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Desiccation Cracking Behaviour and Strength Characteristics of Areca Fiber Reinforced Fine Grained Soils

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Abstract. Stabilization using natural fiber is an inexpensive technique to increase the properties of weak Soil. Soil swell-shrinkage characteristics cause engineering problems or damage to existing structures. Effects causing damage are mainly the demolition of buildings, roads, and pipelines in uncropped soils and the leaching in landfills through desiccation cracks, so a better comprehension of the desiccation cracking process is also essential This study comes out with a Natural material, areca fiber. Areca is accessible adequately in so many regions all over the world, yet its application in geotechnical studies has not been investigated broadly. In this current study, the appropriateness of areca fibre in the stabilization of weak soils is shown through experimental examinations. Bottom ash (BA) is utilized as a stabilizing agent along with areca fibre. The tests conducted are compaction tests, unconfined compression strength (UCS) tests, and a series of wetting-drying cycles, experiments are conducted in the laboratory on the crack parameters like crack density factor (CDF) and crack intensity factor (CIF) characteristics of desiccation cracks on the surface of Soil at different percentages of areca fibers.The image processing technique (DIA) is utilized to quantitatively analyze the morphology characteristics of crack patterns formed at each drying path.

Keywords: Digital image analysis, areca fiber, Unconfined compressive strength

1 Introduction

Soil Stabilization is the adjustment to soils to update their physical properties, like, texture, structure, and permeability and enhance the shear strength of a soil and to govern the shrink-swell properties of Soil. In this modern era, Structures frequently must be based on problematic (weak or expansive) soils. Whereas stabilizing using chemical additives like lime and cement raise environmental issues, their usage has been quite limited, nowadays. In thermal power plants, the major combustion products are fly ash (FA), and Bottom ash (BA). The Utilization of bottom ash is limited due to its slow pozzolanic reaction and less reactivity. But Utilization of BA has a huge potential in the civil engineering field, which has not been explored widely. Fibers can be used to reinforce the Soil. Soil reinforced with fibers goes about as a composite material where fibers improve the tensile strength of the Soil.The stabilization of Soil utilizing fibers assists with enhancing the engineering properties of the

Soil [17]velde1999. Enhancement in the tensile strength; shear strength, CBR, and bearing properties of the Soil is observed with the reinforcement of Soil with fibers exposed to different sorts of stresses [15]Tang et al. 2012);[3]Chaduvula et al. (2016).Stabilization of expansive soils using new natural fiber named areca fiber along with bottom ash has improved the characteristics of Soil effectively. [11] Sudhakaran et al. (2018). The subsequent wetting-drying cycles, especially the second cycle, led to a significant rearrangement of soil particles and modification of pore system [13]Tang et al. (2016). mechanical and hydraulic properties gets modified due to the presence of desiccation cracks in Soil therfore weakening the performance of Soil with respect to various engineering disciplines, particularly geotechnical,geological, and environmental engineering. In reality, cracks may build soil compressibility and consolidation rate and lessen soil strength [9]Morris(1992).. A desiccation crack is probably going to show up when the surface tensile stress reaches soil tensile strength or when volume shrinkage is constrained[4]Corte(1964). Be that as it may,progressively quantitative investigations on desiccation cracking behaviour of expansive Soil are carried out through image processing techinique has shown significan [1]Abu-Hejleh and Znidarčić (1995);[6]Lakshmikantha et al. (2009);[16]Umana et al. (2016);[2]Auvray et al. (2014)

This study targets exploring the desiccation cracking behavior at a series of wetting drying cycles, and strength characteristics of fiber (areca-fiber) and bottom ash(BA) stabilized clayey Soil. The geometrical and morphological characteristics of the crack samples were quantitatively analyzed, utilizing an image processing technique.

2 Materials and Methods

2.1 Soil and bottom ash

The Soil utilized in this study is procured from Kolhapur Maharashtra, India. The collected Soil has been air-dried and broken into pieces to pass through 4.75 mm. The bottom ash samples utilized in this study is obtained from the Udupi Power Plant, Mangalore, Karnataka, India. Bottom ash is one of the parts of the non-combustible residue of the combustion process in a furnace. The specific gravity obtained as 2.42 as per IS 2720, Part 3 (BIS 1980; ASTM 2014). The grain size distribution of the Soil was found by carrying out both wet sieve and dry sieve analyses per IS 2720.Fig1 shows the particle size distribution of clay and bottom ash indicates that Soil is clayey and the bottom ash contains graded silted content. Table1 shows the physical properties of Soil.

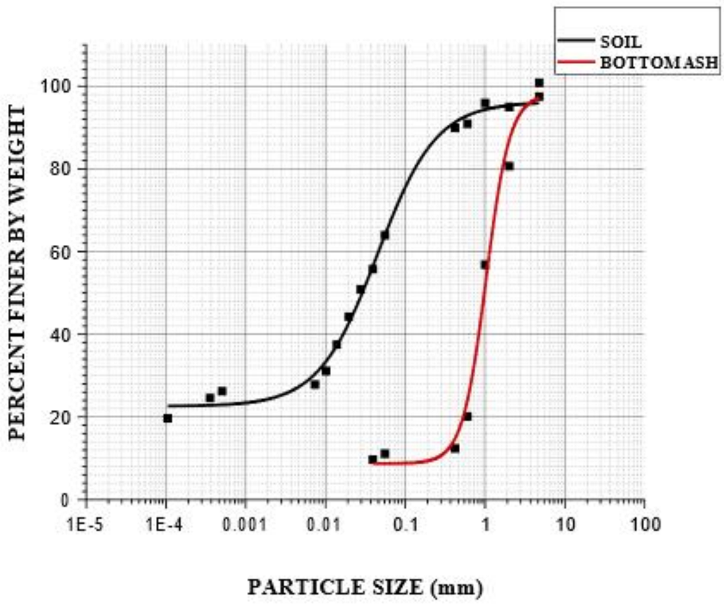


Fig. 1. Grain size distribution curve of Soil.

Table 1. Soil properties

Parameters	value
Specific Gravity	2.65
Clay(%)	26.8
Silt(%)	43
Sand(%)	30.2
Liquid limit(%)	42.14
Plastic limit (%)	18.2
Shrinkage limi(%)	14.5
Optimum Moisturecontent (%)	28.04
Maximum Dry density(gm/cc)	1.45
Soil classification(IS)	CI

2.2 Areca fiber

Areca belongs to the Arecaceae(Palmae) palm family and aercoideae subfamily that grows mostly in East Africa, Asia and tropical pacific. In India, Karnataka and Kerala are the largest areca nut-producing states. In this study, the areca fiber is collected from Kannur district, Kerala. Table 2 shows the areca fiber properties. To increase the flexural strength and durability properties of areca fiber it is chemically treated with KOH solution [18]Venkateshappa(2010). initially, the fibers were soaked in water for ten days and after drying them again soaked in KOH solution for ten days and later washed with (CH3COOH)Acetic acid and cleaned with running water if any acid traces remaining on fibers and dried for ten days.

Table 2. Properties of Areca Fibers

Parameters	value
Tensile strength (Mpa)	876 to 948
Elongation of the break(%)	1.47 to 1.8
Diametre(mm)	0.8 to 1.8
Density(gm/cm3)	1.34 to 1.45
Young's Modulus(GPa)	42 to 48

3 Experimental Program

3.1 Compaction tests

Maximum dry density(MDD) and Optimum moisture content (OMC) for different proportions of Soil and BA were determined by conducting compaction tests. the compaction apparatus consists of height of 127.3mm and 100mm internal diametre with a falling hammer weight of 2.6 kg with 25 blows/layer in three layers for the proctor compaction curve

3.2 Unconfined compressive strength

Three samples were prepared for each test according to the MDD and OMC of the mix obtained from the standard proctor compaction tests. The soil-BA mixture was prepared by adding the required amount of water and mixing it properly in a wet state. The mixing was done by hand, and good care was provided to prepare a uniform mix. The specimens (38-mm inner diameter and 76 mm long) were prepared and tested per IS 2720, Part 10 (BIS 1991). The prepared mixes are placed inside the mould and compacted. The specimens are then removed from the mould. The UCS tests were conducted on soil-BA mix samples (with varying percentage of BA) to obtain at the optimum content of BA

3.3 Image analysis

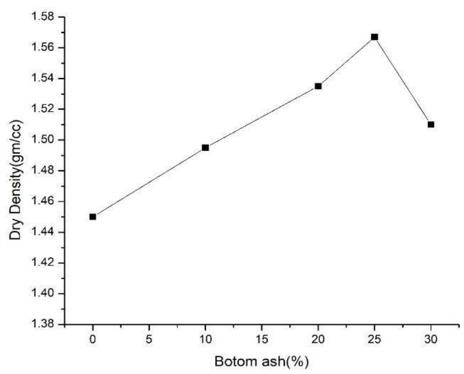
The collected Soil is intially air-dried, crushed, and then sieved at 2 mm in the laboratory. Saturated slurry specimens are prepared by blending dry soil powder with distilled water. The saturated, slurry soil specimens at different fiber contents of 125 and 250 aspect ratio of fibers and optimum bottom ash content 25%, are prepared by blending with distilled water. The water content of the slurry was about equal to the liquid limit. The quantity of slurry mixture was poured onto the 13cm circular mould Air bubbles in the mix are removed by placing the glass plate on a vibration machine for 15 min. Specimens were kept in an oven at temperature (45°C) for drying; Specimens were brought near to the setup where the camera is placed on the platform. Plumb-bob is used to ensure that the camera is vertical to the specimen surface. The camera clicked photographs from a constant height of 30cm. In this study, the image-processing technique introduced by Liu et al. (2008) and Tang et al. (2008) was used to characterize the crack pattern quantitively using ImageJ software.

4 Results and Discussions

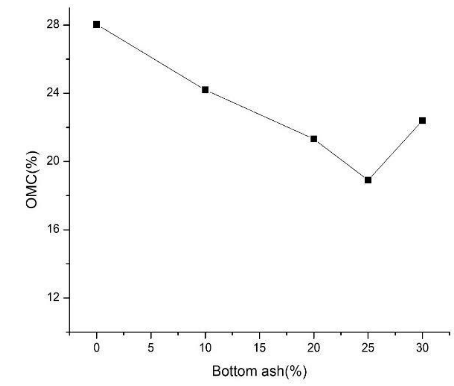
4.1 Compaction tests

Fig 2 shows the variation of OMC(Optimum moisture content) MDD(Maximum Dry density), against the varying percentage of the BA from 0 to 30%. From Fig2(a), clearly shows that with the increase in BA percentage , there is increase in the MDD of the mixtures; but after 25% BA, the MDD got decreased. A similar observations are reported by [11]Sudhakaran et al. (2018). addition of BA up to 25% might enhanced the gradation of the soil-BA mix and thus improves the MDD,while adding beyond 25% of bottom ash may interrupt the intergranular packing of Soil and leads to the reduction in MDD and the substitution of higher content of BA also reduces the MDD as the specific gravity of bottom ash is lower compared to Soil

As the bottom ash content increases the OMC got decreased till 25% and beyond 25% the OMC increased from the Fig2(b). Similar trends in OMC and MDD were reported by several previous studies [10]osinubi(2000);[11]Sudhakaran(2018). The reduction in optimum water content states that the stabilization of Soil can be carried out at lower water content. besides, the increase in MDD illustrates the eligibility of soil-BA mixtures to be used as subgrade and embankment material.



(a)



(b)

Fig. 2. Variation of Dry density of Soil with bottom ash percentage (b) Variation of OMC of Soil with bottom ash percentage

4.2 Unconfined compressive strength tests

Fig 3 shows the variation of UCS at varying percentages of BA without any curing. UCS test results, shows that with the increase in BA content up to 25% the strength of the Soil is enhanced, And there is a huge reduction in UCS at 30% of BA. The decrease in UCS after 25% may be due to the reduction in MDD that was noticed in Standard proctor compaction test results. The particle packing was reduced with the reduction in density of Soil. As a result, the unconfined compressive strength decreased with 30% bottom ash. from the above compaction and UCS test results, 25% BA can be examined as optimum content for further studies.

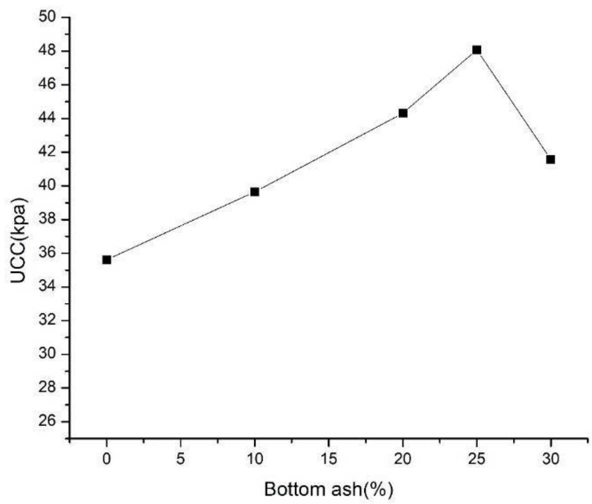
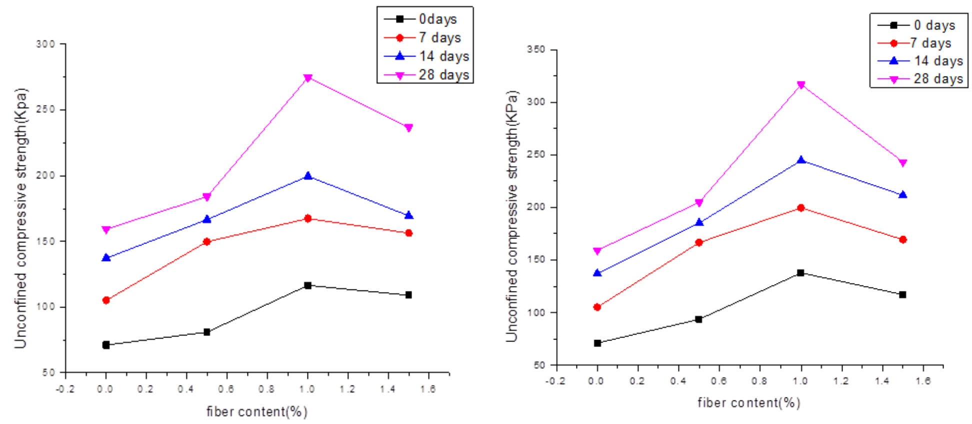


Fig. 3. Variation of UCC value with varying percentages of bottom ash

Fig 4 shows the UCS variation of the soil-BA mix with a varying percentage of fiber for curing periods of 7, 14, 28 days of aspect ratio 150 and 250. The test results indicates that the UCS value improved significantly with the increase in percentages of areca fiber. particularly, the increase in the UCS till 1% of fiber content is due to the enhancement in the better gradation, cohesion and interlocking or packing of Soil and BA .while the UCS decreased with 1.5% of fibre content, At the point when the fibre content is more than the 1% fibre content, the appropriation of the fibre in the Soil is uneven, compared with the past low content, some portion of the fibres is locally gathered in Soil, the majority of the fibres can't contact with the clay particles, and accordingly, they can't completely play the job of reinforcement; these fibres separate the clay particles, and the integrity of clay is decimated.



(a) (b)

Fig. 4. Variation of shear strength of Soil with bottom ash and fiber(%) (a) aspect ratio 150 (b) aspect ratio 250

4.3 Image analysis

The effect of fiber length and drying-wetting (D-W) cycles on fiber-reinforced expansive clay is examined by the image analysis results. The crack parameters like average crack width (wavg), average clod area, and crack intensity factor (CIF) and Crack density factor(CDF) are measured for every sample. The crack measurements are analyzed in detail in an image analysis program, ImageJ (\cite{el2017image}
The shortest possible distance between two arbitrarly chosen points on each boundary of the opposite cells is measured as crack width. The ratio of total area of cracks,Ac,to the total area of specimen At is measured as CDF and to toal area of reduced specimen is measured as CIF.using image processing technique the crack patterns obtained For each test, were quantitatively analyzed .

Effect of Wetting drying cycles

After the first drying cycle, a regular crack patterns for 150 and 250 aspect ratio is observed. It very well may be seen that the sample surface has been part of a few individual clods by the crack network. The states of crack segments and clods are generally smooth and regular. clods were generally pentagons and quadrangles. A total detail perception of the crack pattern gives that the greater part of the crack segments is opposite to one another. The crack patterns of fiber-reinforced soil samples at various fiber contents of 125 and 250 aspect ratio and optimum bottom ash content 25%,at the each wetting drying cycle are shown in Fig5 and Fig6.

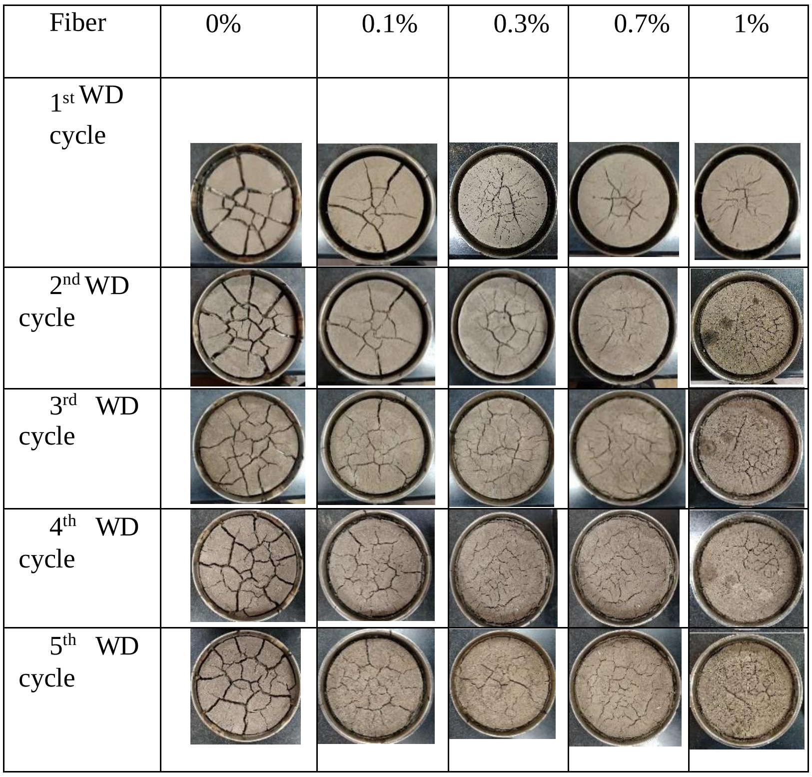


Fig. 5. Crack patterns of Aspect ratio 150

After the second wetting drying cycle, prompt breakdown of the clods was observed. The clods got increased marginally.Some new micro cracks showed up on the sample surface. And the crack density factor(CDF), Crack intensity factor, the number of clods increased while the average area of clods and width of cracks decreased compared with the first wetting drying cycle. This occurrence could be imputed due to the elements mentioned below: The additional water exhausted molecule holding capacity and modified soil structure. The disintegration of clods might be due to Internally generated forces, such as differential swelling pressure. Entrapment and pressurization of air rise inside the clods strengthened the destruction of soil-structure

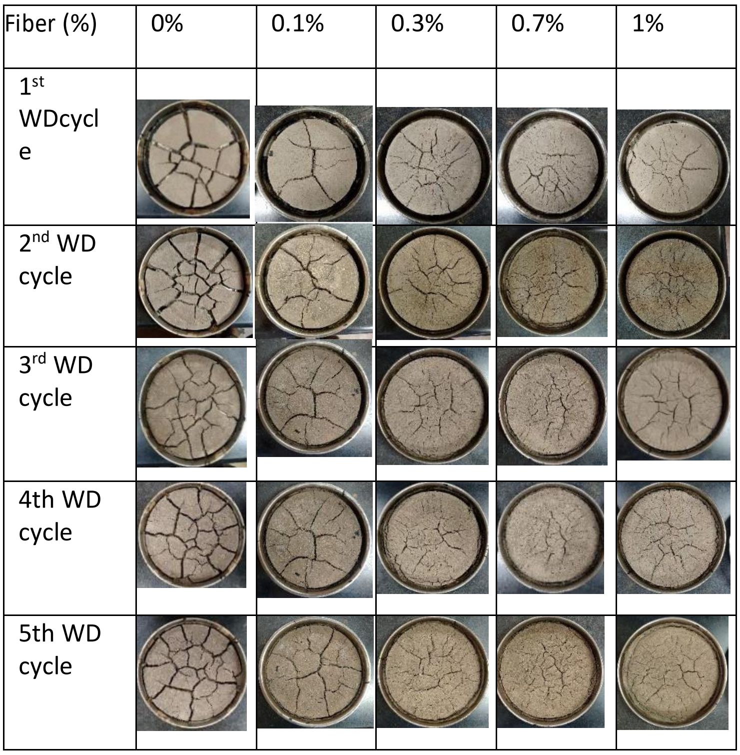


Fig. 6. Crack patterns of aspect ratio 250

At the point when water was placed into the glass cup, it entered inside the clods driven by capillary forces. This fairly severe hydration procedure can prompt entanglement and pressure development of air bubbles. Since capillary initially develops in the smallest pore spaces, the pore air is expelled and slowly assembles in macrobpores. From one perspective, with a progressive gathering of pore air, the air bubble volume increments and prompts soil destruction. Then again, as hydration continues, the pressure Pa inside the air bubbles increments because of the meniscus imbibition.

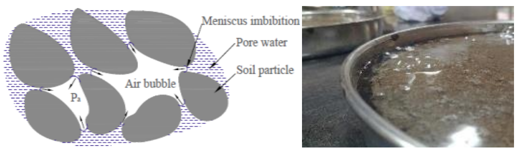


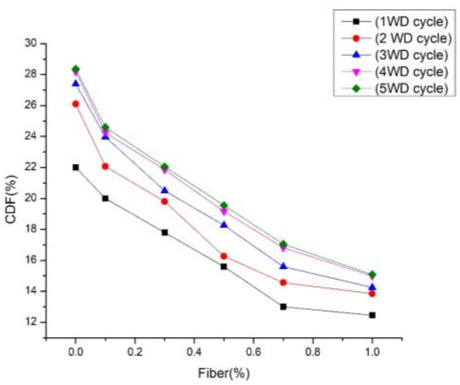
Fig.7. Meniscus imbibition during wetting

Pa(*pressure inside the air bubble*) exceeds the binding strength of neighborhood particles,leads to mini-explosions of Soil- structure and ultimately cause general damage. Sometimes, air bubbles might be locked up and cannot escape outside due to the pressure equilibrium between the air bubbles and soil structure. This phenomenon was confirmed [13]Tang et al (2016) the picture shown in Fig 6. The entrapped air bubble amplify the disaggregation of the neighbouring Soil.

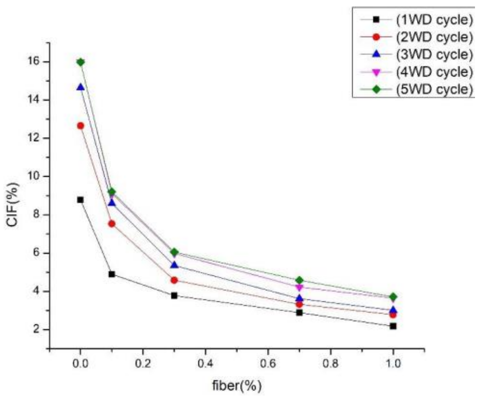
After the third wetting drying cycle, a similar trend has been observed first cracks were disappeared entirely, and new microcracks were observed. After a fourth wetting drying cycle, no new cracks have been noticed. The reason is that stability of the clod during the third wetting path is greatly controlled by the binding strength in between the formed aggregates in the second wetting-drying cycle. There is no significant change in the CDF, CIF, the width of cracks, length of cracks and number of clods average area of clods.In view of the quantification results of the crack patterns; it very well may be presumed that the cracking behaviour reached at equilibrium state after the Soil experienced four wetting-drying cycles.

Effect of the fiber content

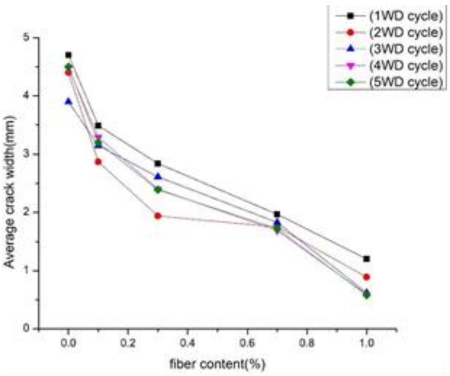
The usual morphological and geometrical features of crack patterns also change with the fiber content. This is imputed due to the ``bridging'' effect of fibers, which alters the intrinsic development and release of the tensile stress field in a soil specimen and, eventually, gives rise to variation in the mode of crack initiation and propagation and also the distribution characteristics. Quantification of the crack parameters as shown In the Fig7 and Fig8 of aspect ratio 150 and 250 demonstrated that the inclusion of fibers greatly decreased the crack density and intensity Fig8(a) and Fig8(b), crack width Fig8(c) and average clod area Fig8(d) while an increase in the number of clods Similar trends has been observed in 250 aspect ratios shown in Fig9. By fiber inclusion, the morphology of the crack patterns was effected greatlty. The total number of wide cracks diminished, and the toal number of fine cracks expanded altogether with the increase of fiber content; the crack networks changed continuously from a dependable ordinary structure to an irregular structure, and a large number of dead-end cracks or single cracks that don't intersect other cracks were recognized.The inclusion of fiber has decreased the Crack Density Factor (CDF), crack intensity factor (CIF) and crack width by increasing the fiber content from 0.1% to 1%.



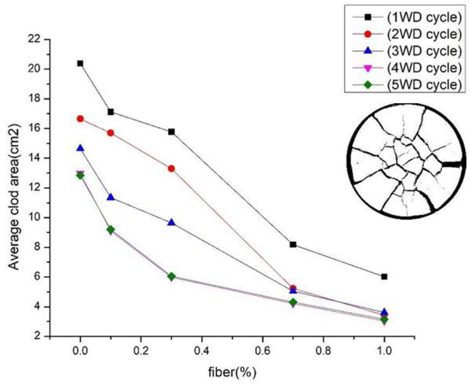
(a)Crack Density Factor



(b)Crack Intensity Factor

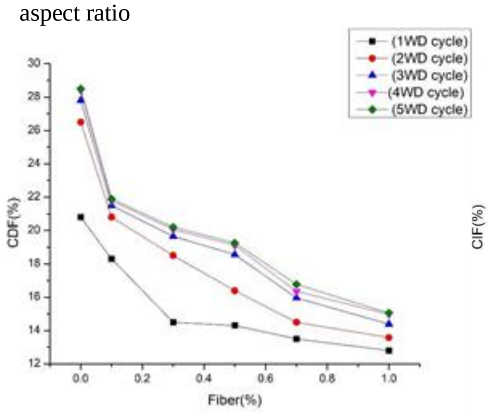


(c) Aevragec crack width

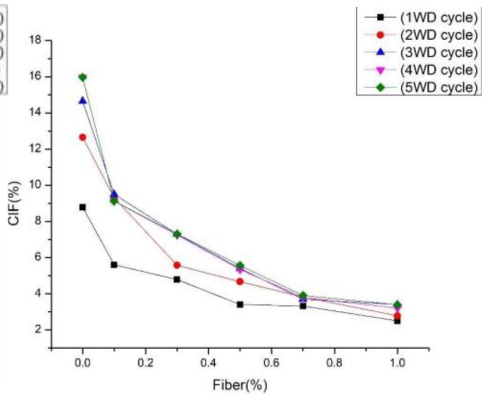


(d)Average Clod Area

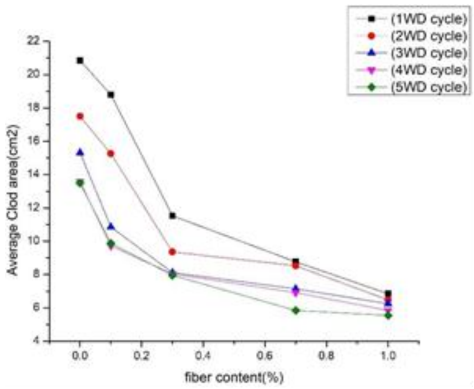
Fig. 8. Variation of crack quantitative parameters with varying percentage of the fiber 150 aspect ratio



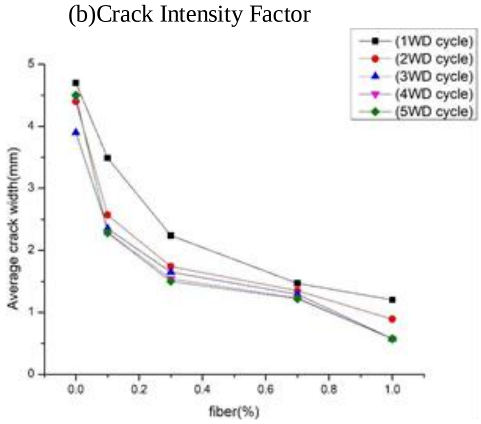
(a)Crack Density Factor



(b)Crack Intensity Factor



(c) Average Clod area



(d)Average Crack Width

Fig.9. Variation of crack quantitative parameters with varying percentage of the fiber of 250 aspect ratio

Effect of aspect ratio

As the aspect ratio increased the CDF, CIF, and avg width of cracks have been decreased. This is due to the increase in the surface content of the fibre with the Soil as we increased aspect ratio, as the surface contact increases and the more bonding between the soil and fibre increases. Variation of CDF value, Average width and Average clod area with aspect ratio of first wetting drying cycles is shown Fig10.Subsequent wetting drying cycles shown the same trends.

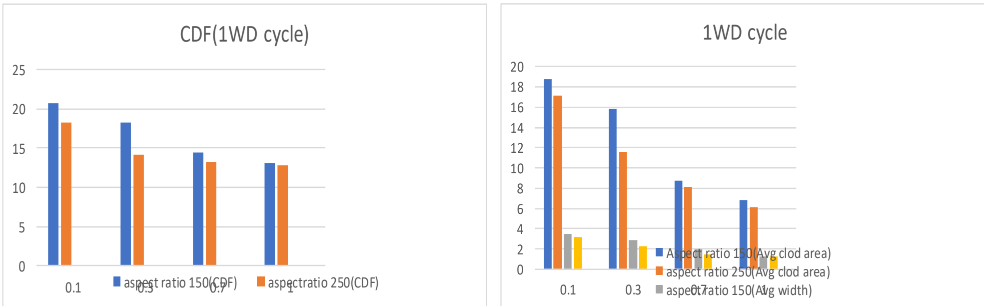


Fig.10. Variation of crack quantitative parameters with Aspect ratio

5 Conclusions

1. By the Addition of BA to Soil till 25% has decreased the OMC , and increased the MDD , but this trend has been reversed with the addition of 30% BA.
2. UCS of the soil-BA mix has been increased up to 25% BA content, and there was a reduction in UCS with 30% BA
3. The results of UCS tests of the soil-BA mix specimens with varying percentages of areca fibers shown that the addition of fiber-enhanced the strength of the soil-BA mix significantly.
4. Addition of 1% areca fiber to Soil has increased UCS values for 150 and 250 aspect ratio to 7% and 101% for a curing period of 28 days.
5. The inclusion of fiber has improved the crack resistance capacity greatly due to the higher tensile strength of the Soil. under the range of fiber contents (0%~1%) tested in this study as 1% gives optimum strength, crack reduction in the fiber-reinforced specimens approached 42% and 51.5% reduction of CDF for 150 and 250 aspect ratio and CIF is reduced by 68.8% and 76.8% for 150 and 250 aspect ratio, respectively.
6. The increase in the aspect ratio reduced the CDF by 17.24%, average Crack width by 18.33% and avg clod area by 11.2% due to increased surface contact and bonding strength between Soil and fibre.

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