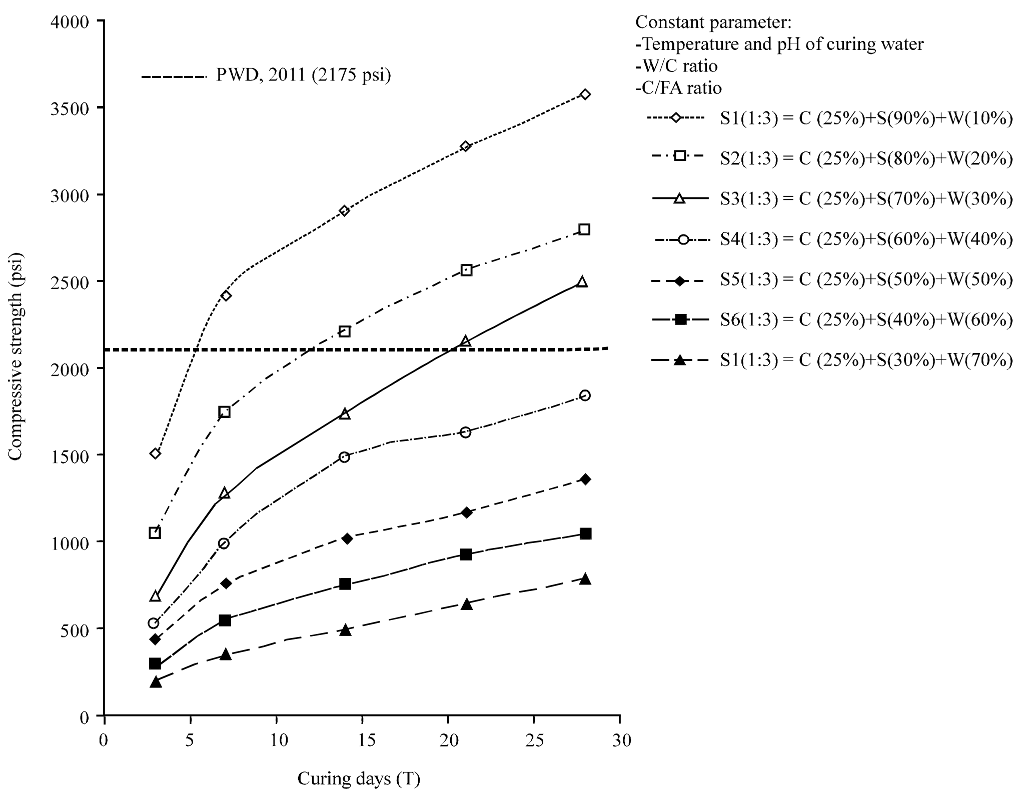

Fig. 1: Compressive strength of SWMB with different ratios of sand and waste

Figure 1 shows the compressive strength behavior of SWMB using a single additive i,e. OPC. This research observed maximum compressive strength 3567 psi at 28 days of curing period obtained for sample S_1 with 25% cement, 90% sand and 10% waste which fulfill the minimum design strength 2175 psi of Public Works Department of Bangladesh standard (PWDB, 2011) for using as paving block. On the contrary, lowest compressive strength 783 psi was obtained for sample S_7 with 25% cement, 30% sand and 70% waste which was too below the standard of PWDB (2011). Similar results have been reported by Primanda and Rahardyan (2010) on solidification of bearing factory solid waste. The study revealed that if the waste quantity increases, compressive strength of SWMB decreases. It was primarily because the solid waste largely organic matter it would deteriorate with time. Organic compounds can also retard the cement setting process by forming a protective layer around the cement grain, thus hindering the hydration (Omar *et al.*, 2008). The study found that sample S_3 (30% waste as substitute of fine aggregate) was the optimum economical mixing composition as containing highest waste and lowest cement content among the sample S_1-S_3 which compressive strength showed 2494 psi (at 28 days of curing) and also fulfill the minimum strength criteria of PWDB (2011) for paving block. Figure 2 to 8 shows the percentage of metals such as Fe, Cu and Ni entrapped (i.e., immobilization) within the solidified matrix with respect to the total availability of metal over 28 days curing period for mixing composition S_1 to S_7. It was seen from the observation that percentage of metal immobilization decreases with increases of waste content than cement. The higher the cement content, the lower the mobility of metal from the matrix bond (Malviya and Chaudhary, 2006).

Fe showed the highest and excellent fixation in the solidified waste mortar matrices, where the percentage ranges from 95-96.59% for S1-S7 mixing composition.

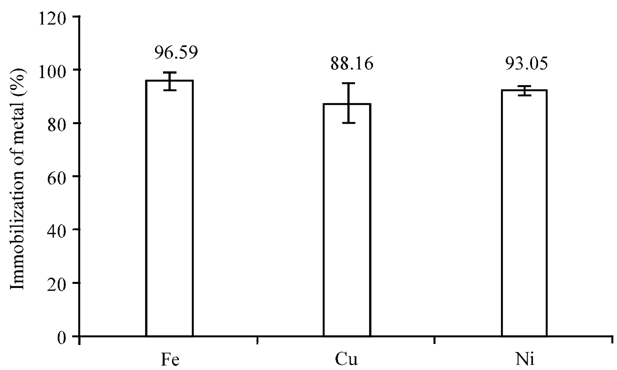

Fig. 2: Immobilization of Fe Cu and Ni in sample S1

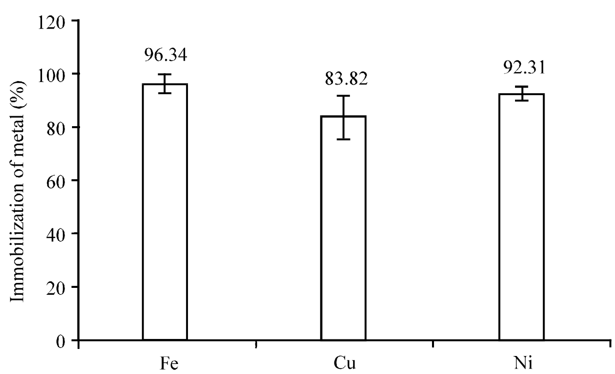

Fig. 3: Immobilization of Fe, Cu and Ni in sample S2

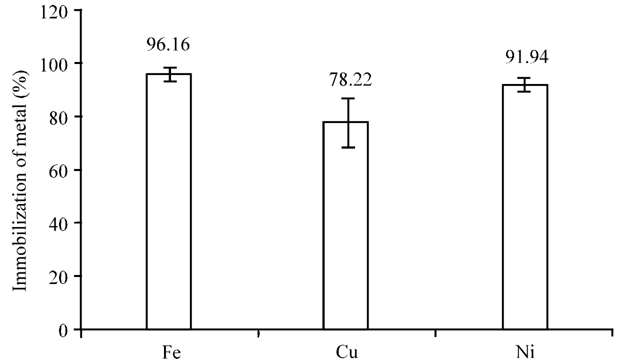

Fig. 4: Immobilization of Fe, Cu and Ni in sample S3

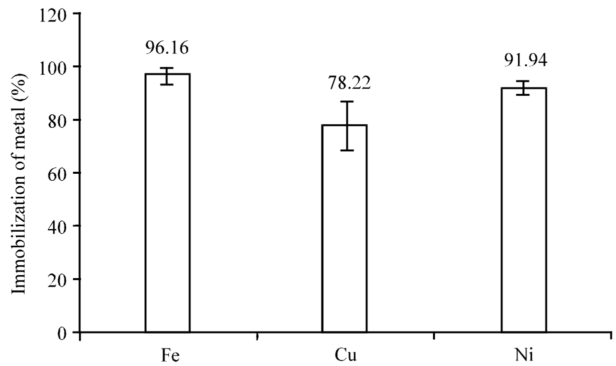

Fig. 5: Immobilization of Fe, Cu and Ni in sample S4

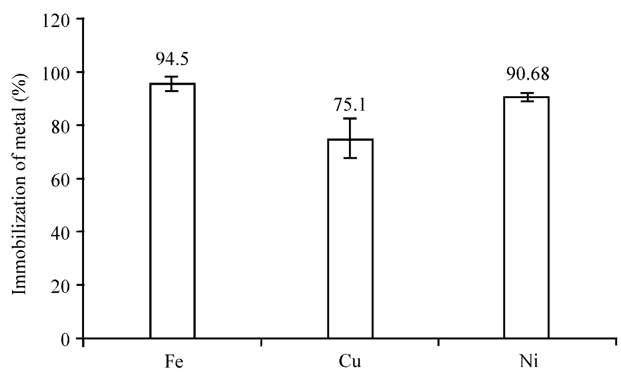

Fig. 6: Immobilization of Fe, Cu and Ni in sample S5

Moreover, lowest immobilization was observed for Cu in the ranges from 72.64-88.16%. Similar results were reported for Zn by Omar *et al.* (2008), percentage of immobilization was ranges from 92.8-95.5% on solidification of petroleum refinery activated sludge.

From this research it is undoubtedly clear that solidification and stabilization technology is very effective to form solid paving materials by using waste as fine aggregate. In addition, release of heavy metals from cement-waste matrix to the environment is greatly reduced. Otherwise, there

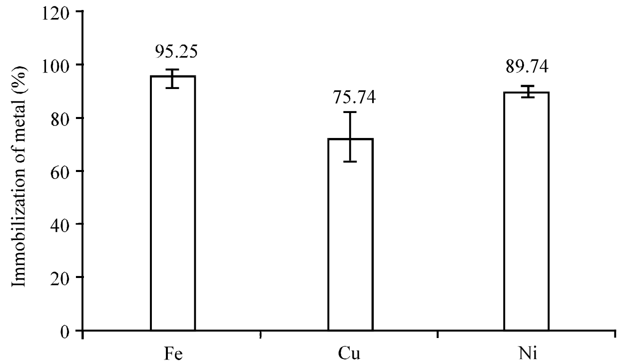

Fig. 7: Immobilization of Fe, Cu and Ni in sample S6

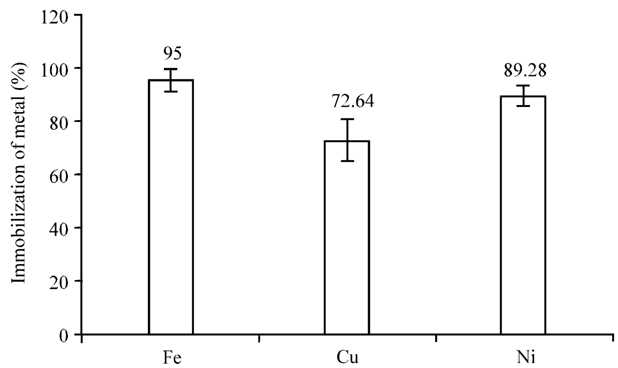

Fig. 8: Immobilization of Fe, Cu and Ni in sample S7

might be a great chance to wash away the heavy metals from landfill waste to the near low land areas and surface water body such as stream, lake, pond, irrigated land, river etc. through leaching from the landfill sites. The entrance of toxic metals to the food chain may prolong adverse impact on human and livestock (Ryskamp, 2010). Stabilization of solid waste is practiced in many countries because this process reduces not only the volume of solid waste at landfill site but also reduce the risk of environmental pollution (Haque *et al*., 2013).

CONCLUSION

In this research, landfill decomposed solid waste was solidified/stabilized by using Oridinary Portland Cement following the requirements of paving block to minimize the solid waste load at landfill sites and scale of heavy metal contamination to the environment around the landfill sites. The study revealed that 30% waste as substitution of total volume of fine aggregate having mix proportion 1:3 (OPC: Fine aggregate), was optimum mixing composition for paving block that satisfied the minimum compressive strength (28 days curing period) requirement of Bangladesh standard. In addition, significant percentage of each tested heavy metals were immobilized within the solidified matrix bond that pose the lower possibility of heavy contamination to the environment. So, solidification/stabilization technology might be a promising solution to reduce the waste load at landfill sites, land reclamation and sustainable waste management. Solidified waste materials cane used as environmental friendly re-usable products in construction purposes.

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