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Stabilization of Medium Expansive Soils in Pakistan Using Marble Industrial Waste and Bagasse Ash

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Abstract: *This paper reports an investigation of suitability of industrial and agricultural waste (i.e. marble waste and bagasse ash) on the geotechnical properties of medium expansive soils, located across Kohat city, of Khyber Pakhtunkhwa Pakistan. As most part of Pakistan falls in semi-arid zone, the geology and climatic conditions in Kohat produce widespread distribution of swelling clays. Such soils possesses a variety of undesirable characteristics i.e. immensely affect the pavements, boundary walls, slab-on-grade members and other infrastructure. Soil samples were collected, cataloged, subjected to multitude of geotechnical tests and submitted to anti-expansive treatment using prescribed percentages of stabilizers. The investigation includes chemical analysis i.e. X-Ray Diffraction (XRD) Analysis, Scanning Electron Microscopy (SEM), X-Ray Fluorescence (XRF) tests, and evaluation of geotechnical properties such as moisture-density relationships, Atterberg limits, unconfined compressive strength, swell pressure and free swell. When blended with both stabilizer materials, the compatibility and strength characteristics are improved and plasticity is significantly reduced. From the viewpoint of economy, blending of soil using 4-6% bagasse ash and/or 8-10% marble industrial waste is recommended. This paper summarizes the results of identification, characterization and stabilization techniques to eliminate the expansively of swelling soils.*

Keywords: *Expansive soil, Stabilization of soils, XRD, SEM, Marble industrial waste, Bagasse ash*

1. Introduction

"Expansive soils" are also termed as Swelling soils or Active soils or Calamitous soils wherein massive volume changes are experienced due to moisture entry. They are distributed worldwide especially in arid zones (leading to moisture deficiency in soils and rocks) where suitability of clayey minerals formation of smectite group prevails. The swelling of clay mineral is mainly associated with three parameters: geology, the engineering factors of the soil, and local environmental conditions [1,2,3]. Also, the clay mineral has very high adsorptive capacity for water [4]. Swelling soils occur in those regions where repeated periods of rainfall and drought are observed. In Asia, the types of expansive soils in KSA depend upon shale, montmorillonite content and calcareous material and the distribution is function of geology, sedimentation and climate type. Arid climate and severe weathering conditions intensify the presence of such soils [5]. There exist a number of visual indicators which confirm the existence of expansive soils. Such soils are water-sensitive, exhibit low inherent shear strength and are found in different regions across the globe [6]. When subjected to change in moisture, the expansive soils exhibit great change in volume and exert upward pressure on foundations and floor-slabs of various structures. This is due to mineralogical composition of swelling soils which is primarily governed by electric charge on surface of clay mineral, interlayer bonding and cation exchange capacity [7]. The fluctuation of moisture conditions are major cause of disaster may emanate from intense rain, floods and leakages caused in water supply or sewer pipes [1,8]. The distress and damage to infrastructure in Oman is worth-mentioning, which is due to overlooking of problems associated with expansive soils during design and construction phases [3]. The soil characteristics are improved due to cation exchange which is an effective and desirable reaction, and is important indicator of changes in mineralogy of treated soils [4]. The swelling and shrinkage of swelling soils is the response of expansive soils when water gets inside, and therefore lightly loaded structures may encounter settlement and/or heaving [8]. Due to swell pressure the movement of foundations exerts pressure thereby causing cracking of pavements, upheaval and breakup of building foundations, pavements, slopes and linings of the reservoirs as well as channels especially the

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light structures are adversely damaged. The swell pressure ranges from 30 t/m^2 to 150 t/m^2 and heave value is of the order of 10cm to not less than 30cm for expansive soils deposited in a region [3]. The importance of expansive soil can be explained by cost of resulting damages from expansive soils which exceed 10 billion dollars annually in the United States. When SO_4-rich soils are treated using Ca-based stabilizers, it results in 'SO_4-induced heave' due to ettringite formation which is because of reactive nature of SO_4 in soils. Many methods with certain limitations are available in literature to stabilize expansive soils such as using chemical additives, prewetting, moisture control, and thermal methods [10]. Proper design, excavate-and-replace and improving geotechnical properties are three main measures to combat expansive soils, with the third option been focused upon more nowadays by adding various additives such as lime, cement, marble dust, rice husk etc. [8].

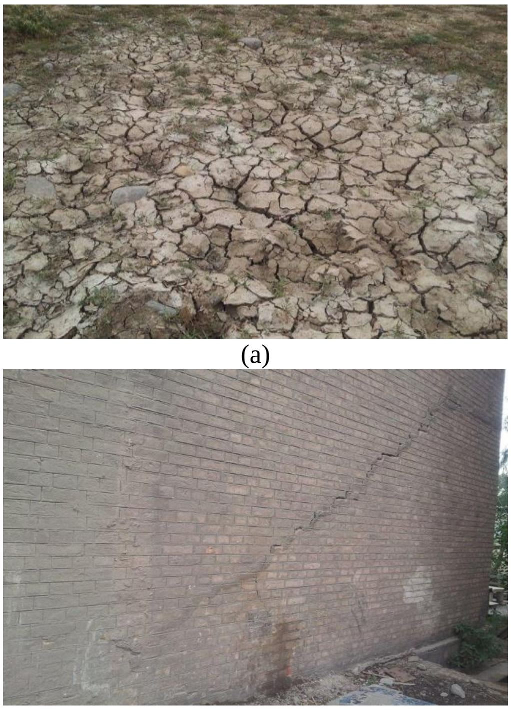
Table 1. *Physical properties of Kohat expansive soil*

Property	Value
Liquid limit, w_L (%)	42.7
Plastic limit, w_P (%)	21.5
Plasticity Index, PI (%)	21.2
Specific gravity, Gs	2.71
Optimum moisture content, w_{opt} (%)	14.9
Maximum dry density, γ_{dmax} (kN/m^3)	18.1
Linear Shrinkage	5%
Shrinkage Ratio	2.13
Particles Sand Silt Clay	 3% 60% 37%
Soil classification	CL or OL

1.1 Literature Review

The engineering characteristics of expansive soils in Pakistan were determined by undertaking research in Punjab and Khyber Pakhtunkhwa provinces of Pakistan (Farooq, 1996). If not effectively stabilized, expansive soils are deemed as one of a potential natural hazard especially to lightly loaded structures and pavements. Many additives like lime (CaO), Ordinary Portland Cement (OPC), fly ash, gypsum, agricultural wastes, industrial wastes, etc. have been used for the stabilization of expansive soils over the past fifty years by a number of researchers [2]. It is found that fly ash, lime, cement and calcium chloride are useful additives and have significantly improved the engineering properties of problematic soils [11]. Qureshi (2006) investigated the effect of lime, OPC and fly ash on the swelling soils of Dera Ismail Khan concluding that lime proved to be more effective stabilizing agent than OPC. Lime is an effective stabilizer of expansive soils that are treacherous in nature due to high potential of volume change [12]. When treated with lime, the properties of clayey materials are changed immediately. As the cohesion is lost and granular nature dominates, there is an overall improvement in mechanical properties of expansive soils [13]. The concepts of special foundations include various piers and moisture barriers are few innovative ways to cater expansive clays [14]. The physiochemical mechanisms involve; cation exchange reaction, Dissociation, Pozzolanic process and cementitious process that mainly governs the soil-lime reactions i.e. improvement in the geotechnical properties. Marble dust was employed in the problematic red tropical soil and significant improvement was observed by Okagbue et al. [8]. In the recent past, a number of researchers have used industrial and agricultural waste material for expansive soil stabilization.

The inevitable use of expansive soil is coupled with their prevalence. Large shrinkage cracks in expansive soils are causing substantial damage to roads, buildings and various underground utilities of Kohat city, as shown in Figure 1 (a and b) below. The varying proportion of Marble industrial waste (MIW) and Bagasse ash (BA) have been used for stabilizing Kohat expansive soils to evaluate effectiveness or otherwise in improving plasticity, compactability, swell potential and strength characteristics. These stabilizer materials are economical and locally available. X-Ray Fluorescence (XRF) tests revealed the chemical composition of both the stabilizer materials. The chief reasons for selecting these materials are that MIW has high CaO content making it suitable to be used in accordance with the most common and traditional stabilizer i.e. Lime. The high mineral content renders it suitable to be used as stabilizer. BA, on the other hand, is pozzolanic in nature and may be used to modify SO_4- rich expansive soil as well. Using these two modifiers, the combination treatments are not studied keeping in view the need of analyzing and covering the isolated effects of stabilizer materials on geotechnical properties in detail and curtailing perplexity of the scope of work [10]. The dual aim was to improve properties of expansive soil and reduce environmental problems currently being encountered. From the standpoint of diminishing the tendency of swelling or shrinkage and to ameliorate the mechanical properties, the stabilization of swelling soils is considered [1]. It is indicated from literature that there are minimal research studies available on stabilizing expansive clays in Kohat. This research is carried out to add to the literature in the same area. On the basis of stated evidences and need for research work, a detailed study was therefore undertaken.



(a)

(b)

Figure 1. *Indicators of Expansive soil in Kohat: (a) Dessication cracks; (b) Wall diagonally cracked*

2. Experimental Investigations

2.1 Research Materials

For this study the soil sample was obtained from sites in Kohat, a small city of Khyber Pakhtoonkhwa. It lies at an altitude of 489 meters from mean sea level. Most of the region is mountainous and is comprised of series of hills. Geotechnical properties of Kohat Expansive soil from Army base camp site (being the worst of two sites that were selected for this study) was collected from an excavated trench (5'x 5'x 5'), tested and analyzed in the Laboratory. The clay samples exhibited milky mottled to light brown color. The Marble Industrial waste (MIW) chosen for this study was obtained from Kainat marble factory situated on Warsak Road, Peshawar. The Sugar-cane bagasse (from sugar refining industry) is usually a waste product which is fibrous in nature, and containing an amount of ethanol vapor in it. Bagasse ash, an industrial by-product of quarries, was obtained from Khazana Sugar Mills, Peshawar.

The X-Ray Fluorescence test was conducted on both samples and the results are summarized in Table 2 and Table 3.

These waste materials are an environmental burden and therefore need to be safely and effectively handled. Using the Los Angeles abrasion machine bagasse in crude form was grinded into powder form. The lumps of marble waste were dried and then pulverized into powder form using wooden pestle. These were oven-dried, passed from Sieve # 40 and sealed in polythene bags to avoid entry of moisture.

Table 2. *Chemical composition of MIW*

CaO	SiO_2	MgO	Na_2O	Al_2O_3	Fe_2O_3	TiO_2	K_2O	MnO	L.O.I*
53.75%	0.95%	0.76%	0.64%	0.16%	0.15%	0.05%	0.04%	0.04%	43.40%

Table 3. *Chemical composition of BA*

SiO_2	CaO	Al_2O_3	Fe_2O_3	MgO	K_2O	Na_2O	TiO_2	MnO	L.O.I*
47.87%	11.69%	10.02%	5.65%	2.76%	2.59%	2.36%	0.78%	0.10%	16.08%

*L.O.I = Loss on Ignition

1.2. Testing methods

To control the harmful effects of expansive soils, different methods are available in literature and selection of a specific method is function of economy and time [7]. The testing program was tailored to evaluate engineering and swelling characteristics of raw and treated expansive soil such as Grain size distribution, specific gravity, pH, Atterberg's limits [20], compaction characteristics, unconfined compressive strength [22], free swell and swell pressure. The design dosage level for MIW and BA was 2, 4, 6, 8 and 10% by weight, in order to study the effectiveness of stabilizers. Powdered MIW and BA were separately added in soil and thoroughly mixed for ten minutes in order to achieve a uniform mix [12]. The level of treatment of the stabilizer materials has been selected using previous research studies carried out. In order to get representative samples for test, quartering was done by dividing Kohat soil heap into 4 equal parts and the MIW and BA was blended with each portion [8]. All experiments were carried out in respective laboratories as per documented ASTM Standards.

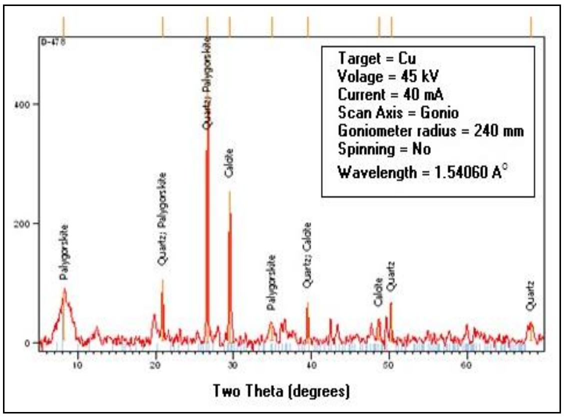


Figure 2. *Diffracting peak patterns of X-rays from planes of minerals in plain expansive soil*

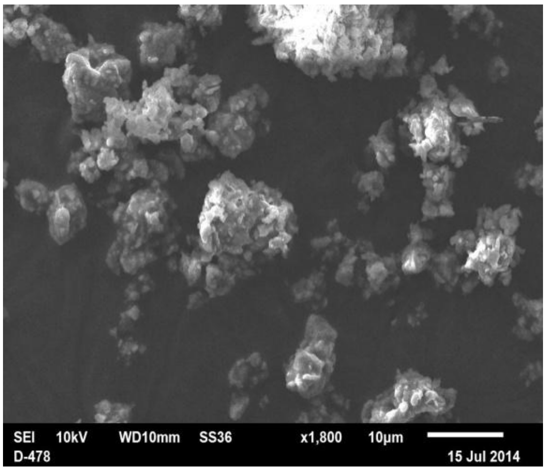


Figure 3. *SEM micrographs for untreated Kohat expansive soil (in-plane)*

3. Experimental Analyses

3.1 Effect on the consistency limits

The Figure 4 shows the effect of MIW and BA treatment on the plasticity index of natural and treated Kohat soils. In this context, it is illustrated that the reduction in Plasticity index (P.I) is due to significant reduction in liquid limits and gentle lowering of plastic limits [17]. The reduction in P.I is due to increase in PL whereas the LL may increase or decrease and is dependent on soil type. In case of MIW-treatment, the LL decreases whereas the increase in PL is high enough, so that over all P.I values decrease constantly. It is due cation exchange which causes flocculation and subsequently reduces the double layer thickness around clay particles [10].

The linear shrinkage also indicates decreasing trend. This is explained by coating of clay particles by MIW particles, thereby flocculating the particles. Clay matrix is filled up whereas voids and amount of water is reduced that renders the clayey soil workable [8]. It can be observed that due to high plasticity of Kohat soil, the effect of BA is comparatively milder which may be attributed to smaller particle size, larger SSA thereby making clay minerals more prone to attack by Lime [4]. A similar trend is observed for Arlington clay (LL=47%) when treated with flyash as has been recorded in case of BA treatment [10]. The effect of addition of two to four percent lime brings about an insignificant change in the P.I value [12]. The Shrinkage limit decreased initially, and then started increasing when MIW percentage exceeded 6%. In addition, it can be observed that marble industrial waste and bagasse ash cause reduction in P.I values of the soil. In general, 8 – 10% MIW and 4 – 6% BA illustrates the optimum amount to decrease the P.I value. This reduction in P.I is indicator of soil improvement [9,13,17]. The result is consistent with other researchers who have utilized similar additives for modifying geotechnical properties of high plastic clays.

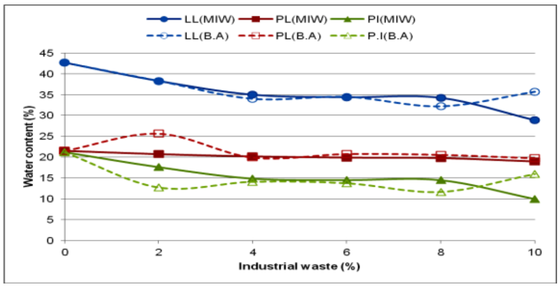


Figure 4. *Variation of consistency limits: (a) MIW-treated soil; (b) BA-treated soil*

3.2 Effect on Compactability

The effect of MIW addition and BA on the compaction characteristics is shown in Figure 5. It is depicted that by using MIW the Maximum Dry Density (MDD) increases upto addition of 4% content and then diminish as dosage is increased. In case of BA, it can be observed the MDD reaches its peak at 6% addition, because the density of BA is more than expansive clayey material [8], and then starts lowering down on further addition of BA content. The shifting of compaction curve to the right and upward illustrates soil stabilization at higher water contents [14]. Exceeding the dosage from optimum amounts increases the OMC which can be associated with presence of additional water particles held in soil structure and higher water absorption by BA and MIW. The net increase in OMC by addition of BA is due to reaction taking place between clay minerals and "CaO" content and for cation exchange reaction to continue more water would be required for mobilizing Ca^{+2} [8]. Upon addition of 8% and 10% lime, i.e. having high CaO content (resembling MIW in this study), in Kashmore expansive clay, the OMC increased from 14.75% value of un-treated expansive soil to 16.5% and 18% respectively; and MDD decreased from 1.89 Mg/m^3 to 1.78 and 1.66 Mg/m^3, respectively. The higher value is due to increased compaction energy (Modified Proctor Test) [12]. The cause of reduction is probably due to particle size and G_s of expansive soil as well as the stabilizer materials. This increase in MDD corresponds to improvement of expansive soil. Also, the reduction in MDD illustrates that in order to attain its MDD it will require low compactive energy [17]. On sites, the swelling soil is not to be compacted more than what is specified in order to achieve more dry density because generally the soil is compacted at 90 – 95% of the MDD.

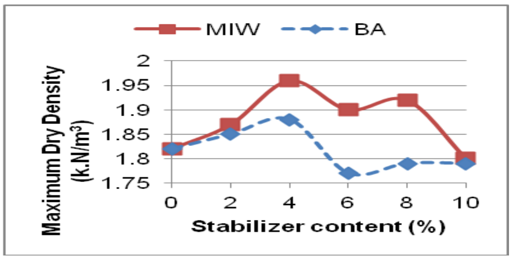


Figure 5. *Variation of compaction characteristics: (a) Maximum dry density*

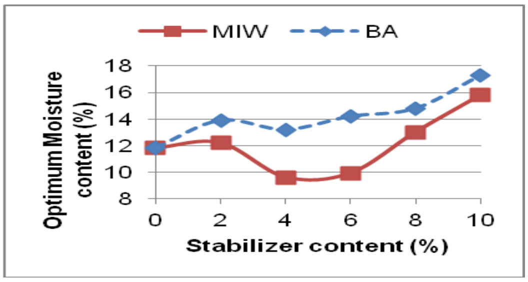


Figure 5. *Variation of compaction characteristics: (b) Optimum moisture content*

3.3 Effect on Swell Potential

Figure 6 shows the swell potential results which indicate that the volumetric free swell of Kohat soil is 75%. At 2% MIW and BA the free swell value is dropped, reaching about 3/4th of the untreated soil. With 8% MIW treatment, the Free swell value decreases to 5% and with 7% BA treatment , the Free swell of this soil lowers down to 7%. The results are in line with the findings obtained from Atterberg's limits. The recommended optimum percentage of lime is 6 – 10% by weight which effectively reduces shrinkage of highly plastic clays. The deep hairline shrinkage cracks vanished in samples treated with 10% lime content. It is also efficacious in decreasing the permeability upto as high as six folds. The MIW contents of more than 10% produce an insignificant increase in compressive strength of the soil [12]. The addition of 6% lime reduce free swell and swell pressure to almost zero value [3]. With further addition of both MIW and BA, an increase in the Free swell values is obtained. This is explained by the high percentages of stabilizer materials addition into the soil. The Kohat soil is less susceptible to lime attack and therefore it acts as fine material when dosage of stabilizer exceeds the optimum and ultimately causes soil to swell [4]. It is also because of increase in permeability of soil due to which moisture is uniformly distributed on compacted soil and reduced unit weight of stabilizer material than Kohat expansive soil, which increase the free swell [10]. At low percentages of stabilizer materials, a higher increase was recorded in swell potential [14]. The G_s of MIW is less than that of BA, therefore the volume of MIW added is higher and MIW-soil mixture workability lowers down at decreased stabilizer content than workability of BA-soil mixture [2].

It can be seen in Figure 6 that swell pressure values of untreated Kohat soil is 192 kPa. It is indicated from test results that swell pressure decreases significantly with addition of stabilizer material. The force generated due to swelling is function of cross-sectional area of sample and not the thickness. Therefore, the time required to wet top portion of 19mm sample is less and that causes rapid stress development which ultimately intensifies the amount of damages caused in rigid structures. Wetting of entire layer is thus necessary for swelling stress to develop [5]. The pozzolanic reaction that forms cementitious products governs the reduction in free swell and subsequent lowering down of swell pressure values. It is also evident that clay particles are amassed by cementation and play a major role in controlling increase in volume of clayey soil upon swelling. This is also explained by decrease of CEC value when the stabilizer material percentage is increased, and that basically is due to formation of new phases. MIW and BA treatment causes the clay particles to become flocculated i.e. more granular, thus decreasing the surface activity and therefore lesser water-adsorptive capacity.

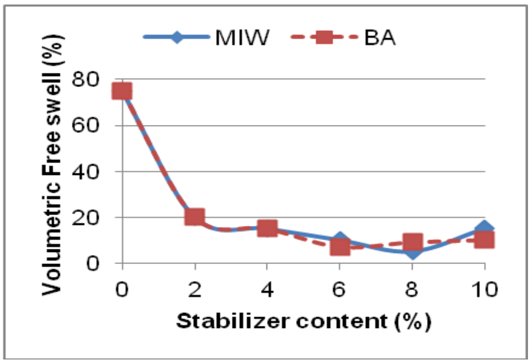


Figure 6. *Swell potential results: (a) Volumetric free swell*

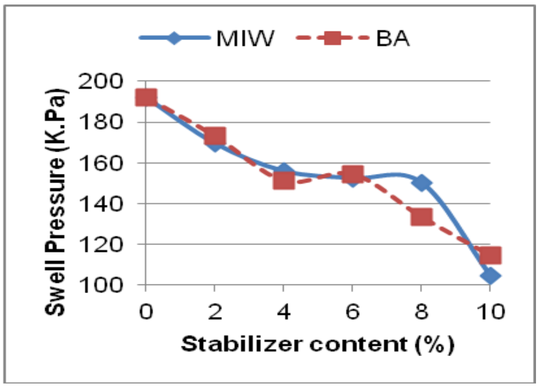


Figure 6. *Swell potential results: (b) Swell Pressure*

3.4 Effect on Compressive Strength

The unconfined compressive strength of untreated and treated specimens, using MIW and BA, was studied at prescribed percentages at interval of 3, 7, 14 and 28 days, as shown in Figure 7. It is interesting to note that by the third day the simple compressive strengths, in case of both the stabilizers, show significant increase with passage of specified time intervals. Comparatively, MIW is efficacious additive for enhancing the unconfined compressive strength of tested soils. The optimum MIW content can be observed as 10%. It is probably due to soil-lime reaction that an increase of 300% and 154% in the unconfined strength is recorded at 3 days and 7 days respectively.

In contrast with BA-soil mixtures, the maximum increase in strength at 7 days is observed to be 46%

when treated with 4% BA content. The increase in unconfined strength i.e. effectiveness of BA at 14 and 28 days is insignificant. This slight increase is due to lack of cementitious properties in BA as presented in Table 3. Considering the findings, it is also observed that with 5% bagasse ash treatment, maximum values of UCS i.e. 3.20 kg/m^2 (KPa), 9.88 kg/m^2, 12.33 kg/m^2, 17.30 kg/m^2 are recorded for 3, 7, 14, and 28 days, respectively as shown in Figure 8(b).

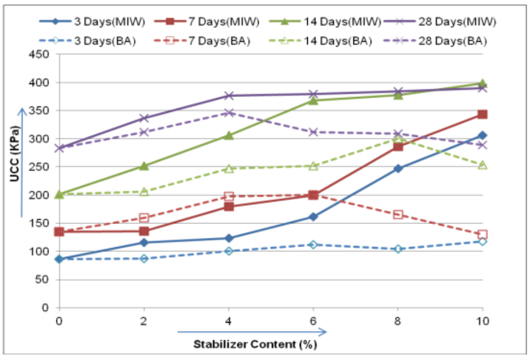


Figure 7. *Effect on unconfined compressive strength: (a) MIW treatment; (b) BA treatment*

4. Conclusions

This paper evaluated the effect of Marble Industrial Waste and Bagasse Ash on the swelling potential of Kohat soil. In this study, the potential expansive soil was identified using laboratory tests, characterized as medium to high swell potential expansive soil and stabilized using locally available industrial and agricultural waste material. The XRD results on Kohat Expansive soil revealed the presence of Polygorskite, also known as Attapulgite (Phyllosilicate category), belonging to smectite group which give it the expansion character. The effect of Marble Industrial Waste (MIW) and Bagasse Ash (BA) on Atterberg's limits, compaction characteristics, swell parameters and unconfined compressive strength (at 3, 7, 14 and 28 days) were investigated and the optimum content was determined for each case. Since a detailed study was required for each modifier to study the effect on swelling soil so no comparisons were made to compare MIW and BA stabilizers.

The conclusions drawn from this research study on the basis of overall results and can be summarized as:

- Marble Industrial Waste (MIW) and Bagasse Ash (BA) reduce the plasticity and ameliorate the texture of expansive soils. MIW-treated soils show considerable reduction. On the A-line chart, the Kohat soil crossed from the clayey region to silty [4]. The extent of diagonal cracking of walls, pronounced desiccation cracks, upheaving and/or cracking of floors and sidewalks indicated the presence of expansive soils in the region.
- The zone of seasonal moisture variation for Kohat expansive soils was found to have an average value of 9.1 feet. This is also known as Active zone depth, and here the expansion due to entry of moisture is intensive in nature. This is a very useful parameter when dealing with design of foundations resting on expansive soils. These soils shall be essentially stabilized till this depth before carrying out constructional work.
- The MIW improves the expansivity nature and render clayey soil workable by coating and binding clay fragments, filling void spaces in between them making soil aggregated which in turn alter the clay minerals effect and thus reducing absorption.
- The MDD of expansive soils is significantly increased with addition of MIW content upto 4% whereas the increase in MDD of BA-treated soil is comparatively lesser reaching its peak value upon 5% addition of BA and then showing similar dropping trend as observed in case of MIW-treated soils. On the same lines, the OMC first decrease till addition of optimum stabilizer content and then start rising as content percentage increases. Based on the results of compaction tests, the addition of 4% marble waste the MDD is observed to have increased by 7.6% as compared for untreated soil. The optimum percentage of bagasse ash is 5% brought an increase of 3.3% in MDD of the untreated soil.
- For soil treated with marble waste the unconfined compressive strength increased with the passage of time, from 3 days to 28 days. The addition of 8% and more MIW enhanced maximum early unconfined strengths thereby decreasing the swell potential. The UCS is rapid and simple to perform but it is not reliable testing method of strength of expansive soils as there is no confinement while testing saturated sample. In contrast, the UCS of unsaturated samples results in misleading values [12]. This increase in strength is attributed to cementitious behaviour of MIW and pozzolanic reaction with expansive soil particles [10]. The unconfined compressive strength had maximum average values at 3, 7, 14 and 28 days when 5% BA was added for treatment, a similar trend was indicated as in case of MIW treatment. The percentage increase in UCS of MIW-treated soils is several times more than BA-treated soils.
- The experimental results indicated that expansion of soil is controlled effectively when 10% marble waste and 7% bagasse ash were mixed with soil separately. The swell pressure lowered with increase of marble waste and bagasse ash (upto 10%) respectively. In general, 8–10% MIW and 4-6% BA show the optimum amount to reduce the PI, decrease volumetric shrinkage, increase the unconfined strength, decrease in swell potential indicate an obvious improvement. It alludes the availability of inexpensive sources of high quality expansive soil stabilizing materials. 3% lime has been declared as optimum by many researchers. The results when compared with present study imply that in order to modify the soil as when lime

is utilized more than triple amount of MIW is needed. A low CaO content has higher rate of attaining strength than higher lime content [3,8].

- Both MIW and BA can potentially stabilize the expansive soil, either solely or mixed with each other. This is beneficial in reducing construction cost and providing an environmental friendly disposal of industrial and agro-industry waste product, especially in countries like Pakistan which is on the road to development [17].

Being considerably less expensive and available in huge quantities, utilization of these waste products as stabilizing material for expansive soil seems to be one of the many visible answers for their safe disposal thereby achieving significant environmental benefits, cost saving in construction projects, reducing land, and water pollution and is obviously a positive welcome development as their use will reduce environmental hazards. BA alone will not achieve comprehensive modification and hence is to be used along with other chemical additives for treating expansive clays [4].

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