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# Evaluation of the Efficacy of Nylon Fibers and Lime in Improving Metakaolin Modified Expansive Soil

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**Abstract.** Expansive Soils are causing severe damages to the structures such as buildings and pavements built over them due to their high degree of swelling and shrinkage. This phenomenon will result in rutting mode of failure requiring immediate strengthening or reconstruction of the whole structure. Thus, for safe design such soils need to be improved before construction. Hence in order to improve the properties of such soils many methods are available like soil stabilization, soil replacement, moisture control, prewetting etc. In recent years, soil stabilization by using various industrial wastes were most common practice. Keeping in view in the present research, experiments were carried out to investigate the performance of different additives like Lime and Metakaolin, which is a pozzolanic material obtained by calcination of Kaolinite clay at temperatures from 700°C to 800°C and further enhancing the treated expansive soil by adding nylon fibres to impart more strength and cater the respective civil engineering infrastructure needs. To understand the performance of stabilized soil, its properties like Atterberg's limits, Compaction parameters, and Penetration parameters were studied in the laboratory. The results yielded an encouraging performance and the efficiency of the added materials. The optimum combination was 6% lime + 15% Metakaolin + 1.5% Nylon fibres which gave the ultimate improvement in the characteristics of the problematic expansive soil. Hence the present paper summarizes the use of nylon fibres and lime as stabilizing materials for improving Metakaolin modified expansive soil as a sustainable alternative.

**Keywords:** Expansive soil, Metakaolin, Lime, Nylon fibres and Strength Characteristics.

## 1 Introduction

Expansive soils, also termed as swelling soils have a tendency to swell and shrink with the variation in moisture content. As a result of which significant distress in the soil occurs, causing severe damage to the overlying structure. The geotechnical behavior of expansive clay soils varies from region to region based on geomorphologic, geological and climatic conditions and mineralogical composition of the soils in the study area. It is a well-known fact that expansive soils pose considerable problems in civil engineering constructions. In India, predominantly expansive soils found in Deccan trap region of Maharashtra, Andhra Pradesh, Karnataka, Madhya Pradesh, Gujarat, and Tamilnadu.

Expansive soil shows the property of high plasticity and water receptivity which makes them highly problematic due to the presence of clay mineral called montmorillonite. More the clay mineral more will be the absorbed water and more will be the volume change. Due to this volume changes, severe distress and excessive settlement will take place in the structure. About 20% of the Indian subcontinent is covered with expansive soils. Expansive clay soil is the most predominant geologic hazard across the India. If such soils not treated well it can cause extensive damages to the structures built upon them. Damage caused by these soils is evidenced in many costly ways and is particularly obvious in buildings and pavements.

Several methods are suggested as solutions to prevent damage to buildings in expansive soil areas, namely: soil replacement, prewetting, compaction control, and chemical treatment. Some of these have been used in this country over the last decade. The selection of an appropriate method depends on ground characteristics, effectiveness, and applicability of the preferred technique, installation and maintenance costs. Among these methods, soil stabilization is a widely accepted technique that process by changing the behavior and properties of soil under certain conditions. Soil stabilization involves changes in properties like increases the strength and density, decreases swelling behavior, etc. Soil stabilization techniques can considerably increase the profiles of the low strength expansive soils to the desired extent. Further, these techniques are very economical and reduce the overall cost of a project.

In recent years, soil stabilization by using various industrial wastes was a most common practice. Keeping in view the present study investigates the performance of different additives metakaolin in combination with lime in improving the strength characteristics of expansive soil. Further, the study was extended to assess the influence of nylon fibers (NF) on the metakaolin and lime Modified Expansive Soil.

## 2 Literature Review

Expansive soils are composed primarily of hydrophilic clay minerals, such as Montmorillonite, and with significant swelling and shrinking characteristics. In the past many researchers have carried out their research work for improving the strength of Expansive soil using different types of admixture at different percentages. A brief review of previous studies on expansive soil is presented in this section and past efforts most closely related to the needs of present work.

Chemical stabilization has been discussed by many authors Al-Rawas and Goosen (2006), Little and Nair (2009). Chemical stabilizers result in improving the CBR and UCS values of the sub-grade soil. The liquid limit and plastic limit of the stabilized soil are improved, especially in the cases of highly plastic clays and silts. The hydration process results in a stabilized soil which exhibits greater shear strength, stiffness, and bearing capacity.

Venkateswarlu et al conducted an experimental study on evaluating the strength characteristics of lime and metakaolin on expansive soil. Optimum values for lime and metakaolin was obtained from laboratory experiments. Cyclic plate test was conducted on untreated and treated subgrade. The load carrying capacity of treated subgrade is high compared to untreated one.

An important phenomenon reported by many researchers is the ability of lime to change the plasticity of soils. Liquid limit and plastic limit are influenced by lime Wilkinson et al (2010), Khattab et al (2007). Expansive soils generally contain clay minerals with expanding lattice structure such as montmorillonite, which has large affinity for water. Therefore, such soils undergo large swelling, leading to severe distress and damage to the overlying structures (Petry et al 2002).

Uma G. Hullur conducted experimental investigation on the behavior of black cotton soil using different admixtures as cement, fly ash, GGBS, silica fume, Metakaolin and RHA. Proctor test wascarried out to find the maximum dry density and optimum moisture content. The results showed 30% ggbfs gave maximum dry density, 30% metakolin gave maximum dry density and concluded that Among the different admixtures, cement, GGBFS and Metakaolin are the one which showed maximum dry density at their optimum level that is 30%.

Gosavi et al (2003) investigated the strength behavior of locally available black cotton soil reinforced with randomly oriented Geotextile woven fabric & fiberglass fibre reported an increase in the value of cohesion & slight decrease in the value of angle of internal friction with addition of 2% of these fibres in black cotton soil.

From the available literature, it can be perceived that limited research has been done to study the effects of Metakaolin in improving the geotechnical properties of expansive soil. Therefore, the present study has been undertaken to investigate the efficacy of nylon fibers and lime in improving Metakaolin modified expansive soil.

## 3 Methodology

There are several methods that have been used to minimize the effect of expansive soils on the structures. These methods include soil replacement, pre wetting, surcharge loading and use of Geosynthetics. The term soil stabilization means the improvement of the stability of bearing power of the soil by the use of controlled compaction, proportioning under the addition of suitable admixtures or stabilizers. Stabilization is one of the economical methods of treating the Black cotton soil to make them suitable for construction.

### 3.1 Materials used

The different variables present study are listed in Table 1 and the properties of collected soil are presented in Table 2.

**Expansive Soil**: The soil sample collected from Komarigiripatnam Oddalarevu' near Amalapuram, in East Godavari District, Andhra Pradesh State, India.' has been selected for the present study after having a visual inspection of it. When a lump of sample was cut with a knife it gave a shining surface hence, it was concluded that the sample is of clayey nature. Laboratory tests were carried out as per the IS Codal Provisions by pulverizing the lumps into individual particles to determine the properties of the selected soil sample as mentioned here under.

**Metakaolin:** The Metakaolin has been procured from Jeetmull Jaichandlall Pvt. Ltd. Chennai, Tamilnadu was used. The physical and chemical characteristics furnished by the manufacturer are moisture content of 0.18 %, specific gravity of 2.65, bulk density of 710 kg/m3 and pH of 7.0. Metakaolin consists majorly of $SiO_2$, Al2$O_3$, and $Fe_2O_3$ contributing 53.7 %, 39.2 %, 3.84 %, of the total. The next most abundant component is titanium oxide, TiO2 (5.97 %). According to ASTM standard specification , the sum of $SiO_2$, Al2$O_3$, $Fe_2O_3$ be $\geq$ 70 % for any material to be used as a pozzolana.

**Nylon fibre:** The nylon ropes were procured from the market and were cut to 2 mm Dia. and 50 mm long are cut into discrete fibres according to the requirement. The basic properties of the fibers were determined and noted that thespecific gravit is 0.9.

**Lime:** Commercial grade lime mainly consisting of 62% CaO and 8% silica was used in this study.

**Table 1.** Variables studied in the present work

| S.No. | Stabilizing Agent | Variables |
|---|---|---|
| 1 | Metakaolin as Replacement | 0, 5, 10, 15, 20 |
| 2 | Lime | 0, 2, 4, 6 |
| 3 | Nylon Fiber (NF) | 0, 0.5, 1,1.5, 2 |

**Table 2.** Properties of expansive soil

| S.No | Property | Value |
|---|---|---|
| 1 | Specific gravity | 2.67 |
| 2 | Differential free swell Index (%) | 104 |
| 3 | Liquid limit (%) | 69.3 |
| 4 | Plastic limit (%) | 25.6 |
| 5 | Plasticity index (%) | 43.7 |
| 6 | Sand Size Particles (%) | 11 |
| 7 | Silt & Clay Size Particles (%) | 89 |
| 8 | IS soil classification | CH |
| 9 | Max. Dry Density (g/cc) | 1.44 |
| 10 | Optimum Moisture Content (%) | 28.3 |
| 12 | Cohesion, C (kPa) | 39 |
| 13 | CBR - Soaked (%) | 1.4 |
| 14 | Angle of Internal Friction, Ø (degrees) | 0 |

# 4 Results and Discussions

In the laboratory, various experiments were conducted by replacing different percentages of Metakaolin in the expansive soil and also further stabilizing it with lime as a binder and further reinforced with nylon fiber. IS light Compaction, UCS and soaked CBR tests were conducted to determine the optimum combination of Metakaolin as a replacement in expansive soil and lime as a binder and further blended with nylon fiber. The influence of the above said materials on the compaction and strength characteristics were discussed in following sections. All the tests were conducted per IS 2720 of Various parts.

## 4.1 Effect of metakaolin and lime on the compaction properties

Figures 1, 2, 5&6 show the variation of Maximum dry density values for replacement of Metakaolin and to the optimum percentage of Metakaolin, percentage addition of lime respectively. It can be observed that the treatment as individually with 15% Metakaolin has moderately improved the expansive soil. Further, it can be inferred that there is a gradual increase in maximum dry density with an increment in the Metakaolin up to 15% with an improvement of about 10.41 % and further addition of lime led to an enhancement in the value by about 10.6%. Replacing the clay with Metakaolin had improved the density. In addition, lime as auxiliary material provided further improvement in the maximum dry density. This can be attributed to the development of a solid matrix of lime and Metakaolin in the presence of optimum moisture content.

## 4.2 Effect of metakaolin and lime on the CBR

Figures 3&7 show the variation of CBR values for replacement of Metakaolin and to the optimum percentage of Metakaolin, percentage addition of lime respectively. It can be observed that the treatment as individually with 15% Metakaolin has moderately improved the expansive soil. It can be inferred from the graphs, that there is a gradual increase in CBR values with an increment in Metakaolin up to 15% with an improvement of about 135.7 % soaked CBR and further addition of lime to the optimum percentage 6% of lime that there is a gradual increase in CBR values with an improvement of about 81.8% for soaked CBR. Replacing the highly compressible material like clay with a sand-sized material can reduce the compressibility and improves the CBR. Further, the presence of china clay and other strengthening agents stiffens slowly in the presence of water and improves the CBR in the long term. It is clear that lime provides additional strength in the presence of water and significantly improves the CBR in soaked condition.

## 4.3 Effect of metakaolin and lime on the strength characteristics

Figures 4& 8, show the variation of UCS Values for replacement of Metakaolin and to the optimum percentage of Metakaolin, percentage addition of lime respectively. From the figures, it was observed that the treatment as individually with 15% Metakaolin has moderately improved the expansive soil. It can be inferred from the graphs, that there is a gradual increase in UCS values with an increment in the % replacement of Metakaolin up to 15% with an improvement of about 61.5 % further addition of lime to the optimum percentage 6% of lime that there is a gradual increase in UCS values with an improvement of about 50%.The Metakaolin, a quantize based porus material has very minimal influence in improving the UCS when replaced. However, when added with lime, due to the formation high strength matrix as a result of pozzolanic reaction significantly improved the UCS.

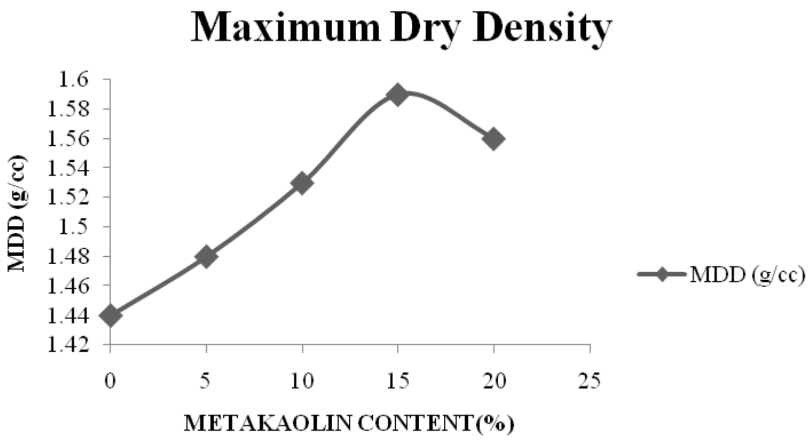


**Fig. 1.** Variation of MDD with % replacement of Metakaolin

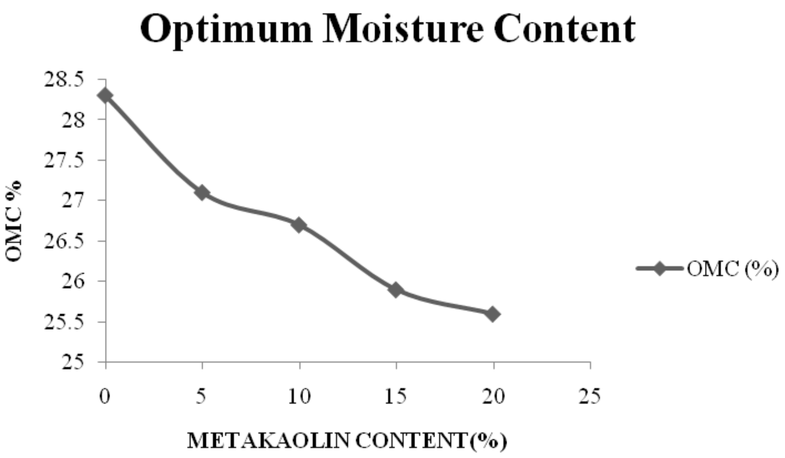


**Fig. 2.** Variation of OMC with % replacement of Metakaolin

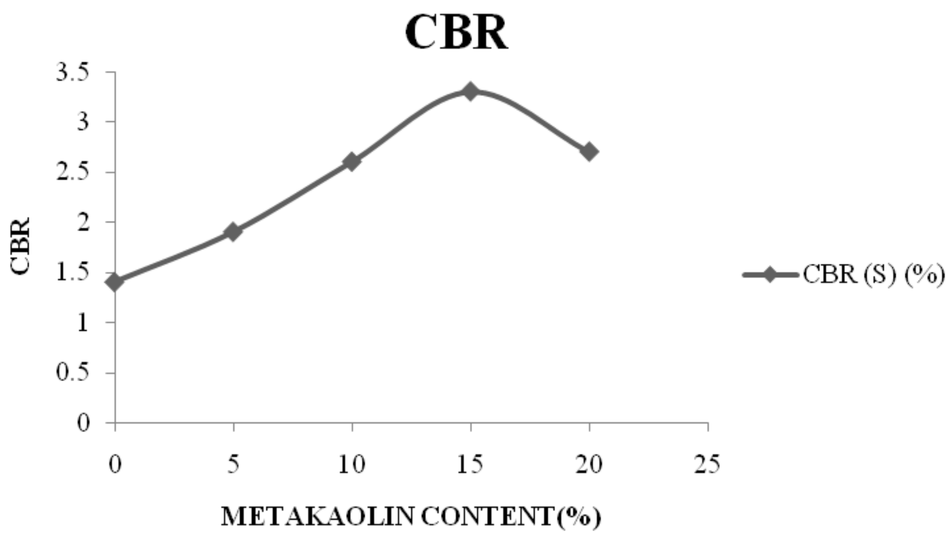


**Fig. 3.** Variation of CBR with % replacement of Metakaolin

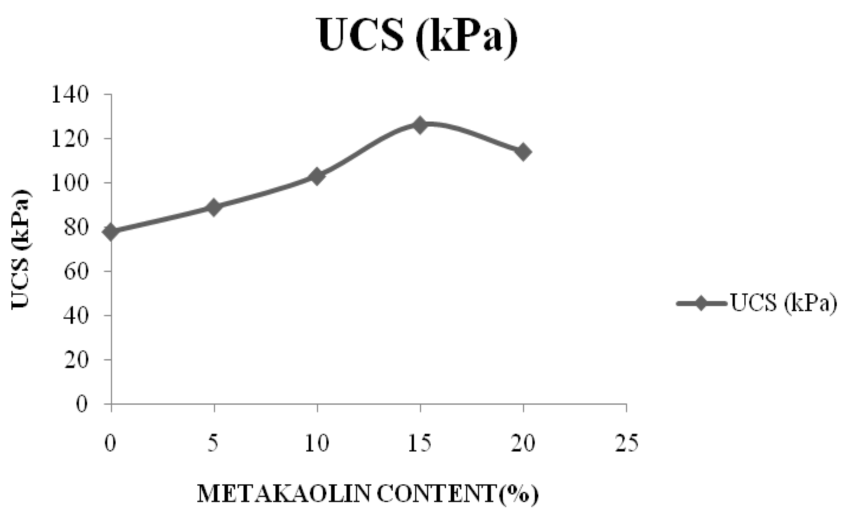


**Fig. 4.** Variation of UCS with % replacement of Metakaolin

It can be inferred from the figures, that there is a gradual increase in the strength properties of the soil with percentage replacement of Metakaolin. From the above results, the 15% replacement of expansive soil with Metakaolin can be considered as optimum.

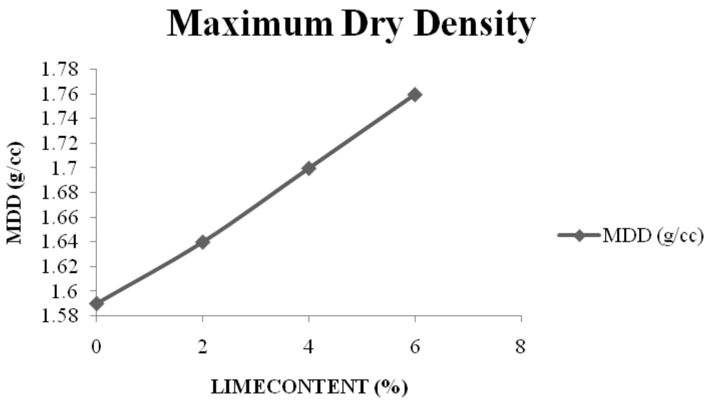


**Fig. 5.** Variation of MDD with % addition of lime

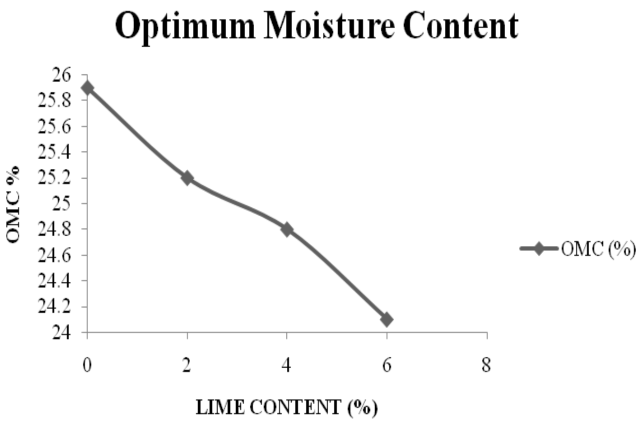


**Fig. 6.** Variation of OMC with % addition of lime

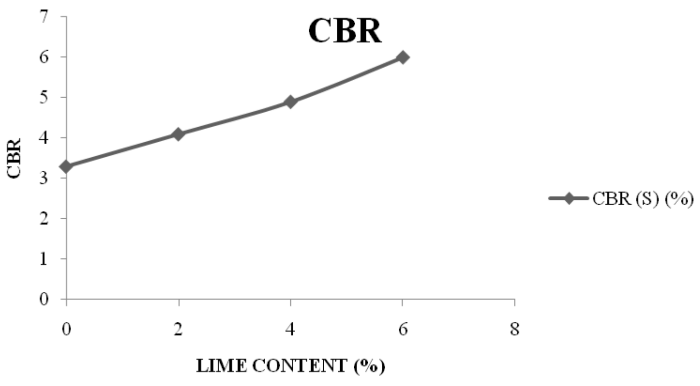


**Fig.7.**Variation of CBR with % addition of lime

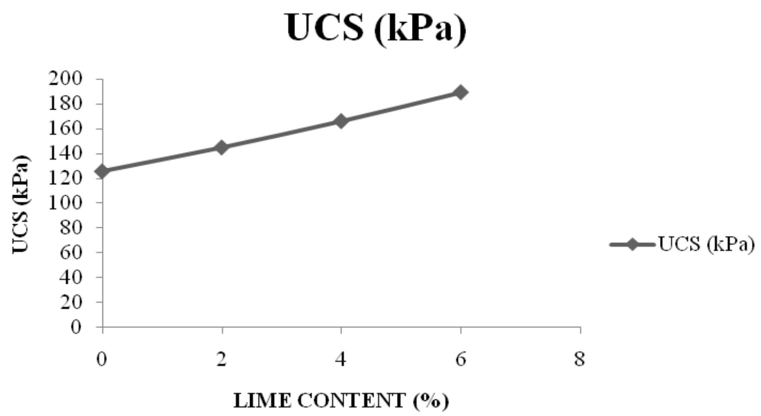


**Fig.8.** Variation of UCS with % addition of lime

It can be perceived that the improvement in the CBR values is significantly higher than compaction and UCS. Though the percent of admixtures were same for all the tests, the reaction time and strength achievement for the soil- Metakaolin -lime matrix would be different. Since UCS and compaction properties are tested immediately after the sample preparation and soaked CBR is tested after 96 hours, the sample got much time to complete the pozzolanic reaction. This resulted in high strength profiles for soaked CBR compared to compaction and UCS.

From the results, the optimum content of lime with 15% Metakaolin as replacement of expansive soil is determined as 6%.Further, tests were conducted for different percentages of nylon fibre by adding to the Metakaolin treated expansive soil with an optimum percentage of lime i.e. 6%.

### 4.4 Effect of nylon fibre on expansive soil with 15% metakaolin as replacement + 6% lime

For the soil- Metakaolin -lime matrix maximum dry density value is 1.76 g/cc from the figure 9 it is found that with the addition of nylon fibres to the soil- Metakaolin -lime mix there was increase in dry density up to 1.7% of addition then decrease subsequently with further addition of fibre content. The increase in dry density may be due to better interaction of soil with fibre. From the figures 10 and 11 it was found that the CBR and UCS value increases with increase in fibre content. When the nylon fibre content is varied, a fall in the CBR and unconfined compressive strength was observed with fibre content greater than 1.5% in case of nylon fibre. Hence it is concluded that fibres at 1.5% yield a maximum value in terms of dry density, CBR and UCS. The increase in the values of MDD, CBR and UCS with addition of 1.5% nylon fibre can attributed to the better orientation of fibres along with the soil particles. However, with further increase in the nylon fibre, accumulation of fibre material is observed which eventually lead to the reduction in the strength of the soil matrix.

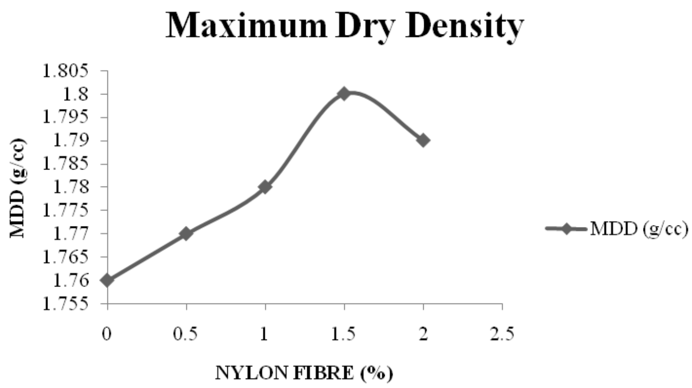


**Fig.9.**Variation of MDD with % of nylon fibre

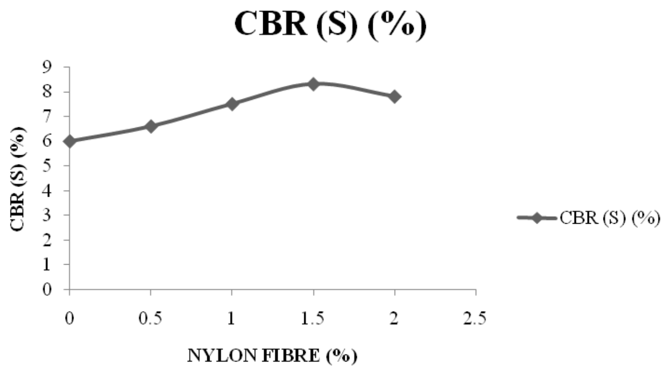


**Fig.10.** Variation of CBR with % of nylon fibre

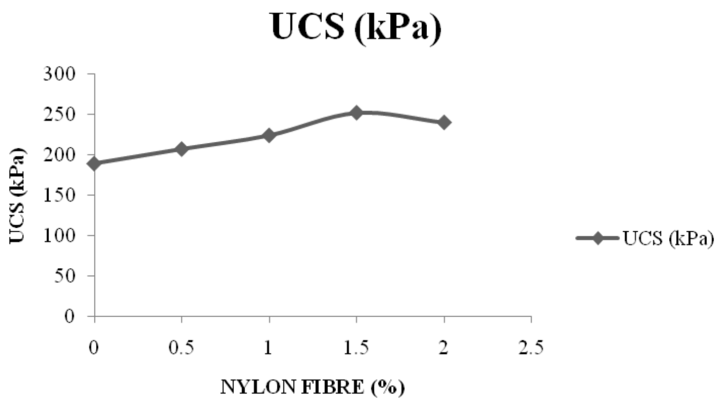


**Fig.11.** Variation of UCS with % of nylon fibre

From the above discussions, the optimum content of nylon fibre with 6.0% lime + 15% Metakaolin as replacement of expansive soil is 1.5%. It is clear that there is an improvement in the behavior of expansive soil stabilized with 6.0% lime + 15% Metakaolin + 1.5 % nylon fibre.

It is evident that the addition of Metakaolin to the virgin expansive soil showed an improvement in compaction and strength characteristics to some extent and on further addition of lime shows prominent results and further blending it with nylon fibre, the improvement was more pronounced. This made the problematic expansive soil which if not stabilized is a discarded material, a useful fill material with better properties. The Metakaolin replacement in the expansive soil has improved its strength and upon further blending with Nylon fibre, the strength has further improved and also these materials have imparted friction to the clayey soil. It can be summarized that the materials Metakaolin, lime and nylon fibre had shown promising influence on the Strength and Penetration properties of expansive soil.

## 5 Conclusions

The following conclusions are made based on the laboratory experiments carried out in this investigation. From the laboratory studies, it is observed that the Expansive Soil chosen was a problematic soil having high swelling, and high plasticity characteristics. The following conclusions are made based on the laboratory experiments carried out in this investigation.

1. It was observed that the treatment as individually with 15% Metakaolin has moderately improved the expansive soil.
2. There is a gradual increase in maximum dry density with an increment in the % replacement of MK up to 20% with an improvement of about 5% and it is observed that for the replacement of 15% there is gradual increase in Maximum dry density about 10.41%.
3. There is an improvement in maximum dry density and also corresponding strength characteristics with an increase in the lime content from 0% to 6% with an increment of 2%.There is an improvement of 135.7% and 61.5% in CBR and UCS respectively for Metakaolin individually and further addition of 6% of lime there is an increment about 81.8% and 50% in CBR and UCS respectively.
4. Further blending with different Nylon Fibers with 0% to 2% with an increment of 0.5% there is increment of CBR and UCS values is about 27.7% and 25.1% respectively.
5. It is evident that the addition of Metakaolin (MK) to the virgin Expansive soil showed an improvement in compaction, strength and penetration characteristics to some extent and on further blending it with lime and Nylon Fibers the strength mobilization was more pronounced.

6. Finally it can be summarized that the materials Metakaolin (MK) and lime and different Nylon Fibers had shown promising influence on the strength characteristics of expansive soil, thereby giving a two-fold advantage in improving problematic expansive soil and also solving a problem of waste disposal.

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