A STUDY ON INFLUENCE OF WASTE RUBBER TYRE CRUMBS ON STRENGTH OF SOIL

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SUBMITTED BY

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UNDER THE SUPERVISION OF

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CANDIDATE'S DECLARATION

I, Aishwarya Kumar Garg, 2K17/ENE/01 a student of M. Tech. (Environmental Engineering), hereby declare that the project Dissertation titled "**A Study On Influence Of Waste Rubber Tyre Crumbs On Strength Of Soil**" which is submitted by me to the Department of Environmental Engineering, Delhi Technological University, Delhi in partial fulfillment of the requirement for the award of the degree of Master of Technology, is original and not copied from any source without proper citation. This work has not previously formed the basis for the award of any Degree, Diploma Associateship, Fellowship or other similar title or recognition to the best of my knowledge.

Place: Delhi (AISHWARYA KUMAR GARG)

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CERTIFICATE

I hereby certify that the report titled "**A Study On Influence Of Waste Rubber Tyre Crumbs On Strength Of Soil**" which is submitted by Aishwarya Kumar Garg, 2K17/ENE/01, Department of Environmental Engineering, Delhi Technological University, Delhi in partial fulfillment of the requirement for the award of the degree of Master of Technology, is a record of the project work carried out by the student under my supervision. To the best of my knowledge, this work has not been submitted in part or full for any Degree or Diploma to this University or elsewhere.

Place: Delhi (Prof. A.K. GUPTA)

Date: SUPERVISOR

ABSTRACT

Tyres used in automobile industries get converted into waste tyres as soon as their treads are worn out. Hence, every year there is an increase in the waste tyres worldwide. As a result, their disposal has become one of the major environmental problems. Millions of discarded tyres are rejected in large piles across the land of a territory as well as dumped in large amount in the landfills every year. These are a threat to the environment because they lead to environmental pollution as well as have a potential to cause fire and health hazards. Being light in weight and having low density as compared to other waste materials, they require a larger volume of landfills. Therefore, the effective re-utilization of waste tyres has attracted the researchers towards itself since the last 2-3 decades. Worn out tyres can be used in a number of ways to reduce environmental problems. Some studies have shown that such tyres in the form of shreds and chips provide a lightweight construction material which generally improves the engineering properties of soils, such as strength, bearing capacity, and CBR values. In the present study an attempt has been made to use the waste rubber tyre crumbs which are small shredded pieces of waste rubber tyres coming to the workshop from dump yards. The crumbs were passed through I.S. 2.8 mm sieve (coarse-grained tyre crumbs) and added in soil samples in proportions of 4%, 8%, 12% and 16% by weight of soil measured dry. OMC and MDD of all the soil-tyre crumb mixtures were determined using heavy compaction and the mixtures were tested for un-soaked CBR values. The test results indicated an improvement in the CBR value at varying proportions of tyre crumbs, 8% being witnessed to report an overall increment of 17.28 (i.e., 122.6% increase) in the CBR value of the soil taken which showed similarity to some previous researches done and supports the method of re-utilizing the cheap waste tyre crumbs as a soil stabilizer which may be useful, for example, in reducing the thickness of filling material required in construction works and the thickness of pavements. For determining shear strength, Unconfined Compressive Strength test was performed on the clayey soil. The crumbs were passed through I.S. 2 mm sieve (medium-grained tyre crumbs) and added in soil samples in proportions of 2%, 4%, 6%, 8% and 10% by weight of soil measured dry. The test results indicated an overall increase in the UCS value as well as shear strength value by 19.25% which were very much similar to those obtained in previous studies. This proves the rubber tyre crumbs to be an effective fill material in back-fills behind retaining structures, bridge abutments and highway embankments.

Further, geo-chemical analysis of the test materials and their composite mixture was done. This includes SEM (Scanning Electron Microscopy), XRD (X-Ray Diffraction) and FTIR (Fourier Transform Infrared spectroscopy). The SEM test resulted that the morphology of the tyre crumbs was such that fibers similar to the follicles of hair were depicted which bind the soil with the rubber crumbs for long. XRD patterns showed amorphous and crystalline behavior of the samples and also some major minerals found therein. Bonds were identified by FTIR analysis which showed that the compounds found in the soil and rubber tyre individually were also present in the composite of the two. Thus, the stabilization of soil with rubber tyre crumbs can be said to be beneficial in an overall context.

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A special word of thanks goes to **Dr. Bharti Singh**, Assistant Professor, Department of Applied Physics, D.T.U for providing me help to conduct XRD of soil, tyre and mixed samples, **Dr. Nitin Puri**, Associate Professor, Department of Applied Physics, D.T.U and his PhD scholars for providing me help to conduct FTIR analysis of soil, tyre and mixed samples.

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(AISHWARYA KUMAR GARG)

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LIST OF SYMBOLS, ABBREVIATIONS AND NOMENCLATURE

OMC = Optimum Moisture Content

MDD = Maximum Dry Density

CBR = California Bearing Ratio

UCS = Unconfined Compressive Strength

XRD = X-Ray Diffraction

SEM = Scanning Electron Microscopy

FTIR = Fourier Transform Infrared Spectroscopy

CHAPTER 1
INRODUCTION

1.1 GENERAL

India's rubber tyre waste generated accounts for about 6-7% of the world-wide total. Its waste generation amounting to exceed 62 million tons per year (as per Press Information Bureau report, 2016) marks an alarming situation of the country. A huge amount of discarded waste rubber tyres and tyre-tubes disturbs the environmentalists all over. Recycled rubber tyres are not of much use due to personal choice of the consumers and lesser life cycle of the recycled product, this also can lead to frequent punctures and wear and tear in the recycled product. As a result, maximum of the used tyre waste are dumped in the landfill sites, piled up in large heaps in the out-skirts of the city or are burnt. Tyres are a non-biodegradable material which adds on to the problem of their disposal.

One of the methods of their disposal can be stabilization of use with this material if they can be converted into chips, shreds, crumbs or powdered form that can easily be mixed with the soil. The soil, if stabilized can prove to be a better sub-grade material in road pavements, parking lots, retaining structures, etc. For use in road pavements one can study the effect these tyre crumbs make over CBR value of the soil whereas variation in shear strength needs to be studied if the aim is to utilize this waste in retaining structures.

1.2 BACKGROUND

Many countries and their government face a lot of problems when it comes to the disposal of waste rubber tyres at an industrial level. World-wide, about 1 billion new tyres are made and the same number gets removed when they have served their full purpose in the vehicles or when their treads get completely worn out. The number of automobile manufacture in India is also at a fast rate so the problem still remains the same.

The rapidly growing industrialization and urbanization has added on to the waste generation and has posed a threat to the environmental conditions. Incineration creates a large amount of ash to generate which pollutes the breathing air for the local residents near the incinerator sites.

Government of India has already banned the use of tyre as a fuel since 2006. The fumes released from its burning are very harmful for the living beings. One can estimate the level of harm the smoke and the nuisance of its foul smell creates by imagining oneself to be standing in the near vicinity of the tyre burning site even for 5 minutes.

Since the past 2-3 decades, environmental and geotechnical engineers have been researching on the proper utilization of tyre waste in construction activities. Hence, it can be a small step in this regard to perform similar type of tests on a soil mixed with rubber tyre crumbs obtained from waste tyres and look for any changes in the strength of soil.

1.3 NEED OF PRESENT STUDY

At times, construction on clayey soil seems to be difficult due to its low strength and high compressibility when water content increases. This behavior of clayey soil lands the construction work into danger. Therefore, instead of searching for a new adequate land, it becomes more feasible to alter the properties of available land. Methods such as compaction, drainage or soil reinforcement can be adopted to stabilize the soil. It can also be done by incorporating various admixtures, for example, lime, cement, fly ash and industrial wastes. Use of waste material for soil stabilization appears to be an attractive solution, because it is cheaper as well as helps in the waste management. Similarly, waste rubber tyre crumbs being light weight having specific gravity ranging between 1.14 to 1.27 and a non-biodegradable material (Oikonomou and Mavridou, 2009) can be effectively used in construction works. Moreover, the landfilling of waste tyres and tubes has been legally banned since July 2006 (Oikonomou and Mavridou, 2009).

Stockpiling, burning and landfilling have been the three usual methods of disposal of waste rubber tyres (Rokade, 2012). Stockpiling is hazardous to health. The combination of rainwater along with dust blown by winds trapped within discarded tyres creates a breeding ground for disease causing mosquitoes. Stockpiling can cause a fire hazard. Fire from rubber tyres emits toxic smoke and contaminates groundwater. Rubber tyres occupy large amount of volume when placed in landfills, thus reduce landfill capacity. Open burning of tyres leads to air pollution and harmful fumes are also released. There is a need of an economical and environmentally viable alternative for the effective utilization of waste rubber tyres. Tyre shreds have been used in reinforcing the sand of shallow footing and it was observed that addition of 10%, 20%, 30%, 40% and 50% tyre shreds by volume increased the Bearing Capacity Ratio(BCR) from 1.17 to 1.83, from 1.6 to 2.2, from 2.15 to 3, from 3.2 to 3.9 and from 2.95 to 3.9 respectively (Hataf and Rahimi, 2006). Rubber strips from a Maruti re-trading company have been used and indicated an increase by 88% in the CBR value of expansive soil at 5% optimum rubber strip content (Rao et al., 2012).Shredded rubber tyre chips of size 25mm X 50 mm showed enhancement in the CBR value in un-soaked condition, the percentage enhancement being 66.28% (Jan et al., 2015). Hence, a study has been done to investigate the use of waste and discarded rubber tyres as an alternative and their potential use in flexible road pavements and parking lots is explored thereof. A basic oral survey was conducted around the rubber tyre workshops in Sitapur Road, Lucknow so as to collect information about the methods of disposal of waste rubber tyres. Most of the tyres which were absolutely useless were either **burnt** or **used as fuel in kilns,** some being melted to make spare rubber parts, toys, etc., which may cause serious problems of **cancer**. Several heaps of waste rubber tyres could be seen near the workshops (fig. 1.1). Therefore, an attempt is made to utilize the crumbs of waste rubber tyres in soil and studying its effect over CBR value, UCS value and further perform analysis on chemical properties of the mix.

Fig. 1.1 Heap of discarded tyres near Tadikhana railway crossing, Sitapur Road, Lucknow

1.4 OBJECTIVES OF THE PRESENT STUDY

Objectives of the present study are:

- To study the effect of rubber crumbs on compaction characteristics of the soil.
- To study the variation in California Bearing Ratio (CBR) values with different percentage of crumbs of rubber tyre.
- To study the variation in Unconfined Compressive Strength (UCS) value with different % of crumbs of rubber tyre.
- To analyze the soil, rubber tyre crumbs and their mixture for geochemical properties by conducting SEM, XRD and FTIR analyses.

1.5 CRUMB RUBBER USED IN THE STUDY

Waste tyres can be used as shock absorbers and vibration absorbers underneath the heavy lathe machines, generators in houses, etc. Civil engineers have utilized this waste in many types of works such as supporters for embankment materials beside the roads (specially in hilly areas), filling materials, soil stabilizer in subgrade soil, retaining structures, etc. In this study crumb rubber of tyres passing through I.S. 2.8 mm sieve is used for CBR test while same passing through I.S. 2 mm sieve (medium grained) is used for UCS test.

The crumbs of waste rubber tyres used in the study are taken by weighing dry for use in the soil sample.

Fig. 1.2 Collecting tyre crumbs from workshop and sieving in the lab

CHAPTER 2
LITERATURE REVIEW

For the present study a wide literature was reviewed out of which some important research papers and their findings have been summarized briefly in the following paragraphs

2.1 REVIEW OF THE PAST STUDIES

Sharma et al. (2018) studied characteristics of polluted soil after studying the result of open dumping of solid waste in mountainous regions of India in Himachal Pradesh. It included geo technical investigation of slag soil and compared it with original soil. Energy Dispersive X-ray Spectroscopy and Scanning Electron Microscopy carried out geochemical analysis.

Five soil samples were collected from the dumpsites of depth 1.5 m, 1m and 0.5 m. Various tests such as Atterberg's limit test, CBR test, specific gravity test, compaction test, grain size analysis, direct shear test and permeability analysis were conducted. The dumpsite soil showed decrease in the values of MDD, cohesion, CBR and specific gravity and increase in the permeability. The final results showed that the geotechnical characteristics of the soil at all the dumpsites was much hampered by the open dumping of the waste.

Suthar and Aggarwal (2018). Tests were performed on pond ash which were stabilized with lime alone in the ratios of 2%, 4%,6%, and 8% by weight and with the combination of lime sludge in the ratios of 5%,10% and 15% by weight. Other test such as were conducted such as XRD and SEM to find the formations of crystalline phases after stabilization. It resulted in the increase of lime content by 4%. More effect was seen in the ratios in soaked condition. Compared to un-stabilized waste, in the stabilized waste, the concentration of metals such as Cu, Zn Ni, Cd and Cr were lower. It was indicated by the results that the mixture of lime, ash, lime sludge had potential application of road sub base material.

Al-Neami (2018) used local materials to stabilize the sand instead of conventional method in an attempt to improve the sandy soil quality. It was mixed with different percentages of waste tyres along with dry sand. The test results showed that it was able to stabilize and shear strength of sand was increased after adding the tyre chips to the sand. On increasing the content of tyre chips in the soil maximum dry density and specific gravity was reduced. On analyzing the results, it was found that the CBR test that the sand that was stabilized with tyre chips gave more CBR as compared to to pure sand. It inferred that on adding the tyre chips the load bearing capacity of the soil is increased due to the increase in the physical bonds between the sand particles.

Rahgozar and Saberian (2016) used peat soil. They added chips of rubber tyre (kept at a constant doze of 10%) that were in shredded form. Stability and bearing capacity tests were done after adding pozzolanic binder at 5,10 and 15 % by weight. UCS, X-ray Fluorescence, SEM tests were performed. Findings were that UCS value was more in case where gypsum and lime were added. 5% was the optimum binder content as per UCS and direct shear tests.

Ravichandran et al. (2016) took 2 problematic soil of clayey origin and mixed them with 5-20% of rubber tyre crumbs for investigating the effect of using tyres as stabilizer. CBR tests showed an enhancement up to the addition of 10% waste. Soil1 showed an improvement of 161% while soil2 of 130%. Drainage properties of the sample were also tested for and positive results for permeability co-efficient were witnessed. Permeability of soil1 increased 3-77 times whereas of soil2 increased 4-101 times the original value in virgin soil. This increment was witnessed as rubber crumbs were mixed from 5-20% respectively.

Jan et al. (2015) performed CBR tests on sub-grade soil used in pavements which was supplemented by chips of tyres of size 25 mm × 50 mm, finding that 66.28% enhancement was reported at the optimum content of tyre chips as 8%.

Saygili (2015) showed interest in the use of dust of marble waste in problematic soil and further looked for microstructure of the treated soil. Ratio of marble dust included 5 to 30% increasing at an interval of 5% each. SEM was done. Results withhold the fact that the construction cost of structures can be cut down with the use of this material. Improvement in shear strength parameters and reduction in swell potential were indicated. It would reduce the nuisance to the environment created due to this waste.

Priyadarshee et al. (2015) mixed fly ash and kaolin clay with tyre material and experiments such as compaction test, CBR test, etc. were done on the two types of mixtures. The results showed an increase in the CBR value in both the conditions. An improvement factor which is the ratio of modified value of CBR to the original value was used to interpret the results. An improvement of as high as that up to 5 was recorded in case of kaolin clay and up to 3 in fly ash.

Karabash et al. (2015) utilized an industrial waste i.e., aluminium pieces to reinforce soil. Clayey soil was used and modified proctor tests and UCS tests were carried out. Content of aluminium was varied from 5% to 20% at an interval of 5 each time. Aluminium was weighed dry and was replaced by the same percent of soil. It increased the MDD and reduced the OMC. UCS value showed a high rise upto 10% waste and thereafter decreased.

Belabdelouahab and Trouzine (2014) worked by keeping sustainable development in mind with the aim of improving thermal stability of road pavements. Asphalt was converted to rubberized asphalt and this was made possible with the use of rubber tyres which could be recovered and reused by this research.

Sellaf et al. (2014) took 2 types of soil and evaluated whether scrap tyre rubber improves the stability of soil or not. The results indicated that if a suitable amount of waste tyre rubber is mixed with the specimen such that the compressibility of the same does not alter then this waste can be used to stabilize the soil.

Bansal et al. (2014) reused the shredded form of tyres to study the effect on the bearing capacity of soil. The results showed an increment of 1.78 times the value as compared to plain soil.

Lepcha et al. (2014) worked to improve weak soils and reviewed the use of tyre chips to strengthen weak soils. An increase in strength was observed that could help the soil to meet the desired design requirements. This made the soil fit for design considerations and the ill-effects that occurred due to weak soils could be eliminated.

Vasudevan et al. (2012) worked in the transportation sector as he understood the need of use of disposed plastic waste to increase the load bearing capacity of roads. He mixed PCA (plastic waste coated aggregate) with bitumen and the result was an improvement in the binding property of bitumen which led to an overall enhancement in the road quality. Road strength increased by 100 % and no potholes were observed to form in the road.

Rao et al. (2012) used strips of rubber in soi and tested CBR values at each content of the additive. Soil used in the study was expansive in nature. %age of rubber strips that proved to be optimum for improving the CBR value by 88% was 5%.

Oikonomou and Mavridou (2009) have given a review of various studies conducted in the field of utilization of rubber tyres in different civil engineering works. In their chapter a number of tests have been summarized which provide an idea that rubber tyres can be effectively used in geotechnical field, transportation engineering for constructing roads as well as other civil engineering activities. Some of the illustrations are workability, mechanical characteristics, water absorption, durability, microstructure, etc.

Prasad et al. (2008) considered the gravel sub-base material for stabilizing it with waste plastic and waste rubber tyre. CBR and direct shear tests were performed. Gravel sub-base layer used in laying of flexible pavement was a subject of study by models made in the lab while addition of these waste materials was incorporated, the adequate content of which were also reported. The flexible pavement model showed a significant enhancement in its capacity to carry load after the addition of these wastes.

Hataf and Rahimi (2006) used tyre shreds of rectangular shape (3cm×12cm in dimension) to reinforce the soil. The shreds were mixed in the proportion of 10-50% by increasing 10% each time. Bearing capacity ratio was observed to improve to 3.9 as compared to that in virgin soil which was 1.17 only. 40% tyre mixed in the soil was found to maximize the BCR.

Cetin et al. (2006) stabilized cohesive clayey soil with two types of tyre chips, one being coarse grained while other being fine grained. They were mixed in the ratio of 10-50% increasing 10% each time. This study was conducted to find whether tyre material can be used as a filling material or not. The results obtained were positive towards the aim of the study as the shear strength increased by 30% in case of addition of fine tyre chips and in case of coarse tyre chips, an increase of 20% was observed in the shear strength.

Foose et al. (1996) aimed at stabilizing sand by mixing dry sand with shredded tyre chips. Certain factors that could influence the shear strength of sand were studied and identification of those factors was done which significantly affected the shear strength by increasing the friction angle ϕ. For calculating the strength of stabilized soils, a model was also evaluated and it was applied to the sand and tyre shred mixture. After studying the results of one shred content, the model could be calibrated for other shred contents.

2.2 REVIEW SUMMARY

After reviewing the above literature, it was observed that some researchers have utilized rubber tyre waste to enhance the strength of sand and some have used it as a backfill material due to its light weight. They have taken different sizes of tyre chips, some have taken two different soil samples as well. Some have used binders such as lime, gypsum, etc. in combination with tyre crumbs. The results were quite varying, although mostly were positive when it comes to Bearing Capacity Ratio, California Bearing Ratio, or Shear Strength for that matter and have reported an improvement in these values at various ranges. Almost no comprehensive study has been conducted in this regard specifically on Lucknow's clayey soil yet, this research studies experimentally the effect of adding different percentages of tyre crumbs to clayey soil. Therefore, it was a motivation to study the effect of waste rubber tyre crumbs on CBR value and UCS value of a clayey soil taking different proportions of waste rubber tyre crumbs by weight (dry) of soil and further analyze geochemical composition and morphology of the new mixture formed thereof so that a new method to utilize this waste can be explored which can ultimately protect the environment.

CHAPTER 3
METHODOLOGY

3.1 GENERAL

This is the most important part of the whole process. It includes material collection, sampling method and the tests conducted on them. Different samples were prepared with varying proportion of soil and rubber tyre crumbs. Effort has been made to find out the optimum value of rubber tyre crumbs by conducting a number of CBR tests on the soil-crumb mixture. Further, to investigate any improvement in the shear strength of the clays soil, UCS test has also been conducted. Later on, geochemical analysis has been carried out to investigate the surface morphology, mineral content and different bonds formation in the soil-tyre mixture.

3.2 CHARACTERIZATION OF MATERIALS USED

3.2.1 SOIL SPECIMEN

Soil used in the experiments was from Airport Authority of India, Amausi Airport, Lucknow where an old parking area was to be renovated into a new parking area. The soil used was clayey in nature. The OMC and MDD of plain soil (without crumb rubber) were determined by using IS heavy compaction whose values are listed in the following table:

Table 3.1 Properties of plain soil

Sr. No.	Parameters	Value
1.	OMC (%)	14.3
2.	MDD (gm/cc)	1.784
3.	Liquid Limit (%)	30
4.	Plastic Limit (%)	22
5.	Plasticity Index (%)	8
6.	Soil classification as per ISCS	CL (Low Compressible Clay)

3.2.2 SCRAP RUBBER TYRE CRUMBS

Scrap rubber tyre crumbs were collected from a local rubber tyre re-cycling workshop near the dumpsite named Sameer Tyre, Sitapur Road, Lucknow. The tyre crumbs do not contain any steel or fluff because these are simply the grinded part of treads that have worn out from the tyre. The rubber tyre crumbs vary from 4.75 mm to less than 0.075 mm (Oikonomou and Mavridou, 2009). The specific gravity of scrap tyre crumbs was tested as per ASTM C127 (2007) guidelines and was found to be 1.15. The sieve analysis of scrap rubber tyre crumbs collected was done as per guidelines of ASTM D422-63 (1998). The sieve analysis gave the following particle size distribution as shown in the figure below:

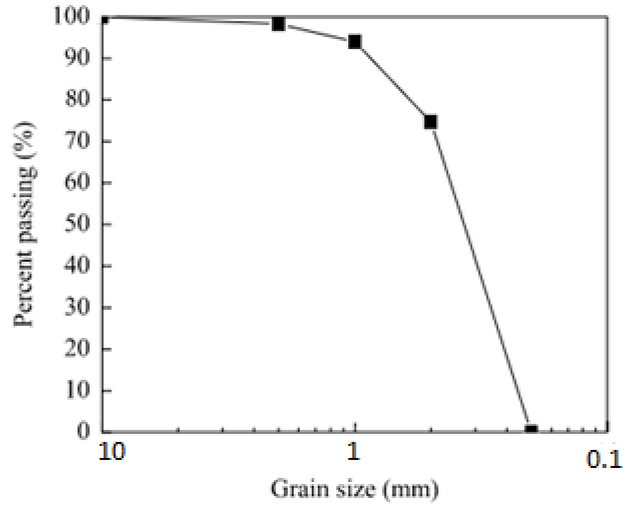


Fig. 3.1 Particle-size distribution of scrap rubber tyre crumbs

Fig. 3.2 Test materials: Scrap rubber tyre crumbs and plain soil sample

3.3 METHODOLOGY CHART

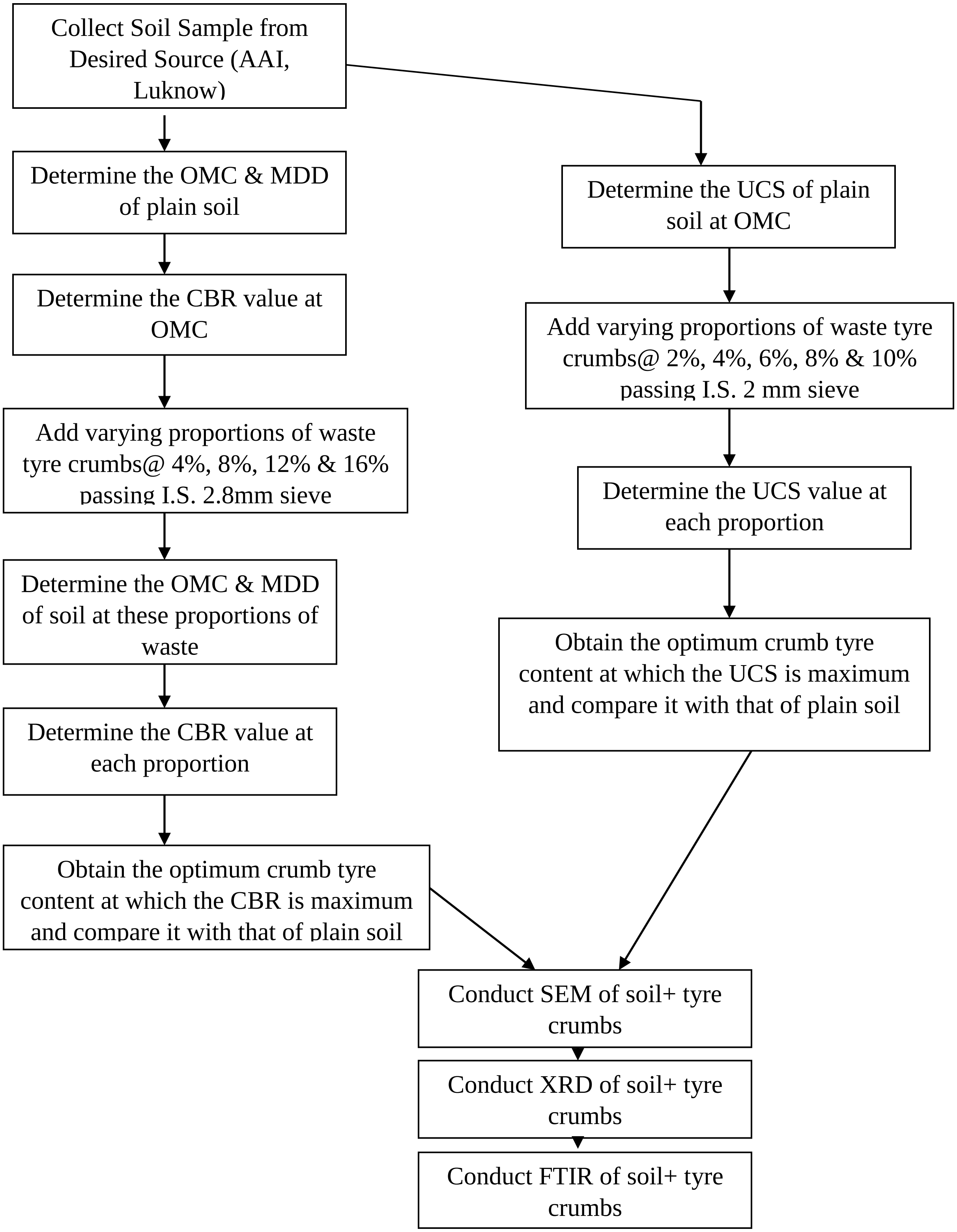


Fig. 3.3 Flow chart of experimental work

Study area was chosen as Lucknow, in which location of Amausi Airport was decided to collect the soil sample. A sufficient amount of sample was collected to carry out the laboratory tests. All the specimens were tested with and without crumb tyre addition to study the effect of soil stabilization.

3.4 MODIFIED PROCTOR TEST

Modified Proctor Test was used to study the compaction characteristics of soil alone as well as soil + rubber tyre crumbs mixed in various proportions. It gives the moisture content at which the dry density is maximum, known as OMC and MDD respectively. The test procedure is performed as per the codal provisions of IS: 2720(Part 8)-1983. The same test procedure is adopted when tyre crumbs in the proportion of 4%, 6%, 8%, 12% and 16% are mixed.

Fig. 3.4 Performing modified proctor test

3.5 CALIFORNIA BEARING RATIO TEST

The CBR test is used mainly in transportation engineering for determining the thickness of sub-grade material required for pavement construction of roads. This was developed by the California Highway Department (O. J. Porter) in 1920's. It was performed according to the codal provisions given in Indian Standard code- IS: 2720(Part 16)-1987. The same test procedure is repeated on mixing the tyre crumbs in the soil at 4%, 8%, 12% and 16%.

CBR value is calculated as per IS: 2720(Part 16)-1987 as follows:

$$\text{CBR} = \frac{\text{Test load corresponding to the chosen penetration from load penetration curve}}{\text{Unit standard load for the same depth of penetration}} \times 100$$

Unit standard load for 2.5 mm and 5 mm are 70 kg/cm^2 and 105 kg/cm^2 respectively as per IS: 2720(Part 16)-1987.

Fig. 3.5 California Bearing Ratio test apparatus

Fig. 3.6 Testing for un-soaked CBR

3.6 UNCONFINED COMPRESSIVE STRENGTH TEST

The main aim of this test is to determine the unconfined compressive strength, which is then used for calculating the unconsolidated undrained (UU) shear strength of the clay under unconfined conditions. The unconfined compressive strength (q_u) the compressive stress at which an unconfined cylindrical specimen of soil fails in a simple compression test (definition as per ASTM standards). Test procedure and sample preparation are adopted as per IS: 2720(Part 10)-1991. In this test in the present study, soil sample passing 2 mm I.S. sieve as well as rubber tyre crumbs passing through 2 mm I.S. sieve, so as to take medium grained rubber crumbs irrespective of different densities, are taken and mixed in different proportions of 2%, 4%, 6%, 8% and 10% and tested for changes in the UCS value. The same test procedure is repeated on mixing the tyre crumbs in the soil at 2%, 4%, 6%, 8% and 10%.

Fig. 3.7 Battering the soil sample **Fig. 3.8 Sieving the soil through I.S. 2 mm sieve**

Fig. 3.9 Sampling in split mold (38 mm dia. X 76 mm length)

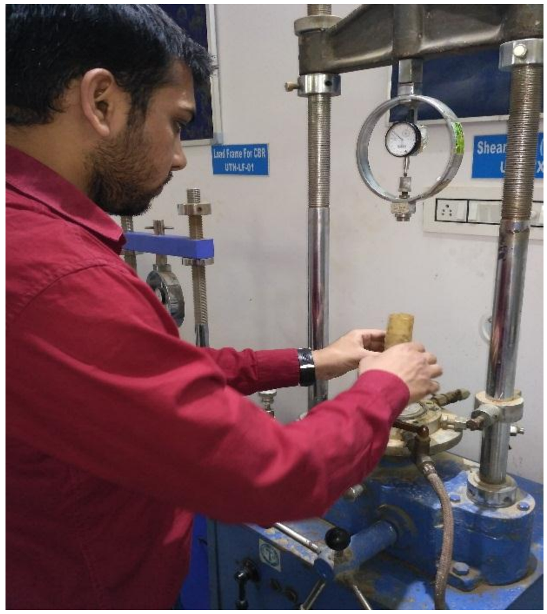


Fig. 3.10 Performing UCS test

3.7 GEO-CHEMICAL ANALYSIS

3.7.1 SCANNING ELECTRON MICROSCOPY

Scanning electron microscopy is used to get the structural details of the surface of the sample at a micro level. It generates 3-D images of the surface morphology. These images help to understand the texture of the sample and can be compared with those of any known materials.

Sometimes it is used along with an EDS (Energy Dispersive X-ray Spectroscope) which gives the elements present in the specimen. SEM imaging is quite different from a simple microscope in the regard that unlike a simple microscope, it uses an electron beam of high energy to be made incident on the object which interacts with the structure of the sample at an atomic level in order to give detailed image of the same. Electron microscope used in this study had a maximum magnifying capacity of up to 10,00000X which could even show the minute details of an eye of a mosquito. The knob of the machine can be set over different areas and the images of the specimen for the desired locations at desired magnifications can be achieved.

Sample Preparation

In the present study a Scanning Electron Microscope- Model "JEOL JSM-7610F" has been used in which the dried rubberized soil sample coated with Platinum + Palladium is inserted and the entire chamber is put to vacuum. Machine used for coating the rubberized soil sample was “JEOL JEC-3000 FC AUTO FINE COATER”.

Fig. 3.11 Scanning Electron Microscope- Model “JEOL JSM-7610F” at B.S.I.P, Lucknow

3.7.2 XRD (X-RAY POWDER DIFFRACTION)

X-ray diffraction method is used to identify the phase of the specimen whether it is more of amorphous nature or crystalline nature. The changes in phase are also recognized with the help of XRD matching software which can occur if thermal changes are there in the sample. It works on the principle of Bragg’s law.

Different types of minerals present in the sample can be interpreted with the result (or report) generated by inputting the .dql file in the matching software which has a large number of data of a variety of known materials. These minerals are shown as identified peak area in the report while some peak area remains unidentified.

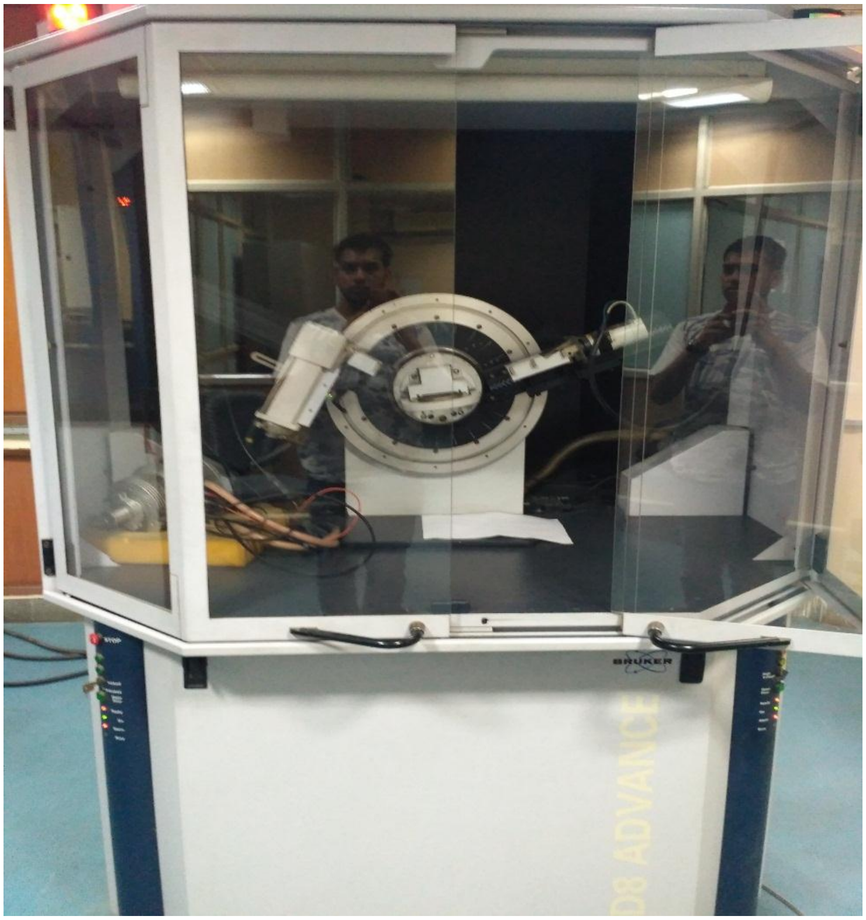


Fig. 3.12 X-ray Powder Diffractometer- Model: “Bruker D8 Advance” in Advanced Instrumentation Lab, Applied Physics Deptt., D.T.U.

Sample Preparation

Sample preparation for XRD analysis is very simple. One needs to crush the sample in powdered form as much as possible and place it in the sample holder. The sample holder filled with powdered sample is then put inside the diffractometer and X-rays are allowed to pass through it.

In the XRD, diffractometer has such a geometrical arrangement, that the X-ray beam is incident on the sample and the sample holder rotates thus rotating the sample at an angle θ. The detector, itself rotating at an angle of 2θ on the other end receives the X-rays diffracted by the sample. A goniometer keeps the angle maintained and rotates the sample also. For powder diffractometers, the XRD data is collected for 2θ ranging nearly from 5-70 degrees.

3.7.3 FTIR ANALYSIS

Fourier Transform Infrared Spectroscopy, also referred as FTIR Spectroscopy or FTIR Analysis, is a technique for analyzing and identifying different materials of organic origin as well as inorganic origin. Sometimes polymers, synthesized fibers and new composites can also be detected for unknown substances formed, new bonds formed, lattice defects, functional groups present, etc.

The FTIR spectrum of a soil sample, rubber tyre crumb sample and a mixture of the two can be analyzed to get details of the minerals present in the soil, chemical compounds present in the rubber tyre and the mixture of both of them. Presence of any foreign matter such as multivalent elements in the sample can account for any defects that could occur in its lattice structure.

How FTIR Works

The principle on which FTIR works is the principle of interferometry. It measures which infrared wavelengths are being absorbed by the sample. For this purpose, an infrared radiation beam is made incident on the material to be tested. The types of molecules present, their components and structural formula can be determined by the absorbance of the sample.

Unknown substances are recognized by searching the spectrum obtained for the sample in a database of reference spectra. Samples as thin as 20 µm can be analyzed by using microscope. By using the microscope in an FTIR, a large number of unknown substances like fibers, remnants, thin films, binders in polymers, etc. can be tested and identified.

Based on the principle of interferometry firstly an interferogram is obtained which is a graph between intensity versus time. As the name suggests, a mathematical method known as Fourier Transform is then used in decoding the signals by which a graph between transmittance (or intensity) and wavenumber (or frequency) is obtained known as FTIR spectra.

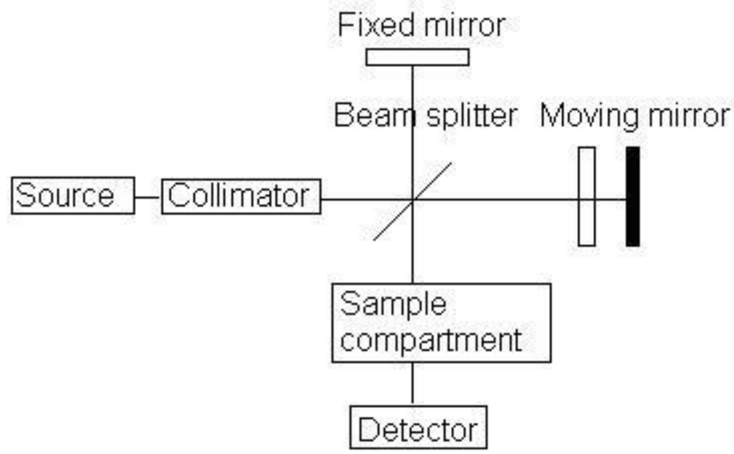


Fig. 3.13 Block diagram of working of FTIR spectrometer

Radiation source used can be either Nerst Glover or Glober source. It will produce the IR radiation, then it will move to the beam splitter. The beam splitter splits the radiation into two equal parts, one part will directly go through the beam splitter in the forward direction (i.e., to the movable mirror) undeflected while the other part gets deflected and goes in upward direction (i.e., to the stationary mirror) after being deflected. The angle of beam splitter is 45 degrees. From the movable mirror, half of the radiation will move towards the radiation source while half goes to the sample. From the stationary mirror, half of the radiation will go to the sample while half again goes to the radiation source after getting deflected from the beam splitter. Ultimately, 2 radiations will be used by the sample which it will absorb. After absorbing it will go to the detector which will produce an interferogram. Then the computer will give the final result generated as FTIR spectra.

Sample Preparation

Materials required for preparing the sample are: IR-grade KBr, mortar and pestle, weighing balance, butter papers, tissue papers, gloves, acetone and spatula.

The proportion of sample:KBr (IR-grade) is taken in the ratio of 1:300 by weight by weighing dry using a balance and crushed using a mortar-pestle arrangement till the powder is finely grinded. With the help of a hydraulic press, pallets are prepared which are further placed in the FTIR spectrometer for obtaining the spectra. The preparation of pallets needs to be done with utter care and the instruments used are cleaned with acetone and wiped off with tissue paper again and again. Since the test is very delicate and needs immense cleanliness while samples are prepared, so that any foreign particles do not get into the sample, it is also mandatory to wear gloves during the entire testing procedure is being carried out.

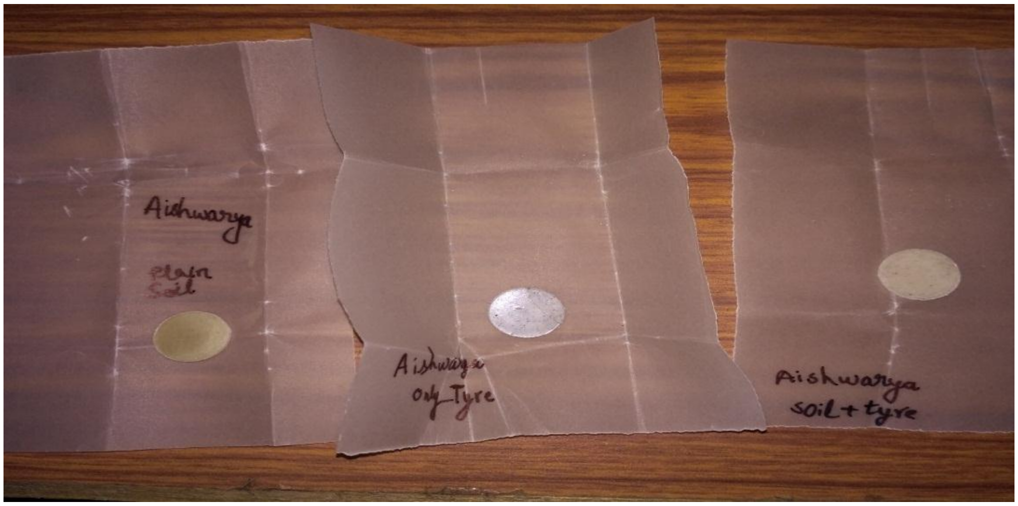


Fig. 3.14 Pallets of plain soil, only tyre crumbs and mixture of both (from L to R)

Fig. 3.15 Hydraulic press used to make pallets for FTIR, Applied Physics Deptt., D.T.U

Testing Process

Step 1: Gently place the sample to be tested in the FTIR spectrometer so that the pallet does not break. The radiation source will produce infra-red radiation which will go to the beam splitter. The beam splitter will split the beam into 2 equal parts. Spectrometer throws light at the sample and measures the amount of the beam and at which frequencies the sample ingests the infrared light through itself. The pallet of the sample must be very thin so as to allow the infrared light to transmit through it. Samples applicable for reflectance test are residual remnants, stains or thin sliced films on a genuinely levelled surface or to some degree flexible materials that are flimsy enough to fit under the microscope's magnifying lens.

Step 2: There is a vast amount of reference database available that holds the data of wide range of spectra, so the effective identification of test-samples can be done from the same. The sub-atomic particles, new bonds formed and functional groups can be resolved through this procedure.

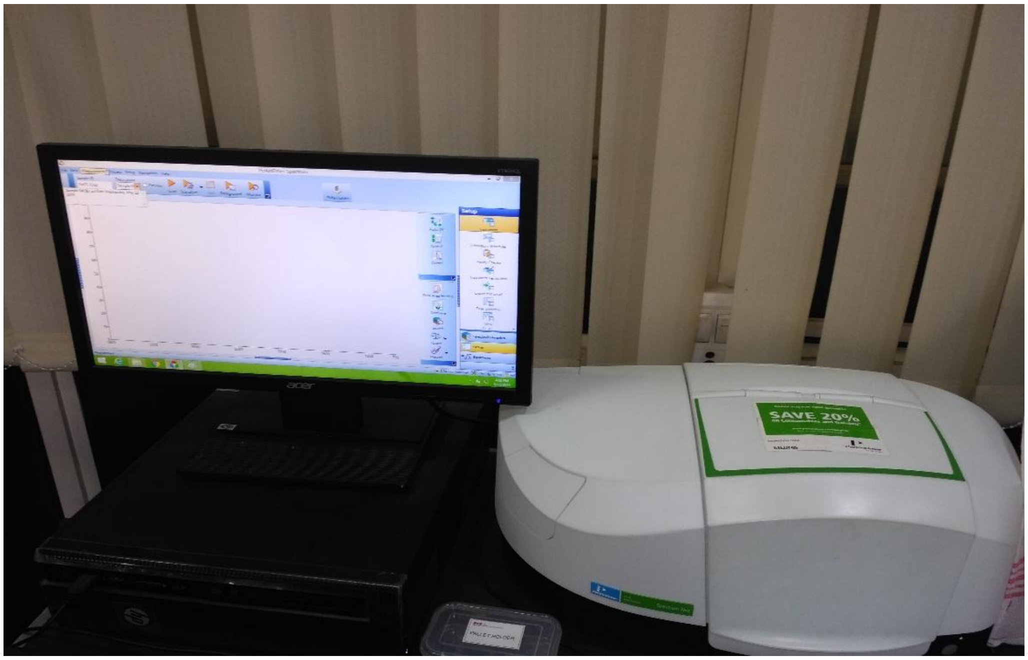


Fig. 3.16 FTIR spectrometer in Applied Physics Deptt., D.T.U

CHAPTER 4

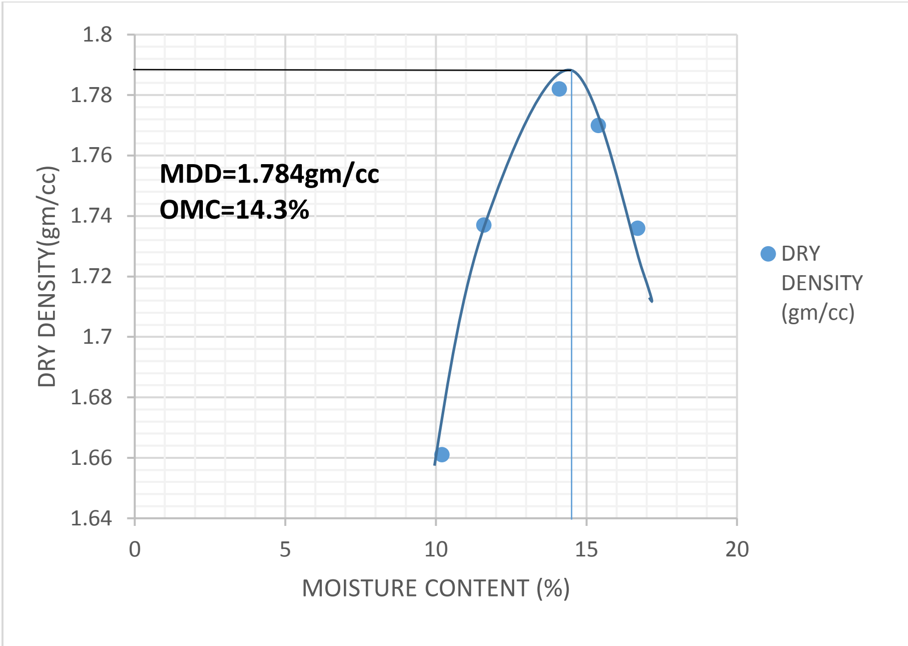
RESULTS AND DISCUSSION

4.1 MOISTURE CONTENT AND DRY DENSITY OF PLAIN SOIL

Optimum moisture content is the amount of water that needs to be added in the soil so that the dry density is maximum. To obtain this value IS heavy compaction test is used in this study. Amount of water is varied in the soil by a particular %age of soil by weight and the compaction test is carried out repeatedly till the weight of the mold starts to first increase and then decrease. The point where the weight is maximum and then starts to decrease, marks the point of maximum dry density. The values of the water content (or moisture content) and the corresponding dry densities obtained by using modified compaction test which are as follows:

Table 4.1: Moisture content and dry density of plain soil

Moisture Content (%)	Dry Density (gm/cc)
10.2	1.661
11.6	1.737
14.1	1.782
15.4	1.77
16.7	1.736



Graph 4.1: Compaction Curve for Soil (without tyre)

It can be observed from above figure that as the moisture content increases the dry density increases with increasing percentage of rubber crumbs after that it decreases. Therefore, maximum dry density is 1.784 gm/cc and optimum moisture content is 14.3%.

4.2 LOAD/AREA VS PENETRATION CURVE FOR PLAIN SOIL FOR UN-SOAKED CBR

When the test specimen is subjected to CBR test, the plunger penetrates the specimen at varying load. The proving ring shows a numerical value which when multiplied by proving ring constant gives the value of load (in kg). This load when divided by area of the plunger gives the load per unit area (in kg/cm^2). The load per unit area values at different penetrations obtained are as follows:

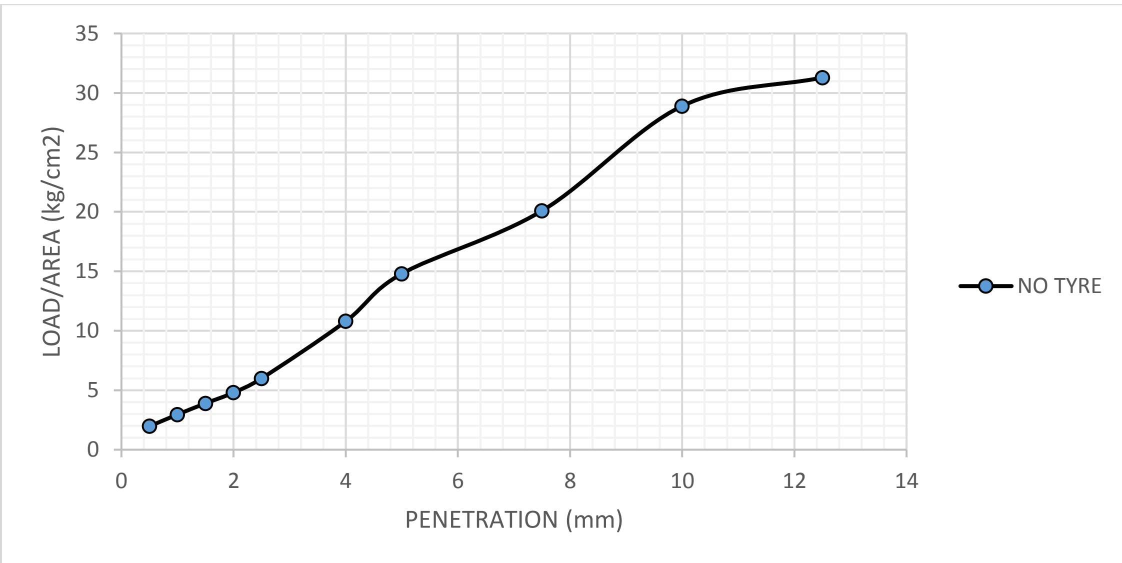
Proving ring constant = 6.47

Area of plunger = 19.64 cm^2

Table 4.2 Penetration and Load/area values of plain soil

Penetration (mm)	Load/Area (kg/cm^2)
0.5	1.97

1	2.96
1.5	3.9
2	4.8
2.5	6
4	10.8
5	14.8
7.5	20.09
10	28.9
12.5	31.29



Graph 4.2: Load/area vs penetration curve for plain soil for un-soaked CBR

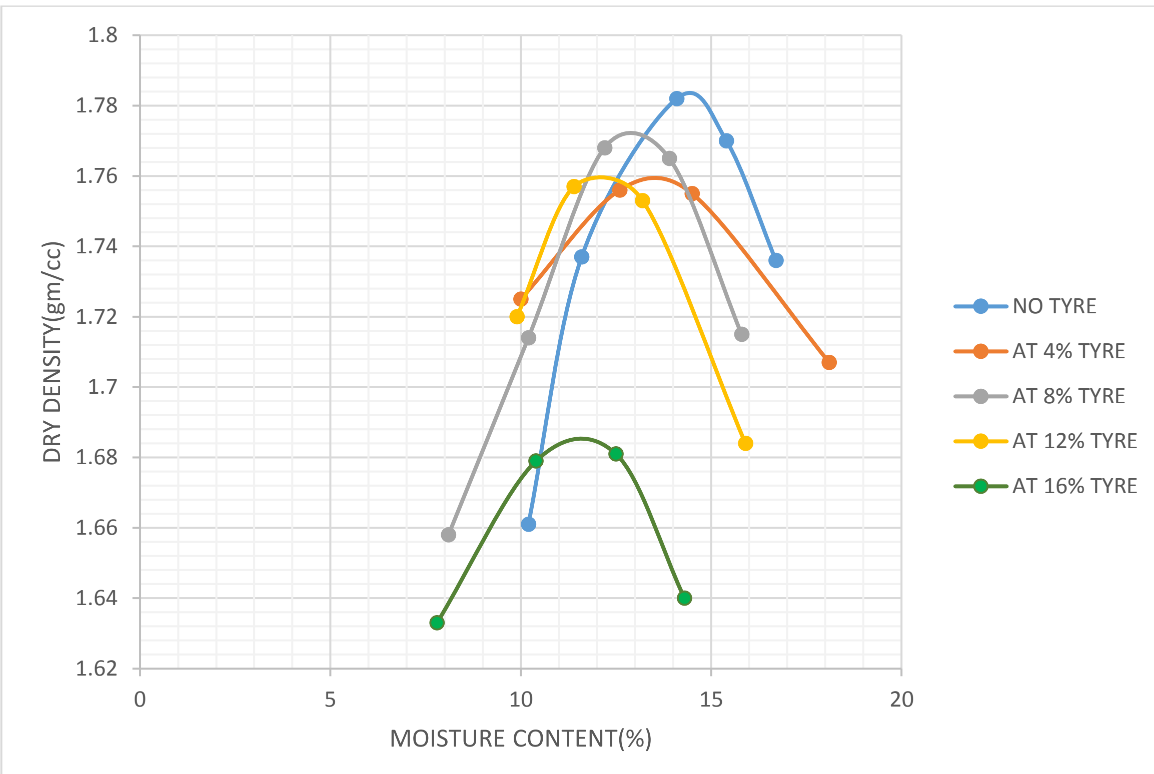
Above figure indicates that load increases with corresponding penetration value for plain soil for un-soaked CBR.

4.3 OMC AND MDD USING IS HEAVY COMPACTION TEST ON SOIL WITH VARYING RUBBER TYRE CRUMBS %AGE.

Following are the values of moisture content and dry densities of soil-tyre crumb mixes combined together and a combined graph is plotted to be able to see the highest tips of each curve (i.e., the OMC of each type sample).

Table 4.3: Combined table of moisture content and dry density of different soil-tyre crumb mixtures

Moisture Content (%)					Dry Density (gm/cc)				
No Tyre	4% Tyre	8% Tyre	12% Tyre	16% Tyre	NO Tyre	4% Tyre	8% Tyre	12% Tyre	16% Tyre
10.2	10.0	8.1	9.9	7.8	1.661	1.725	1.658	1.720	1.633
11.6	12.6	10.2	11.4	10.4	1.737	1.756	1.714	1.757	1.679
14.1	14.5	12.2	13.2	12.5	1.782	1.755	1.768	1.753	1.681
15.4	18.1	13.9	15.9	14.3	1.770	1.707	1.765	1.684	1.640
16.7		15.8			1.736		1.715		



Graph 4.3: Compaction Curve for soil at varying rubber tyre crumb %age

For soil and rubber tyre crumb mixture also the compaction characteristics were studied using IS heavy compaction test. The tests were carried out by replacing the soil with rubber tyre crumbs in the percentages of 4%, 8%, 12% and 16% as per Indian Standards Code (IS: 2720 Part 7 – 1980). The capacity of the mold is 1000cc. It can be inferred from the above curves that the MDD first decreased at 4% crumb and then increased at 8% crumb but after that it decreased at

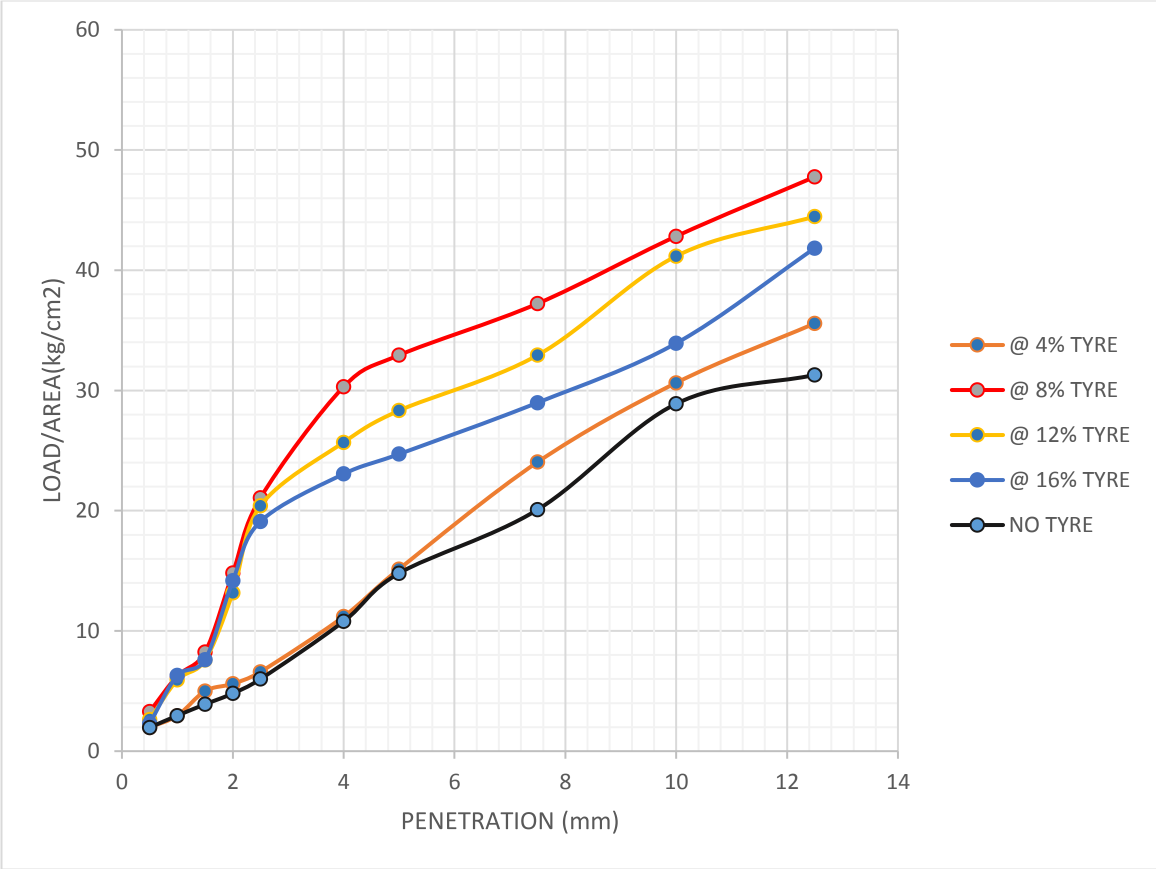
12% and further more decrement was seen at 16%. This makes tyre a usable material as lightweight backfill in retaining structures such as retaining walls. From the above graphs initially, plain soil has the maximum dry density 1.784 g/cc and after adding different proportions of tyre powder the optimum moisture content fluctuates and maximum dry density overall decreases; this is mainly due to the reason that the rubber tyre crumb's specific gravity is very low as compared to that of soil.

4.4 LOAD/AREA VS PENETRATION CURVE FOR SOIL AT VARYING RUBBER TYRE CRUMB %AGE FOR UN-SOAKED CBR

The values of load per unit area at all penetrations i.e., 0.5, 1, 1.5, 2, 2.5, 4, 5, 7.5, 10, 12.5 mm at varying % of rubber tyre constituent are tabulated as follows:

Table 4.4: Combined values of load/area at all penetrations

Penetration (mm)	**Load/Area (kg/cm^2)**				
	@ No Tyre	**@ 4% Tyre**	**@ 8% Tyre**	**@ 12% Tyre**	**@ 16% Tyre**
0.5	1.97	1.97	3.29	2.63	2.3
1	2.96	2.96	6.26	5.93	6.3
1.5	3.9	5.0	8.24	7.58	7.6
2	4.8	5.6	14.82	13.18	14.17
2.5	6	6.6	21.08	20.42	19.11
4	10.8	11.2	30.31	25.69	23.06
5	14.8	15.15	32.94	28.33	24.71
7.5	20.09	24.05	37.23	32.94	28.99
10	28.9	30.64	42.83	41.18	33.93
12.5	31.29	35.58	47.77	44.47	41.84



Graph 4.4: Load/area vs penetration curve for soil with varying rubber tyre crumb %age for un-soaked CBR

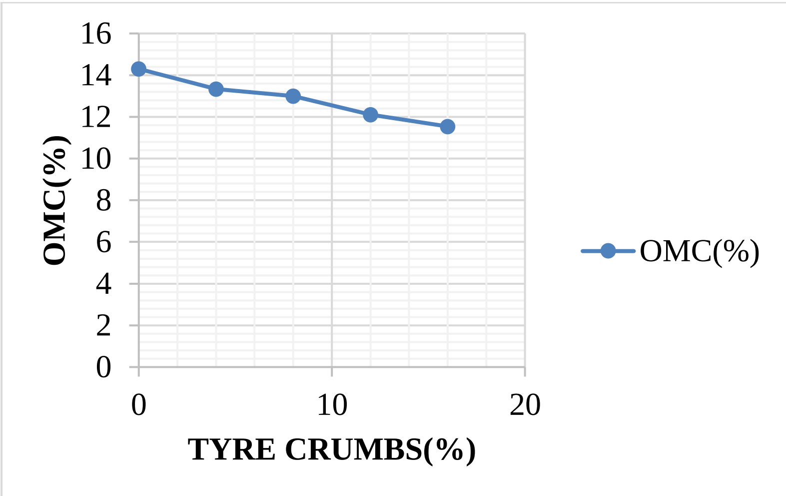
It can be observed that load increases with corresponding penetration value for soil with varying percentage of rubber tyre crumb for un-soaked CBR. Maximum load-penetration characteristics have been observed with the addition of 8% rubber tyre crumb and minimum load- penetration characteristics have been observed with the plain soil. Also, similar load-penetration characteristics have been observed with the addition of 4% rubber tyre crumb and plain soil till penetration value of 5mm. Little similarity in pattern of load-penetration characteristics have been observed with the addition of 8%, 12% and 16% rubber tyre crumb till penetration value of 2.5 mm.

4.5 VARIATION OF OMC WITH VARYING PERCENTAGE OF TYRE CRUMB CONTENT

The OMC values obtained for soils mixed with crumb rubber vary as illustrated by the figure below. The table shows that OMC reduces from 14.3% to 11.54%. on addition of crumb rubber up to 16%. The OMC value may be said to show a reduction due to the lower water absorption capacity of rubber material (crumb rubber). Hence, the OMC decreased for the mix.

Table 4.5: OMC values at different content of tyre crumb in the soil

Tyre Crumbs (%)	OMC (%)
0	14.3
4	13.33
8	13
12	12.1
16	11.54



Graph 4.5: Tyre crumb content in the soil vs OMC

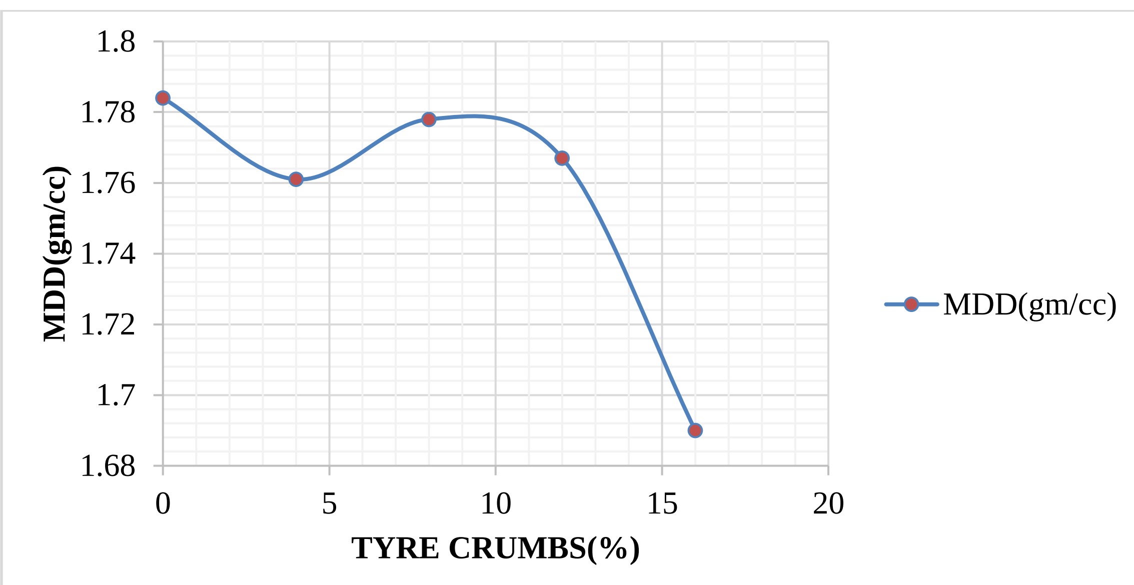
With the addition of 4% OMC decreased to 13.33%. Further observations were made at 8%, 12% and 16% addition of tyre crumb and were found to be 13%, 12.1% and 11.54% respectively.

4.6 VARIATION OF MDD ON VARYING PERCENTAGE OF TYRE CRUMB CONTENT

The MDD values obtained for soils mixed with crumb rubber vary as illustrated by the figure below. The table shows that MDD reduces from 1.784 to 1.69 on addition of crumb rubber up to 16%. The MDD value may be said to show a reduction due to the lower specific gravity of crumb rubber powder as compared to that of plain soil. Also, it does not absorb water, hence MDD decreased for the mix.

Table 4.6: MDD values at different content of tyre crumb in the soil

Tyre Crumbs (%)	MDD (gm/cc)
0	1.784
4	1.761
8	1.778
12	1.767
16	1.69



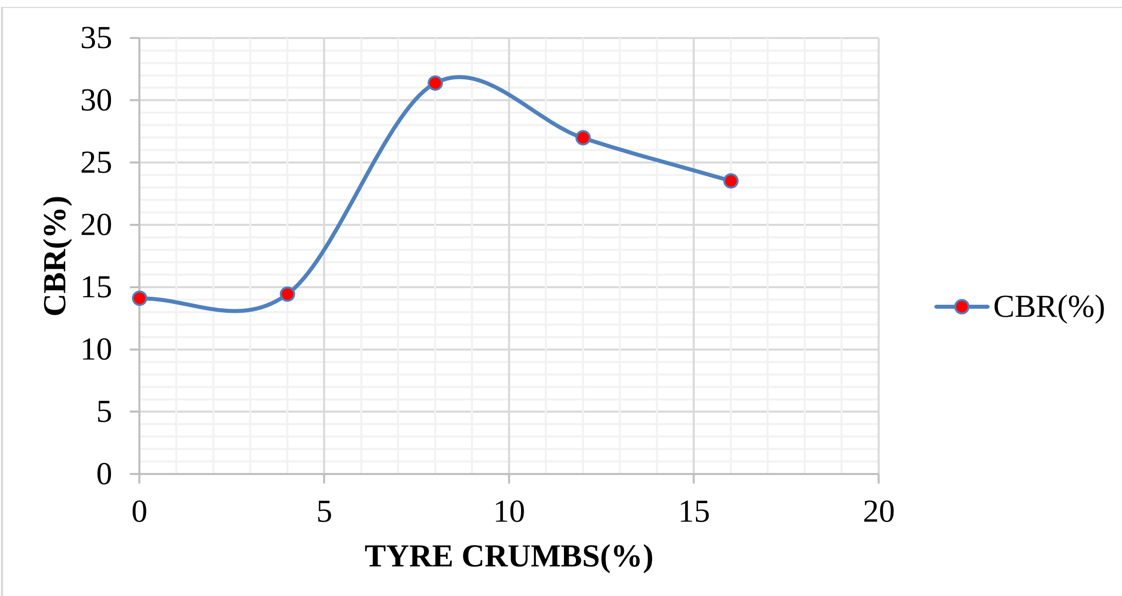
Graph 4.6: Tyre crumb content in the soil vs MDD

With the addition of 4% MDD decreased to 1.761 gm/cc. Further observations were made at 8%, 12% and 16% addition of tyre crumb were found to be 1.778 gm/cc, 1.767 gm/cc and 1.69gm/cc respectively. It can be observed from figure that when the waste tyres content increased in the clay mixture, dry density is reduced due to the nature of tyres crumbs which are considered as a lightweight fill material. This reduction has a useful nature in embankment construction because when such mixture is used in fills, the lateral earth pressure will decrease.

4.7 VARIATION OF CBR ON VARYING THE % OF TYRE CRUMB CONTENT

Table 4.7: CBR values at different content of tyre crumb in the soil

Tyre crumbs (%)	CBR (%)
0	14.09
4	14.43
8	31.37
12	26.98
16	23.53



Graph 4.7: Tyre crumb content in the soil vs CBR

The CBR value of soil and rubber tyre crumbs increased upto the addition of 8% crumb rubber powder after which it started decreasing. It may be due to the higher percentage of rubber material which adds on to the compressibility of the mixture. Rubber tyre crumbs mixed with the soil indicated an improvement in CBR value with its addition from no tyre content to 4% to 8%. At 8% tyre crumb content, the CBR value was found to maximize. A significant increase of 122.6 % in the un-soaked CBR was indicated at 8% tyre crumb content. Improvement in the CBR value can be helpful in reducing the overall pavement thickness and altogether the total cost incurred in road construction too. This can be applicable for the construction of parking lots as well which bear a huge amount of vehicular load.

4.8 VARIATION OF UCS VALUE ON VARYING THE % OF TYRE CRUMB CONTENT

First of all, the soil is completely battered using wooden mortar and pestle, so that any stone or brick particles do not get cracked. The soil passing 2 mm sieve as well as rubber tyre crumbs passing 2 mm sieve (so that rubber particles can replace the soil in the mixture properly) are taken for UCS test as mentioned previously in chapter 3.

UCS tests were carried out as per IS: 2720 (Part-10), 1991 on the soil samples on varying the percentages of crumb rubber to determine the UCS value so as to evaluate the feasibility of soil stabilized with crumb rubber to be used as a fill material. All the tests were conducted on soil mixed with crumb rubber, the sample being prepared at OMC obtained corresponding to that particular soil-crumb rubber mixture. The soil was mixed with crumbs of rubber tyre of 2%, 4%, 6%, 8% and 10% ratio by dry weight of soil and UCS test were conducted on these soil-crumb rubber mixtures. The calculated UCS value of the soil and soil + crumb rubber mixtures was determined and is summarized below. The variation of UCS and hence the shear strength values on varying the percentages of crumb rubber is shown in the graphs as plotted below.

Mass of dry soil lump = 27.2 gm

Vol. of Hg displaced by soil lump = 17 cc

Density of soil = m/v = 27.2/17 = 1.6 gm/cc

OMC of plain soil = 14.3%

M = ϱ x v = 1.6 * 87 (Vol. of cylindrical sampler) = 139.2 gm of soil is taken

14.3% water by volume of soil is added in the plain soil i.e. 0.143*139.2 = 19.90 cc water to be added.

Dia. of mold = 38 mm

Length of mold = 2 x Dia. = 76 mm

Least Count = 0.30

UCS value calculation:

(1) at no tyre (failure at 1 min)

Load = Dial gauge reading x L.C.= 14 x 0.30 = 4.20 Kg

UCS = Load/ Corrected Area = 4.20/11.51 = 0.36490 Kg/cm^2 = 0.03579 N/mm^2

(2) at 2% tyre (failure at 2 min)

Load = 15 * 0.30 = 4.50 Kg

UCS = 4.50/11.72 = 0.38395 Kg/cm^2 = 0.03766 N/mm^2

(3) at 4% tyre (failure at 2 min)

Load = 17 * 0.3 = 5.10 Kg

UCS = 5.10/11.72 = 0.43515 Kg/cm^2 = 0.04268 N/mm^2

(4) at 6% tyre (failure at 2 min)

Load = 17 * 0.3 = 5.10 Kg

UCS = 5.10/11.72 = 0.43515 Kg/cm^2 = 0.04268 N/mm^2

(5) at 8% tyre (failure at 2 min)

Load = 16 * 0.3 = 4.80 Kg

UCS = 4.8/11.72 = 0.40955 Kg/cm^2 = 0.04017 N/mm^2

(6.1) at 10% tyre (failure at 1 min)

Load = 16 * 0.3 = 4.80 Kg

UCS = 4.80/11.51 = 0.41702 Kg/cm^2 =0.04091 N/mm^2

(6.2) at 10% tyre (failure at 2 min)

Load = 20 * 0.3 = 6.0 Kg

UCS = 6.0/11.72 = 0.51194 Kg/cm^2 = 0.05022 N/mm^2

4.8.1 COMPARISON OF UCS SAMPLES BEFORE AND AFTER FAILURE

The UCS samples before and after failure can be compared as shown below:

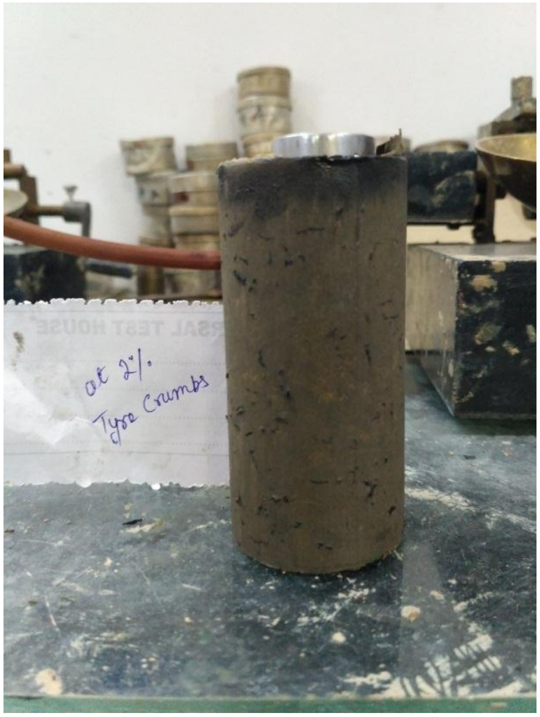


Fig. 4.1(a): Sample at 2% tyre crumbs

Fig. 4.1(b): Failure at 2 % tyre crumbs

Fig. 4.2(a): Sample at 4% tyre crumbs

Fig. 4.2(b): Failure at 4 % tyre crumbs

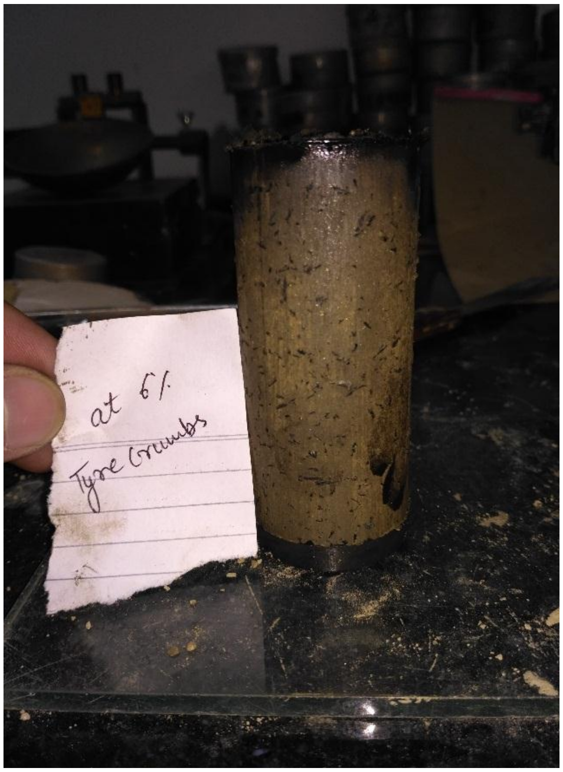


Fig. 4.3(a): Sample at 6% tyre crumbs

Fig. 4.3(b): Failure at 6 % tyre crumbs

Fig. 4.4(a): Sample at 8% tyre crumbs

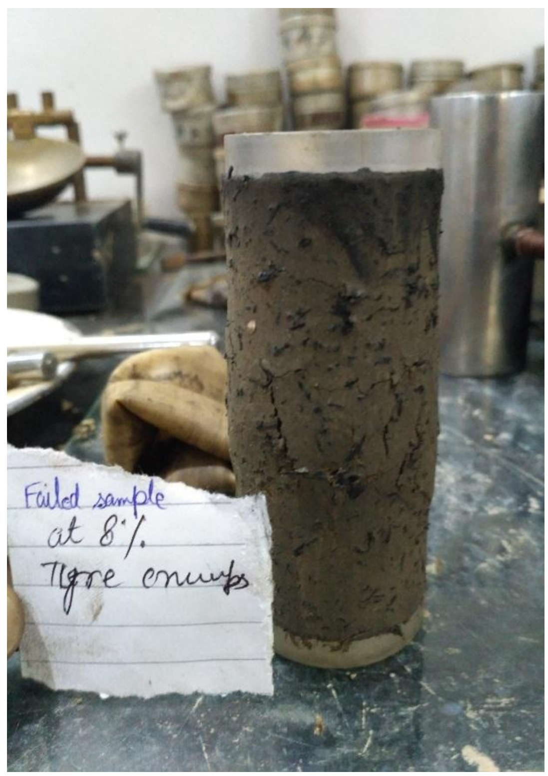


Fig. 4.4(b): Failure at 8 % tyre crumbs

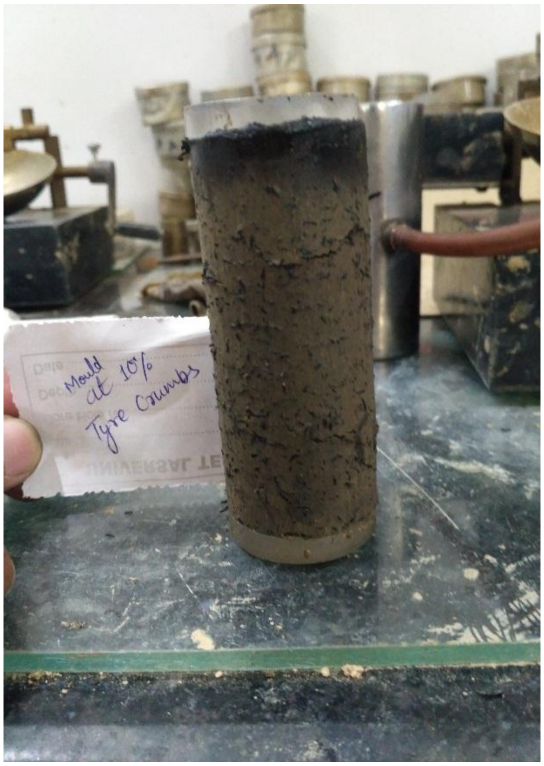
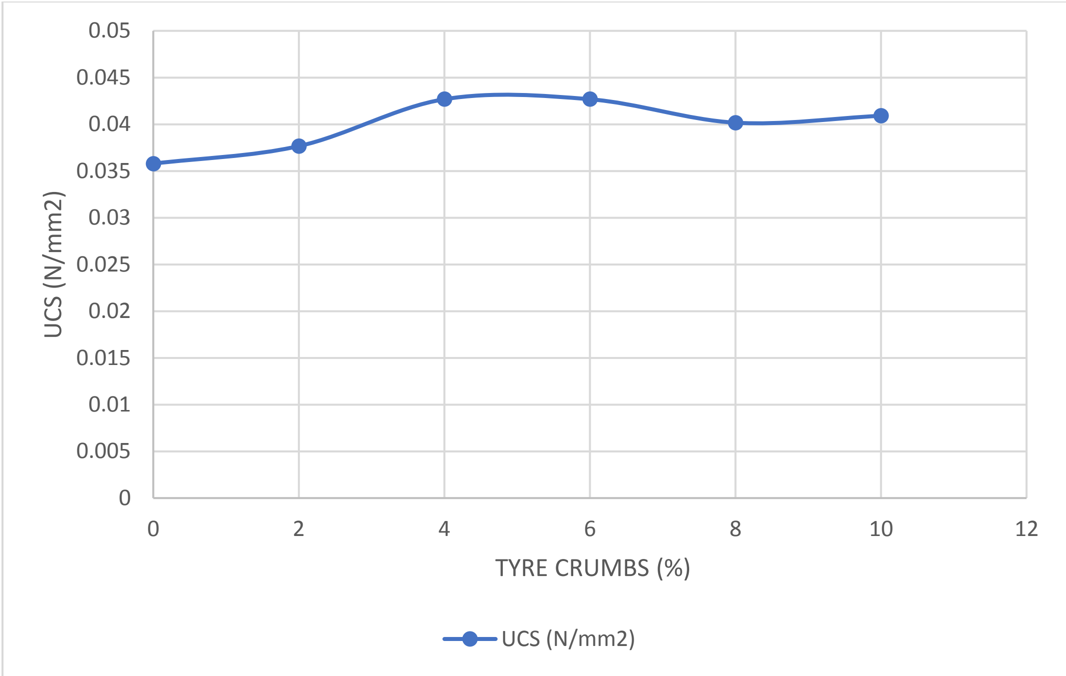


Fig. 4.5(a): Sample at 10% tyre crumbs **Fig. 4.5(b): Failure at 10% tyre crumbs**

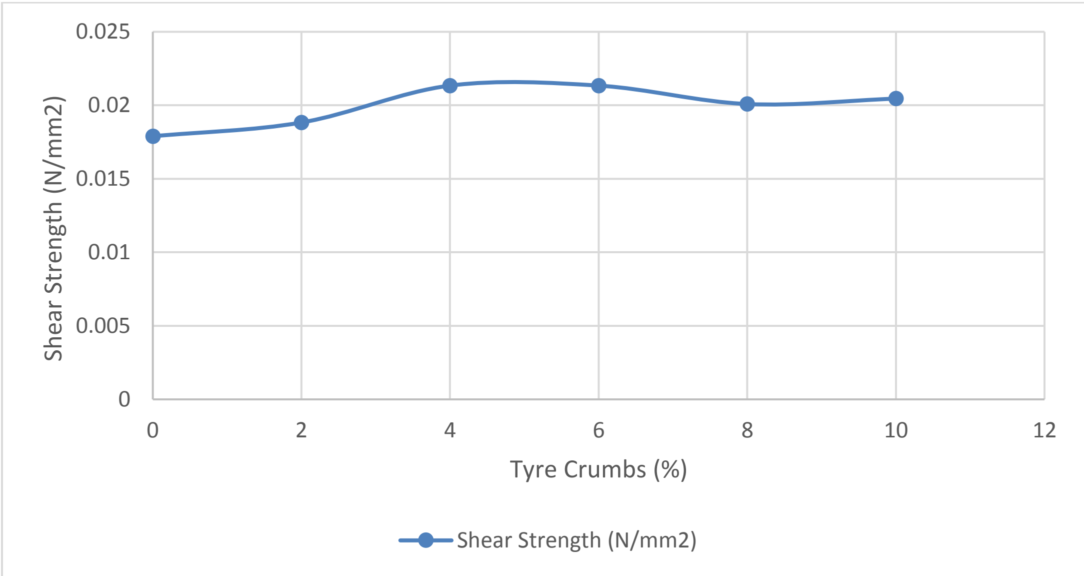
It was seen that the amount of bulging increases in the sample as the crumb rubber content increases. This is a type of shear failure which may be due to higher amount of rubber material causing overall compressibility of the mixture to get increased.

Table 4.8: UCS values at different content of tyre crumb in the soil

Tyre crumbs (%)	**Failure Time (min)**	**Dial gauge reading**	**UCS value (q_u) (N/mm^2)**	**Shear strength(q_u/2) (N/mm^2)**
No Tyre	1	14	0.03579	0.017895
2	2	15	0.03766	0.018830
4	2	17	0.04268	0.021340
6	2	17	0.04268	0.021340
8	2	16	0.04017	0.020085
10	1	16	0.04091	0.020455
	2	20	0.05022	0.025110



Graph 4.8: Variation in UCS with different percentage of tyre crumb content in the soil



Graph 4.9: Variation of shear strength with different percentage of tyre crumb in the soil

Initially the value of failure load increased upto 4 to 6 % of rubber tyre crumbs addition after which it started to decrease. At tyre crumb content of 4-6%, the UCS value was observed to maximize. An overall increment of 19.25% in the UCS value and hence in the shear strength value was observed at tyre crumb content ranging between 4-6%. Later on, it was observed that at 10% addition of rubber tyre crumb in the soil as shown above the failure load value started to fluctuate. At 10% crumb rubber, the 2^{nd} failure point at 2 minutes could not be represented in graph, but at this point the fluctuation in reading indicated that the test shall be stopped and further more addition of crumbs is not recommendable. Hence exact failure cannot be determined further and the further addition of crumbs of rubber tyre was thus stopped.

4.9 GEO CHEMICAL ANALYSIS

4.9.1 SCANNING ELECTRON MICROSCOPY

In this study, SEM images have been captured to observe the morphology features of tyre, soil and soil + rubber tyre crumbs samples. The microstructure of soil+ rubber tyre mixture is analyzed with the help of a scanning electron microscope. The following SEM images reveal the morphology of the soil+ rubber tyre mixture as shown below:

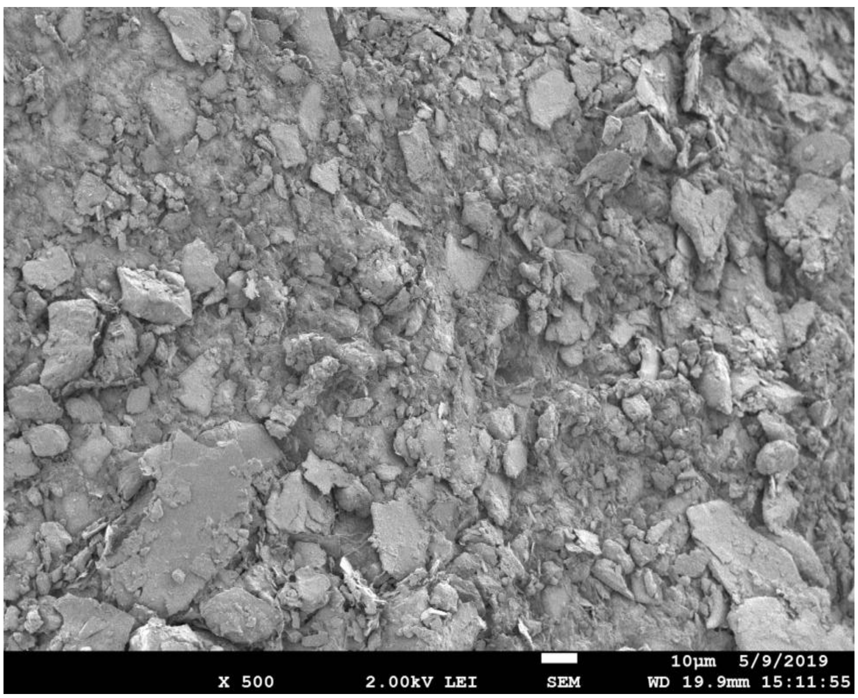


Fig. 4.6: SEM image of tyre at 500 magnification

From the SEM analysis of rubber tyre crumb, it was observed that particles are non- uniformly distributed and unevenly spread. The morphology of the rubber particles was not completely spherical but irregularly shaped, with different sizes. The particles seem to be arranged in haphazard order.

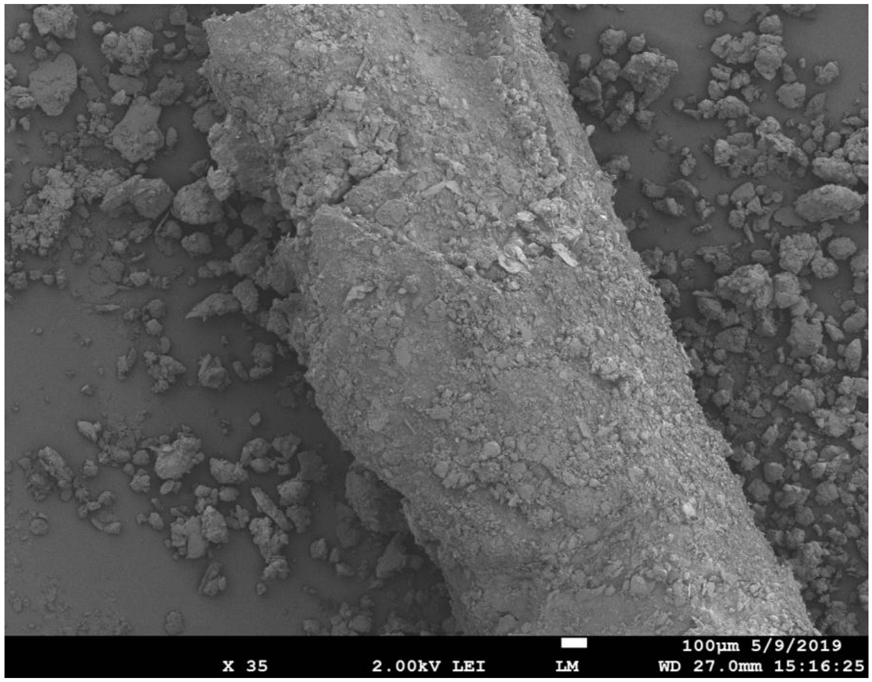


Fig. 4.7: SEM image of soil stabilized with rubber tyre crumb at 35 magnification

From the above SEM image, it can be inferred that the moist soil particles stick efficiently over the rubber crumbs which is good from the bonding point of view of the mixture.

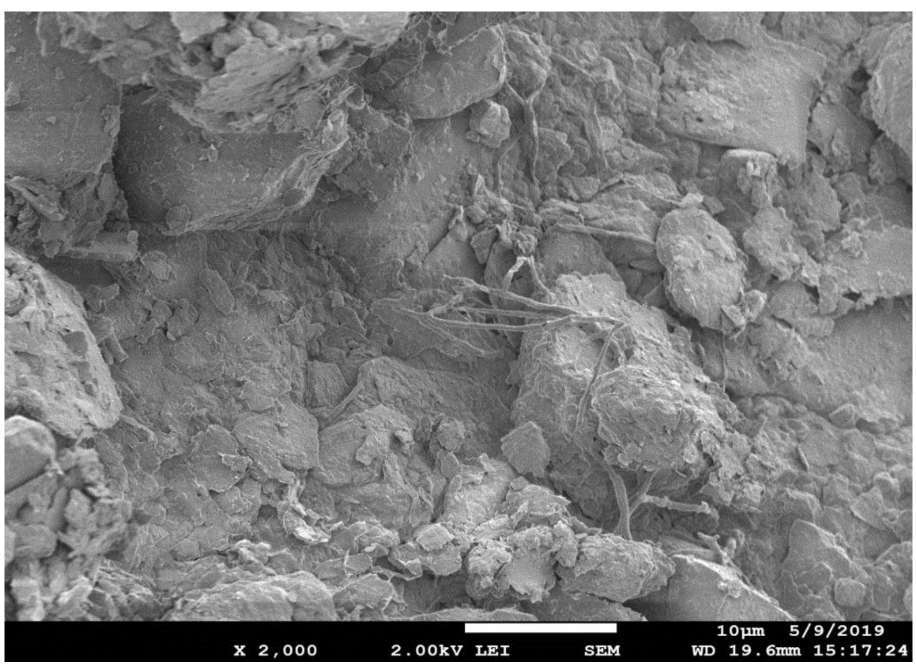


Fig. 4.8: SEM image of tyre crumb at 2000 magnification

From the above SEM image, it can be seen clearly that the rubber tyre crumbs contain certain fibrous structures at various places. This may be due to polymer structure of the tyre crumbs. These thin fibers are no less than any binding agent when it comes to the breaking of tyre pieces inside the sub-grade material or fill-material after a long time for that matter.

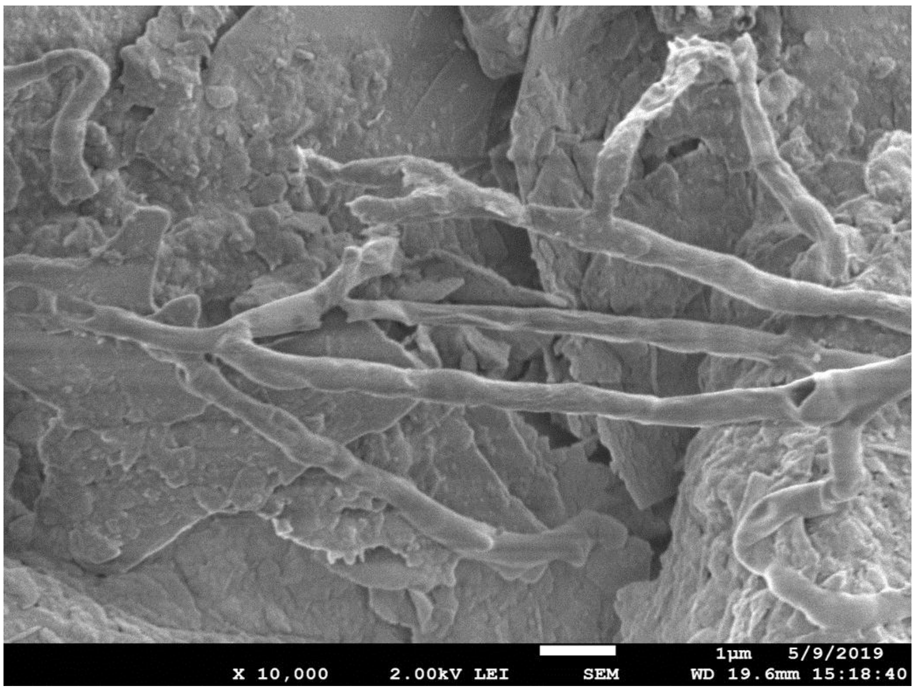


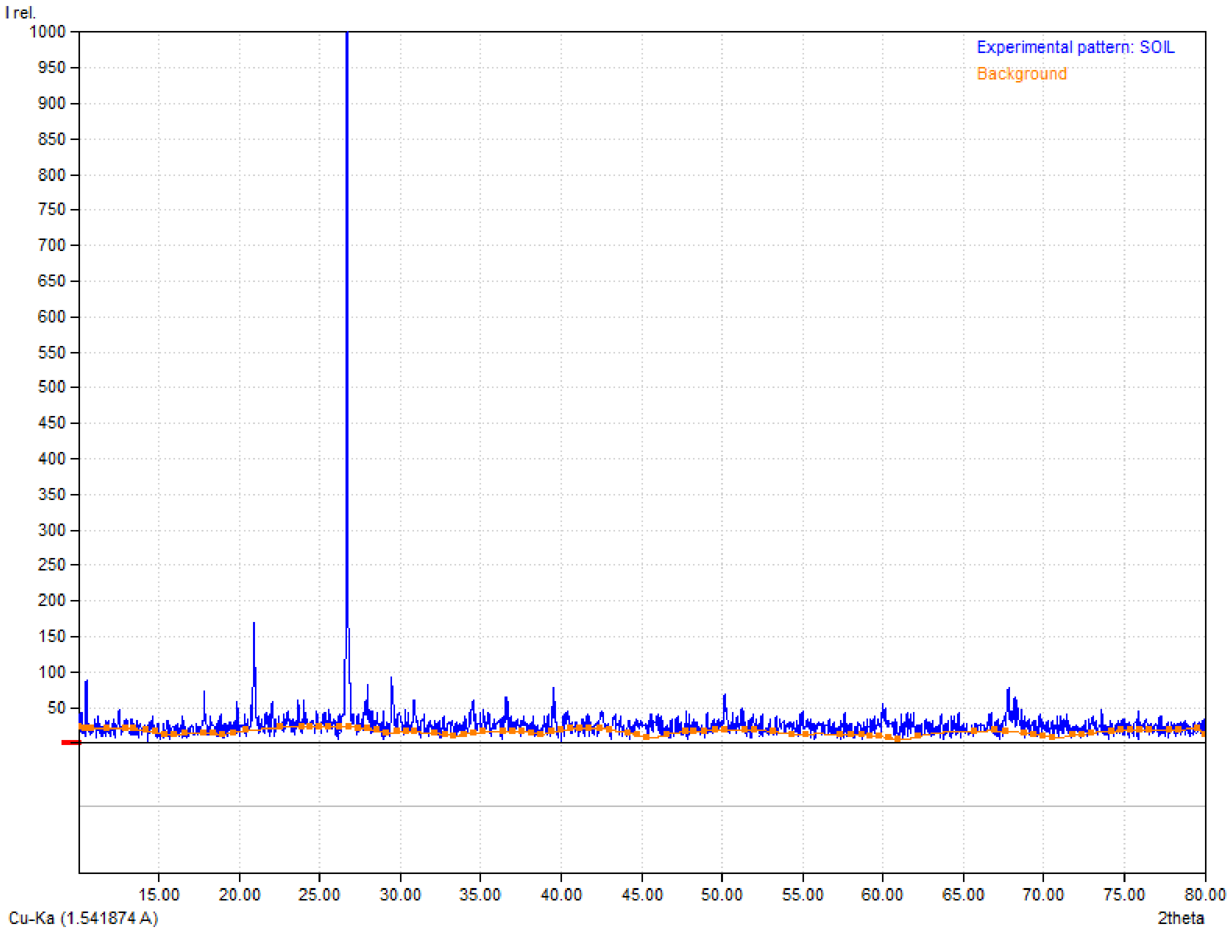
Fig. 4.9: SEM image of tyre crumb at 10000 magnification

In order to look for detailed structure of the fibers present in the rubber tyre crumb, a further magnification of 10000 was done over one of the clusters of those fibers. This group of fibers can be seen clearly in the above figure. It is indicated that the fibers are thin and long and in the form of follicles of hair which can anchor the rubber particles to each other just like hair follicles anchor the hair deep into the skin. This may also help the soil particles to remain entangled with the rubber crumbs even if the rubber particles show any cracks at a later stage while serving as sub-grade in roads or fill-material in retaining structures.

4.9.2 XRD PATTERN ANALYSIS

The mineralogical composition of the soil, tyre and soil with tyre samples were recognized based on researches made by Carver, Moore and Reynolds, and Brindley and Brown, some of the scientists in the past. Use of JCPDS (Joint Committee on Powder Diffraction Standards) table is also required for this purpose. Minerals were estimated in a semi-quantitative way as per the works of Galan, Klages and Hopper. Clay minerals were quantified by taking into consideration the peak area by taking the height above the background for each diagnostic reflection at 2.0 mm intervals across the peak. This technique consumes less time and incorporates a good compromise between the two methods peak height and peak area.

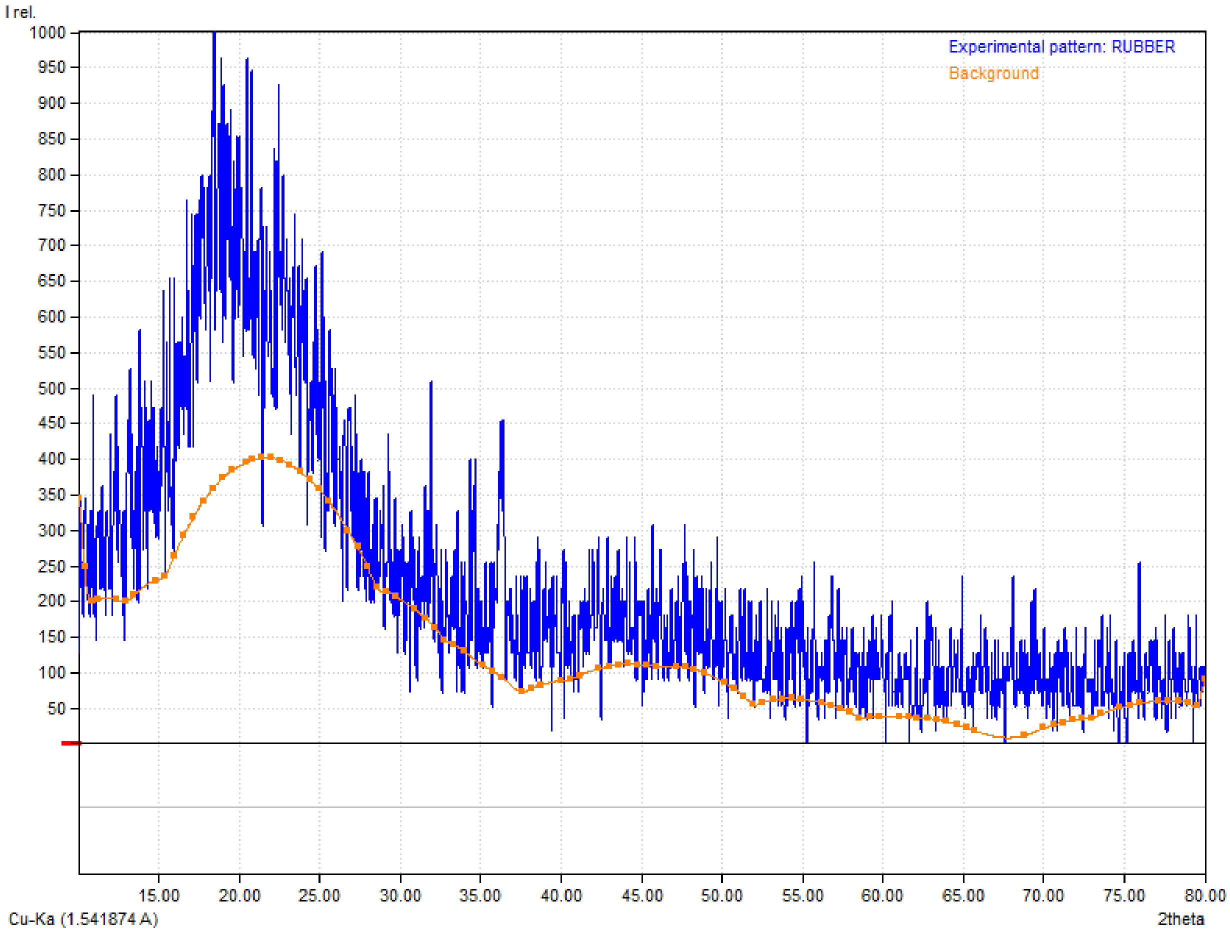
A summary of the detailed XRD reports for plain soil, rubber tyre crumbs and their mixture is as follows:



Graph 4.10: XRD pattern analysis of plain soil

The soil sample showed a degree of crystallinity of 42.78% while amorphous content (weight %) was 57.22%.

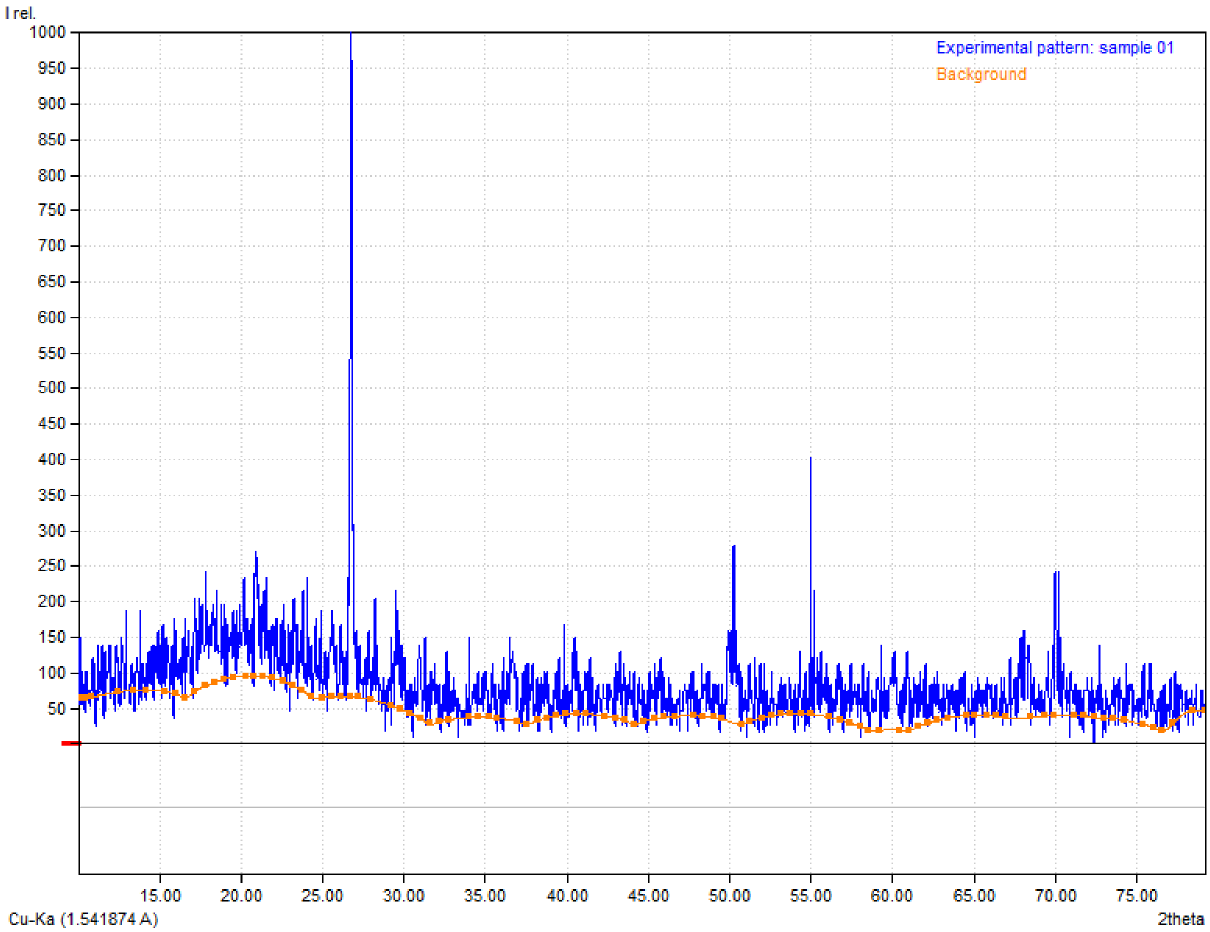
Matched phases indicated the presence of Quartz (92.1%), Dolomite (3.9%), Periclase (1.8%), Cristobalite (1.9%), NbU (0.2%), Calcium (0.1%) and Molybdenum (0.1%). 27.9% peak area remained unidentified. Major components are Quartz, Dolomite and Cristobalite, which must be present as the soil is clayey in nature.



Graph 4.11: XRD pattern analysis of rubber tyre crumbs

The tyre crumb sample showed a degree of crystallinity of 41.49% while amorphous content (weight %) was 58.51%.

Matched phases indicated the presence of 1,4-bis-(Chlorosulfonyl)octafluorobutane [$C_4Cl_2F_8O_4S_2$] (60.3%), Nonaborane [B_9H_{15}] (23.4%), Pentaborane(9) [B_5H_9] (8.2%) and Sulphur tri-oxide [SO_3] (8.1%). 32.1% peak area remained unidentified.



Graph 4.12: XRD pattern analysis of soil combined with rubber tyre crumbs

The soil + tyre crumb sample showed a degree of crystallinity of 45.99% while amorphous content (weight %) was 54.01%.

Matched phases indicated the presence of $AlTi_3$ (91-9%), Silica [SiO_2] (3.5%), Iseite [$Mn_2Mo_3O_8$] (3.0%), Carbon di-sulphide [CS_2] (0.5%), Pyroxene-ideal [MgO_3Si] (0.4%), Rubidium Manganese Oxide (0.1%) and traces of other compounds. 34.1% peak area remained unidentified. One of the compounds shows the combination of Si, O along with Al and Li which may be due to lattice defects in Quartz part of the soil.

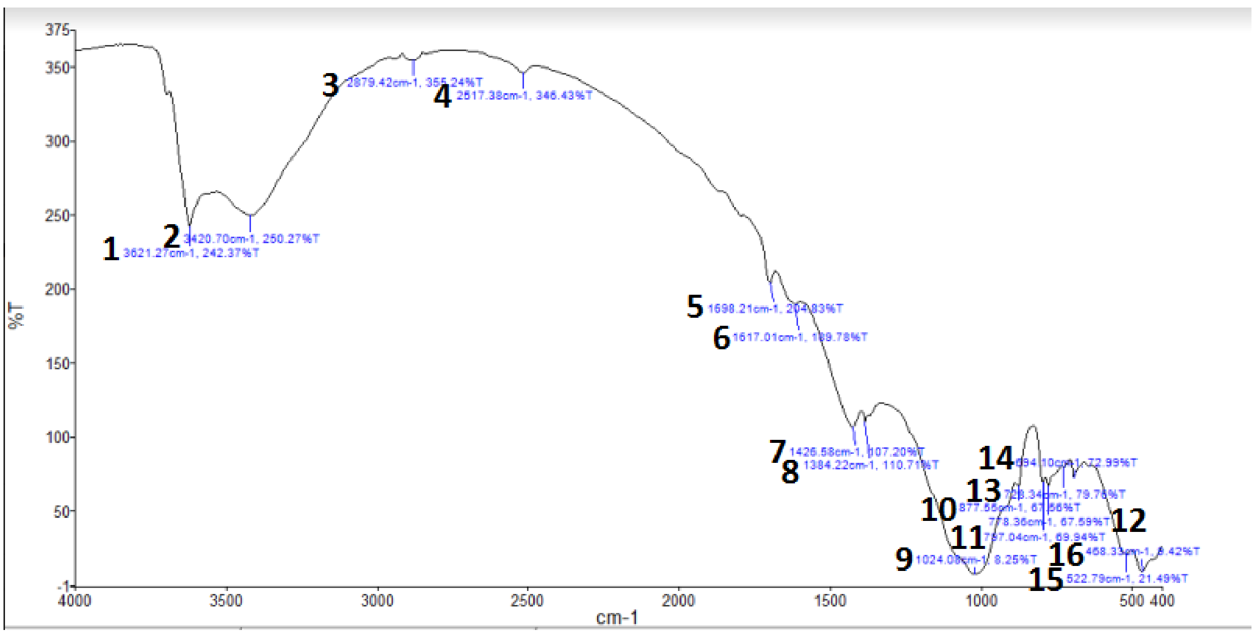
[Note: Pyroxenes are silicates of Sodium, Calcium, Magnesium, Iron and Aluminium]

Since the mixture of soil with rubber tyre crumbs consists of such compounds which have elements both from soil as well as tyre, it can be inferred that a proper bonding between the two materials have been formed.

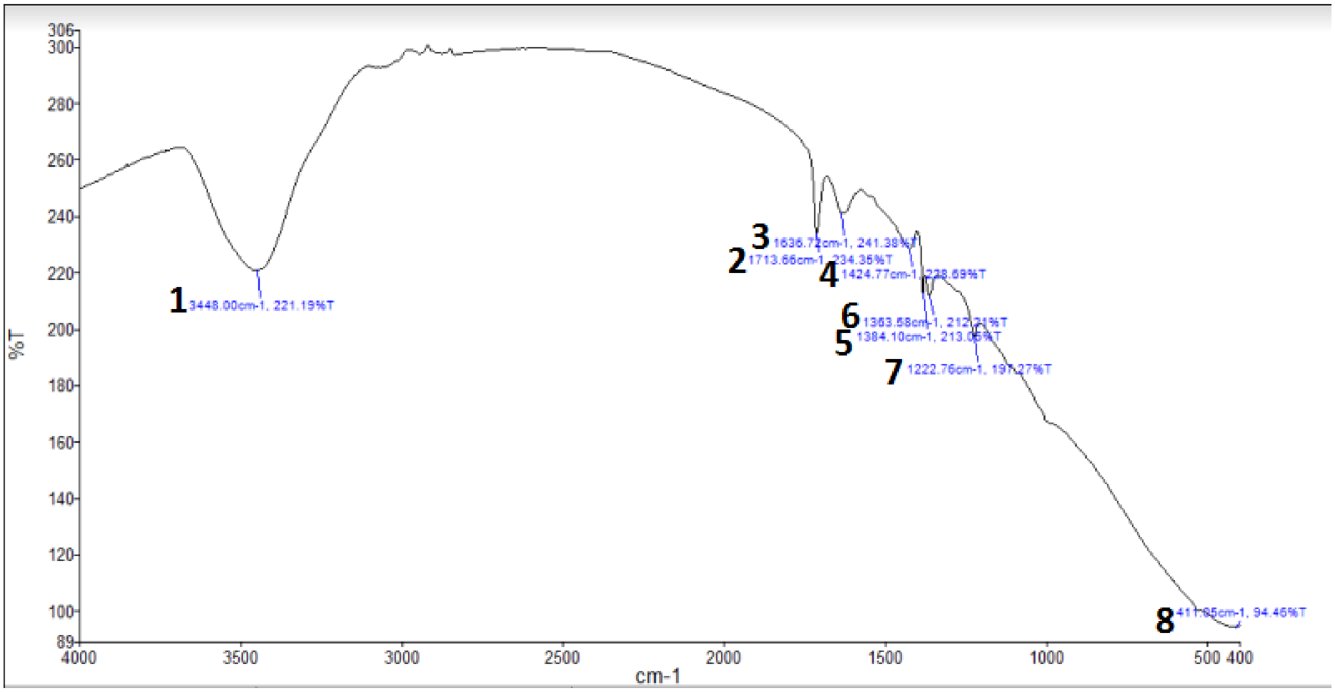
The soil sample alone was initially more amorphous and less crystalline and so were the tyre crumbs but after the combination of the two, the resulting mixture was found to be more crystalline than the individual samples of soil and tyre crumbs and their individual amorphous natures were seen to suppress in the mixture.

4.9.3 FTIR ANALYSIS

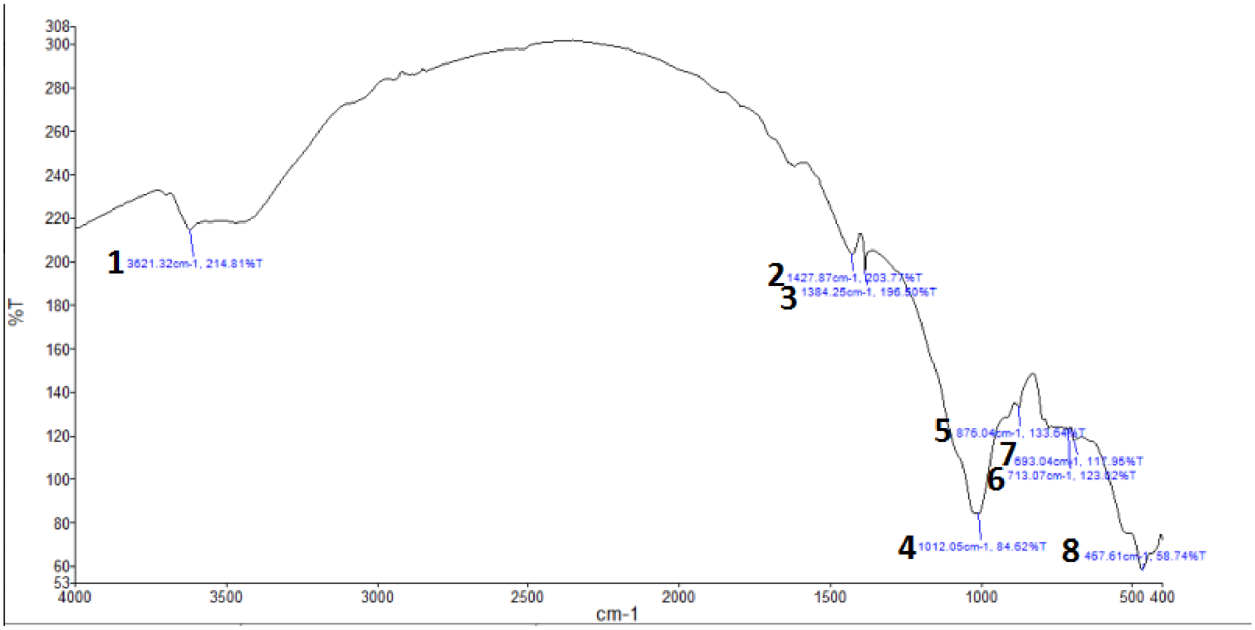
A wide range of bonds along with the possible functional groups can be determined with the help of the table of some characteristic FTIR absorptions (refer Appendix 1). If the peaks formed during the FTIR test happen to lie within the given range it is indicative of the type of bond that may be present in the sample and hence the functional groups can help to judge the minerals present in the sample.



Graph 4.13: FTIR spectrum of plain soil sample



Graph 4.14: FTIR spectrum of rubber tyre crumbs



Graph 4.15: FTIR spectrum of soil + rubber tyre crumbs

The FTIR results of rubber tyre mainly indicate the presence of C-H rock bonds (peak 6) in the rubber tyre crumbs which may be due to the presence of styrene-butadiene copolymer which is the primary ingredient of rubber tyre. Some peaks of soil are found to suppress in the composite (i.e., mixture). In the FTIR result of the mix, aromatic rings (C-C stretch) are indicated by peak 2, while other aromatic rings (C-H “oop”) are indicated by peak 5 and 6; also peak 7 in the mix indicates C-Cl stretch bond which may be due the presence of $C_4Cl_2F_8O_4S_2$ in the rubber.

CHAPTER 5

CONCLUSION AND FUTURE SCOPE

5.1 CONCLUSION

1. The optimum moisture content of the soil on varying the percentage content of tyre crumbs is observed to slightly decrease with increase in tyre content in the soil although the change is not much significant.

2. The maximum dry density shows a little uneven behavior but is observed to show an overall decrease with the increase in tyre content in the soil. The low specific gravity of tyre material may be responsible for this reduction.

3. Un-soaked CBR value does not show much change at 4 % tyre crumb but a significant increase of 122.6 % at 8 % tyre crumb as compared to plain soil is observed which decreases on further increasing the tyre content to 12 % and 16 %. This result was of very much similarity to the results obtained by Priyadarshee Akash et al., 2015, in which an improvement factor of upto 5 was observed for clay+tyre mixture.

4. 8 % rubber tyre crumb mixed with the soil may be stated as optimum tyre crumb content for maximum un-soaked CBR value in this study but the result can't be generalized as varying results may be obtained with various soil types and tyre sizes.

5. Although a large increase in the un-soaked CBR value is observed at a particular % rubber tyre crumb mixed in the soil but it does not assure to occur always as different studies show different patterns.

6. UCS value gradually increased from no-tyre content to 2% to 4-6% but further started decreasing at 8% tyre crumb content and later on fluctuations in failure point were observed at 10% tyre content hence the addition of tyre crumbs was stopped further. This may be due to increase in plasticity due to more amount of tyre content in the soil.

7. A maximum shear strength of 0.021340 N/mm^2 was observed at 4-6% tyre crumb (medium-grained i.e., passing 2 mm sieve) content which was about 19.25% higher as compared to that of plain soil.

8. The above result holds similarity with one of the previous studies conducted by Cetin et al., 2006, in which clayey soil with low compressibility was used and fine tyre chips (passing 0.425

mm sieve) and coarse tyre chips (between 2 mm and 4.75 mm) were added in the clayey soil, the results of which indicated that shear strength increased by 30% for fine and by 20% for coarse grained tyre chip mixtures.

9. UCS value did not show a vast amount of change but the gradual increment in the UCS value proves to be useful as it indicates an increase in the shear strength of clayey soil which can be used along with medium grained tyre crumbs to serve as back-fill material behind retaining structures, bridge abutments, highway embankments, etc.

10. SEM showed that the particles of rubber tyre were irregularly arranged but consisted of fibrous structures which can be capable of keeping the rubber tyre and the soil particles bounded together for long duration even if the tyre crumbs burst (due to temperature changes) at a later stage.

11. In the XRD analysis it is found that the mixture of soil with rubber tyre crumbs consists of such compounds which have elements both from soil as well as tyre. Therefore, it can be inferred that a proper bonding between the two materials have been formed. Also, the soil sample alone was initially more amorphous and less crystalline but the resulting mixture was found to show overall higher percentage of more crystalline behavior.

12. Some basic bonds and functional groups could be analyzed with the FTIR analysis but a detailed study needs to be done at a higher level which can be a future scope as well.

5.2 FUTURE SCOPE

The main problem of today's world is uncontrolled developmental activities which might increase the standard of living but are in return turning the earth unfit for living. So, the need of the hour as an environmental engineer is to save the environment at any cost. Here is some future scope of studies in this area:

- The entire exercise may be done on various soils for arriving at conclusions having wider applications.
- Variations in some other geotechnical parameters such as hydraulic conductivity, consolidation parameters can be studied.

- Crumb rubber treated soil can be studied for durability by studying factors like drying and wetting, freezing and thawing actions and its capability to respond to the action of various chemicals like alkalis, sulphides, chlorides, etc. may also be explored.
- Identify other wastes such as plastic waste, marble slurry, coconut-coir fiber, wastes from temples etc. and investigate their contribution in enhancing the strength of construction materials wherever possible.
- There are chances of certain chemicals and toxic hydrocarbons getting leached into the fertile soil if this waste is used as sub-grade in road construction. In that case a further study can be done to explore any admixture that can keep the tyre waste intact upto a certain level only under the earth.

APPENDIX 1

Table of Characteristic IR Absorptions

Frequency cm^{-1} (Wavenumber)	**Bond**	**Functional group**
3640-3610(s,sh)	O-H stretch, free hydroxyl	Alcohols, phenols
3500-3200(s,b)	O-H stretch, H-bonded	Alcohols, phenols
3400-3250(m)	N-H stretch	1°, 2° amines, amides
3300-2500(m)	O-H stretch	Carboxylic acids
3330-3270(n,s)	-C=C-H:C-H stretch	Alkynes(terminal)
3100-3000(s)	C-H stretch	Aromatics
3100-3000(m)	=C-H stretch	Alkenes
3000-2850(m)	C-H stretch	Alkanes
2830-2695(m)	H-C=O:C-H stretch	Aldehydes
2260-2210(v)	C =N stretch	Nitriles
2260-2100(w)	-C=C- stretch	Alkynes
1760-1665(s)	C=O stretch	Carbonyls (general)
1760-1690(s)	C=O stretch	Carboxylic acids
1750-1735(s)	C=O stretch	Esters, saturated aliphatic
1740-1720(s)	C=O stretch	Aldehydes, saturated aliphatic
1730-1715(s)	C=O stretch	α,β-unsaturated esters
1715(s)	C=O stretch	Ketones, saturated aliphatic
1710-1665(s)	C=O stretch	α,β-unsaturated aldehydes, ketones
1680-1640(m)	-C=C- stretch	Alkenes
1650-1580(m)	N-H bend	1° amines
1600-1585(m)	C-C stretch (in-ring)	Aromatics
1550-1475(s)	N-O asymmetric stretch	Nitro compounds

1500-1400(m)	C-C stretch (in-ring)	Aromatics
1470-1450(m)	C-H bend	Alkanes
1370-1350(m)	C-H rock	Alkanes
1360-1290(m)	N-O symmetric stretch	Nitro compounds
1335-1250(s)	C-N stretch	Aromatic amines
1320-1000(s)	C-O stretch	Alcohols, carboxylic acids, esters, ethers
1300-1150(m)	C-H wag(-CH_2X)	Alkyl halides
1250-1020(m)	C-N stretch	Aliphatic amines
1000-650(s)	=C-H bend	Alkenes
950-910(m)	O-H bend	Carboxylic acids
910-665(s,b)	N-N wag	1°, 2° amines
900-675(s)	C-H "oop"	Aromatics
850-550(m)	C-Cl stretch	Alkyl halides
725-720(m)	C-H rock	Alkanes
700-610(b,s)	-C=C-H: C-H bend	Alkynes
690-515(m)	C-Br stretch	Alkyl halides

m = medium, w=weak, s=strong, n=narrow, b=broad, sh=sharp

(Source: FTIR lab, Applied Physics Deptt. D.T.U.)

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AHIEVEMENT AND PAPER PRESENTATION

- Delivered a presentation on topic "**Use of waste rubber tyre crumbs to improve the CBR value of soil**" in Annual Student's Convention Prastuti-2019, organized by Jagan Institute of Management Studies (JIMS) in association with DTU.

- Received "**Most Innovative Idea**" on topic "**Use of waste rubber tyre crumbs to improve the CBR value of soil**" in Annual Student's Convention Prastuti-2019, organized by Jagan Institute of Management Studies (JIMS) in association with DTU.

- Participated in the TEQIP-III sponsored 2nd international conference on **SUSTAINABLE TECHNOLOGIES FOR ENVIRONMENTAL MANAGEMENT (STEM-2019)** held during 25-26 March, 2019 organized in DTU.