A COMPARATIVE STUDY ON THE INFLUENCE OF TRADITIONAL, NON-TRADITIONAL AND BY-PRODUCT STABILIZERS ON GEOTECHNICAL PROPERTIES OF KUTTANAD CLAY

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Abstract - *In developing countries like India the most important requirement of any project are its cost, performance, durability and time. There is an urgent need for development of new techniques which enhances the geotechnical properties of soil, as the methods used conventionally were very uneconomical and time consuming. Construction of engineering structures on weak or soft soil is considered as unsafe and highly risky due differential settlements, poor shear strength, high compressibility and high plasticity characteristics. It is necessary to adopt safer, economically feasible, environmentally sound and cost effective materials to improve geotechnical properties of Kuttanad clay, by utilizing three different locally available stabilizers such as Traditional stabilizer (Metakaolin), Non-traditional stabilizer (Terrazyme) and By-product stabilizer (Crumb Rubber Powder). The present study is to do an experimental investigation on the influence of 2%, 4%, 6%, 8% and 10% of Metakaolin , 200ml/1m^3, 200ml/1.5m^3, 200ml/2m^3, 200ml/2.5m^3 and 200ml/3m^3 of Terrazyme and 5%, 10%, 15% and 20% of Crumb Rubber Powder on geotechnical properties of Kuttanad clay by conducting Atterberg Limits test , Triaxial Compression test and One Dimensional Consolidation test. Further a comparative study is done on the optimum values of these materials and approached a pertinent conclusion on which stabilizer gives maximum improvement in shear strength, reduce compressibility and plasticity characteristics after varied curing periods of 3, 7 and 14 days. The test results indicate that 6% of Metakaolin, 200ml/2m^3 of Terrazyme and 10% of Crumb Rubber Powder are experimentally proved as optimum values. Kuttanad clay treated with Traditional stabilizers showed maximum improvement in shear strength behavior, reduced plasticity and consolidation characteristics after 14 days of curing period when compared to Non-traditional and By-product stabilizers.*

Key Words**: Geotechnical properties, Kuttanad clay, Metakaolin, Terrazyme, Crumb Rubber Powder, Atterberg Limits, Triaxial Compression, One Dimensional Consolidation, Traditional, Non-traditional, By-product, Stabilizers, Shear strength, Compressibility and Plasticity.**

1. INTRODUCTION

The construction of engineering structures on fine grained soil is a challenging task and therefore considered as one of the biggest concerns in geotechnical engineering. The behaviour of structures to be safe and stable, it depends on the properties of the soil on which they are constructed and the load bearing capacity of the soil can be improved by undertaking a variety of ground improvement techniques. Soil Stabilization is the modification of soils by blending cost effective and locally available materials to enhance their physical and geotechnical properties. Soft clays generally display extremely low strength, high compressibility, low permeability, high plasticity characteristics and consequently low quality for construction. Thus, treatment of soil is necessary by mixing various economically feasible and environmentally sound stabilizers that can be effectively embraced to improve the strength and deformation characteristics of the soft clays.

Kuttanad region is well known for its unique agricultural land in Kerala. Kuttanad soil is fine grained soil and it is categorised as one of the problematic soils in the world. A good portion of this region lies below mean sea level and during raining season the area is submerged under water more than a month in every year. The increase in population and the development of the area has demanded construction activities to be undertaken in Kuttanad region. It is necessary to adopt safer, economically feasible, environmentally sound and cost effective materials to improve geotechnical properties of Kuttanad clay, by utilizing three different locally available stabilizers such as

Traditional stabilizer (Metakaolin), Non-traditional stabilizer (Terrazyme) and By-product stabilizer (Crumb Rubber Powder).

Metakaolin is a supplementary cementing material manufactured from kaolin. It is neither a by-product of any industrial process nor formed naturally. Metakaolin contains high percentage of aluminosilicates. Generally it is compatible with all types of chemical admixtures. It has many advantages compared to other mineral additives. This material is economical, operational and performance based. The most important benefit of metakaolin is its easiness in handling and mixing.

The use of Bio enzymes in soil has emerged as one of the renewable technologies for drastically improving soil properties and it is eco friendly and economical in long run. The enzymes have a unique property when added to soil, it increases the wetting and bonding capacity of the soil particles that allows soil material to become more easily wet and more densely compacted. In order to stabilize soils, a number of chemical additives both inorganic and organic have been used for improving strength and durability of soil. Chemical stabilization is a process by adding chemical additives like enzymes to the soil uniformly that physically blend with soil particles which alters and enhance the geotechnical properties of soil by providing higher soil compaction and strength. Enzymes are expected to be very soil specific.

Developing countries like India mainly depend on the transportation sector for their economical growth. There is a continuous development and growth in the usage of motor vehicles which causes noise pollution, air pollution etc. Disposal of waste tyres are challenging task due to its long life and non-biodegradable nature of rubber. Various industrial wastes such as Crumb rubber powder a by-product of used automotive tyres that are recycled rubbers retrieved from discarded used truck scrap tyres by crushing and removal of the textiles and metal fibres are effectively used as a soil replacement material which not only solves environmental problems but also provides a new resource for construction industry and an economically feasible disposal method of waste tyres to conserve natural resources.

2. LITERATURE REVIEW

Leong Sing Wong and Roslan Hashim (2013) demonstrated the application of kaolin as a pozzolanic additive of stabilized peat. In addition to kaolin, Portland composite cement, calcium chloride and silica sand were used as the materials to stabilize the peat. To achieve such aim, test specimens of both untreated and stabilized peats were tested in laboratory in order to evaluate its Unconfined Compressive Strength (UCS) and rate of permeability. Each test specimen was prepared in such a way that it has to simulate the in situ condition of deep peat stabilization by deep mixing method. It was found that test specimen with 10% partial replacement with kaolin has the highest UCS that exceeds the minimal required UCS of 345 kPa. The test specimen was subjected to 100 kPa initial pressure and cured in water for 7 days. The UCS of the test specimen was discovered to be 33.7 times greater than that of untreated peat specimen. In laboratory permeability tests, the rate of permeability of untreated peat was found to be 6.43×10^{6} times higher than that of stabilized peat. UCS of stabilized peat increased while increasing its binder dosage, silica sand dosage, initial pressure, and duration of curing in water. Combined action among the hydrolysis of the cement, the pozzolanic reaction of kaolin, and the filler effect of well graded silica sand in the stabilized peat. **Zhang Tongwei and Yue Xibing (2014)** conducted a comprehensive study on the macro-strength and micro-structure development of cement-stabilized Lianyungang marine clay mixed with Metakaolin (MK). The results showed that the unconfined compression strengths of cemented soils containing 3% and 5% MK are approximately 2.0–3.0 times of that of materials without MK, that is MK can effectively improve the quality of cemented soils. The strength increased significantly when the MK content was less than 3%. This effect was attenuated at MK contents above 3%. Additionally, the strength with MK after 7 days curing periods is approximately 0.87 times of that after 28 days, while this ratio is 0.58 for the soils lacking MK, which indicates that the cemented soils containing MK show sufficient earlier strength than those lacking MK. **C. Venkatasubramanian and G. Dhinakaran (2011)** studied the influence of four different dosages of enzyme on three different soils on its strength parameters after 2 and 4 weeks of curing period from the application of bio enzyme. It is inferred from the results that addition of bio enzyme significantly improved Unconfined Compressive Strength (UCS) and California Bearing Ratio (CBR) values of selected samples. **A. U. Ravi Shankar and Harsha Kumar Rai (2009)** studied the effect of enzyme on lateritic soil and blended lateritic soil in terms of unconfined compressive strength, CBR, compaction and permeability. Their study found that Bio-Enzyme stabilization showed medium improvement in physical properties of lateritic soil. Enzyme was found to be ineffective for improving the consistency limits of lateritic soil. CBR value showed 300% increment while unconfined compressive strength increased by 450% and permeability decreases by 42%. **G. Venkatappa Rao and R.K. Dutta (2006)** conducted a study to assess the behaviour of the admixtures, compressibility and triaxial compression tests were carried out by varying chip size and chip content. On the whole the results reveal that the tyre chip–sand admixtures up to 20% chip content behave like gravel–sand mixtures. The strength shows a marginal improvement. Also the compressibility becomes excessive for a chip content of more than 20%. In view of this, the use of tyre chips and sand mixture is advantageous in construction of highway embankments up to a maximum height of 10 m. Thus their replacement in a conventional fill material is advantageous in terms of use of waste tyres.

Ghatge Sandeep Hambirao and Dr.P.G.Rakaraddi (2014) conducted an experimental investigation on shredded rubber from waste tyres chosen as the reinforcement material and cement as binding agent which was randomly included into the soil at three different percentages of fibre content, i.e. 5% 10% and 15% by weight of soil. The investigation has been focused on the strength behaviour of soil reinforced with randomly included shredded rubber fibre. The samples were subjected to California bearing ratio and unconfined compression tests. The tests have clearly shown a significant improvement in the shear strength and bearing capacity parameters of the studied soil. The results obtained are compared with unreinforced samples and inferences are drawn towards the usability and effectiveness of fiber reinforcement as a replacement for deep or raft foundation and on pavement sub grade soil as a cost effective approach. Increases in CBR value significantly reduce the total thickness of the pavement and hence the total cost involved in the project. The low strength and high compressible soft clay soils were found to improve by addition of shredded rubber and cement. It can be concluded that shredded rubber fibre can be considered as a good earth reinforcement material.

3. MATERIALS USED

The materials used for the tests include Kuttanad clay, Traditional stabilizer (Metakaolin), Non-traditional stabilizer (Terrazyme) and By-product stabilizer (Crumb Rubber Powder). The details of the materials used in this study are given below:

3.1 Kuttanad Clay

In this experimental study, the required quantity of Kuttanad clay was collected from Nedumudi in Upper Kuttanad region, Alappuzha district, Kerala shown in Figure 1. Representative samples were collected from a depth of 7m to 8m from ground surface. The properties of soil were determined by standard test procedures as per SP: 36 (Part 1) - 1987 and tabulated as per provisions of Indian Standard Code of practice. The basic index and engineering properties of the soil were determined by conducting various preliminary laboratory tests such as Moisture Content, Specific Gravity, Grain Size Distribution, Atterberg Limits, Standard Proctor Compaction, Triaxial Compression Test and One Dimensional Consolidation Test. The results obtained were presented in Table 1.

Fig -1: Kuttanad Clay

Table -1: Properties of Kuttanad clay

Properties	Results
Colour	Dark Grey
Natural Moisture Content (%)	105
Specific Gravity	2.40
Grain Size Distribution	
Clay (%)	83
Silt (%)	13
Sand (%)	4
Atterberg Limits	
Liquid Limit (%)	130
Plastic Limit (%)	42
Plasticity Index (%)	88
Flow Index (%)	102
Toughness Index (%)	0.86
Soil Classification	CH (Inorganic Clay of High Plasticity)
Standard Proctor Compaction Test	
Maximum Dry Density (g/cm^3)	1.38
Optimum Moisture Content (%)	27
Triaxial Compression Test	
Cohesion (kN/m^2)	12.5
Angle of Internal Friction (°)	3
One Dimensional Consolidation Test	
Coefficient of Consolidation (cm^2/sec)	4.25×10^{-6}
Coefficient of Volume Change (cm^2/kg)	0.072
Compression Index	0.661
Degree of compressibility	Very Highly Compressible

3.2 Metakaolin (MK)

Metakaolin is fine aluminosilicate having pozzolanic activity. It is manufactured by the calcination process of Kaolinite clays at a temperature of 550°C-900°C. Metakaolin used in this study is shown in Figure 2 and it was aquired from Ashirwad Chemicals, Chennai, India. For improving the geotehnichal properties of problematic Kuttanad clay, Metakaolin is chosen as a Traditional stabilizer. It is white in colour and amorphous. It had specific gravity of 2.5. Narrow limits of chemical composition and minor amounts of impurity components are present in Metakaolin obtained from purest grades of Kaolinite.

The physical properties and chemical composition of Metakaolin are shown in Table 2 and Table 3 respectively.

Fig -2: Metakaolin

Table -2: Physical Properties of Metakaolin

Colour	White
Shape	Oval and Flaky
Size	2-10µm
Physical form	Powder
Specific Gravity	2.5
Specific Surface Area	10-25 m^2/g

Table -3: Chemical composition on Metakaolin

Composition	**Percentage (%)**
Silica (SiO_2)	52.10
Alumina (Al_2O_3)	40.50
Ferric oxide (Fe_2O_3)	2.50
Calcium oxide (CaO)	1.00
Magnesium oxide (MgO)	0.19
Sodium oxide (Na_2O)	0.12
Potassium oxide (K_2O)	0.50
Loss on ignition (LOI)	0.68

3.3 Terrazyme (TZ)

Terrazyme is a natural, non-toxic, non-corrosive and non-inflammable liquid, produced by formulating vegetable and fruit extracts. Terrazyme used in this study was obtained from Avijeeth Agencies, Anna Nagar East, Chennai, India, shown in Figure 3. For improving the geotehnichal properties of problematic Kuttanad clay, Terrazyme is chosen as a Non-traditional stabilizer. Terrazyme is specially formulated to modify the engineering properties of soil. They require dilution in water before application. Terrazyme improves the properties of soil and strength of soil significantly. The physical properties and dosage of Terrazyme are shown in Table 4 and Table 5 respectively.

The use of Terrazyme enhances weather resistance and increases load bearing capacity of soils. These features are particularly evident in fine-grained soils such as clay in which the formulation affects the swelling and shrinking behaviour. This formulation has the ability to change the matrix of the soil so that after compaction the soil loses its ability to reabsorb water and the mechanical benefits of compaction are not lost even after water is reapplied to the compacted soil. They also improve chemical bonding between soil particles and creating a more permanent structure that is more resistant to weathering, water penetration and wear and tear. Their efficiency depends upon the amount of dose, type of soil available and field conditions. These organic enzymes come in liquid form. They are perfectly soluble in water, brown in colour with smell of molasses. Their aroma has no effect. Neither gloves nor masks are required during handling.

Fig -3: Terrazyme

Table -4: Physical Properties of Terrazyme

Identity	N-zyme
Hazardous Components	None
Boiling Point	100°C
Melting Point	Liquid
Specific Gravity	1.05
Evaporation Rate	Same as water
Solubility in Water	Complete
Appearance/Colour	Brown clear liquid
Odour	Non-obnoxious
Explosion Hazard	None

Table -5: Dosage of Terrazyme

Dosage of Terrazyme	ml/kg of soil (Dry)
200ml/1m³	0.145
200ml/1.5m³	0.097
200ml/2m³	0.072
200ml/2.5m³	0.057
200ml/3m³	0.048

3.4 Crumb Rubber Powder (CRP)

Crumb Rubber Powder used in this study was collected from Dolphin Rubber Industries, Kottayam, Kerala, India shown in Figure 4. For improving the geotehnichal properties of problematic Kuttanad clay, Crumb Rubber Powder is chosen as a By-product stabilizer. For this study, the Crumb rubber powder was produced from used automobile tyres by ambient process through mechanical shredding, where scrap tyre rubber is ground or processd at or above ordinary room temperature at ambient temperature. Steel was removed by magnetic separation and one part of textile fibre was removed by density. The physical properties and chemical composition of Crumb Rubber Powder are shown in Table 6 and Table 7 respectively.

Fig -4: Crumb Rubber Powder

Table -6: Physical Properties of Crumb Rubber Powder

Colour	Black
Shape	Irregular
Surface Texture	Rough
Specific Gravity	1.25
Particle Size	1.18 mm down size (IS sieve) / 10 to 40 mesh

Table -7: Chemical Composition of Crumb Rubber Powder

Composition	Percentage (%)
Rubber	54
Carbon Black	29
Textile	2
Oxidize Zinc	1
Sulphur	1
Additives	13

4. EXPERIMENTAL INVESTIGATION

4.1 Influence of Metakaolin, Terrazyme and Crumb Rubber Powder on Atterberg Limits

In this study, the influence of Metakaolin, Terrazyme and Crumb Rubber Powder on the plasticity characteristics of Kuttanad clay was determined by conducting Atterberg limits test as per IS: 2720 (Part 5) – 1985. An experimental investigation on Atterberg limits were conducted on the soil samples treated with 2%, 4%, 6%, 8% and 10% of Metakaolin , 200ml/1m³, 200ml/1.5m³, 200ml/2m³, 200ml/2.5m³ and 200ml/3m³ of Terrazyme and 5%, 10%, 15% and 20% of Crumb Rubber Powder after varied curing periods of 3, 7 and 14 days. Atterberg limits test was conducted to determine the influence of three different stabilizers on Liquid Limit (LL), Plastic Limit (PL) and Plasticity Index (PI) and the rate of decrease in plasticity characteristics after varied curing periods. Tests also aimed to determine the optimum values of these materials.

4.2 Influence of Metakaolin, Terrazyme and Crumb Rubber Powder on Shear Strength Characteristics

In this study, the influence of Metakaolin, Terrazyme and Crumb Rubber Powder on the shear strength characteristics of Kuttanad clay was determined by conducting Triaxial Compression test as per IS: 2720 (Part 11) - 1981. An experimental investigation on Shear strength parameters were conducted on the soil samples treated with 2%, 4%, 6%, 8% and 10% of Metakaolin , 200ml/1m³, 200ml/1.5m³, 200ml/2m³, 200ml/2.5m³ and 200ml/3m³ of Terrazyme and 5%, 10%, 15% and 20% of Crumb Rubber Powder after varied curing periods of 3, 7 and 14 days. Further study was conducted on evaluating the Shear strength behavior of the soil samples treated with optimum values of Metakaolin, Terrazyme and Crumb Rubber Powder after varied curing periods of 3, 7 and 14 days for different normal stresses of 0.5kg/cm², 1kg/cm² and 1.5kg/cm². Triaxial Compression test was conducted to determine the influence of three different stabilizers on Cohesion(C), Angle of Internal Friction (Φ) and Shear strength and the rate of increase in Shear strength characteristics after varied curing periods. Tests also aimed to determine the optimum values of these materials.

4.3 Influence of Metakaolin, Terrazyme and Crumb Rubber Powder on Consolidation Characteristics

In this study, the influence of optimum values of Crumb Rubber Powder, Terrazyme and Metakaolin on the Consolidation characteristics of Kuttanad clay was determined by conducting One Dimensional Consolidation test as per IS: 2720 (Part 15) – 1986. An experimental investigation on Consolidation characteristics were conducted on the soil samples treated with optimum values of Metakaolin, Terrazyme and Crumb Rubber Powder separately after 14 days of curing period. Consolidation test was conducted to determine the influence of optimum values of three different stabilizers on Coefficient of Consolidation (C_v), Compression Index (C_c) and Coefficient of Volume Change (m_v) and the rate of decrease in Consolidation parameters after 14 days of curing period.

5. RESULTS AND DISCUSSION

5.1 Influence of Metakaolin on Atterberg Limits after 0, 3, 7 and 14 days of Curing period

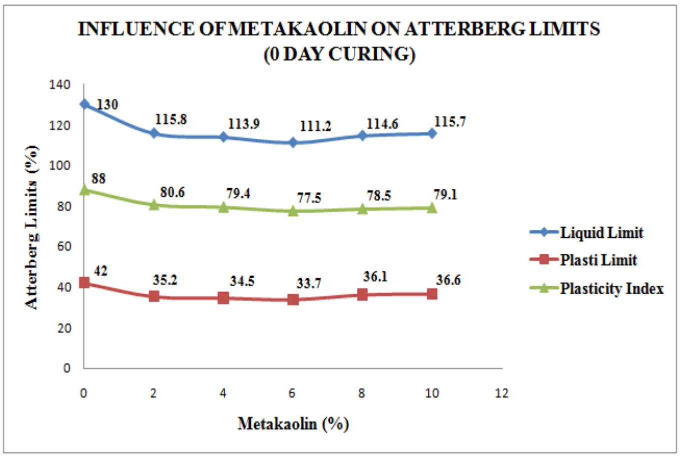

Chart -1: Influence of Metakaolin on Atterberg Limits without curing

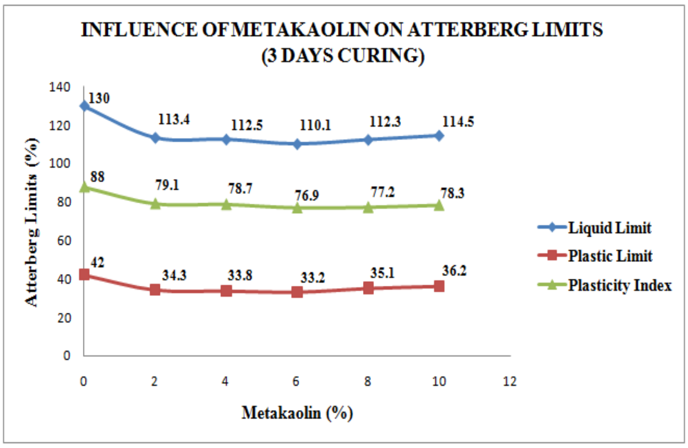

Chart -2: Influence of Metakaolin on Atterberg Limits after 3 days curing

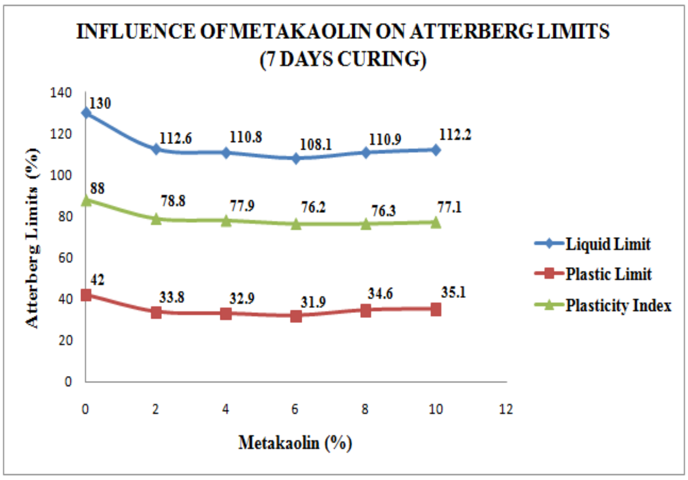

Chart -3: Influence of Metakaolin on Atterberg Limits after 7 days curing

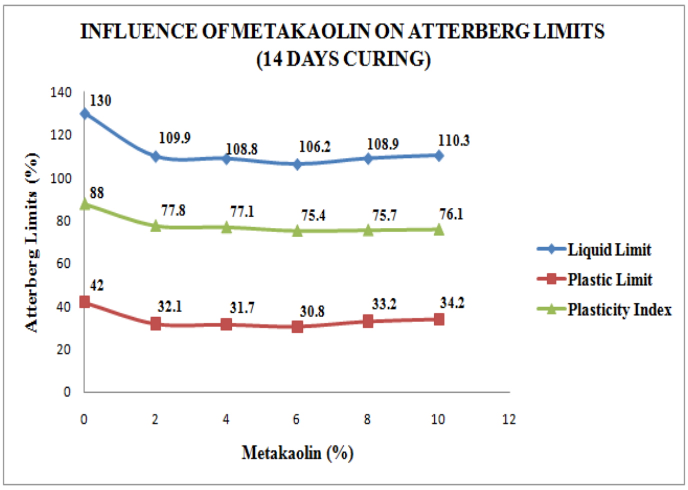

Chart -4: Influence of Metakaolin on Atterberg Limits after 14 days curing

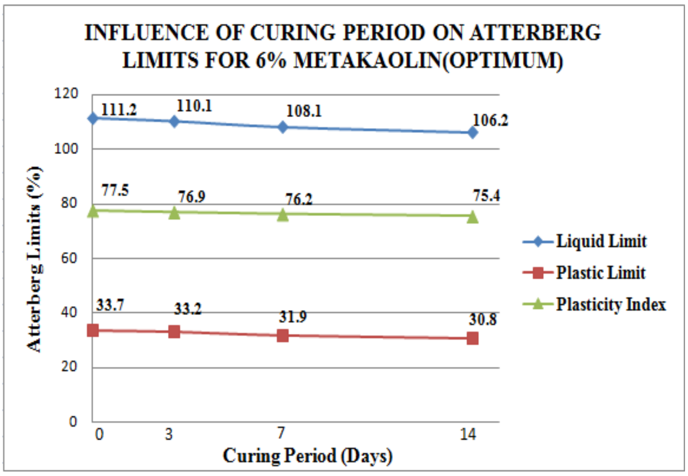

Chart 5: Influence of curing period on Atterberg Limits for 6% of Metakaolin

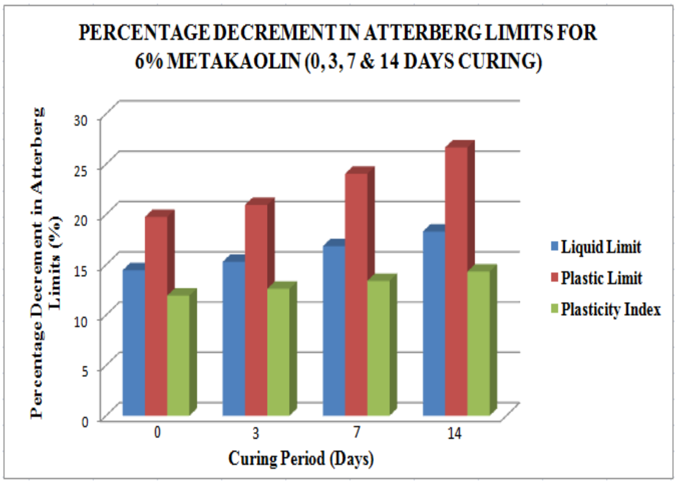

Chart 6: Percentage Decrement in Atterberg Limits for 6% of Metakaolin

5.2 Influence of Terrazyme on Atterberg Limits after 0, 3, 7 and 14 days of Curing period

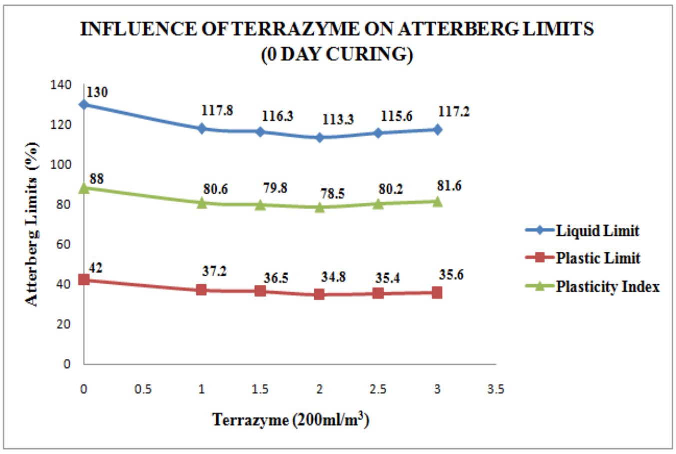

Chart -7: Influence of Terrazyme on Atterberg Limits without curing

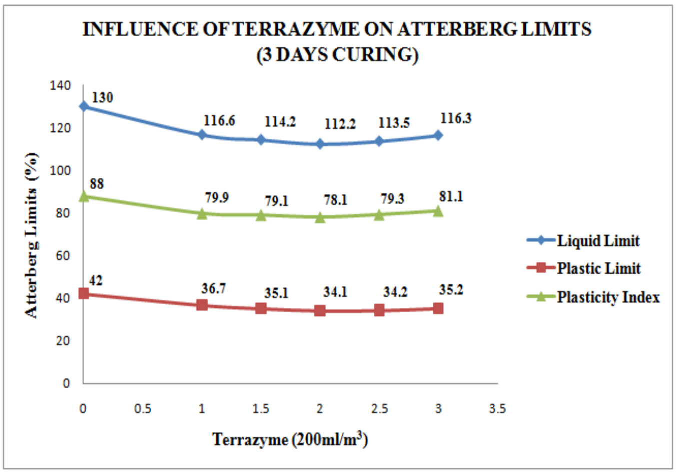

Chart -8: Influence of Terrazyme on Atterberg Limits after 3 days curing

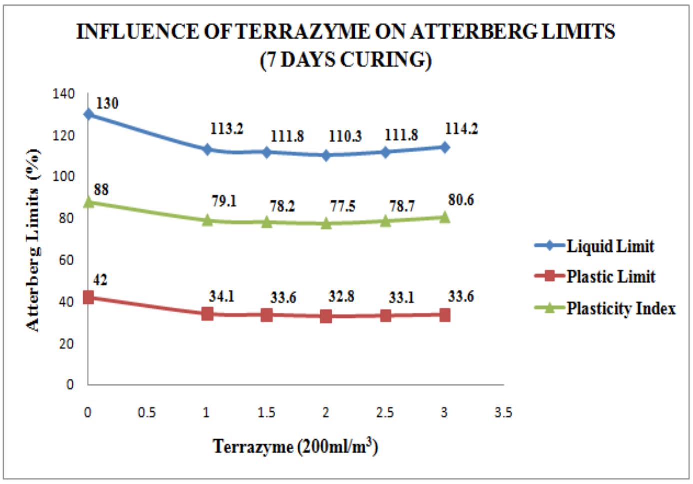

Chart -9: Influence of Terrazyme on Atterberg Limits after 7 days curing

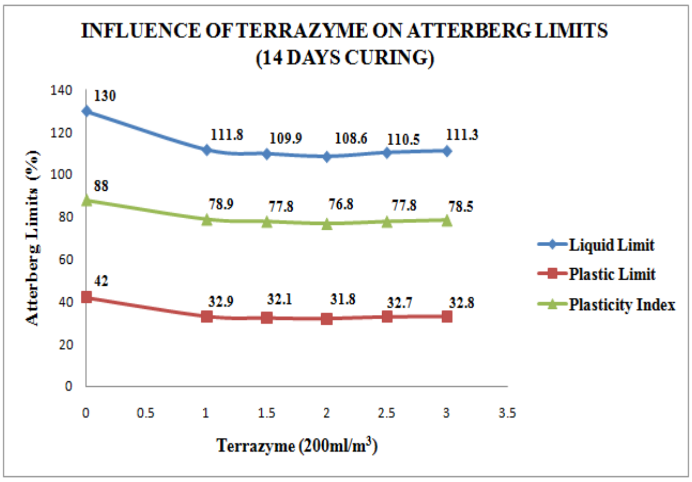

Chart -10: Influence of Terrazyme on Atterberg Limits after 14 days curing

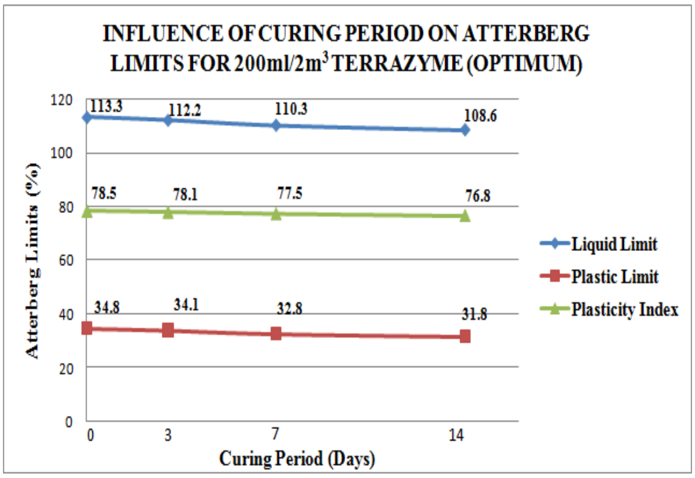

Chart 11: Influence of curing period on Atterberg Limits for 200ml/2m³ of Terrazyme

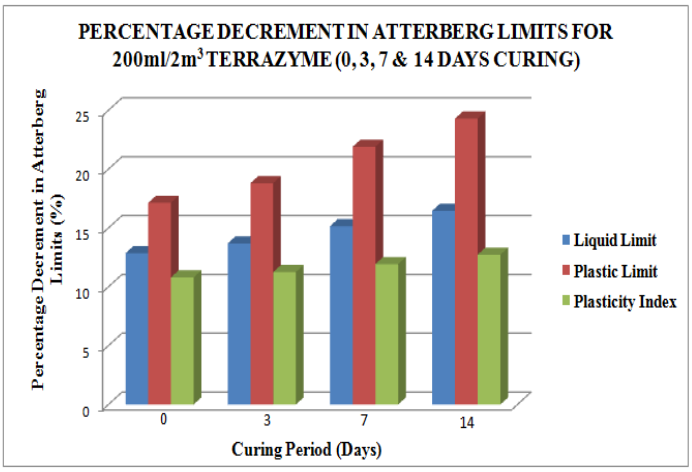

Chart 12: Percentage Decrement in Atterberg Limits for 200ml/2m³ of Terrazyme

5.3 Influence of Crumb Rubber Powder on Atterberg Limits after 0, 3, 7 and 14 days of Curing period

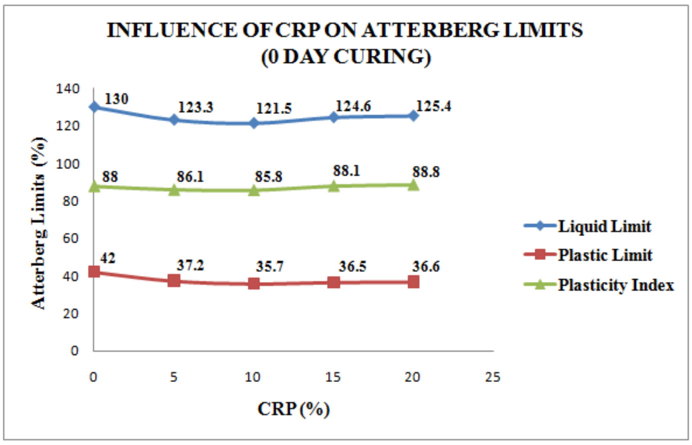

Chart -13: Influence of Crumb Rubber Powder on Atterberg Limits without curing

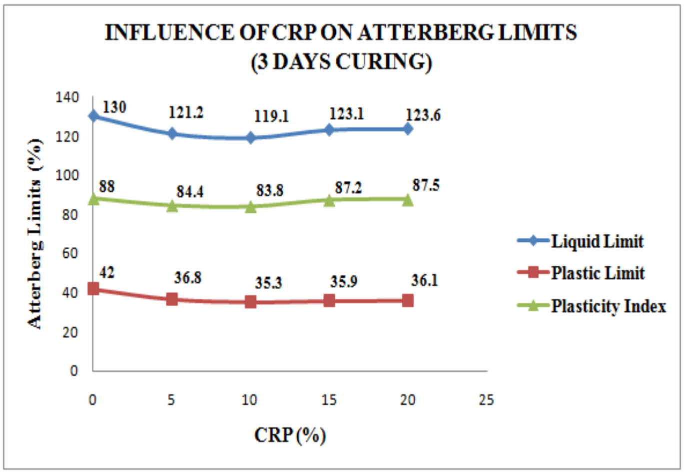

Chart -14: Influence of Crumb Rubber Powder on Atterberg Limits after 3 days curing

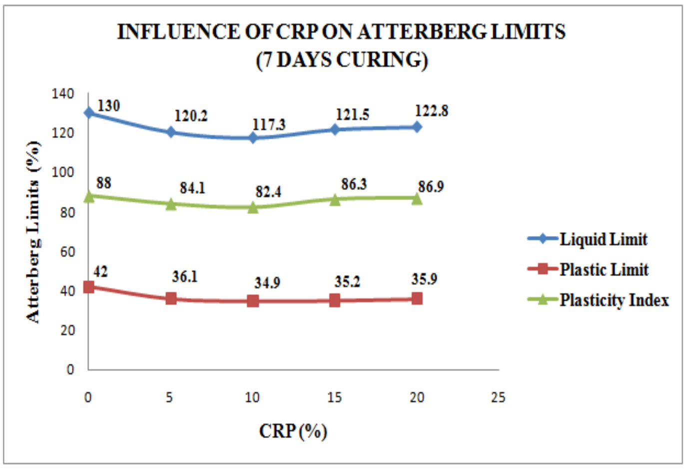

Chart -15: Influence of Crumb Rubber Powder on Atterberg Limits after 7 days curing

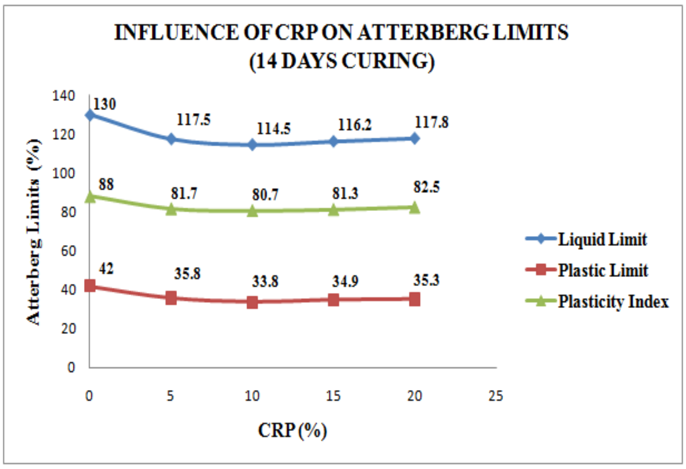

Chart -16: Influence of Crumb Rubber Powder on Atterberg Limits after 14 days curing

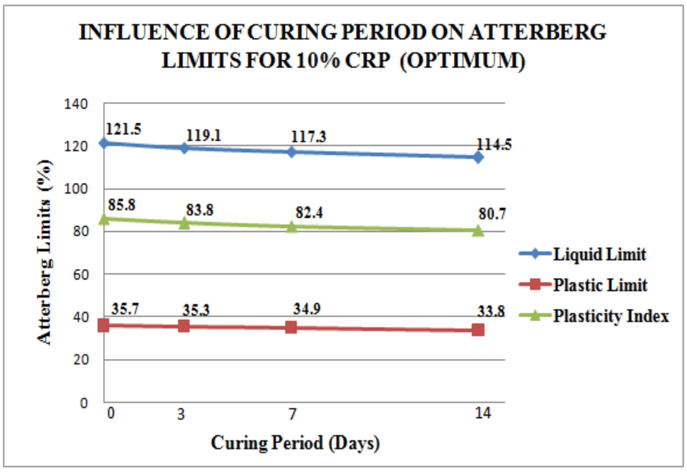

Chart -17: Influence of curing period on Atterberg Limits for 10% of Crumb Rubber Powder

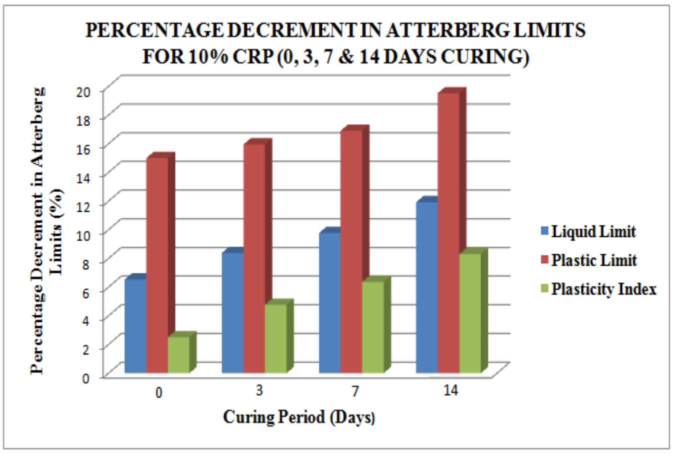

Chart -18: Percentage Decrement in Atterberg Limits for 10% of Crumb Rubber Powder

The percentage decrement in Atterberg limits for soil samples treated with optimum values of 6% of Metakaolin, 200ml/2m³ of Terrazyme and 10% of Crumb Rubber Powder, continuously increased with increase in curing period.

The results indicated a maximum decrement of 18.3% (liquid limit), 26.7% (plastic limit) and 14.3% (plasticity index) for soil samples treated with an optimum value of 6% of Metakaolin when compared to 200ml/2m³ of Terrazyme with a decrement of 16.5% (liquid limit), 24.3% (plastic limit) and 12.7% (plasticity index) and 10% of Crumb Rubber Powder with a decrement of 11.9% (liquid limit), 19.5% (plastic limit) and 8.3% (plasticity index) after a curing period of 14 days.

5.4 Influence of Metakaolin on Shear Strength Characteristics after 0, 3, 7 and 14 days of Curing period

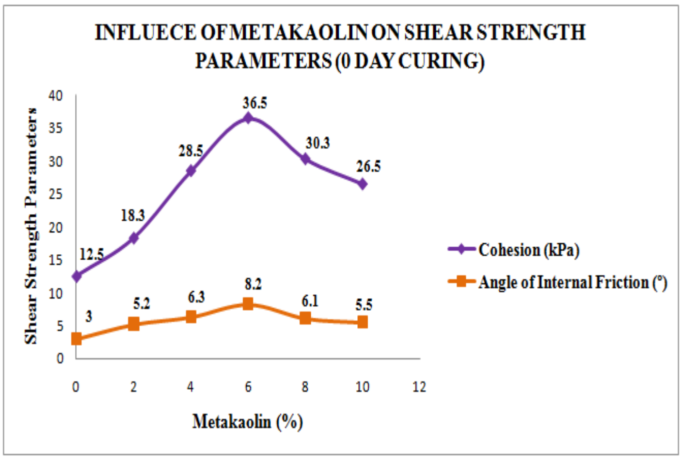

Chart -19: Influence of Metakaolin on Shear Strength Parameters without curing

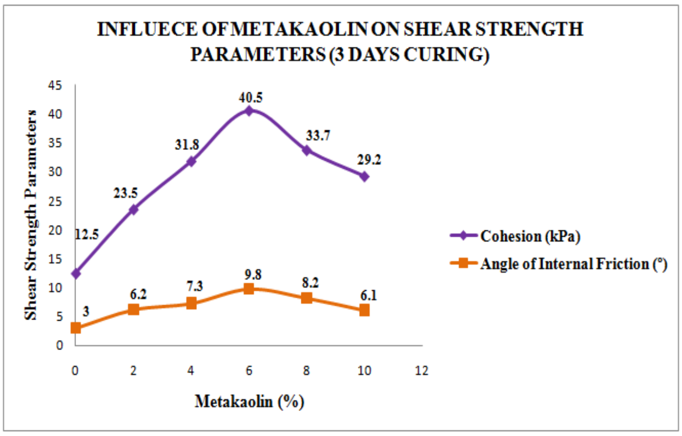

Chart -20: Influence of Metakaolin on Shear Strength Parameters after 3 days curing

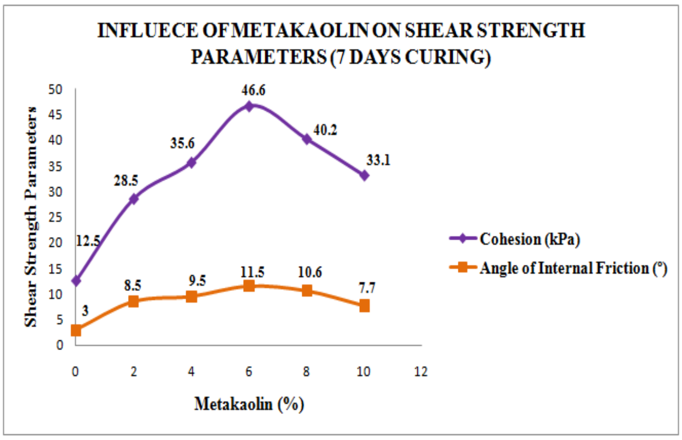

Chart -21: Influence of Metakaolin on Shear Strength Parameters after 7 days curing

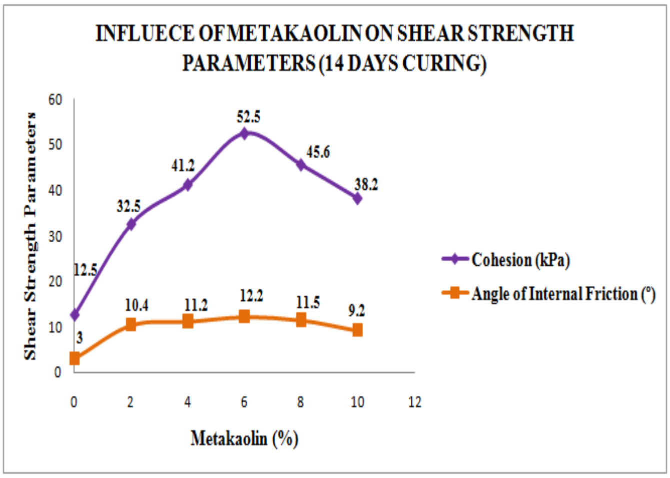

Chart -22: Influence of Metakaolin on Shear Strength Parameters after 14 days curing

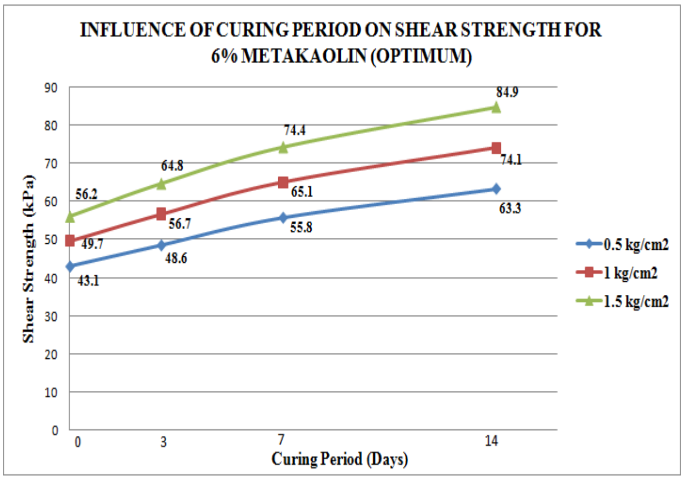

Chart -25: Influence of curing period on Shear Strength for 6% of Metakaolin

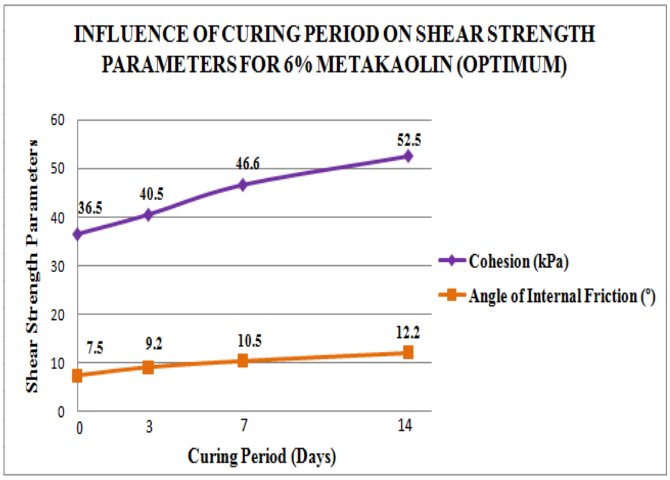

Chart -23: Influence of curing period on Shear Strength Parameters for 6% of Metakaolin

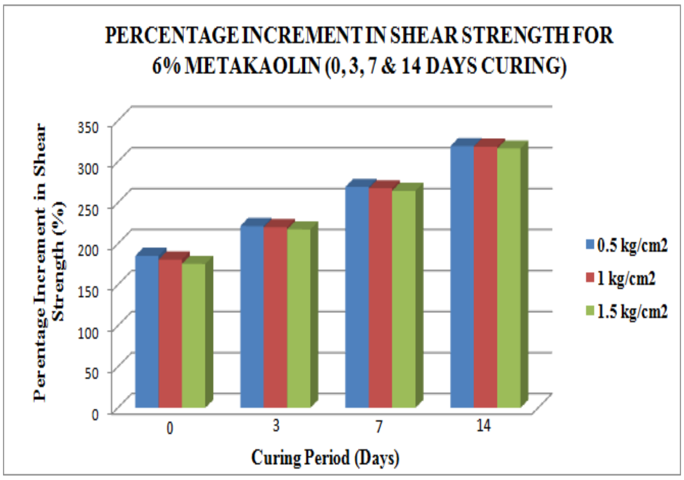

Chart -26: Percentage Increment in Shear Strength for 6% of Metakaolin

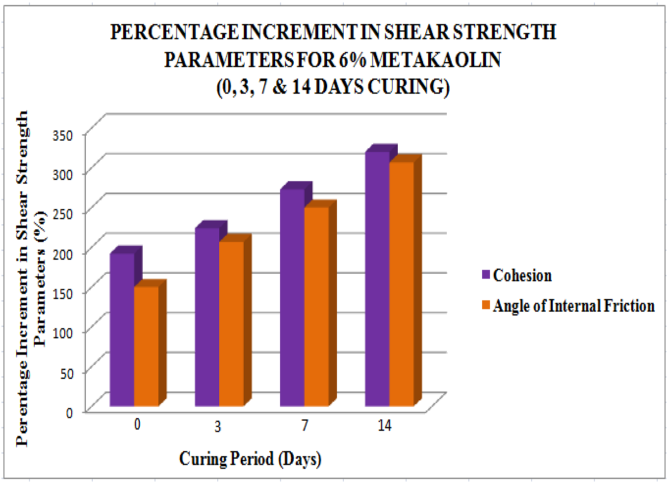

Chart -24: Percentage Increment in Shear Strength Parameters for 6% of Metakaolin

5.5 Influence of Terrazyme on Shear Strength Characteristics after 0, 3, 7 and 14 days of Curing period

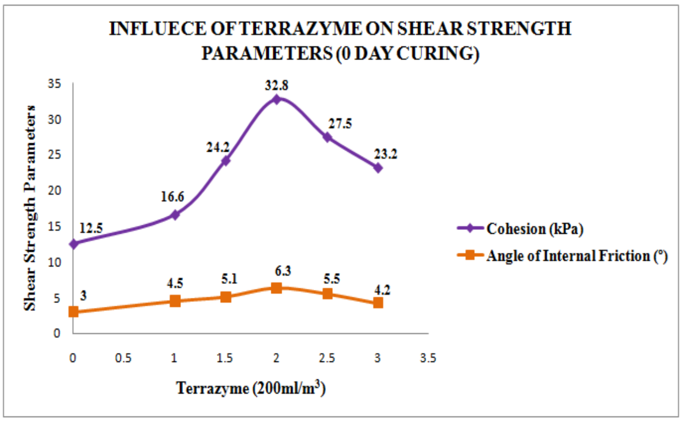

Chart -27: Influence of Terrazyme on Shear Strength Parameters without curing

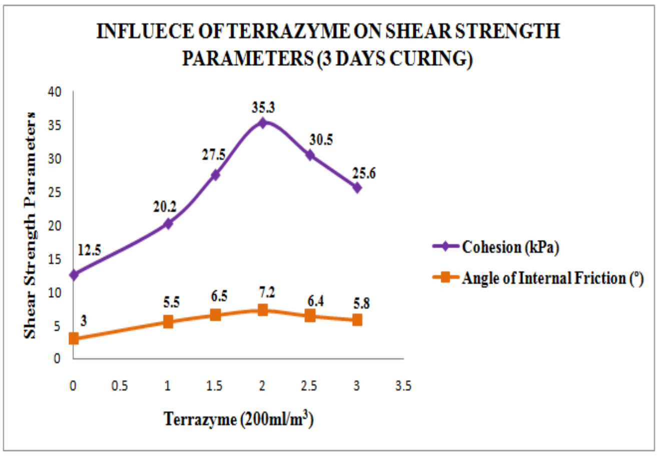

Chart -28: Influence of Terrazyme on Shear Strength Parameters after 3 days curing

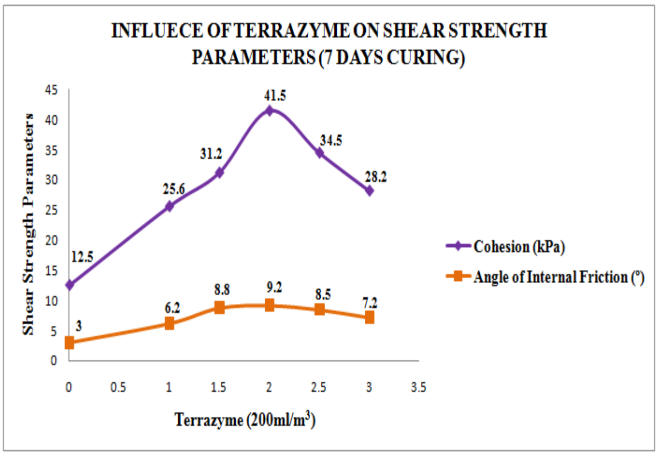

Chart -29: Influence of Terrazyme on Shear Strength Parameters after 7 days curing

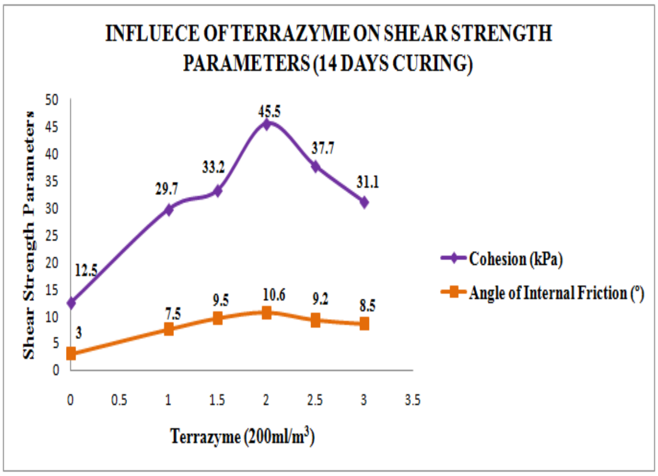

Chart -30: Influence of Terrazyme on Shear Strength Parameters after 14 days curing

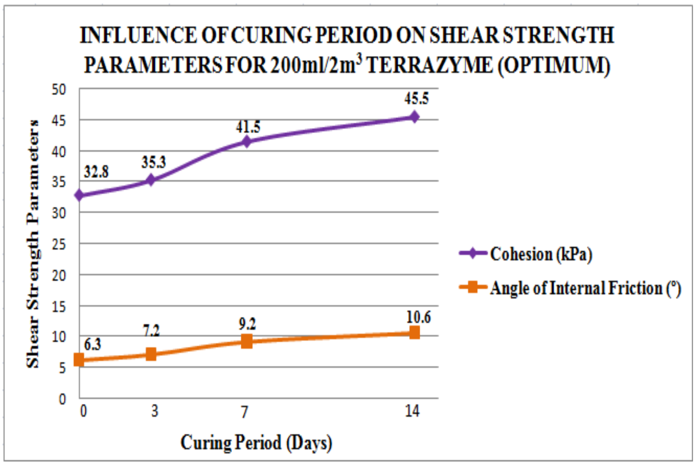

Chart -31: Influence of curing period on Shear Strength Parameters for 200ml/2m³ of Terrazyme

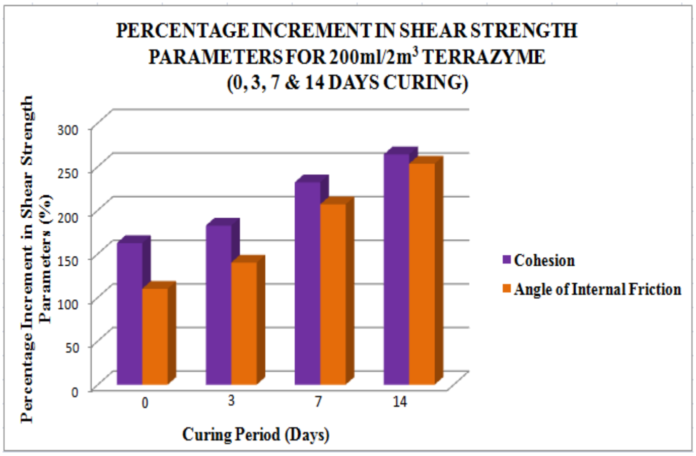

Chart -32: Percentage Increment in Shear Strength Parameters for 200ml/2m³ of Terrazyme

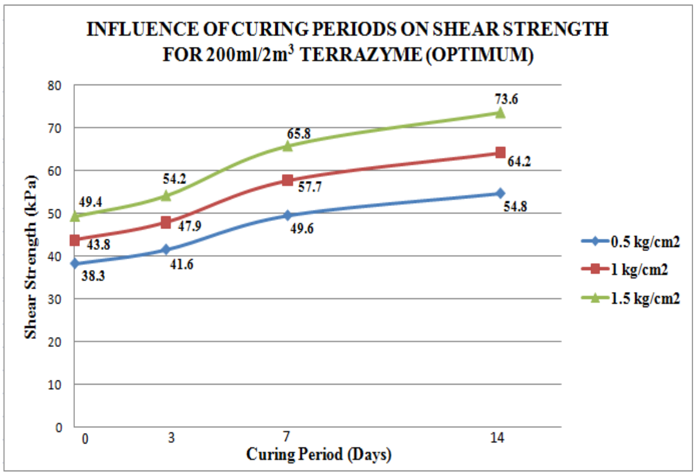

Chart -33: Influence of curing period on Shear Strength for 200ml/2m³ of Terrazyme

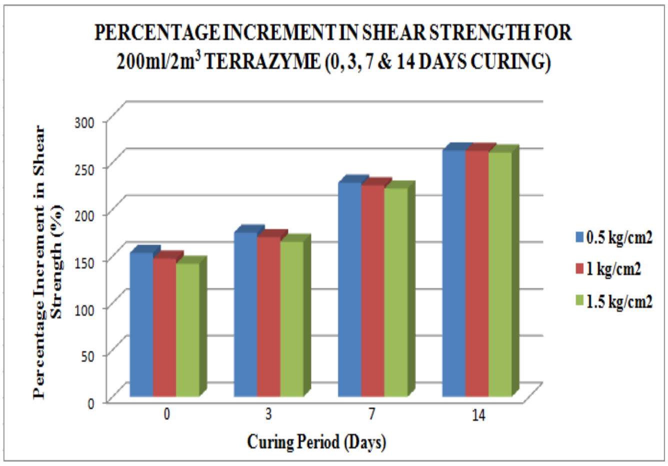

Chart -34: Percentage Increment in Shear Strength for 200ml/2m³ of Terrazyme

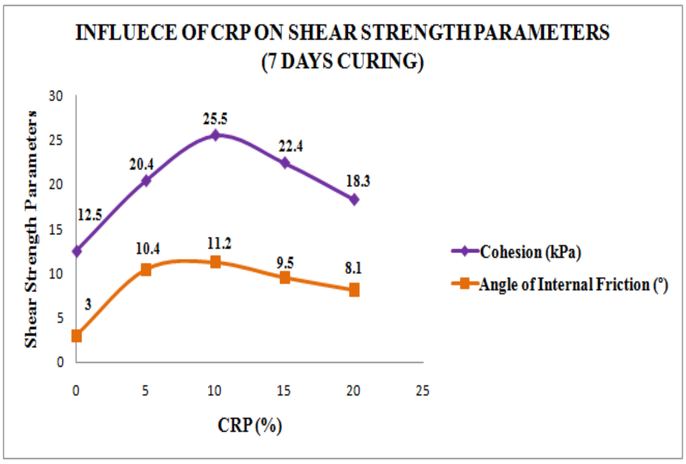

Chart -37: Influence of Crumb Rubber Powder on Shear Strength Parameters after 7 days curing

5.6 Influence of Crumb Rubber Powder on Shear Strength Characteristics after 0, 3, 7 and 14 days of Curing period

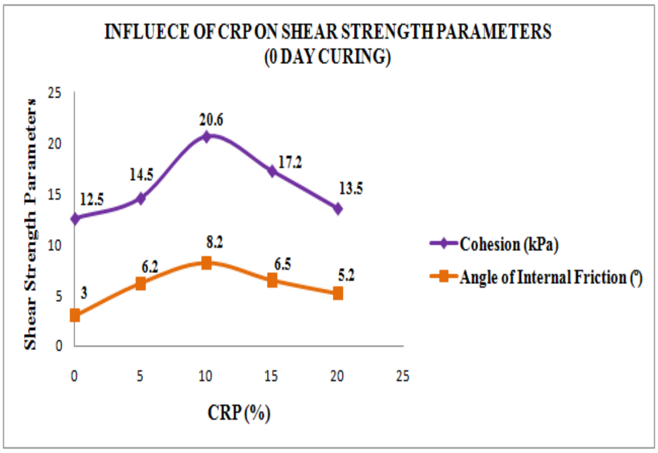

Chart -35: Influence of Crumb Rubber Powder on Shear Strength Parameters without curing

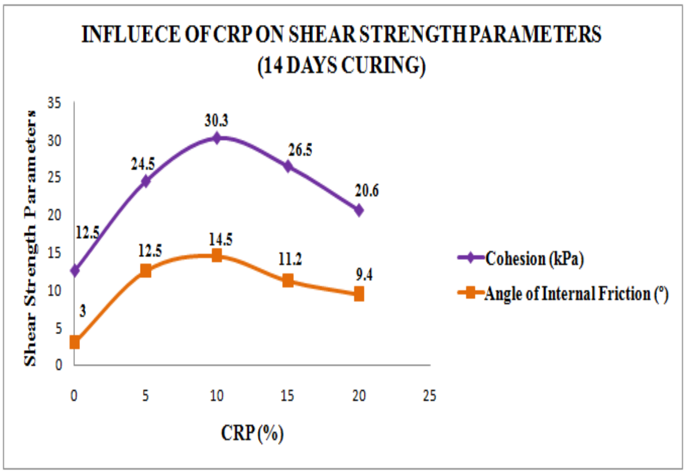

Chart -38: Influence of Crumb Rubber Powder on Shear Strength Parameters after 14 days curing

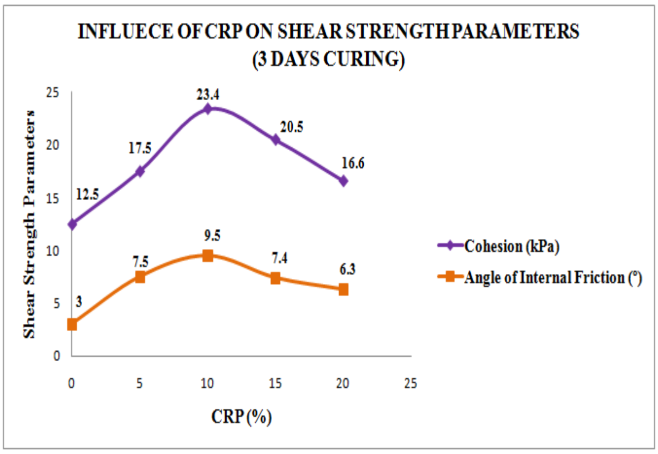

Chart -36: Influence of Crumb Rubber Powder on Shear Strength Parameters after 3 days curing

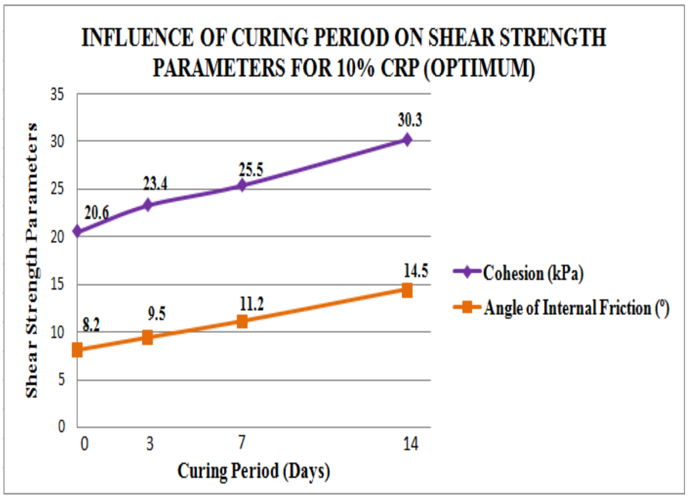

Chart -39: Influence of curing period on Shear Strength Parameters for 10% of Crumb Rubber Powder

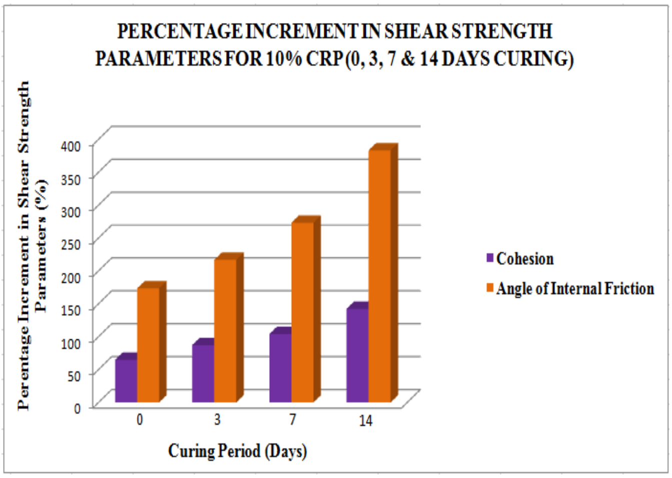

Chart -40: Percentage Increment in Shear Strength Parameters for 10% of Crumb Rubber Powder

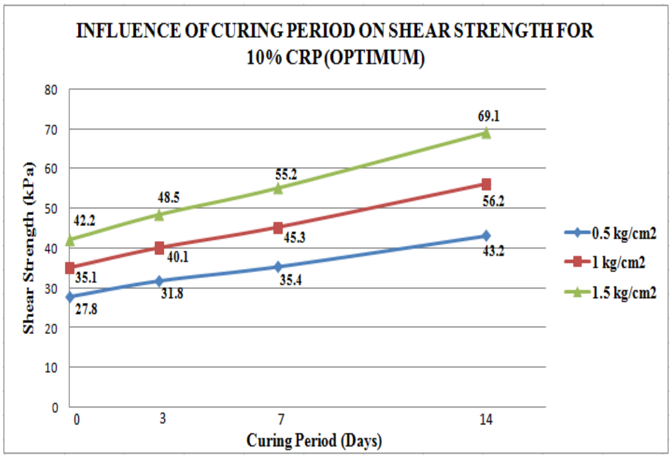

Chart -41: Influence of curing period on Shear Strength for 10% of Crumb Rubber Powder

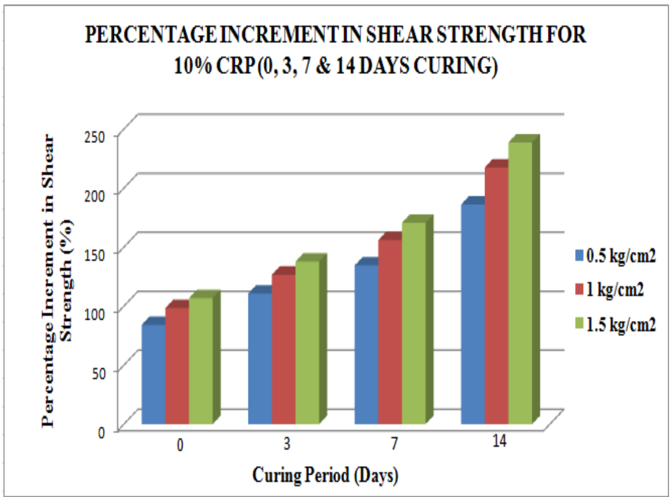

Chart -42: Percentage Increment in Shear Strength for 10% of Crumb Rubber Powder

The results indicated a maximum increment of 320% in Cohesion for soil samples treated with an optimum value of 6% of Metakaolin when compared to 200ml/2m^3 of Terrazyme with an increment of 264% and 10% of Crumb Rubber Powder with 142.4% increment after a curing period of 14 days. It also indicated a maximum increment of 383.3% in Angle of internal friction for soil samples treated with an optimum value of 10% of Crumb Rubber Powder when compared to 6% of Metakaolin with an increment of 306.7% and 200ml/2m^3 of Terrazyme with 253.3% increment after a curing period of 14 days.

The percentage increment in Shear strength for soil samples treated with an optimum value of 6% of Metakaolin and 200ml/2m^3 of Terrazyme moderately decreased with the application of normal stresses from 0.5kg/cm^2 to 1.5kg/cm^2 with increase in curing period. While the percentage increment in Shear strength for soil samples treated with an optimum value of 10% of Crumb Rubber Powder continuously increased with the application of normal stresses from 0.5kg/cm^2 to 1.5kg/cm^2 with increase in curing period.

5.7 Influence of Optimum values of Metakaolin, Terrazyme and Crumb Rubber Powder on Consolidation Characteristics after 14 days of Curing period

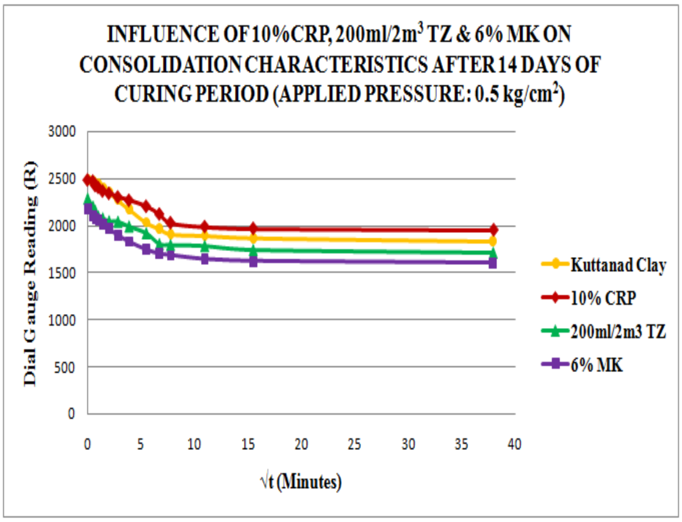

Chart -43: Influence of Optimum values of Metakaolin, Terrazyme and Crumb Rubber Powder on Consolidation Characteristics after 14 days curing under an Applied Pressure of 0.5 kg/cm^2

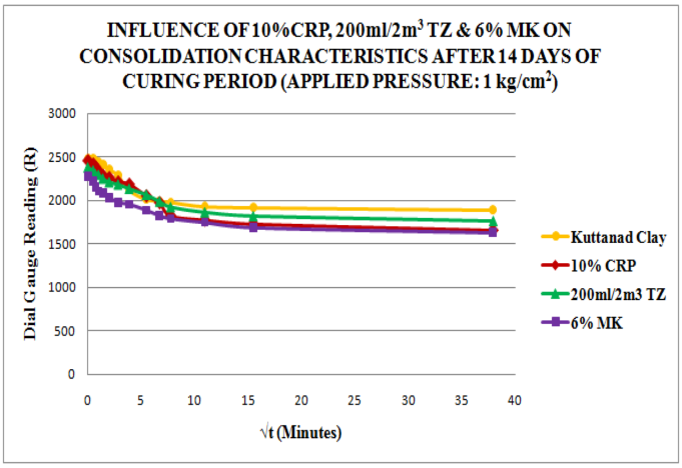

Chart -44: Influence of Optimum values of Metakaolin, Terrazyme and Crumb Rubber Powder on Consolidation Characteristics after 14 days curing under an Applied Pressure of 1.0 kg/cm²

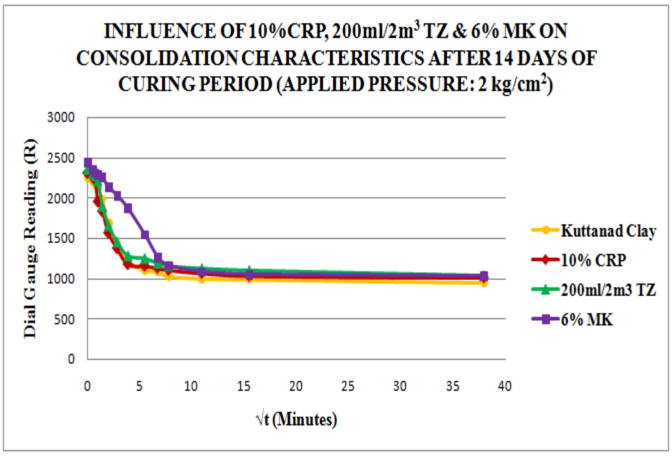

Chart -45: Influence of Optimum values of Metakaolin, Terrazyme and Crumb Rubber Powder on Consolidation Characteristics after 14 days curing under an Applied Pressure of 2.0 kg/cm²

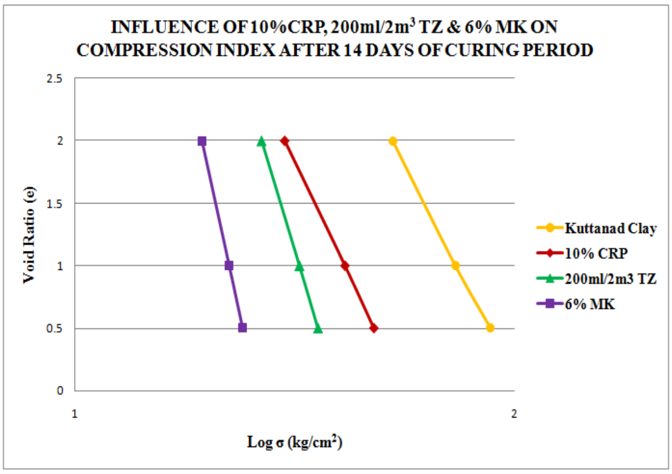

Chart -46: Influence of Optimum values of Metakaolin, Terrazyme and Crumb Rubber Powder on Compression Index after 14 days curing

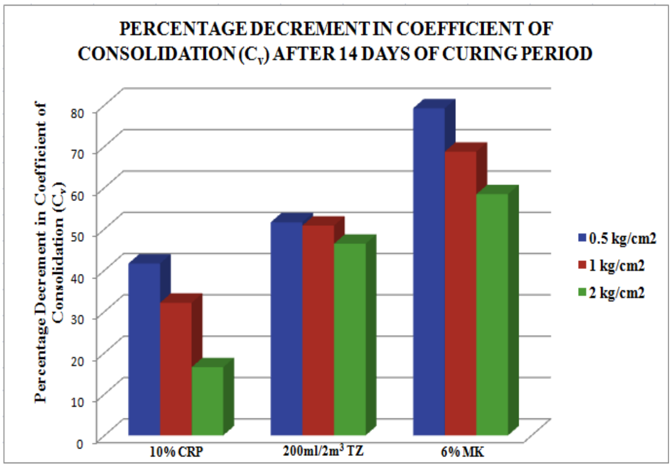

Chart -47: Percentage Decrement in Coefficient of Consolidation after 14 days curing

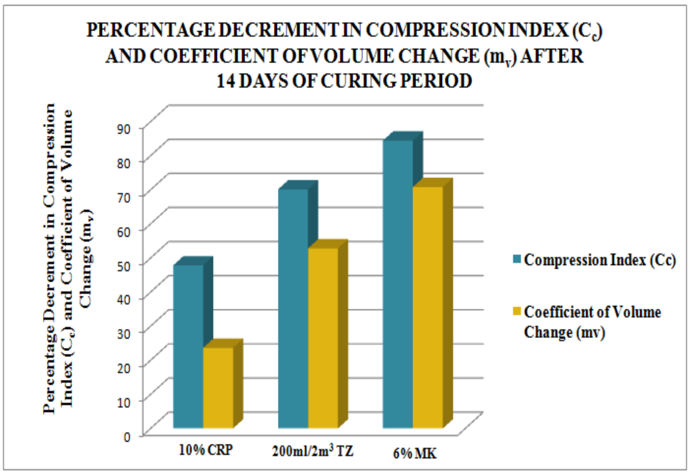

Chart -48: Percentage Decrement in Compression Index and Coefficient of Volume Change after 14 days curing

The percentage decrement in Coefficient of Consolidation for soil samples treated with optimum values of 6% of Metakaolin, 200ml/2m³ of Terrazyme and 10% of Crumb Rubber Powder after 14 days of curing period, continuously decreased with an increase in applied pressure from 0.5 kg/cm² to 2 kg/cm².

The results indicated a maximum decrease in Coefficient of Consolidation of 1.13x 10^{-7} cm²/sec for 6% of Metakaolin when compared to 200ml/2m³ of Terrazyme of 2.63 x 10^{-7} cm²/sec and 10% of Crumb Rubber Powder of 3.17 x 10^{-7} cm²/sec, under 0.5 kg/cm² applied pressure after 14 days of curing period. Further it revealed that 6% of Metakaolin had maximum decrease in Compression Index of 0.103 with degree of compressibility reduced to slightly compressible and Coefficient of Volume Change of 0.021 cm²/kg when compared to 200ml/2m³ of Terrazyme with 0.204 and 0.034 (Moderately compressible) and 10% of Crumb Rubber Powder with 0.345 and 0.055 (Highly compressible) after 14 days of curing period.

6. CONCLUSIONS

1. The test results from Atterberg limits and Triaxial compression it was indicated that 6% of Metakaolin, 200ml/2m³ of Terrazyme and 10% of Crumb Rubber Powder are experimentally proved as optimum values.
2. The results revealed that with an increase in curing period the plasticity characteristics of Kuttanad clay treated with Metakaolin, Terrazyme and Crumb Rubber Powder progressively decreased to a minimum value.
3. The results revealed that with an increase in curing period the Shear strength characteristics of Kuttanad clay treated with Metakaolin, Terrazyme and Crumb Rubber Powder progressively increased to a maximum value.
4. The percentage increment in Shear strength for soil samples treated with optimum values of 6% of Metakaolin, 200ml/2m³ of Terrazyme and 10% of Crumb Rubber Powder continuously increased with increase in curing period.
5. The results revealed a moderate decrease in Coefficient of Consolidation for soil samples treated with optimum values of 6% of Metakaolin, 200ml/2m³ of Terrazyme and 10% of Crumb Rubber Powder after 14 days of curing period.
6. The percentage decrement in Compression Index and Coefficient of Volume Change for soil samples treated with optimum values of 6% of Metakaolin, 200ml/2m³ of Terrazyme and 10% of Crumb Rubber Powder continuously increased after 14 days of curing period.
7. Kuttanad clay treated with Traditional stabilizers showed maximum improvement in shear strength behavior, reduced plasticity and consolidation characteristics after 14 days of curing period when compared to Non-traditional and By-product stabilizers.

7. FUTURE SCOPE OF STUDY

The study can be extended by conducting an experimental investigation on the combined effect of Traditional, Non-traditional and By-product stabilizers on geotechnical properties of soil after varied curing period.

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