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RESEARCH ARTICLE

GEO-ENGINEERING POTENTIALITY OF ELECTROCOAGULATED METAL HYDROXIDE SLUDGE (EMHS) FROM TEXTILE INDUSTRY AND EMHS AMENDED SOIL FOR USING AS BUILDING MATERIAL

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ABSTRACT

Various types of dyes, polymers, resins, salts and pigments are widely used in the textile industries which influence different properties of Electrocoagulated Metal Hydroxide Sludge (EMHS), generated by Electrocoagulation (EC) technique during wastewater treatment. In this study, geo-engineering properties (moisture content, specific gravity, Atterberg limit (plastic limit, liquid limit, plasticity index, liquidity index) and linear shrinkage) of EMHS from a textile industry and EMHS amended soil were investigated by standard method (British Standard Method 1377) to find the potentiality for using as building material. EMHS contained very high limit of all geo-engineering properties compared to soil. Very high iron content in EMHS, dissociated from anodes used in wastewater treatment, increased the specific gravity. Linear shrinkage showed strong positive correlation with plastic limit, liquid limit and plasticity index. It was found that EMHS can be feasible for making building materials i.e., blocks or bricks, as a substitute of soil for up to 30%. Use of EMHS as building blocks may reduce environmental disposal problem of sludge and initiate sustainable management of sludge in long run.

INTRODUCTION

The textile industry, the flagship of Bangladesh, is the top foreign exchange earning industry of the country. During the last few decades, the growing load of pollution from textile industries is a common problem to sustainable development of environmental system and the community health that menaces the whole of mankind (Rahman *et al.,* 2008). As a mandatory rule set by the government of Bangladesh, every industry must the waste effluent before discharging to the environmental compartments. But these treatment systems produce huge volume of sludge that is residual or semi-solid material in nature. This bulky waste by-product is considered as a nuisance for the industrial units and environment due to its management (Weng *et al.,* 2003; Balasubramania *et al.,* 2006; Baskar *et al.,* 2006). Electrocoagulated Metal Hydroxide Sludge (EMHS) is generated during treatment of industrial wastewater by electrocoagulation (EC) technique that holds variety of metal hydroxide of responding sacrificial anode material dissociated during wastewater treatment of respective industry (Golder *et al.,* 2006**)**. As textile industry use different type of chemicals, salts, dye stuff, resins, polymers and pigments in different stage of its operation, all these substances removed by EC and EMHS also hold them. EMHS tends to be readily settable because it is composed of mainly metallic oxides/hydroxides and can be separated faster by filtration (Mollah *et al.,* 2001**)**. Moreover surface of EMHS may contain dye stuff that are generally attach due to physical absorption of dye by active coagulant of iron or aluminum during removal of dye (Mollah *et al.,* 2010).

In Bangladesh, all types of sludge are disposed in landfill site haphazardly or openly which leads to soil, surface water and groundwater contamination (Thomson *et al.,* 2009). Heavy metal content i.e., Cd, Zn, Cu, Cr, Co, Fe, Pb, Mn, Ni, Hg etc in sludge is a great concern as their non-biodegradable nature, long biological half-lives and their potential to accumulate in different body parts (Manahan, 2005; Chen *et al.,* 2005; Wilson and Pyatt, 2007; Islam *et al.,* 2009). Metal containing sludge application in agricultural land is risky because it can affect food quality and safety (Muchuweti *et al.,* 2006). Therefore, development of new technologies to

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recycle, reuse and convert waste materials into reusable materials is critically important for protection of our environment and to alleviate sludge disposal problem. Sludge may be regarded as a resource which should be recycled in a proper way and sustainable sludge handling method meets requirements of efficient recycling of resources without supply of harmful substances to humans or the environment. A possible long-term solution appears to be recycling of the EMHS sustainably and using it for beneficial purposes through solidification that stabilizes and solidifies components of waste. The solidified product is disposed off to a secure landfill site or it can be recycled and reused as construction materials like bricks, concrete or building blocks if it meets the specific strength requirement (Rahmat, 2001).

The prospective benefits of using sludge as building blocks additives include immobilizing toxic and heavy metal in the fired matrix, oxidizing organic matter and destroying any pathogen during the firing process and reducing the frost damage based on the results of several full or bench scale studies (Tay and Show, 1993; Lin and Weng, 2001; Weng *et al.*, 2003). For this regard, preliminary assessment of geo-engineering properties of EMHS as a raw material for making building materials is necessary. Basic geo-engineering properties include moisture content, specific gravity, Atterberg limit (liquid limit, plastic limit, plasticity index, and liquidity index), linear shrinkage etc. Hence present work was aimed to investigate these geo-engineering properties of EMHS and EMHS amended soil focusing its reuse potentiality as building materials.

MATERIALS AND METHODS

The wet EMHS samples were collected from Adury Knit Composite Ltd. (Geographic Location: $24^{0}02'$ N latitude and $90^{0}44'$ E longitude), Karardi, Narshingdi, Bangladesh. This industry uses iron anode during the treatment of effluents by EC technique. The soil sample was collected from local brick field. The collected samples were stored into separate plastic container and stored at ambient temperature prior to analysis. For geo-engineering properties investigation, 100% EMHS and 100% soil was taken at first, and then EMHS was mixed with soil at 10, 20, 30 and 40% respectively on weight basis. The geo-engineering properties of EMHS, soil and EMHS amended soil were investigated by British Standard (BS) 1377 (1990) as given in Table 1.

RESULTS AND DISCUSSION

Moisture content of the studied soil and EMHS sample was 43.4 and 92.85%, respectively. Moisture content of the composite containing 10, 20, 30 and 40% EMHS with soil was 55.2, 70.3, 73.9 and 77.6%, respectively (Fig 1). The obtained result suggested that with the addition of EMHS with soil, the moisture content of the mixture increased. EMHS was wet in nature and due to adsorption and absorption of water by the body surface, EMHS contained very high moisture content that make it less effective for making building material. But dry condition of EMHS can eliminate the problem. This property has negligible influence on overall building material manufacturing process.

Specific gravity of soil and clay in their natural state depends on their mineral composition, particle size, distribution of components, texture, resulting void ratio and moisture contents. Specific gravity of the sample containing 10, 20, 30, 40% of EMHS in the soil was 2.75, 2.77, 2.80 and 2.82, respectively (Fig 1). EMHS contained more specific gravity than that of soil. The value was found 2.3 to 2.8 in the iron rich clay minerals (Grim, 1960). 1.75 industrial wastewater treatment plant sludge (Weng *et al.*, 2003), 2.32 in common effluent treatment plants sludge (Baskar *et al.*, 2006), 2.4 in textile sludge (Balasubramania *et al.*, 2006), 2.75 in waste gold mill tailings (Roy *et al.*, 2007). In addition of EMHS in soil, specific gravity of the mixture was increased due to presence of very high iron content in EMHS that was dissociated from the anode electrodes made of iron during EC operation in the textile industry. This property has very limited influence in the preparation of any constructional material. Atterberg limit is an important geo-engineering property of soil and sludge. Plastic limit of the soil and EMHS sample was 21.3 and 62%, respectively. As the EMHS was added to the soil, the plastic limit of the mixture was increased. Sample containing 10, 20, 30 and 40% of EMHS in soil showed plastic limit as 29.9, 33.4, 34.3 and 42.1%, respectively (Fig 1). Due to polymeric substances used in the textile industry as well as organic portion of wastewater influenced the plastic nature of EMHS. Lin and Weng (2001) used oven dried sewage sludge ash in different percentage to soil and for 0, 10, 20, 30, 40 and 50% mixture, plastic limit varied as 20.21, 24.08, 26.53, 28.25, 29.26 and 33.71%, respectively. Craig (1990) mentioned that most fine-grained soils exist naturally in the plastic state and the plasticity due to the presence of clay minerals or organic minerals. Sludge used in present study was wet in nature and water also added, so its plastic limit was very high compared to others (Weng *et al.*, 2003). Results reviled that EMHS can be used as a substitute of soil up to 30% for making building materials (Lin and Weng, 2001; Weng *et al.*, 2003; Balasubramania *et al.*, 2006). In dry basis more wet addition with the soil was also possible for making building materials.

EMHS contained very high liquid limit and the value increased when EMHS was introduced in to the soil (Fig 2). When EMHS was added in the soil as 10, 20, 30 and 40% by weight, liquid limit of the mixture was as 55.75, 66.8, 78.30 and 95.5%, respectively. British Standard 1377 (1990) and Head (1992) mentioned that in low plasticity clay the liquid limit is less than 30%, in intermediate plasticity clays, the liquid limit ranges from 30 to 50% and the high plasticity clays, the liquid limit is more than 50%. So the soil that was used in present study was in intermediate plasticity clays. If EMHS was considered as soil, then it was categorizes as high plastic. Liquid limit was found 38% in industrial wastewater treatment plant sludge by Weng *et al.*, (2003) and when this sludge mixed with soil at 10, 20, 30 and 40% on weight basis, the liquid limit varied as 39, 41, 45 and 46%, respectively. Liquid limit as 38.09% was found in sewage sludge by Lin and Weng (2001). Fine soils containing significant amount of organic matter usually have high to extremely high liquid limit (Craig, 1992). Previous study suggested that EMHS as a substitute of soil, by up to 30%, can be effectively used for making different types of building materials such as pavement block, hollow block and brick (Lin and Weng, 2001; Weng *et al.*, 2003; Balasubramania *et al.*, 2006). Extremely high liquid

Table 1. Name, specific method and using formula of geo-engineering properties of samples

Properties		Specific Method	Using Formula
Moisture Content (W)		Oven-drying Method	$W = \frac{m_2 - m_3}{m_3 - m_1} \times 100$ Where, m_1= Mass of container (gm), m_2= Mass of wet sample and container (gm), m_3= Mass of dry sample and container (gm)
Specific Gravity (Gs)		Small Pyknometer Method	$Gs = \frac{m_2 - m_1}{(m_4 - m_1) - (m_3 - m_2)}$ Where, m_1= Mass of the small dry pyknometer (gm), m_2= Mass of the small dry pyknometer and dry soil (gm), m_3= Mass of the small pyknometer, soil and water (gm), m_4= Mass of the small pyknometer and water (gm)
Atterberg Limit	Liquid Limit (LL)	Fall Cone Penetrometer	Relationship between cone penetration and moisture content was plotted in semi-log paper where cone penetration was plotted on log scale. Moisture content corresponding to a cone penetration of 20 mm was taken as the liquid limit of the sample.
	Plastic Limit (PL)	Rolling Thread Method	$PL = \frac{m_2 - m_3}{m_3 - m_1} \times 100$ Where, m_1= Mass of container (gm), m_2 = Mass of thread of sample and container (gm), m_3= Mass of dry thread of sample and container (gm)
	Plasticity Index (PI)		$PI = LL - PL$ Where, LL= Liquid limit (%), PL= Plastic limit (%)
	Liquidity Index (LI)		$LI = \frac{W - PL}{PI}$ Where, W= Moisture content of the sample (%). PL= Plastic limit of the sample (%), PI= Plasticity index of the sample (%)
Linear Shrinkage (LS)		Oven-drying Method	$LS = \frac{L_1 - L_2}{L_1} \times 100$ Where, L_1= Initial length of the sample (cm), L_2= Oven dried length of the sample (cm)

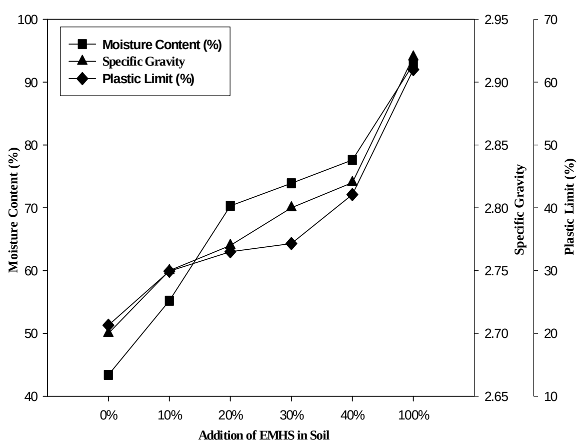

Fig. 1. Moisture content, specific gravity and plastic limit of EMHS and EMHS amended soil

limit value of EMHS may be due to its high moisture content and organic matter. At the same time water was added to the samples that also influenced to very high liquid limit. High load bearing structure cannot be made on this sludge or sludge amended soil. Plasticity index of studied soil was 24.4%. As EMHS contained very high liquid limit and plastic limit values, plasticity index was also high (278%). Sample containing 10, 20, 30 and 40% of EMHS in soil, had a plasticity index of 25.8, 35.4, 44 and 53.4%, respectively (Fig 3). Mitchell (1976) pointed that organic matter may cause high plasticity. Bell (2000) showed that organic clays have high plasticity index, generally range from 17 to 35%. Weng *et al.*, (2003) mixed sewage sludge with soil (plasticity index 18%) at 10, 20, 30 and 40% on weight basis and then found the plasticity index as 17, 16, 15 and 13%, respectively. During wastewater treatment through EC technique polymers were added to aggregate the sludge. This may increase the plastic limit and plasticity index of EMHS. Mixture congaing up to 30% EMHS in soil was in the feasible limit for using as building materials. Liquidity index indicates the nearness of a natural soil to the liquid limit (Lambe and Whitman, 2006). Soil sample and EMHS had a liquidity index of 0.89 and 0.13, respectively. While the value for sample containing 10, 20, 30 and 40% of EMHS in soil was 0.86, 1.04, 0.9 and 0.66, respectively (Fig 3).

Linear shrinkage of the studied soil sample and EMHS was 9.92 and 30.49%, respectively. As the amount of EMHS was increased in the mixture, linear shrinkage also increased (Fig 3). Linear shrinkage for mixture containing 10, 20, 30 and 40% EMHS in soil was 11.4, 12.85, 14.28 and 18.31%, respectively. High linear shrinkage caused for large moisture content and liquid limit of the EMHS. Shrinkage on soil caused by loss of pore water and has enormous damage to structures built on or with clays. Mitchell (1976) mention that the greater the plasticity, the greater the shrinkage on drying. According to Hobbs *et al.*, (1982) clay with linear shrinkage less than 5% are “non-critical”, 5% to 8% are “marginal” and value more than 8% are “critical”. But there are no such regulations for sludge. As EMHS contained high plastic limit, it contained high linear shrinkage. Moreover due to very high liquid limit of EMHS, its linear shrinkage was also high. But, particularly, EMHS amended soil complied with the result to ensure its feasibility for making building materials. The relationship between linear shrinkage and plastic limit was given in Fig 4a. As linear shrinkage increased, the plastic limit of the samples also increased (R^2 = 0.96). So both properties were strongly and positively correlated. Liquid limit and linear shrinkage of the samples was strongly positively correlated (R^2 = 0.94) (Fig 4b). As the plasticity index increased, the liquid limit of the samples was also increased simultaneously

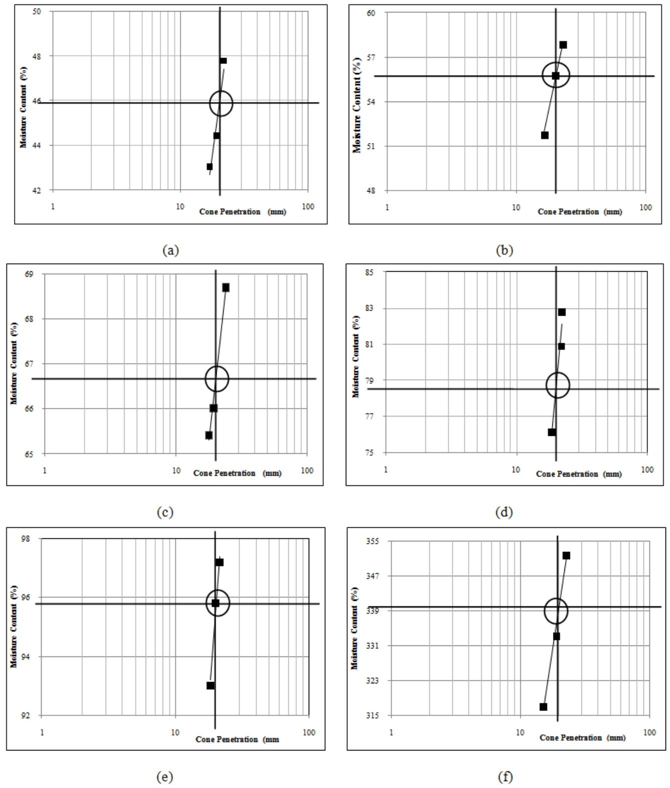

Fig.2. Liquid limit of samples- (a) 100% soil, (b) soil with 10% EMHS, (c) soil with 20% EMHS, (d) soil with 30% EMHS, (e) soil with 40% EMHS and (f) 100% EMHS.

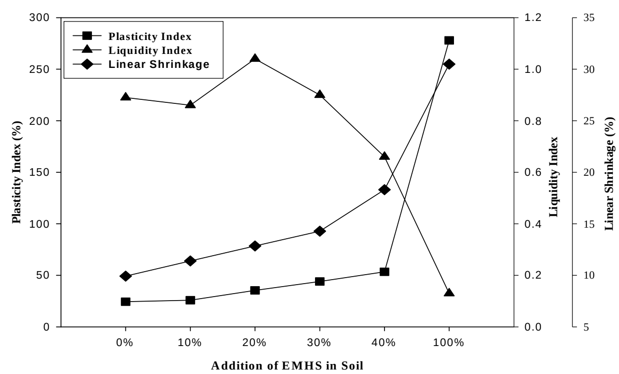

Fig. 3. Plasticity index, liquidity index and linear shrinkage of EMHS and EMHS amended soil

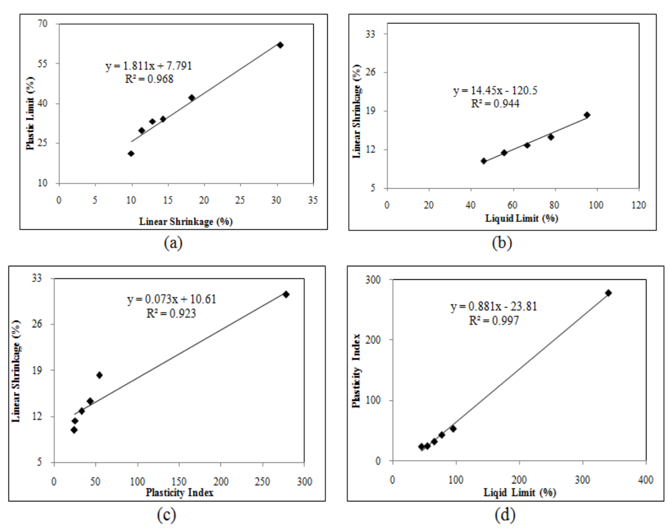

Fig. 4. Relationhip among different geo-engineering properties of the samples- (a) linear shrinkage and plastic limit, (b) liquid limit

(R^2 = 0.97) (Fig 4c). Meanwhile, when the liquid limit of the samples increased, the plasticity index also increased (Fig 4d).

ENVIRONMENTAL SIGNIFICANCE OF THE WORK

There is a common tendency of the industrial unit to discharge their waste sludge in to the different compartment of the environment without prior treatment. This ill attitude can create severe problem on terms of soil, water and air pollution. This study investigated some basic properties of EMHS for assessing its beneficial feasibility for making building material i.e., bricks, blocks and other. Utilization or reuse of EMHS as construction and building materials or building blocks is a win-win strategy because it not only converts the waste materials into useful materials but also alleviates the disposal problem.

CONCLUSION

Some selected geo-engineering properties EMHS from textile industry and EMHS amended soil were investigated in present work. Moisture content, specific gravity, plastic limit, liquidity index and linear shrinkage of the studied EMHS were 92.85%, 2.92, 62%, 0.13 and 30.4%, respectively. EMHS was in high plasticity range and critical in respect of linear shrinkage. Values of all these properties of EMHS were higher than normal soil and other textile and sewage sludge because of the presence of various polymers, resins, chemicals, salts, dyes and other organic materials in EMHS. Iron content from the sacrificial anode also influenced high specific gravity of EMHS. As more EMHS was added in the soil all the properties of the mixture also showed an increasing trend. On the basis of studied properties it can be concluded that such EMHS can be added to soil at up to 30% by weight basis for making constructional material such as bricks, blocks, hallow blocks, pavement tiles etc that may reduce disposal problem and initiate sustainable sludge management in the long run.

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