"Stabilization of black cotton soil using thermally treated untanned leather waste"

A PROJECT

Submitted in partial fulfillment of the requirements for the award of the degree of

BACHELOR OF TECHNOLOGY

IN

CIVIL ENGINEERING

Under the supervision of

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HIMACHAL PRADESH, INDIA

May, 2019

STUDENTS DECLARATION

I hereby declare that the work presented in the Project report entitled **"Stabilization of black cotton soil using thermally treated untanned leather waste"** submitted for partial fulfilment of the requirements for the degree of Bachelor is Technology in Civil Engineering at Jaypee University of Information Technology, Waknaghat is an authentic record of my work carried under the supervision of Mr. Niraj Singh Parihar. This work has not been submitted elsewhere for the reward of any other degree/diploma. I am fully responsible for the contents of my project report.

Signature of student

Ankush Kumar, Vibhor Gautam

(151694, 151691)

CERTIFICATE

This is to certify that the work which is being presented in the project report titled **"STABILIZATION OF BLACK COTTON SOIL USING LEATHER INDUSTRY WASTE"** in partial fulfillment of the requirements for the award of the degree of Bachelor of Technology in Civil Engineering and submitted to the Department of Civil Engineering, Jaypee University of Information Technology, Waknaghat is an authentic record of work carried out by by **ANKUSH KUMAR(151694)** and **VIBHOR GAUTAM(151691)** during a period from August, 2018 to May, 2019 under the supervision of **Mr. NIRAJ SINGH PARIHAR** Assistant Professor, Department of Civil Engineering, Jaypee University of Information Technology, Waknaghat.

The above statement made is correct to the best of our knowledge.

Date…………………........

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JUIT, Waknaghat	JUIT, Waknaghat	

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We also thank **Dr. Ashok Kumar Gupta, Professor and Head of Department**, Department of Civil Engineering, , for consent to include copyrighted pictures as a part of our report. We also thank **Mr. Amar Kumar, Mr. Jaswinder Deswal, Mr. Itesh Singh**, Technical and laboratory, Department of Civil Engineering, Jaypee University of Information Technology, for providing us with all the facilities, necessary components and excellent working conditions required to complete the project. We thank all the people for their help directly and indirectly to complete our project.

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ABSTRACT

The black cotton soil is found in central and southern parts of India. This soil is good from the point of view of farmers because it has a good moisture holding capacity but from the engineering point of view, black cotton soil has a problematic nature due to its expansive and shrinkage nature with the addition/loss of moisture.

Leather industries produce a lot of waste and most of the side products are waste.

Untanned leather waste can be used to increase the strength, swelling properties due to the presence of lime present in it which can be used to stabilize the black cotton soil on the increasing addition of waste ranging from 2%, 4%, 6%, 8% and 10% by weight of soil and also by thermally treating the waste ash ranging from 200ºC, 400ºC, 600ºC before addition into the black cotton soil.

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LIST OF ABBREVIATIONS

Serial No.	Abbreviation Used	Description
1	BCS	Black cotton soil
2	UCS	Unconfined Compression Test
3	CBR	California Bearing Ratio
4	OMC	Optimum Moisture Content
6	MDD	Maximum Dry Density

Chapter 1

Introduction

1.1 Introduction

Black cotton soil has high swelling rate and shrinkage rate when moisture content changes. It is a good type of soil for farmers because it contains high amounts of minerals essential for growth of plants and it has a water holding capacity but in engineering, this soil is very troublesome. The main mineral is montmorillonite which is responsible for the expansive behaviour of soil. When the moisture content is low, cracks are developed without any warning. In India, deposits of black cotton soil are in abundant in central and southern parts.

The leather industry produces a lot of waste during the process of making leather.
There are three types of wastes generated by the leather industry.

1. Waste generated after fleshing and liming process (untanned leather waste)
2. Waste generated after tanning process (tanned leather waste).
3. Waste generated from trimming, drying and neutralization process.

Liming is one of the most important step in making of leather. In the liming process, the skin/hides of the animal are made to soak in an alkali solution to remove extra fat, hairs and proteins.

Lime can be used to stabilize and modify the engineering properties of the black cotton soil. When the calcium cations are released by the hydrated lime, the normal cations present on the surface of black cotton soil are replaced. The calcium present in the lime reacts with the silicates and aluminates present in the black cotton soil. Lime stabilization of the soil can result in high strength.

1.2 Objectives

- To activate the untanned leather waste by providing thermal treatment at different temperatures.

- To determine the change in the strength and swelling parameter of the black cotton soil by using thermally treated untanned leather waste.

- To find the favorable content of the untanned leather waste ash used for the stabilization of black cotton soil.

CHAPTER 2

LITERATURE REVIEW

2.1 Literature review conclusions

1. **.K.J Osinubi(2009). "Lime stabilization of black cotton soil using bagasse ash as admixture"**

Key points:-

- On the basis of soaked CBR and durability values, it is recommended that black cotton soil can be stabilized for road construction using 8%lime/4% baggash ash admixture at standard proctor compaction.

2. **Shailendra Singh, Hemant B. Vasaikar(2013). "Stabilization of black cotton soil using lime"**

Key points:-

- Experimental work has been carried out with 4% and 6% of lime content.The experimental work is based on different percentages of lime, liquid limit, plastic limit, OMC, CBR test, grain size analysis and swelling pressure.

3. **HN Ramesh, Krishna Manoj, HV Mamatha(2010). "Compaction and strength behavior of lime coir fiber treated black cotton soil"**

Key points:-

- Coir used in this study is processed fiber from the husk of coconuts and 4% lime is added.
- Black cotton soil treated with 4% lime and reinforced with coir fiber shows ductility behavior before and after failure. An optimum fiber content of 1%(by weight) with aspect ratio of 20 for fiber was recommended for strengthening the soil.

4. **Pankaj R Modak, Prakash B Nangare, Sanjay D Nagrale. (2012)"Stabilization of black cotton soil using admixtures"**

Key Points:-

- Different quantities of lime and fly ash are added to the black cotton soil and the experiments conducted on these soil mixes.

- The result shows that the use of lime and fly ash increases the CBR values i.e the strength of soil to a great extent.

5. **Indian Geotechnical Conference(2010). "Effect of lime stabilization on properties of black cotton soil"**

Key points:-

- The hydrated lime reacts with clay particles and permanently transforms them into a strong cementitious matrix.
- The plastic nature of soil decreases and the stiffness of soil increases as the lime content increases.

6. **Dilip Shrivastava, A K Singhai, R K Yadav(2014). "Effect of lime and rice husk ash in Engineering properties of black cotton soil".**

Key points:-

- A series of laboratory experiments have been conducted on 5% lime mixed with black cotton soil blended with rice husk ash in 5%, 10%, 15% and 20% by weight of dry soil.
- The experimental results showed a significant increase in CBR and UCS strength.

7. **Chethan Marol, Anand Neeralakeri(2016). "Experimental Study on Soil Stabilization using Admixtures"**

Key points:-

- The experiments are conducted on black cotton soil properties like optimum moisture content, dry density, different quantities of lime and fly ash are added to the soil.
- The result shows that the use of lime and fly ash increases the soil stabilization.

2.2 Summary of literature review

- It was concluded that addition of lime has increased the plastic limit, shrinkage limit, optimum moisture content.

- As we add more waste to the soil, there is an increase in UCS.

- Mixing of lime increased the CBR value

- Mixing of lime permanently increases the strength of the soil.

Chapter 3
Materials

3.1.1 Introduction

Black cotton soils are generally clayey, deep and impermeable. They exhibit high rate of swelling and shrinkage when exposed to changes in moisture content and hence have been found to be most troublesome from engineering consideration. These soils are made up of volcanic rocks and lava flow.

Mostly a very big part of India known by its famous name Deccan plateau has majority of black cotton soil in India. This portion consists of mainly Maharashtra and Karnataka including some parts of Gujrat and Madhya Pradesh.

3.1.2 Procurement

The black cotton soil for this project was procured from Guna, Madhya Pradesh.

Figure 3.1 Natural Black Cotton Soil

3.2 Leather Industry Waste

3.2.1 Introduction

There are following steps involved in the making of leather: -

- Curing process – Prevention of animal skin from rotting by the process of freezing/salt/use of additives.
- Soaking process – To clean and remove debris from the skin of animal, the skin is soaked in water for few days.
- Liming process - In the liming process, the skin/hides of the animal are made to soak in an alkali solution to remove extra fat, hairs and proteins. Untanned leather waste is obtained after the liming process which contains lime.
- Fleshing process – The extra skin matter, fats and tissues are removed by machine.
- De liming process – The alkali is made to neutralized and the pH is maintained.
- Bating process – the pelt made of skin is treated with additives, it is made clean and flat for further processing.
- Tanning process – The proteins in skin are converted into a more stable material. A collagen like structure is made to balance it against heats, acids and alkalis. Mostly chromium is added in the tanning process.
- Shaving process - On the non-grain side of the pelt, leather is shaved to achieve uniform thickness.
- Neutralization process – The extra chemicals left are eliminated and the leather is moved ahead for further processing.
- Final drying process – Usually a moisture content of 10-20% is reduced.
- Finishing process – The finishing process includes the color, defects control, gloss control, providing protective layer including resistance to acids, abrasion etc.

3.2.2 Procurement

The waste obtained for this project is lime fleshing waste from Leather Industry complex, Kapurthala, Jalandhar, Punjab

The lime leather waste (untanned leather waste) was burnt openly and was later grinded in fine ash.

The ash was passed through 425-micron sieve and then stored in a container.

Figure 3.2 Raw Untanned leather waste

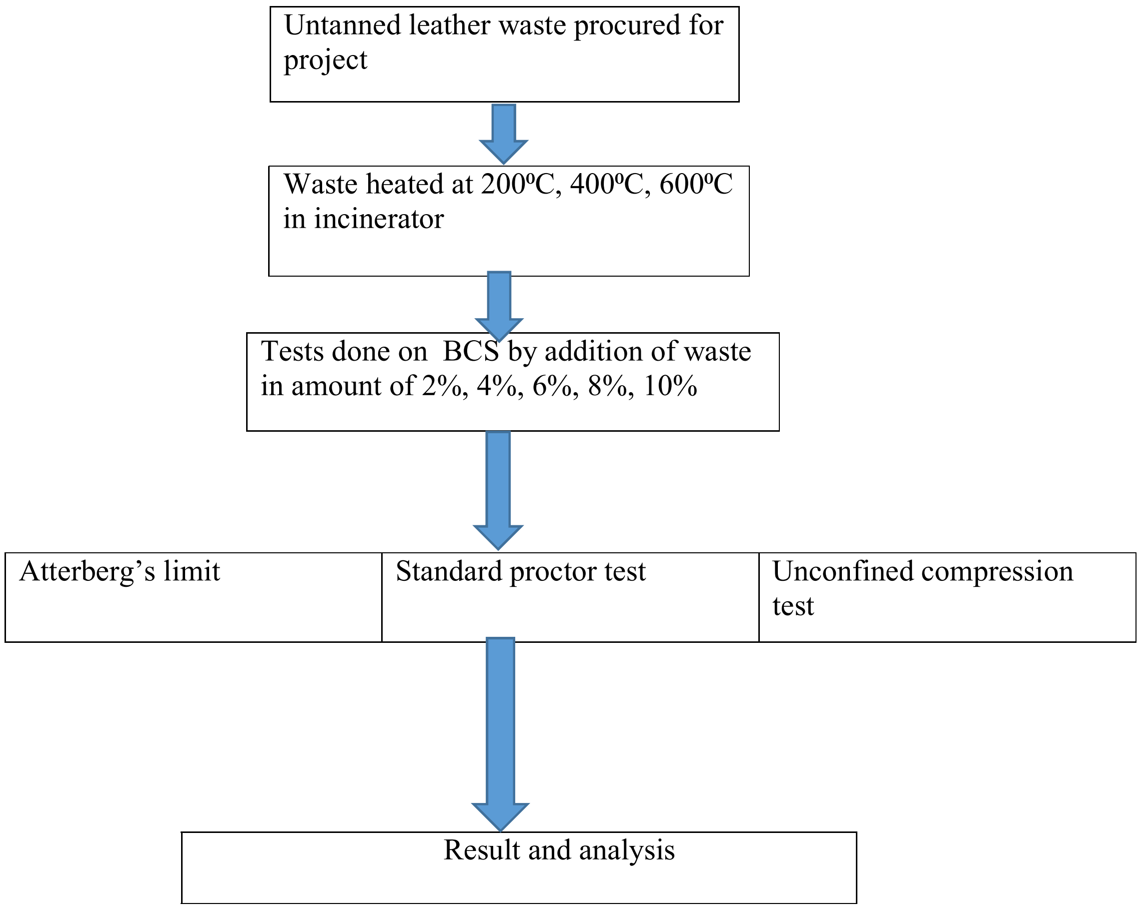
Fig 3.3 Untanned leather ash after heating at 200ºC in incinerator

Fig 3.4 Untanned leather ash before heating in incinerator

Chapter 4

METHODOLOGY

4.1 Work plan



4.2 Testing methodology

4.2.1 Dry sieve analysis

Materials required:-

1. Stack of test sieves
2. Weighing machine
3. Sieve shaker
4. Oven

Procedure:-

1. An oven dried sample that weighs exactly of 500g is taken.
2. Lumps should be crushed.
3. Find the weight of sample in gm.
4. Prepare the sieve shaker and pan at bottom.
5. Measure the weight of retained material in each sieve after stopping the sieve shaker.

4.2.2 Liquid limit

Materials required:-

1.Liquid limit device(cassagrande)

2. Groove

3. China dish

4. Spatula

5. 425 micron sieve

6. Weighing balance

Procedure:-

1. Weigh about 130 gram of soil and pass it through sieve of size 425 micron.

2. Add the soil in china dish and mix water in it an, mix it thoroughly.

3. Mix the paste until a uniform thickness is achieved.

4. Using spatula acquire some paste and place in in the cassagrande cup uniformly.

5. Acquire the groove and make a straight cut in the centre of cassagrande cup.

6. Start the device and note down the no of blows until the partition done using groove comes in contact.

7. Acquire some paste from cup and put it in sampler.

8. Weight of sample and sampler is noted.

9. Repeat the steps 4-9.

10. Keep the samplers in oven.

11. Weigh the sampler after 24 hours and readings are noted..

12. Calculate the liquid limit.

4.2.3 Plastic limit

Materials required:-

1. Glass plate
2. Spatula
3. Oven
4. Samplers

Procedure:-

1. Rolling the soil sample into a ball and then rolling carefully in threads of uniform thickness of 3mm approximately.
2. The average of three moisture content is calculated and find out the plastic limit value.

4.2.4 Shrinkage limit

Materials required:-

1. China dish
2. Spatula
3. Weighing machine
4. Sieve
5. Mercury
6. Samplers

Procedure:-

1. Pass the soil through 425 micron sieve.
2. Find the weight of the sampler.
3. Fill the soil sample in the sampler.
4. Find the weight of the sampler + sample.
5. Keep the sampler in oven.
6. By displacing the mercury in china dish, find out the volume of dry sample.
7. Note the weight of mercury displaced.

4.2.5 Standard proctor test

Materials required:-

1. Weighing machine
2. Rammer(2.5kg weight)
3. Standard proctor mould(944cc capacity)

Procedure:-

1. Take 5kg of soil and add fixed amount of water content in 0.08%, 0.1%, 0.14%, 0.17%, 0.20% and 0.22%.
2. Take the weight of proctor removing the base plate.
3. Fill the soil in three layers and give each layer 25 blows using rammer.
4. Remove the top layer of soil using spatula.
5. Weigh the proctor+soil.
6. Repeat the process until the weight starts to decrease.

4.2.6 Unconfined Compression test

Materials used:-

1. Standard proctor mould
2. UCS machine
3. Weighing machine

Procedure:-

1. Compact the soil using the proctor at OMC.
2. Insert the UCS sampler into the compacted soil.
3. Remove the soil sampler.
4. Cut the soil sample according to required dimensions.
5. Place the sample obtained in the UCS machine.
6. Calculate the UCS and stress-strain curve.

CHAPTER 5

RESULTS AND DISCUSSIONS

5.1 Test performed on black cotton soil

5.1.1 Sieve analysis

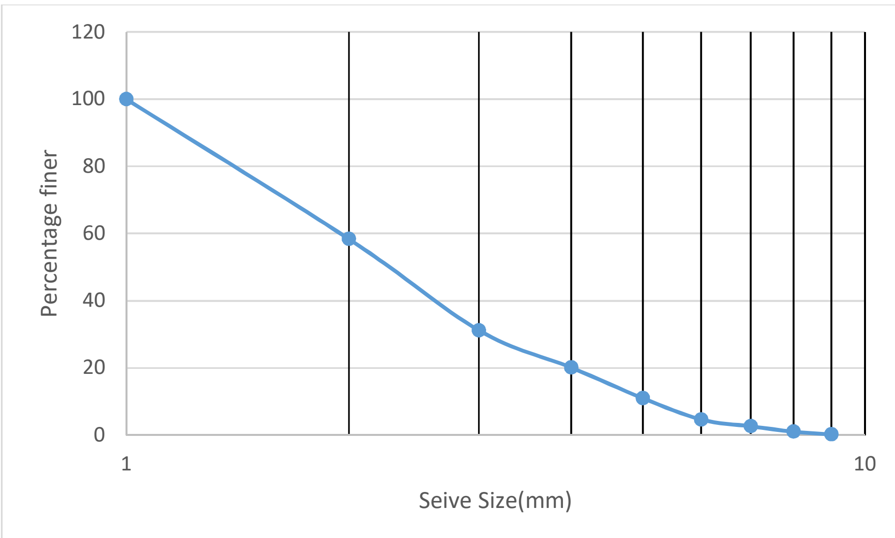


Figure 5.1 Distribution of particle size of black cotton soil

The detail of dry sieve analysis is taken from **(Annexure 1.1.1)**

The percentage soil retained on 75 micron sieve is 24%.

The percentage soil passing through 75 micron sieve is76%.

According to IS:1948-1970, soil is determined as fine type to soil. The percentage of soil which has passed 75 micron sieve is more than 50%.

5.1.2 Liquid limit

That moisture content at which the soil will start showing liquid behaviour. The value corresponding to 25 blows is the moisture content (liquid limit).

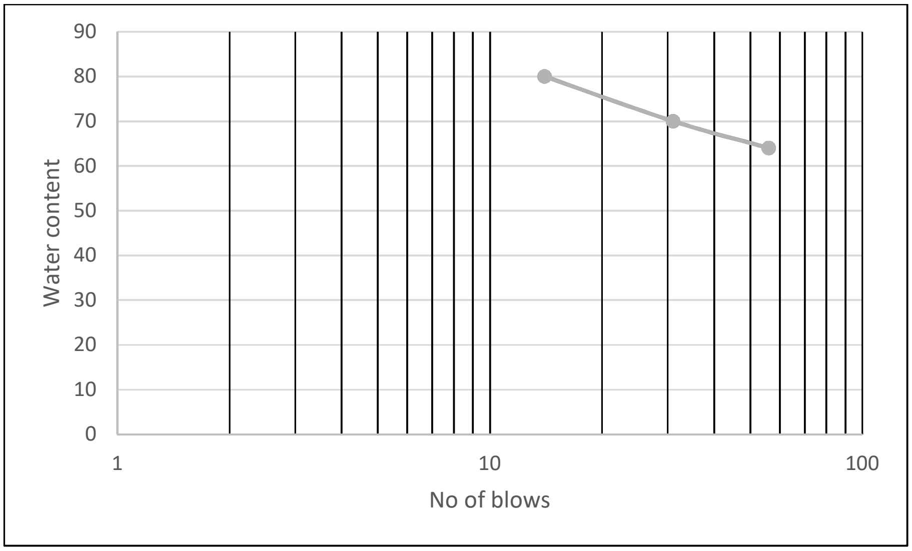


Figure 5.2 Liquid limit of plain BCS

The liquid limit of the sample is 70.6%.

The detail of liquid limit (Plain BCS) is taken from **(Annexure 1.1.2)**

5.1.3 Plastic limit

That moisture content at which the soil will start to behave as plastic material.

The plastic limit of the sample is 39.72%.

The detail of plastic limit (Plain BCS) is taken from **(Annexure 1.1.3)**

5.1.4 Plasticity index

The moisture content in which the soil remains in plastic state.

Numerically plasticity index = liquid limit – plastic limit

PL=70.6-39.72= 30.88

5.1.5 Shrinkage limit

That water content where the more loss of water content does not result in more volume reduction.

The shrinkage limit of the sample is 9.37%.

The detail of shrinkage limit (Plain BCS) is taken **from (Annexure 1.2.31)**

5.1.6 Compaction

That moisture content at which maximum dry density is obtained.

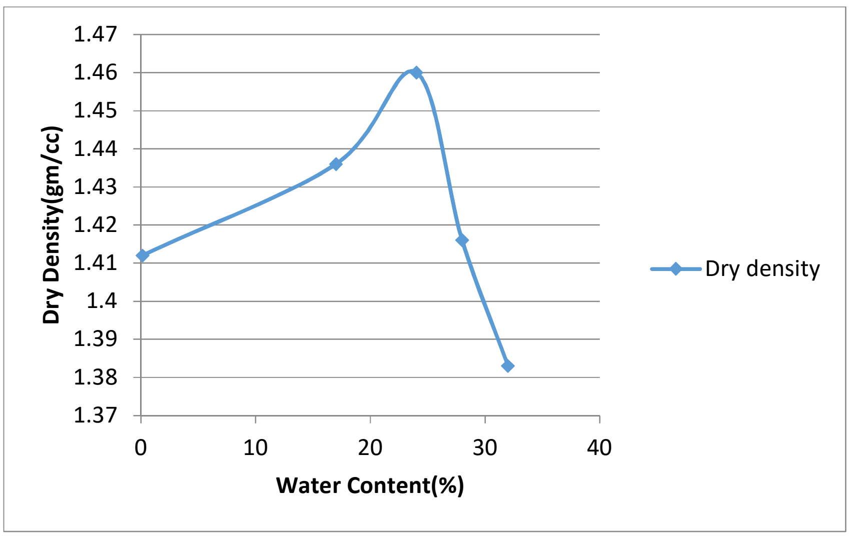


Figure 5.3 The MDD of the sample is 1.465 and OMC is 22%

The detail of compaction curve is taken from **(Annexure 1.1.4)**

5.1.7 Unconfined Compressive strength

The unconfined compressive strength of soil is measured.

The load determined is 0.13KN and displacement is 4.22mm.

UCS is 108.31KN/m²

5.2 Tests performed of BCS+ untanned waste

5.2.1 Liquid limit(200ºC)

Waste in quantity of 2%, 4%, 6%, 8%, 10% mixed with BCS by weight of soil

BCS+2% untanned leather waste added (200ºC)—

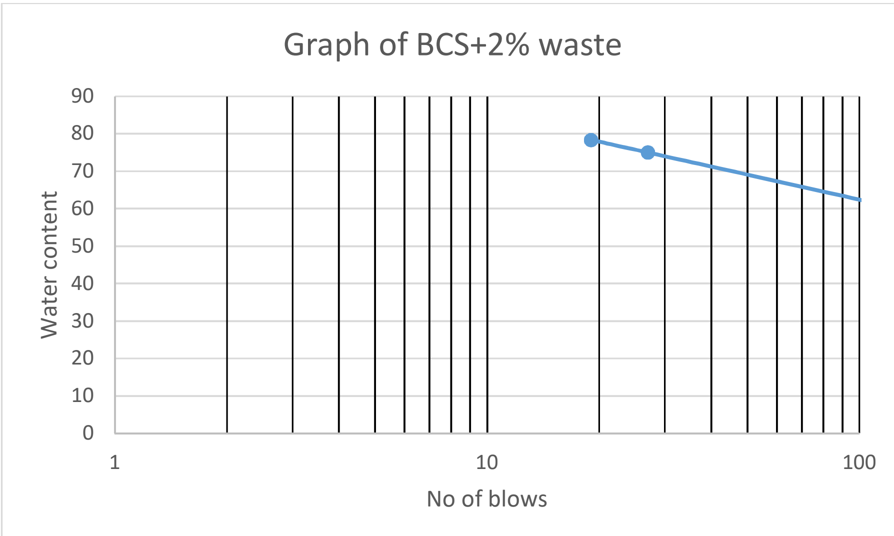


Figure 5.4 The liquid limit for the sample is 73.4%.

The detail of liquid limit (BCS+2% at 200ºc) is taken from **(Annexure 1.2.1)**

BCS+4% untanned leather waste added (200ºC)—

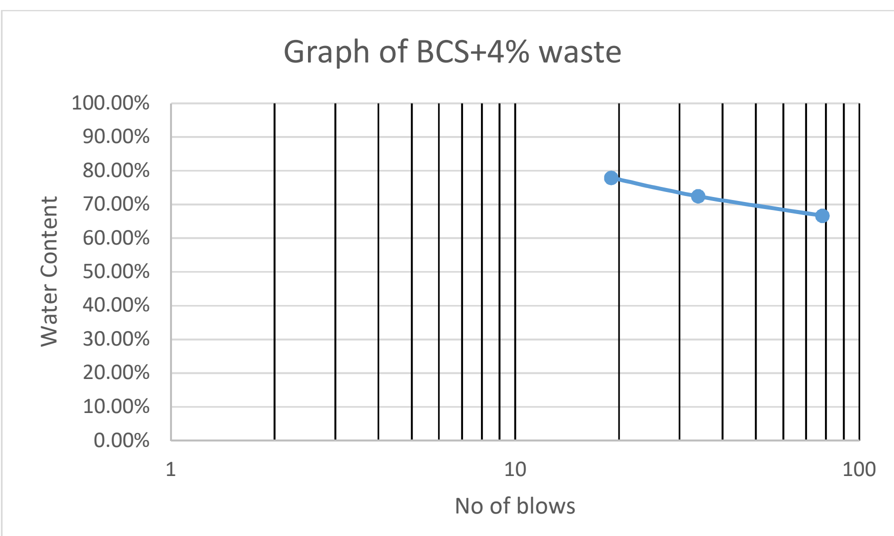


Figure 5.5 The liquid limit for the sample is 75.88%.

The detail of liquid limit (BCS+4% at 200ºc) is taken from **(Annexure 1.2.2)**

BCS+6% untanned leather waste added (200ºC)—

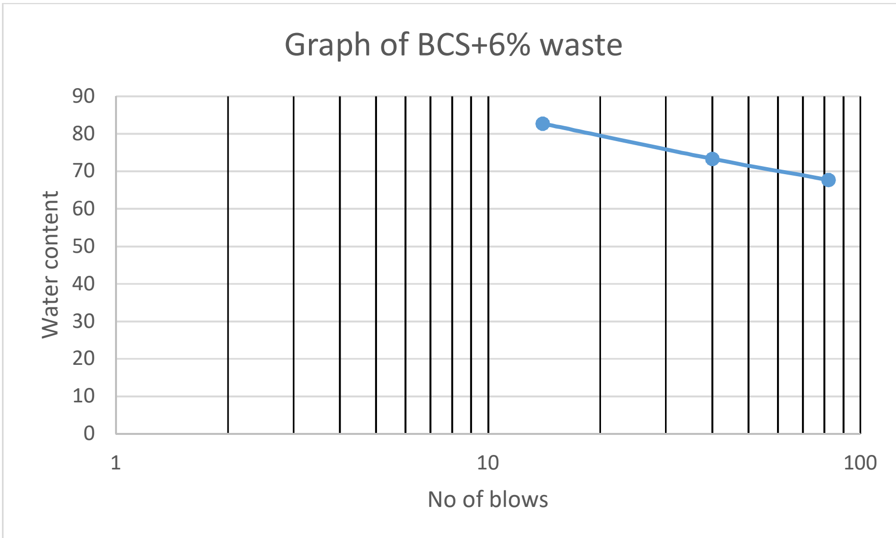


Figure 5.6 The liquid limit for the sample is 78.1%.

The detail of liquid limit (BCS+6% at 200ºc) is taken from **(Annexure 1.2.3)**

BCS+8% untanned leather waste added (200ºC)—

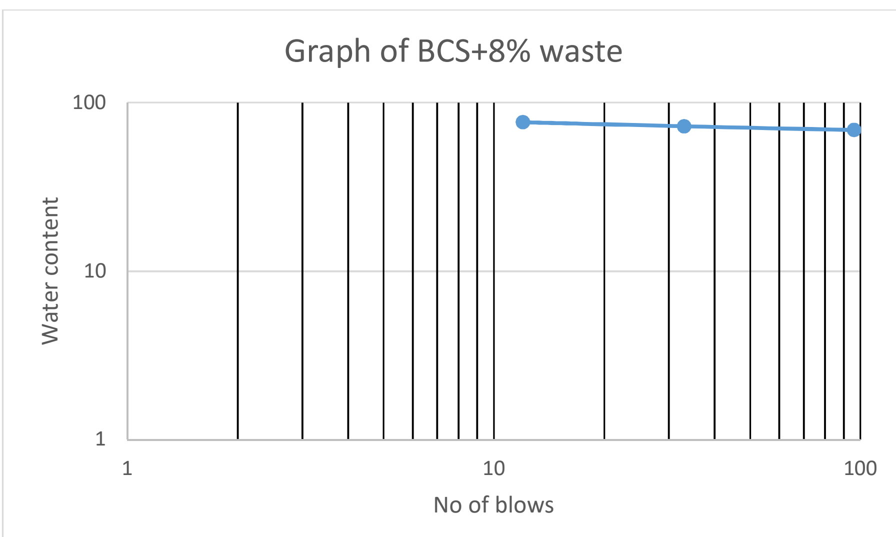


Figure 5.7 The liquid limit for the sample is 76.47%.

The detail of liquid limit (BCS+8% at 200ºc) is taken from **(Annexure 1.2.4)**

BCS+10% untanned leather waste added (200^oC)

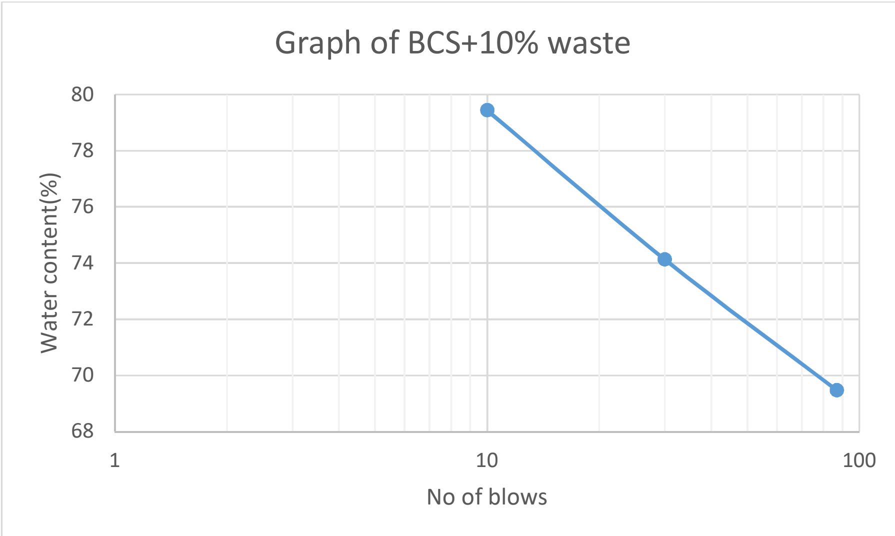


Figure 5.8 The liquid limit of the sample is 75.2%

The detail of liquid limit (BCS+10% at 200^{o}c) is taken from **(Annexure 1.2.5)**

5.2.1.1 Variation of the liquid limit and waste content

Waste content(%) (200^{o}C)	**Liquid Limit(%)**
0%	70.6
2%	73.4
4%	75.88
6%	78.1
8%	76.47
10%	75.2

Table 1 Variation of liquid limit and waste content (200^{o}C)

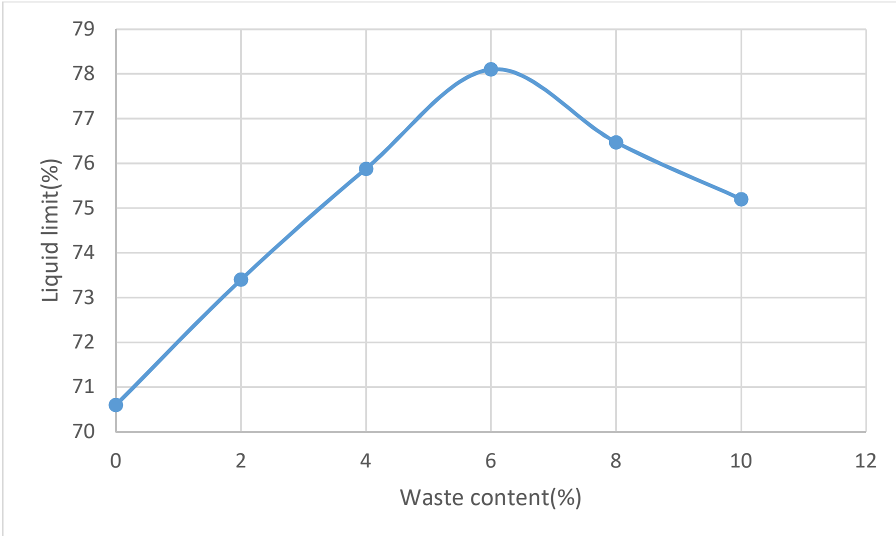


Figure 5.9 Variation of liquid limit and waste content (200ºC)

From the graph it can be concluded that liquid limit of BCS increases till 6% waste content. As the waste content is increased, the liquid limit tends to decrease. The liquid limit reaches the maximum value at 6% waste i.e. 78.1% and minimum at 10% waste i.e. 75.2%.

5.2.2 Liquid limit(400ºC)

BCS+2% untanned leather waste added

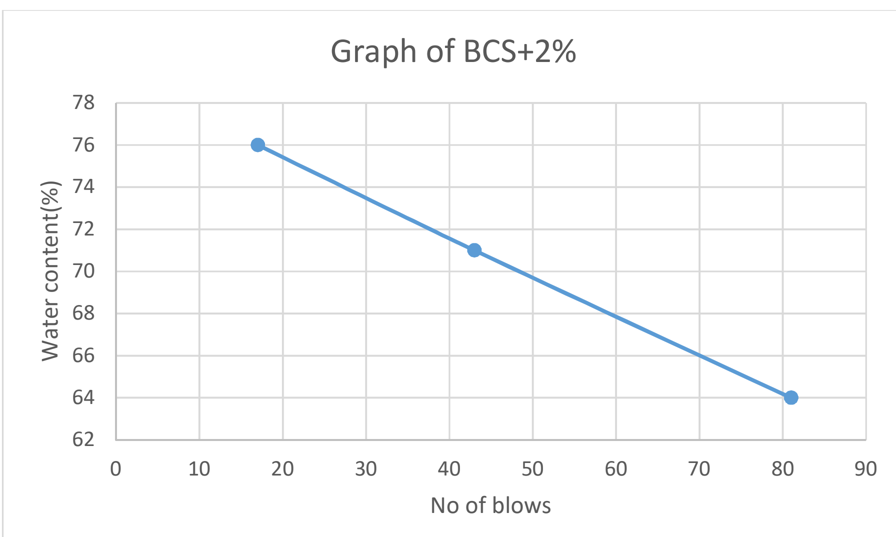


Figure 5.10 Liquid limit of the sample is 73.1%.

The detail of liquid limit (BCS+2% at 400ºc) is taken from **(Annexure 1.2.6)**

BCS+4% untanned leather waste added

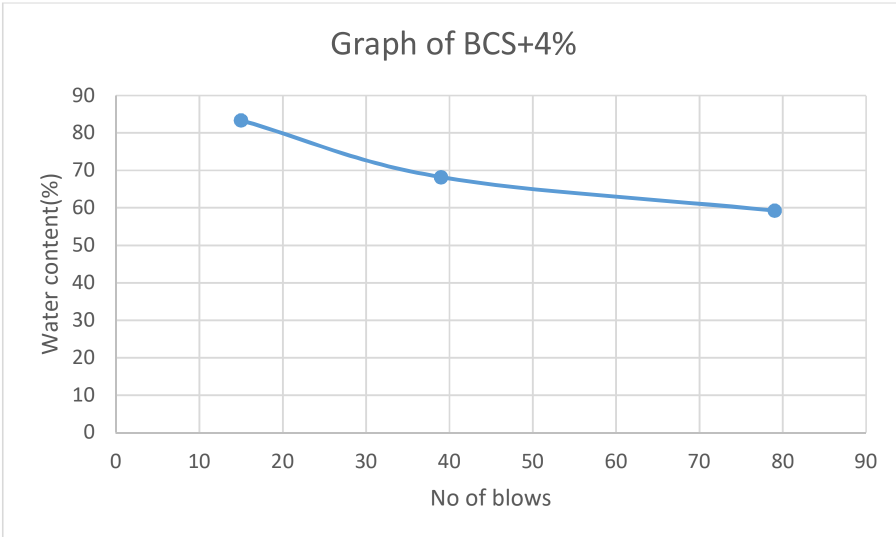


Figure 5.11 Liquid limit of the sample is 76.1%

The detail of liquid limit (BCS+4% at 400ºc) is taken from **(Annexure 1.2.7)**

BCS+6% untanned leather waste added

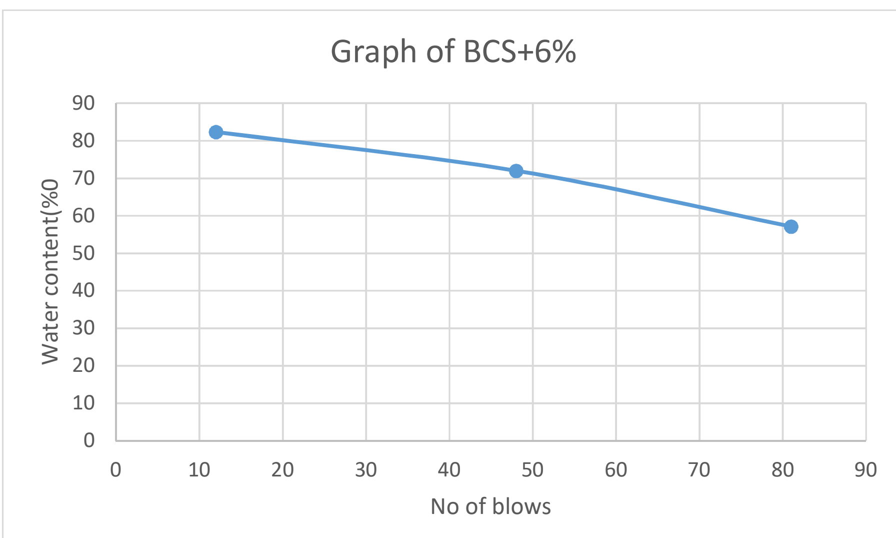


Figure 5.12 Liquid limit of the sample is 79.2%.

The detail of liquid limit (BCS+6% at 400ºc) is taken from **(Annexure 1.2.8)**

BCS+8% untanned leather waste added

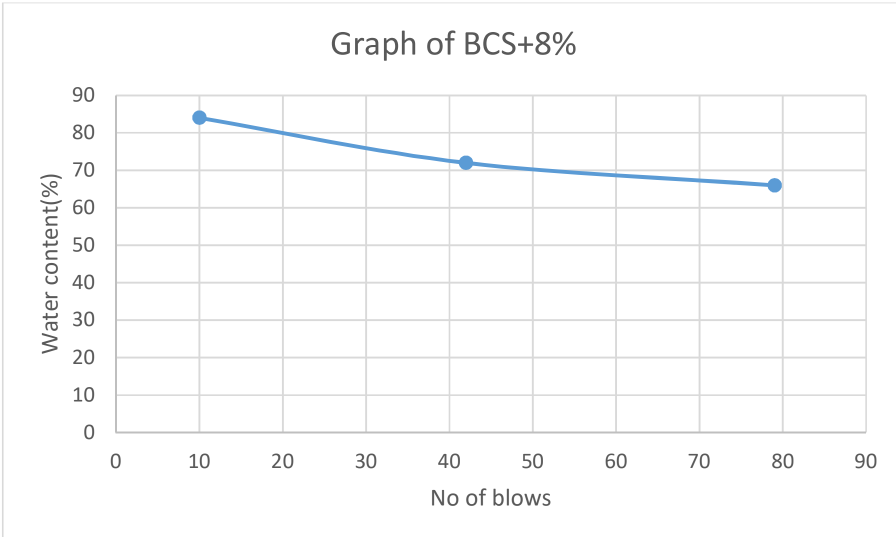


Figure 5.13 Liquid limit of the sample is 78.2%

The detail of liquid limit (BCS+8% at 400ºc) is taken from **(Annexure 1.2.9)**

BCS+10% untanned leather waste added

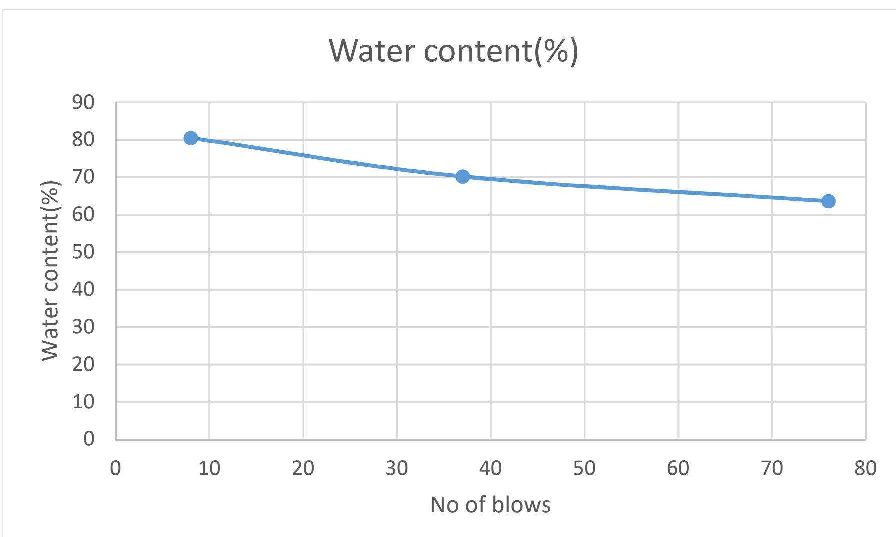


Figure 5.14 Liquid limit of the sample is 76.8%.

The detail of liquid limit (BCS+10% at 400ºc) is taken from **(Annexure 1.2.10)**

5.2.2.1 Variation of liquid limit and waste content (400ºC)

Waste content(%)	Liquid limit(%)
0	70.6
2	73.1
4	76.1
6	79.2
8	78.2
10	76.8

Table 2 Variation of liquid limit and waste content at 400ºC

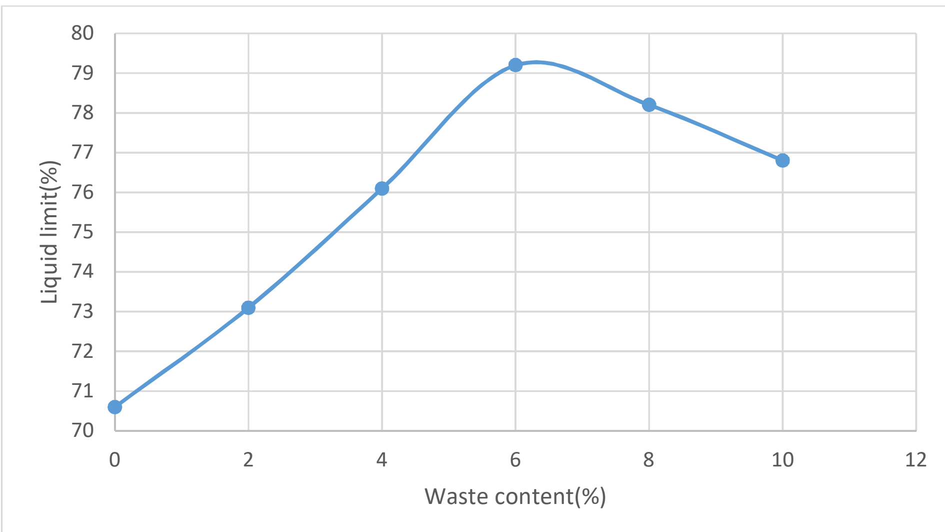


Figure 5.15 Variation of liquid limit and waste content (400ºC)

From the graph it can be concluded that liquid limit of BCS increases till 6% waste content. As the waste content is increased, the liquid limit tends to decrease. The liquid limit reaches the maximum value at 6% waste i.e. 79% and minimum at 10% waste i.e. 77%.

5.2.3 Liquid limit (600ºC)

BCS+2% untanned leather waste added

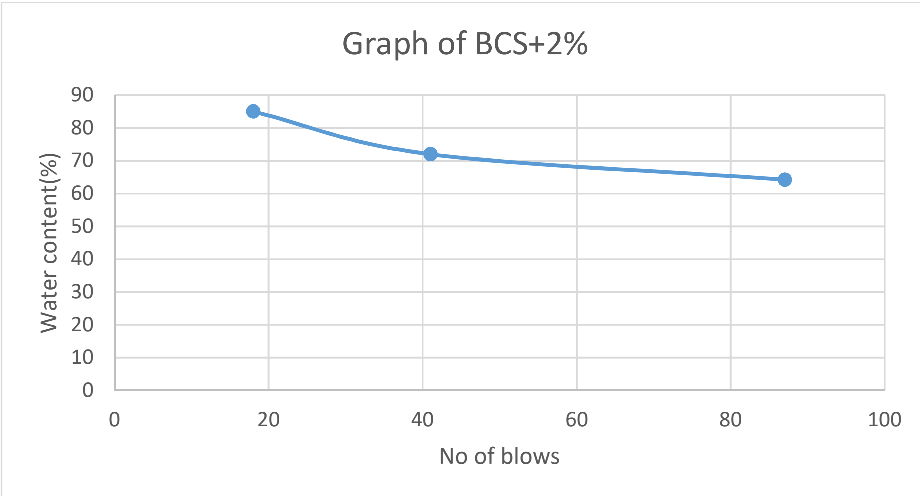


Figure 5.16 Liquid limit of the sample is 76.12%.

The detail of liquid limit (BCS+2% at 600ºc) is taken from **(Annexure 1.2.11)**

BCS+4% untanned leather waste added

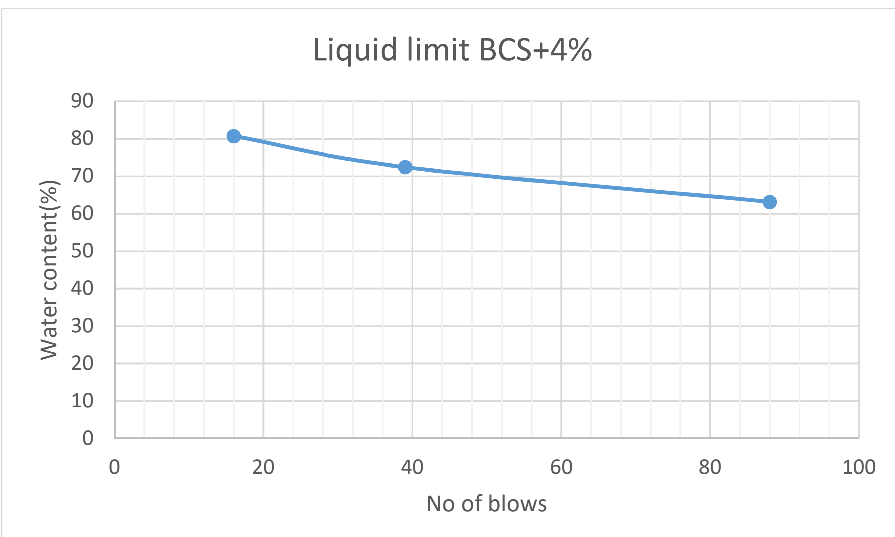


Figure 5.17 Liquid limit of the sample is 77.8%.

The detail of liquid limit (BCS+4% at 600ºc) is taken from **(Annexure 1.2.12)**

BCS+6% untanned leather waste added

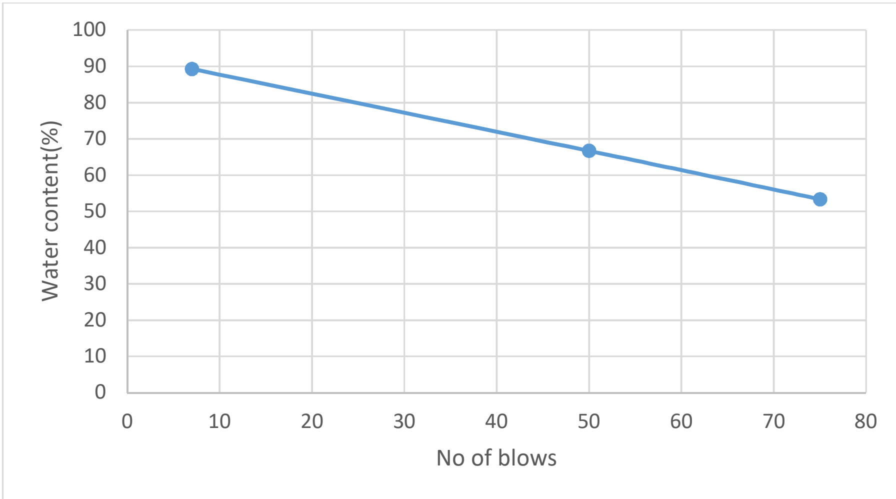


Figure 5.18 Liquid limit of the sample is 79.5%

The detail of liquid limit (BCS+6% at 600ºc) is taken from **(Annexure 1.2.13)**

BCS+8% untanned leather waste added

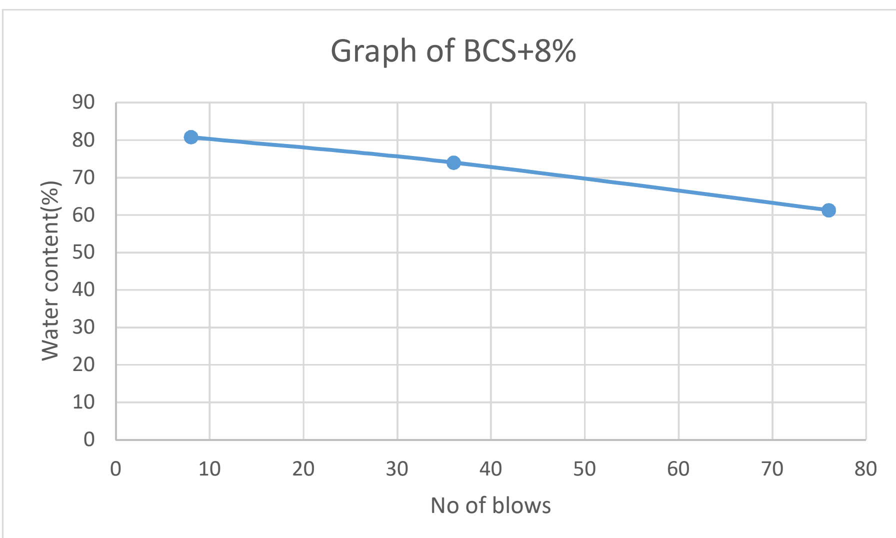


Figure 5.19 Liquid limit of the sample is 79.2%.

The detail of liquid limit (BCS+8% at 600ºc) is taken from **(Annexure 1.2.14)**

BCS+10% untanned leather waste added

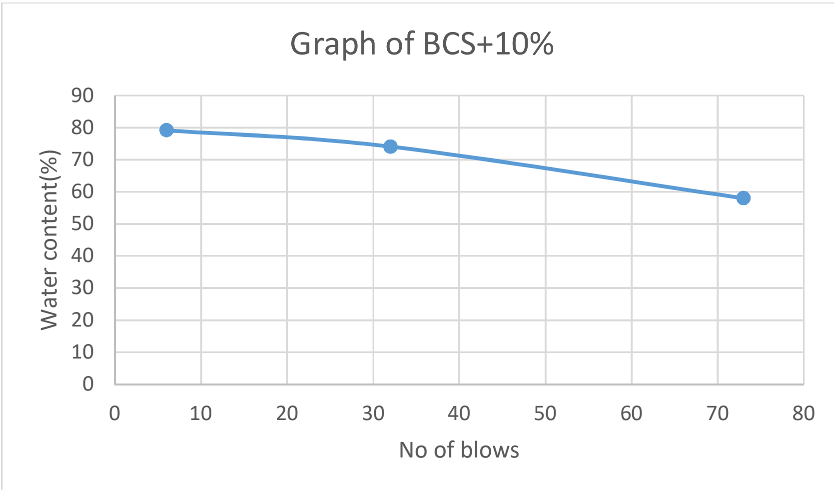


Figure 5.20 Liquid limit of the sample is 76.8%.

The detail of liquid limit (BCS+10% at 600ºc) is taken from **(Annexure 1.2.15)**

5.2.3.1 Variation of liquid limit and waste content

Waste content %	**Liquid limit(%)**
0	70.6
2	76.12
4	77.8
6	79.5
8	79.2
10	76.8

Table 3 Variation of liquid limit and waste content at 600ºC

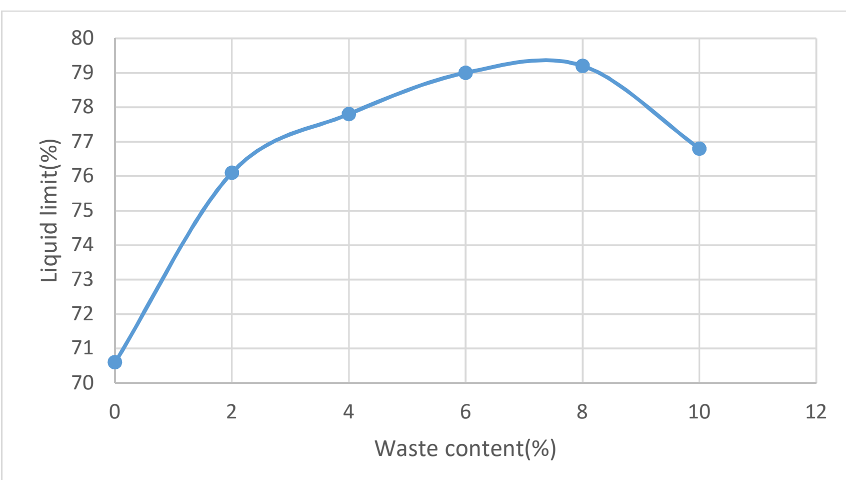


Figure 5.21 Variation of liquid limit and waste content

From the graph it can be concluded that liquid limit of BCS increases till 6% waste content. As the waste content is increased, the liquid limit tends to decrease. The liquid limit reaches the maximum value at % waste i.e. 79.2% and minimum at 10% waste i.e. 76.8%.

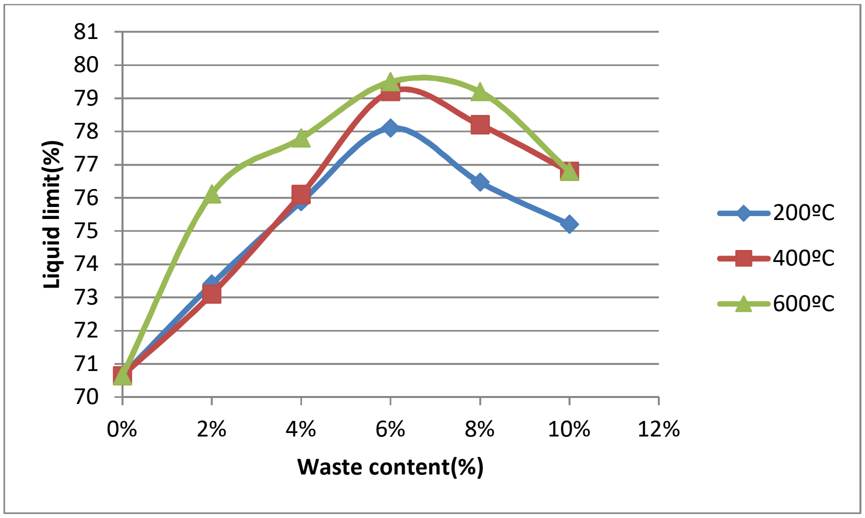


Figure 5.22 Variation of liquid limit with waste content at different temperatures

5.2.3.2 Variation of plasticity index at different temperatures

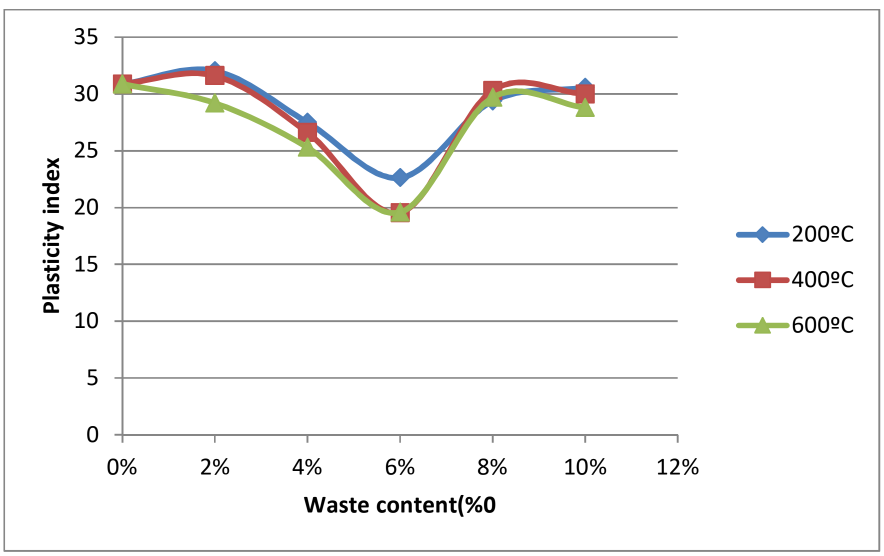


Figure 5.23 Variation of plasticity index at different temperatures

Plasticity index decreases till addition of 6% untanned leather waste ash because of the generation of silica gel that further improves the gross water holding capacity of the black cotton soil. There is an unfavourable effect after 6% waste content.

5.2.4 Plastic limit

5.2.4.1 Variation of plastic limit and waste content (200ºC)

Waste content(%) (200ºC)	Plastic Limit(%)
0%	39.72
2%	41.36
4%	48.36
6%	55.47
8%	47.093
10%	44.63

Table 4 Variation of plastic limit and waste content (200ºC)

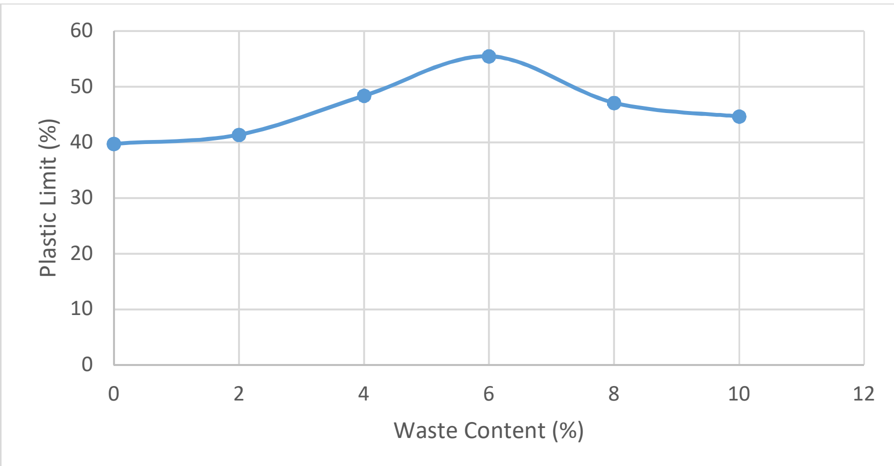


Figure 5.24 Variation of plastic limit and waste content (200ºC)

From the graph it can be concluded that plastic limit of BCS increases till 6% waste content. As the waste content is increased, the plastic limit tends to decrease. The plastic limit reaches the maximum value at 6% waste i.e. 55.47% and minimum at 10% waste i.e. 44.63%.

5.2.4.2 Variation of plastic limit and waste content(400ºC)

Waste content(%)	Plastic limit(%)
0	39.72
2	41.50
4	49.5
6	59.65
8	47.9
10	46.8

Table 5 Variation of plastic limit and waste content at (400ºC)

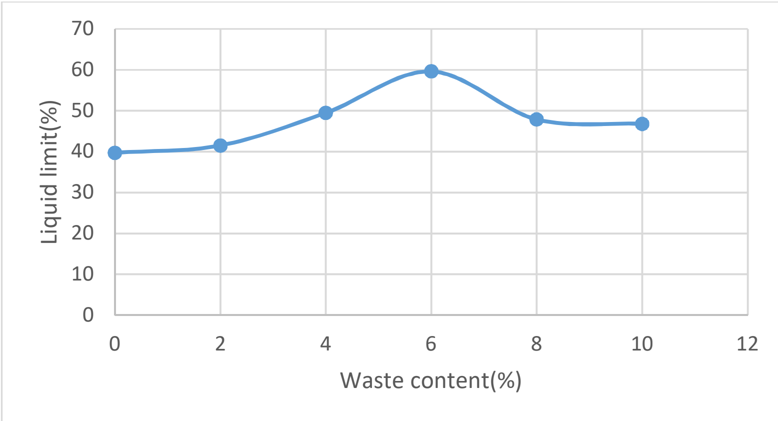


Figure 5.25 Variation of plastic limit and waste content

From the graph it can be concluded that plastic limit of BCS increases till 6% waste content. As the waste content is increased, the plastic limit tends to decrease. The plastic limit reaches the maximum value at 6% waste i.e. 59.65% and minimum at 10% waste i.e. 46.8%.

5.2.4.3 Variation of plastic limit and waste content (600ºC)

Waste content(%)	Plastic limit(%)
0	39.72
2	46.92
4	52.5
6	59.9
8	49.5
10	48

Table 6 Variation of plastic limit and waste content (600ºC)

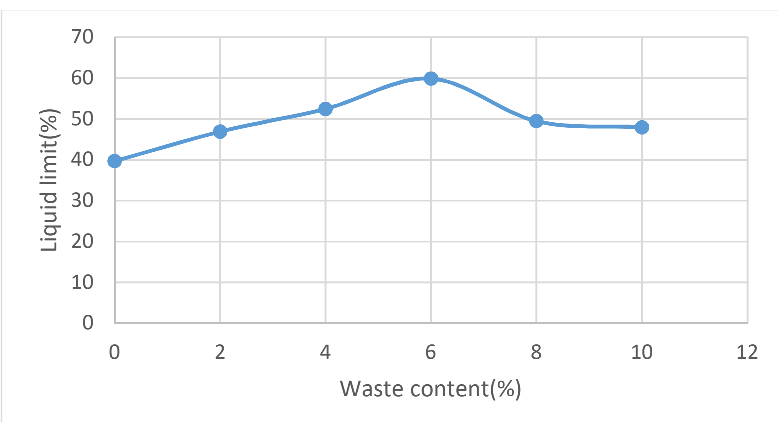


Figure 5.26 Variation of plastic limit and waste content (600ºC)

From the graph it can be concluded that plastic limit of BCS increases till 6% waste content. As the waste content is increased, the plastic limit tends to decrease. The plastic limit reaches the maximum value at 6% waste i.e. 59.9% and minimum at 10% waste i.e. 48%.

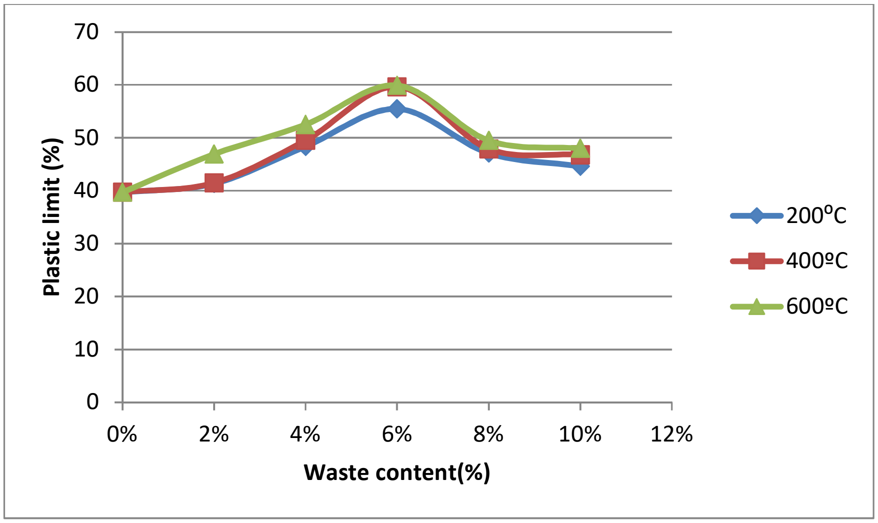


Figure 5.27 Variation of plastic limit with waste content at different temperatures

The double diffuse layer is decreased resulting in the increase of charge concentration and viscosity of the pore fluid, resulting in increase of the interparticle shear resistance which leads to increase of the plastic limit till 6%. There is an unfavourable effect after 6% waste content.

5.2.5 Shrinkage Limit

5.2.5.1 Shrinkage limit (200⁰C)

Waste content(%)	**Shrinkage limit (%)**
0	9.377
2	12.04
4	12.86
6	13.98
8	14.22
10	15.01

Table 7 Variation of shrinkage limit and waste content (200⁰C)

Figure 5.28 Variation of shrinkage limit and waste content (%)

The detail of shrinkage limit (200⁰C) is taken from **(Annexure 1.2.31)**

The maximum value of shrinkage limit is 15.01%

5.2.5.2 Shrinkage limit (400ºC)

Waste content(%)	Shrinkage limit (%)
0	9.377
2	12.26
4	13.84
6	14.45
8	14.87
10	15.99

Table 8 Variation of shrinkage limit (%) and waste content (%)

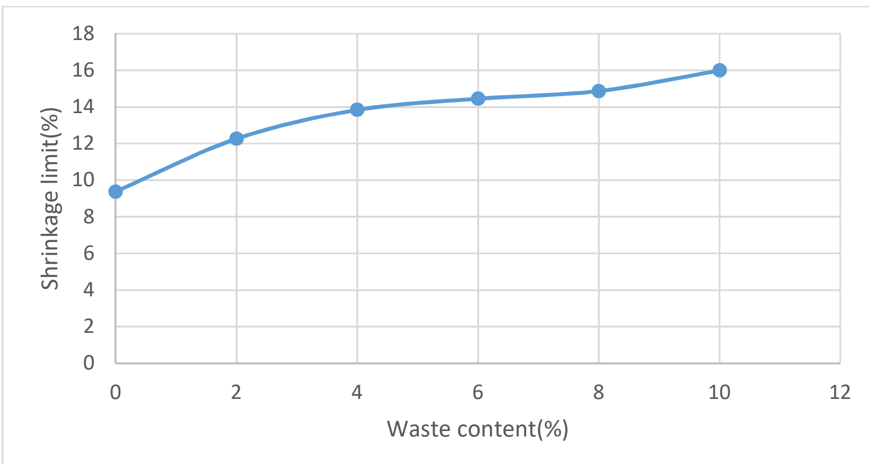


Figure 5.29 Variation of shrinkage limit (%) and waste content (%)

The maximum value of shrinkage limit is 15.99%.

The detail of shrinkage limit (400ºC) is taken from **(Annexure 1.2.32)**

5.2.5.3 Shrinkage limit (600ºC)

Waste content(%)	Shrinkage limit (%)
0	9.377
2	12.79
4	14.21
6	15.28
8	16.2
10	17.15

Table 9 Variation of shrinkage limit (%) and waste content (%)

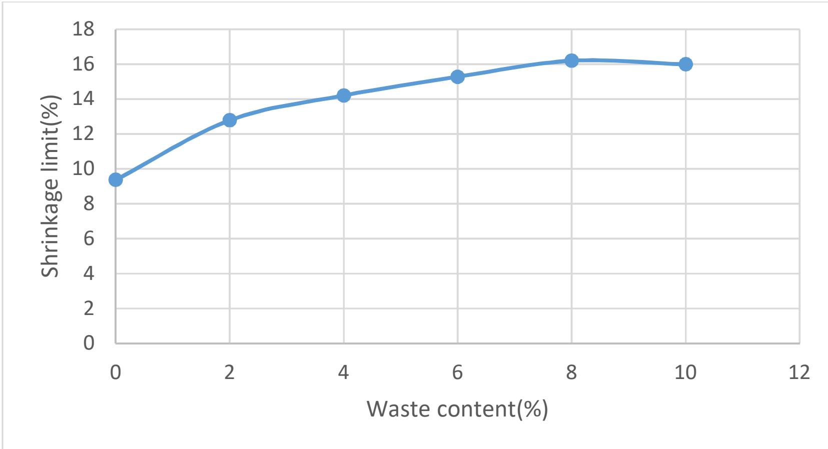


Figure 5.30 Variation of shrinkage limit (%) and waste content (%)
The maximum value of shrinkage limit is 17.25%.
The detail of shrinkage limit (600ºc) is taken from **(Annexure 1.2.33)**

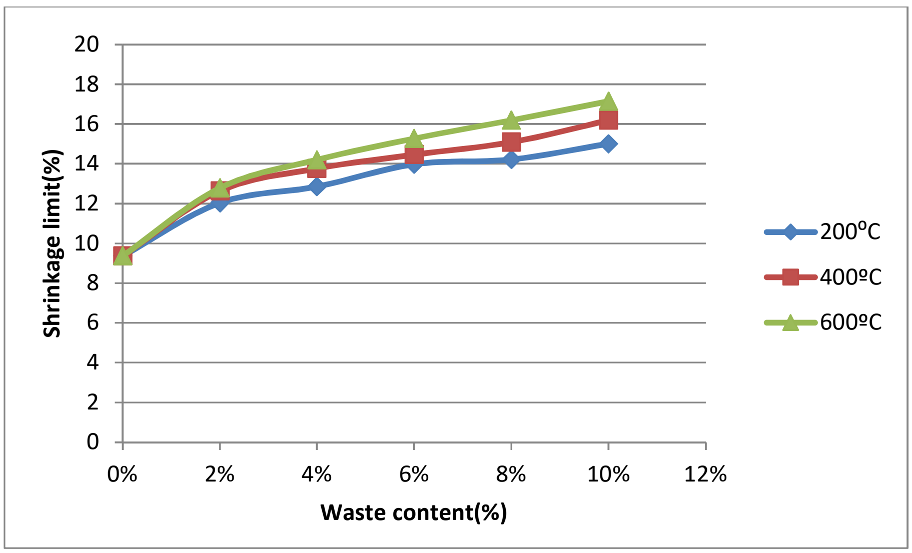


Figure 5.31 Variation of shrinkage limit with waste content at different temperatures

5.2.6 Compaction Curve

5.2.6.1 Compaction Curve (400 ⁰C)

Compaction Curve of BCS + 2% untanned leather waste added

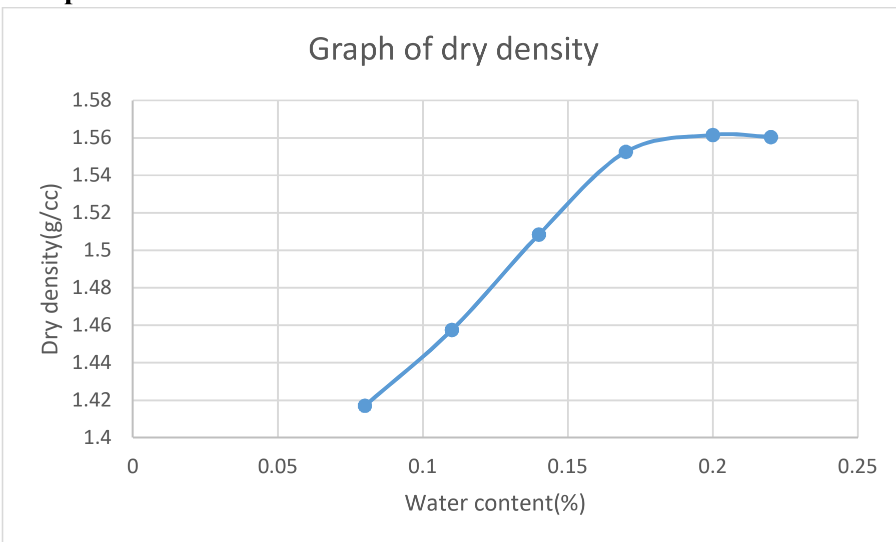


Figure 5.32 MDD is 1.561 g/cc and OMC is 20%.
The value of compaction curve (BCS+2% at 400⁰C) is taken from **(Annexure 1.3.1)**

Compaction Curve of BCS + 4% untanned leather waste added

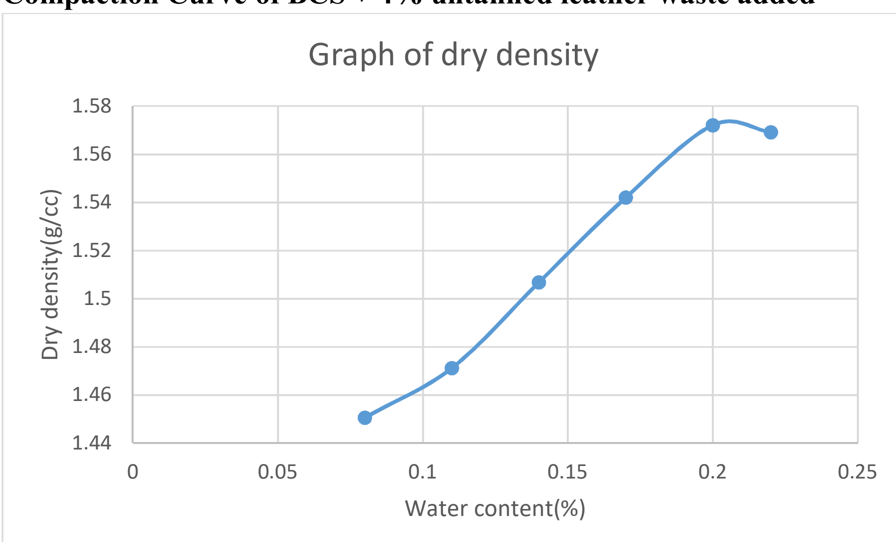


Figure 5.33 MDD is 1.572 g/cc and OMC is 19.8%
The value of compaction curve (BCS+4% at 400⁰C) is taken from **(Annexure 1.3.2)**

Compaction Curve of BCS + 6% untanned leather waste added

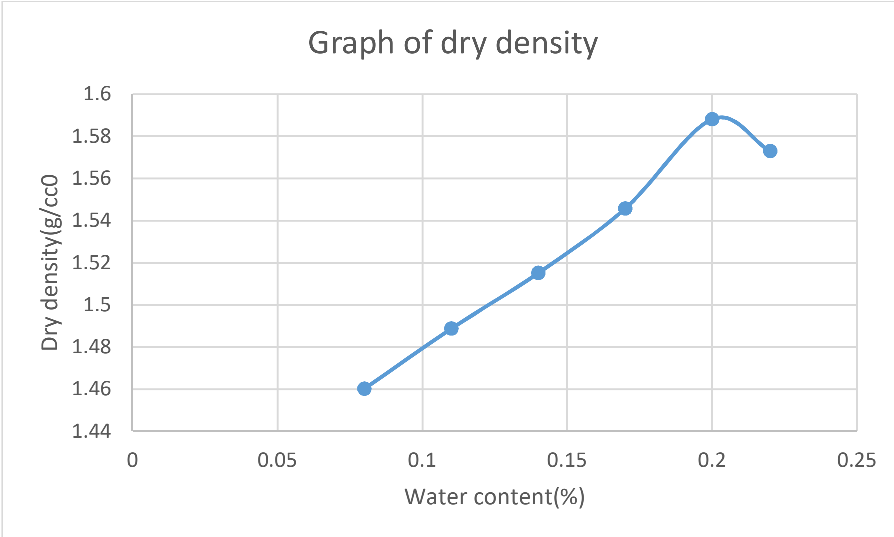


Figure 5.34 MDD is 1.588 g/cc and OMC is 19.9%.
The value of compaction curve (BCS+6% at 400ºC) is taken from **(Annexure 1.3.3)**

Compaction Curve of BCS +8% untanned leather waste added

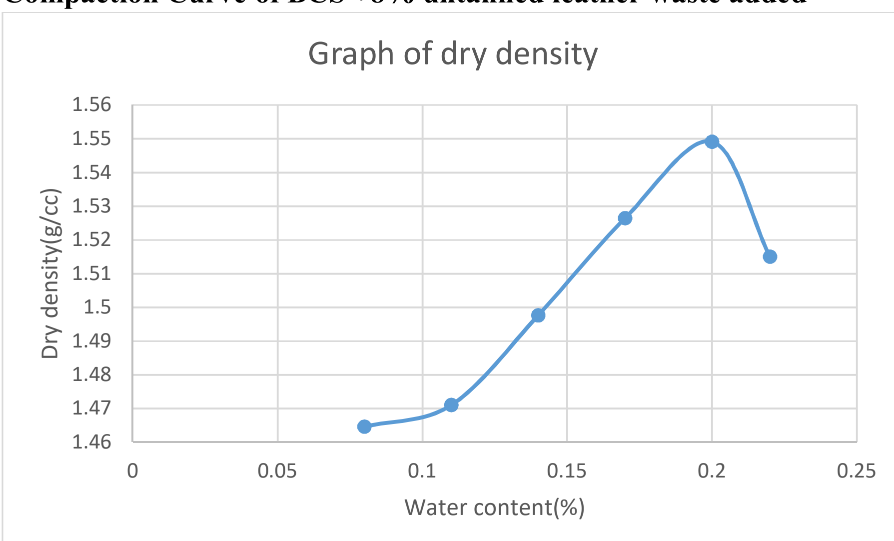


Figure 5.35 MDD is 1.549 g/cc and OMC is 20%
The value of compaction curve (BCS+8% at 400ºC) is taken from **(Annexure 1.3.4)**

Compaction Curve of BCS + 10% untanned leather waste added

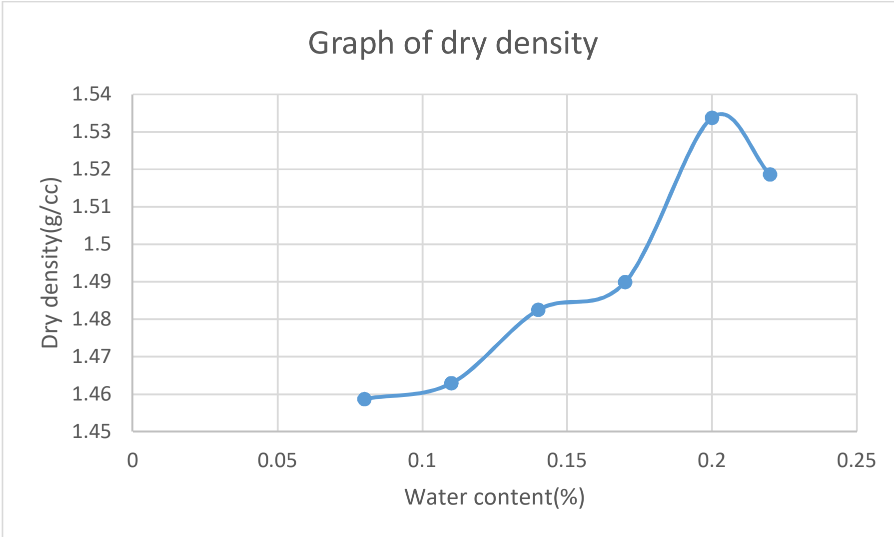


Figure 5.36 MDD is 1.533 g/cc and OMC is 19.8%

The value of compaction curve (BCS+10% at 400ºC) is taken from **(Annexure 1.3.5)**

5.2.6.2 Variation of MDD and waste content (400ºC)

Waste content (%)	MDD (g/cc)
0	1.465
2	1.561
4	1.572
6	1.588
8	1.549
10	1.533

Table 10 Variation of MDD and waste content (400ºC)

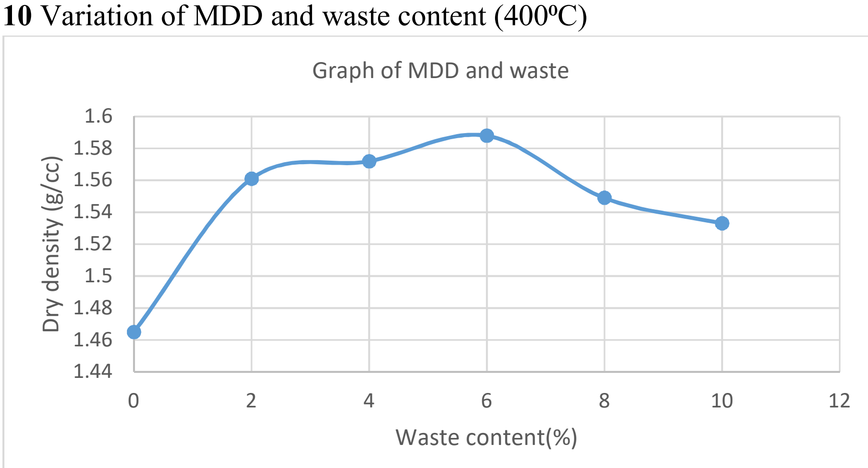


Figure 5.37 Variation of MDD and waste content(400ºC)

From the graph, it can be concluded that the MDD is increased till 6% at 1.588 g/cc and reaches a minimum value at 10% waste content

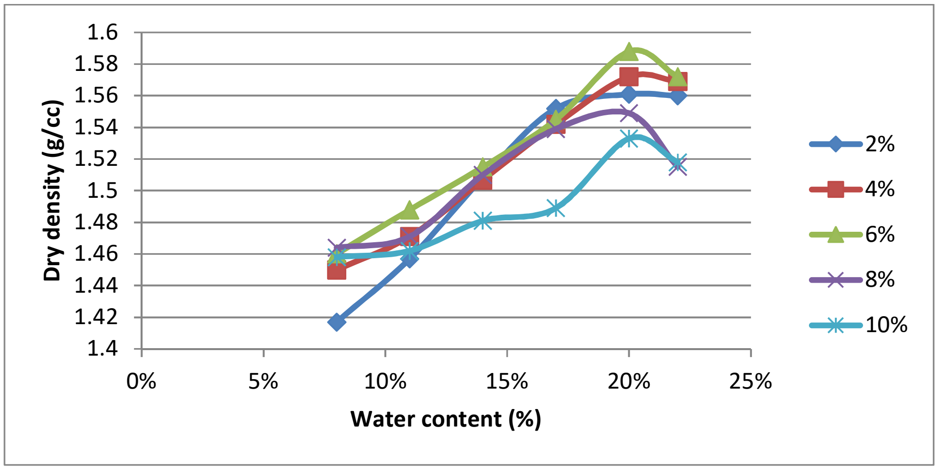


Figure 5.38 Variation of dry density with water content at 400ºC

5.2.6.3 Compaction Curve (600ºC)

Compaction Curve of BCS + 2% waste added

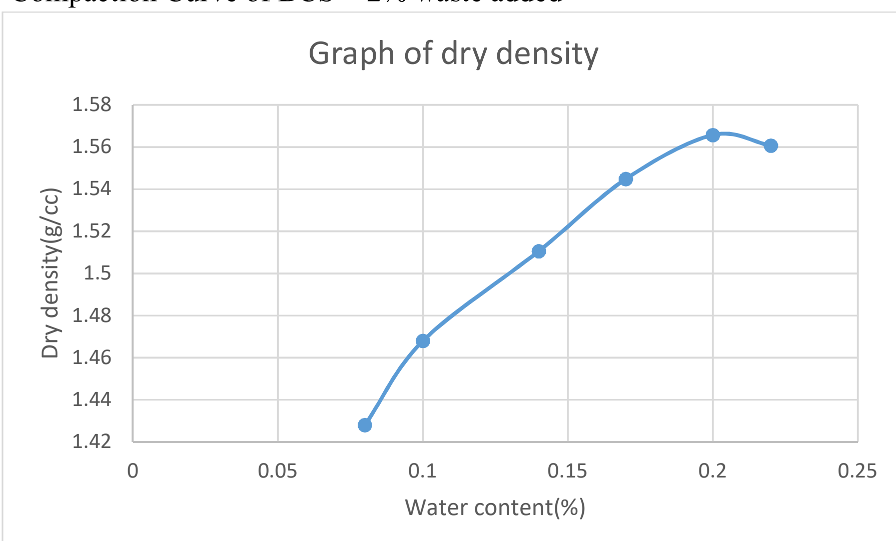


Figure 5.39 MDD is 1.565 g/cc and OMC is 20%

The value of compaction curve (BCS+2% at 600ºC) is taken from **(Annexure 1.3.6)**

Compaction Curve of BCS + 4 % waste added

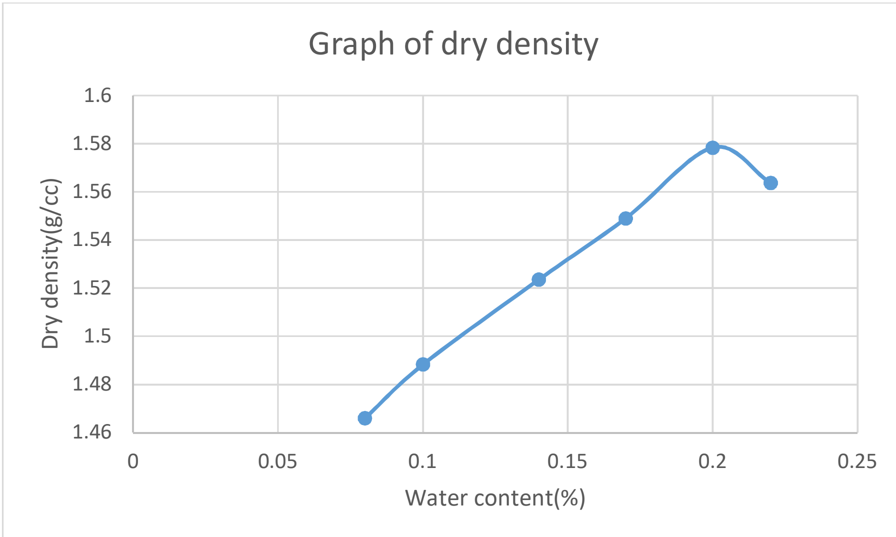


Figure 5.40 MDD is 1.578 g/cc and OMC is 19.9%

The value of compaction curve (BCS+4% at 600^{o}C) is taken from **(Annexure 1.3.7)**

Compaction Curve of BCS + 6% waste added

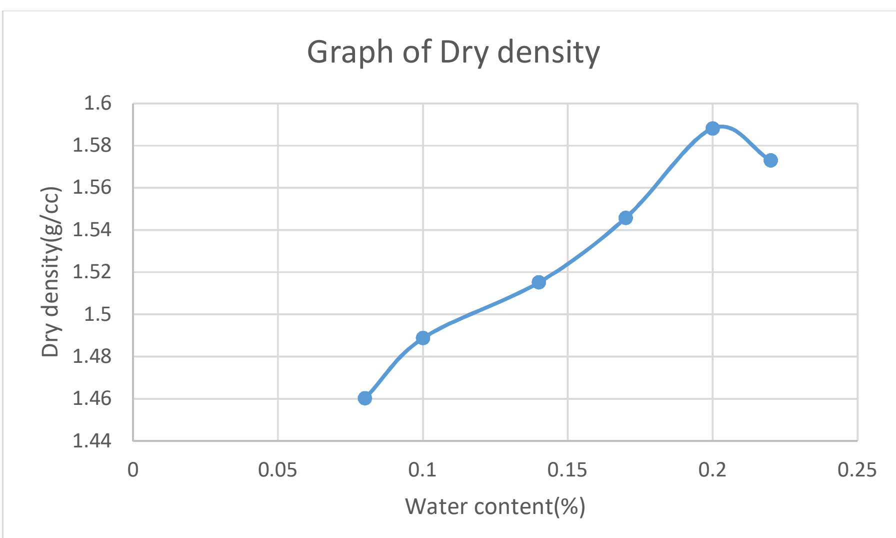


Figure 5.41 MDD is 1.599 g/cc and OMC is 20%

The value of compaction curve (BCS+6% at 600^{o}C) is taken from **(Annexure 1.3.8)**

Compaction Curve of BCS + 8% waste added

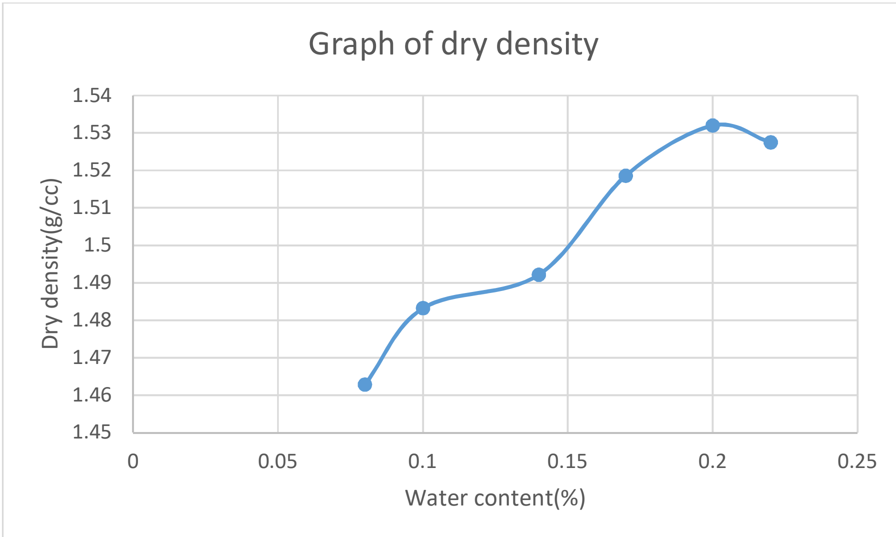


Figure 5.42 MDD is 1.531 g/cc and OMC is 20%

The value of compaction curve (BCS+8% at 600°C) is taken from **(Annexure 1.3.9)**

Compaction Curve of BCS + 10% waste added

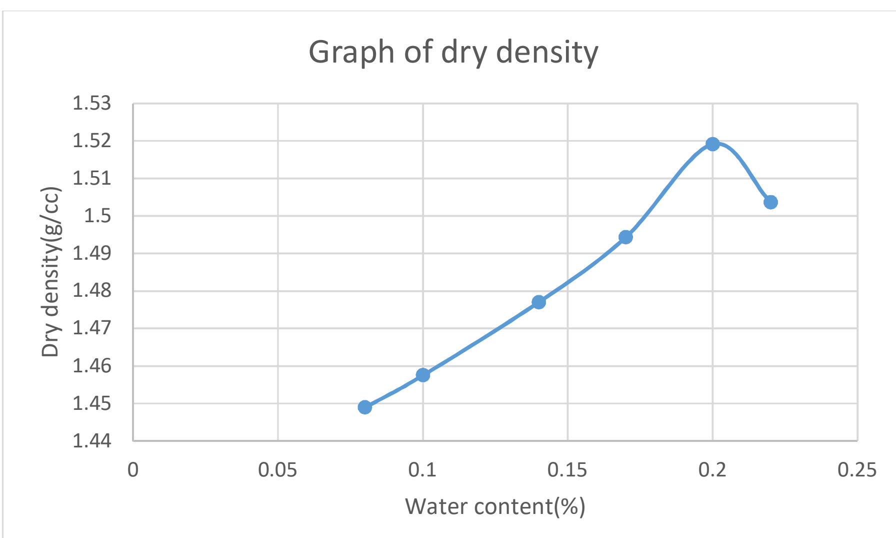


Figure 5.43 MDD is 1.519 g/cc and OMC is 20%

The value of compaction curve (BCS+10% at 600°C) is taken from **(Annexure 1.3.10)**

5.2.6.4 Variation of MDD and waste content (600ºC)

Waste content (%)	MDD
0	1.465
2	1.565
4	1.578
6	1.599
8	1.531
10	1.519

Table 11 MDD and waste content (600ºC)

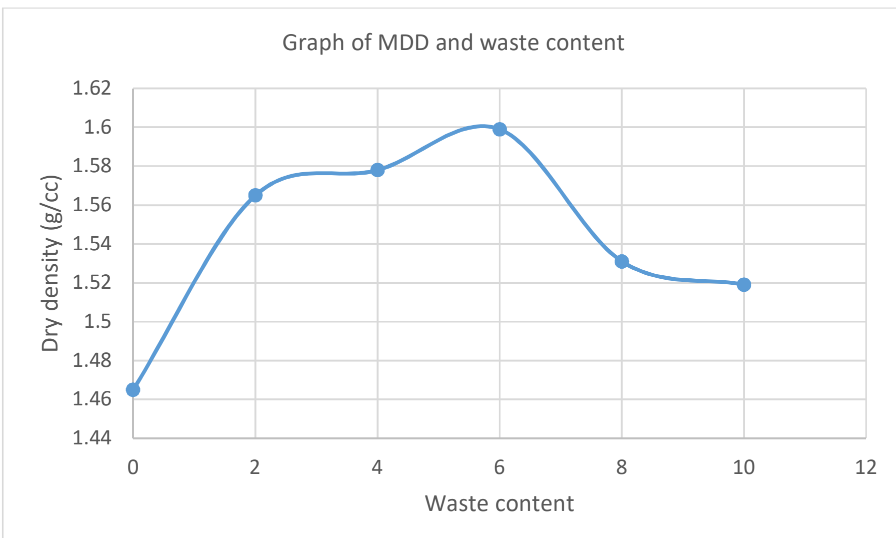


Figure 5.44 Variation of MDD and waste content (600ºC)

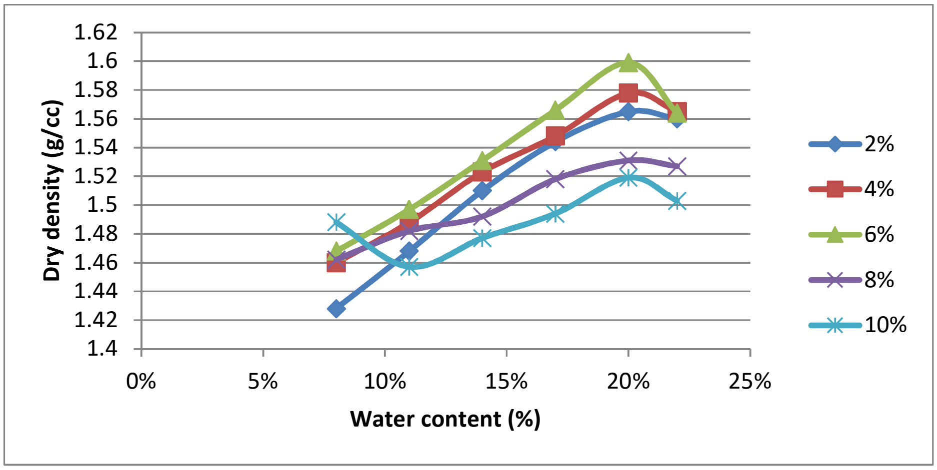


Figure 5.45 Variation of dry density with water content at 600ºC

5.2.7 UCS (Unconfined Compressive Strength)

5.2.7.1 UCS (400ºC)

UCS of BCS + 2% untanned leather waste added

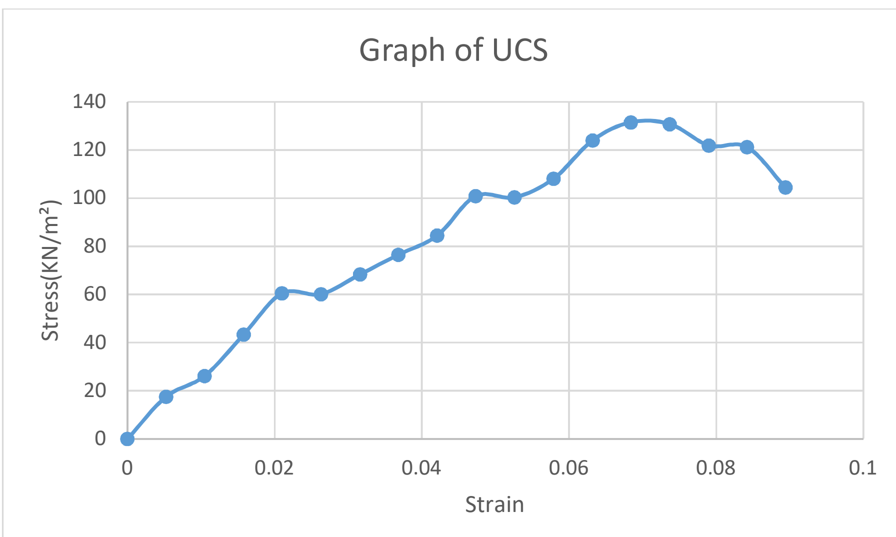


Figure 5.46 UCS of BCS+ 2% waste added (400ºC)

UCS of the sample is 131.49 kN/m²

The value of the UCS(BCS+2% at 400ºC) is taken from **(Annexure 1.4.1)**

UCS of BCS + 4% untanned leather waste added

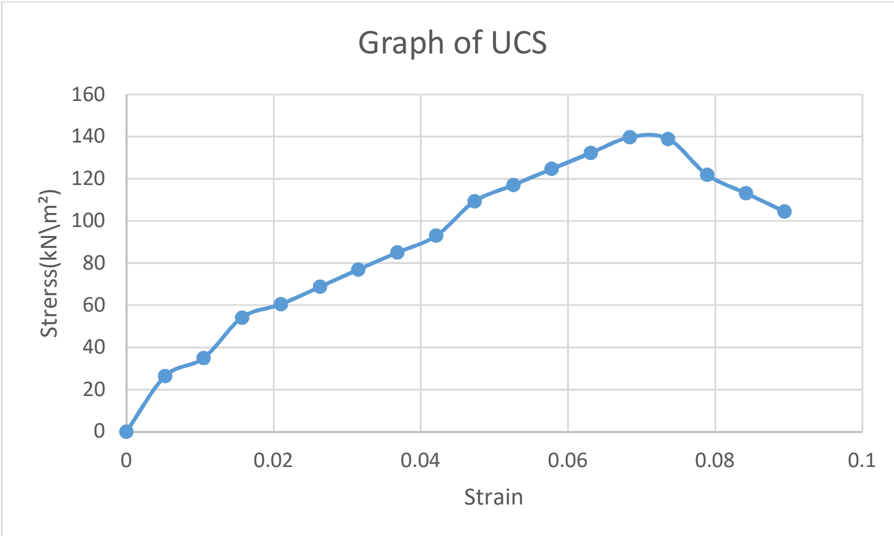


Figure 5.47 UCS of BCS+4% waste added (400ºC)

UCS of the sample is 139.71 kN/m²

The value of the UCS(BCS+4% at 400ºC) is taken from **(Annexure 1.4.2)**

UCS of BCS + 6% untanned leather waste added

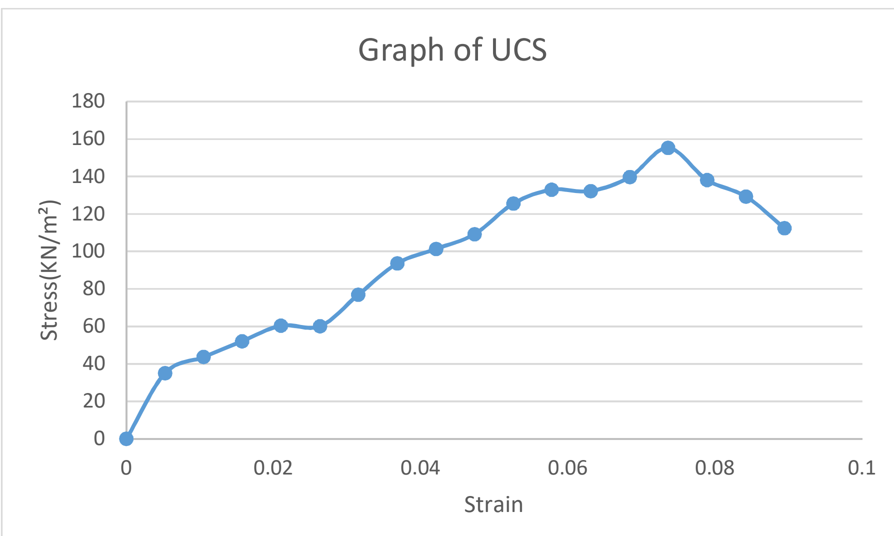


Figure 5.48 UCS of BCS+ 6% waste added (400ºC)

UCS of the sample is 155.26 kN/m²

The value of the UCS(BCS+6% at 400ºC) is taken from **(Annexure 1.4.3)**

UCS of BCS +8 % untanned leather waste added

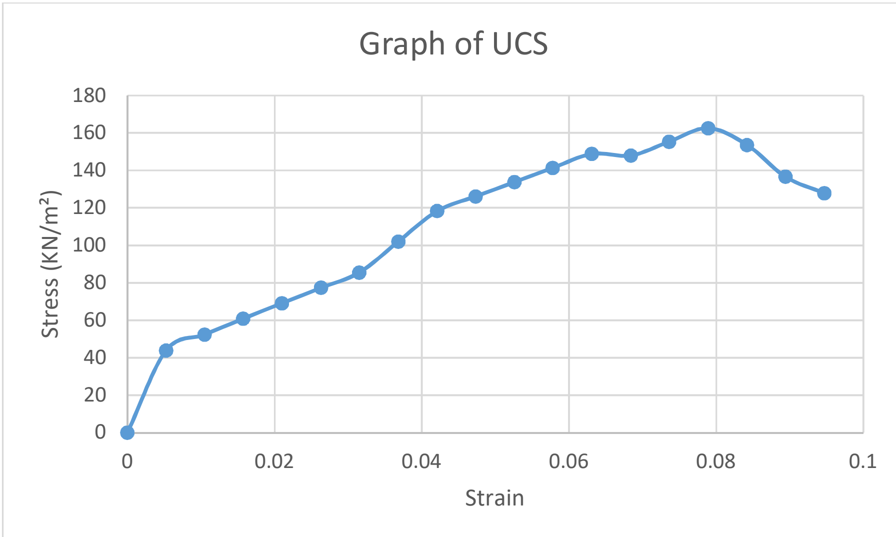


Figure 5.49 UCS of BCS+ 8% waste added (400ºC)

UCS of the sample is 162.5 kN/m²

The value of the UCS(BCS+8% at 400ºC) is taken from **(Annexure 1.4.4)**

5.2.7.2 Variation of UCS and waste content (400ºC)

Waste content (%)	Stress (N/m²)
0	108.31
2	131.49
4	139.71
6	155.26
8	162.5

Table 12 Variation of UCS and waste content (400ºC)

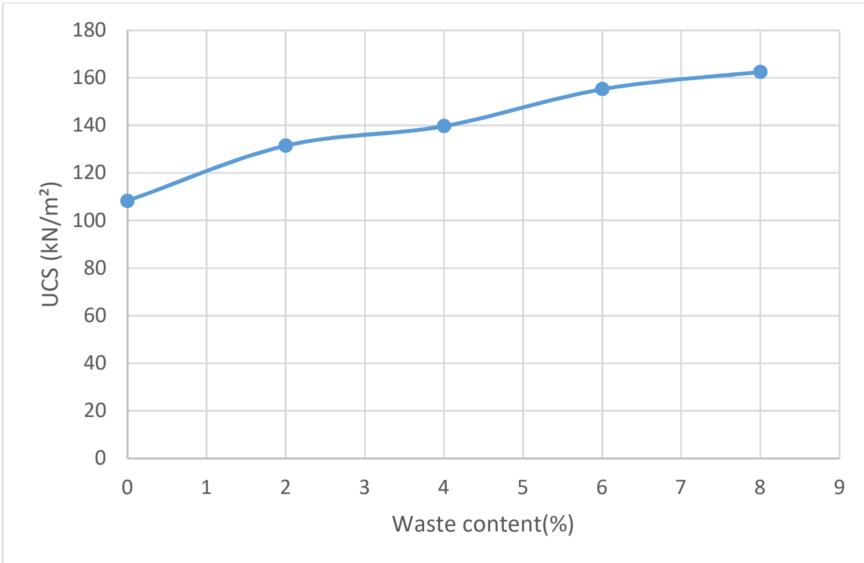


Figure 5.50 Variation of UCS and waste content (400ºC)

UCS of the sample is increasing with the addition of waste content. The maximum value is 162.5 kN/m² at 8% waste content.

5.2.7.3 UCS (600ºC)

UCS of BCS +2 % untanned leather waste added

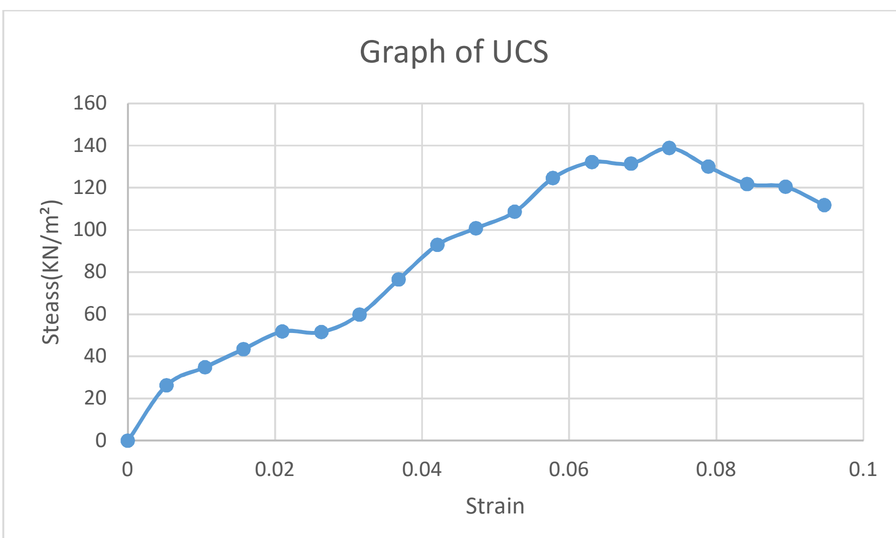


Figure 5.51 UCS of BCS + 2% waste added (600ºC)

UCS of the sample is 132.24 kN/m²

The value of the UCS(BCS+2% at 600ºC) is taken from **(Annexure 1.4.5)**

UCS of BCS + 4% untanned leather waste added

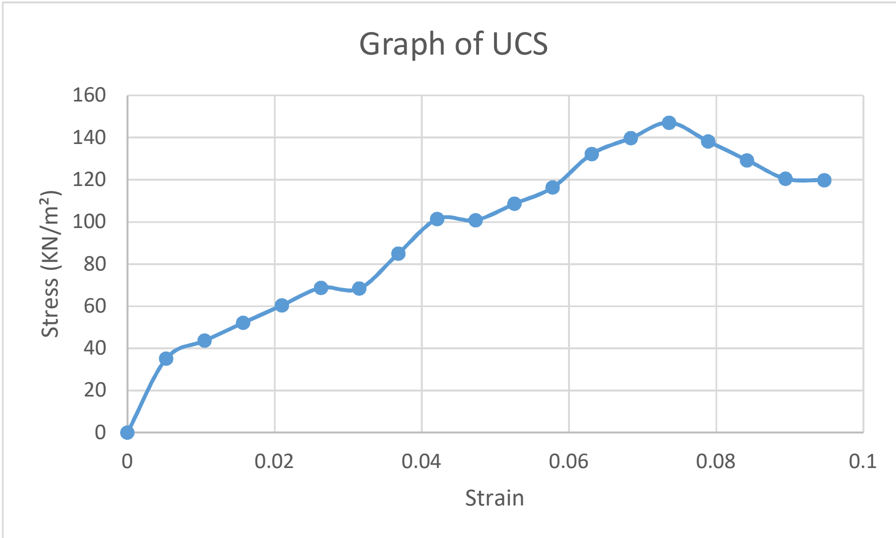


Figure 5.52 UCS of BCS + 4% waste added (600ºC)

UCS of the sample is 147.09 kN/m²

The value of the UCS(BCS+4% at 600ºC) is taken from **(Annexure 1.4.6)**

UCS of BCS +6 % untanned leather waste added

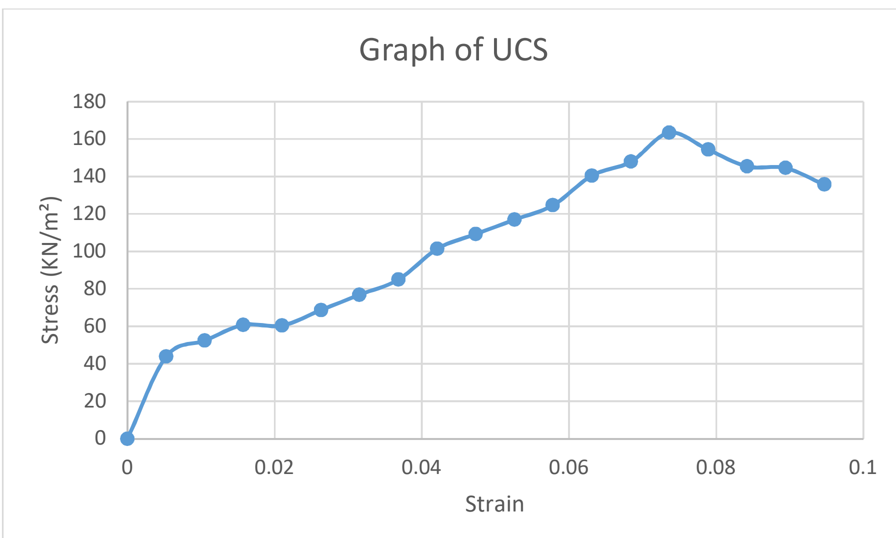


Figure 5.53 UCS of BCS + 6% waste added (600º

UCS of the sample is 163.44 kN/m²

The value of the UCS(BCS+6% at 600ºC) is taken from **(Annexure 1.4.7)**

UCS of BCS +8 % untanned leather waste added

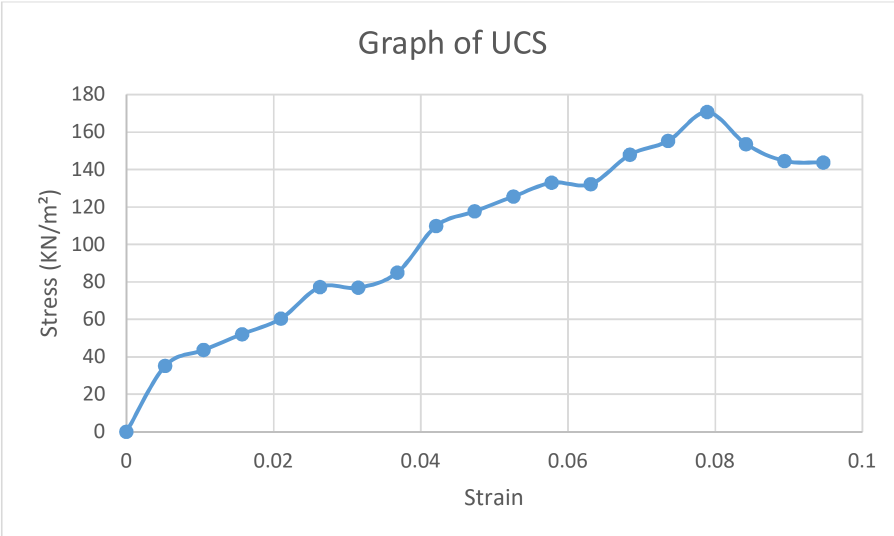


Figure 5.54 UCS of BCS+ 8% waste added (600ºC)

UCS of the sample is 170.63 kN/m²

The value of the UCS(BCS+8% at 600^{o}C) is taken from **(Annexure 1.4.8)**

5.2.7.4 Variation of UCS and waste content (600ºC)

Waste content (%)	**Stress (kN/m²)**
0	108.31
2	132.24
4	147.09
6	163.44
8	170.63

Table 13 Variation of UCS and waste content (600ºC)

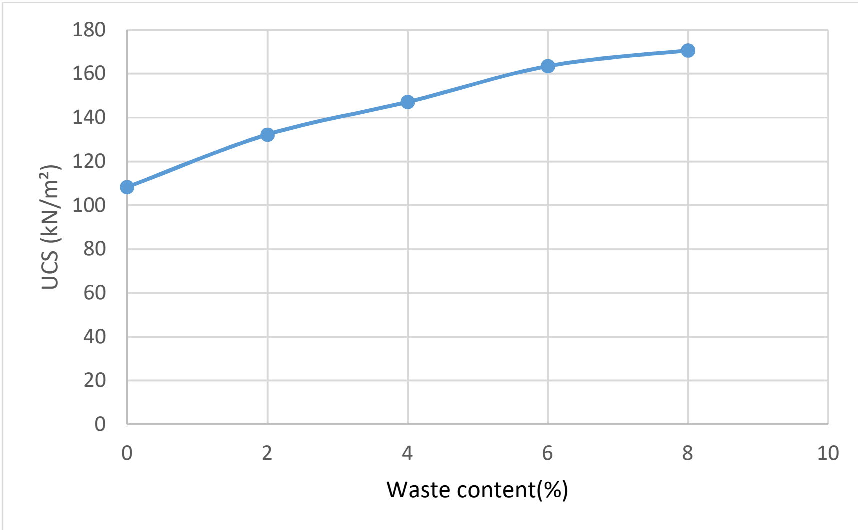


Figure 5.55 Variation of UCS and waste content (600ºC)

UCS of the sample is increasing with the addition of waste content. The maximum value is 170.63 kN/m² at 8% waste content.

5.2.7.5 Variation of UCS with waste contents at different temperatures

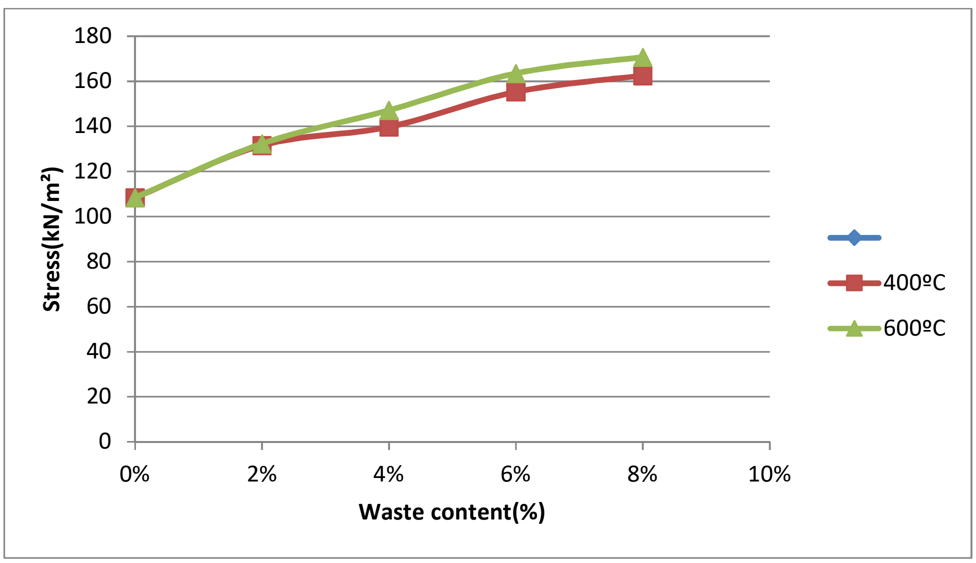


Figure 5.56 Variation of UCS with different waste contents at different temperatures

There is formation of CSH (Calcium silicate hydrate) and CASH(Calcium Aluminate Silicate Hydrate) resulting in the increase in strength.

CHAPTER 6

Conclusion

- By thermally treating 1 kg of untanned leather waste in incinerator, approximately 30%-33% yield of ash is obtained i.e. 300gm-330gm.

- As untanned leather waste ash was thermally treated (200°C,400°C,600°C), there was increase in the plastic limit. Maximum value of 59.9% was observed at 6% (600°C).

- As untanned leather waste ash is thermally treated (200°C,400°C,600°C), there was increase in the shrinkage limit. Maximum value of 17.15% was observed at 10% (600°C).

- As untanned leather waste ash is thermally treated (200°C,400°C,600°C), there was increase in the UCS. Maximum value of 170.63 kN/m^2 was observed at 10% (600°C).

- As untanned leather waste ash is thermally treated (200°C,400°C,600°C), there was decrease in dry density. Minimum value of 1.519 g/cc was observed at 10% (600°C).

- With increase in the waste content, the charge concentration and viscosity of pore fluid increases resulting in decrease of the diffuse double layer.

- There is formation of CSH (Calcium silicate hydrate) and CASH (Calcium Aluminate Silicate Hydrate) resulting in the increase in strength. This is because lime in the waste requires extra water for hydration reactions.

- Optimum waste content was found to be 6% in atterberg's limit at different variation of temperatures.

Future Scope

- By adding untanned leather waste at different contents by thermally treating at different temperatures, more varied results can be determined.

- The black cotton soil is abundant in India. By stabilizing it, we can get a good quality of soil for foundation.

- Using untanned leather waste as an additive shows the growth in strength and swelling properties of the black cotton soil.

- More varied results can be obtained of swelling tests by adding different waste contents at different temperature variations.

- Different types of skin matter can be used which contains lime as it can show different results.

Reference

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4. Dr. Akshaya Kumar Sabat(2012); " A Study on Some Geotechnical Properties of Lime Stabilized Expansive Soil – Quarry Dust Mixes" International Journal of Emerging trends in Engineering And Development, Volume 1 issue2, pp 2249-6149

5. Shailendra Singh, Hemant B. Vasaikar(2013); "Stabilization of Black Cotton Soil using Lime" International Journal of Science and Research, Volume 6 issue14, pp 2319-7064

6. R.K Etim, A.O Eberemu, K.J Osinubi(2017); "Stabilization of Black Cotton Soil with Lime and Iron ore tailings admixture" Journal of Transportation Geotechnics, Volume 5 issue9, pp 2214-3912

ANNEXURE

ANNEXURE 1.1

Annexure 1.1.1

IS Sieve (mm)	Retained soil	Retained soil weight percentage	Cumulative % retained	Percentage finer
4.75	0	0	0	100
2	620	42.10	41.60	58.40
1	392	24.90	68.80	31.20
0.6	185	12.33	79.90	20.10
0.425	130	9.12	89.02	10.98
0.212	95.6	6.37	95.39	4.61
0.15	30	2.00	97.39	2.61
0.075	24	1.60	98.99	1.01
pan	16	1.01	100.00	0.00

Table 14 Dry sieve analysis (Plain BCS)

Annexure 1.1.2

No of blows	Container weight (g)	Sample + Container weight (g)	Oven dried sample + weight of container (g)	Moisture content(%)
14	19.2	23.2	21.4	80.81%
31	19.6	23	21.6	70.03%
56	19.1	21.9	20.8	64.70%

Table 15 Liquid limit (Plain BCS)

Annexure 1.1.3

Empty container weight (g)	Wet sample + container weight (g)	Oven dry sample + container weight (g)	Moisture Content(%)
19.1	25.6	23.8	38.29787234
20.7	27.5	25.5	41.66666667
20.2	27.3	25.3	39.21568627

Table 16 Plastic limit (Plain BCS)

Annexure 1.1.4

Mould weight + weight of base plate	Weight of mould+soil + base plate	Water Content	Compacted soil	Bulk density	Dry density
(g)	(g)	(%)	(g)	(g/cc)	(g/cc)
3660	5035	0.05	1375	1.4550265	1.38573948
3660	5125.4	0.1	1465.4	1.5506878	1.40971621
3660	5197.4	0.14	1537.4	1.6268783	1.42708623
3660	5259.7	0.18	1599.7	1.6928042	1.43457986
3660	5317.2	0.2	1657.2	1.7536508	1.46137566
3660	5328	0.22	1668	1.7650794	1.44678636

Table 17 Compaction Curve (Plain BCS)

ANNEXURE 1.2

Annexure 1.2.1

No of blows	Container weight (g)	Sample + container weight (g)	Oven dried sample +Weight of container (g)	Moisture content (%)
109	19.6	22.67	21.5	61.57%
32	20.2	23.7	22.2	75%
16	19.4	23.6	21.79	78.35%

Table 18 Liquid limit (BCS+2% waste added at 200 ºC)

Annexure 1.2.2

Number of blows (n)	Container weight (g)	Sample + Container weight (g)	Oven dried sample + Weight of Container (g)	Moisture Content (%)
78	20.2	23.7	22.3	66.66666667
34	19.6	22.6	21.34	72.4137931
19	19.6	24.4	22.3	77.77777778

Table 19 Liquid limit (BCS + 4% waste added at 200ºC)

Annexure 1.2.3

Number of blows (n)	Container weight (g)	Sample + Container weight (g)	Oven dried sample+ weight of container (g)	Moisture Content (%)
82	19.1	24.3	22.2	67.7419355
40	19.6	24.8	22.6	73.3333333
14	19.3	24.6	22.2	82.7586207

Table 20 Liquid limit (BCS + 6% waste added at 200ºC)

Annexure 1.2.4

Number of blows (n)	container weight (g)	Sample + Container weight (g)	Oven dried sample+ Weight of container (g)	Moisture content(%)
96	19.1	24.5	22.3	68.75
33	19.6	24.6	22.5	72.4137931
12	19.3	22.3	21	76.4705882

Table 21 Liquid limit (BCS+ 8% waste added at 200ºC)

Annexure 1.2.5

Number of blows (n)	Container weight (g)	Sample + Container weight (g)	Oven dried sample+ Weight of container (g)	Moisture content(%)
87	19.1	22.32	21	69.47368421
30	19.4	22.9	21.41	74.12935323
10	18.7	23.24	21.23	79.44664032

Table 22 Liquid limit (BCS+ 10% waste added at 200ºC)

Annexure 1.2.6

Number of blows (n)	Container weight (g)	Sample + Container weight (g)	Oven dried sample+Weight of Container (g)	Water Content (%)
81	20.2	22.34	21.5	64.61538462
43	19.7	23.8	22.1	70.83333333
17	19.8	23.7	22.01	76.47058824

Table 23 Liquid limit (BCS +2 % waste added at 400ºC)

Annexure 1.2.7

Number of blows (n)	Container weight (g)	Sample + Container weight (g)	Oven dried sample+Weight of Container (g)	Water Content (%)
79	20.1	24.4	22.8	59.25925926
39	19.6	23.3	21.8	68.18181818
15	19.9	23.2	21.7	83.33333333

Table 24 Liquid limit (BCS +4 % waste added at 400ºC)

Annexure 1.2.8

Number of blows (n)	Container weight (g)	Sample + Container weight (g)	Oven dried sample+Weight of Container (g)	Water Content (%)
81	21.1	24.4	23.2	57.14285714
48	19.5	23.1	21.6	71.42857143
12	20.1	23.2	21.8	82.35294118

Table 25 Liquid limit (BCS +6 % waste added at 400ºC)

Annexure 1.2.9

Number of blows (n)	Container weight (g)	Sample + Container weight (g)	Oven dried sample+Weight of Container (g)	Water Content (%)
79	21.3	24.5	23.2	68.42105263
42	19.4	23.4	21.7	73.91304348
10	20.2	23.3	21.9	82.35294118

Table 26 Liquid limit (BCS +8 % waste added at 400ºC)

Annexure 1.2.10

Number of blows (n)	Container weight (g)	Sample + Container weight (g)	Oven dried sample+Weight of Container (g)	Water Content (%)
76	21.1	24.7	23.3	63.63636364
37	19.2	23.2	21.5	73.91304348
8	20.9	23.3	22.2	84.61538462

Table 27 Liquid limit (BCS +10 % waste added at 400ºC)

Annexure 1.2.11

Number of blows (n)	Container weight (g)	Sample + Container weight (g)	Oven dried sample+Weight of Container (g)	Water Content (%)
87	20.1	24.7	22.9	64.28571429
41	19.5	23.5	21.8	73.91304348
18	19.7	23.4	21.7	85

Table 28 Liquid limit (BCS +2 % waste added at 600ºC)

Annexure 1.2.12

Number of blows (n)	Container weight (g)	Sample + Container weight (g)	Oven dried sample+Weight of Container (g)	Water Content (%)
88	20.6	23.7	22.5	63.15789474
39	19.6	24.6	22.5	72.4137931
16	19.2	23.9	21.8	80.76923077

Table 29 Liquid limit (BCS +4 % waste added at 600ºC)

Annexure 1.2.13

Number of blows (n)	Container weight (g)	Sample + Container weight (g)	Oven dried sample+Weight of Container (g)	Water Content (%)
75	19.2	23.8	22.2	53.3333333
55	19.6	24.6	22.6	66.6666667
7	19.4	24.7	22.2	89.2857143

Table 30 Liquid limit (BCS +6 % waste added at 600ºC)

Annexure 1.2.14

Number of blows (n)	Container weight (g)	Sample + Container weight (g)	Oven dried sample+Weight of Container (g)	Water Content (%)
76	19.2	24.2	22.3	61.2903226
36	19.4	24.1	22.1	74.0740741
8	19.2	23.9	21.8	80.7692308

Table 31 Liquid limit (BCS +8 % waste added at 600ºC)

Annexure 1.2.15

Number of blows (n)	Container weight (g)	Sample + Container weight (g)	Oven dried sample+Weight of Container (g)	Water Content (%)
73	19.1	24.3	22.4	57.5757576
32	19.3	24	22	74.0740741
6	19.2	23.5	21.6	79.1666667

Table 32 Liquid limit (BCS +10% waste added at 600ºC)

Annexure 1.2.16

Empty container weight (g)	Wet sample + container weight (g)	Oven dry sample + container weight (g)	Moisture Content(%)
19.2	26.7	24.5	41.50943396
18.8	26.5	24.2	42.59259259
20.2	27.2	25.2	40

Table 33 Plastic limit (BCS +2% waste added at 200ºC)

Annexure 1.2.17

Empty container weight (g)	Wet sample + container weight (g)	Oven dry sample + container weight (g)	Moisture Content(%)
20.1	27.1	24.8	48.93617021
19.6	26.5	24.2	50
19.8	27.4	25	46.15384615

Table 34 Plastic limit (BCS +4% waste added at 200ºC)

Annexure 1.2.18

Empty container weight (g)	Wet sample + container weight (g)	Oven dry sample + container weight (g)	Moisture Content(%)
18.8	25.9	23.4	54.34782609
19.6	26.5	24.1	53.33333333
20.1	26.8	24.32	58.76777251

Table 35 Plastic limit (BCS +6% waste added at 200ºC)

Annexure 1.2.19

Empty container weight (g)	Wet sample + container weight (g)	Oven dry sample + container weight (g)	Moisture Content(%)
20.6	27.5	25.3	46.80851064
19.2	26.8	24.3	49.01960784
19.8	27.2	24.89	45.38310413

Table 36 Plastic limit (BCS +8% waste added at 200ºC)

Annexure 1.2.20

Empty container weight (g)	Wet sample + container weight (g)	Oven dry sample + container weight (g)	Moisture Content(%)
20.8	28.3	25.9	47.05882353
19.4	26.6	24.4	44
19.2	26.2	24.1	42.85714286

Table 37 Plastic limit (BCS +10% waste added at 200ºC)

Annexure 1.2.21

Empty container weight (g)	Wet sample + container weight (g)	Oven dry sample + container weight (g)	Moisture Content(%)
7.8	12.9	11.4	41.66666667
7.5	10.5	9.6	42.85714286
7.5	10.3	9.5	40

Table 38 Plastic limit (BCS +2% waste added at 400ºC)

Annexure 1.2.22

Empty container weight (g)	Wet sample + container weight (g)	Oven dry sample + container weight (g)	Moisture Content(%)
7.6	11.4	10.2	46.15384615
19.1	22.6	21.3	59.09090909
19.3	23.8	22.4	45.16129032

Table 39 Plastic limit (BCS +4% waste added at 400ºC)

Annexure 1.2.23

Empty container weight (g)	Wet sample + container weight (g)	Oven dry sample + container weight (g)	Moisture Content(%)
17.5	21.4	19.8	69.56521739
20.1	24.5	23	51.72413793
18.6	22.7	21.2	57.69230769

Table 40 Plastic limit (BCS +6% waste added at 400ºC)

Annexure 1.2.24

Empty container weight (g)	Wet sample + container weight (g)	Oven dry sample + container weight (g)	Moisture Content(%)
19.6	22.9	21.7	57.14285714
18.1	20.3	19.6	46.66666667
20.6	23.4	22.6	40

Table 41 Plastic limit (BCS +8% waste added at 400ºC)

Annexure 1.2.25

Empty container weight (g)	Wet sample + container weight (g)	Oven dry sample + container weight (g)	Moisture Content(%)
19.8	23.1	22.1	43.47826087
18.2	20.4	19.7	46.66666667
21.6	23.4	22.8	50

Table 42 Plastic limit (BCS +10% waste added at 400ºC)

Annexure 1.2.26

Empty container weight (g)	Wet sample + container weight (g)	Oven dry sample + container weight (g)	Moisture Content(%)
19.7	22.8	21.8	47.61904762
18.6	22.1	21	45.83333333
18.8	22.1	21	50

Table 43 Plastic limit (BCS +2% waste added at 600ºC)

Annexure 1.2.27

Empty container weight (g)	Wet sample + container weight (g)	Oven dry sample + container weight (g)	Moisture Content(%)
19.7	22.5	21.5	55.55555556
20.4	23.8	22.6	54.54545455
18.4	27.2	24.1	54.38596491

Table 44 Plastic limit (BCS +4% waste added at 600ºC)

Annexure 1.2.28

Empty container weight (g)	Wet sample + container weight (g)	Oven dry sample + container weight (g)	Moisture Content(%)
18.8	22.7	21.3	56
19.5	23.8	22.2	59.25925926
20.1	23.7	22.3	63.63636364

Table 45 Plastic limit (BCS +6% waste added at 600ºC)

Annexure 1.2.29

Empty container weight (g)	Wet sample + container weight (g)	Oven dry sample + container weight (g)	Moisture Content(%)
18.6	20.4	19.8	50
19.8	21.8	21.2	42.85714286
19.2	20.8	20.2	60

Table 46 Plastic limit (BCS +8% waste added at 600ºC)

Annexure 1.2.30

Empty container weight (g)	Wet sample + container weight (g)	Oven dry sample + container weight (g)	Moisture Content(%)
18.5	20.4	19.8	46.15384615
19.9	21.8	21.2	46.15384615
19	20.8	20.2	50

Table 47 Plastic limit (BCS +10% waste added at 600ºC)

Annexure 1 .2.31

BCS + waste added (%)	Empty ahrinkage dish weight w1 (g)	Shrinkage dish + wet sample w2 (g)	Shrinkage dish + dry sample w3(g)	Dry soil sample(g)	Mercury displaced by sample (g)	Volume of dry sample(g)	Wet soil sample (g)	Water content (%)	Shrinkage limit	Mean
BCS	31.1	68.2	54.6	23.5	168.5	12.38971	37.1	57.872	9.148	9.377
	30.8	69.7	56.3	25.5	175.3	12.88971	38.9	52.549	9.607	
2%	33.8	68.7	54.4	20.6	165.7	12.18382	34.9	69.417	12.83	12.04
	21.5	70	53.5	32	152	11.17647	48.5	51.563	11.99	
	35.1	67.4	53.3	18.2	160.4	11.79412	32.3	77.473	11.29	
4%	34.4	65.8	55.9	17.2	165.7	12.18382	31.4	82.558	14.79	12.86
	32.7	67.6	52.9	20.2	159.9	11.75735	34.9	72.772	12.96	
	33.1	71.3	57.6	24.5	174	12.79412	38.2	55.918	10.83	
6%	33.6	64.3	50.4	16.8	168.1	12.36029	30.7	82.738	14.41	13.98
	36.2	69.8	55	18.8	157.8	11.60294	33.6	78.723	13.63	
	29.6	66.7	51.5	21.9	158.9	11.68382	37.1	69.406	13.9	
8%	33.6	61.3	48	14.4	174.3	12.81618	27.7	92.361	15.81	14.22
	36.5	69.9	55.5	19	170	12.5	33.4	75.789	16.11	
	37.6	72.1	58.4	20.8	168.3	12.375	34.5	65.865	10.75	
10%	32.2	61.9	48	15.8	165.4	12.16176	29.7	87.975	14.06	15.01
	34.3	72.4	57.7	23.4	170.2	12.51471	38.1	62.821	14.42	
	28.9	69.5	53.9	25	168.3	12.375	40.6	62.4	16.54	

Table 48 Shrinkage limit (200ºC)

Annexure 1.2.32

BCS + waste added (%)	Empty ahrinkage dish weight w1 (g)	Shrinkage dish + wet sample w2 (g)	Shrinkage dish + dry sample w3(g)	Dry soil sample(g)	Mercury displaced by sample (g)	Volume of dry sample(g)	Wet soil sample (g)	Water content (%)	Shrinkage limit	Mean
BCS	31.1	68.2	54.6	23.5	168.5	12.38971	37.1	57.872	9.148	9.377
	30.8	69.7	56.3	25.5	175.3	12.88971	38.9	52.549	9.607	
2%	33.4	68.7	54.4	21	166.4	12.23529	35.3	68.095	12.83	12.64
	22.7	66.5	51	28.3	164	12.05882	43.8	54.77	13.14	
	35.8	70.5	56	20.2	159.8	11.75	34.7	71.782	11.93	
4%	35	66.3	50	17.2	164.8	12.11765	31.3	81.977	13.82	13.77
	35.5	67.3	52.9	17.4	160.1	11.77206	31.8	82.759	13.4	
	37.3	71.8	57.6	20.3	170	12.5	34.5	69.951	14.09	
6%	33.6	63.4	49.8	16.2	172.4	12.67647	29.8	83.951	15.04	14.47
	36.2	70.8	56.1	19.9	162.5	11.94853	34.6	73.869	14.11	
	29.6	66.7	51.5	21.9	160	11.76471	37.1	69.406	14.27	
8%	33.1	61.3	48	14.9	172.4	12.67647	28.2	89.262	14.34	15.1
	36.5	69.9	55.5	19	170	12.5	33.4	75.789	16.11	
	37.6	73.2	58.4	20.8	165	12.13235	35.6	71.154	14.87	
10%	32.3	64.5	50.1	17.8	164.7	12.11029	32.2	80.899	15	16.22
	34.3	72.4	57	22.7	163.3	12.00735	38.1	67.841	15.72	
	29.4	71.2	55.5	26.1	174.4	12.82353	41.8	60.153	17.94	

Table 49 Shrinkage limit (400ºC)

Annexure 1.2.33

BCS + waste added (%)	Empty ahrinkage dish weight w1 (g)	Shrinkage dish + wet sample w2 (g)	Shrinkage dish + dry sample w3(g)	Dry soil sample(g)	Mercury displaced by sample (g)	Volume of dry sample(g)	Wet soil sample (g)	Water content (%)	Shrinkage limit	Mean
BCS	31.1	68.2	54.6	23.5	168.5	12.38971	37.1	57.872	9.148	9.377
	30.8	69.7	56.3	25.5	175.3	12.88971	38.9	52.549	9.607	
2%	32.5	69.1	54.4	21.9	165.7	12.18382	36.6	67.123	13.9	12.79
	20.8	70.4	53.5	32.7	152	11.17647	49.6	51.682	12.96	
	34.6	67.5	53.3	18.7	160.4	11.79412	32.9	75.936	11.52	
4%	34.3	65.4	55.9	17.2	165.7	12.18382	31.1	80.814	13.05	14.21
	28.7	68.1	52.9	24.2	159.9	11.75735	39.4	62.81	12.88	
	38.7	71.8	57.6	18.9	174	12.79412	33.1	75.132	16.69	
6%	35.5	64.4	50.4	14.9	168.1	12.36029	28.9	93.96	16.91	15.28
	37.3	69.7	55	17.7	157.8	11.60294	32.4	83.051	13.91	
	29.9	66.9	51.5	21.6	158.9	11.68382	37	71.296	15.02	
8%	32.1	62.4	49	16.9	174.3	12.81618	30.3	79.29	14.06	16.2
	36.9	69.6	55.5	18.6	170	12.5	32.7	75.806	14.84	
	37.5	74.1	58.5	21	168.3	12.375	36.6	74.286	19.69	
10%	33.3	62.6	48.4	15.1	165.4	12.16176	29.3	94.04	16.7	17.15
	35.6	72	57.2	21.6	170.2	12.51471	36.4	68.519	16.09	
	29.9	72.1	55.8	25.9	168.3	12.375	42.2	62.934	18.67	

Table 50 Shrinkage limit (600ºC)

ANNEXURE 1.3

Annexure 1.3.1

Mould weight + weight of base plate	Weight of mould+soil + base plate	Water Content	Compacted soil	Bulk density	Dry density
(g)	(g)	(%)	(g)	(g/cc)	(g/cc)
3660	5106.3	0.08	1446.3	1.5304762	1.41710758
3660	5133.5	0.11	1528.9	1.6178836	1.45755279
3660	5285	0.14	1625	1.7195767	1.50840063
3660	5376.6	0.17	1716.6	1.8165079	1.55257089
3708	5478.8	0.2	1770.8	1.8738624	1.56155203
3660	5459.1	0.22	1799.1	1.9038095	1.56049961

Table 51 Compaction Curve (BCS +2% waste at 400ºC)

Annexure 1.3.2

Mould weight + weight of base plate	Weight of mould+soil + base plate	Water Content	Compacted soil	Bulk density	Dry density
(g)	(g)	(%)	(g)	(g/cc)	(g/cc)
3660	5140.6	0.08	1480.6	1.5667725	1.45071527
3660	5189.4	0.1	1529.4	1.6184127	1.47128427
3660	5283.3	0.14	1623.3	1.7177778	1.50682261
3660	5365	0.17	1705	1.8042328	1.54207932
3660	5442.7	0.2	1782.7	1.886455	1.57204586
3660	5469.1	0.22	1809.1	1.9143915	1.56917339

Table 52 Compaction Curve (BCS +4% waste at 400ºC)

Annexure 1.3.3

Mould weight + weight of base plate	Weight of mould+soil + base plate	Water Content	Compacted soil	Bulk density	Dry density
(g)	(g)	(%)	(g)	(g/cc)	(g/cc)
3660	5150.3	0.08	1490.3	1.577037	1.46021948
3660	5207.6	0.1	1547.6	1.637672	1.48879269
3660	5292.3	0.14	1632.3	1.7273016	1.51517683
3660	5369.1	0.17	1709.1	1.8085714	1.54578755
3660	5461	0.2	1801	1.9058201	1.58818342
3660	5473.5	0.22	1813.5	1.9190476	1.57298985

Table 53 Compaction Curve (BCS+6% waste added at 400ºC)

Annexure 1.3.4

Mould weight + weight of base plate	Weight of mould+soil + base plate	Water Content	Compacted soil	Bulk density	Dry density
(g)	(g)	(%)	(g)	(g/cc)	(g/cc)
3660	5113.3	0.05	1453.3	1.5378836	1.46465105
3660	5189.2	0.1	1529.2	1.6182011	1.47109187
3660	5287.6	0.14	1627.6	1.722328	1.51081407
3660	5362.2	0.17	1702.2	1.8012698	1.53954687
3660	5416.7	0.2	1756.7	1.8589418	1.54911817
3660	5406.7	0.22	1746.7	1.8483598	1.51504901

Table 54 Compaction Curve (BCS+8% waste added at 400ºC)

Annexure 1.3.5

Mould weight + weight of base plate	Weight of mould+soil + base plate	Water Content	Compacted soil	Bulk density	Dry density
(g)	(g)	(%)	(g)	(g/cc)	(g/cc)
3660	5107.4	0.05	1447.4	1.5316402	1.45870496
3660	5180.7	0.1	1520.7	1.6092063	1.46291486
3660	5256.3	0.14	1596.3	1.6892063	1.48175996
3660	5321.4	0.18	1661.4	1.7580952	1.48991122
3660	5399.3	0.2	1739.3	1.8405291	1.53377425
3660	5410.9	0.22	1750.9	1.8528042	1.51869199

Table 55 Compaction Curve (BCS+10% waste added at 400ºC)

Annexure 1.3.6

Mould weight + weight of base plate	Weight of mould+soil + base plate	Water Content	Compacted soil	Bulk density	Dry density
(g)	(g)	(%)	(g)	(g/cc)	(g/cc)
3660	5117.5	0.08	1457.5	1.542328	1.42808152
3660	5186	0.1	1526	1.6148148	1.46801347
3660	5287.4	0.14	1627.4	1.7221164	1.51062842
3660	5368.1	0.17	1708.1	1.8075132	1.5448831
3660	5435.5	0.2	1775.5	1.878836	1.56569665
3660	5459.3	0.22	1799.3	1.9040212	1.56067309

Table 56 Compaction Curve (BCS+2% waste added at 600ºC)

Annexure 1.3.7

Mould weight + weight of base plate	Weight of mould+soil + base plate	Water Content	Compacted soil	Bulk density	Dry density
(g)	(g)	(%)	(g)	(g/cc)	(g/cc)
3660	5156.2	0.08	1496.2	1.5832804	1.46600039
3660	5207.1	0.1	1547.1	1.6371429	1.48831169
3660	5301.3	0.14	1641.3	1.7368254	1.52353105
3660	5372.6	0.17	1712.6	1.8122751	1.5489531
3660	5449.8	0.2	1789.8	1.8939683	1.57830688
3660	5462.7	0.22	1802.7	1.907619	1.56362217

Table 57 Compaction Curve (BCS+4% waste added at 600ºC)

Annexure 1.3.8

Mould weight + weight of base plate	Weight of mould+soil + base plate	Water Content	Compacted soil	Bulk density	Dry density
(g)	(g)	(%)	(g)	(g/cc)	(g/cc)
3660	5158.9	0.08	1498.9	1.5861376	1.46864589
3660	5216.6	0.1	1556.6	1.6471958	1.4974507
3660	5309.8	0.14	1649.8	1.7458201	1.53142115
3660	5392.2	0.17	1732.2	1.8330159	1.56668023
3660	5473.4	0.2	1813.4	1.9189418	1.59911817
3660	5463.7	0.22	1803.7	1.9086772	1.56448955

Table 58 Compaction Curve (BCS+6% waste added at 600ºC)

Annexure 1.3.9

Mould weight + weight of base plate	Weight of mould+soil + base plate	Water Content	Compacted soil	Bulk density	Dry density
(g)	(g)	(%)	(g)	(g/cc)	(g/cc)
3660	5153	0.08	1493	1.5798942	1.46286498
3660	5201.8	0.1	1541.8	1.6315344	1.48321308
3660	5267.5	0.14	1607.5	1.7010582	1.49215632
3660	5339	0.17	1679	1.7767196	1.51856374
3660	5397.2	0.2	1737.2	1.8383069	1.5319224
3660	5421	0.22	1761	1.8634921	1.52745251

Table 59 Compaction Curve (BCS+8% waste added at 600ºC)

Annexure 1.3.10

Mould weight + weight of base plate	**Weight of mould+soil + base plate**	**Water Content**	**Compacted soil**	**Bulk density**	**Dry density**
(g)	(g)	(%)	(g)	(g/cc)	(g/cc)
3660	5138.8	0.08	1478.8	1.5648677	1.4489516
3660	5175.1	0.1	1515.1	1.6032804	1.45752766
3660	5251.2	0.14	1591.2	1.6838095	1.4770259
3660	5312.2	0.17	1652.2	1.7483598	1.49432461
3660	5382.7	0.2	1722.7	1.822963	1.5191358
3660	5393.6	0.22	1733.6	1.8344974	1.50368636

Table 60 Compaction Curve (BCS+10% waste added at 600ºC)

ANNEXURE 1.4

Annexure 1.4.1

Deformation	Load Sample	Corrected area	Strain	Stress
0	0		0	0
0.4	0.02	1139.537566	0.005263158	17.55097909
0.8	0.03	1145.598936	0.010526316	26.18717516
1.2	0.05	1151.725134	0.015789474	43.41313612
1.6	0.07	1157.917204	0.021052632	60.45337243
2	0.07	1164.176216	0.026315789	60.1283543
2.4	0.08	1170.503261	0.031578947	68.34666991
2.8	0.09	1176.899454	0.036842105	76.47212319
3.2	0.1	1183.365934	0.042105263	84.50471416
3.6	0.12	1189.903867	0.047368421	100.848483
4	0.12	1196.514444	0.052631579	100.2913091
4.4	0.13	1203.198883	0.057894737	108.0453131
4.8	0.15	1209.958427	0.063157895	123.9712015
5.2	0.16	1216.79435	0.068421053	131.4930497
5.6	0.16	1223.707955	0.073684211	130.7501511
6	0.15	1230.700571	0.078947368	121.8817993
6.4	0.15	1237.773563	0.084210526	121.1853318
6.8	0.13	1244.928324	0.089473684	104.4236825

Table 61 UCS (BCS+ 2% waste added at 400ºC)

Annexure 1.4.2

Deformation	Load Sample	Corrected area	Strain	Stress
0	0		0	0
0.4	0.03	1139.537566	0.005263158	26.32646864
0.8	0.04	1145.598936	0.010526316	34.91623354
1.2	0.06	1151.725134	0.015789474	52.09576334
1.6	0.07	1157.917204	0.021052632	60.45337243
2	0.08	1164.176216	0.026315789	68.7181192
2.4	0.09	1170.503261	0.031578947	76.89000365
2.8	0.1	1176.899454	0.036842105	84.96902577
3.2	0.11	1183.365934	0.042105263	92.95518557
3.6	0.13	1189.903867	0.047368421	109.2525233
4	0.14	1196.514444	0.052631579	117.0065273
4.4	0.15	1203.198883	0.057894737	124.667669
4.8	0.16	1209.958427	0.063157895	132.2359483
5.2	0.17	1216.79435	0.068421053	139.7113653
5.6	0.17	1223.707955	0.073684211	138.9220356
6	0.15	1230.700571	0.078947368	121.8817993
6.4	0.14	1237.773563	0.084210526	113.1063097
6.8	0.13	1244.928324	0.089473684	104.4236825

Table 62 UCS (BCS+ 4% waste added at 400ºC)

Annexure 1.4.3

Deformation	Load Sample	Corrected area	Strain	Stress
0	0		0	0
0.4	0.04	1139.537566	0.005263158	35.10195819
0.8	0.05	1145.598936	0.010526316	43.64529193
1.2	0.06	1151.725134	0.015789474	52.09576334
1.6	0.07	1157.917204	0.021052632	60.45337243
2	0.07	1164.176216	0.026315789	60.1283543
2.4	0.09	1170.503261	0.031578947	76.89000365
2.8	0.11	1176.899454	0.036842105	93.46592835
3.2	0.12	1183.365934	0.042105263	101.405657
3.6	0.13	1189.903867	0.047368421	109.2525233
4	0.15	1196.514444	0.052631579	125.3641364
4.4	0.16	1203.198883	0.057894737	132.9788469
4.8	0.16	1209.958427	0.063157895	132.2359483
5.2	0.17	1216.79435	0.068421053	139.7113653
5.6	0.19	1223.707955	0.073684211	155.2658045
6	0.17	1230.700571	0.078947368	138.1327058
6.4	0.16	1237.773563	0.084210526	129.264354
6.8	0.14	1244.928324	0.089473684	112.4562735

Table 63 UCS (BCS+ 6% waste added at 400ºC)

Annexure 1.4.4

Deformation	Load Sample	Corrected area	Strain	Stress
0	0		0	0
0.4	0.05	1139.537566	0.005263158	43.87744773
0.8	0.06	1145.598936	0.010526316	52.37435031
1.2	0.07	1151.725134	0.015789474	60.77839057
1.6	0.08	1157.917204	0.021052632	69.0895685
2	0.09	1164.176216	0.026315789	77.3078841
2.4	0.1	1170.503261	0.031578947	85.43333739
2.8	0.12	1176.899454	0.036842105	101.9628309
3.2	0.14	1183.365934	0.042105263	118.3065998
3.6	0.15	1189.903867	0.047368421	126.0606038
4	0.16	1196.514444	0.052631579	133.7217455
4.4	0.17	1203.198883	0.057894737	141.2900248
4.8	0.18	1209.958427	0.063157895	148.7654418
5.2	0.18	1216.79435	0.068421053	147.9296809
5.6	0.19	1223.707955	0.073684211	155.2658045
6	0.2	1230.700571	0.078947368	162.5090657
6.4	0.19	1237.773563	0.084210526	153.5014203
6.8	0.17	1244.928324	0.089473684	136.5540463
7.2	0.16	1252.166279	0.094736842	127.7785568

Table 64 UCS (BCS+ 8% waste added at 400ºC)

Annexure 1.4.5

Deformation	Load Sample	Corrected area	Strain	Stress
0	0		0	0
0.4	0.03	1139.537566	0.005263158	26.32646864
0.8	0.04	1145.598936	0.010526316	34.91623354
1.2	0.05	1151.725134	0.015789474	43.41313612
1.6	0.06	1157.917204	0.021052632	51.81717637
2	0.06	1164.176216	0.026315789	51.5385894
2.4	0.07	1170.503261	0.031578947	59.80333617
2.8	0.09	1176.899454	0.036842105	76.47212319
3.2	0.11	1183.365934	0.042105263	92.95518557
3.6	0.12	1189.903867	0.047368421	100.848483
4	0.13	1196.514444	0.052631579	108.6489182
4.4	0.15	1203.198883	0.057894737	124.667669
4.8	0.16	1209.958427	0.063157895	132.2359483
5.2	0.16	1216.79435	0.068421053	131.4930497
5.6	0.17	1223.707955	0.073684211	138.9220356
6	0.16	1230.700571	0.078947368	130.0072525
6.4	0.15	1237.773563	0.084210526	121.1853318
6.8	0.15	1244.928324	0.089473684	120.4888644
7.2	0.14	1252.166279	0.094736842	111.8062372

Table 65 UCS (BCS+ 2% waste added at 600ºC)

Annexure 1.4.6

Deformation	Load Sample	Corrected area	Strain	Stress
0	0		0	0
0.4	0.04	1139.537566	0.005263158	35.10195819
0.8	0.05	1145.598936	0.010526316	43.64529193
1.2	0.06	1151.725134	0.015789474	52.09576334
1.6	0.07	1157.917204	0.021052632	60.45337243
2	0.08	1164.176216	0.026315789	68.7181192
2.4	0.08	1170.503261	0.031578947	68.34666991
2.8	0.1	1176.899454	0.036842105	84.96902577
3.2	0.12	1183.365934	0.042105263	101.405657
3.6	0.12	1189.903867	0.047368421	100.848483
4	0.13	1196.514444	0.052631579	108.6489182
4.4	0.14	1203.198883	0.057894737	116.356491
4.8	0.16	1209.958427	0.063157895	132.2359483
5.2	0.17	1216.79435	0.068421053	139.7113653
5.6	0.18	1223.707955	0.073684211	147.09392
6	0.17	1230.700571	0.078947368	138.1327058
6.4	0.16	1237.773563	0.084210526	129.264354
6.8	0.15	1244.928324	0.089473684	120.4888644
7.2	0.15	1252.166279	0.094736842	119.792397

Table 66 UCS (BCS+ 4% waste added at 600ºC)

Annexure 1.4.7

	Load			
Deformation	Sample	Corrected area	Strain	Stress
0	0		0	0
0.4	0.05	1139.537566	0.005263158	43.87744773
0.8	0.06	1145.598936	0.010526316	52.37435031
1.2	0.07	1151.725134	0.015789474	60.77839057
1.6	0.07	1157.917204	0.021052632	60.45337243
2	0.08	1164.176216	0.026315789	68.7181192
2.4	0.09	1170.503261	0.031578947	76.89000365
2.8	0.1	1176.899454	0.036842105	84.96902577
3.2	0.12	1183.365934	0.042105263	101.405657
3.6	0.13	1189.903867	0.047368421	109.2525233
4	0.14	1196.514444	0.052631579	117.0065273
4.4	0.15	1203.198883	0.057894737	124.667669
4.8	0.17	1209.958427	0.063157895	140.5006951
5.2	0.18	1216.79435	0.068421053	147.9296809
5.6	0.2	1223.707955	0.073684211	163.4376889
6	0.19	1230.700571	0.078947368	154.3836124
6.4	0.18	1237.773563	0.084210526	145.4223982
6.8	0.18	1244.928324	0.089473684	144.5866373
7.2	0.17	1252.166279	0.094736842	135.7647166

Table 67 UCS (BCS+ 6% waste added at 600ºC)

Annexure 1.4.8

	Load			
Deformation	Sample	Corrected area	Strain	Stress
0	0		0	0
0.4	0.04	1139.537566	0.005263158	35.10195819
0.8	0.05	1145.598936	0.010526316	43.64529193
1.2	0.06	1151.725134	0.015789474	52.09576334
1.6	0.07	1157.917204	0.021052632	60.45337243
2	0.09	1164.176216	0.026315789	77.3078841
2.4	0.09	1170.503261	0.031578947	76.89000365
2.8	0.1	1176.899454	0.036842105	84.96902577
3.2	0.13	1183.365934	0.042105263	109.8561284
3.6	0.14	1189.903867	0.047368421	117.6565636
4	0.15	1196.514444	0.052631579	125.3641364
4.4	0.16	1203.198883	0.057894737	132.9788469
4.8	0.16	1209.958427	0.063157895	132.2359483
5.2	0.18	1216.79435	0.068421053	147.9296809
5.6	0.19	1223.707955	0.073684211	155.2658045
6	0.21	1230.700571	0.078947368	170.634519
6.4	0.19	1237.773563	0.084210526	153.5014203
6.8	0.18	1244.928324	0.089473684	144.5866373
7.2	0.18	1252.166279	0.094736842	143.7508764

Table 68 UCS (BCS+ 8% waste added at 600ºC)