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ENHANCING TENSILE STRENGTH IN CLAYS USING POLYPROPYLENE FIBERS

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ABSTRACT: The geotextile industry research and development is growing at a fast rate and new products of variable specifications are now available for earthworks and design engineers. The polypropylene fiber material is non-biodegradable which can stand aggressive chemical exposure when placed along with soil media. This research is conducted on a polypropylene fiber reinforced soil treated with chemical admixture in order to study the interlocking mechanism and to study the extent of improvement on their tensile behaviour. Locally available plastic clay was selected for this investigation. The extent of improvement by the polypropylene fibres inclusion on the tensile behaviour was evaluated by carrying out a series of Brazilian tensile strength tests. The dominant mechanism responsible for the increase in tensile strength properties has been proposed. The effect of various geotechnical parameters like grain size distribution, density and moisture content on the tensile strength improvement has been discussed. The study shows that the addition of polypropylene fibers alone to highly plastic clay will not suffice the tensile strength requirements. The polypropylene fibers when added with lime of 6% can improve the tensile strength by further 13 to 28% depending on the dose or fiber content.

Keywords: Clay, Crack, Lime, Expansive soil, Polypropylene fiber, Brazilian tensile strength,

1. INTRODUCTION

The clay or intact soil material remains intact when a sufficient cohesive or attraction force is holding the grains together. The material is disintegrated when this force is not sufficient to hold the grains particularly when the material is subjected to pull, bending or even temperature gradient. This study is performed to measure the tensile strength of polypropylene fiber reinforced highly plastic clay before and after treating it with lime.

The idea of computing tensile test strength indirectly goes back to 1943 as quoted by Li and Wong [1]. Tensile strength of compacted clays has been the subject matter of interest since the seventies of the twentieth century. Fang and Fernandez [2] presented a method for measuring tensile strength of soils. This test became popular and many versions were later introduced to measure the tensile strength indirectly [3]. The procedure is standardized by the ASTM D3967-08 [4] and suggested by the International Society for Rock Mechanics in 1981[5]. It is either carried out as direct measurement of tension or indirectly by calculating bending stresses. This study considered flattened Brazilian test similar to the approach of Agaiby [6]. Introduction of fibers to soil mixtures and clay is an ancient technique used to enhance the adhesion and erosion resistance properties. Natural fibers or organic straw material derived from dried plants or grasses can provide more tensile strength by bonding clay lumps or clay particles with additional link. The natural organic material is not expected to hold strong for extended periods. Adding polypropylene fibers is thought to be of advantage due to uniformity and better control. Freilich et al. [7] provided evidence that clays reinforced with fibers can have reduced crack sizes and reduced crack depths but it did show that the number of surficial cracks increase. The polypropylene fibers manufactured as an additive to concrete is too smooth to be easily bonded to clay particles. Considering the addition of a cementing agent in the form of lime is supposed to overcome this problem.

2. MATERIAL AND METHODS

Clay material from Al-Qatif town located in the Eastern province of Saudi Arabia was used in this study. Al Qatif clay is classified as highly plastic clay (CH) in accordance with ASTM D2487 [8]. This clay is well known for its aggressive swell and shrinkage properties [9-11]. Several research studies were performed to characterize and evaluate this type of clay [8-10]. The standard proctor maximum dry density is measured at 11.5 to 12 kN/m^3 [12]. The optimum moisture content is reported as 30 to 32%. Al Qatif clay indicated liquid limit of 130 to 150 with plasticity index in the order of 60 to 70 [9-12] and exhibits relatively higher swell phenomena and is sensitive to direction of sampling [13]. Analytical grade 'lime' in the form of 'Calcium Hydroxide', supplied by Winlab Chemicals, UK, has been used in this study.

The polypropylene material used in this study is 12mm in length and were obtained from Propex operating company, LLC, United Kingdom. This fiber is fine monofilament with a melting point of 162 º C (324 ºF) and ignition point of 593º C (1100º F). The material is of low electrical and thermal conductivity. The specific gravity is in the order of 0.91. The guidelines as specified in ASTM D 3967 [4] were followed. Each and every sample was carefully prepared in a mold of inner dimension of 50 mm and 100 mm in length. In order to have a uniform density static compaction was adopted using two piston rods; one at the top and bottom. The samples were prepared at dry density of 12 kN/m^3 and were kept for 7 days curing at constant humidity conditions (maintaining a relative humidity of 95%). Samples were loaded through a spacer applying load through a flat surface. The machine is equipped with a calibrated proving ring and displacement dial gauge. Failure tensile strength T is calculated using the following formula:

$$T = 2P/ \pi DL \qquad (1)$$

Where
P = applied load
D = diameter of the specimen
L = length of the specimen

3. EXPERIMENTAL PROGRAM

The investigation program included two sets of samples prepared in cylindrical moulds in order to assess the influence of fibers in reinforcing the clay. One set was Al-Qatif clay reinforced with fibers using three different dosages i.e., 600, 900 and 1200 gm added based on dry weight of clay. For the second set it included addition of 6% lime for the same dosages.

The tensile strength of clay is extremely low and hardly taken into account in practice. It is widely variable and dependant on the structure, state of packing and soil suction. As discussed in earlier sections, the mixture was proportioned and prepared as a homogeneous mix and then statically compacted in a cylindrical mould of 5 cm diameter and 10 cm length. The two sets of samples were left to cure for 7 days period under controlled humidity conditions. Each mix was prepared in two samples and the results were reported as an average value. In order to view the profile of stress strain relationship of fiber reinforced clay, the tensile strength was recorded at fixed intervals and the strain rate was maintained at 0.3 mm/min.

4. RESULTS AND DISCUSSIONS

The test results indicated that adding fibers without a cementing agent is unlikely to enhance any tensile strength to the clay material. The tensile strength reported for clays without fiber reinforcement was 54.4 kPa (Fig. 1). The addition of fiber alone to clay had a detrimental effect on the tensile strength enhancement at 600 gm/m^3. These values further reduced at 900 gm/m^3 dosage but however, slight increase is seen at 1200 gm/m^3 as seen from Fig. 1. This increase is attributed to increased fiber addition which act as continuous elements in a given sample. Up on addition of lime the tensile strength increased considerably. The addition of fibers with lime improved the tensile strength by 13 to 28%. This study suggests that the use of fibers without a cementing agent is of little or no benefit to highly clays in general and more so for highly plastic clays like Al-Qatif in particular (Table 1).

Observations on modes of failures indicate ductile behavior which is facilitated by the fibers as seen from Fig. 2. Failure plains started close to the edges before the major splitting failure plain is developed at the central zone of the sample (Fig's 3 to 6). The tensile stress increased monotonically with the increase in displacement before the tensile strength i.e., the peak tensile stress reached. The load application angle determines the location of crack initiation [14]. A typical splitting profile for fiber reinforced clay in the absence of lime is shown in Table 2.

Edge cracks are sometimes referred to as wing cracks in the literature and claimed that they normally stop when the central cracks are initiated [14-15]. The bond between fibers and the clay is dependent on the geometry of clay particles, grain size distribution, void ratio and state of compaction [15]. The influence of these parameters can be judged theoretically based on contact areas between fibers and clay particles. Further, at higher loads the resultant interfacial shear resistance is contributed by both the bonding strength developed due to the addition of lime as well as frictional component due to the addition of fiber which effectively restricts the movement of fibers in soil matrix and keep them intact. Similar observations were observed by Tang et al. [15].

Table 1 Splitting Tensile Strength (kPa) for Fiber Reinforced Clay

Fiber amount gm/m^3	0% Lime	6% Lime
0	54.43	133.43
600	54.06	150.46
900	53.37	165.87
1200	56.59	171.16

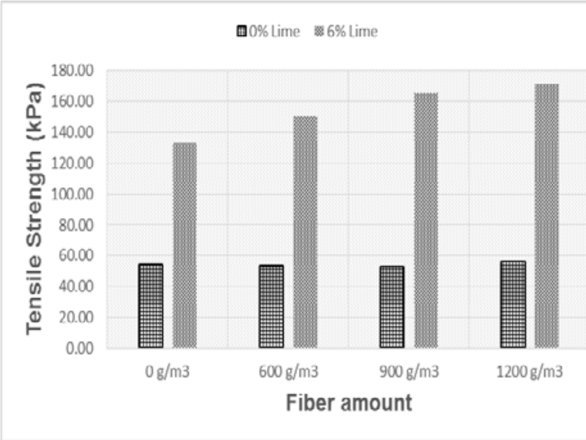

Fig 1. Tensile strength of fiber reinforced clays before and after lime treatment.

Table 2. Splitting tensile strength profile for fiber reinforced clay with 900 gm per cubic meter.

Deformation Dial Reading	Load Dial Reading	Displacement (mm)	Applied Loading (N)	Splitting Strength (kPa)
0	0	0	0.00	0.00
20	6.2	0.2	44.81	5.71
40	12	0.4	86.73	11.04
60	18	0.6	130.10	16.56
80	22.5	0.8	162.62	20.71
100	27.5	1	198.76	25.31
120	34	1.2	245.74	31.29
140	40.5	1.4	292.71	37.27
160	45.5	1.6	328.85	41.87
180	49.5	1.8	357.76	45.55
200	51.3	2	370.77	47.21
220	53.8	2.2	388.84	49.51
240	54.5	2.4	393.90	50.15
260	55.8	2.6	403.29	51.35
280	56.5	2.8	408.35	51.99
300	58	3	419.20	53.37
320	57	3.2	411.97	52.45
330	57	3.3	411.97	52.45
340	56.5	3.4	408.35	51.99

Strain rate is 0.3 mm/min. Deformation Dial: 1 unit = 0.01 mm; Proving Ring Load Dial: 1 unit = 0.737 Kg.

Finally, it can be seen that, the tensile strength of fiber reinforced soil is dependent on two factors which include the tensile strength of natural soil as well as the tensile reinforcement benefit derived from fiber inclusion in the presence of lime. With increase in fiber dosage, the stress-strain profile revealed that the residual stresses increased along with increase in peak stress intensity (Table 1). This will effectively arrest the desiccation cracking occurring due to reduction of plasticity up on addition of lime [16].

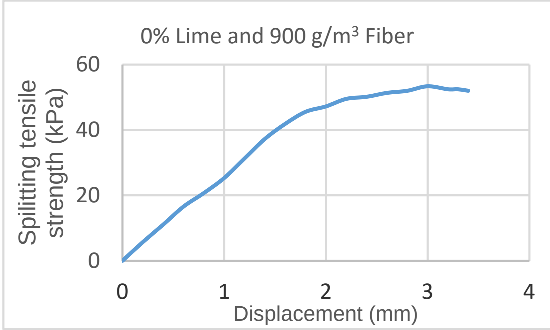

Fig. 2 Profile of splitting tensile strength of fiber reinforced clay

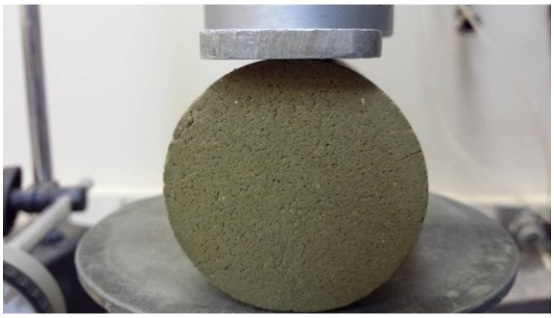

Fig. 3 Failure planes starting at the edges of the sample

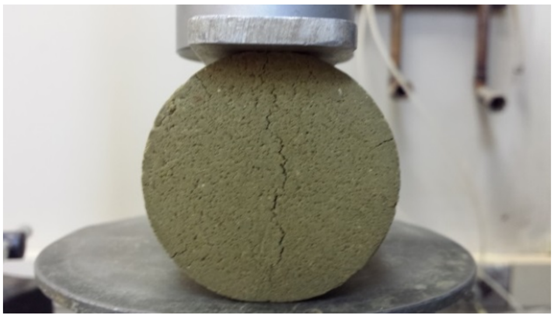

Fig. 4 Prominent splitting area starts centrally

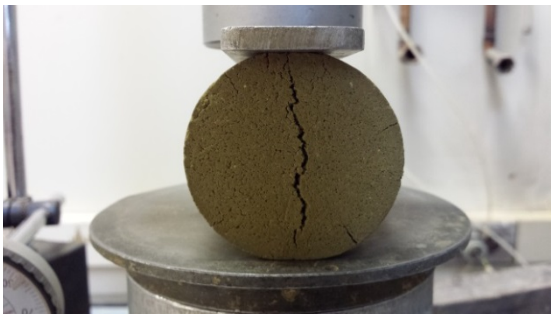

Fig. 5 Progressive splitting area centrally

Fig. 6 Failure state reached

The moisture content also play a major role as it is related to the level of compaction since the water trapped in intra-aggregate pores affects the particle surface forces which in-turn significantly affects the soil water characteristic behavior [13, 17]. The capillary forces are once again heavily controlled by inter-aggregate pore water which even dictates the rate of gain of strength for lime treated soils [9]. In this study, it is found that the addition of fiber significantly affects the number and size of available pores in the clayey soil which significantly affects the tensile strength behavior.

5. CONCLUSION

The study shows that the addition of polypropylene fibers alone to highly plastic clay will not suffice the tensile strength requirements. The bond between the fibers and clay cannot be established without considering a cementing agent. Up on addition of lime, the tensile strength capacity of fiber-reinforced soil increased by more than 100%. The polypropylene fibers when added with lime of 6% can improve the tensile strength by further by 13 to 28% depending on the dose or fiber content. Further, the addition of fiber, imparts ductile characteristics and this can have significant applications where large deformation are expected beyond the elastic or semi-elastic zone. Further, for the soil under consideration, a linear relationship exists between the tensile strength increment at each fiber dosage increment and it can be used to predict the rate of gain of tensile strength at other dosages. The cracking phenomena in the tested samples revealed that cracks originated from the rim of the sample leading to a major splitting failure plane up to the central zone.

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