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Assessment of Desiccation Cracks in Soil fused with Biochar and Dolochar using Digital Image Processing

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Abstract. The Expansive soils exhibit high swelling and shrinkage characteristics, cracking and stickiness which causes poor yielding of crops and high seepage of ground water through concerned soil. The cracking resistance of soil can be enhanced to maximize the yield and control seepage. In the present study, industrial waste biochar and dolochar was added with locally collected soil to assess the effects of those sustainable materials on engineering properties of soil as well as on enhancing the cracking resistance. Atterberg limits, free swelling index as well compaction characteristics, and Unconfined compressive strength tests on expansive soil were carried out at three different biochar contents (i.e., 2.5%, 5%, and 10%) and three dolochar contents (i.e., 5%, 10%, and 20%) added with bentonite. The development and proliferation of fractures in a desiccated soil specimen were captured using a digital image capturing device and processed. The results showed that at 5% biochar and 10% dolochar, optimum values were obtained. The crack intensity factor (ratio of the area of the cracks to the total specimen area), the average width, and the total area of cracks decreased with increasing biochar up to 5% and dolochar up to 10%, thereby increasing the relative integrity of the specimen.

Keywords: Biochar, Dolochar, Bentonite, Desiccation cracking.

1 Introduction

Soil cracking is a complicated phenomenon that is impacted by several characteristics such as soil mineralogy, temperature fluctuations, and soil layer thickness. Soil cracking patterns are influenced by the alternating soaking and drying of soils, as well as the physiochemical qualities present in soil. Prior research has shown that soil and crack geomorphology can have a considerable impact on the intrinsic qualities of the soil. Desiccation fissures developed on the soil's top surface can affect the soil's characteristics linked to geotechnical, hydraulic, and environmental applications. Changes in moisture content, stiffness, and tensile strength of the soil can cause cracking patterns to form. Cracks form on the soil surface because of the drying process caused by the evaporation of water from the exposed soil surface, which is mostly caused by volumetric shrinkage of the soil. When the threshold condition is achieved, desiccation fractures appear on the soil's surface. The tensile strains created during water evaporation are also connected to crack growth. When the tensile stresses created surpass the soil's natural tensile strength, fractures can grow and degrade the soil.

Soil cracking originates weaker soil zones and can cause stability concerns in dams, tailing ponds, earthen embankments, landfills, liners, and other structures. The increased hydraulic conductivity caused by crack development can substantially impair the effectiveness of contamination barriers. Moisture infiltration caused by cracking has a significant impact on the stability of natural slopes and vertical cuts, as well as the carrying capacity of the foundation. Crack propagation may be efficiently prevented by enhancing soil strength and treating the soil with appropriate additions such as lime, cement, and sand. Water evaporation from an exposed soil surface generally leads to volumetric shrinkage of the soil. Desiccation fissures form in the soil and appear on the soil surface after the threshold condition is achieved. Some of the criteria that aid in understanding crack connectivity include the morphological properties of the soil-crack pattern, such as crack area density, crack length, and crack breadth. The assessment and study of these factors can aid in understanding the variance in crack pattern propagation and characterization of soil cracking behavior, as well as its effect on geotechnical and environmental applications. Imaging methods may be used to efficiently study fracture forms and propagation. Furthermore, numerical analysis can be performed to investigate the fracture pattern in soil.

2 Materials and Methodology

2.1 Materials

There are two types of materials taken for analysis, such as biochar and dolochar along with the locally available soft soil. The soil used for the purpose of testing was taken from the shores of the nearby river by using means of local transportation and was stored carefully. Before conducting various tests, the soil was crushed into required size using appropriate sieves, then it was oven dried for 24 hours and finally it was used for various experiments.

Biochar. The biochar collected is a compound which is rich in carbon content and produced by the pyrolysis of biomass at a relatively elevated temperature under limited availability of oxygen. Pyrolysis is a typical process for manufacturing biochar in an oxygen-controlled environment, such as turning biomass into oil or to produce hydrogen, which enhances the economic effectiveness of extracting and transportation of the biomass to the facilities where it will be converted into various forms. “Slow pyrolysis” is a process involving the breakdown of biomass by heating over a considerable length of time (generally 3 to 5 days) to create enormous volumes of gas biochar, and oil. To prepare the biochar, air-dried wheat straw was heated at a rate of 7°C/min in a heating furnace until the temperature of carbonization grew up to 400°C. Then it was cleaned and sieved through appropriate sieve sizes before conducting all the experiments. Initially, the biochar was characterized for determining its index properties. Before adding into the soil, it was kept in the oven for at least 24 hours and then it was taken out and cooled outside for half an hour before starting any kinds of experiments.

Dolochar. The dolochar samples were broken down into pieces having very small dimensions and then sieved by passing them through a 4.75 mm IS sieve. Dolochar is a sponge iron by-product with no clay component. The dolochar is non-expansive and non-plastic in nature. Because dolochar is a by-product of sponge iron, its specific gravity is higher than Expansive soil. The collected samples were oven dried for 24 hours initially before commencement of any experiments. To access the capability of the taken additives for reducing the desiccation cracks, three different proportions were chosen for biochar and dolochar individually. For biochar, 2.5%, 5% and 10% compositions were taken for preparation of the samples whereas for dolochar, 5%, 10% and 20% were taken as the appropriate proportions. As the soil taken was of intermediate compressibility, bentonite was also added along with biochar and dolochar separately to visualize its effects on enhancing the cracking resistance of soil.

Bentonite. The bentonite used in this study was sodium (Na^+) bentonite. It was stored in an oven for 24 hours for complete removal of any sort of moisture from it and then was used as a binding material in this specific study.

Sample preparation. The soil taken was of medium compressibility with IS classification of MI (intermediate compressible silty soil). Hence to convert the soil into a more expansive form to facilitate the cracks and to see the effects of the additives such as biochar and dolochar, bentonite was also added in the soil. Then finally, biochar and dolochar were added into the bentonite-amended soil such that the samples were prepared with the mixtures of 3 types of materials, i.e. soil, bentonite and biochar/ dolochar. Hence a total of 8 samples were prepared for all the tests that are conducted, i.e., Base soil (S), Soil+10% Bentonite (S10B), Soil+10% Bentonite+2.5% biochar (S10B2.5BI), Soil+10% Bentonite+5% biochar(S10B5BI), Soil+10% Bentonite+10% biochar (S10B10BI), Soil+10% Bentonite+5% dolochar (S10B5D), Soil+10% Bentonite+10% dolochar (S10B10D), Soil+10% Bentonite+20% dolochar (S10B20D).

2.2 Methodology

Primary tests. Desiccation tests were conducted as the primary tests. The Bentonite amended samples after adding the biochar and dolochar were mixed thoroughly and prepared for desiccation cracking tests. For accessing the crack resistance of biochar and dolochar, the soil samples were prepared with adding biochar, dolochar separately along with addition of bentonite as well.

Initially, the soil was passed through 425-micron IS sieve, and oven dried for 24 hours in 105℃ temperatures. All the requisite additives were also prepared in similar manner. Then the soil and additives mixture were placed in between specially prepared rubber containers, filled thoroughly with the help of spatula and given pressure to prepare the samples having same thickness for all the samples. For desiccation cracking, two factors are predominant, i.e., the thickness of soil sample and the amount of water added. Depending on the thickness of the sample and the amount of water added to the soil, the time required for the desiccation cracks to appear varies between a few hours to a few days to months, even years.in order to facilitate the development of cracks in the soil sample, the thickness of the samples was kept very less so that cracks can be generated within the due period. The amount of water should also be taken into consideration since it is another predominant factor for desiccation cracking. In our case, the samples were prepared at liquid limit so that a uniform thickness of the soil sample can be generated, thereby the top surface of the soil will be smooth which will be convenient while image acquisition and the processing of the images will be easier to conduct.

After preparation of the samples, they were kept in laboratory condition for sufficient period for the cracks to develop on the surface of the soil samples. Generally, a period of 24 hours to 72 hours is sufficient for the cracks to be developed depending on the amount of water added and the thickness of the samples.

Secondary tests. A certain set of tests were conducted with the bentonite amended soil added with biochar and dolochar to determine the effect of those additives on engineering properties of soil. The grain size distribution of the soil and the additives were determined by both dry sieving and hydrometer analysis according to IS: 2720 (Part-4): 1985 [7]. The specific gravity of the soil as well as the additives were determined in accordance with IS: 2720 (Part-3): 1980 [3]. The Atterberg limits of the soil-bentonite mixture along with the prepared samples were determined according to IS: 2720 (Part 5): 1985 [6].

Compaction characteristics. The standard compaction test was performed on the sample in accordance with IS code: 2720 (part 7): 1980 [4] for light compaction.

Free swell index. The free swell index (FSI) was performed to determine the potential of a sample to swell i.e., swelling index of the sample as per IS code: 2720 (Part XL): 1977 [5]. Two oven dried specimens of 50g each passing through 425µ IS sieve was taken and was poured in 100ml capacity glass cylinder filled one with distilled water while another with kerosene oil up to 100ml mark. The entrapped air was removed by shaking or stirring with glass rod and the sample was allowed for suspension at least 24 hours. The reading of the final volume of sample in each cylinder was noted and free swell index was calculated.

Unconfined compressive strength. UCS of a specimen is defined as the strength corresponding to either the failure stage or the maximal vertical strain (ε) equal to 20% of the original height, whichever arrives first. The specimens were sheared at a strain rate of 1.2 mm/min in this investigation. IS code: 2720 (part 10): 1991 [1] was used to conduct the UCS test. A typical compression testing equipment was used to perform the UCS test on samples. The tested specimens had a height of 72 mm and a diameter of 36 mm.

Image acquisition. The images of the top surfaces of the cracks were taken using a digital image capturing device. The captured images are taken with a pixel size of 64 mega pixels, i.e. 9248×6936 number of pixels were present in the image. Since the height of capturing the images influences the size of the pixels, the images were taken at 3 constant heights, i.e., 15cm, 21.5cm and 23.5cm. also to check the gradual development of the cracks, the pictures were taken at a regular interval, i.e., 3h, 6h and then finally at 24h. since there were 8 number of samples present, which are, S, S10B, S10B2.5BI, S10B5BI, S10B5D, S10B10D and S10B20D. Hence, a total of 81 number of pictures were taken for analysis. Images taken at a height of 15cm and after 3h from the time of preparation of the samples are shown in fig. 1.

Fig. 1. Images of the samples taken for analysis.

Image processing and alterations. After taking the pictures, they were transferred into a computer for processing. Initially the background of the images was removed, and a circular portion was cut in the middle of the samples. It was done to remove the effect of the boundaries. Since when the soil gets dried up, some of the soil layers gets attached to the boundaries of the container in which they were kept and by which there is a presence of a greater number of cracks in the peripheries of the soil samples as compared to the central positions. The pictures captured at different heights had different number of pixels present in them, which is why it was also necessary to keep the area taken into consideration constant for all the pictures taken at a constant height. Hence, three types of pre-sets were prepared, for pictures taken at 15cm, the area taken was having greater number of pixels as compared to the pictures taken at a height of 23.5 cm. hence to keep the uniformity and integrity of the samples intact, different pre-sets were used for pictures taken at different heights. After separating the background from the image, this image was processed using “MATLAB-2020”.

Data Extraction The images are analyzed using different commands such as imread, uigetfile, rgb2gray etc. via MATLAB software. Later, the image was converted into greyscale from the original RGB format which contains a series of colors and data, which interacts with the cracks while processing and might give erroneous results. By turning the image into grey scale, the cracks and rest of the soil was distinctly visible. A visual representation of the changes in the top surface of the soil after altering it through MATLAB to identify the patterns of the cracks in soil is shown in fig. 2.

Fig. 2. Background removal and quantification of cracks using MATLAB digital image processing.

Masking with a threshold. The noise present in the image was reduced using the masking feature present in MATLAB. For this, a low threshold and high threshold was defined and the function “imfill” was used to create the mask. Then the function “bwareafilt” was used to further enhance the mask using the lower and higher threshold values**.**

Data interpretation. The area and width of the cracks are calculated from the converted pixelated image. In the image, only white colored skeletal lines are present which are easy to calculate areas for, which are later analyzed for cracking characteristics of different specimens.

To quantify the crack resisting characteristics of the additives, certain parameters were defined. The first parameter was “total area” of the cracks which is basically the addition of all the areas of the cracks generated in the specimen. However, the total area can't give any information regarding the number of cracks generated in the specimen, which is why another parameter was taken into consideration, known as "average area". This new parameter was able to quantity the number of cracks as well. But we couldn't compare specimens having different top surface area with the help of either of those parameters, as pictures taken from different heights cannot be compared extensively as their area will be different. Which is why, to normalize the area values in a single scale, another parameter was defined which is known as "area ratio" or "cracking index" or "desiccation ratio". It is defined as the ratio of total area of the cracks generated to the total top surface area of the specimen.

This cracking index has been widely used in the past as well to quantify the cracking characteristics. A higher value of cracking index signifies a greater number of crack generation and lower efficiency of crack resistance for a given additive. The entire process of extraction of useful crack related data from raw images is explained using a flowchart in fig. 3.

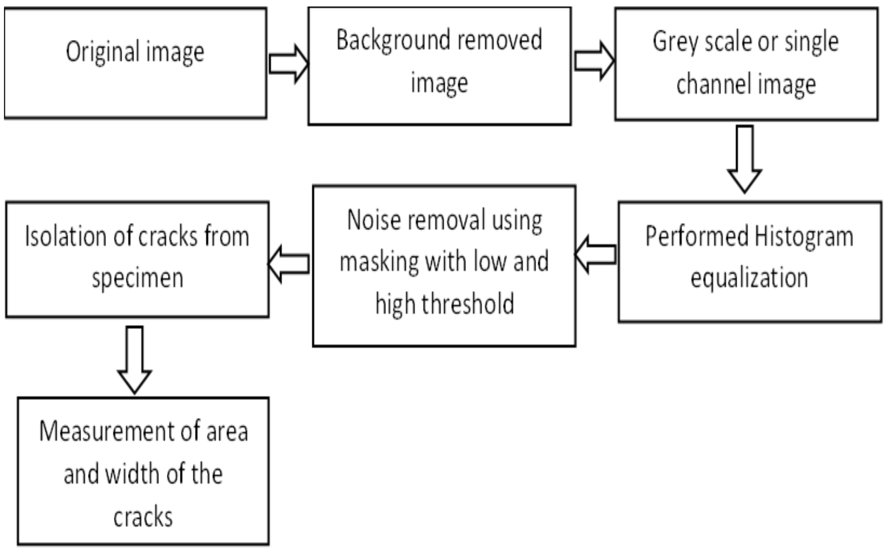

Fig. 3. Schematic diagram of quantification of cracks generated using MATLAB digital image processing.

3 Results and Discussions

3.1 Effect on Free Swell Index

The variation of Differential free swell index (DFS) with percentage composition of biochar and dolochar is shown in the fig. 4. The DFS value for biochar reduces up to 5% and then it remains constant which shows that addition of biochar reduces the swelling. However no observable trend was obtained in case of addition of dolochar.

According to yang and Zhang et. al, the rate of evaporation curve of biochar is a steep curve which may be divided into 3 stages, i.e., rapid, steady, and slow. Biochar decreases the initial rate of evaporation when the biochar percentage is at 5%. Hence the water holding capacity of biochar increases resulting lesser compression and thereby reducing the value of DFS. However, after the biochar percentage is increased beyond 5%, the initial rate of evaporation increases again, resulting increment in DFS value.

In case of dolochar, the fractal dimension of the soil sample decreases as dolochar concentration increases, while the water content of the soil sample increases. Because of the dolochar's wide pores and specific surface area, stable agglomerates of dolochar with soil particles are easily formed, thereby reducing the volume of the dolochar amended soil samples with increase in percentage of dolochar, which in turn reduces the DFS value gradually.

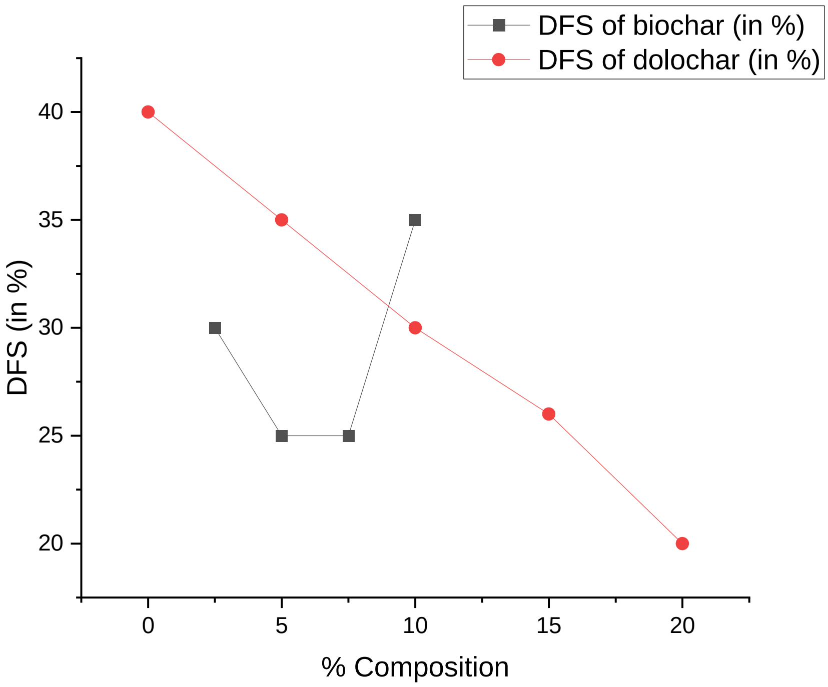

Fig. 4. Variation in DFS with % composition of biochar and dolochar.

3.2 Changes in cracking characteristics

One of the first parameters defined in the analysis was the total area of the cracks. It was the simplest and basic characteristics defined. It was defined as the area of all the cracks generated in a certain specimen. The cracking resistance of the additives were assessed from this parameter. The variation of total area of the cracks with the percentage composition of biochar and dolochar is shown in fig. 5.

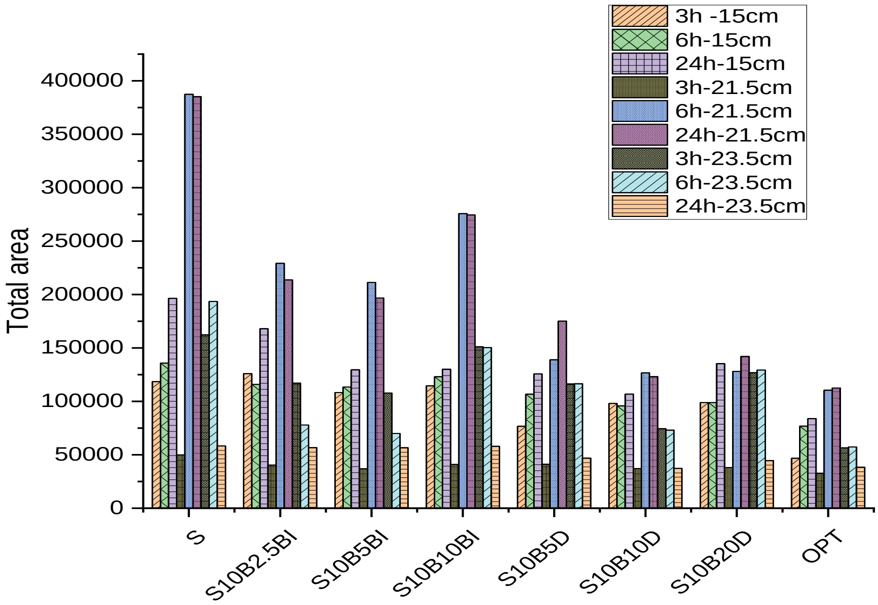

Fig. 5. Variation of total area of cracks for the compositions.

From fig. 5, it can be observed that for S10B5BI, and S10B10D, the values were lesser as compared to other values, and then the values of total area were least for the optimum percentage composition, i.e., S10B5BI10D.

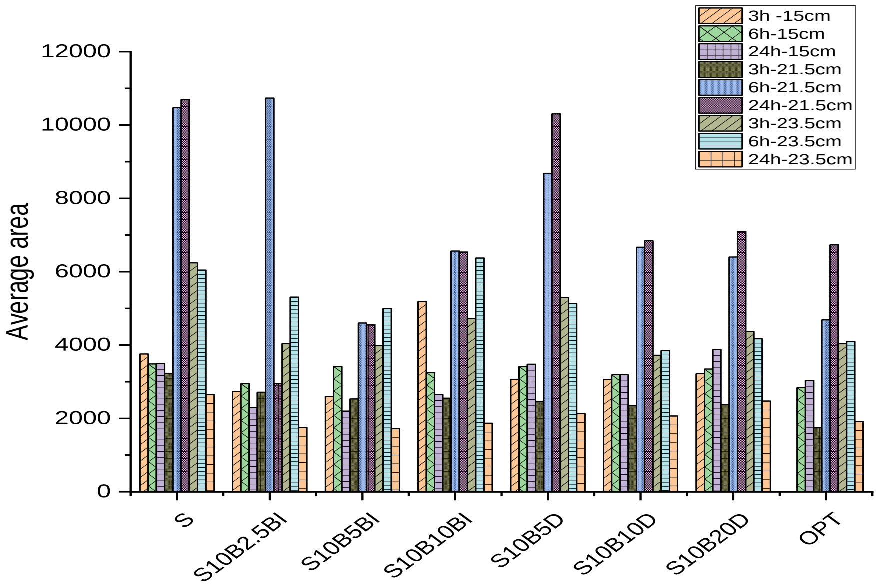

Fig. 6. Variation of average area of cracks for the compositions.

The values of total area of cracks averaged over the no of cracks generated are termed as average area of cracks. In addition to the total area of cracks, average area also considered the number of cracks generated in a particular specimen since if the number of cracks is higher, the average area will be lower and vice versa. However, if the total area is also decreasing, the average area will reduce as well. The variation of average area of the cracks with different percentage compositions of biochar and dolochar is presented in fig. 6.

From fig. 6, it was concluded again that the average area of cracks was minimum for the samples S10B5BI and S10B10D in most cases of the specimens. Average area of cracks is maximum for S10B10BI during the initial period since there are introduction of very minute cracks but in a very large number. This increases the average area of the cracks, but the practical significance of this curve is not of much importance.

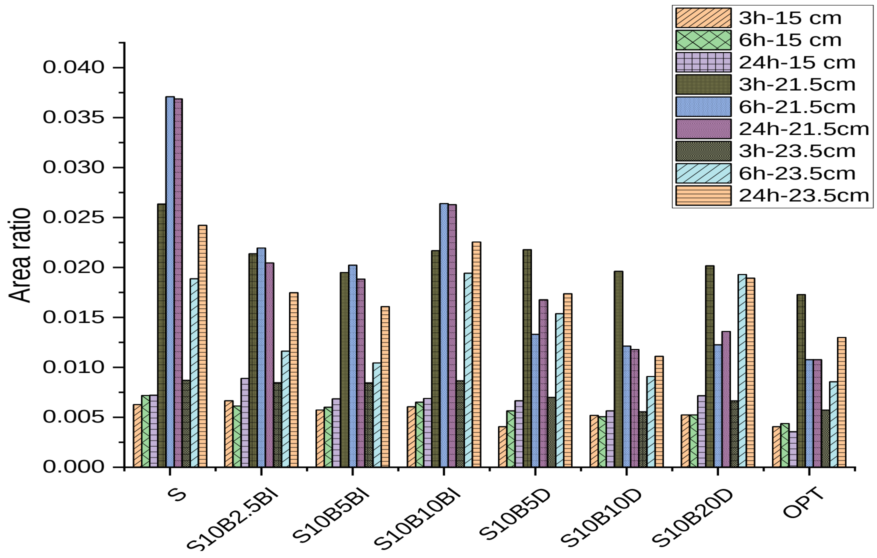

Fig. 7. Variation of cracking index for the compositions.

The cracking index is defined as the ratio of area of the cracks to the total top surface area of the specimen. The top surface area for the samples taken from a height of 15cm, 21.5cm and 23.5cm were 18895914, 10446273, and 6701206 pixels respectively since the diameter of the specimens taken were 4905, 3647, 2921 pixels.

The variations of cracking index with different compositions of biochar and dolochar are shown in fig. 7. For maximum cases, again the area ratio is minimum for the samples S10B5BI and S10B10BI, which are considered as the optimum samples in our test. The area ratio is decreasing by the addition of biochar and dolochar up to 5%, and 10% respectively and beyond which it keeps on increasing. The comparison between area ratio of different samples over time are shown below for 15cm and 21.5cm of heights.

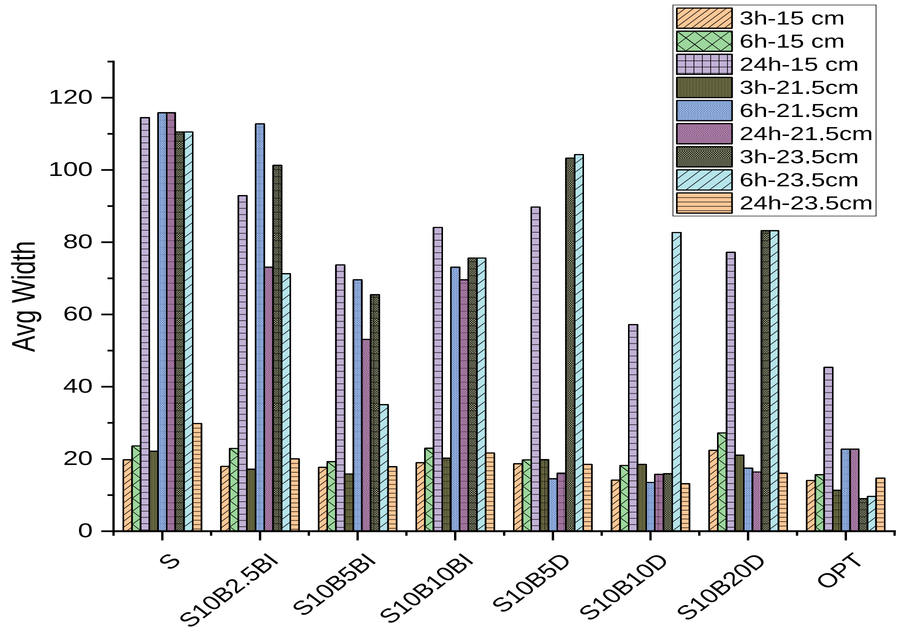

Fig. 8. Variation of average width of cracks for the compositions.

The variation of average width of the cracks generated are shown in fig. 8. It can be observed that the minimum width of cracks was observed for the samples S10B5BI, S10B10D and S10B5BI10D, which again proves the optimum dosage of biochar and dolochar for mitigation of cracks.

4 Conclusions

From the study, following are some of the conclusions that are derived.

- The differential free swell values decrease by addition of biochar up to 5% and then it keeps steady up to 7.5% and then starts on increasing. There is no trend followed by addition of dolochar in bentonite amended soil.
- By addition of biochar in bentonite added soil, the fractal dimensions reduced significantly. The total area, average area, and area ratio (cracking index) reduced with the increase in biochar content up to 5% beyond which they started to increase. Similar trends were found out by addition of dolochar as well however for dolochar, the optimum percentage at which minimum number of cracks were formed were found to be 10%.
- From the quantitative analysis of cracks, it was found that by the addition of biochar, the total area, average area, area ratio and the average width are reduced by 33%, 37%, 5% and 35% respectively at its optimum content which is 5%. Similarly, by addition of dolochar the total area, average area, area ratio and the average width are reduced by 45%, 28%, 21% and 50% respectively at its optimum content which is at 10% dolochar. By adding both the optimum percentages of biochar and dolochar in the soil, the reduction in to-

tal area, average area, area ratio and the average width were 57%, 135, 50% and 69% respectively.

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