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Improvement of Geotechnical Properties of Soil using Calcium Carbide, Waste Foundry Sand and Polypropylene Fibre

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Abstract

This paper discusses the applications of industrial waste like waste foundry sand (10%, 20%, 30%, and 40%) and calcium carbide residue (3%, 6%, 9%, and 12%) blended with polypropylene fibre (0.25%, 0.50%, 0.75%, and 1%) for soil stabilization. The purpose of this study is to develop a composite of clayey soil mixed with different additives, so it can be used for improving the geotechnical properties of the clayey soil. Multiple tests are conducted including differential free swell, Atterberg's limits test, compaction tests, unconfined compression test (UCS): and California-bearing ratio test (CBR) on clay soil individually and in different combinations and proportions with additive mixed with each other. The optimum percentage for the additives is found by performing differential free swell index and Atterberg limits test. The results demonstrate that the inclusion of additives in the clayey soil decreases the differential free swell and plasticity index of the composite but raises the composite UCS and CBR values. The maximum increase in the UCS and CBR values is obtained for optimum combination of C:PP:WFS:CC:76.25:0.75:20:3. Based on the CBR values, the thickness of flexible pavement is designed using the IITPAVE software. The results of the software analysis show a reduction in the pavement thickness for various values of commercial vehicles per day (1000, 2000, and 5000) for all combinations. The maximum reduction in layer thickness and construction costs is noticed for C:PP:WFS:CC:76.25:0.75:20:3. To further examine the improvement in the geotechnical properties of soil, calcium carbide residue, and waste foundry sand can be blended with nano-additives for potential uses.

Notations

CC	Calcium Carbide Residue
WFS	Waste Foundry Sand
PP	Polypropylene
UCS	Unconfined Compression Strength
CBR	California Bearing Ratio
MDD	Maximum Dry Density
OMC	Optimum Moisture Content
C	Clay

1. Introduction

Clay is an expansive soil that is found naturally across the world. The clay shows poor geotechnical properties such as low strength and high compressibility, which is a major challenge for construction and other geotechnical engineering applications [1, 2, 3]. The expansive soil having minerals like montmorillonite, illitte introduce high shrinkage, and swelling of the clay. The swelling pressure results in the heaving and lifting of the structure; this results in damage to the civil infrastructure, roadways, bridges, buildings, etc. made on to clayey soil, so basically, the clayey soil has excessive settlement, and low-bearing capacity or shear strength properties [4]. To improve the bearing strength of clayey soil, we introduced different admixtures or materials that result in

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increasing the shear strength parameter of the soil. The waste material such as waste foundry sand can be utilized, which is of waste by-product of industries that is needed to be disposed [5, 6]. Soil stabilization is the technique to improve the geotechnical properties of the clayey soil. Various research works in the past have been conducted to improve geotechnical properties of soil, by soil stabilization technique using different admixture at different proportions [5-9].

Calcium carbide (CC) residue is a by-product of the acetylene gas manufacturing process, which is used as a sustainable additive for many years [10, 11]. CC is formed from hydrolysis reaction, and contain mainly calcium carbide and some other components such as calcium carbonate, sulphide, metal oxides, silicon dioxide. Recent findings from a number of research have demonstrated that CC stabilisation has the ability to improve the expansive soils' strength properties, dispersibility, and swelling potential [10, 12]. Many laboratory studies have shown that CC can be used as soil stabilizer and in the pavement applications [10]. The strength, durability, microstructure of soil stabilized with calcium carbide residue has been studied to identify whether it can be used as a pavement material or not [13, 14]. In UCS tests, various CC dosages were tested, and the highest gains in strength were obtained by adding 9% CC to clayey soil. The UCS was raised by 4.7 and 6.8 times that of untreated soil after 9% CC was added to the tested bentonite and CC-stabilized kaolin saw a 3.8- and 5.8-fold increase in its UCS as compared to untreated soil [15]. The engineering qualities of CC stabilised clayey soil treated with fly ash and biomass have improved, and show high strength as compared to hydrated lime [14].

The other ways by which calcium carbide residue can be utilized so its disposal problem can be solved are by using calcium carbide residue as a filler for the modification of 3D printed materials. It was concluded that in comparison with pure plastic the calcium carbide residue-based material shows low shrinkage [16]. In some other studies, the effects of calcium carbide residue addition on the sulphate resistance of metakaolin-based geopolymer were investigated, and it was determined that calcium carbide residue addition to metakaolin-based geopolymer can produce high compressive strength with improved sulphate resistance compared to the ordinary Portland cement [17]. Calcium carbide residue can be used as an alkali activator to prepare fly ash (FA)-based geopolymers without any alkali supplementation and help in reducing the negative impact of fly ash and calcium carbide residue on environment [18].

Waste foundry sand is an industrial waste product, which is discarded and not reused so if it can be used for soil stabilization the problem of its disposal can be removed. Some efforts have been made in recent past to use waste foundry sand in civil engineering construction. The use of waste foundry as admixture is successfully done in landfill liners [19], pavement bases [20], asphalt concrete [21], and embankment constructions [22].

Blending with foundry sand improves the compaction qualities of waste heavy clay [23, 24]. The unconfined compression test and California-bearing ratio experiments on soil mixed with waste foundry sand show that WFS offers soil high load bearing capacity, and may be utilized as a subgrade material in pavement design [20]. The addition of foundry sand up to 40% ratio in clayey soil obtain highest MDD, UCS, CBR values and improved soil properties [24]. The experiment was carried out on foundry sand mixed with cement kiln dust along with soil to see whether it would be acceptable to be used as a material in the construction of pavements [25]. The excess foundry system sand offers a viable and economical alternative as a subbase material in pavements [26].

Another than using in soil stabilization the WFS can be utilized in different situations so its disposal problem can be solved and it does not cause any environmental problems to society. In recent times, the use of waste foundry in self-compacting concrete was successfully done, and it was observed that the inclusion of WFS in concrete can improve its strength in later stages [27]. The use of WFS in ultra high-performance concrete as an aggregate replacement at 20% shows improvement in cracking load, yield load, and ultimate load [28]. The use of WFS as a replacement of river sand can be done [29]. The other method of utilizing the WFS is by constructing concrete paving block; the use of WFS will also reduce the consumption of natural resources and excess dumping of WFS, which is harmful to the environment [30].

Another technique for increasing the strength of clay soils with poor engineering properties is soil stabilisation with fibres [31, 32, 33]. Soil stabilization can be done by two ways chemical and mechanical technique. In this study, we used mechanical approach for soil stabilization. The mechanical approach uses reinforcement supports using fibres. The fibre that can be used for reinforcement purposes are natural fibre, jute, palm fibre, polyester, polyethylene, glass fibre, and polypropylene fibre [34].

The PP fibre has a high tensile strength, thermal resistivity, and acid and alkali resistance. The effectiveness of PP fibre in improving geotechnical characteristics of clayey soil were studied, and it was found that at optimum value of 1% the UCS value increase 1.3 times more than plain soil [32]. In other research works, the effectiveness of fibre was investigated and it was concluded that optimum percentage is 1% for soil stabilization, at 1% UCS value was highest and free swell index of soil reduces to zero [35]. The impacts of hydrated lime and bagasse fibres on the engineering characteristics and behaviour of expansive soils were studied and the findings of this study demonstrate that, when additive percentages and curing times were increased, the compressive strength of expansive soil increase, also when bagasse fibre reinforcement was combined with hydrate lime, linear shrinkage of expansive soil decreased [35]. The mixture of black cotton soil, fly ash, and polypropylene fibre is a useful method, especially for ground development and engineering tasks on soft soil [36].

In addition to the methods of waste utilisation presented in this paper, there are various other methods of waste utilisation. Some involve the use of industrial waste mixed with nano-additives to catalyse hydration processes and reinforce the structure of soil and matrix of concrete composites. The use of nano-additives mixed with industrial waste has been done previously in various studies. The researcher looked at how nano-silica (nS) affects the mechanical properties and micro-structure of CFA(Coal Fly Ash) cement concretes. The study used 5% nS and three different amounts of CFA, which were 0%, 15%, and 25% by volume. When nS and CFA are used together, they work well to improve the mechanical properties and microstructure of the concrete. The best improvement was seen when the nS and CFA added was 5% and 15%, respectively. Compared to control concrete, the 28-day compressive strength and breaking tensile strength went up by 37.68% and 36.21%, respectively [37]. The use of Fly ash as a substitute of ordinary Portland cement increases the performance of concrete but reduces the early strength. Research has been undertaken to increase the early strength of the concretes with FA through the application of a specially dedicated chemical nano admixture (NA) in the form of seeds of the C-S-H phase and it show improvement in early strength of concrete [38]. In another study, extensive investigations on the fracture mechanics parameters of quaternary binder concretes (QBC) were conducted. The fly ash and silica fume were used with nano silica as a substitute of Ordinary Portland Cement. The conducted studies found that the QBC containing: 80% OPC, 5% FA, 10% SF, and 5% nS have shown the best results. The use of additives increases the strength and fracture parameters of concrete also these additives slightly heterogenized the structure of quaternary binder concretes, it made composite more ductile and less brittle [39-41]. The use of nanotechnology with concrete technology were done. The concrete was prepared with a quaternary binder containing various percentages of selected supplementary cementitious materials (SCMs) and research concludes that quaternary green concrete containing SCMs could be a technically and environmentally superior alternative to plain concretes [42]. Therefore, for future scope, for the improvement in the geotechnical properties of soil, calcium carbide residue, and waste foundry sand can be blended with nano-additives for potential uses.

2. Materials

2.1. Soil

The soil used in the study is clayey soil. It was obtained from district Bilaspur of Himachal Pradesh. The soil was dried in sunlight and then oven dried before being pulverised with a pulveriser. Various physical parameters of the soil used in the study have been determined using ASTM standards and Indian standards. After performing the wet sieve analysis test (ASTM D6913-04): the gradation curve of the soil is shown in Figure 1 was obtained and 91% of the soil passed through 75 micron sieve. The fraction passing through 75 micron is analysed by hydrometer method (ASTM D422-63). The soil has been classified as high plasticity soil (CH) according to unified soil classification system (ASTM D1557). Other tests conducted on soil sample were Atterberg limit test (ASTM D4318): specific gravity (ASTM D854): and compaction properties (ASTM D698) of soil. The geotechnical properties and mineral composition of the clayey soil are tabulated in Table 1 and Table 2, respectively. Scanning electron microscopy test was performed for mineralogical composition of soil.

Table 1. Physical parameters of the soil.

Soil parameters	Value
Soil	CH
Activity of soil	1.33
Specific gravity	2.61
DFS (%)	25
Liquid limit of soil (%)	60
Plastic limit of soil (%)	21
Plasticity iIndex(%)	39
OMC (%)	16
MDD (g/cc)	1.75

Table 2. Mineral content of clayey soil.

Mineral composition	Content (%)
Oxygen, O	46.8
Silicon, Si	20
Aluminium, Al	8.8
Potassium, K	1.5
Titanium, Ti	3
Magnesium, Mg	2.5
Carbon, C	11

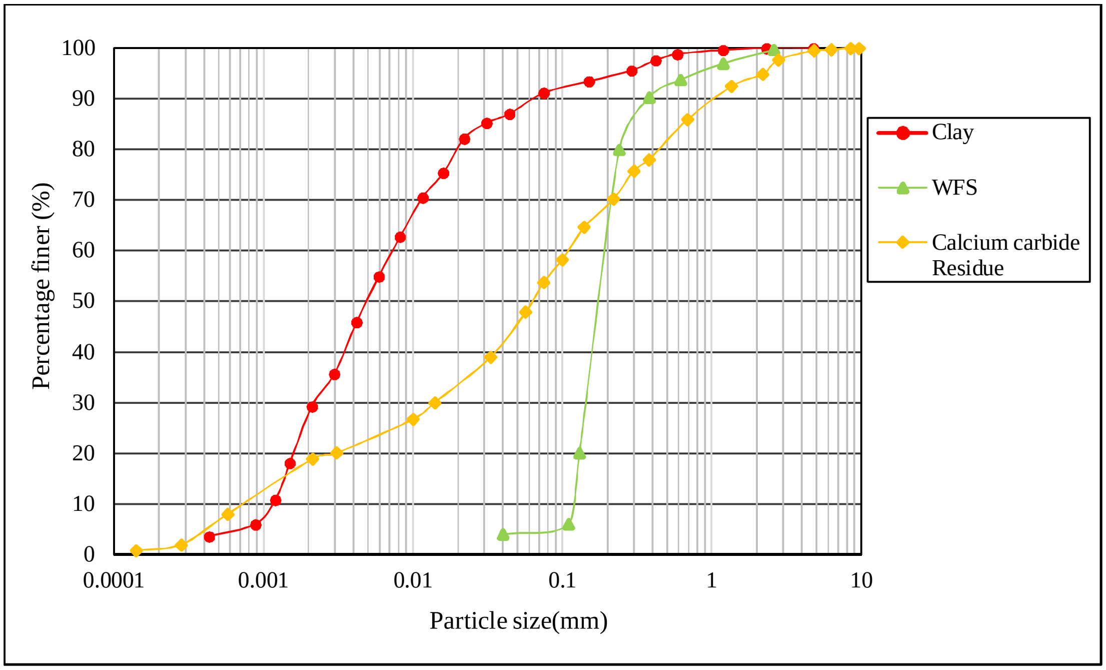

Figure1. Particle size distribution curve for different admixtures.

2.2. Calcium carbide

It is a by-product of acetylene gas industry but due to its high alkalinity and water content, calcium carbide waste causes significant damage to surface and ground water.

The calcium carbide utilised in the research was purchased from a hardware store in District Hamirpur, Himachal Pradesh. It was crushed into the powder form and pass through the 425 micron sieve before being used. The specific gravity of the calcium carbide residue used is approximately 2.20. Calcium carbide residue has the following chemical formula, as shown in Table 3.

2.3. Waste foundry sand

It is high-quality homogeneous silica sand used to create mould and cores for metal castings. Waste foundry sand from different industries possess different chemical and physical characteristics but generally foundry sand is made up of more than 85% high-quality silica sand, 7-10% bentonite clay, 2-3 % water, and less than 5% marine coal. The waste foundry sand was supplied from Shakti Foundries in Ludhiana (Punjab). The chemical compositions of the WFS are shown in Table 4.

Table 3. Chemical composition of calcium carbide residue used in study.

Chemical composition	Content (%)
Calcium carbide, C_aC_2	85.8
Calcium nitride, Ca_3N_2	7.76
Calcium phosphide, Ca_3P_2	4.8
Silicon carbide, SiC	1
Calcium sulfide, CaS	1.5

2.4. Polypropylene fibers

It acts as a reinforcement in soil. They reduce the swelling and shrinking capability of soil. Shear strength corresponding to normal stress increases with increase in percentage of fibers. It was supplied from the Radhekrishna Chemical company, Mumbai, and its properties are shown in Table 5.

Table 4. Chemical composition of waste foundry sand.

Chemical composition	Content (%)
Silicon dioxide, SiO_2	85
Aluminium oxide, Al_2O_3	6.27
Ferric oxide, Fe_2O_3	4.4
Magnesium oxide, MgO	0.7
Titanium dioxide, TiO_2	0.18
Potassium oxide, K_2O	1
Calcium oxide, CaO	0.9
Strontium Oxide, SrO	0.03
Sodium Oxide, Na_2O	0.5
Magnesium (III) oxide, Mn_2O_3	0.05
Sulphur trioxide, SO_3	0.3

Table 5. Physical and chemical characteristics of fibre used.

Serial number	Physical and chemical properties	Values
1	Fibre type	Single Fibre
2	Unit weight (g/cc)	0.91
3	Average length (mm)	12
4	Average diameter (mm)	0.034
5	Breaking tensile strength (MPa)	450
6	Modulus of elasticity (MPa)	3500

3. Result and Discussion

3.1. Differential free swell index

The DFS test was conducted according to IS 2720: Part 40(1977). The DFS of soil treated with additive are depicted in Figure 2 and Figure 3. The DFS of soil founded out to be 25%. With increase in the calcium carbide residue on varying percentage (3%, 6%, 9%, 12%) and WFS (10%, 20%, 30%, 40%) content, the value of differential free swell index reduces to zero at 9% calcium carbide residue and 20% waste foundry sand content, respectively. Similar behaviour of decreasing free swell index with increasing calcium carbide residue had been studied in past [47]. The reduction of DFS on adding CC may be due to cation exchange reaction of calcium with soil particle. After addition of calcium carbide residue more than 9% in the soil, the PH value will be high, which can break down the soil aggregates and make clay particles dispersed. This can cause the increase in the value of differential free swell (DFS): which means it has more potential to swell, and the reduction due to adding WFS may be because of addition of bigger size particles in the clayey soil. Same trends were found in the past [7, 8].

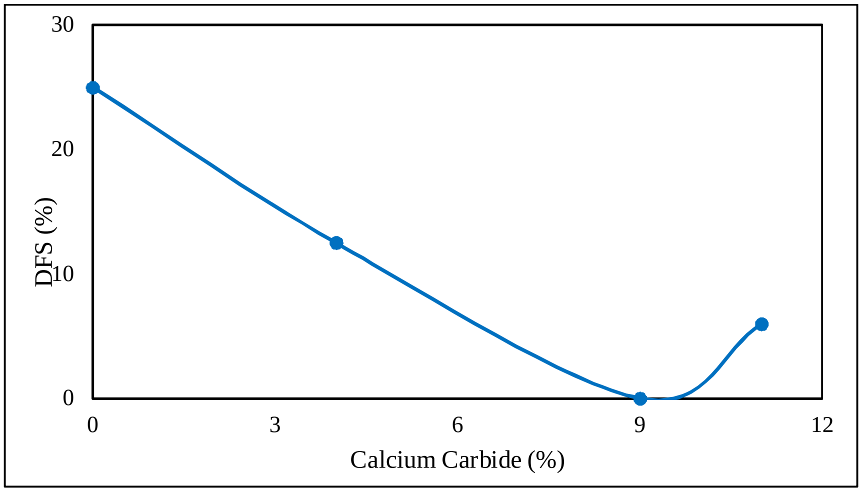

Figure 2. DFS value of CC mixed soil.

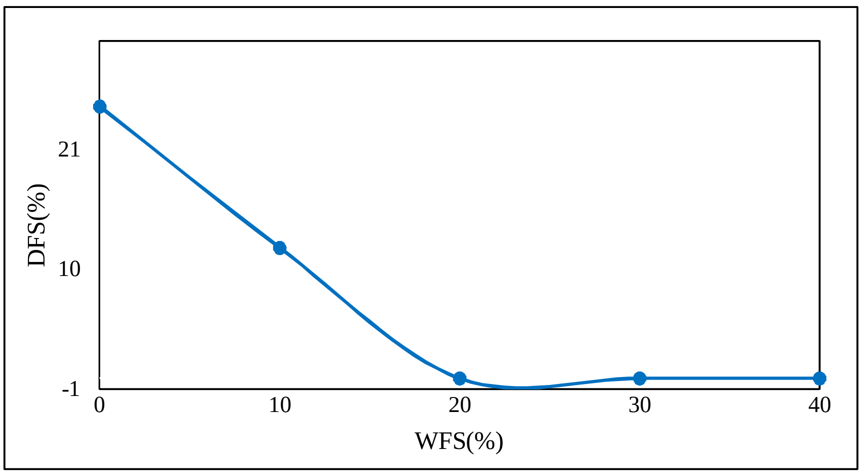

Figure 3. DFS value of WFS mixed soil.

3.2. Consistency limits

The liquid limit and plastic limit of soil found are 60% and 21%, respectively. The clayey soil has a plasticity index of 39%. The clay is of high plasticity, so it needed to be stabilized before using in the construction purposes. Clay has been stabilised by using additive. The untreated soil falls in the CH (high plasticity) category. The addition of calcium carbide residue and waste foundry sand changed soil category to CI and MI, respectively.

When clay is mixed with polypropylene fibre in proportions of 0.25%, 0.50%, 0.75%, and 1%, there is a gradual decrease and increase in liquid limit and then it starts decreasing (Figure 4). The addition of polypropylene beyond 0.75% does not vary plasticity index much. Hence, it can be considered as the optimum value. The increase in liquid limit may be due to small water retaining capacity of fibre, in contrast to the water repellent nature of the polypropylene fibre. Overall, the plasticity index of the combination reduced. The same trend was recorded in the past [43].

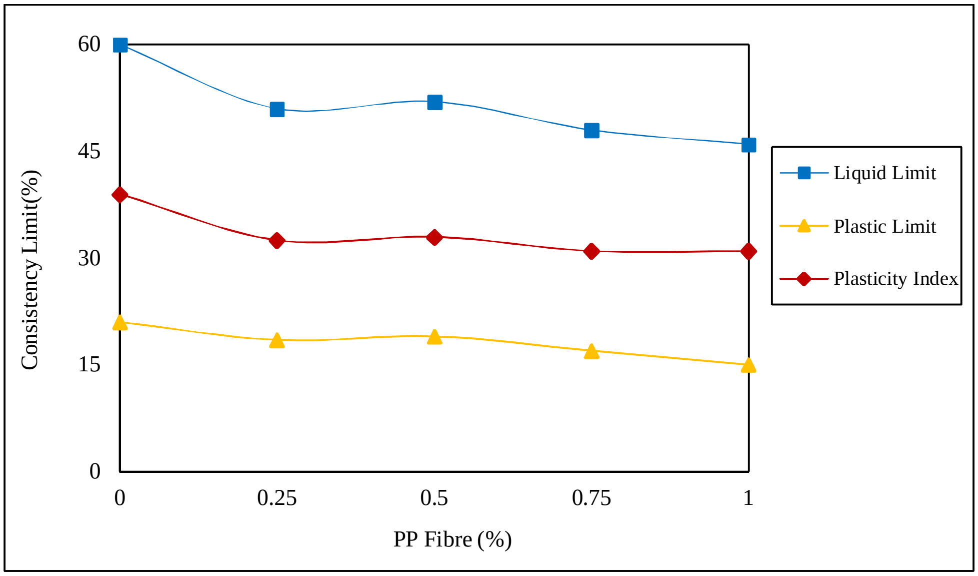

Figure 4. Consistency limit test for PP fibre mixed with soil.

The addition of varying percentage of 10%, 20%, 30%, 40% waste foundry sand in to clayey soil decrease the consistency limit of mixture. After 20% waste foundry sand, the plasticity index remains constant (Figure5). Thus C:WFS:80:20 was taken as the optimum value for stabilization of the soil. The decrease in PI may be because of the addition of waste foundry sand since waste foundry sand having bigger size particles, which are relatively bigger compared to clayey soil particles, which results in decrease in both the liquid limit and plastic limit of soil results in decreasing the plasticity index of the soil. Similar trends in consistency limit with varying WFS have been recorded in the past [7, 8].

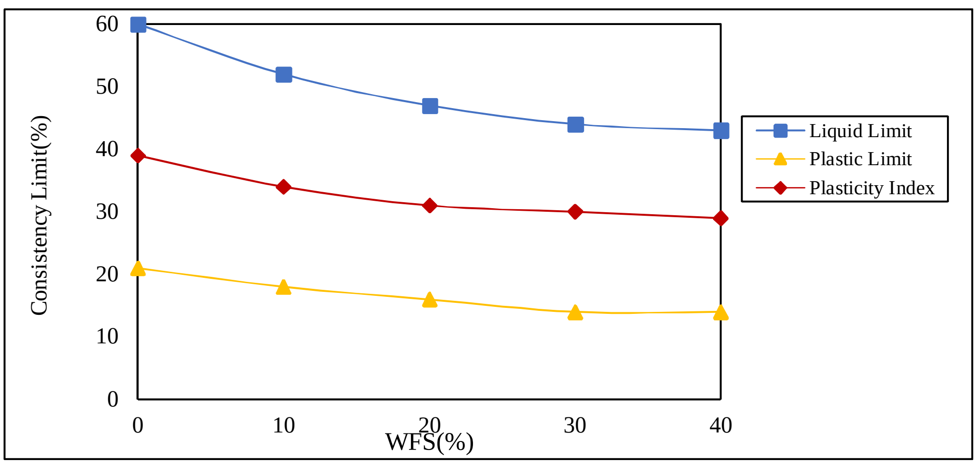

Figure 5. Consistency limit test for WFS mixed with soil.

The addition of 3%, 6%, 9%, and 12 % calcium carbide residue in clayey soil reduced the liquid limit but it also increased the plastic limit of soil significantly (Figure 6). The higher plastic limit may be due to higher pore fluid viscosity, which causes increase in shear resistance between the particles and thus increases the plastic limit. The change in plasticity index of the soil may be brought about by the cation exchange reaction, which results in adsorption of Ca^{2+} ions and as well as the due to flocculation of soil particles. The decrease in plasticity index is significant up to 9% calcium carbide residue after that the change in plasticity index is minimal. This means that maximum adsorption of Ca^{2+} occurs at 9% calcium carbide residue content. Thus C:CC:91:9 was considered the optimum mixture. Similar trends in consistency limit has been recorded in the past [10, 11].

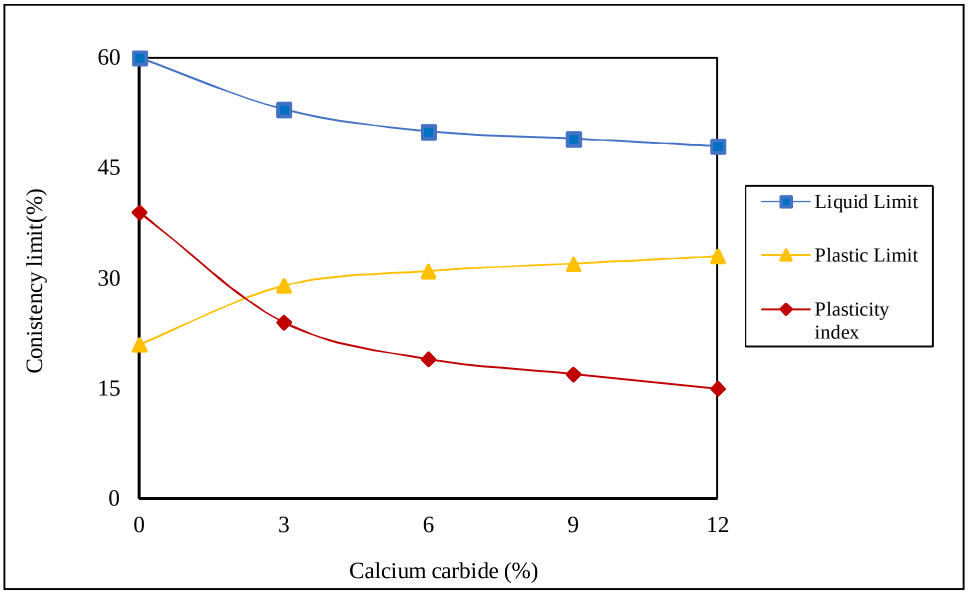

Figure 6. Consistency limit test for calcium carbide residue mixed with soil.

The PP fibre was mixed with WFS, and it leads to decreases in plasticity index to 21 (Figure 7). In this, PP fibre was constant at 0.75%, and waste foundry sand was varied in 10%, 20%, 30%, and 40%. There was decrease in the liquid limit and plastic limit of the soil, subsequently leading to the fall in the plasticity index of the composition. There was large decrease up to 10% waste foundry sand, after that plasticity index value was improved significantly. Thus C:PP:WFS:89.25:0.75:10 was selected as the optimum value for the compaction test. The reduction in plasticity index may be due to fact that addition of waste foundry sand decreases the specific surface area.

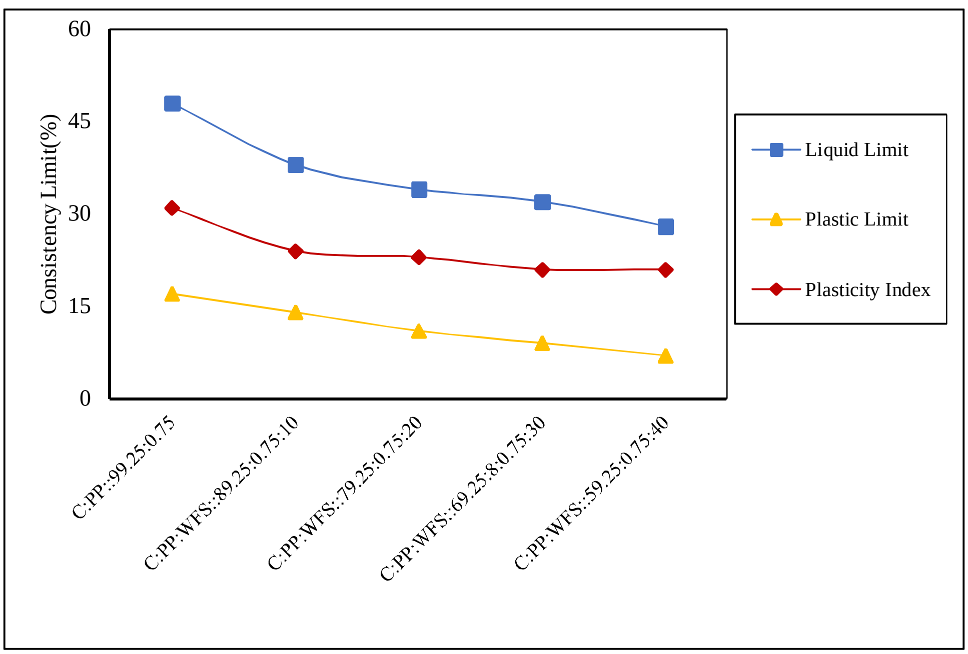

Figure 7. Consistency limit test for PP-WFS mixed soil.

The combined action of polypropylene and calcium carbide residue decreases the plasticity index of combination (Figure 8). The plasticity index value of mixture reduced to 9. The percentage of polypropylene fibre was kept constant at 0.75%, and calcium carbide residue was varied in 3%, 6%, 9%, and 12%. After 6% calcium carbide residue addition the decrease in plasticity index was not much so C:PP:CC:93.25:0.75:6 was chosen as the optimal composition. The lowering of the plasticity index may be because of the depletion in the thickness of double diffuse layer with increasing in calcium carbide residue content mixture.

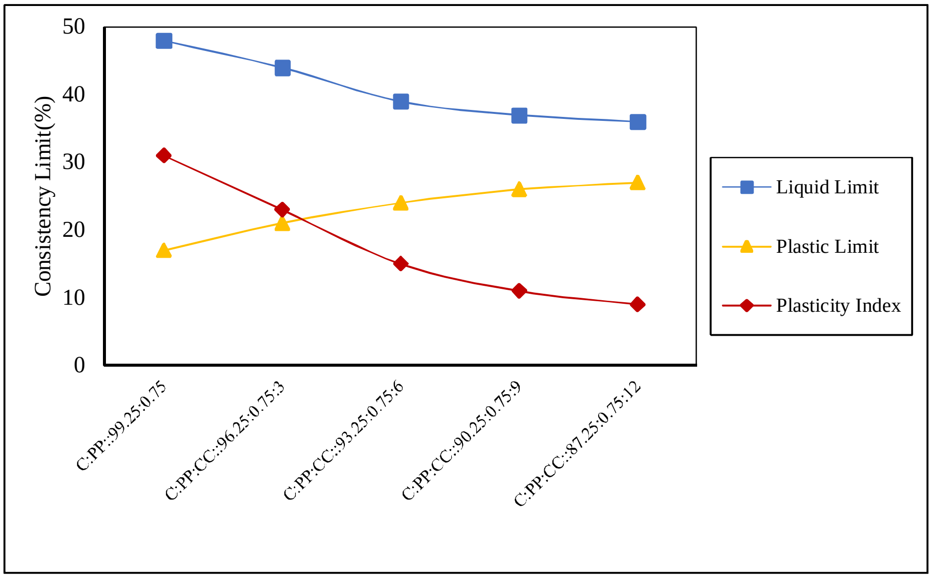

Figure 8. Consistency limit test for PP fibre-CC mixed with soil.

The combined mixture of clay with waste foundry sand and calcium carbide residue reduces the plasticity index to 9 (Figure 9). The waste foundry sand (20%) kept constant with varying calcium carbide residue (3%, 6%, 9%, 12%). With the increase of calcium carbide residue to 6% in C:WFS mixture, there was reduction in consistency limits, after that plasticity index reduced in very small margin. Thus mixture of C:WFS:CC:74:20:6 can be selected as optimal. There was fall in liquid limit, which may be because of the release of cations in fluid leading to increase in the electrolyte absorption of pore water. The higher plastic limit may be due to higher pore fluid viscosity, which causes increase in shear resistance between the particles and thus increases the plastic limit.

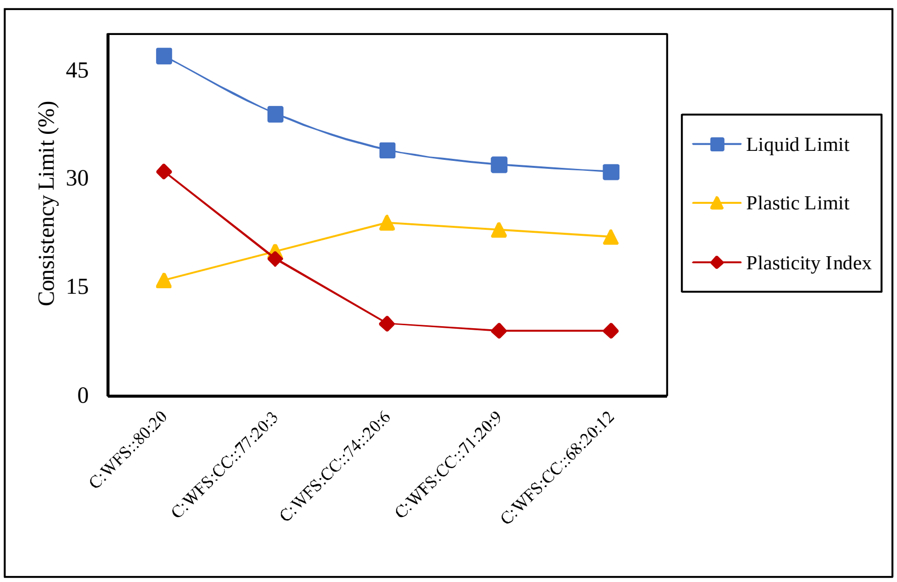

Figure 9. Consistency limit test for WFS-CC mixed with soil.

The combined addition of polypropylene fibre, waste foundry sand, and calcium carbide residue lower the plasticity value to 8 (Figure 10); in this polypropylene and waste foundry sand were kept same as 0.75% and 20%, respectively, and calcium carbide residue percentage (3%, 6%, 9%, and 12%) was varied. With the adding of 3% calcium carbide residue in composite soil, the plasticity index of composite decreased, the 3% dosage of calcium carbide residue was considered optimum here as reduction for next combination was minimal or in small margin. So C:PP:WFS:CC:76.25:0.75:20:3 was considered as the optimum value.

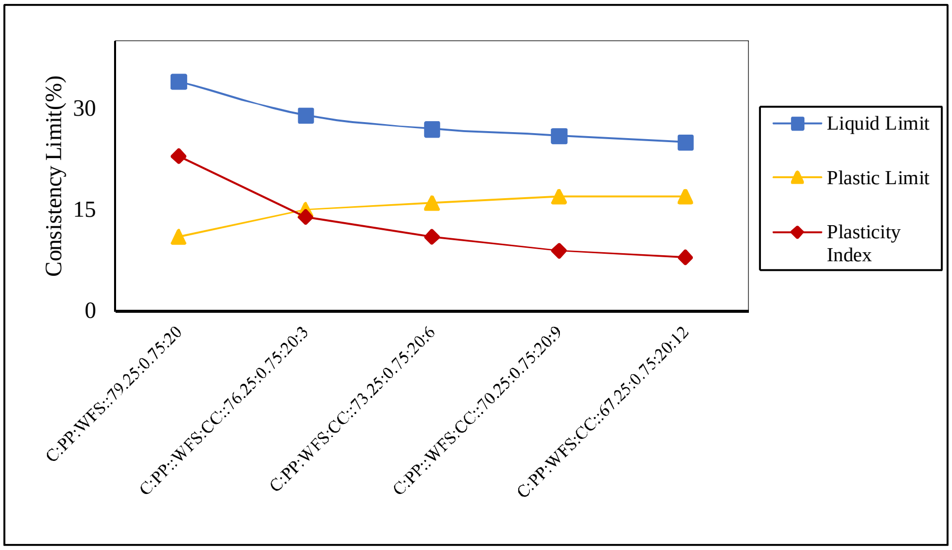

Figure 10. Consistency limit test for CC-PP fibre-WFS mixed with soil.

3.3. Compaction characteristics

The standard proctor test was performed on clayey soil alone and for optimum combination with clayey soil. The optimum moisture content and maximum dry density of untreated clayey soil were discovered to be 16% and 1.75 g/cc, respectively.

Maximum dry density rises monotonically as fibre content is increased from 0.25% to 1% (Figure 11). This demonstrates how the incorporation of polypropylene fibre into soil significantly improves its compatibility over conventional soil. On increasing the proportion of PP fibre as 0.25%, 0.5%, 0.75%, 1%; the OMC of soil decreases from 16% to 14% and the MDD increases from 1.75 g/cc to 1.81 g/cc. The decrease in OMC may be because of hydrophobic nature of the polypropylene fibre, and increase in MDD may be due to better frictional resistance between fibre and surrounding soil particles. Similar trend was found in the past [43].

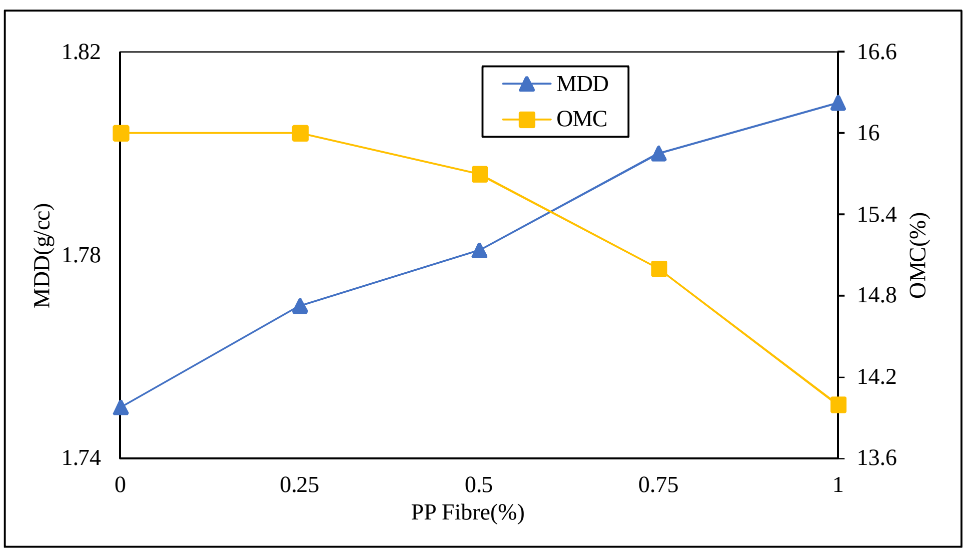

Figure 11. OMC and MDD variations with PP fibre.

When various quantities of WFS in 10%, 20%, 30%, and 40% were added in clay soil, the optimum moisture content and maximum dry density increase from 16% to 18.4% and 1.75 to 1.79 g/cc, respectively (Figure 12). Clayey soil's MDD value goes up as its WFS content goes up. Since the specific gravity of waste foundry sand is more than that of clayey soil could cause the maximum dry density value of the combination to increase, further rise in maximum dry density value of clayey soil with increasing waste foundry sand concentration may be attributed to waste foundry sand particles having a larger surface area than soil particles. The higher OMC value of the combination may be due to bentonite, which is present in WFS already and has a high montomoraillite content, which makes it greater in holding water. Same behaviours were observed in the past [6-8].

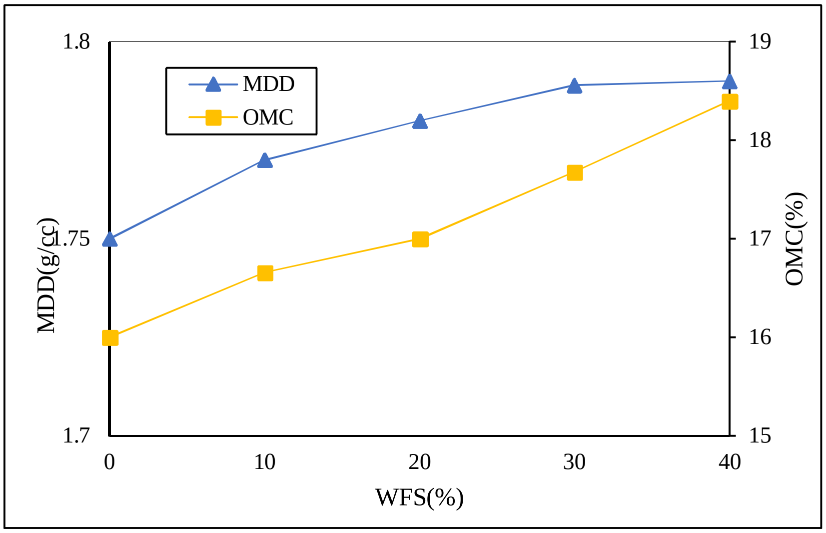

Figure 12. OMC and MDD variation with WFS.

On adding calcium carbide residue in varying percentages of 3%, 6%, 9%, and 12% the optimum moisture content of clayey soil increases from 16% to 18% and maximum dry density of the soil decreases from 1.75 g/cc to 1.60% (Figure 13). The increase in moisture content is caused by the pozzolanic interaction of clay particles with calcium carbide residue similarly the decrease in maximum dry density is caused by the calcium carbide's lower specific gravity than clayey soil. A similar behaviour was seen in the past [11].

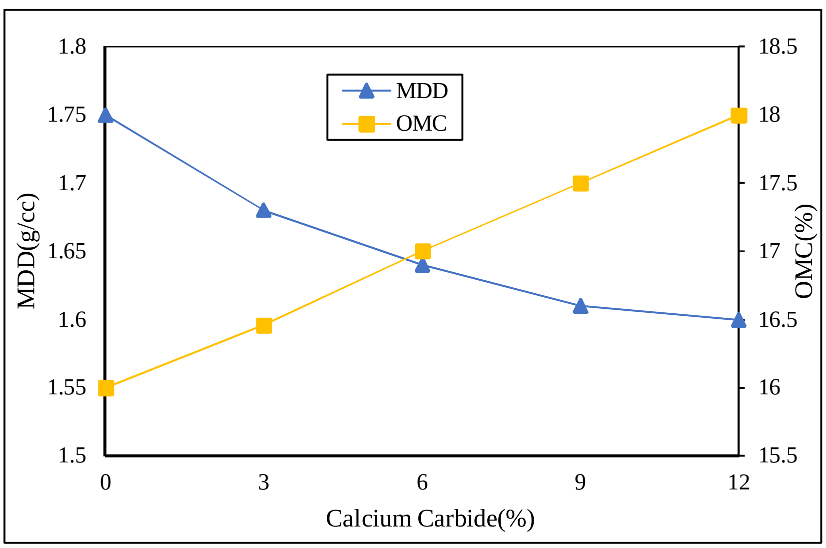

Figure 13. OMC and MDD variation with CC.

The addition of varying WFS (10%, 20%, 30%, and 40%) in optimum value of PP fibre at 0.75% increase both optimum moisture content and maximum dry density of the mixture from 15% to 17% and 1.80 to 1.85 g/cc, respectively (Figure 14). The increase in optimum moisture content may be because of the presence of bentonite in the WFS, which increases the water retaining capacity of the mixture; furthermore the in maximum dry density may be due to coarser nature of WFS leading in densify the soil structure.

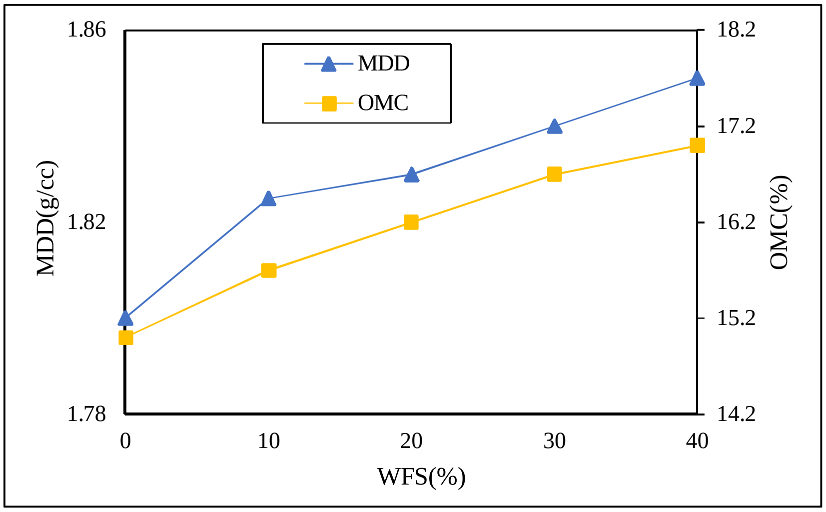

Figure 14. OMC and MDD variation by keeping PP fibre (0.75%) constant and varying WFS content.

The addition of CC (3%, 6%, 9%, and 12%) in optimum value of PP fibre at 0.75% increases OMC from 15% to 18% (Figure 15) as the addition of CC results Ca^{2+} cation to adsorb on the surface of clayey particles soil and results in flocculation of particles, which results in the increase in the OMC value. The inclusion of calcium carbide residue also decreases MDD value from 1.80 to 1.69 g/cc the reduction of maximum dry density value is due to decrease in specific gravity of C:CC mixture with increasing percentage of calcium carbide residue in it.

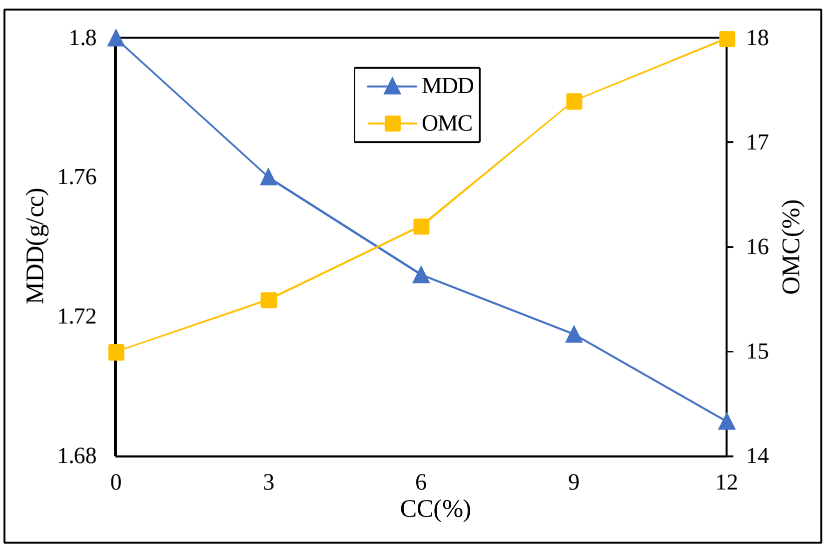

Figure 15. OMC and MDD variation by keeping PP fibre constant (0.75%) and varying calcium carbide residue content.

In clayey soil, the simultaneous effect of calcium carbide residue with various percentages of 3%, 6%, 9%, and 12% at a waste foundry sand content of 20%, enhanced OMC to 21% and decreased MDD of composite to 1.67g/cc, respectively (Figure 16). The decrease in maximum dry density is because of decreasing density of the composite with the continuously increase in the percentage of the calcium carbide residue in clayey soil. The pozzolanic interaction between clay and calcium carbide residue may be responsible for the increase in optimal moisture level.

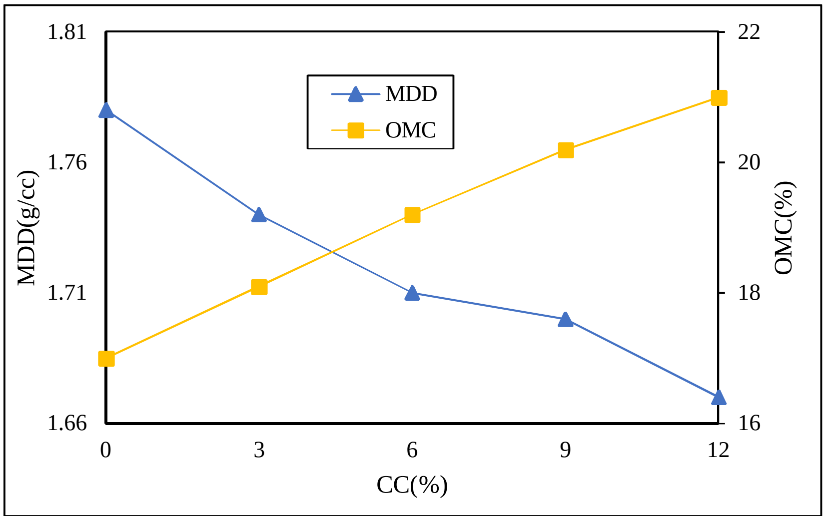

Figure 16. OMC and MDD variation by keeping WFS constant (20%) and varying calcium carbide residue content.

The addition of calcium carbide residue, foundry sand, polypropylene fibre to clay soil increases the optimum moisture content from 16.2% to 17.2%, and decreases the MDD from 1.83 to 1.76 g/cc, with waste foundry sand and fibre held constant at 20% and 0.75%, respectively, whereas calcium carbide residue concentration varied (3%, 6%, 9%, and 12%). The increase in optimum moisture content may be attributed to the fact that there is increase in surface area leads to more water absorption capacity and small water retaining capability of the fibre. Also decrease in maximum dry density may arise from particle assembly to occupy more space when calcium carbide residue introduced in the composition. The variation in optimum moisture content and maximum dry density is shown in Figure 17.

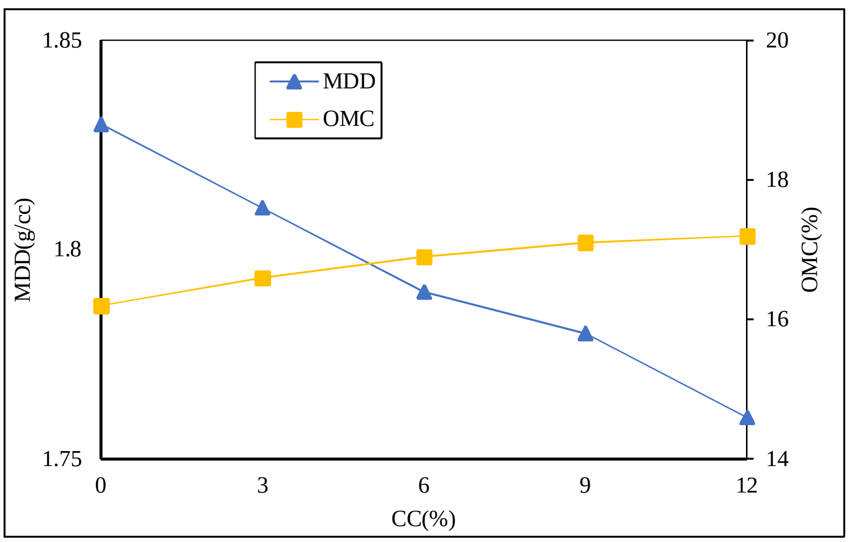

Figure 17. OMC and MDD variation by keeping PP fibre (0.75%) and WFS (20%) constant and varying CC content.

3.4. Unconfined compressive strength test

UCS tests were performed on untreated clayey soil and with various blends of calcium carbide residue, waste foundry sand, and polypropylene fibre according to ASTM D2166-16. The purpose of these experiments was to determine the influence that different admixtures had on the strength characteristics of clayey soil. The UCS values of soil for 1, 7, and 28 days of curing were determined to be 320 kPa, 443 kPa, and 548 kPa, respectively. When different admixture were added in different proportion varying PP (0.25%, 0.50%, 0.75, 1%): waste foundry sand (10%, 20%, 30%, 40%): calcium carbide residue (3%, 6,9%, 12%); the highest value was found for combination of C:PP:99.25:0.75,C:WFS: 80:20, and C:CC:91:9 for 28 days were 600 kPa, 655 kPa and 710 kpa, respectively with respect to untreated clayey soil UCS (548kPa): respectively. The combined action of admixture was also studied; when the clayey soil was blended with polypropylene (0.75%) and waste foundry sand in the varying percentage of WFS (10%, 20%, 30%, 40%) proportions the optimum combination was found to be (C:PP:WFS:89.25:0.75:10); the resultant UCS value was 760 kPa after 28 days curing period; further study was conducted on optimum combination of C:PP:CC:93.25:0.75:6 and the UCS value rose up to 819 kPa. It was also concluded that on adding calcium carbide residue and WFS in proportions (C:WFS:CC:74:20:6); the UCS at 28 days curing time obtained was 861KPa; and lastly, the maximum value after UCS test was attained as 935 kPa after adding CC, WFS, and PP combined in untreated soil in the proportion (C: PP:WFS:CC:76.25:0.75:20:3). The UCS value continuously goes on increasing with increasing in curing period for various combinations.

Addition of calcium carbide residue increase the UCS continuously as more pozzolanic component is available and it results in more cementous compound formation in soil structure results in increasing UCS value and strength characteristics of soil. Since a more compact cementous composition is available the soil can resist more compressive load. A similar trend was observed in the past [44].

The addition of WFS shows increment in UCS value; the improvement in UCS may be because of the reduction in void ratio due to compaction of soil structure. The void ratio of the clay (fine grained soil) is more than that of waste foundry sand (coarser material; therefore, the addition of coarser material in clay reduces the void ratio of the mixture. The coarser particles result in resisting higher compressive load. Similar results were found in the previous study [35].

The increase in UCS value is acquired when PP fibre is added in optimum percentage (0.75%) in the clayey soil; in the previous study, there was a rise in UCS with the introduction of fibre [45]. When the fibre content is low, they are randomly distributed leading to increase in failure risk along the interfaces between soil and PP fibre. With increase in fibre content voids of the sample reduces as fibre act as a filler material filling up the voids and density of clay increases, which makes the contact area between the fibres and surrounding soil increasing, which directly leads to increase in friction between soil and fibre. Thus the soil sample treated with fibre attained higher strength and stable value with increase in curing time at later stage showing post strong behaviour. But by increasing percentage beyond optimum the lot of fibre filaments gather to form cluster inside the soil sample due to electrostatic attraction and make fibre difficult to distribute uniformly and reduces effect of fibre reinforcement. The stress strain curves for 28 days are shown in Figure 18.

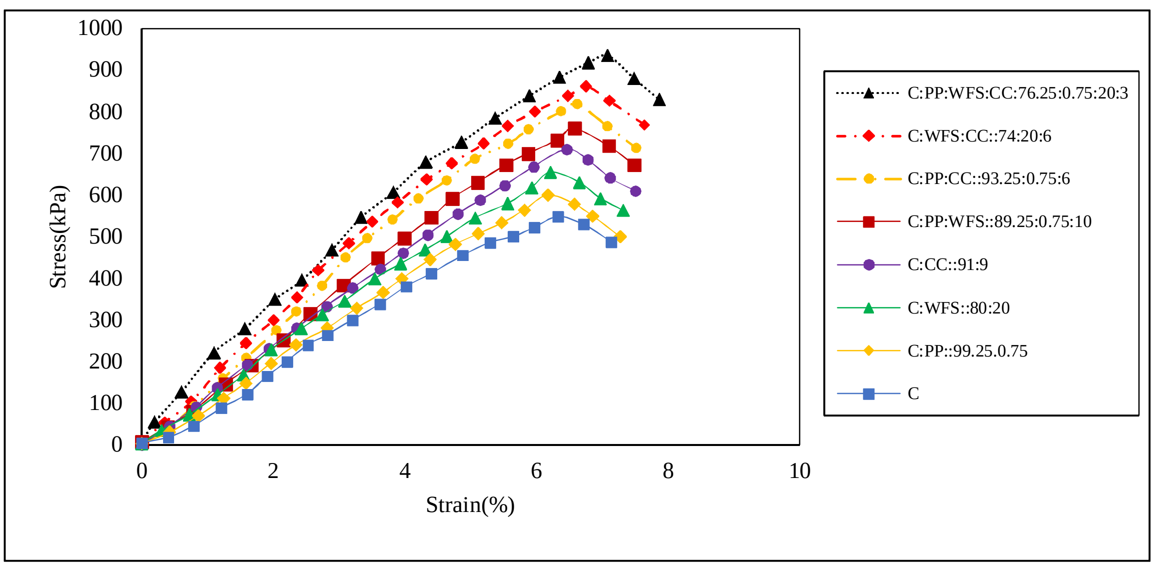

Figure 18. Curves of stress and strain for twenty-eight-day curing period.

3.4.1. Curing period

The consequences of curing duration on the UCS value of different mixes were explored further, and the results indicated that the UCS values of all composites rose as the curing period was increased from 1 to 7 and subsequently to 28 days. This was the case regardless of the combination. When the curing duration was extended from 1 to 7 and 28 days, respectively, a percentage increase of 18.76% and 41.2% was observed for the C:PP:WFS:89.25:0.75:10 mixture; similarly, for the C:PP:CC:93.25:0.75:6 combination, when the curing period was increased from 1 to 7 and 28 days, respectively, a percentage increase of 21% and 38% was observed. Further studied shows that for the C:WFS:CC:74:20:6 mixture; when the curing time was increased from 1 day to 7 days and then to 28 days, respectively, there was a 17.2 and 36 percent rise in the UCS value; and lastly, for the C:PP:WFS:CC:76.25:0.75:20:3 combination a percentage increase of 21.2% and 36.4% was noticed for 1 to 7 and 28 days, respectively. A curing period of 28 days provided adequate time for better interaction between binders and soils particles, which resulted in a more interlocking structure for the soil-binder mixtures, and hence increase the strength of soil. UCS values of different combination at different days during curing period are shown in Figure 19.

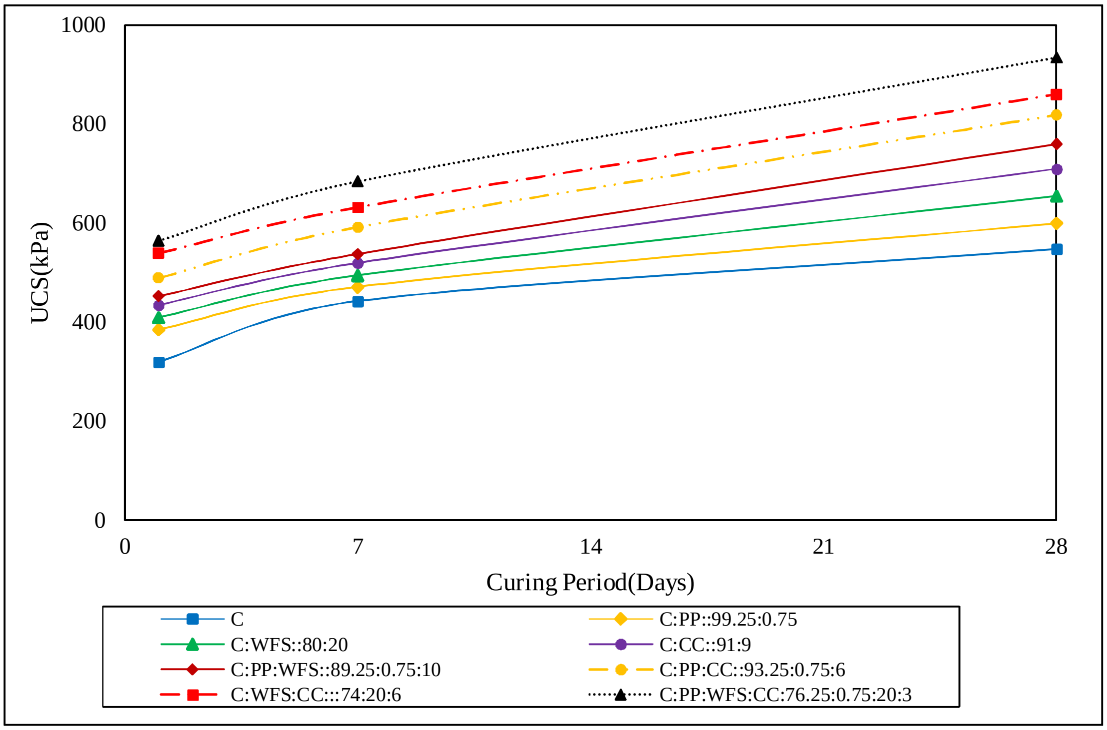

Figure 19. UCS values of different combination at different days during curing period.

3.5. California-bearing ratio test

Soil stabilisation is critical in pavement design because it enhances the strength of subgrade soils. The series of CBR tests were done under soaked conditions according to ASTM D1883-05 (2005). For curing, the samples were soaked in water for four days.

For the soaked condition CBR value was found to be 3% (Figure 20): which is less than 5%, and considered poor in India as per IRC-SP-77 (2008): so it needed to be improved before using for pavement design. Various material has been used such as calcium carbide residue, waste foundry sand and polypropylene fibre as additive to increase bearing strength of Soil; and it shows enormous improvement in CBR value with the inclusion of these materials in clayey soil.

When soil is mixed with 0.75% optimum PP fibre, the CBR value increases from 3 to 5.7% (Figure 20). Due to increase in frictional resistance between surrounding soil and polypropylene fibre, the bearing value of the clayey soil improves. Same effect has been found in the past [46].

CBR value increase from 3% to 6.4 % (Figure 20) at optimum value of 20% WFS in clayey soil. The increase in CBR is because of silica present in WFS that react with clayey soil leading to better interlocking of WFS with soil leading to increase in strength of soil. The clay soil used in this research work has significant amount of calcium compounds. Therefore, calcium compounds react with water and release Ca^{2+}, which reacts with silica present in WFS and promotes the formation of calcium silicate hydrates. Ca^{2+} +OH^- + silica = Calcium silicate hydrate. Similar results were found by in the past [6, 7].

The CBR increased from 3% to 7.2% (Figure 20); at optimum value of 9% calcium carbide residue, the increase in CBR value is because of high concentration of clay mineral present in soil that react with binder. The increase is also because of formation of densely packed structure due to decrease in void ratio that reflects the consumption of cementous material in filling up the voids. The cementitious material is formed due to pozzolanic reaction between soil particles and binder. Calcium silicate hydrate (C-S-H) and calcium alumina hydrate (C-A-H) are the cementitious compound that are formed after pozzolanic reactions. A similar trend has been studied in the past [12].

For optimum combination of C:PP:WFS:89.25:0.75:10 the increased value of CBR was recorded as 8.1% (Figure 20). This may be because of better binding properties of the silica in WFS with clayey soil and better frictional resistance between surrounding soil and fibre.

For optimum combination of C:PP:CC:93.25:0.75:6, the CBR value increased to 8.8% (Figure 20). The increases in CBR value of mixture with clayey soil may due to cation exchange process present in calcium carbide which results in flocculation of soil and better binding between particles and ultimately results in the enhancement of the composite's strength.

The CBR value increased to 9.6% (Figure 20) when the optimal combination of C:WFS:CC:74:20:6 is used. This increase is due to production of cementous material due to reaction between soil particles and calcium carbide residue filling voids and increasing bearing capacity of soil.

For optimum combination of C:PP:WFS:CC:76.25:0.75:20:3 the CBR value increased to 11% (Figure 20). The increase may be attributed to the presence of silica in WFS, as well as the pozzolanic interaction between clay mineral and calcium carbide residue, which bond together to form a stiffer structure with greater bearing capacity.

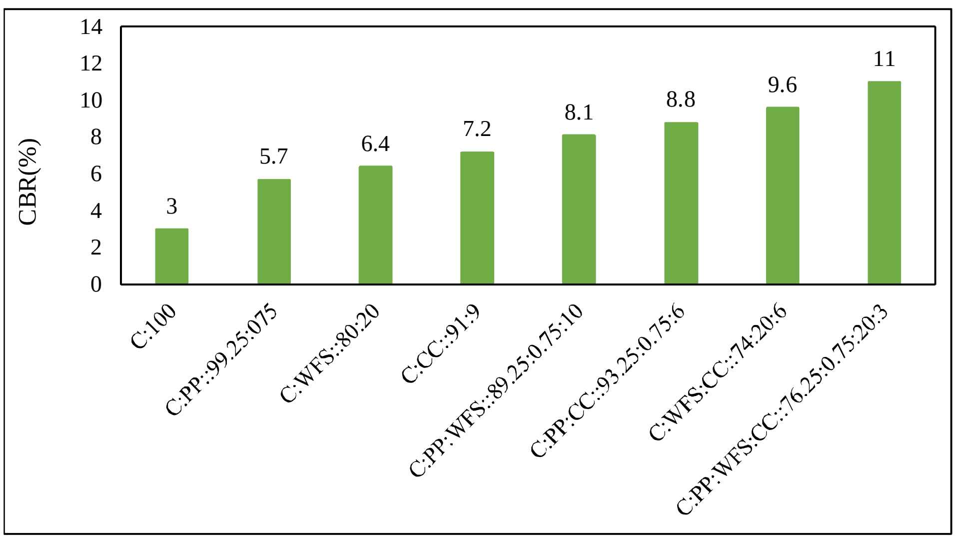

Figure 20. CBR value of clayey soil at optimum value with different combinations.

3.5.1. Pavement design

Rigid pavements account for less than 10% of road infrastructure, whereas flexible pavements account for the remaining 90% in India. Traffic conditions of the region and subgrade soil properties are important parameters to consider while designing flexible pavement. As the CBR value varies, so does the pavement thickness. The pavement thickness reduces with increase in CBR and increase with decrease in CBR value. Smaller pavement thickness requires less bitumen, lowering cost of construction. In the current investigation, the IITPAVE programme was used to calculate the change in pavement thickness induced by changing the CBR value.

3.5.2. IITPAVE

The IITPAVE programme was developed to analyse linear elastic multi-layered flexible pavements. It is a software application that uses mechanistic analytical pavement designs to evaluate pavement responsiveness. Its objective is to calculate the entire thickness of the road pavement, along with the depth of specific layer, necessary to bear the expected traffic on the road, while also maintaining appropriate pavement performance under realistic environmental circumstances. The IITPAVE software can estimate the stress-strain values induced at various spots in the pavement by a continuously distribution of the traffic load on the road's surface. Table 6 displays the input values assumed for the pavement design. The layer thickness should be such that the resultant stress-strain value must be lower than the permitted stress-strain value obtained using an elastic linear layer model.

Table 6. Input values assumed for flexible pavement.

Input	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

3.5.3. Analysis of result

Permitted horizontal tensile strain (εt) values and permitted vertical compressive strain (εv) values were computed using the IITPAVE software. The horizontal tensile strain is responsible for the fatigue cracks and the vertical compressive strain is responsible for the rutting in pavement; both decrease when the subgrade was mixed with additive than that of untreated clayey soil subgrade. With the addition of additive in clay, the thickness of the pavement layers continues to decrease for the same traffic load and subsequently the thickness of the pavement layers increased when commercial vehicle per day were increased for the same pavement. Figure 21, Figure 22, and Figure 23 indicate that for 1000 commercial vehicles per day, 3000 commercial vehicles per day and 5000 commercial vehicles per day, the thickness falls from 570 mm to 410 mm, 710 mm to 580 mm, and 740 mm to 610 mm, respectively. The decrease in pavement thickness significantly reduces the cost of pavement construction.

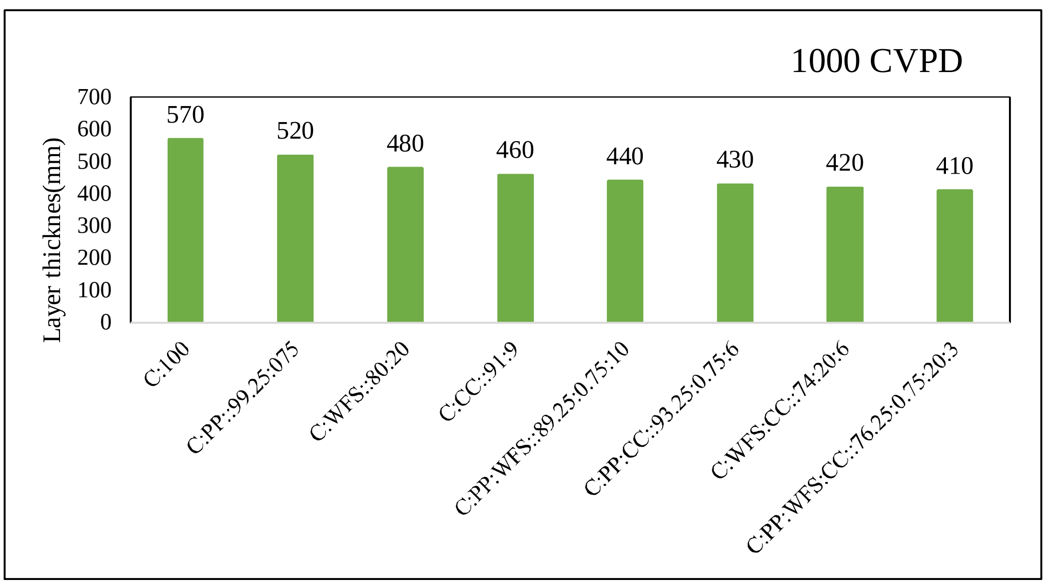

Figure 21. Pavement thickness for 1000 commercial vehicle per day.

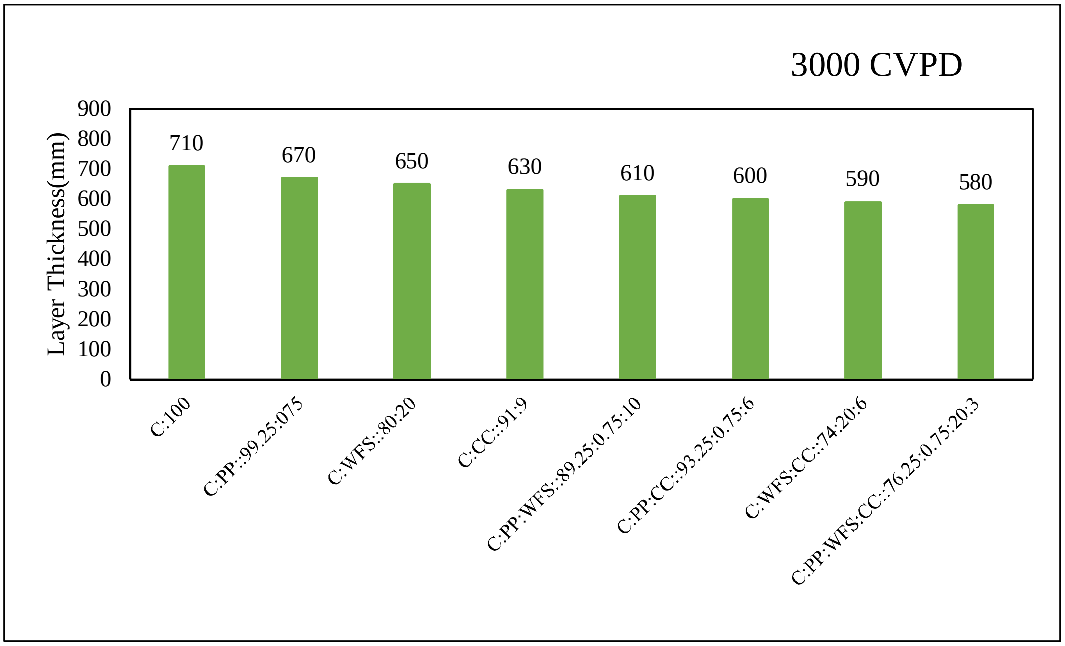

Figure 22. Pavement thickness for 3000 commercial vehicle per day.

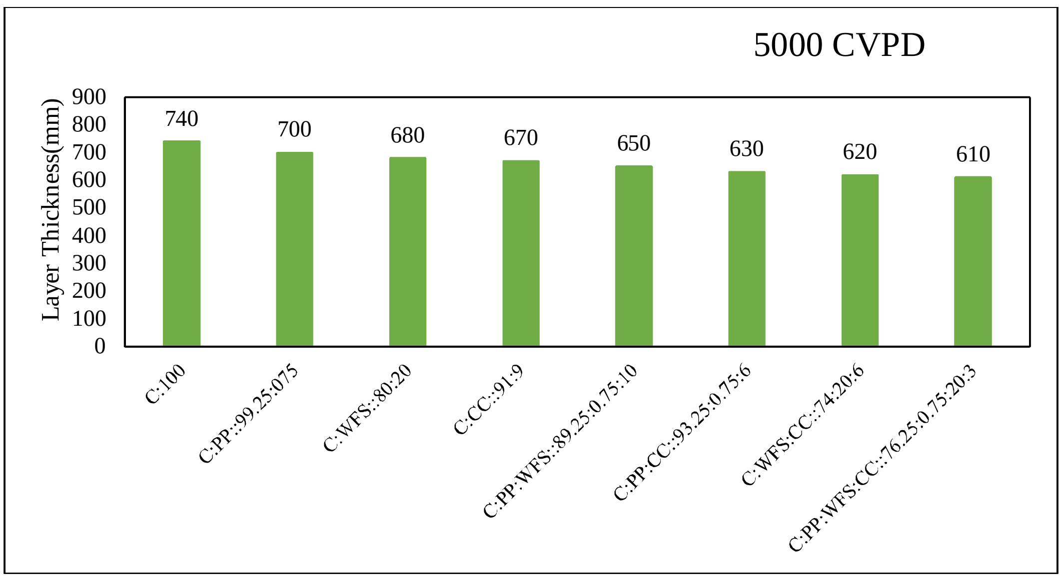

Figure 23. Pavement thickness for 5000 commercial vehicle per day.

3.5.4. Resilient modulus

The subgrade acts mostly elastically under temporary traffic loads, with small irreversible deformation in one pass. A material's resilient modulus is a measurement of its elastic behaviour. It provides a measure of material rigidity as well as a parameter for examining material rigidity under different conditions such as humidity, stress level, and density. A repeated 3-axial test for soil resilient modulus can be performed in the lab using the methods provided in AASHTO T307-99. Table demonstrates resilience modulus values for different blends with clayey soil; it shows that stabilising clayey soil with various additives leads rise in resilience modulus values. The pavement made with stabilised soil subgrade has more strength and is thus more durable and long-lasting. Table 7 represents the resilient modulus changes with increase in CBR value.

Table 7. Resilient modulus for various combinations.

Optimum combinations (%)	Design CBR(%)	CVPD (both sides)	Resilient modulus		
			$M_{subgrade}$	$M_{granular}$	$M_{bitumen}$
C:PP:99.25:0.75	5.7	1000	55.65	174	2000
		3000	55.65	192	3000
		5000	55.65	196	3000
C:WFS:80:20	6.4	1000	58.60	183	2000
		3000	58.60	200	3000
		5000	58.60	204	3000
C:CC:91:9	7.2	1000	61.65	189	2000
		3000	61.65	210	3000
		5000	61.65	214	3000
C:PP:WFS:89.25:0.75:10	8.1	1000	65.77	199	2000
		3000	65.77	220	3000
		5000	65.77	225	3000
C:PP:CC:93.25:0.75:6	8.8	1000	70.22	209	2000
		3000	70.22	234	3000
		5000	70.22	238	3000
C:WFS:CC:74:20:6	9.6	1000	77.25	220	2000
		3000	77.25	248	3000
		5000	77.25	250	3000
C:PP:WFS:CC: 76.25:0.75:20:3	11	1000	81.66	228	2000
		3000	81.66	257	3000
		5000	81.66	260	3000

3.5.5. Analysis of cost of pavement designed

The Himachal Pradesh Public Works Division releases the cost and technical parameters and properties of every material for all flexible road pavement layers. The Schedule of Rates 2020 manual is utilized to figure out the cost of every layer [48]. Road length chosen in this analysis was 1000 m, and the pavement was designed solitary for single lane road. The following layers are taken into account:

bituminous concrete (BC): dense bituminous macadam (DBM): water-bound macadam (WBM): sub-base (SB): sub-grade (SG).

The cost calculations of the subgrade course in Indian Rupee (INR) were computed. The construction cost for different layers including the sub grade layer consisting of clayey soil were computed. The total cost for 1000 CVPD, 3000 CVPD, and 5000 CVPD were calculated and it comes out to be 1, 30, 27, 430; 1,71, 09, 305; and 1, 78, 55 ,655, respectively. Similarly the construction cost for several layers including the subgrade layer which is composed of clayey soil combined with the additive at optimum combination of (C:PP:WFS:CC:76.25:0.75:20:3) were founded to be 85,54,168;1,29,92,231; and 1, 38, 67, 018. Based on the results, the cost reductions for 1000 CVPD, 3000 CVPD, and 5000 CVPD was 34.33%, 24.06%, and 22.33%, respectively (Figure 24).

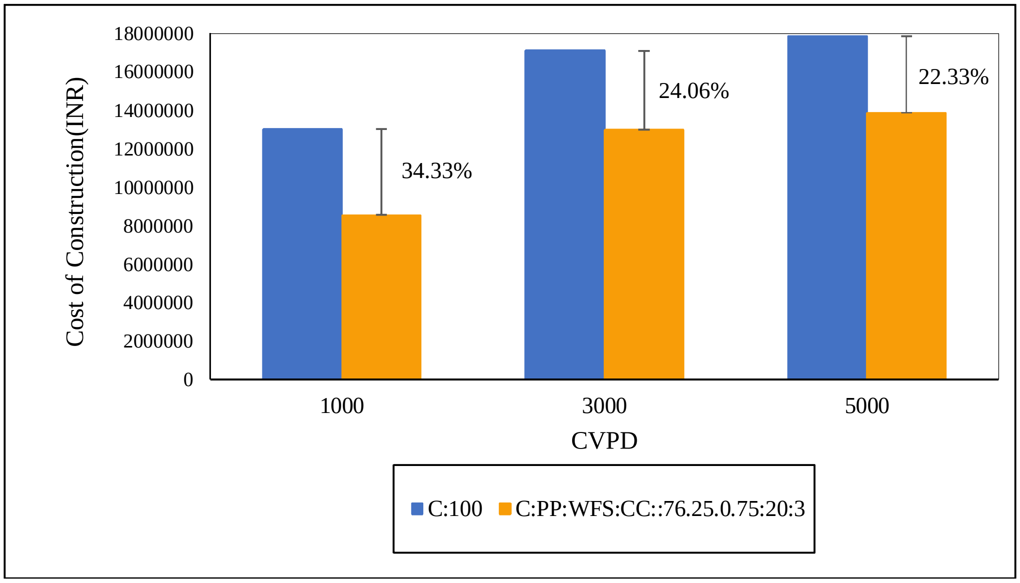

Figure 24. Cost reduction in pavement construction by using admixtures.

4. Conclusions

To enhance the geotechnical qualities of the clayey soil, the efficacy of calcium carbide residue as a binder and waste product from acetylene factories, waste foundry sand as industrial waste, and polypropylene as a fibre were investigated. The following are the primary findings reached:

- The differential free swell of soil reduced to 0 with increase in calcium carbide residue up to 9% after that the DFS value increases with further increase in CC percentage. Similarly, the differential free swell of soil reduced to 0 with increase in WFS up to 20% and then it remains same. The use of calcium carbide residue, waste foundry sand, and polypropylene fibre, both individually and in combination to others, lowered the soil's plasticity index. The combination of 9% calcium carbide residue, 20% waste foundry sand, and 0.75% polypropylene fibre was discovered to be optimal for individual combinations.
- The addition of varying calcium carbide residue reduces the MDD and increases the OMC for C:WFS:80:20, C:PP:99.25:0.75, and C:PP:WFS:79.25:0.75:20 combinations; and when WFS is added to the C:PP:99.25:0.75 combination, the MDD and OMC of soil both increases.
- The clayey soil's UCS increase when calcium carbide residue, waste foundry sand and polypropylene fibre are added alone or in combination. The highest UCS value for 28 days attained was 935 kPa for the best combination of C:PP:WFS:CC:76.25:0.75:20:3.
- Soaked CBR test was conducted and the CBR value shows increment with addition of CC, WFS, and PP fibre individually and in combination with each another. The CBR value increase to 11% for the best combination of C:PP:WFS:CC:76.25:0.75:20:3.
- IIT PAVE software was used to find the thickness of subgrade layer for all optimal combinations. As CBR value increases for different combinations, it reduced the thickness of subgrade layer. When similar pavement structure with a purely clayey soil subgrade layer, is compared with a soil subgrade layer that used the ideal composition of C:PP:WFS:CC:76.25:0.75:20:3 into the pavement structure, it reduced the overall cost of pavement by 34.33%, 24.06%, and 22.33%, for 1000, 3000, and 5000 CVPD, respectively. As a result, inclusion of polypropylene (0.75%): waste foundry sand (20%): and calcium carbide residue (3%) into clay soils increased the sub-grade layer strength, while the construction cost for flexible pavement design decreases.

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Conflict of interest: The authors declare that they have no conflict of interest.
Data availability: The data associated with this study will be provided on request.

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بهبود خواص ژئوتکنیکی خاک با استفاده از کاربید کلسیم، ضایعات ماسه ریخته‌گری و الیاف پلی پروپیلن

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چکیده:

این مقاله کاربردهای ضایعات صنعتی مانند ماسه ریخته‌گری زباله (10٪، 20٪، 30٪ و 40٪) و باقیمانده کاربید کلسیم (3٪، 6٪، 9٪ و 12٪) مخلوط شده با الیاف پلی پروپیلن (0,25٪) 0,50%، 0,75% و 1% برای تثبیت خاک را مورد بحث قرار می‌دهد.. هدف از این مطالعه ایجاد ترکیبی از خاک رسی مخلوط با مواد افزودنی مختلف است تا بتوان از آن برای بهبود خواص ژئوتکنیکی خاک رسی استفاده کرد. آزمایش‌های متعددی از جمله تورم آزاد تفاضلی، آزمایش محدودیت‌های آتربرگ، آزمایش‌های تراکم، آزمایش فشرده‌سازی نامحدود (UCS)؛ و آزمون نسبت باربری کالیفرنیا (CBR) روی خاک رسی به‌صورت جداگانه و در ترکیب‌ها و نسبت‌های مختلف با افزودنی مخلوط با یکدیگر انجام می‌شود. درصد بهینه برای افزودنی‌ها با انجام شاخص تورم دیفرانسیل آزاد و آزمون محدودیت‌های آتربرگ بدست می آید. نتایج نشان می‌دهد که گنجاندن مواد افزودنی در خاک رسی باعث کاهش تورم و شاخص انعطاف پذیری آزاد تفاضلی کامپوزیت می‌شود اما مقادیر UCS و CBR کامپوزیت را افزایش می‌دهد. حداکثر افزایش در مقادیر UCS و CBR برای ترکیب بهینه C:PP:WFS:CC:76.25:0.75:20:3 به دست می‌آید. بر اساس مقادیر CBR، ضخامت روسازی انعطاف پذیر با استفاده از نرم افزار IITPAVE طراحی شده است. نتایج تحلیل نرم افزاری کاهش ضخامت روسازی را برای مقادیر مختلف خودروهای تجاری در روز (1000، 2000 و 5000) برای همه ترکیب‌ها نشان می‌دهد. حداکثر کاهش ضخامت لایه و هزینه‌های ساخت برای C:PP:WFS:CC:76.25:0.75:20:3 مشاهده می‌شود. برای بررسی بیشتر بهبود خواص ژئوتکنیکی خاک، باقیمانده کاربید کلسیم و ماسه ریخته گری زباله را می توان با افزودنی‌های نانو برای استفاده های بالقوه مخلوط کرد.

کلمات کلیدی: خاک رسی، تراکم، محدودیت‌های قوام، نسبت باربری کالیفرنیا، مقاومت فشاری نامحدود.