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Improving Characteristics of Clayey Soil Using Basalt Fibre, Construction and Demolition Waste and Calcium Carbide

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Abstract: When exposed to changes in moisture, highly compressible clay soils usually show the characteristic of swelling and shrinking and have very poor strength properties. The infrastructures standing on such soil produce fractures as a result of this feature, making the buildings unstable and liable to collapse. By enhancing the characteristics of clayey soils using soil stabilization can improve their engineering properties. The purpose of this paper tends to investigate the use of construction and demolition waste (C&D), basalt fibre (BF) and calcium carbide (CCR) for stabilization of highly compressible clayey soil. Several laboratory experiments including differential free swell (DFS), Atterberg limits, standard proctor and unconfined compressive strength (UCS) are conducted on soil alone and in combination with admixtures used. Based on UCS result, optimum percentages of C&D waste, basalt fibre and calcium carbide obtained were further tested for California bearing ratio (CBR). The findings show rising UCS and CBR values with addition of 21% C&D waste, 0.3% basalt fibre and 4% calcium carbide in combination to each other with clayey soil. The thickness for flexible pavement was developed using IITPAVE software for CBR values based on specifications of IRC: 37-2018. The software results revealed a decrease in pavement thickness for all combinations of commercial vehicle daily counts of 1000, 3000, and 5000. When clayey soil is combined with C&D waste (21%), BF (0.3%), and CCR (4%) in combination, the greatest reduction in subgrade layer thickness and cost is observed. This method not only improves the geotechnical characteristics of the subgrade layer, aids in decreasing the thickness of the pavement, is highly cost-effective, and resolves the issue of disposal of C&D waste and environmental degradation due to CCR.

Keywords: Clayey soil, unconfined compressive strength, California bearing ratio, construction and demolition waste, basalt fibre, calcium carbide, pavement thickness

1. Introduction

Clayey soils have poor strength properties and a high potential for swelling and shrinkage, both of which are detrimental to structures built on them. Massive settlements and destabilization are brought on by cracks in the structures constructed on these soils. Numerous methods have been employed in the past to address issues brought on by clayey soils (Singh et al., 2014; Kumar et al., 2016; Juneja & Sharma, 2022; Juneja & Sharma, 2022). The process of enhancing the geotechnical and index properties of such soils is known as soil stabilization (Kolias et al., 2005; Harichane et al., 2011). The research showed that each year India produces between 11.46 and 14.69 million tons of C&D waste. As C&D waste accumulates over time, it takes up a significant area of land and impacts the urban qualities environment (Fatta et al., 2013). The use of C&D waste as aggregates in pavements has been investigated by a number of scholars (Ransinchung et al., 2012). If construction debris is used for soil stabilization and pavement construction, it can be the most effective waste management remedy (Sharma et al., 2019) stabilized soil using C&D waste and glass, which alleviated waste disposal concerns and decreased stabilization expenses. Abhijith et al., (2014) evaluated the

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effect of C&D waste on black cotton soil. They found that as stabilizer content increased, PI and OMC reduced and MDD increased. Based on the strength test, 10% C&D waste is ideal, and adding 10% stabilizer increased the soil's SBC from 1411 to 2148 kN/m2. Sharma and Sharma, (2019, 2020) concluded that 24 percent pulverized construction demolition waste reduces DFS to zero, increases soaked CBR value to 5.04, and boosts plasticity index to 7.6%. Also 24% of C&D waste had a 28-day UCS 184% greater than virgin soil, increasing secant modulus 94% and improves permeability.

Basalt fibre has been regarded as the "21st century's nonpolluting green material." Basalt fibres are sustainable, inflammable, explosion-proof, and non-toxic to air and water. Environmental protection, excellent tensile strength, resistance to corrosion, and chemical stability are all features of basalt fibres (Lund, Lund M. Tensile Strength of Glass Fibres. Dissertation, Aalborg University. 2010.). Shear stress can be converted to tensile strength by high-tensile-strength fibres, thus makes the failure plane ductile and strengthens the soil (Chauhan et al., 2008; Zhou et al., 2019). In soft and swelling soil, basalt fibre, increases shear strength, UCS, and reduce swell-shrink potential there by reducing volume change (Kaniraj & Gayathri, 2006; Consoli et al., 2011). Longer fibres are stronger up to 12 mm when length is constant, and increased fibre content reduces strength with an optimal fibre content of 0.25 percent. Clay soil that has been stabilized with fibres is "post-strong" and gradually deforms (Gao et al., 2015). The friction and viscosity of the soil are increased by basalt fibre and silica dust. According to Orakoglu & Liu, (2017) more basalt fibre content minimizes the strength loss caused by freeze-thaw degradation. Loess's strength and resistance to freeze-thaw were strengthened by the inclusion of basalt fibre with a recommended length of 12mm and a basalt content of 0.5% to 1.5% (Dong et al., 2022).

Calcium carbide residue (CCR) is a byproduct of the acetylene synthesis process resulting from the hydrolysis of calcium carbide (CaC2). Due to its high alkalinity and water content, CCR waste causes significant damage to open and subsurface water (Sharma & Reddy, 2004). Du et al. (2011) have suggested using CCR for ground modification. According to Somna et al. (2011) the cementitious reaction between fly ash component SiO2 and CCR component Ca(OH)2 resulted in C-S-H gel, which increased mixture strength. Horpibulsuk et al. (2013) reported better and stronger CCR-stabilized clayey soil engineering as compared to hydrated lime. Noolu et al. (2019) study CCR's effect on black cotton soil deformation results shows that CCR minimizes plasticity and enhances undrained shear strength. Chindaprasirt et al. (2020) examine the CCR-stabilized lateritic soil in order to calculate the UCS, E50, and CBR. In lateritic soil, Ca(OH)2 from CCR combines with silica and alumina in the soil, thus increasing its engineering properties.

It is clear from prior research investigations that adding C&D, basalt fibre (BF), and calcium carbide (CCR) enhances strength of clayey soil. The strength properties of clayey soils utilizing a combination of C&D, basalt fibre, and calcium carbide have not been studied before. Keeping in view the research gap, this study is focused on to evaluate the effect of these materials by varying their percentages on geotechnical properties of clayey soil.

2. Materials Used

2.1 Clayey Soil

The clay used for this research was obtained from the village Jukhala, district of Bilaspur, Himachal Pradesh. The soil samples collected up to a depth 1-1.5meters below the surface is collected, sealed, and transported to the laboratory of NIT Hamirpur for experimental work. The soil is completely dried in natural sunlight and pulverized using a pulverizer. For determining the different physical qualities of the soil, applicable ASTM (American Society for Testing and Materials) standards were used. The soil has been classified by the USCS (Unified Soil Classification System) as a clay soil having high plasticity (CH). The particle size distribution curve for soil used is given in Fig. ***1***. Geotechnical Properties and mineralogical composition of the clayey soil used are mentioned in **Error! Reference source not found.** and **Error! Reference source not found.**.

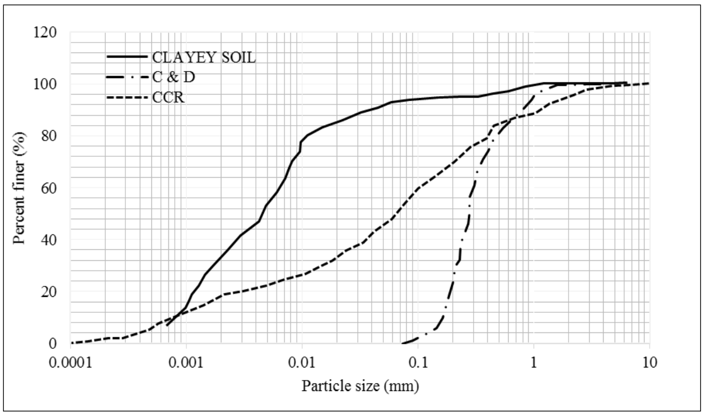

Fig. 1 - Particle size distribution curve for clayey soil, C&D waste and calcium carbide (CCR)

Table 1 - Geotechnical Properties of clayey soil

Soil characteristics	Value
Differential free swell index, (%)	40
Specific gravity	2.59
Maximum dry density, (g/cc)	1.76
Optimum moisture content, (%)	16.5
Liquid limit, (%)	53
Plastic limit, (%)	20
Plasticity Index, (%)	33
Classification	CH
Unconfined compressive strength, (kPa)	514
Soaked California bearing ratio, (%)	2.3

Table 2 - Mineralogical composition of clayey soil

Mineral components	Percentage, (%)
Oxygen, O	45.5
Silicon, Si	18.6
Carbon, C	10.9
Aluminium, Al	8.69
Titanium, Ti	2.51
Magnesium, Mg	2.30
Potassium, K	1.86
Iron, Fe	1.42

2.2 C&D Waste

The C&D waste for present research was acquired from the dismantled beams of a structure near Hamirpur, HP. The material was brought to the laboratory in fibre bags. In the laboratory, C&D was dried before being crushed to a particle size range of 4.75–0.075 mm and sieved. To prevent modifications in moisture content, the C&D waste was kept in polythene bags that were tightly sealed. Based on particle size distribution curve C&D waste can be categorized as SP (poorly graded sand) according to Indian standard soil classification system (IS1498 1970). The characteristics of the C&D waste used mentioned in **Error! Reference source not found.**.

Table 3 - Geotechnical properties of C&D waste

C&D waste characteristics	Value
Specific gravity	2.52
Maximum dry density, (g/cc)	1.68
Optimum moisture content, (%)	12.5
Classification	SP

2.3 Basalt Fibre

Basalt fibre used for research is provided by the Go green products Company Chennai, Tamil Nadu. The length of basalt fibre used in this research is 12mm. Before the strip of basalt fibre is distributed in the soil sample, it is split and then evenly integrated into the clayey soil. The basalt fibre is thread - like structures, and its fundamental physical and mechanical characteristics are outlined in **Error! Reference source not found.**.

Table 1 - Characteristics of basalt fibre (BF)

Property	Value
Colour	Golden brown
Length, (mm)	12
Diameter, (µm)	13-20
Specific gravity	2.61
Tensile strength, (MPa)	3000-4500

Modulus of elasticity, (GPa)	85-90
Water absorption, (%)	<0.3%

2.4 Calcium Carbide

The powder mixture of calcium carbide (CCR) was supplied from an industrial supplier. The powder mixture then dry sieved through No. 40, 425 micron sieve to eliminate heavier particles. The CaO content of CCR used in the present study is exceptionally high and it also consist number of pozzolanic contents implies that it should act vigorously to form a cementitious substance. The chemical constituent of CCR mentioned below in **Error! Reference source not found.**.

Table 5 - Characteristics and chemical composition of calcium carbide (CCR)

Characteristics	Value
Specific gravity	2.32
Specific surface area, (m^2/g)	24.66
Chemical composition, (%)	
Calcium oxide (CaO)	71.56
Silicon dioxide (SiO_2)	7.64
Aluminium oxide (Al_2O_3)	3.08
Iron oxide (Fe_2O_3)	3.45
Magnesium oxide (MgO)	0.7
Sulphur trioxide (SO_3)	0.61
Potassium oxide (K_2O)	8.61
Loss on ignition (LOI)	1.45

3. Results and Discussion

3.1 Differential Free Swell Index

DFS index for clayey soil was calculated to be 40%. Which tend to decrease as the amount of C&D (7%, 14%, 21% and 28%) waste increases and reaches zero at 21% C&D waste (Figure 2). With further increase in C&D waste, the DFS value remains unchanged. This can be attributed due to higher proportion of coarse particles in the soil–C&D mixture, which reduces surface activity. The decreasing trend in DFS index with inclusion of C&D was evidenced earlier by researchers (Sharma & Sharma, 2019-2020; Sharma and Hymavathi, 2016).

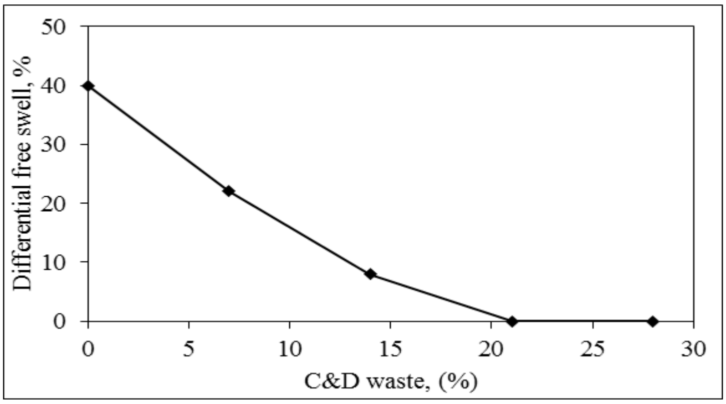

Fig. 2 - DFS for soil with C&D waste in different percentages

Addition of 8 percent CCR (4, 6, 8 and 10%) into clayey soil decreased DFS value up to 3%, and subsequent additions of CCR to soil had a minimal impact on the DFS value (Figure 3). According to Mahesh et al. (2021), treating soil with CCR significantly reduced its ability to swell. This is because the cementitious material interacts with the clay particles.

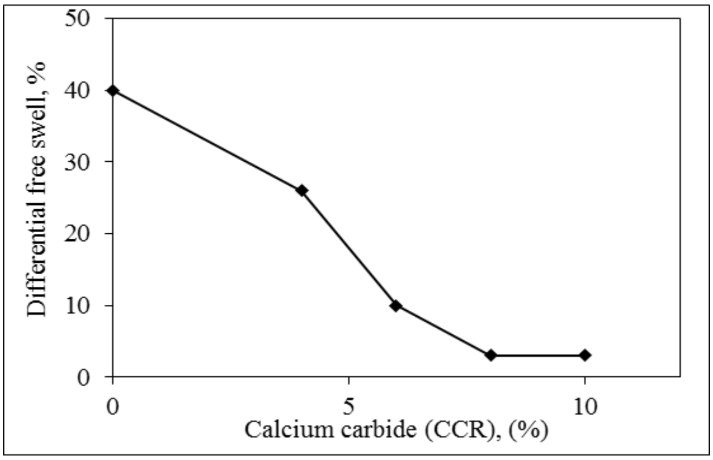

Fig. 3 - DFS for soil with calcium carbide in different percentages

3.2 Consistency Limits

Based on the test conducted, it was found that liquid limit (LL) and plasticity index (PI) of the clayey soil were 53% and 33%. As per the PI chart, the values of the LL and PI fall within range of clayey soil having high plasticity (i.e., CH). Thus, soil needs stabilization before being subjected to any type of construction work.

When 7, 14, 21, or 28% C&D is added with clayey soil LL along with PI decrease. This decrease in LL may be due to the non-plastic and granular structure of C&D waste particles, which further leads to less swelling of the soil (**Error! Reference source not found.**). Addition of 21% C&D waste may be considered optimal because further additions would make it unusable due to higher sand content lead to lower binding properties as a result of decreased cohesion. The same behaviour has been observed in C&D waste-stabilized clayey soils in the past (Abhijith et al., 2014; Sharma & Hymavathi, 2016; Sharma & Sharma, 2021).

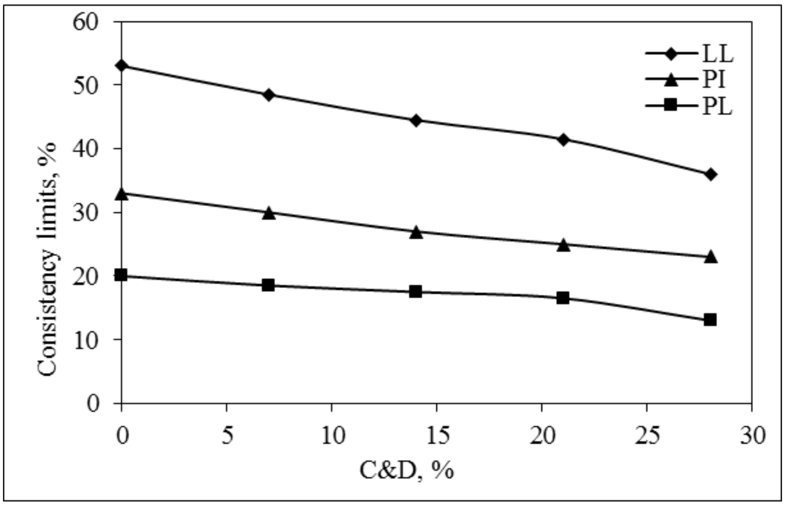

Fig. 4 - Consistency limits for C&D waste mixed clayey soil

Adding 0.2, 0.3, 0.4, and 0.5 percent BF to clayey soil lead to small increase in LL and PL and, consequently, decrease in PI. The PI decreases as fibre content increases from 0.2 to 0.4 percent; further addition shows no significant decrease (**Error! Reference source not found.**). Thus, 0.4 percent can be taken as the optimum content for further soil stabilization processes. The increase in LL can be explained by the fact that fibre itself absorbs water. Researchers have observed an analogous trend of BF treated clayey soil (Ayothiraman and Singh, 2017**Error! Reference source not found.**).

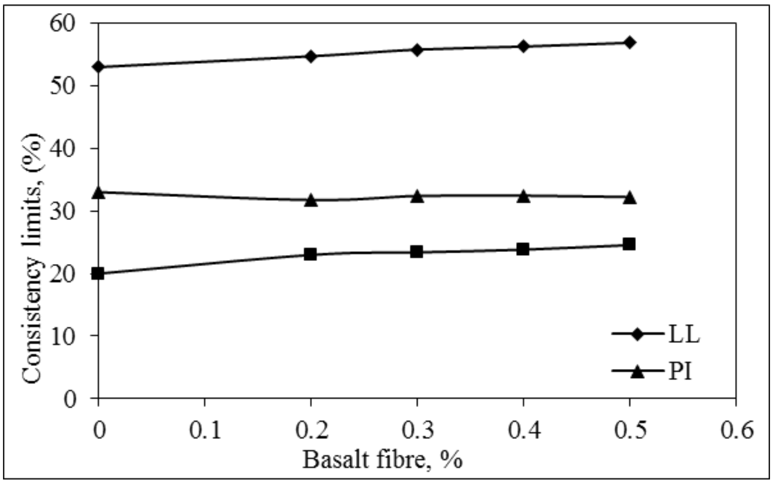

Fig. 5 - Consistency limits of basalt fibre mixed clayey soil

Addition of 4, 6, 8 and 10 percent CCR to clayey soil leads to decreases in LL and the PL tends to increase, causes decrease in PI (**Error! Reference source not found.**). Addition of CCR in excess of 8% did not result in significant decrease in PI; therefore, it may be regarded as optimal level for soil stabilization. The decrease in PI is result of flocculation, which causes a larger and stiffer aggregation of clay particles as a result of Ca^{2+} absorption during cation exchange phenomenon. Although, when CCR exceeds 8 percent, the decrease in PI is negligible. A few researchers in the past have observed that CCR-stabilized soil exhibits similar behaviour Horpibulsuk et al. (2013).

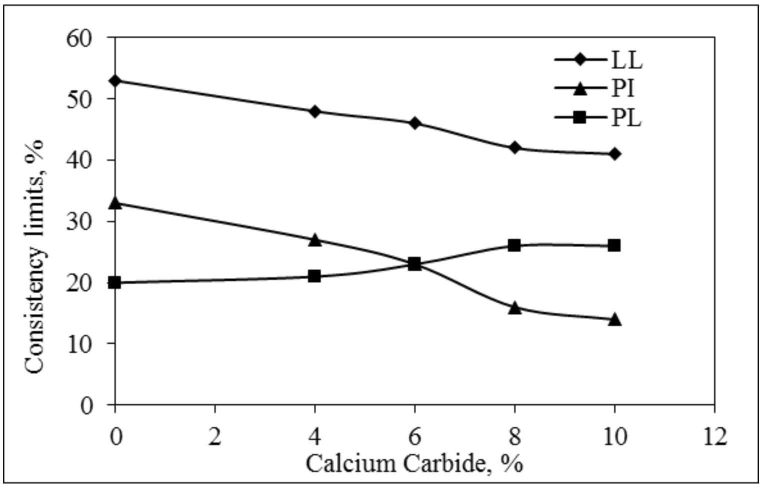

Fig. 6 - Consistency limits of CCR mixed clayey soil

The combined effect of BF in varying proportions of 0.2, 0.3, 0.4, and 0.5 percent and C&D waste (21 percent, based on DFS) increases the LL slightly and significantly, increases the PL of the composite, which decreases PI (**Error! Reference source not found.**). Maximum decrease in PI is when BF content of 0.3% is added to clayey soil containing 21% C&D waste. However, after 0.3 percent BF, there was little change in the PI; therefore C: C&D: BF: 78.7:21:0.3 may be chosen for soil stabilization. This is possibly because of the increase in liquid limit due to absorption by fibre and decreased the clayey soil's ability to swell due to larger particles of C&D waste.

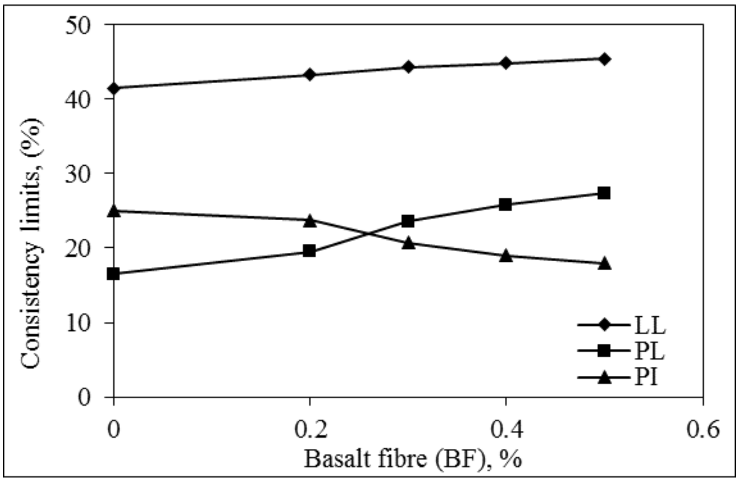

Fig. 2 - Consistency limits of BF-C&D waste mixed clayey soil

Addition of 4% to 10% CCR and 0.4% BF to soft soil reduction in LL and surge in the PL is observed. The PI of composite decreased the most when 8 percent CCR was added to BF-stabilized soil (**Error! Reference source not found.**). Further addition of CCR to BF-stabilized clayey soil in excess of 8 percent did not result in greater variation in PI; therefore, the combination C: BF: CCR: 91.6:0.4:8 may be considered optimal for soil stabilization.

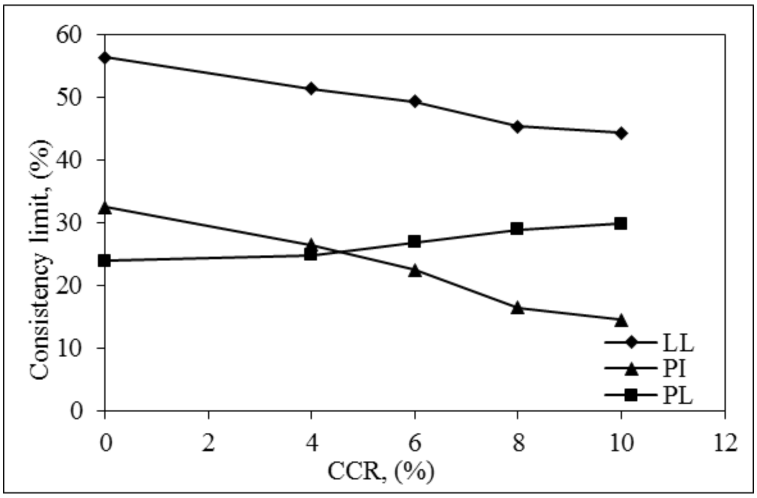

Fig. 8 - Consistency limits of CCR-BF mixed clayey soil

On addition of 4 to 10 percent of CCR and 21 percent C&D to clayey soil reduces LL and increased PL. Maximum reduction in composite PI occurred when 6 percent CCR was added to C&D waste-stabilized soil (**Error! Reference source not found.**). Inclusion of CCR in excess of 6 percent to C&D waste-stabilized clayey soil did not lead to a greater variation in PI; therefore, C: C&D: CCR in the ratio of 73:21:6 may be considered optimal for soil stabilization.

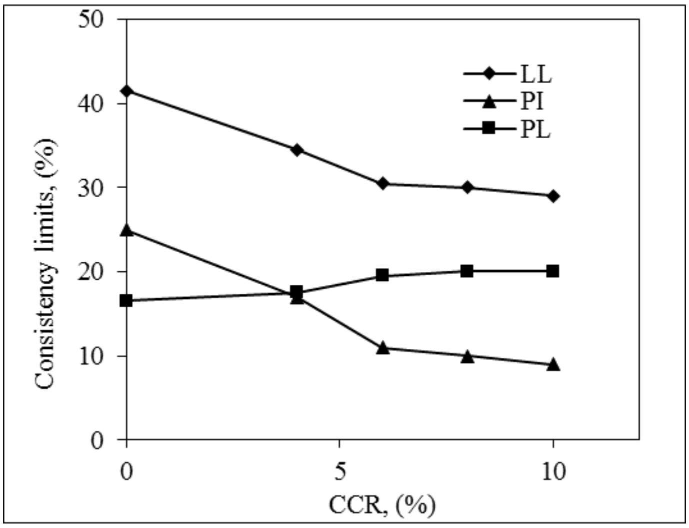

Fig. 9 - Consistency limits of CCR-C&D waste mixed clayey soil

The addition of increasing amounts of CCR (4, 6, 8, and 10 percent) to the C:C&D:BF::78.7:21:0.3 mixture reduce d the LL and marginally increased the PL of the composite (**Error! Reference source not found.**). The PI of the composite declined significantly upon addition of CCR up to 4 percent in the C: C&D: BF mixture, and increasing the CCR content more than 4% resulted in a very small percentage variation in the PI of combination; therefore, 4% CCR can be considered as the optimal percent for stabilizing soil when combined with the optimal contents of C&D (21 percent) and BF (0.3 percent).

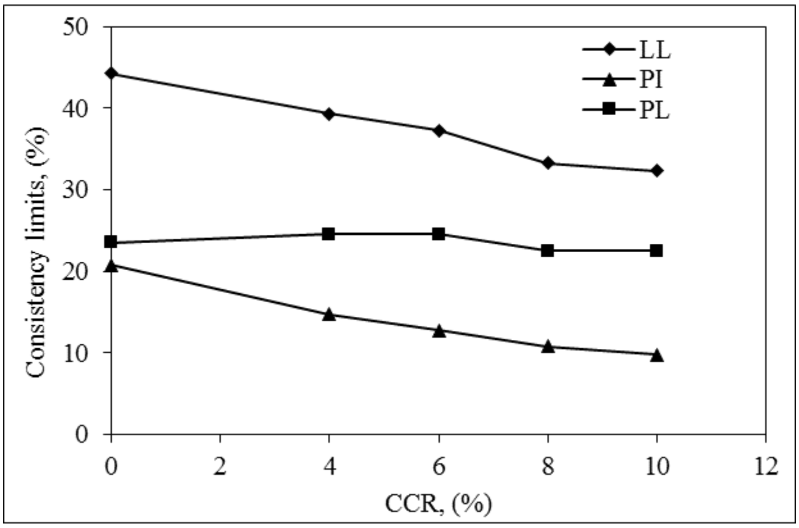

Fig. 3 - Consistency limits for C&D-BF-CCR mixed clayey soil

3.3 Compaction Characteristics

Optimum moisture content (OMC) and Maximum dry density (MDD) of clayey soil were obtained as 16.5% and 1.76 g/cc. The addition of C&D (7, 14, 21, and 28%) in clayey soil reduces OMC from 16.5% to 12% and MDD from 1.76 to 1.65 g/cc (**Error! Reference source not found.**). Reduction in OMC is attributable to the presence of sand because it has a lesser specific surface area as of soil. There are two possible explanations for the decline in MDD can be: because C&D waste has a lower specific gravity than soil, and the result of the flocculation or aggregation of unreacted cement opposes densification. Some researchers had previously observed a decrease in MDD and OMC due to incorporation of C&D waste into clayey soil (Sharma & Sharma, 2019-2020; Sharma & Hymavathi, 2016; Sharma and Hymavathi 2016).

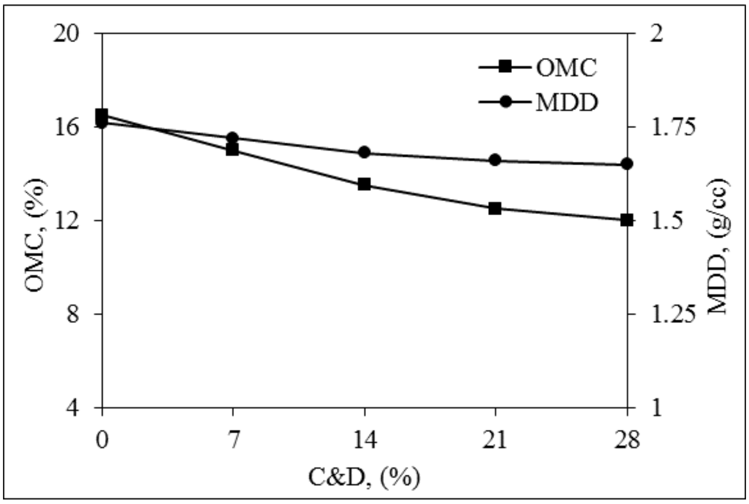

Fig. 11 - Variations of MDD and OMC with different percentages of C&D waste

In clayey soil, adding BF in different percentages of 0.2%, 0.3%, 0.4%, and 0.5% resulted in an increase in OMC from 16.5 to 19.5 percent and a decreases MDD 1.76 to 1.70g/cc (**Error! Reference source not found.**). Fibres added to the soil increase its porosity, which raises the OMC and necessitates the use of more water to achieve MDD. Another factor contributing to an increase in the OMC percentage is the ability of fibre to absorb moisture, even to a lower extent. The substitution of fibres in soil and the lesser density of fibres in comparison to soil can both contribute to MDD loss. Additionally, fibres act as reinforcement create a flexible conditions in soil and counteract compressive strength. As a result, maximum fibre-reinforced soil has a lower dry specific gravity. Other studies have made reference to this finding (Bharwaj and Walia, 2016; Bhardwaj et al., 2017; Ranjan et al., 1994).

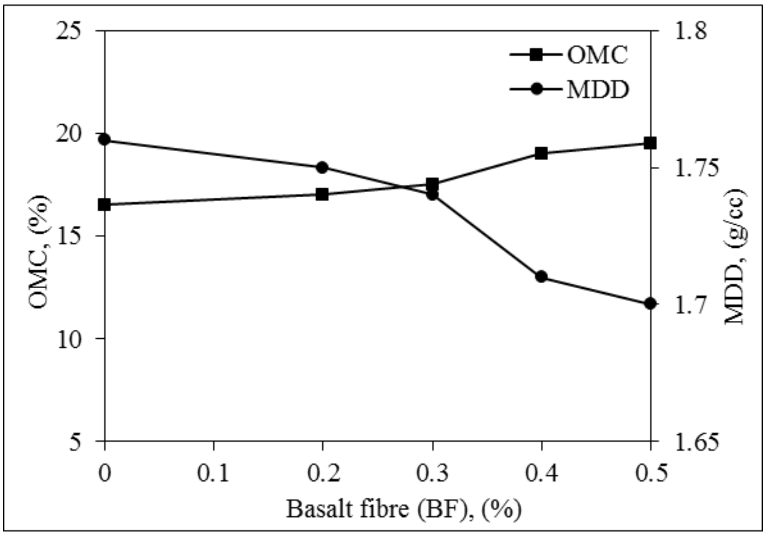

Fig. 12 - Variations of MDD and OMC with different percentages of basalt fibre (BF)

When CCR is added to soft clay at varying percentages of 4, 6, 8, and 10 percent, it resulted in an increase in OMC from 16.5 to 20 percent and decrease MDD from 1.76 to 1.64 g/cc (**Error! Reference source not found.**). As CCR content increases, the MDD decreases due to lower specific gravity of CCR, which lowers the mixture's overall weight. Another factor could be a change in stabilized soil's ability to compact due to variations in particle aggregation during the compaction. Variation in surface area due to introduction of CCR is linked to reduction in the water sensitivity of CCR-stabilized soil, which has been assumed to explain the rising trend in OMC. After a certain percentage of CCR was added, the MDD and OMC changed less with each additional percentage of CCR because the calcium ions from the CCR were in equilibrium with the negatively charged clay particles. Some researchers have reported an analogous trend for CCR treated soil (Horpibulsuk et al., 2013; Horpibulsuk et al., 2015; Jiang et al., **Error! Reference source not found.**2015).

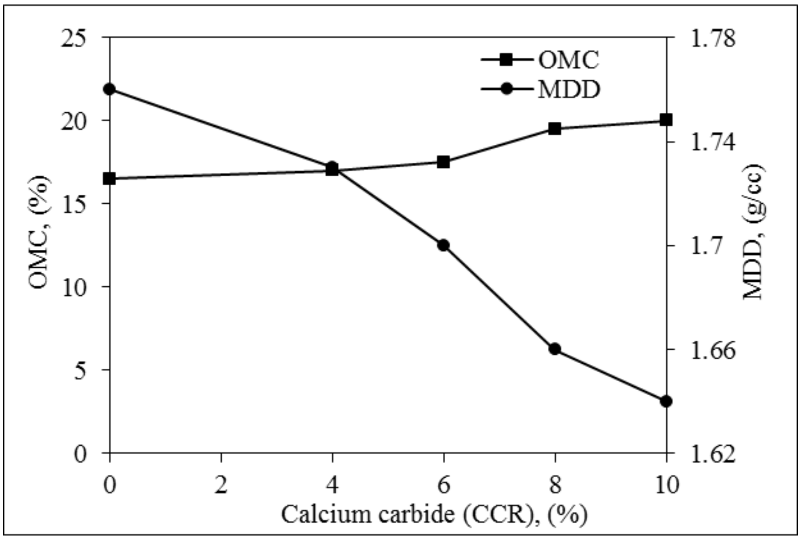

Fig. 13 - Variations of MDD and OMC for varying percentages of calcium carbide (CCR)

Adding BF (in various percentages 0.2, 0.3, 0.4, and 0.5 percent) in combination with optimal C&D waste content (21 percent) in clay increases OMC from 12.5 to 15.5 percent and MDD from 1.66 to 1.60 g/cc (Figure 14). The rise in OMC might be attributable to fact that fibre absorbs moisture, even if to a lesser extent. The additional reduction in MDD value caused by adding BF to C&D waste stabilize poor soil may be because of the reduced density of BF fibers, especially in comparison to that of the soil-C&D mixture.

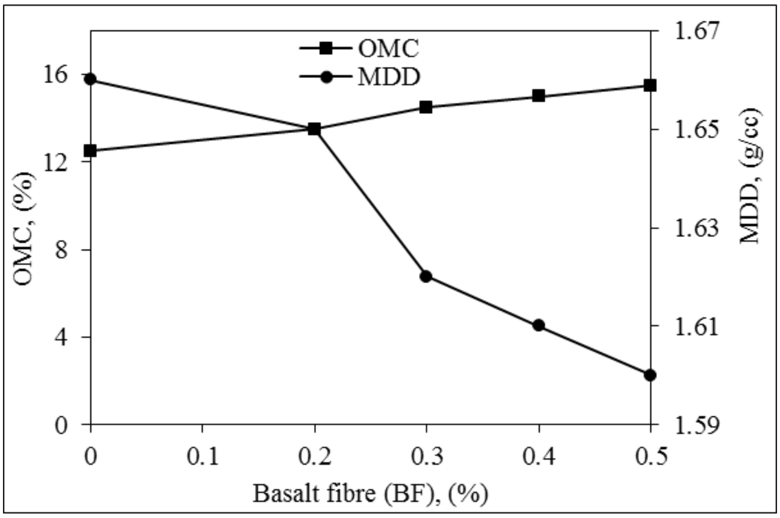

Fig. 14 - Variation of OMC and MDD with varying percentage of BF keeping C&D waste constant (i.e. 21%)

The OMC value increases from 19 to 22.5 percent when varying amounts of CCR (4, 6, 8, and 10 percent) are added to the C: BF: 99.6:0.4 mixture, while MDD decreases from 1.71 to 1.59 g/cc (Figure 15). Increase in OMC might attribute to the fact that, as CCR content increases, increase in moisture has minimal effects on dry unit weight and water-absorbent by fibres. Decrease in MDD might be attributed to the lesser CCR and BF density.

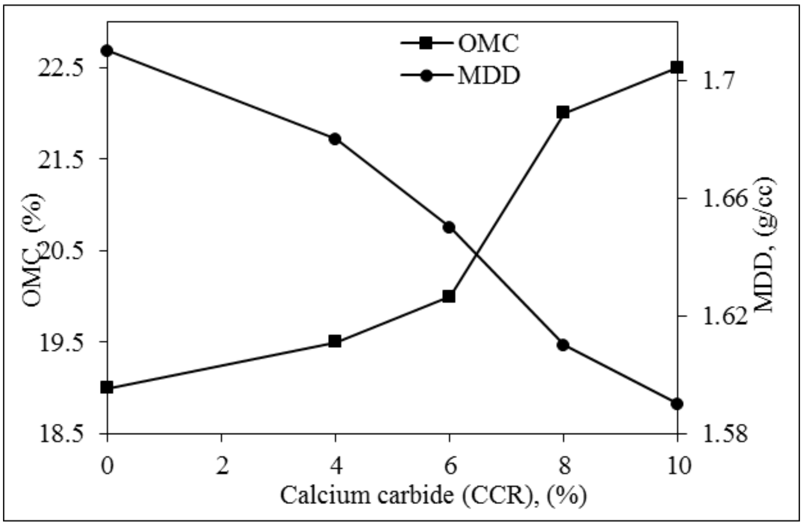

Fig. 15 - Variation of MDD and OMC on varying the content of CCR and keeping BF constant (i.e. 0.4%)

On adding varying amounts of CCR (4, 6, 8, and 10 percent) to the C:C&D:79:21 mix, OMC increases from 12.5 to 15.5 percent, while MDD decreased from 1.66 to 1.54 g/cc (Figure 16). Decrease in MDD value may be attributable to the clayey soil's smaller specific gravity and the rapid creation of cementitious products. This decrease in MDD correlates to rise in optimal water content (OWC). With increase in CCR, the admixture induces changes in specific surface area and the moisture-absorption of the CCR in addition to C&D waste stabilized clay decreases, i.e. a significant increase in moisture contents results in only a minimal variation in dry unit weight. A few researchers have observed similar behavior of a CCR-stabilized clay soil in the past Phetchuay et al. (2015).

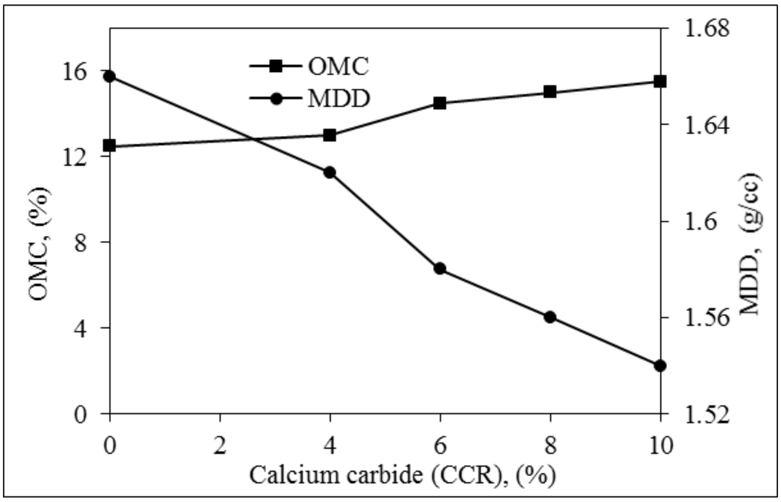

Fig. 16 - Variation of percentage of CCR by keeping C&D waste constant (i.e. 21%)

The addition of CCR (4, 6, 8, and 10 percent) to the C: C&D: BF: 78.7:21:0.3 mixture increased OMC by 14.5 to 18.5 percent and decreased MDD by 1.62 to 1.50 g/cc (**Error! Reference source not found.**). Increase in OMC might be attributable to rise in surface area and capacity to absorb water. Decrease in MDD might be attributable to the lower density of the BF relative to that of the soil and lesser specific gravity of CCR along with the creation of the cementitious product.

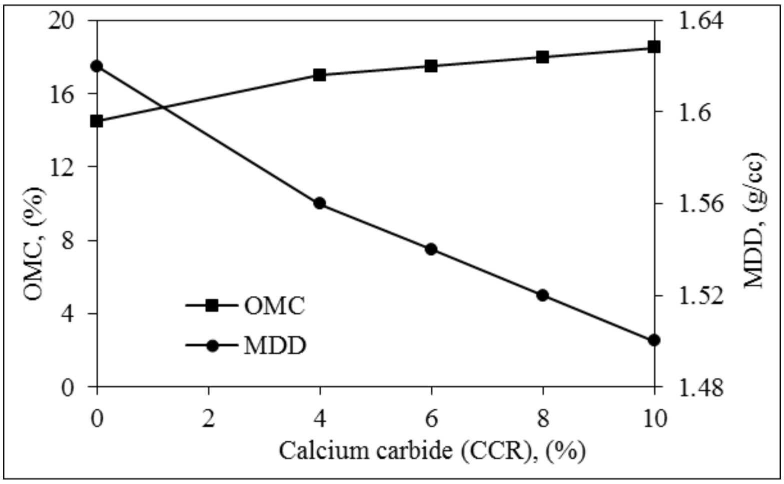

Fig. 17 - Variation of percentage of CCR keeping C&D waste (21%) and BF (0.3%) constant

3.4 Unconfined Compressive Strength Test

Unconfined Compressive Strength (UCS) test was carried on both unadulterated clay and various mixtures of C&D waste, basalt fibre with calcium carbide as conformance with ASTM D2166-16 to identify the effect of the admixtures on the soil's strength properties. The observed UCS values of clayey soil cured for 3 days, 7days and 28 days are 313kPa, 421kPa and 514kPa respectively. With addition of 21 per cent C&D waste, 0.4 per cent basalt fibre and 8 per cent calcium carbide individually with clayey soil the UCS values for curing period of 28 days found to increased value of 886kPa, 640kPa and 950kPa. Further UCS test is performed to find combined effects of the optimum amounts on UCS. Results shows adding C&D waste with basalt fibre to clay in the optimum quantity resulted in UCS of 1060 kPa after curing for 28 days (C:C&D:BF::78.7:21:0.3); on the other hand, adding C&D waste and calcium carbide to clayey soil in the optimum quantity resulted in the UCS value of 1269kPa (C:C&D:CCR::73:21:6); while addition of basalt fibre and calcium carbide in clay in optimum percent attained UCS value of 1098kPa (C:BF:CCR::91.6:0.4:8). The highest value of UCS was obtained after inclusion of C&D waste, basalt fibre, and calcium carbide together with clayey soil in the optimal combination (C:C&D:BF: CCR::74.7:21:0.3:4) was found as 1394kPa beyond which any further increase in UCS value is almost negligible for 28 days curing.

It has also been documented in the past that the UCS value increases as C&D waste increases up to its optimal amount in clayey soil (Ransinchung et al., 2012; Sharma & Hymavathi, 2016; Sharma & Hymavathi, 2016). The increase in UCS value is due to pozzolanic/cementitious reaction between clayey soil and C&D waste which leads to alteration in properties of clayey soil.

Increase in UCS and ductility is observed due to inclusion of the BF up to its optimum content, which was also previously observed (Gao et al., 2015; Sharma, 2017). With increase in fibre content density increases which make the contact area between the fibres and surrounding soil increasing this directly leads to increase in friction between soil and fibre.

Results from previous research on the effect of adding CCR to clayey soils have shown that the soil's strength characteristics are enhanced after the addition of CCR Phetchuay et al. (2015). Which may be is due to presence of significant amount of $Ca(OH)_2$ in CCR which increases with increase in CCR content and curing time.

Additional research to consider the impact for curing time on UCS for a number of different mixes found that as curing time was increased 3, 7 and 28 days, UCS was found to increase for all the combinations. For C:C&D:BF::78.7:21:0.3 combination, percentage of 5 percent and 118 percent was seen as the curing duration was extended from 3 to 7 days and 28 days; for C:C&D:CCR::73:21:6 combination, a percentage increase of 73 percent and 139 percent been observed as the curing duration was extended from 3 to 7 days and 28 days lastly for C:C&D:BF:CCR::74.7:21:0.3:4 combination, a percentage increase of 67 percent and 188 percent been observed as curing duration was extended from 3 to 7 days and to 28 days (**Error! Reference source not found.**).

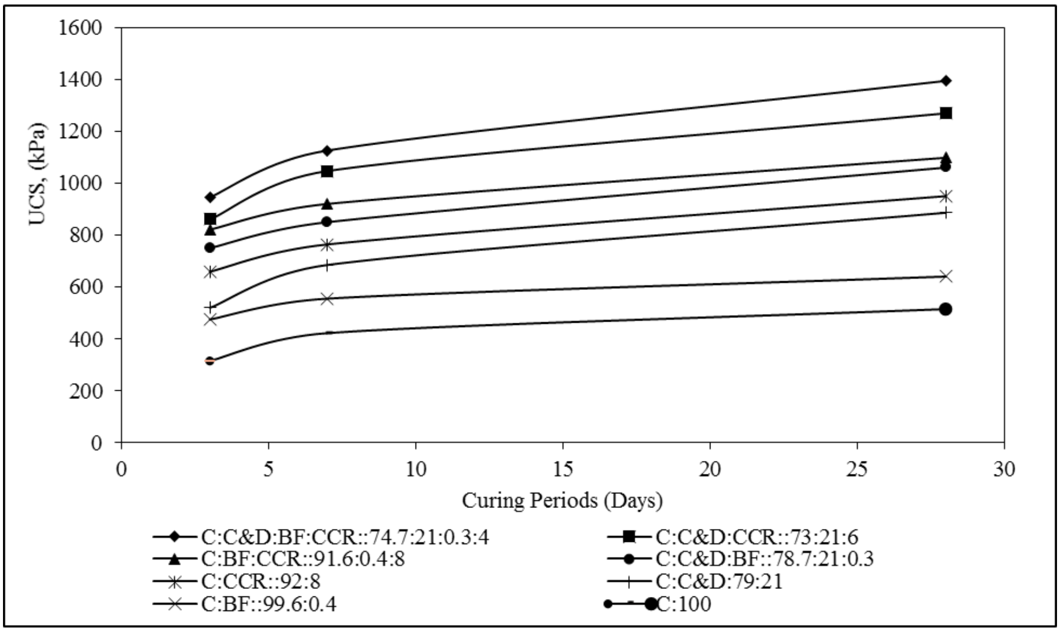

Fig. 18 - UCS for clayey soil improved using various proportions of admixtures for different curing periods

3.5 California Bearing Ratio

The California bearing ratio (CBR) test is employed to assess the load-bearing potential of subgrades used to construct flexible pavements. In accordance with ASTM D1883-05 (2005), for pure clay and clay treated with C&D waste, BF, and CCR in wet condition, a number of CBR tests were carried out. The specimens are compressed at their MDD and ideal water content, as per standard Proctor compaction procedure. In an effort to simulate the adverse moisture conditions that may result from rain or flooding, specimens were submerged in a storage tank over four days.

Based on the results of soaked CBR test, CBR value for soil samples was found to be 2.3%. As per IRC-SP-77 (2008) CBR value of soil less than 5% are typically considered poor, therefore it is not recommended in India to use such soil without any improvement to soil. Despite the short curing time, inclusion of additives C&D waste, BF with CCR significantly increased CBR value of clayey soil (**Error! Reference source not found.**).

Clayey soil's CBR enhanced from 2.3% to 5.7% when the optimal amount of BF 0.4 percent was added. Due to generation of friction opposition among the fibre and adjoining soil improves strength of clay that has been stabilized with BF. Similar results were observed in the past (Sharma, 2017; Bhardwaj and Walia, 2016; Bhardwaj et al., 2017; Ramesh et al., 2019). CBR for clayey soil enhances from 2.3% to 6.1% with optimal C&D waste content (21%). This is caused by existence of sand in C&D waste that mobilize shear resistance angle, thereby results in higher strength and ability to resist larger compressive loads. In the past, some researchers have observed a similar trend Sharma and Hymavathi (2016**Error! Reference source not found.**).

When optimum CCR (8%) added to clayey soil, CBR value increased from 2.3 to 7.8%; which may be due to large amount of clay particles that react with binding material. This finding is thought to be the outcome of the development of hydration as well as cementitious reactions with regard to curing time, during which cementitious products like calcium silicate hydrate (C-S-H) and calcium alumina hydrate (C-A-H) are produced and begin aiding in the cementation bond formation around grains. Various researchers have observed comparable results in the past Jiang et al. (2015). In addition, a CBR finding for optimal mix is studied, and result shows that CBR for clay increases dramatically.

CBR increases from 2.3% to 9.3% for optimal combinations for C&D waste with basalt fibre (C:C&D:BF::78.7:21:0.3).The enhancement in CBR might be attributable with shear resistance provided by the C&D waste and frictional resistance provided by the fibre to the clayey soil.

CBR improve from 2.3% to 9.8% for an optimum combination of BF and calcium carbide (C: BF: CCR: 93.6:0.4:8) in clayey soil. Increased CBR might be result of pozzolanic reaction leading to the formation of cementitious products and the surface resistance provided by the fibres.

CBR increases from 2.3% to 10.4% for optimal combinations of C&D waste with calcium carbide (C: C&D: CCR: 73:21:6). Increased CBR might be result of C&D providing greater resistance to load and the pozzolanic reaction caused by CCR causing particle aggregation which binds them together.

CBR increases from 2.3% to 10.6% for optimal combinations of C&D waste, BF along with CCR (C: C&D: BF: CCR:: 74.7:21:0.3:4) Increase CBR might be due to the fact that shear resistance provided by the C&D waste, frictional forces provided by the fibre, and the addition of calcium carbide result in the formation of a concrete mixture product.

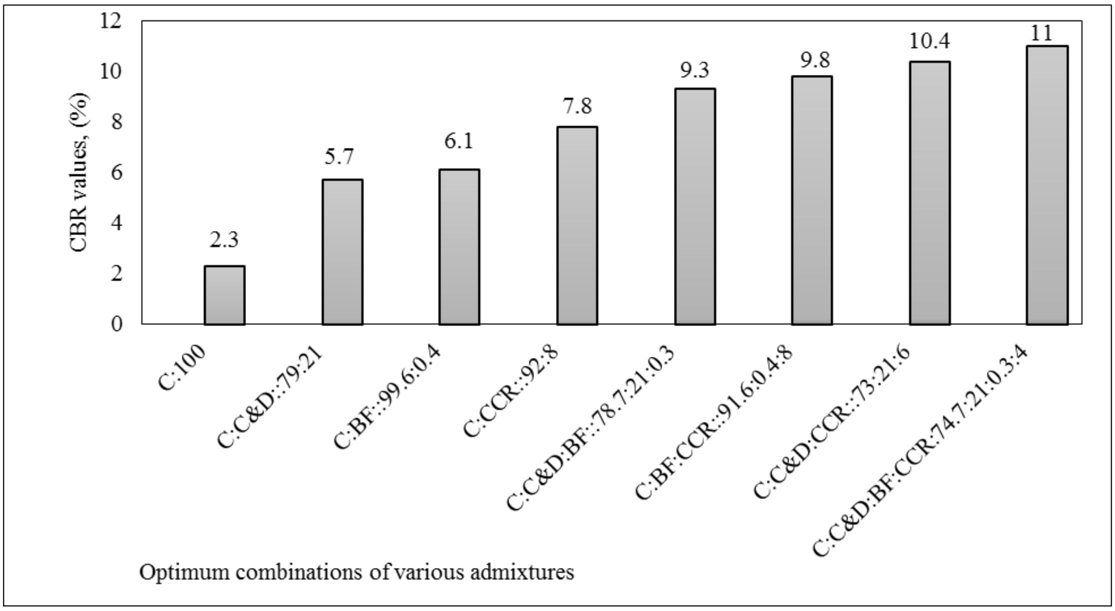

Fig. 19 - CBR values for optimum combinations of various admixtures

4. Pavement Design

Through India, concrete pavements contribute to less than 5% of total roadways, while flexible pavements comprise the remaining 95%. The subgrade properties upon which road are placed; the applied loads and the environment are significant characteristics to design flexible pavement. As the CBR value increases there is decrease in pavement thickness and vice versa. With reduction in pavement thickness less amount of bitumen is required for construction of pavement thus making the process of flexible pavement design more cost-efficient. In present research IITPAVE application utilized to calculate fluctuation of pavement thickness with change in CBR values.

4.1 IITPAVE Software

To examine layered pavement systems with continuous elastic properties a software IITPAVE was used. The purpose of this software is to evaluate the response of pavement on the basis of mechanistic analytical pavement layout. In order to support the anticipated traffic load and ensure proper pavement functioning for present weather conditions, it is essential to figure out the total thickness of pavement along with thickness of each layer. The strain, stress, and deformations induced at various pavement points by a single load that is evenly distributed across the road's surface can be estimated by using this software. Table 6 displays the program's input values. It must be assumed that the stress/strain values formed are lower than those found using the elastic linear layer model in IRC-37 owing to the thickness of the overlay.

Table 6 - Assumed input values for flexible pavement

Input name	Value
Carriageway width after construction	Single lane
Classification of road	Major district road (MDR)
Design life (n)	15 years
Growth rate (r)	5%
Terrain	Hilly
Construction period	1 year

4.2 IITPAVE Result Analysis

In present study, IITPAVE software is used to estimate allowable vertical compressive strain (v) at top of subgrade layer and allowable horizontal tensile strain (t) at bottom of bituminous layer. The stabilized clayey soil leads to decrease in the fatigue cracks and rutting which are consequences of the horizontal tensile and vertical compressive strains. The design thickness of subgrade required goes on reducing as CBR increases equivalently.

Figures 20, 21, and 22 show that as traffic increases from 1000 CVPD to 3000 CVPD to 5000 CVPD overall thickness of pavement increases while design thickness for pavement reduces from 590 to 430 mm, 800 to 630 mm, and 810 to 640 mm for 1000, 3000, and 5000 commercial vehicle per day. Reduction in design thickness decreases the cost of pavement construction.

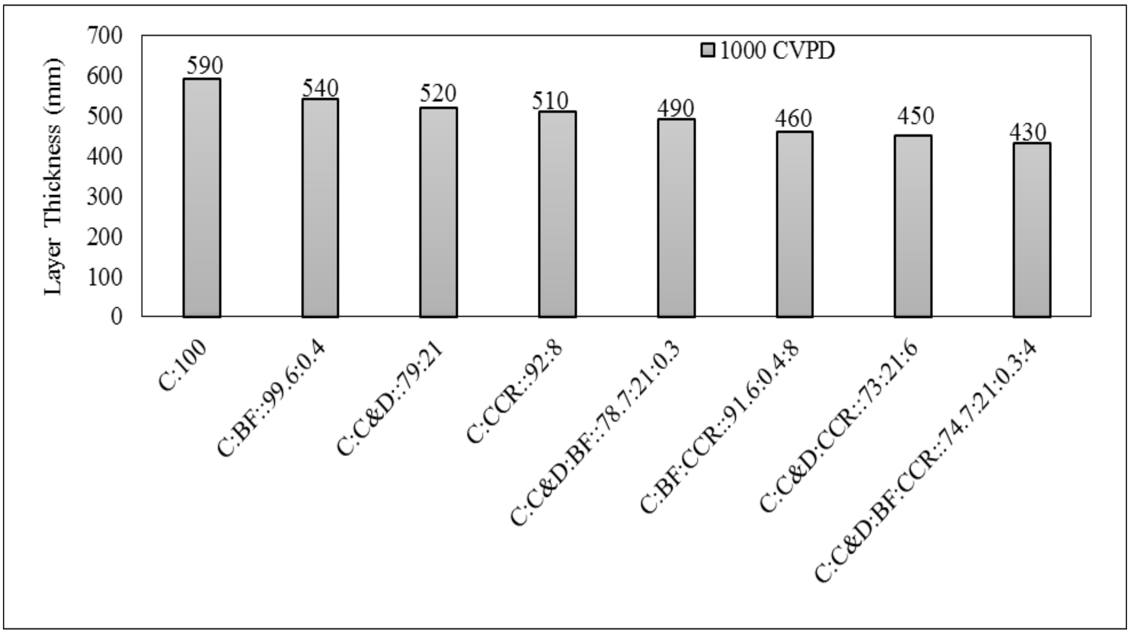

Fig. 20 - Pavement thicknesses for 1000 CVPD

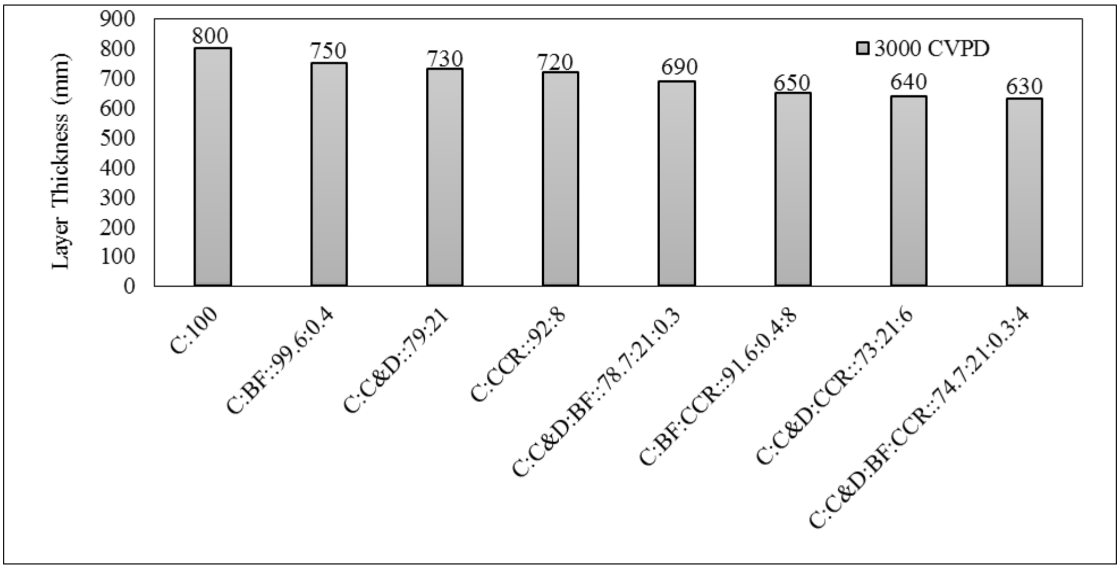

Fig. 21 - Pavement thicknesses for 3000 CVPD

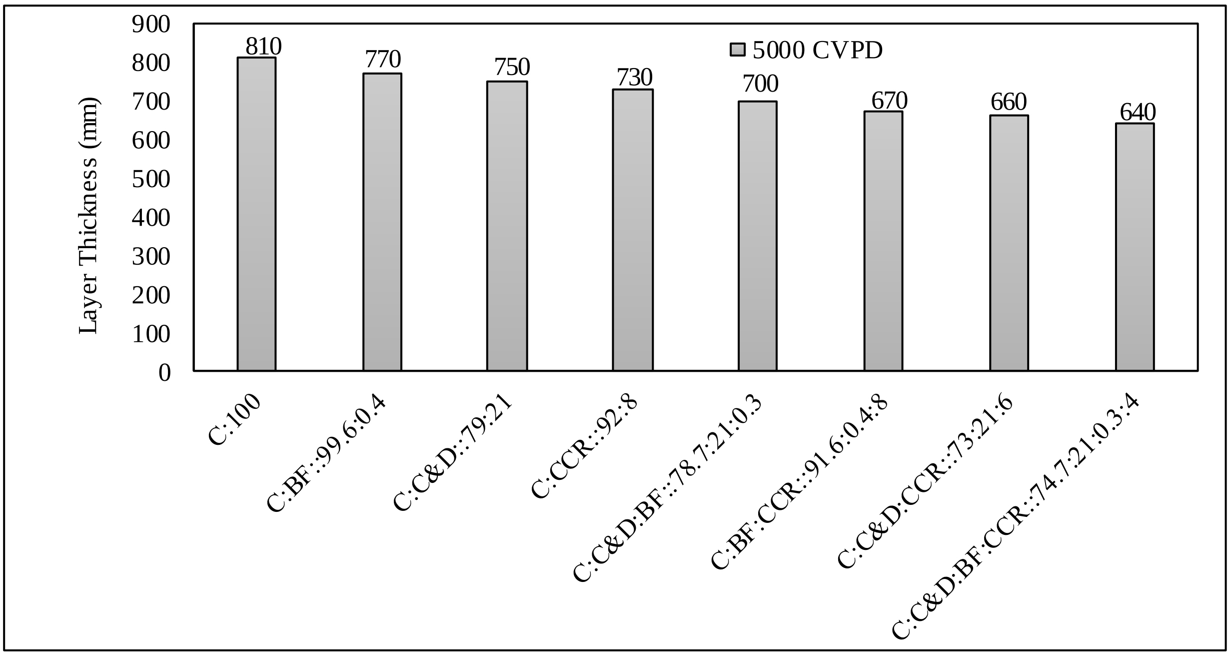

Fig. 22 - Pavement thicknesses for 5000 CVPD

4.3 Resilient Modulus

Subgrade behaves elastically under transient traffic volumes by producing very small permanent deformation due to single cycle of vehicle. Resilient modulus assesses elastic properties of material in laboratory analysis based on recoverable compression. It provides an indicator of material rigidity as well as a criterion for examining rigidity under various situations such as moisture, density, and level of stress.

Resilient modulus of soil can be determined by performing a repetitive three-axial test in laboratory. But equipment involve in test is very expensive therefore resilient modulus for different layers of pavement can be calculated using equations mentioned in IITPAVE software.

Stabilization of clayey soil using different admixtures significantly increases the resilience modulus. This can be shown in **Error! Reference source not found.**. The pavement built utilizing stabilized soil for subgrade has a greater strength, increases the stability and making it long-lasting.

Table 7 - Resilient modulus for various admixtures

Optimum combinations	**Design CBR (%)**	**CVPD (both side)**	**Resilient modulus**		
			$MR_{Subgrade}$	**$MR_{Granular}$**	**$MR_{Bitumen}$**
C:BF::99.6:0.4	5.7	1000	56.32	180	2000
		3000	56.32	204	3000
		5000	56.32	207	3000
C:C&D::79:21	6.1	1000	59.17	185	2000
		3000	59.17	210	3000
		5000	59.17	213	3000
C:CCR::92:8	7.8	1000	60.84	187	2000
		3000	60.84	215	3000
		5000	60.84	217	3000
C:C&D:BF::78.7:21:0.3	9.3	1000	73.92	221	2000
		3000	73.92	249	3000
		5000	73.92	255	3000
C:BF:CCR::91.6:0.4:8	9.8	1000	69.89	218	2000
		3000	69.89	245	3000
		5000	69.89	247	3000
C:C&D:CCR::73:21:6	10.4	1000	76.39	222	2000
		3000	76.39	254	3000
		5000	76.39	263	3000

C:C&D:BF:CCR::74.7:21:0.3:4	11	1000	81.66	234	2000
		3000	81.66	270	3000
		5000	81.66	275	3000

4.4 Cost Analysis for Flexible Pavement

Every year for various flexible pavement strata, Himachal Pradesh PWD releases price per unit of every material along with its engineering characteristics. Schedule of Rates manual is used to determine the cost of every layer. In this study, a road length of 1000 meters was considered, and the pavement was made to accommodate just one subgrade soil. Layers considered are Subgrade (SG), Sub base (SB), Water-bound macadam (WBM), Dense bituminous macadam (DBM), Bituminous concrete (BC).

The building expenses of different layers, along with subgrade layer, composed clay with optimum mixture (C:C&D:BF:CCR::74.7:21:0.3:4) and clayey soil alone is calculated. If the subgrade is composed of the ideal combination, the study indicates that savings done on expenses for 1000, 3000, and 5000 CVPD is 30.12%, 26.19%, and 30%, respectively (C:C&D:BF:CCR::74.7:21:0.3:4) this can be seen in **Error! Reference source not found.**.

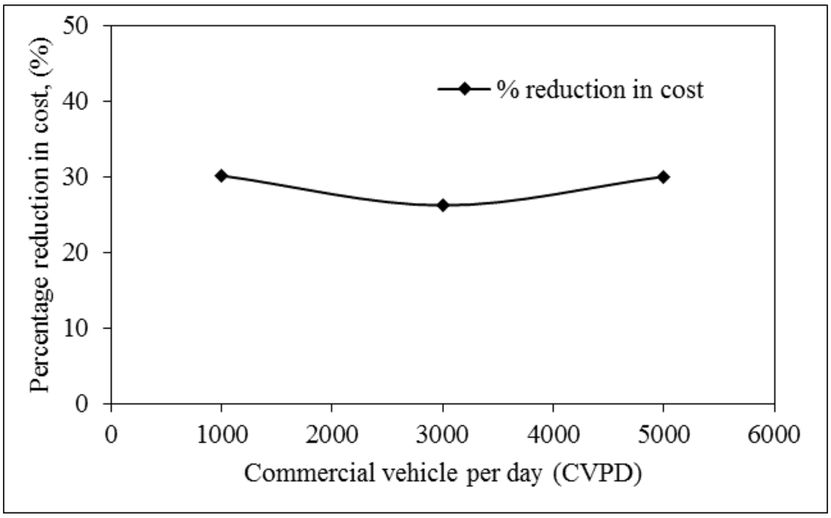

Fig. 23 - Percentage reduction in cost for different CVPD

5. Conclusions

Outcome of present research shows that stabilizing clayey soil is suitable to be used in subgrade material. Importance of findings is that as compared to studies involves stabilization using calcium carbide (CCR) in more quantity results in higher cost of construction, the present study shows that even less quantity of calcium carbide involving lower cost of construction can also results in stronger subgrade material. Addition of 21% C&D waste, 0.3% BF and 4% CCR enhances strength properties of clayey soil. However, BF which is naturally occurring green material and C&D waste whose disposal is still a concern when used as stabilizer decreases environmental pollution.

Important conclusions drawn from the present study are as follows:

- Differential free swell index of clayey soil decreases with the addition of 21 C&D wastes and attains value zero at 21% C&D waste. Further addition had no influence on the composite. Increasing proportions of CCR in clayey soil decreases the differential free swell index and reaches 3 percent with the addition of 8% CCR; further any percentage reduction is insignificant.
- The plasticity index of clayey soil is reduced with inclusion of C&D waste, BF, and CCR, both independently and in amalgamation. Addition of 21% C&D waste, 0.3% BF, and 4% CCR is considered to be reasonable for durability and workability of soil.
- The OMC of clayey soil increases with addition of BF and CCR and decreases with C&D waste. However, MDD decreases due to addition of C&D waste, BF and CCR.
- When C&D waste, BF, and CCR are added to clayey soil independently or together, the UCS of the clayey soil increases. C:C&D:BF:CCR::74.7:21:0.3:4 has the highest 28 days UCS value, followed by C:C&D:CCR::73:21:6, C:C&D:BF::78.7:21:0.3 and C:BF:CCR::91.6:0.4:8.

- Adding C&D waste, BF, and CCR alone and in combination increases soaked CBR value of clayey soil. C:C&D:BF:CCR:74.7:21:0.3:4 has the highest soaked CBR value, followed by C:C&D:CCR:73:21:6, C:C&D:BF:78.7:21:0.3 and C:BF:CCR::91.6:0.4:8.
- IITPAVE software is used to estimate the thickness of pavement layer based on CBR values of optimum combinations shows that layer thickness decreases from 590 to 430mm, 800 to 630mm and 810 to 640mm for 1000, 3000 and 5000 CVPD. The maximum reduction in layer thickness is noticed for C:C&D:BF:CCR:: 74.7:21:0.3:4.
- The introduction of various additives increases the resilient modulus of subgrade components, signifying an improvement in elastic properties. With the inclusion of different additives, resilient modulus of subgrade components increases.
- The total cost of construction reduces when the subgrade layer in pavement is made of optimum combination (C:C&D:BF:CCR::74.7:21:0.3:4) by 30.12%, 26.19% and 30% for 1000CVPD, 3000CVPD and 5000CVPD as compared to subgrade layer consist of clayey soil only. Therefore, 21% C&D waste, 0.3% basalt fibre and 4% basalt fibre when mixed with clayey soil improves strength of subgrade layer.
- The result of investigation shows that using C&D waste, basalt fibre and calcium carbide with clayey soil not only reduces the pavement thickness but also enhances its CBR value. Using these materials in stabilizing reduces environmental degradation. The use of C&D waste together with calcium carbide is probably going to be the first option when it comes to choosing the material to be used since it is so readily accessible.

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