
Ageing Effect On Shear Strength Of Mixed Kaolinite-Bentonite And Sand Clay Minerals

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Abstract: Fine-grained soils are mainly composed of kaolinite, montmorillonite, illite clay mixtures in various ratios beside sand in the natural world. Only demographically significant areas are being studied for the shear behavior of these soils, which takes a lot of time and money. Clay's basic behaviour demonstrates a lower shear strength magnitude, In order to solve this issue, extensive research was done to boost clay's shear strength. In view of increasing shear strength of clay , in this experimental study , different proportions of clay minerals were taken namely kaolinite ,bentonite and natural sand, which depict the kaolinitic , montmorillonitic and sand in nature. At the outset, out of 3 ingredients, Bentonite was kept constant at 10% and other ingredients namely kaolinite & sand were varied with minimum and maximum fines in the mix proportions. Further similar sets of experimentation were done with Kaolinite & Sand variations as explained, each time keeping the bentonite proportion constant at variation from 20 to 80%. Each sample with the pre-decided proportion was tested for its unconfined compressive strength by fixing the OMC and MDD as per required value which were done precedingly. Prepared samples were kept in plastic pouch for the period of 30,60 and 90 days . These samples were also observed for SEM analyses for microstructure study. From this experimental analysis it was observed that the unconfined compressive strength and shear parameters like cohesion, and angle of internal friction were increased with different ageing span varying from zero to 90 days and also analysed in terms of their respective microstructures.

The results shows that the trend of increasing shear strength with 0 to 90 days of ageing effect as well as increase in Bentonite content in the mix proportion . Unconfined compressive strength (q_u) increased from 78 kpa to 110 kpa(for minimum bentonite of 10%) with increase in ageing from 0 to 90 days and observed 140 kpa to 204 kpa with the increase of bentonite in the mix proportion (maximum content of 80%) subjected to ageing effect from 0 to 90 days . From SEM analysis it was observed that crystalline white lumps and agglomerate structure were formed with increasing bentonite content in the mix proportion and ageing effect from zero to 90 days. It was responsible for the increase in strength and shear parameters of the mix proportion.

Keywords: Unconfined compressive strength, Ageing effect of shear.

1. Introduction

Soil clay mineralogy has a stronger physical-chemical influence on the behavior of fine-grained soil, it behaves differently. In addition to other clay minerals and non-clay minerals, the natural soils contain two extreme clay minerals, kaolinite and montmorillonite, in varying amounts. The engineering behavior, particularly the physio-chemical behavior of naturally occurring fine-grained soils, is caused by these clay minerals. Any natural soil's relative activity is determined by the relative percentage of various clay minerals in that soil. It is well knowledge that the clay's mineralogical composition has a significant impact on the soil's physical characteristics. In contrast to montmorillonite soil, which has a dominance of repulsive forces, kaolinitic dominating soil has a flocculent structure as a result of the dominance of attractive forces. However, depending on how dominantly the clay mineral is present in the soil mix, the attracting and repulsive forces may be balanced in Kaolinite-Montmorillonite soils. The conflicting behavior of soils containing kaolinite and montmorillonite in varying quantities has a significant impact on the engineering behavior of soils.

The density shift that takes place during secondary compression is not the only factor contributing to the increased strength and stiffness of clay. Instead, it is the outcome of persistent particle rearrangement that has enhanced surface roughness and macro-interlocking of particles.

In the current experimental work, it can be seen that increasing the amount of bentonite clay in the mix leads to an increase in the undrained shear strength when compared to increasing the amount of kaolinite in the mix. Aging effect from 0 to 90 days influences the increase in undrained shear strength of the mix proportion .

1.1 Significance of Research

On an engineering time-scale, Creep is proposed by Mesri et al. [1] and Schmertmann [2] as the major aging mechanism of granular systems. There are other factors besides increased particle packing during secondary compression that lead to an increase in strength and stiffness. Instead, it is the outcome of persistent particle rearrangement that has enhanced surface roughness and macro-interlocking of particles. The fact that locked sands exist and exhibit tensile strength even in the absence of binding cement—a finding that Richards [3] examined—corroborates this.It has been demonstrated that materials with higher angular particle counts are more prone to creep deformations, as reported by Mejia et al. [4].Due to a more anisotropic starting fabric, isotropic compression studies by Kuwano[5] revealed that radial creep stresses were larger than axial strains in soils with angular particles as opposed to soils with rounded particles. Because of their greater range of stable contacts and capacity for interlocking, angular particles can lengthen the duration of creep and intensify its aging effect. Since spherical particles can reorganize more readily than elongated ones by Oda [6], rounder particles initially creep at a higher velocity before settling Because of this, any aging impact on rounded particles often disappears quickly when new stress conditions are applied to the soil.

Lade[7] notes that when a continuous shear load is applied to loose sand, there is significant creep and volumetric contraction.

In the course of creep, mechanical aging primarily increases strength and stiffness in the direction of previously applied force (Howie et al.,[8]). When the sand was loaded in a direction that was orthogonal to the applied shear force during creep, no increase was seen by Losert et al.[9].

The aging process may be influenced by chemical processes. In the past, interparticle bonding has been the most popular idea to explain aging processes in sand. When a quasi-preconsolidation pressure was present in the field, Terzaghi first used the term "bond strength" (Schmertman [2]).

Strong proof that some aging is caused by a chemical mechanism was found. Nevertheless, there have been a number of situations where cementation turned out to be an improbable process of aging, at least in the short term. As an illustration, dry granular soils can gradually become more stiff and strong studied by Losert et al., [9]. Since moisture is needed to drive the solution and precipitation reactions involving silica or other cementing agents, cementation in dry sand is rare.

The importance of the mechanisms involved in the artificial mix percentage subjected to various energy levels and performed unconfined compressive strength with aging from 0 days to 90 days is presented in the current experimental study. It demonstrates how, from zero to ninety days of age, the shear parameter and compressive strength vary. The manufactured mix proportions underwent microscope analysis to reveal surface shape or topography.

2. Materials and Methods

2.1 Materials

Materials used for the experimental study are as follows

1. River sand passing 425 micron
2. Commercially available Clay minerals (Kaolinite and Bentonite)

Clay minerals and river sand will be collected and stored in separate plastic bins. For preparation of the sample, they will be kept in oven for a period of 24 hours for oven drying, after which they will be kept for cooling at room temperature. Prepared mix proportions of kaolinite-bentonite-sand mixtures representing kaolinitic soil , montmorillonitic soil and kaolinitic-montmorillonitic soils are available in nature.

Careful selection can be made to select the mix proportions that is lowest fines of 60% and highest fines of 90% and varying bentonite from 10 to 80 percent were selected and taken for the experimental work . Table 1 presents the range of mix proportion selected for experimental work.

Table 1 : Mix proportions

Mix Proportion	Combination
1a	10B + 50K + 40S
1b	10B + 80K + 10S
2a	20B + 40K + 40S
2b	20B + 70K + 10S
3a	30B + 30K + 40S
3b	30B + 60K + 10S
4a	40B + 20K + 40S
4b	40B + 50K + 10S
5a	50B + 10K + 40S
5b	50B + 40K + 10S

6a	60B + 10K + 30S
6b	60B + 30K + 10S
7	70B + 20K + 10S
8	80B + 10K + 10S

*B-bentonite, K-Kaolinite, S-sand

Mix proportion 1a represents lowest fine content (50%) of 10% bentonite , 50% kaolinite and 40% sand , mix proportion 1 b represents highest fine content (90%)of 10% bentonite , 80% kaolinite and 10% sand .Similarly mix proportion 2 to mix proportion 8 represents the minimum (50 to 60%) and maximum fine content (90%) , also bentonite content in the mix proportion is varying from 20% to 80% (mix proportion 2 to 8) .

2.2 Methods

The following tests were conducted on soils under study.

- Specific gravity (G): The density bottle method was used to determine the specific gravity of the soils, the test liquid used was distilled water. (IS: 2720 – Part – 3, 1980) (Reaffirmed: 2021)
- Liquid limit (W_L): The percussion (Casagrande methods were used to estimate the liquid limits of the soils. (IS: 2720 – Part 5, 1985) (Reaffirmed: 2020)
- Plastic limit test (W_P): The rolling thread of 3 mm method was used to determine the plastic limit of the soils (IS: 2720 – Part 5, 1985) (Reaffirmed: 2020)
- Shrinkage limit (W_S): The displacement method using mercury was used to obtained the shrinkage limit of the soils (IS: 2720 – Part 6, 1972) (Reaffirmed: 2021)
- Compaction characteristics of soils: The standard or Light Compaction [IS: 2720-Part 7 (1980)] (Reaffirmed:2021), tests were conducted on the soils under study.
- Unconfined Compressive strength(qu)for determining compressive strength of mix proportions for 0 to 90 days of aging .

3. Results and Discussion

Table-2 shows the index properties of the mix proportion. From the table it can be observed that the liquid limit , plastic limit and shrinkage limit varies from 47 to 127% , 32 to 45% and 25 to 13.2% respectively with increase in bentonite clay in the mix proportion from 10% to 80% .

For the listed mix proportions , Standard light compaction test were conducted and obtained OMC and MDD , it can be used in conducting unconfined compressive strength to obtain unconfined compressive strength for the mix proportions ,subjected to ageing from 0 to 90 days that is experiment conducted on 0 days , 30 days , 60 days and 90 days of duration . Table 2 presents the index properties of mix proportions

Table 2

Index Propoerties				
Mix Proportion	Combination	Liquid limit(%)	Plastic Limit (%)	Shrinkage Limit(%)
1a	10B + 50K + 40S	47	32	25
1b	10B + 80K + 10S	69	38	30
2a	20B + 40K + 40S	50.28	32.2	24.17
2b	20B + 70K + 10S	64.93	39.3	29.63
3a	30B + 30K + 40S	50.93	33.65	20.18
3b	30B + 60K + 10S	82.37	39.8	28.2
4a	40B + 20K + 40S	66.62	33.8	18.62
4b	40B + 50K + 10S	94.32	40	22.9
5a	50B + 10K + 40S	70.6	34	14.6
5b	50B + 40K + 10S	107	41.5	19.06
6a	60B + 10K + 30S	87.5	35.5	14.2
6b	60B + 30K + 10S	109	41.7	18.61
7	70B + 20K + 10S	119.91	41.83	17.99
8	80B + 10K + 10S	127.01	44.49	13.2

Table 3 presents Unconfined compressive strength (q_u) of the mix proportion.

Table 3

Mix Proportion	**Combination**	**Unconfined Compressive strength (kPa)**			
		0 days	30 days	60 days	90 days
1a	10B + 50K + 40S	78	98	104	110

1b	10B + 80K + 10S	86	110	126	130
2a	20B + 40K + 40S	84	118	130	136
2b	20B + 70K + 10S	94	122	134	140
3a	30B + 30K + 40S	90	124	136	148
3b	30B + 60K + 10S	104	132	140	154
4a	40B + 20K + 40S	100	140	150	156
4b	40B + 50K + 10S	116	150	156	166
5a	50B + 10K + 40S	112	152	164	170
5b	50B + 40K + 10S	126	164	172	180
6a	60B + 10K + 30S	116	158	170	178
6b	60B + 30K + 10S	136	176	184	188
7	70B + 20K + 10S	124	170	176	186
8	80B + 10K + 10S	140	184	198	204

Figures 1 through 8 represents the variation of unconfined compressive strength (q_u) with ageing for the mix proportions 1a thorough 8, having combination of mix proportions where percent fines (F),50<F>90 for representation only .

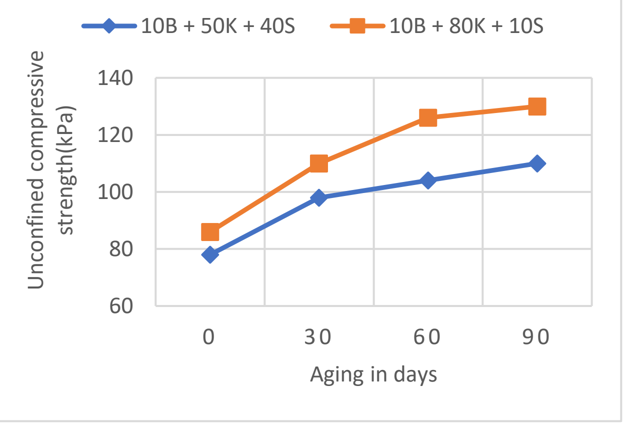

Fig 1: Variation of q_u with aging for Mix Proportion 1a & 1b

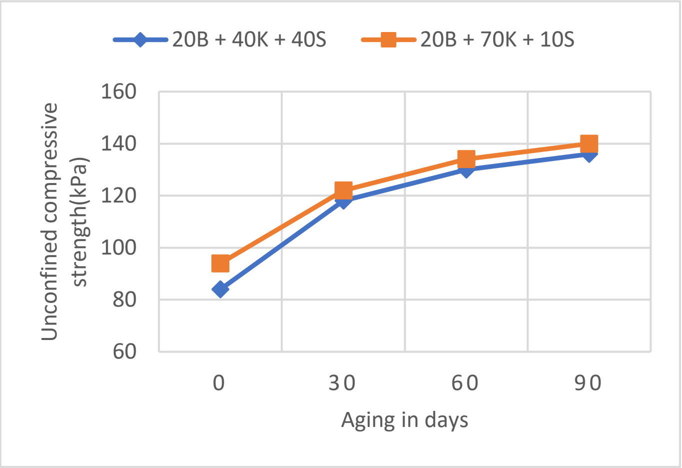

Fig 2: Variation of q_u with aging for Mix Proportion 2a & 2b

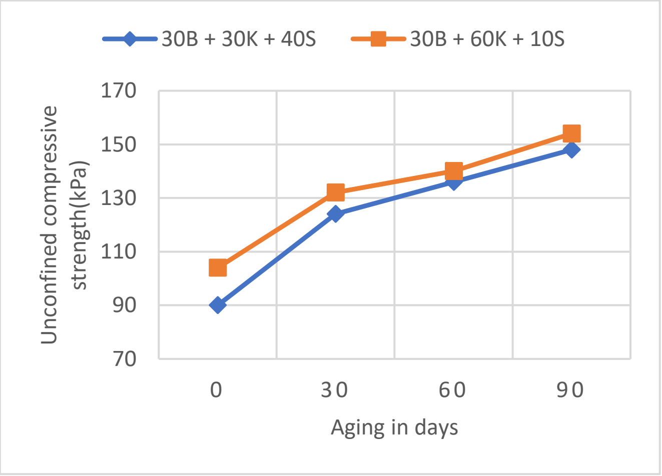

Fig 3: Variation of q_u with aging for Mix Proportion 3a & 3b

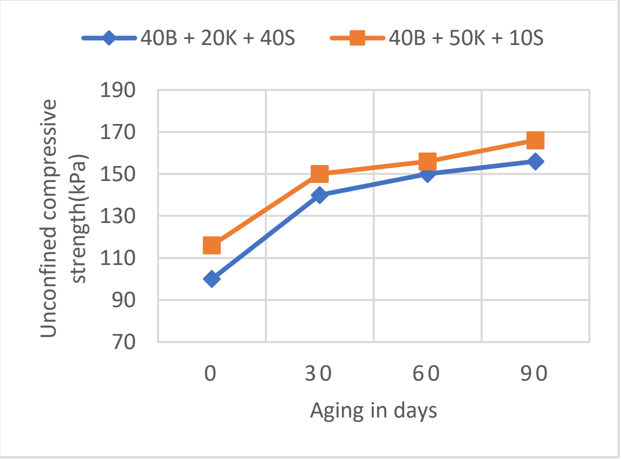

Fig 4: Variation of q_u with aging for Mix Proportion 4a & 4b

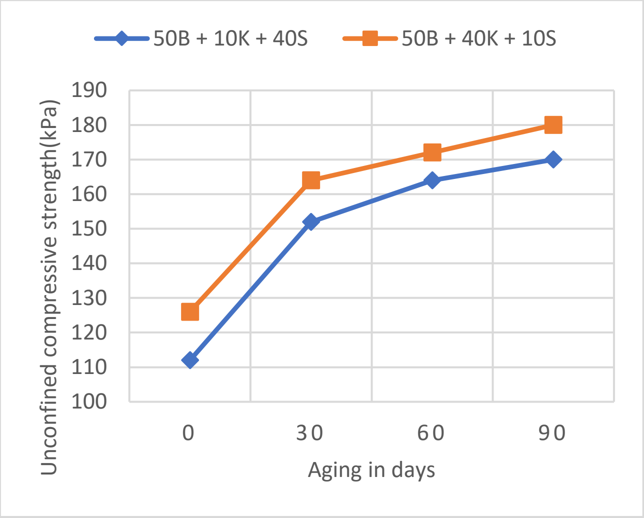

Fig 5: Variation of q_u with aging for Mix Proportion 5a &5b

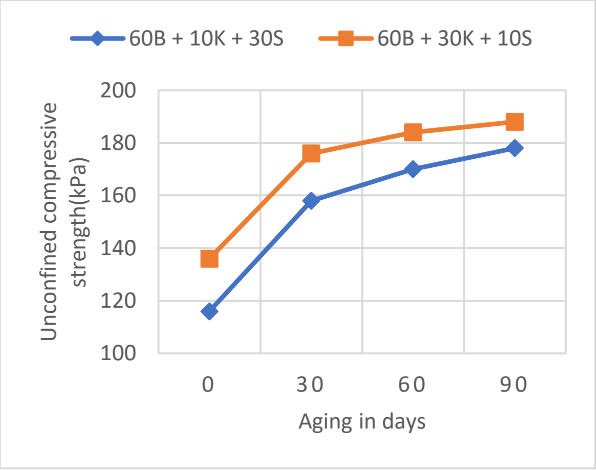

Fig 6: Variation of q_u with aging for Mix Proportion 6a &6b

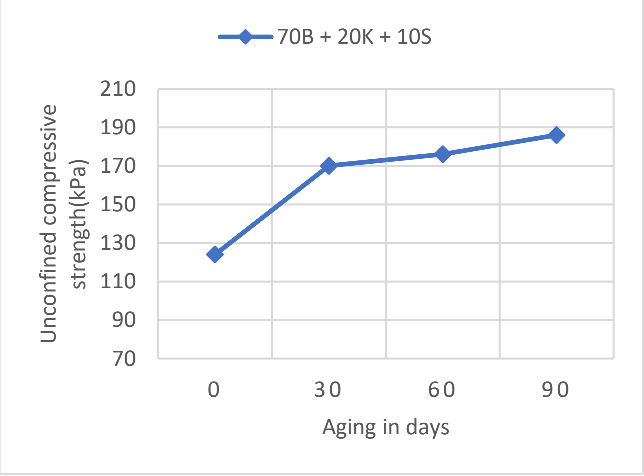

Fig 7: Variation of q_u with aging for Mix Proportion 7

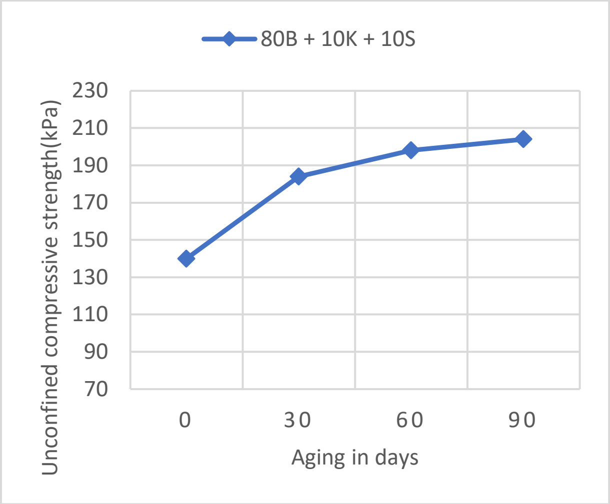

Fig 8: Variation of q_u with aging for Mix Proportion 8

From figures it can be observed that Unconfined compressive strength (q_u) were increased with increasing ageing effect .

Table 4: Mobilized compressive strength for mix proportions

Mix Proportion	Combination	Mobilized Compressive strength (%)	
		0-30 DAYS	30-90 days
1a	10B + 50K + 40S	62.5	37.5
1b	10B + 80K + 10S	54.5	55.5
2a	20B + 40K + 40S	65.5	34.5
2b	20B + 70K + 10S	61	39.0
3a	30B + 30K + 40S	58.50	41.50
3b	30B + 60K + 10S	56.0	44.0
4a	40B + 20K + 40S	71.0	29.0
4b	40B + 50K + 10S	68.0	32.0
5a	50B + 10K + 40S	69.0	31.0
5b	50B + 40K + 10S	70.0	30.0

6a	60B + 10K + 30S	68.0	32.0
6b	60B + 30K + 10S	770	23.0
7	70B + 20K + 10S	74.0	26.0
8	80B + 10K + 10S	69.0	31.0

The mobilized compressive strength expressed in percentage for MP-3 to MP-10 for zero to 30 days and 30 to 90 days are presented in the Table 2 . Mobilized compressive strength with a time period of 0 to 30 days varies from 54.5 percent for MP-3, 77% for MP-9 where the remaining 55.5 to 23 percent of compressive strength attained for the remaining period of 60 days.

3.1 SEM Analysis

The failure soil sample obtained from UCS is taken for microstructure analysis. The mix proportions 1a and 8 were selected for SEM analysis . Mix proportion 1a represents lower shear strength (10B+80K+10S) and mix proportion 8 represents higher shear strength (80B+10K+10S) obtained from the UCS experimental work .

Figure 9 and 10 represents SEM analysis for zero days aging for the mix proportion 10B+80K+10S & 80B+10K+10S respectively . Similarly Figure 11&12, 13&14, 15&16 represents 30,60& 90 days of aging for the Mix proportions 10B+80K+10S & 80B+10K+10S.

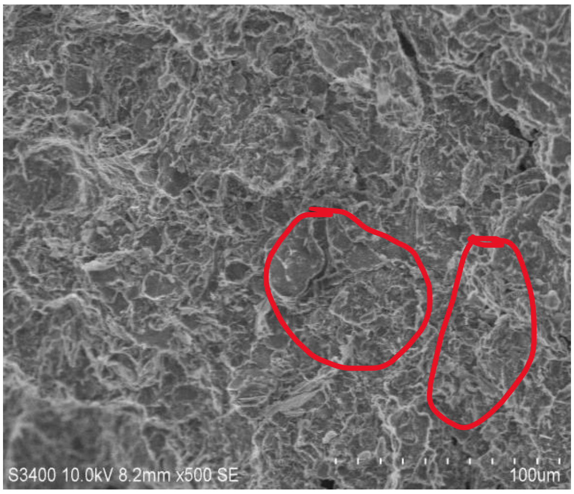

Fig 9 : SEM of 10B+80K+10S (zero days aging)

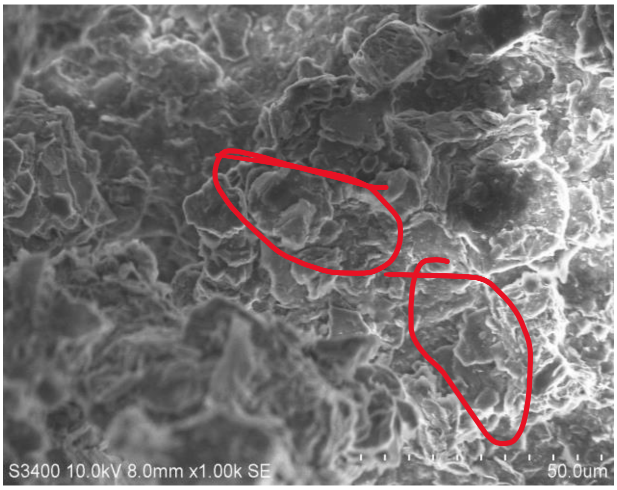

Fig 10 : SEM of 80B+10K+10S (zero days aging)

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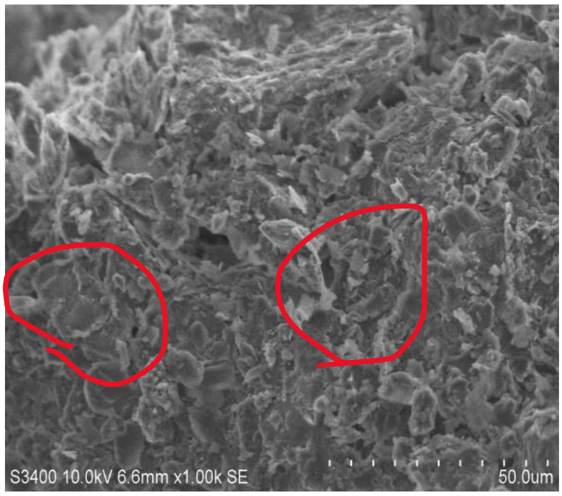

Fig 11 : SEM of 10B+80K+10S (30 days aging)

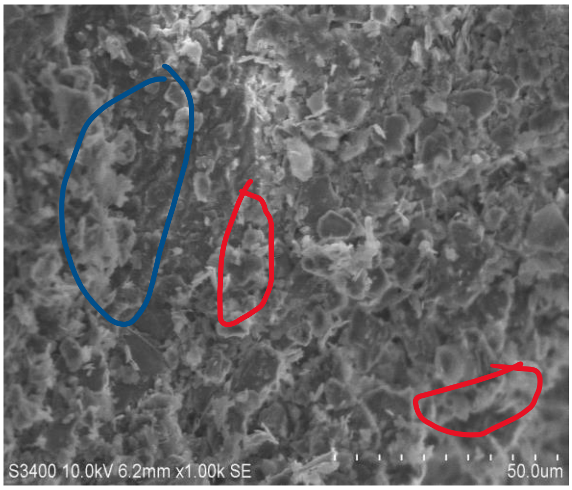

Fig 12 : SEM of 80B+10K+10S (30 days aging)

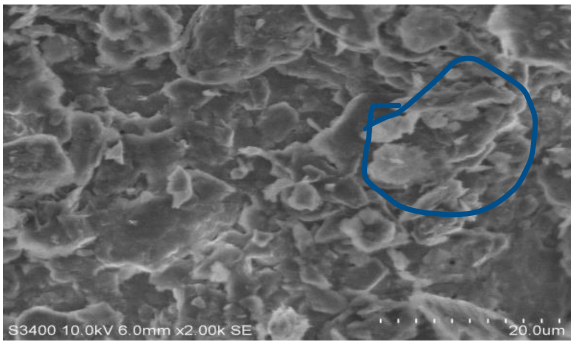

Fig 13 :SEM of 10B+80K+10S (60 days aging)

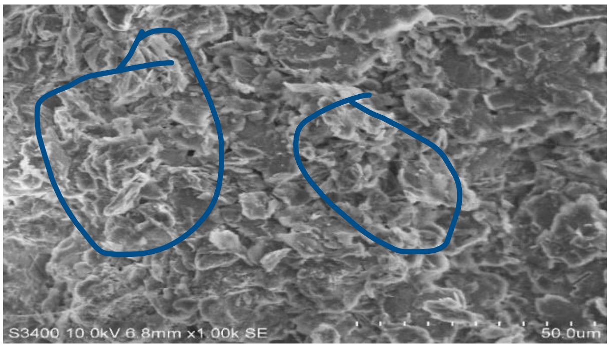

Fig 14 : SEM of 80B+10K+10S (60 days aging)

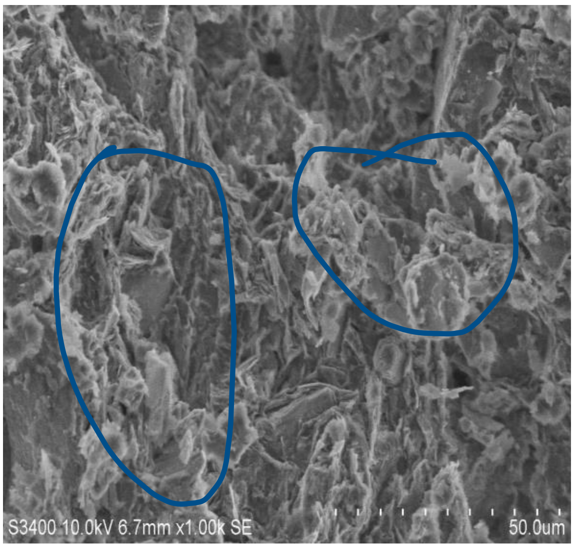

Fig 15 : SEM of 10B+80K+10S (90 days aging)

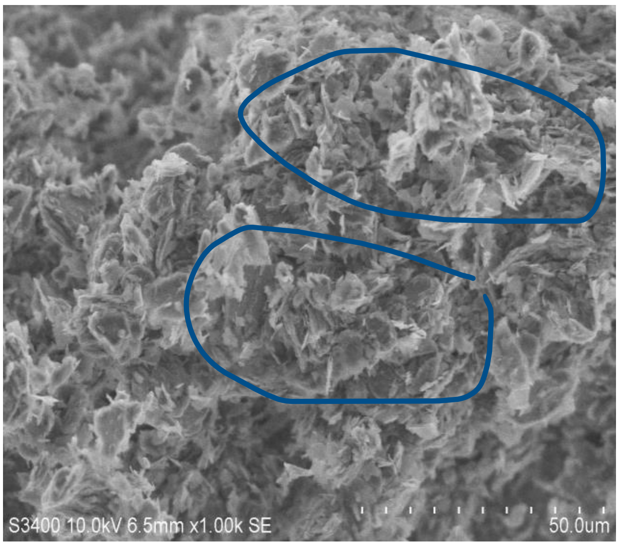

Fig 16 : SEM of 80B+10K+10S (90 days aging)

From the Figures 9 to 16 , the following observations can be made.

- Red marking shows discontinuous and porous surface structure and blue marking shows the formation of white lumps in the surface of the mix proportion.

- From figure 9 and 10 it can be clearly observed that, more void spaces and dispersed structure in mix proportions 10B+80K+10S& 80B+10K+10S for zero days ageing.
- From figure 11 and 12(30 days ageing) it is showing void spaces as well as formation of little white lumps can be observed in the figure 12 that is mix proportion 80B+10K+10S.
- Similarly in figure 13 and 14 (60 days ageing), it can be observed that while lumps are formed, and it is more in 80B+10K+10S and that will be responsible for the denser structure.
- Figure 15 and 16 represents the mix proportion for 90 days ageing and it can be observed that more white lumps, interlocking arrangement, and agglomerate structure formation in figure 16 compared to figure 15, these are responsible for denser and leads to increase in shear strength.

4. Conclusions

- Unconfined compressive strength of mix proportion progressively increases at a higher rate within 45 days of aging and varies progressively at a steady rate from 45 to 90 days.
- For mix proportions 1 to 8, the difference between the minimum values of q_u for zero days of aging varies from 1.1 to 1.17 folds.
- For 90 days of aging the difference between maximum values of q_u varying from 1.02 to 1.18 folds.
- For MP-7 & MP-8, the difference between minimum to maximum values of q_u increases from 1.5 to 1.46 respectively.
- Further the variation of q_u between zero to 90 days of aging increases from 1.41 folds to 1.64 folds for 50 percent fines in the mix proportions 3 to 8.
- Similarly for 90 percent fines the variation of q_u between zero to 90 days of aging increases from 1.38 folds to 1.51 folds.
- From SEM analysis, it was concluded that with an increase in aging formation of white agglomerates occurs and it is responsible for the higher shear strength and with increase in bentonite content intern leading to higher white lumps and increases shear strength in mix proportion.

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