"EFFECT OF CURING TIME AND CURING STRESS ON UNCONFINED COMPRESSIVE STRENGTH OF CEMENT-SOIL MIXTURE"

Project Report

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

BACHELOR OF TECHNOLOGY
IN
CIVIL ENGINEERING

By

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To

JAYPEE UNIVERSITY OF INFORMATION TECHNOLOGY

WAKNAGHAT, SOLAN – 173234

HIMACHAL PRADESH, INDIA

MAY 2017

CERTIFICATE

This is to certify that the work which is being presented in the project report titled **"EFFECT OF CURING TIME, CURING STRESS ON UNCONFINED COMPRESSIVE STRENGTH OF CEMENT-SOIL MIXTURE"** in partial fulfilment 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 **DEEPAK KUMAR HARITWAL**(Enrolment no. 131621) and **ABHISHEK SHARMA** (Enrolment no. 131679) during a period from July 2016 to May 2017 under the supervision of **Mr. SANTU KAR**, Assistant Professor, Department of Civil Engineering, Jaypee University of Information Technology, Waknaghat.

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

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The topic **"EFFECT OF CURING TIME, CURING STRESS ON UNCONFINED COMPRESSIVE STRENGTH OF CEMENT-SOIL MIXTURE"** was very helpful to us in giving the necessary background information and inspiration in choosing this topic for the project. Our sincere thanks to our Project Guide **Mr. SANTU KAR,** faculty of Civil Engineering Department for having supported the work related to this project. Their contributions and technical support in preparing this report are greatly acknowledged.

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ABSTRACT

The new ground improvement techniques, linking to strengthen the weaker soils and to increase the strength characteristics and stiffness of different types of soils, cement stabilization is showed to be very effective. In the cement stabilization, the “curing time” and the “curing stress” are important factors but inadequate literature shows the importance of the curing conditions, mainly time. To attain this, unconfined compression tests have been conducted on a type of soil by varying the percentage of cement content from 8 to 12 percentage and check the unconfined compression strength at different curing days like 3, 7, 14, 28 and 56 days separately and also a curing stress of 5kpa is being used along with curing time to check the combined effect of both curing time and curing stress. The results show that the curing time and the curing stress have a significant effect on the unconfined compressive strength and curing time is the dominant factor and, it is found that on the addition of cement content, the engineering properties are also affected. It was found that addition of cement in the soil results in decreases the compressibility of the soil and the mixture become brittle also it will leads to increased unconfined compressive strength when compared to unimproved soils. Also, the unconfined compressive strength of the cement-soil mixture increases with curing time and with vertical confining stress. The existence of fibbers in the cement-soil mixture can significantly improve its ductility which will help in overcome the problem of brittles in the soil.

OBJECTIVES

The specific objectives of the study are as follows:

- To find out the effect of different curing days on unconfined compressive strength of cement soil mixture.
- To find out the effect of curing stress on unconfined compressive strength of cement soil mixture.

CHAPTER 1

1.1. INTRODUCTION AND BACKGROUND

There are different ground improvement techniques in which cement soil mixture is also an important method because of its low cost and its efficiency also to improve the engineering properties of soft soils, materials, such as cement and fibber, is being used along with the soil mass. The cement soil mixture increases the strength of the soil but on the other hand it will also increases the brittleness of the mixture which can be counterattack by using fibres in the cement soil mixture. Cement soil mixture have low compressibility and low permeability and high strength if it is being matched with ordinary soft soils.

The method is not consistent and its name is also not fixed and this technique is called by different name by different scientist according to the mixing techniques like “deep mixing method” and “cement Deep soil mixing” by Bergado(1960) and Dailer and Yang(2005).

The technique of using cement in the soil to improve the properties of the soil for various purposes is being used by Port and Harbour research institute japan for the first time in 1970 and thereafter these technique CSM, has been utilized in many applications throughout the world. Cement soil mixture was used to strengthen the embankment of San Francisco’s largest potable water reservoir, to stabilize the contaminated sediments in Newark Bay, and to reinforce a slope to maintain its integrity during seismic.

Typical applications of Cement soil mixture include liquefaction mitigation soil and foundation stabilization, vibration reduction and excavation support walls. Structures such as high-speed rail tracks and wind turbines, have employed the use of CSM to improve foundations.

Current design criterion assumes shear strength parameters are obtainable through the measurement of unconfined compressive strength at 28-day curing time, without considering the effects of curing time and curing stress and the simplified design criterion does not reflect the field behaviour of cement soil mixtures.

When cement and/or fibber are used to strengthen soft soils, some considerations include the curing time or curing stress effect on UCS Separately, curing time and curing stress effect on UCS together, changing of the strength or strain at failure by addition of fibber, and the post peak strength behaviour of cement-soft soil Mixture with included fibber. To understand the properties of cement soil mixture, a series of unconfined compression tests were conducted with special attention being paid to the effects of curing time and vertical curing stress.

1.2. IMPORTANCE OF THE PROJECT

- ❖ The construction of heavy structures on soils of low relative density and especially in seismic –prone areas.
- ❖ The advantage of deep soil mixing method is that it not only improves the strength of ground, but is a superior method for the limitation of settlement.
- ❖ Cement soil mixture increases the stiffness of the soil and also some other engineering properties.
- ❖ Increasing the soil bearing capacity and a decrease in compressibility shall be gained, which in turn reduces the overall foundation cost by allowing the superstructure to be built on shallow footings rather than pile.
- ❖ Cement soil mixture has been found to improve the resistance against freeze-thaw effect. It is being detected that, resistance against freeze-thaw and wet-dry cycling increase with the use of cement in soil because this mixture ultimately increase the unconfined compression strength of soil.
- ❖ The project will help us to find out the optimum cement content that must be used to attain the maximum unconfined compressive strength and also find out the effect of cement content on curing days so that we can vary our cement content according to curing time to meet our need.

1.3. SCOPE

- The mixture becomes brittle when large amount of curing stress is applied.
- Specimen with higher curing stresses fails at lower vertical strain and this is valid for both cement and cement fibre improved soil specimen.
- Less amount of fibre that is generally less than 0.3% do not change the UCS too much.
- It is unlikely that UCS will increase linearly and infinitely with increasing curing stress after certain higher range of 400kpa.
- Formost of the situations, loads will be applied after 28-day strength is reached. Studying the effects of curing time and curing stress on UCS could lead to a more reasonable and economical mixture design.
- The plastic limit of cemented soil increases, while liquid limit decreases with increasing cement content.
- CSM effectively increase their shear strength, but the same time the mixture also become brittle.
- Therefore to avoid this brittleness, we generally add fibres in cement soil mixture to improve the ductility.

1.4. RESEARCH METHODOLOGY

In order to study improved soil behaviour, these soils were treated with Portland cement. Woodward (2005) tells that, the cement content used for cement-soil mixture in practice is around 10% of dry soil weight. Cement content has strong effects on the properties of the mixture, so the mixtures is being treated with different cement contents so as find the effect more accurately.

In this particular project we had use a local soil the properties of the soil is being mentioned later on this report. For our experimental work we had use 3 different cement content that are 8%, 10% and 12% cement content. The water content that is being used for these 3 different cement content is being calculated by the ordinary proctor test and we had get different OMC (optimum water content) corresponding to the maximum dry density as for different cement content. The purpose of using different cement content is to find the optimum cement content that must be used for various purposes. To check the effect of curing time first we had choose 3,7,14,28 and 56 days of curing without applying any curing stress and later on we moved to apply curing stress along with the curing period to check their combined effect.

The 3 different cement content is being mixed with water that corresponds to maximum dry density to make the slurry. This slurry was then introduced to the soil mixture and thoroughly mixed for approximately ten minutes.

All the specimens will go under the UCS test and the data is being recorded. Using a strain rate equal to 1% of initial specimen length per minute (equalling 1.25 mm/min), a data acquisition system was used to record the applied load and measured deflection. The test proceeded until failure occurred. The data were then loaded into a spreadsheet so that area corrections could be made and the unconfined compressive strength calculated.

The UCS testing program can be divided into two different procedures: one where strength gain is analysed based on curing time without applying curing stress and another one where vertical curing stress and curing time are both considered. For every test 2 samples are prepared and tested.

The Unconfined compressive strength of installed CSM will be affected by both curing time and curing stress. The stress vs. vertical strain curves from UCS tests for cement-improved after 3,7,14 28, and 56 day of curing time without curing stress should be presented.

The procedure is like that first we use 8% cement content and we make different UCS specimen. Now the curing of the specimen is being done, the curing which we used is membrane curing. First we have to make samples and cured it for 3days and calculate its UCS strength after 3, 7, 14, 28 days. Next make the samples and cured it for 7 days and calculate it UCS after 7, 14, 28 days. Similarly make samples for 14 days and 28 days curing and calculate its UCS strength at 14, 28 days and 56 days respectively.

Similarly these whole procedure of curing and calculation of the UCS strength is done for 10% and 12 % cement content. We have to make graphs corresponding to stress and strain behaviour for every cement content corresponding to different curing days.

The application of curing stress during specimen preparation can greatly increase UCS for cement-improved for that we will check the UCS on cement soil specimen at curing stress of 5 Kpa. And for this the whole procedure is being done similarly but these time a curing stress is being applied.

CHAPTER 2

2.1. LITERATURE REVIEW

Ryan Daniel Starchier (University of South Carolina)

- The current criterion to evaluate the mechanical properties of cement-soil mixture mainly focuses on one parameter, unconfined compressive strength (UCS) considering the effects of curing time and curing stress.
- Formost of the situations, loads will be applied after 28-day strength is reached. Studying the effects of curing time and curing stress on UCS could lead to a more reasonable and economical mixture design.

Christensen (1969)

- Found that treating soil with cement reduced the plasticity index while increasing the shrinkage limit, unconfined compressive strengths, triaxial compressive strength, and cation exchange capacity.

Zhang and Tao (2008)

- Concluded that the water to cement ratio used to improve soil influences UCS and durability. Also, UCS increased with increasing cement content and decreased with increasing water to cement ratio. Molding moisture and dry unit weight also were found to contribute to strength.

Horpibulsuk (2001) and Horpibulsuket al. (2004a&b, 2005)

- While researching cemented-marine clays, Horpibulsuk (2001) and Horpibulsuket al. (2004a&b, 2005) found that the compressibility during the post-yield state is governed mainly by the cement content, and the cohesion and the friction angle both tend to increase with cement content.

Moses et al. (2003) and Moses and Rao (2009)

- While studying the behavior of cemented marine clay under monotonic and cyclic loading tests, Moses et al. (2003) and Moses and Rao (2009) found that stress-

- Controlled tests are appropriate to evaluate the strength of cement-soft soil mixtures, because then mixture is brittle and failure often occurs at low strains.

Khelifa Harichane1, Mohamed Ghrici1, Said Kenai2 Received: December 2009, Revised: July, 2010, Accepted: September 2010

- The OMC decreased and the MDD increased as NP content increases from 0 to 20%. The increase in dry density is an indicator of improvement of soil properties. Hossain used volcanic ash from natural resources for stabilization of two soils and observed an increase in OMC and a decrease in MDD as volcanic ash content increased from 0 to 20%.

(Rocha et al. 1961; Abboud 1973).

- studies have indicated that at very low cement contents, improvement in strength is due to an increase in friction angle rather than cohesion Research has also shown that cohesion increases with curing time while friction angle remains constant (Nash et al. 1965; Wissa et al. 1965; Abboud 1973).

(ACI 230.1R-90 1990).

- Cement can be applied to stabilize any type of soil, except those with organic content greater than 2% or having pH lower than 5.3 .Many studies have shown that granular soils and clayey materials with low plasticity index are better suited to be stabilized with cement.

- The addition of cement was also found to increase optimum water content but decrease the maximum dry density ***(Tabatabi 1997).*** However report by ***ACI committee 230 (1990)*** states that cement treatment causes changes in maximum dry density and optimum water content, but the direction of changes is not predictable. In addition cement treatment causes immediate decrease in water content ***(Bergado et al. 1996).***

(Bergado et al. 1996)

- Cement treated materials behave in a more brittle manner than non-treated materials. Reported that cement treatment changes the behavior of soft clay from normally consolidated to over consolidated state.

Mitchell (1976):

- The relationship between unconfined compressive strength and curing time for a given soil and cement content was presented by
- $A_1 = A_2 + K\log(d1/d2)$
- A_1 =Unconfined compressive strength at age of d1 days (psi)
- A_2 =Unconfined compressive strength at age of d2 days (psi)
- *K*= 70C for coarse-grained soils and*K*= 10C for fine-grained soils, (C: Cement content, percent by weight)

CHAPTER 3

3.1. EXPERIMENTAL PROGRAMMES

TABLE 3.1 PROPERTIES OF SOIL

SIEVE ANALYSIS	RESULTS
SAND	13%
SILT	30%
CLAY	57%
LIQUID LIMIT	66%
PLASTIC LIMIT	37%
PLASTICITY INDEX	29%
OPTIMUM MOISTURE CONTENT	
SIMPLE SOIL	12%
8% CEMENT CONTENT	12%
10% CEMENT CONTENT	15%
12% CEMENT CONTENT	16%
OPTIMUM DRY DENSITY(KN/m^3)	
SIMPLE SOIL	1.61 KN/m^3
8% CEMENT CONTENT	1.71 KN/m^3
10% CEMENT CONTENT	1.79 KN/m^3
12% CEMENT CONTENT	1.81 KN/m^3

TABLE 3.2 SAMPLE PROPERTIES FOR UCS TEST

LENGTH OF THE SAMPLE	76 mm
DIAMETER OF THE SAMPLE	38 mm
STRAIN RATE	1.25mm/ min
PROVING RING CONSTANT	0.023
DIAL GAUGE CONSTANT	0.1
CROSS-SECTIONAL AREA OF THE SAMPLE(mm^2)	1133.54
LENGTH TO DIAMETER RATIO	2:1
CORRECTED AREA	A/1-€

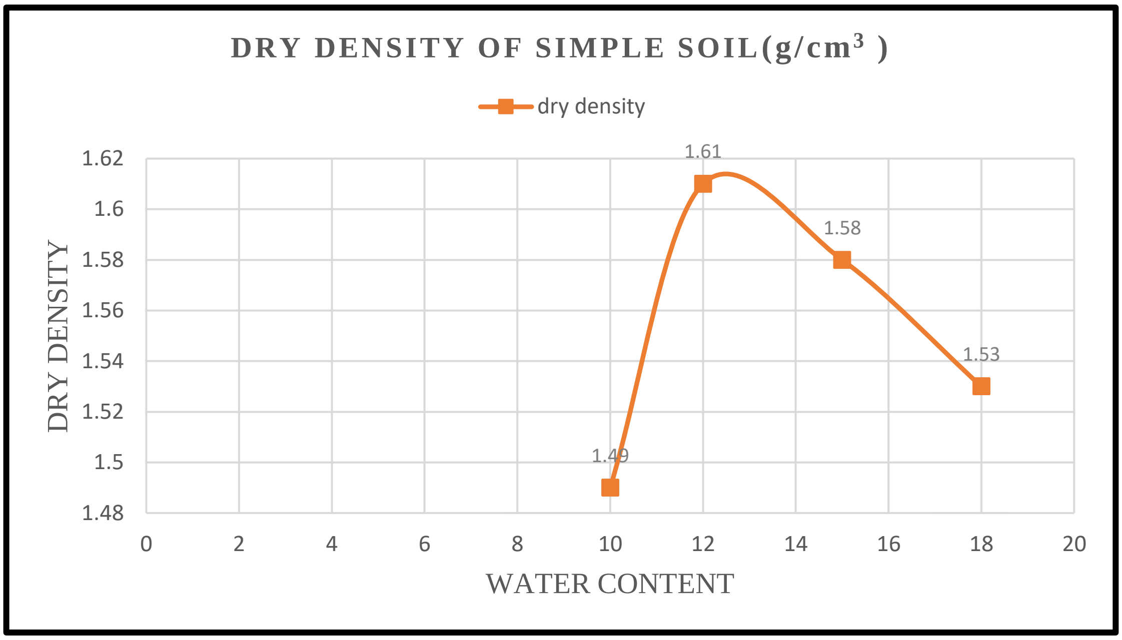


Figure 3.1. DRY DENSITY AND WATER CONTENT OF SIMPLE SOIL

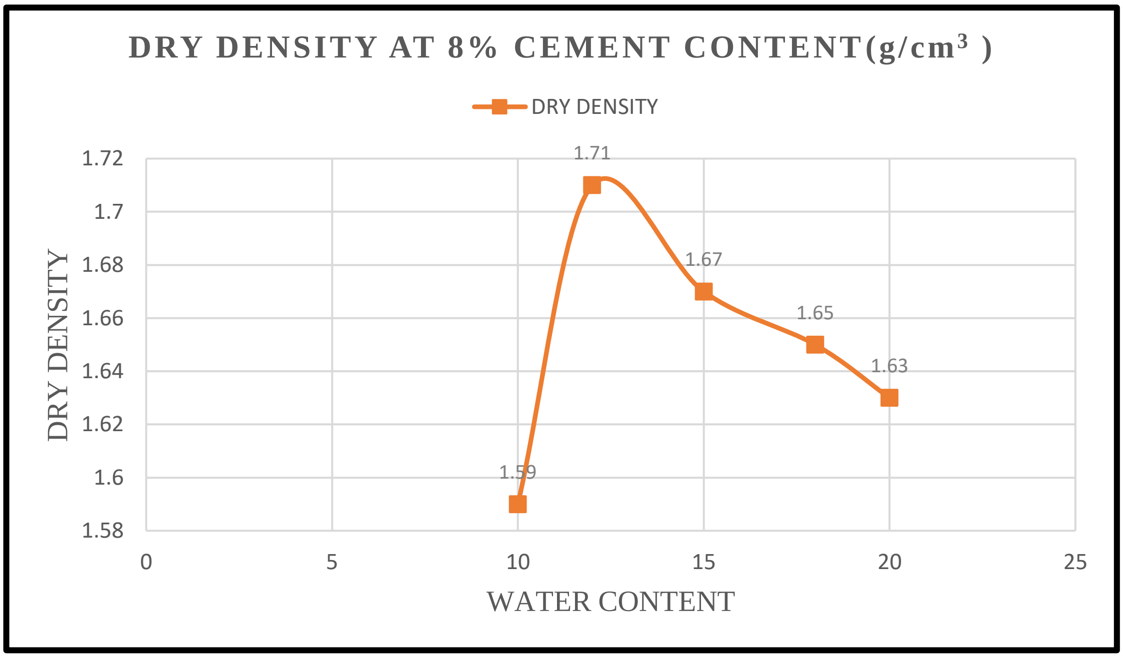


Figure 3.2. DRY DENSITY AND WATER CONTENT FOR8% CEMENT CONTENT

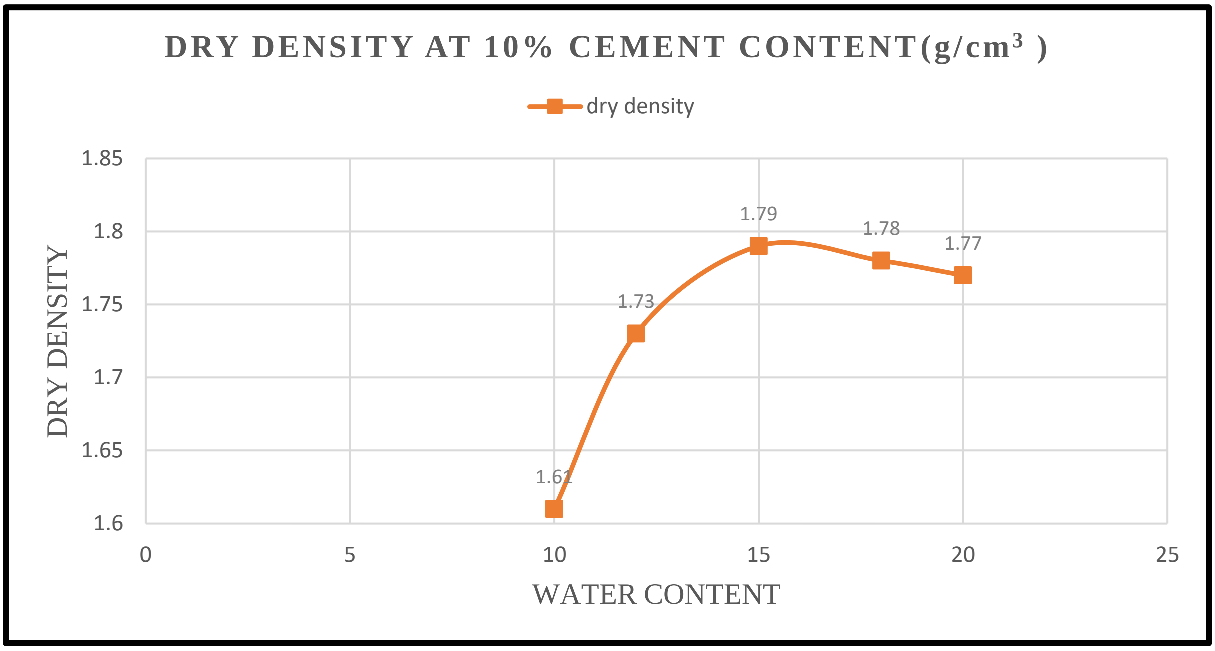


Figure 3.3. DRY DENSITY AND WATER CONTENT FOR 10% CEMENT CONTENT

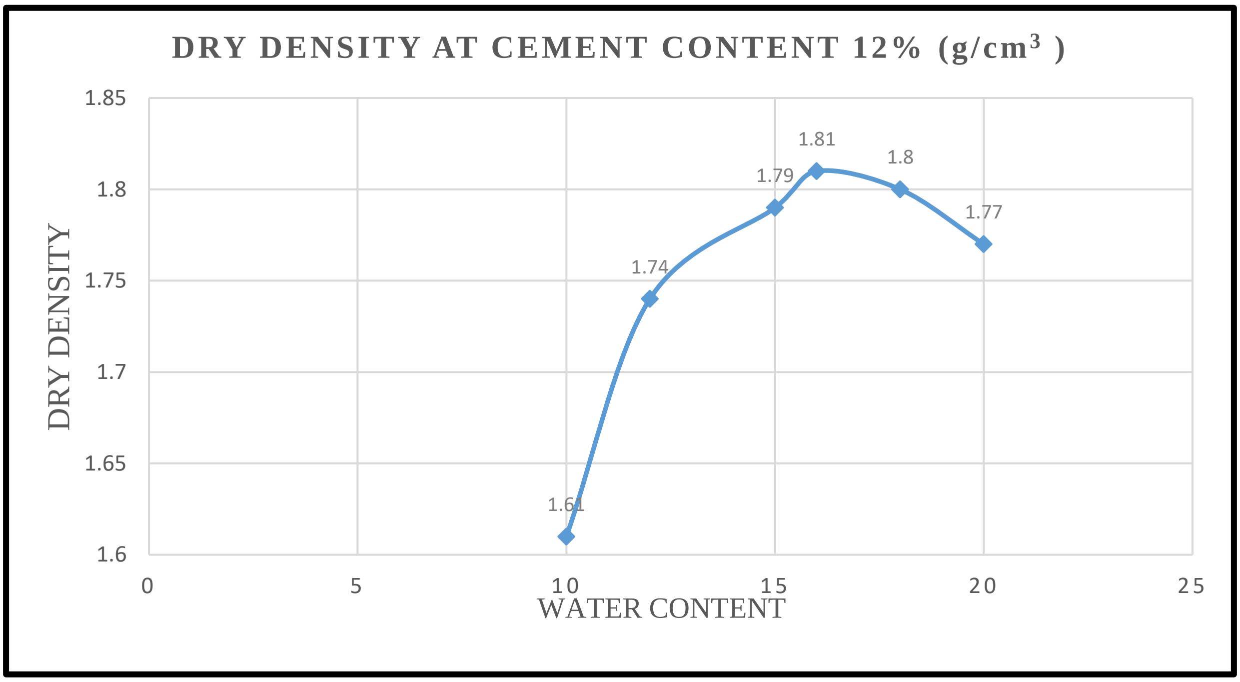


Figure 3.4. DRY DENSITY AND WATER CONTENT FOR 12% CEMENT CONTENT

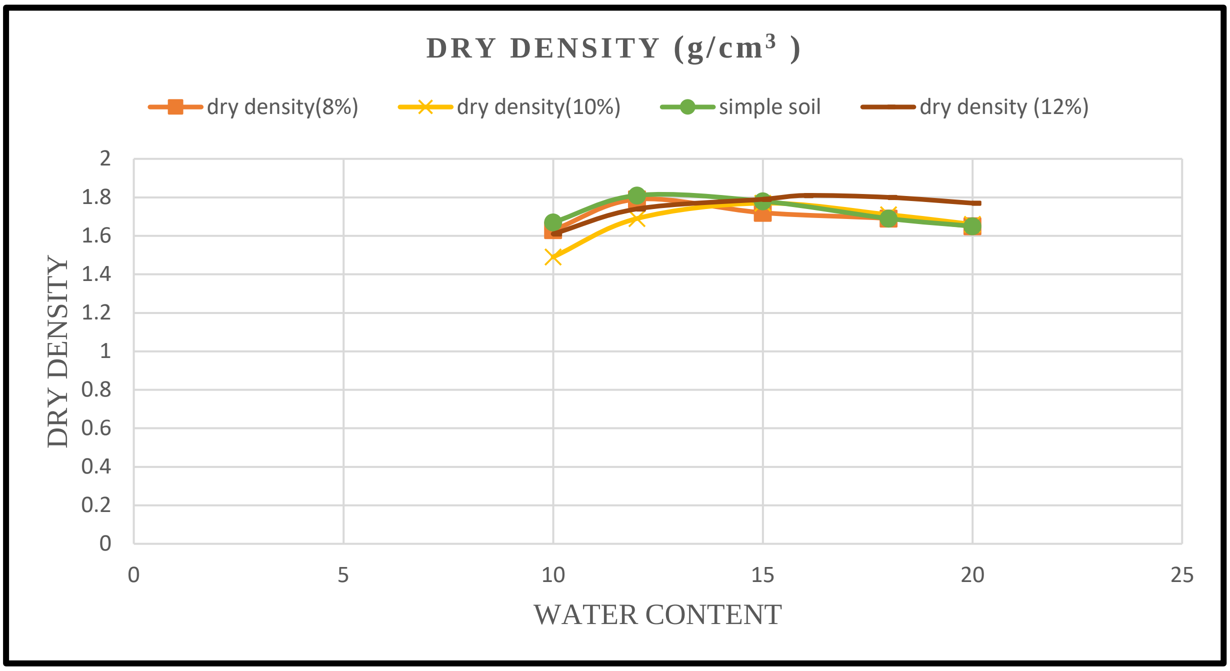


Figure 3.5. DRY DENSITY AND WATER CONTENT FOR DIFFERENT CEMENT CONTENT

MAKING OF CEMENT SLURRY

SAMPLE PREPARATION

SAMPLES AT DIFFERENT CEMENT CONTENT

MEMBRANE CURING OF SAMPLES

UNCONFINED COMPRESSIVE TEST

FAILURE TYPE 1

FAILURE TYPE 2

FAILURE TYPE 3

FAILURE TYPE 4

CHAPTER 4

FINAL RESULTS OF UCS TEST (without curing stress)

TABLE NO 4.1: STRENGTH AT DIFFERENT DAYS FOR 8% CEMENT CONTENT

SR NO.	STRENGTH (N/m^2)	DAYS	3 DAYS CURING	7 DAYS CURING	14 DAYS CURING	28 DAYS CURING
1	AT 3RD DAY	3	176.698	176.698	176.698	176.698
2	AT 7TH DAY	7	274.86	313.292	313.292	313.292
3	AT 14TH DAY	14	332.87	351.511	371.0398	371.0398
4	AT 28TH DAY	28	410.096	429.62	447.94	488.21

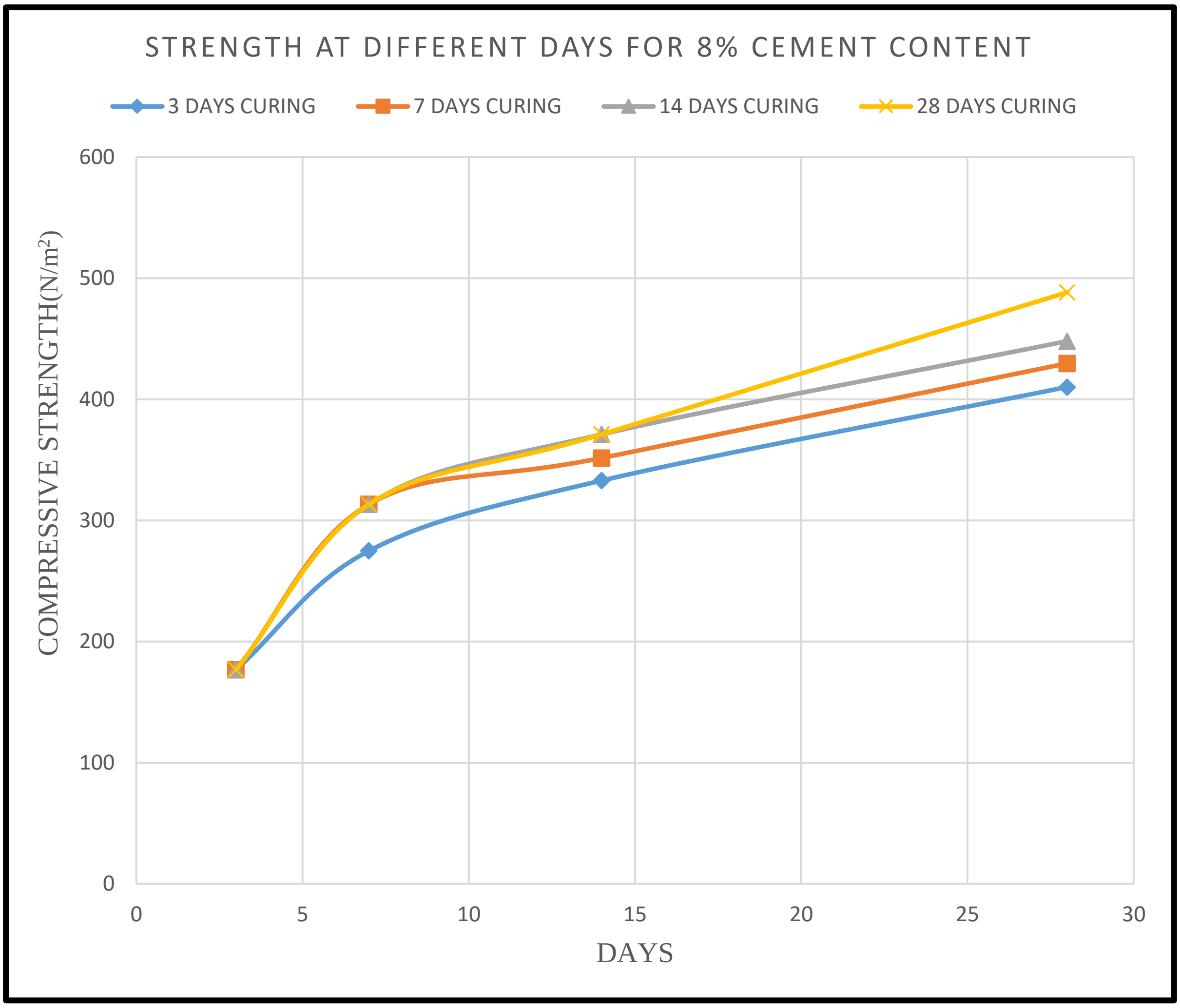


Figure 4.1. STRENGTH AT DIFFERENT DAYS FOR 8% CEMENT CONTENT

FINAL RESULTS OF UCS TEST

TABLE NO 4.2: STRENGTH AT DIFFERENT DAYS FOR 10% CEMENT CONTENT

SR. NO	STRENGTH (N/m^2)	DAYS	3 DAYS CURING	7 DAYS CURING	14 DAYS CURING	28 DAYS CURING
1	AT 3RD DAY	3	236.225	236.225	236.225	236.225
2	AT 7TH DAY	7	332.87	410.096	410.096	410.96
3	AT14THDAY	14	389.52	429.625	488.321	488.321
4	AT28THDAY	28	428.47	486.9	506.37	525.81

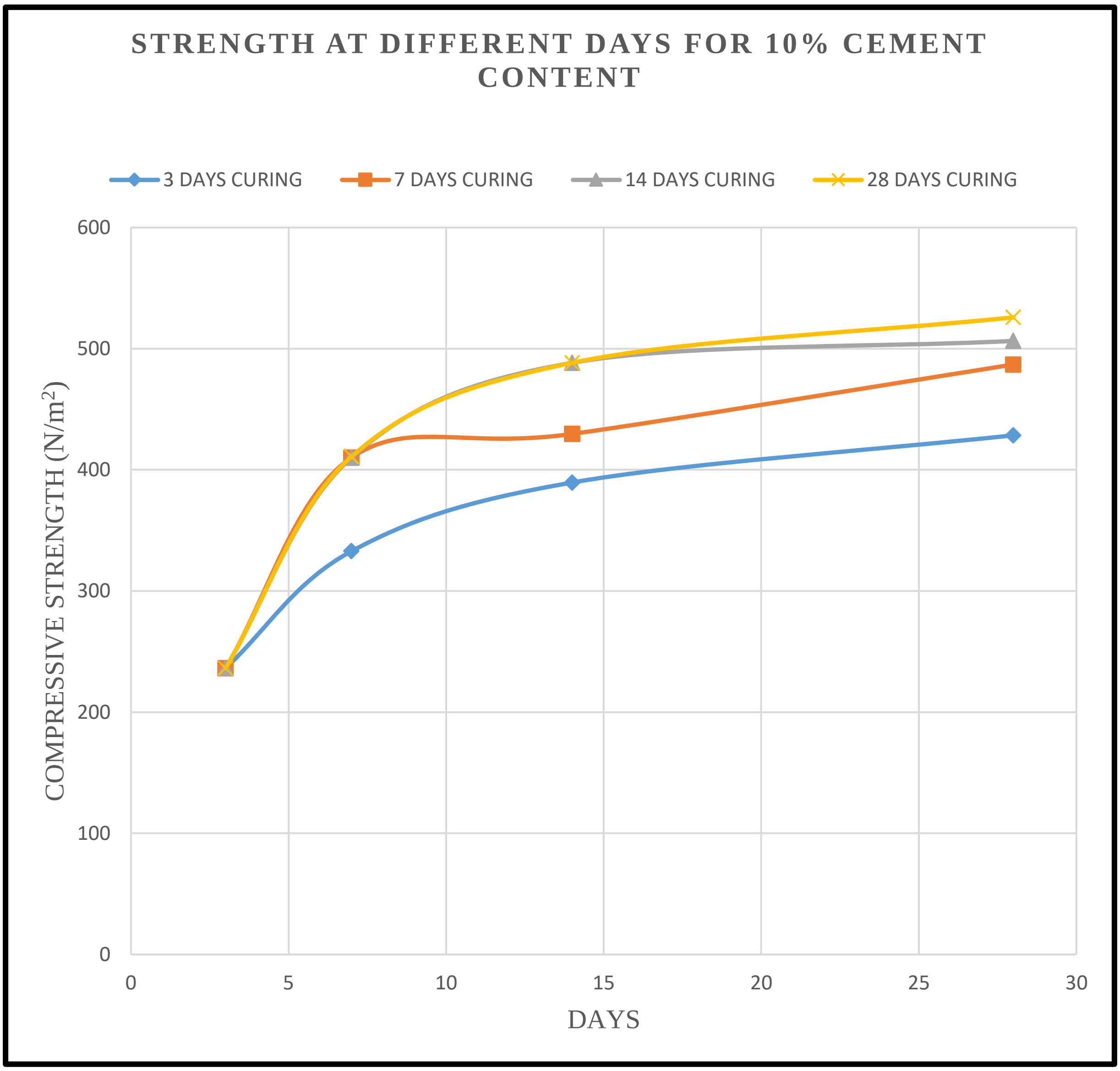


Figure 4.2. STRENGTH AT DIFFERENT DAYS FOR 10% CEMENT CONTENT

FINAL RESULTS OF UCS TEST

TABLE NO 4.3: STRENGTH AT DIFFERENT DAYS FOR 12% CEMENT CONTENT

SR NO	STRENGTH	DAYS	3 DAYS CURING	7 DAYS CURING	14 DAYS CURING	28 DAYS CURING
1	AT 3RD DAY	3	235.597	235.597	235.597	235.597
2	AT 7TH DAY	7	313.292	332.87	332.873	332.873
3	AT 14TH DAY	14	332.87	353.396	372.0345	372.0345
4	AT 28TH DAY	28	390.56	429.625	449.153	488.096

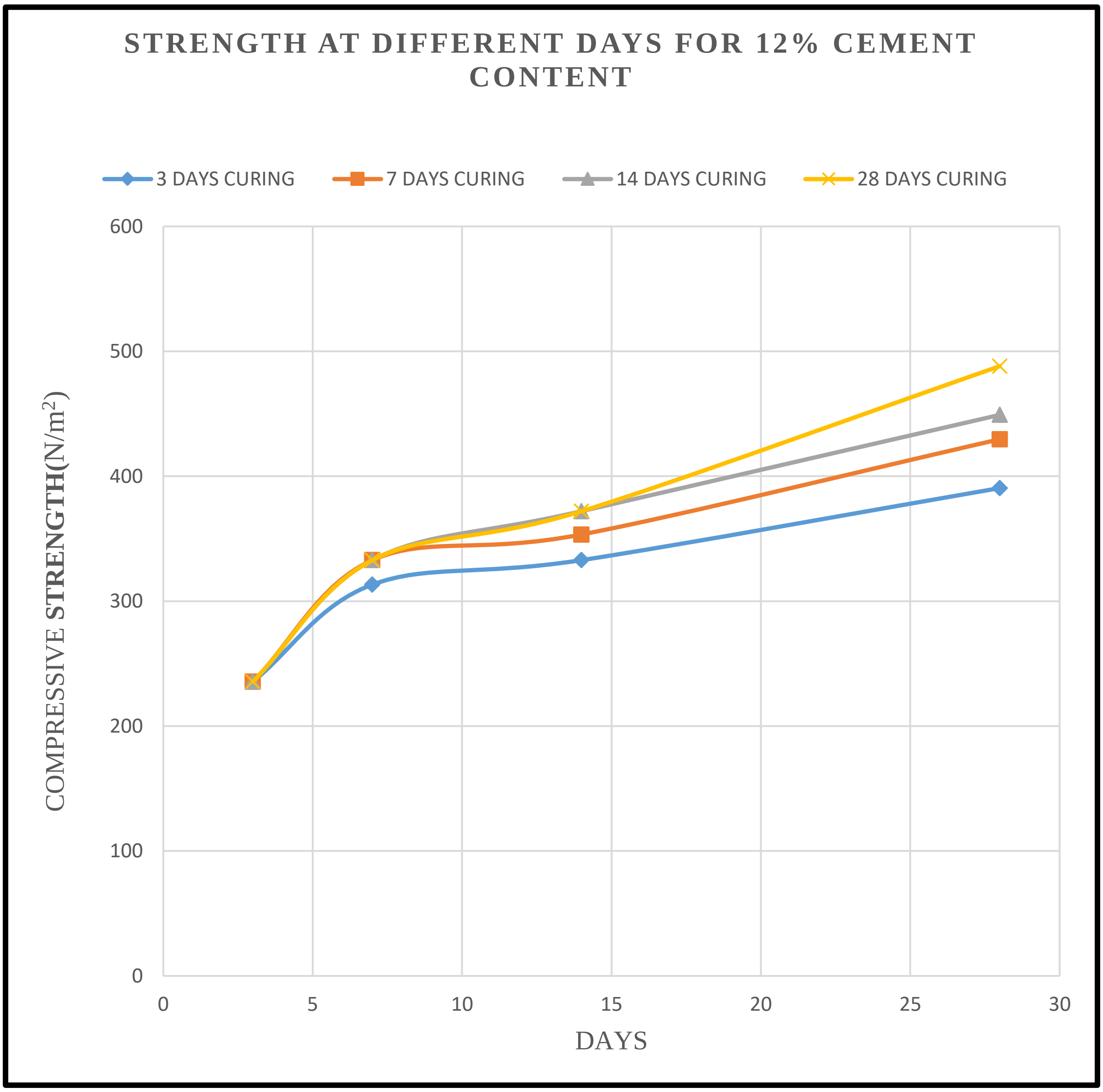
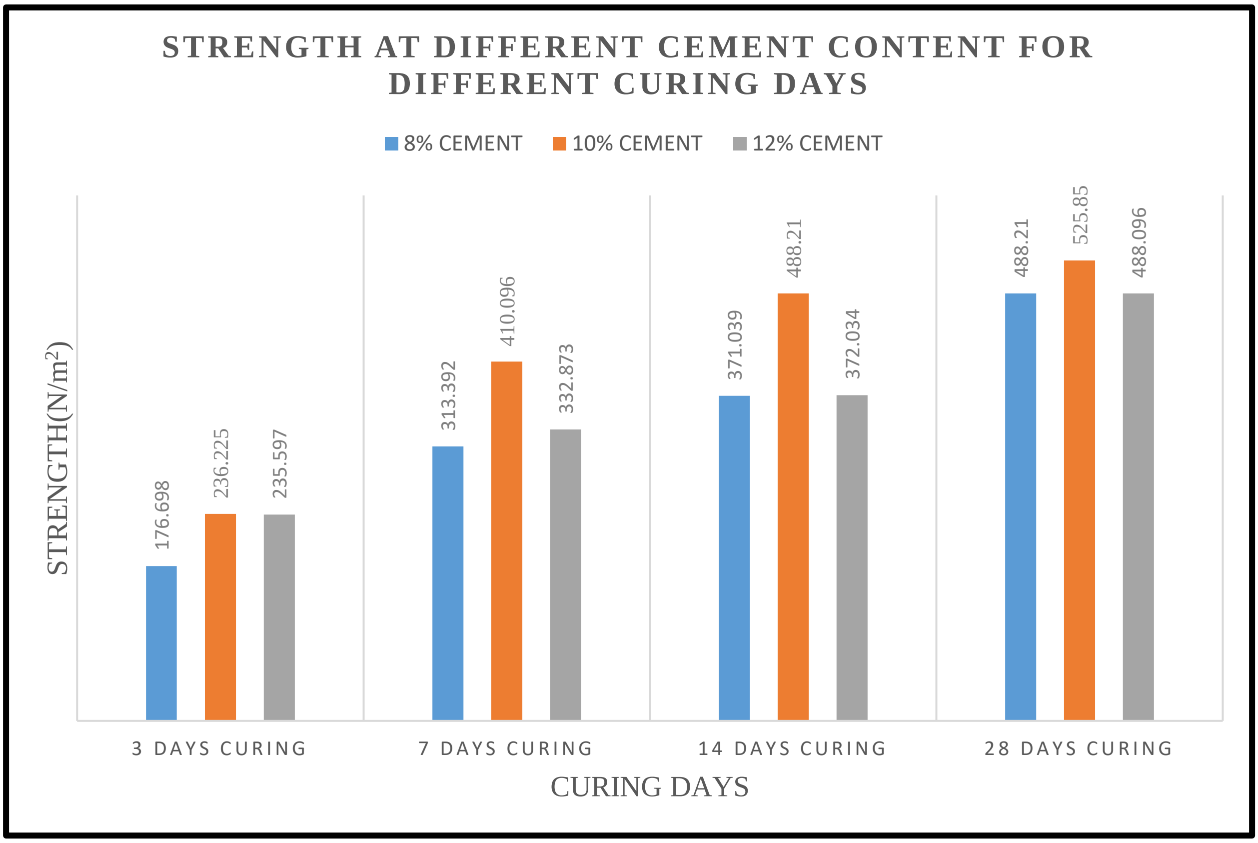
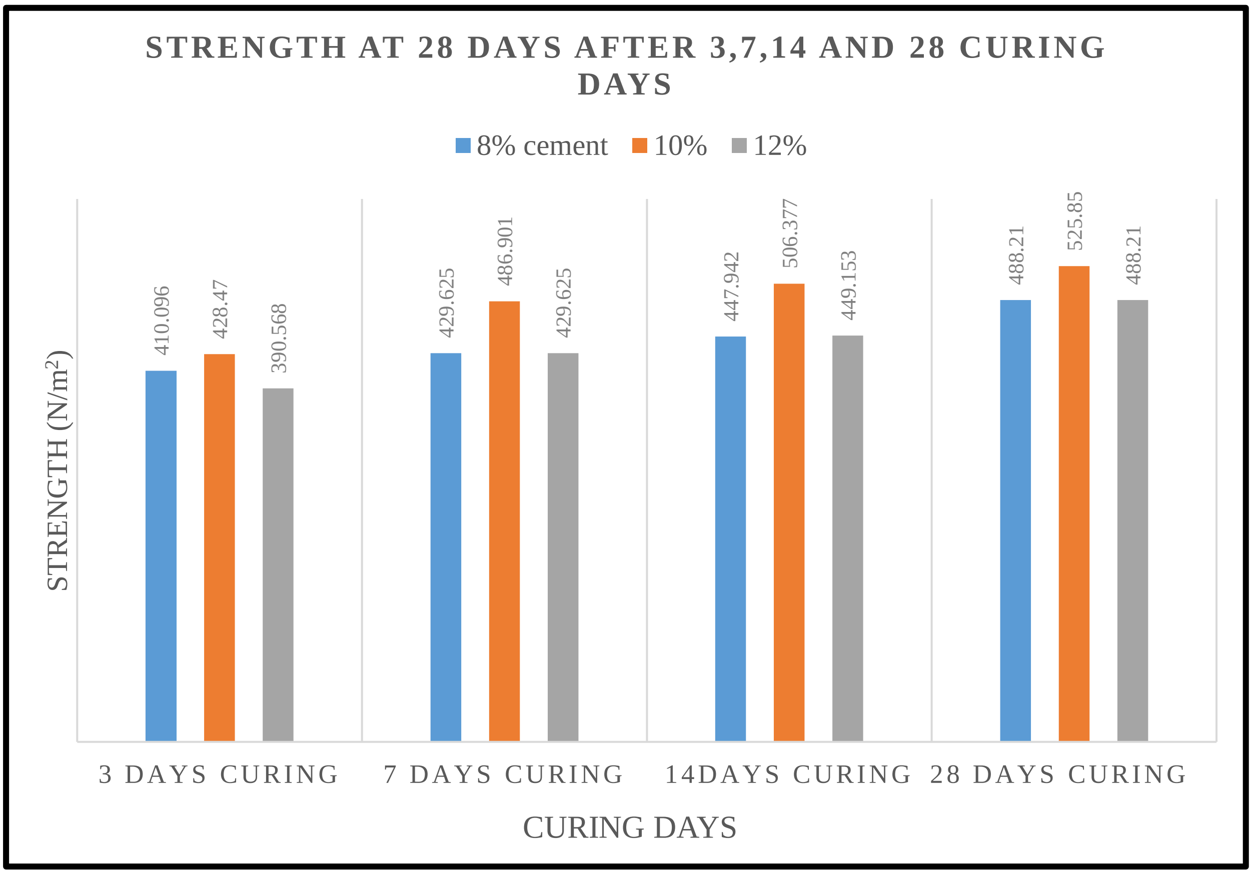
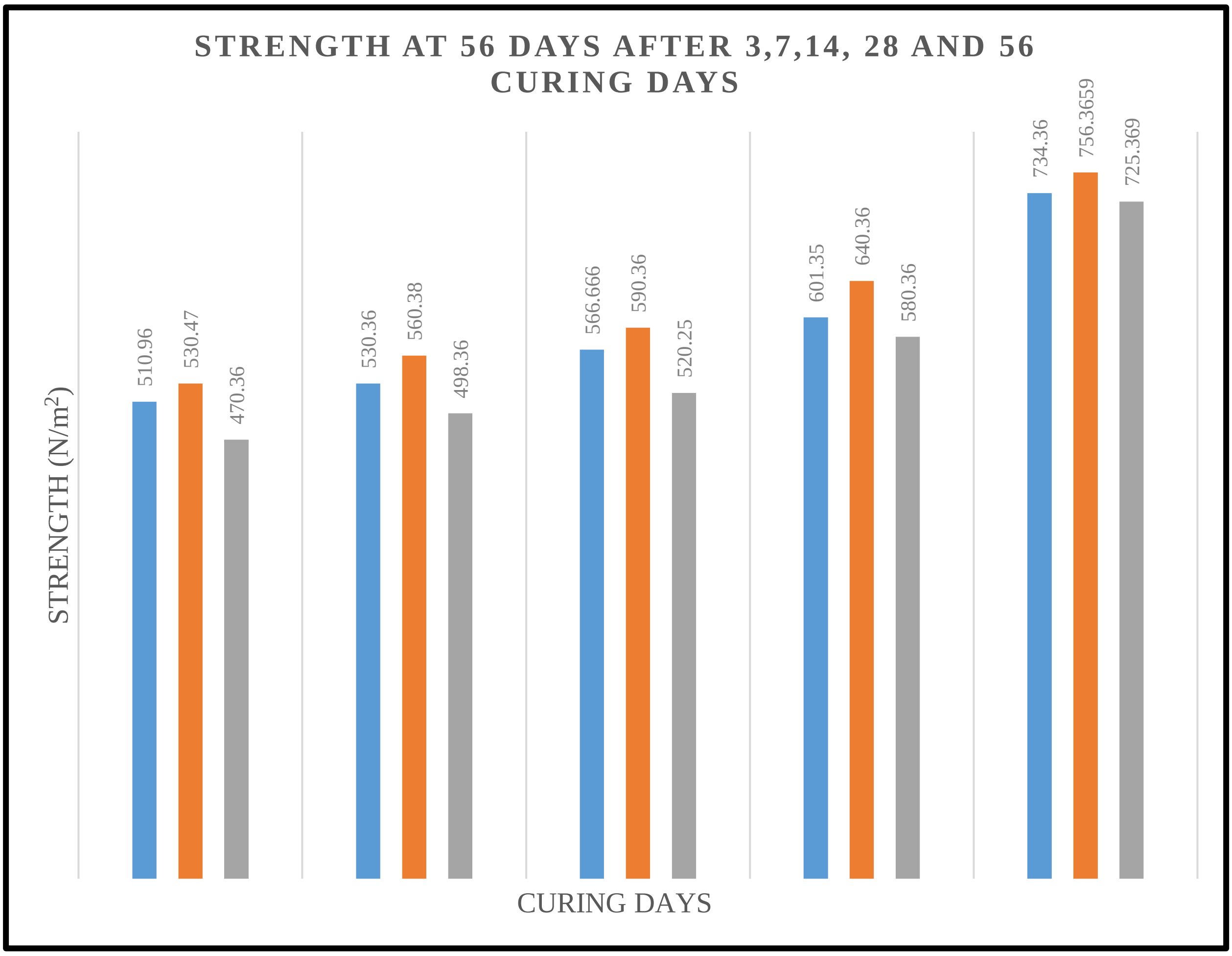


Figure 4.3. STRENGTH AT DIFFERENT DAYS FOR 12% CEMENT CONTENT



COMPARISON OF STRENGTH AT DIFFERENT CURING DAYS FOR DIFFERENT CEMENT CONTENT


STRENGTH AT 28 DAYS AFTER 3,7,14 AND 28 CURING DAYS
8% cement
10%
12%
STRENGTH (N/m2)
410.096
428.47
390.568
429.625
486.901
429.625
447.942
506.377
449.153
488.21
525.85
488.21
3 DAYS CURING
7 DAYS CURING
14DAYS CURING
28 DAYS CURING
CURING DAYS

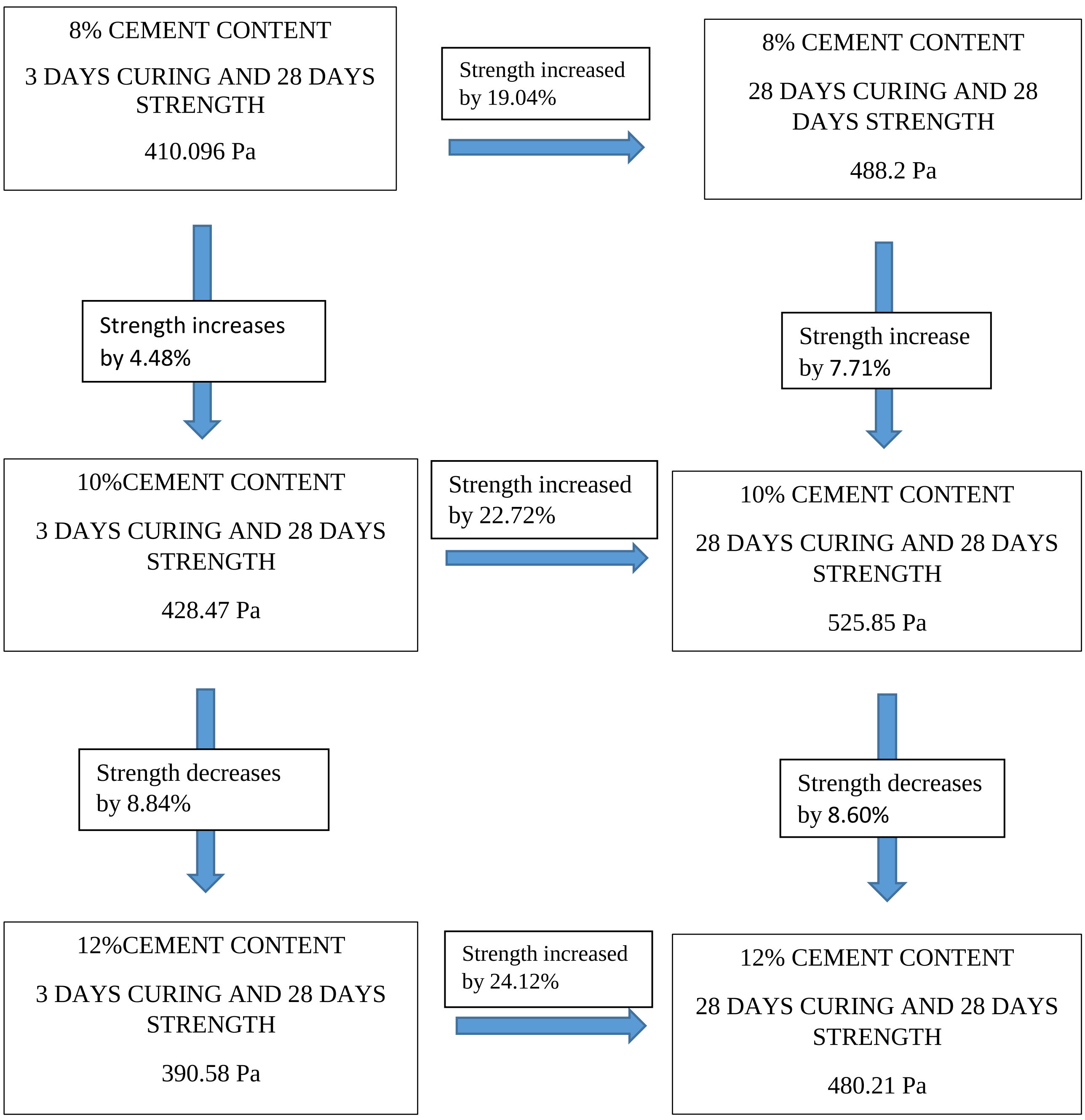

STRENGTH AT 56 DAYS AFTER 3,7,14, 28 AND 56 CURING DAYS
STRENGTH (N/m2)
CURING DAYS
510.96
530.47
470.36
530.36
560.38
498.36
566.666
590.36
520.25
601.35
640.36
580.36
734.36
756.3659
725.369

OUTCOMES FROM EXPERIMENT (WITHOUT CURING STRESS)

- We have conducted number of UCS Tests on soil with different cement contents. The cement content generally we used with soil are 8%, 10% and 12%. From results we generally concluded that for soil that we are using, 10% cement content is the optimum cement content, because after this cement content the strength of specimen generally started to decrease. On Further experiments we found that it is not the cement content that is playing a vital role in increasing the strength but it is the curing days which have increased the strength to greater extent. So it is not economical to use the high percentage of cement content. We can increase the strength by increasing the curing days.

- On early curing days like 3, 7 or 14 days, strength for different cement contents does not very much. But strength at higher days like 28 days, strength going to vary at higher rates for different cement contents. The slope of strength from 14 to 28 days is generally more as compare to slope of strength from 3 to 14 days. So it is the curing days which is generally the major factor in improving the strength. From our results we found that to get higher strength at earlier or higher stages we have to use 10% cement content to increase the durability of cement soil specimen.

FLOW CHART


8% CEMENT CONTENT
3 DAYS CURING AND 28 DAYS STRENGTH
410.096 Pa
Strength increased by 19.04%
8% CEMENT CONTENT
28 DAYS CURING AND 28 DAYS STRENGTH
488.2 Pa
Strength increases by 4.48%
Strength increase by 7.71%
10%CEMENT CONTENT
3 DAYS CURING AND 28 DAYS STRENGTH
428.47 Pa
Strength increased by 22.72%
10% CEMENT CONTENT
28 DAYS CURING AND 28 DAYS STRENGTH
525.85 Pa
Strength decreases by 8.84%
Strength decreases by 8.60%
12%CEMENT CONTENT
3 DAYS CURING AND 28 DAYS STRENGTH
390.58 Pa
Strength increased by 24.12%
12% CEMENT CONTENT
28 DAYS CURING AND 28 DAYS STRENGTH
480.21 Pa

CHAPTER 5

5.1. PREPARATION OF APPARATUS

During specimen apparatus preparation, polyvinyl chloride (PVC) pipes with 55 mm inside dia and 215 mm height were cut. Specimen carefully compacted such that honeycombs were avoided and cured in moisture closet with curing temperature of 21 degree Celsius. At base, plate of 85mm is taken in which there is a hole provided for holding of specimen of 38 mm dia as same as sample dia,so that during curing stress it does not move from its place.

Base plate

Specimen resting on base plate

Base plate is sealed from bottom to avoid leakage of water for proper curing.PVC Pipe of 55mm dia is fixed with base plate with M-seal. There should be proper fixing to avoid any leakage of water.

Fill the pipe with water till specimen's height .Plate of dia less than PVC pipe is taken and rest in on specimen. Apply curing stress of 5 kpa on it and keep it for 3 days or 7days curing.

After the curing time was reached, they were taken out from designed apparatus. Then Specimens were subjected to unconfined compressive tests. The Strain rate applied is 0.3per minute. Desired result are shown in graphs.

CHAPTER 6

UCS RESULTS WITH CURING STRESS

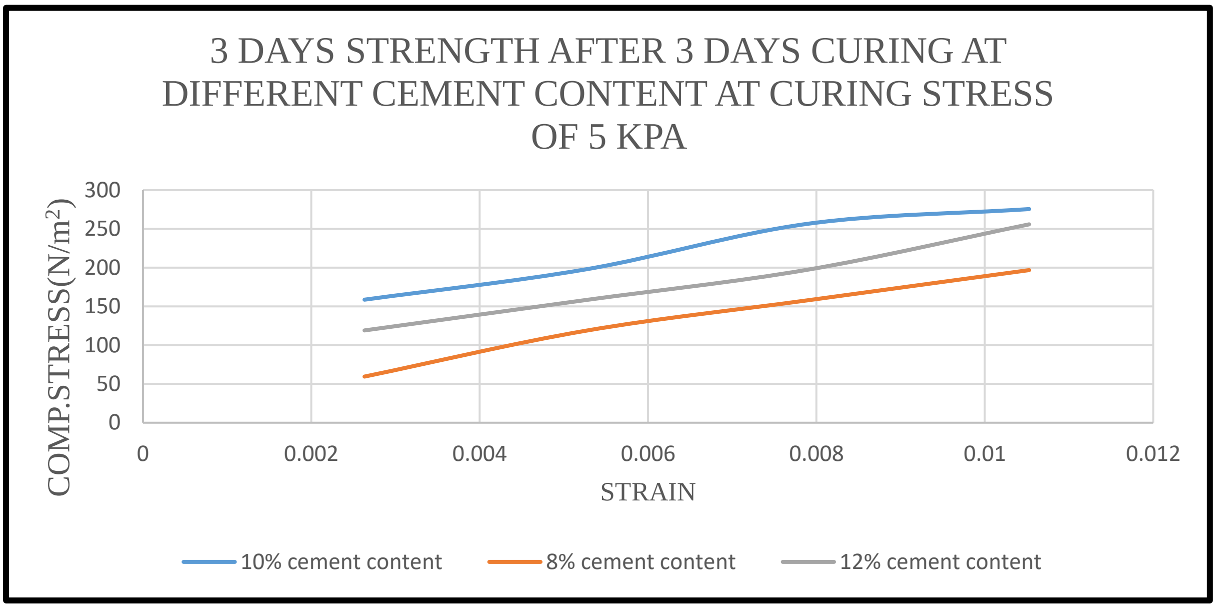


FIG 6.1 3 days strength after 3 days curing at different cement content with curing stress.

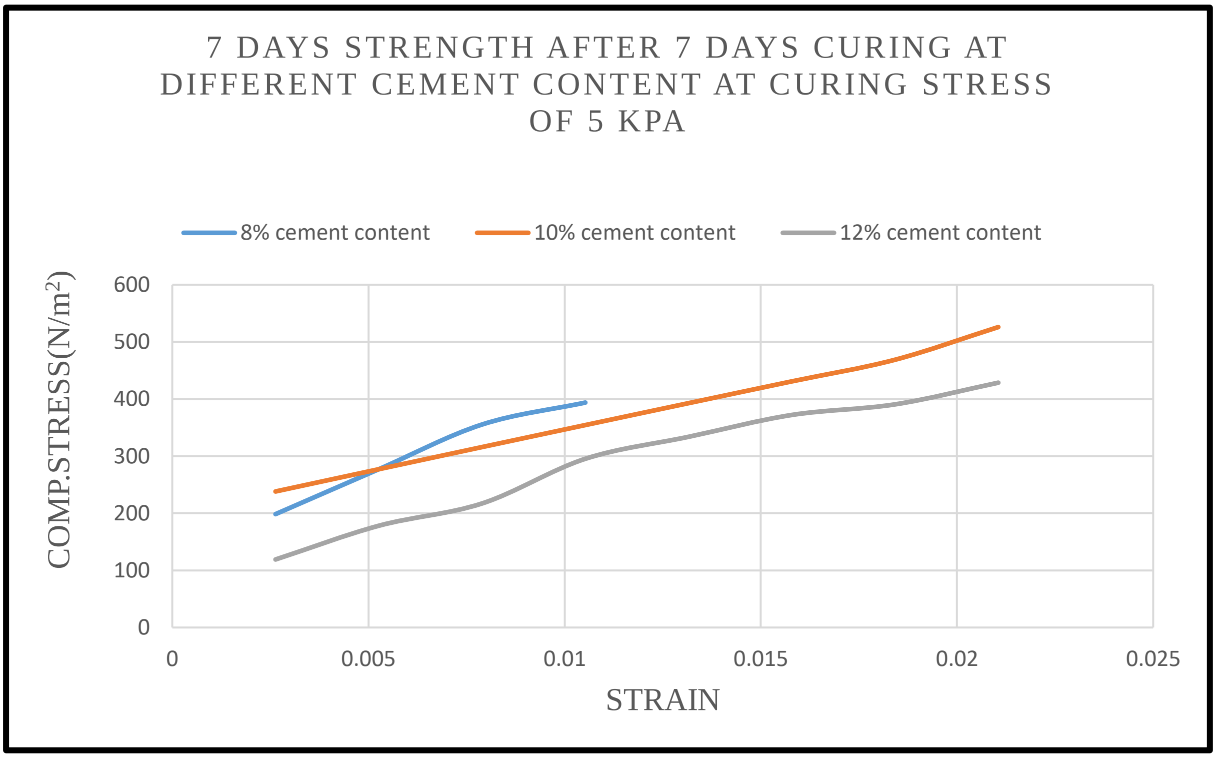


FIG 6.2 7 days strength after 7 days curing at different cement content with curing stress.

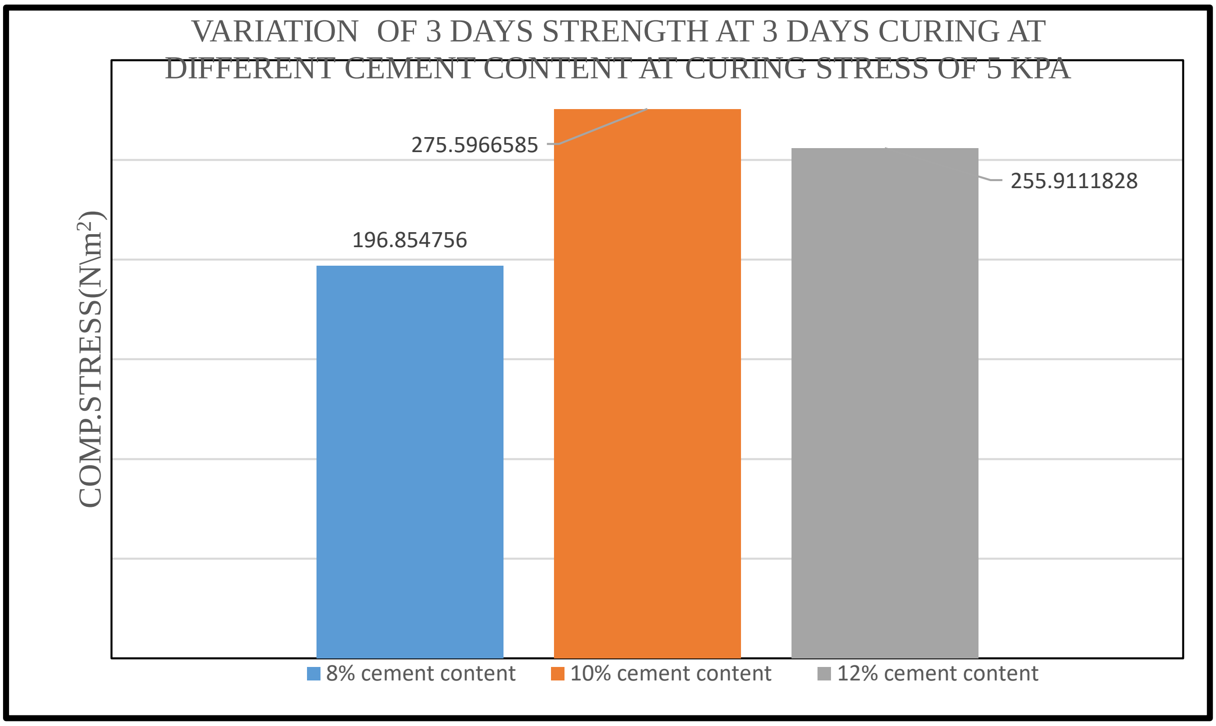


FIG 6.3 variation of 3 days strength at 3 days curing at different cement content at curing stress.

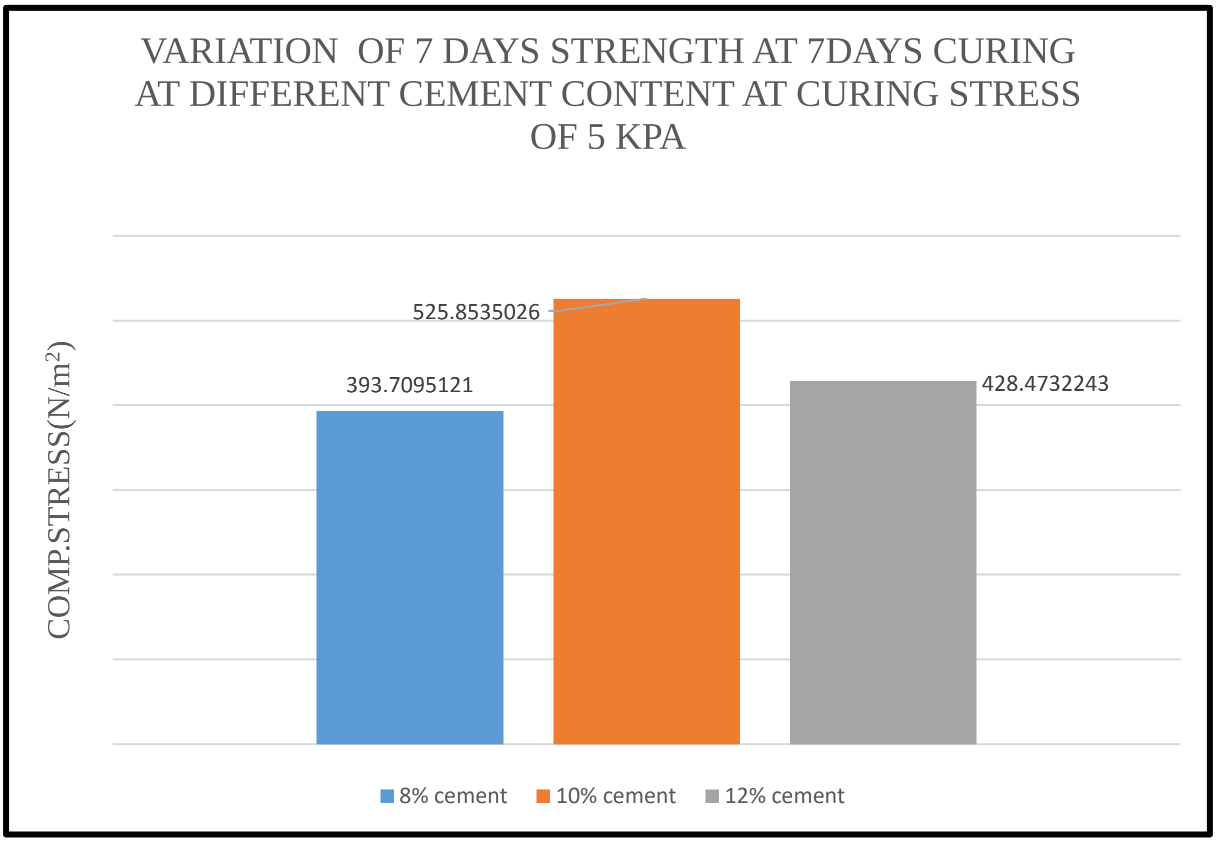


FIG 6.4 variation of 7 days strength at 7 days curing at different cement content at curing stress.

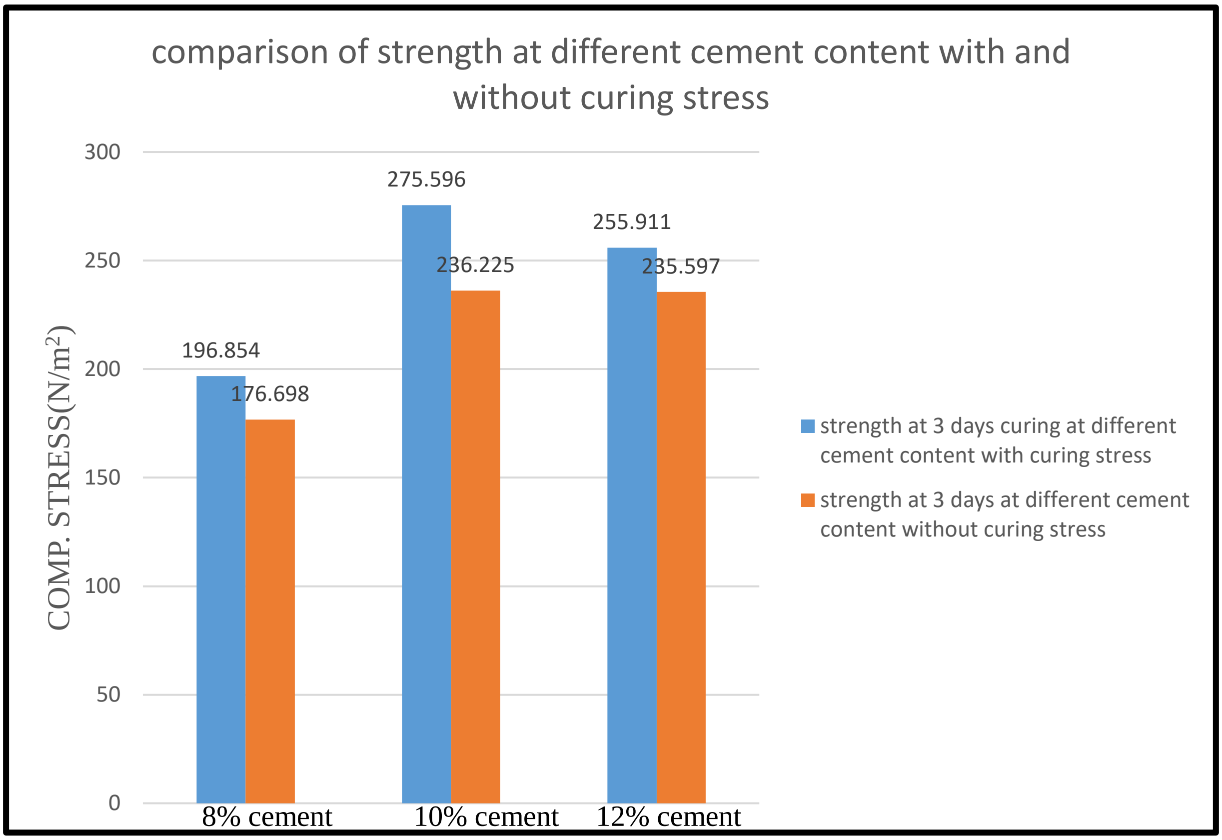


FIG 6.5 comparison of strength at different cement content with and without curing stress

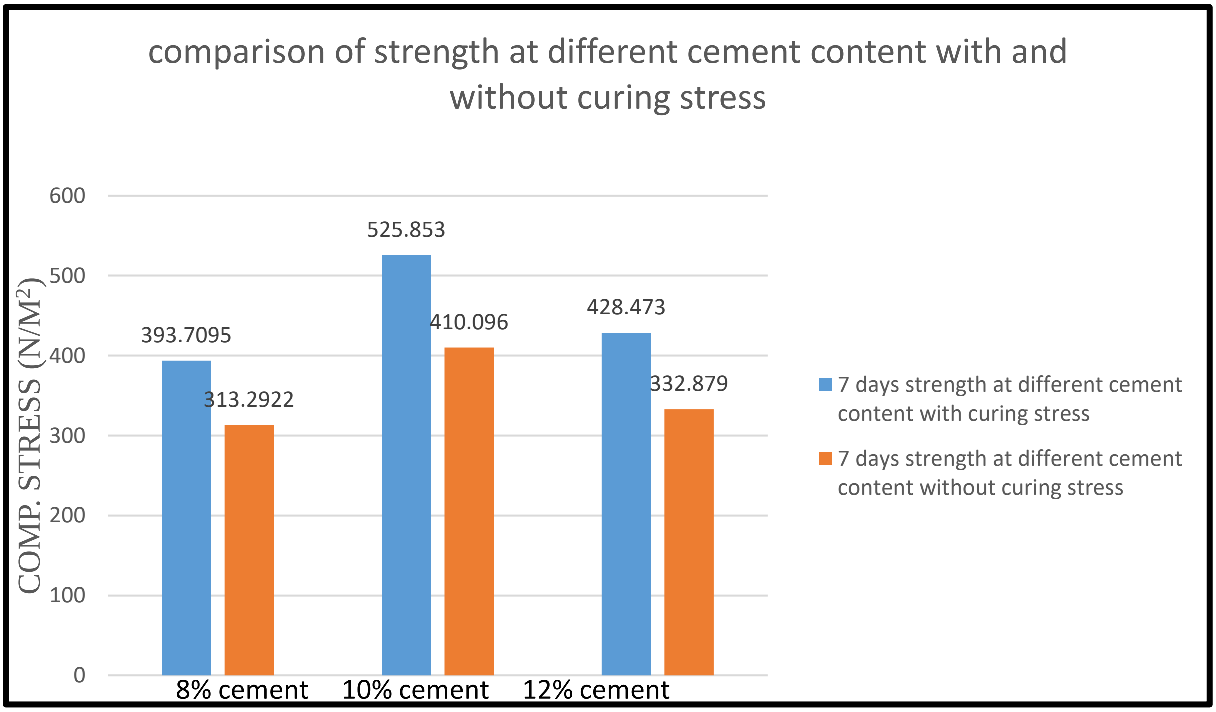


FIG 6.6 comparison of strength at different cement content with and without curing stress

CHAPTER 7

DISCUSSION

A series of UCS tests on cement improved soils were conducted to gain a basic knowledge of the mechanical behaviour of these mixtures. UCS tests were analysed based on strength gain due to curing time and strength gain due to curing stress and curing time.

According to our UCS results, the UCS of cement-soil mixture increases with curing time and curing stress. It is seen that strength gain can be modelled as a power function.. The stiffness of the mixture can be significantly increased when the mixture is cured under vertical curing stress, compared with the mixture without curing stress. For example, cement-improved specimens at 3-day curing time can experience a 11.44% increase in secant modulus by applying 5 kPa curing stress and cement-improved specimens at 7-day curing time can experience a 25.66% increase in secant modulus by applying 5 kPa curing stress From consolidation test results, it can be seen that the introduction of cement can reduce the compressibility index by 30-70% and increase the strength by 10 -30% by applying curing stress.

Future work should include the development of a comprehensive numerical model through collecting high quality data, including consolidation results. Also, a comprehensive constitutive model for cement-soil mixture for higher loading conditions can be developed because in our work, we have applied a maximum load of 5 kpa according to our apparatus limit. In addition, UCS tests gives useful information like shear strength, strain at failure values Also, and the post peak strength behaviour is demonstrated. The limitations of using UCS as design criterion are obvious due to perceived strength gain with respect to curing time and curing stress and the need for different tests, like triaxial extension or compression tests.

. For future , we can compare the compressive strengths at higher days like 14,28 and 56 days.1n our project work, with respect to curing time we have found the strengths at 7,14,28 and 56 days for different cement content like 8%,10% and 12% cement content, in which we find that 10% is the optimum cement content for construction work. By applying curing stress on specimens with different cement contents with curing, compressive strength shows a remarkable increase at their earlier days like 3 or 7 days

ANNEXURE

UNCONFINED COMPRESSION TEST

CEMENT CONTENT 8% (3DAYS CURING)

TABLE NO A.1. Sample no 1(3days strength after 3days curing):

Proving ring	dial gauge	Strain	corrected area(cm^2)	comp. stress (N/m^2)
2	20	0.002631579	1137.102375	39.68508114
4	40	0.005263158	1140.110582	79.16074232
6	60	0.007894737	1143.134748	118.4269836
8	80	0.010526316	1146.175	157.4838048
9	100	0.013157895	1149.231467	176.6980855

TABLE NO A.2. Sample no 2(7days strength after 3days curing):

Proving ring	dial gauge	Strain	corrected area(cm^2)	comp. stress (N/m^2)
7	20	0.002631579	1137.102375	138.897784
10	40	0.005263158	1140.110582	197.9018558
12	60	0.007894737	1143.134748	236.8539671
13	80	0.010526316	1146.175	255.9111828
14	100	0.013157895	1149.231467	274.8636886

TABLE NO A.3. Sample no 3(14days strength after 3days curing):

Proving ring	dial gauge	Strain	corrected area(cm^2)	comp. stress (N/m^2)
7	20	0.002631579	1137.102375	138.897784
10	40	0.005263158	1140.110582	197.9018558
12	60	0.007894737	1143.134748	236.8539671
14	80	0.010526316	1146.175	275.5966585
15	100	0.013157895	1149.231467	294.4968092
17	120	0.015789474	1152.304278	332.8730157

TABLE NO A.4. Sample no 4(28days strength after 3days curing):

Proving ring	dial gauge	Strain	corrected area(cm^2)	comp. stress (N/m^2)
10	20	0.002631579	1137.102375	198.4254057
12	40	0.005263158	1140.110582	237.482227
14	60	0.007894737	1143.134748	276.3296283
16	80	0.010526316	1146.175	316
17	100	0.013157895	1149.231467	333.7630505
19	120	0.015789474	1152.304278	372.0345469
21	140	0.018421053	1155.393566	410.0966234

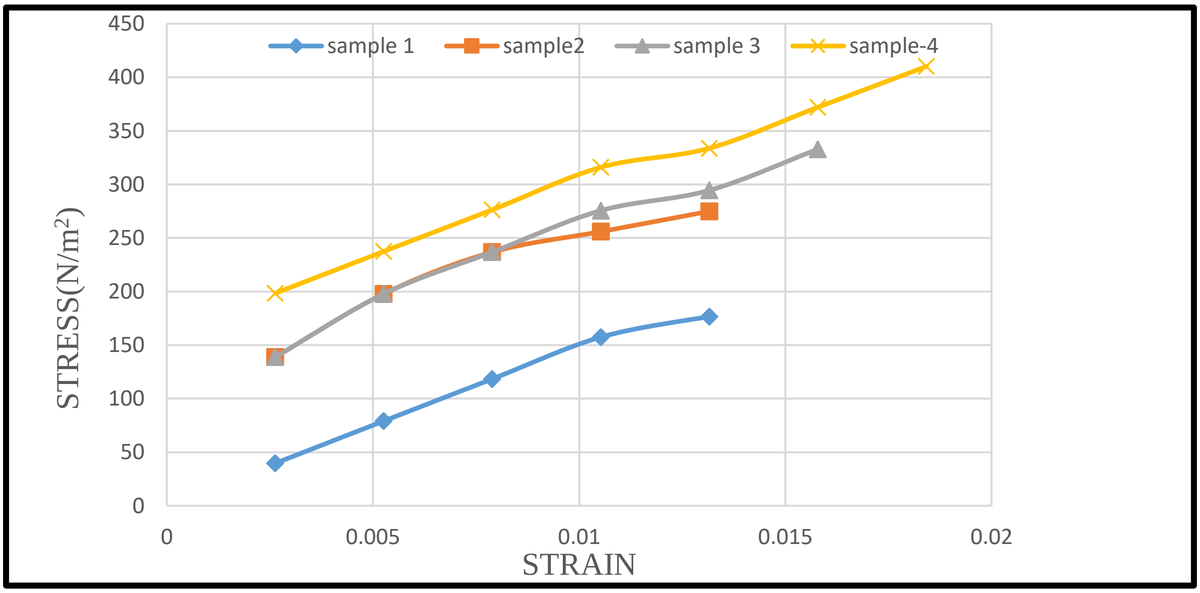


Figure A.1. Stress- strain curve for cement content 8% (3days curing)

UNCONFINED COMPRESSION TEST

CEMENT CONTENT 8% (7DAYS CURING)

TABLE NO A.5. Sample no 1(7days strength after 7days curing):

Proving ring	dial gauge	Strain	corrected area(cm^2)	comp. stress (N/m^2)
6	20	0.002631579	1137.102375	119.0552434
8	40	0.005263158	1140.110582	158.3214846
10	60	0.007894737	1143.134748	197.3783059
12	80	0.010526316	1146.175	236.2257072
14	100	0.013157895	1149.231467	274.8636886
16	120	0.015789474	1152.304278	313.29225

TABLE NO A.6. Sample no 2(14days strength after 7days curing):

Proving ring	dial gauge	Strain	corrected area(cm^2)	comp. stress (N/m^2)
8	20	0.002631579	1137.102375	158.7403245
10	40	0.005263158	1140.110582	197.9018558
12	60	0.007894737	1143.134748	236.8539671
13	80	0.010526316	1146.175	255.9111828
14	100	0.013157895	1149.231467	274.8636886
16	120	0.015789474	1152.304278	313.29225
18	140	0.018421053	1155.393566	351.5113915

TABLE NO A.7. Sample no 3(28days strength after 7days curing):

Proving ring	dial gauge	Strain	corrected area(cm^2)	comp. stress (N/m^2)
9	20	0.002631579	1137.102375	178.5828651
11	40	0.005263158	1140.110582	217.6920414
12	60	0.007894737	1143.134748	236.8539671
13	80	0.010526316	1146.175	255.9111828
15	100	0.013157895	1149.231467	294.4968092
18	120	0.015789474	1152.304278	352.4537813
22	140	0.018421053	1155.393566	429.6250341

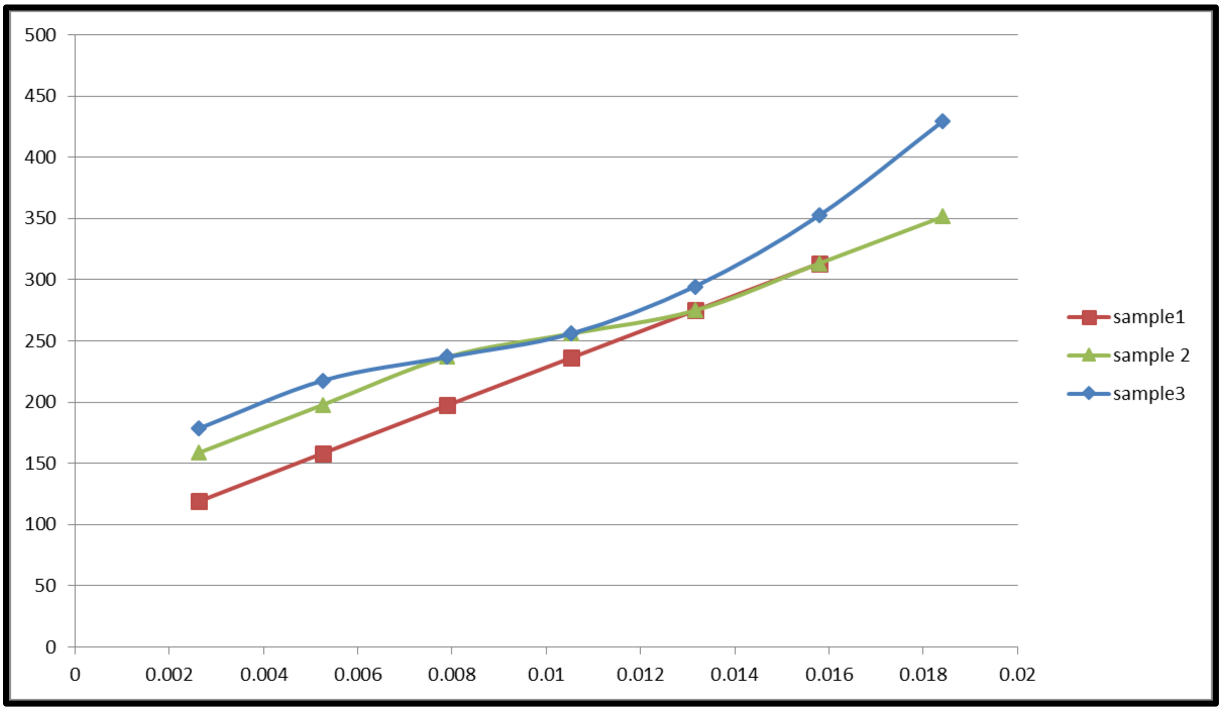


Figure A.2 Stress- strain curve for cement content 8% (7days curing)

UNCONFINED COMPRESSION TEST

CEMENT CONTENT 8% (14DAYS CURING)

TABLE NO A.8. Sample no 1(14days strength after 14days curing):

Proving ring	dial gauge	Strain	corrected area(cm^2)	comp. stress (N/m^2)
11	20	0.002631579	1137.102375	218.2679463
12	40	0.005263158	1140.110582	237.482227
14	60	0.007894737	1143.134748	276.3296283
16	80	0.010526316	1146.175	314.9676097
17	100	0.013157895	1149.231467	333.7630505
18	120	0.015789474	1152.304278	352.4537813
19	140	0.018421053	1155.393566	371.0398021

TABLE NO A.9. Sample no 2(28days strength after 14days curing):

Proving ring	dial gauge	Strain	corrected area(cm^2)	comp. stress (N/m^2)
12	20	0.002631579	1137.102375	238.1104868
13	40	0.005263158	1140.110582	257.2724125
15	60	0.007894737	1143.134748	296.0674589
17	80	0.010526316	1146.175	334.6530853
19	100	0.013157895	1149.231467	373.0292917
21	120	0.015789474	1152.304278	411.1960782
22	140	0.018421053	1155.393566	429.6250341
23	160	0.021052632	1158.499462	447.94928

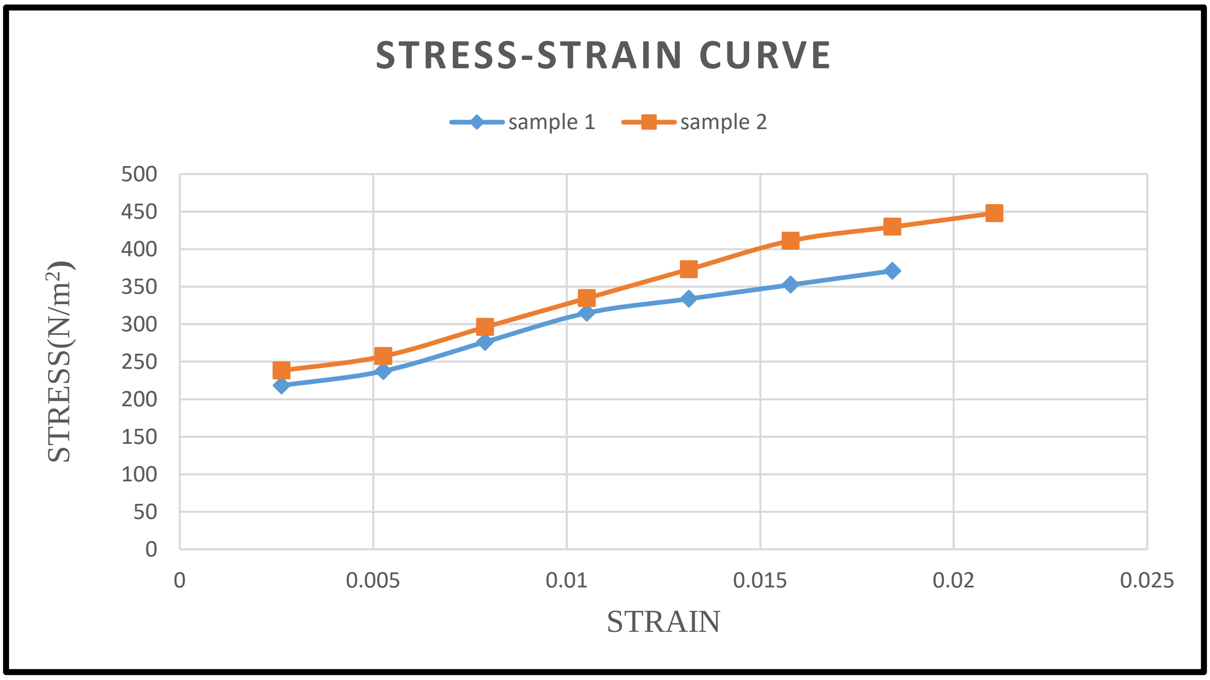


Figure A.3 Stress- strain curve for cement content 8% (14days curing)

UNCONFINED COMPRESSION TEST

CEMENT CONTENT 8% (28DAYS CURING)

TABLE NO A.10. Sample no 1(28days strength after 28days curing):

Proving ring	dial gauge	Strain	corrected area(cm^2)	comp. stress (N/m^2)
14	20	0.002631579	1137.102375	277.795568
16	40	0.005263158	1140.110582	316.6429693
17	60	0.007894737	1143.134748	335.5431201
19	80	0.010526316	1146.175	374.0240365
21	100	0.013157895	1149.231467	412.2955329
22	120	0.015789474	1152.304278	430.7768438
25	140	0.018421053	1155.393566	488.210266

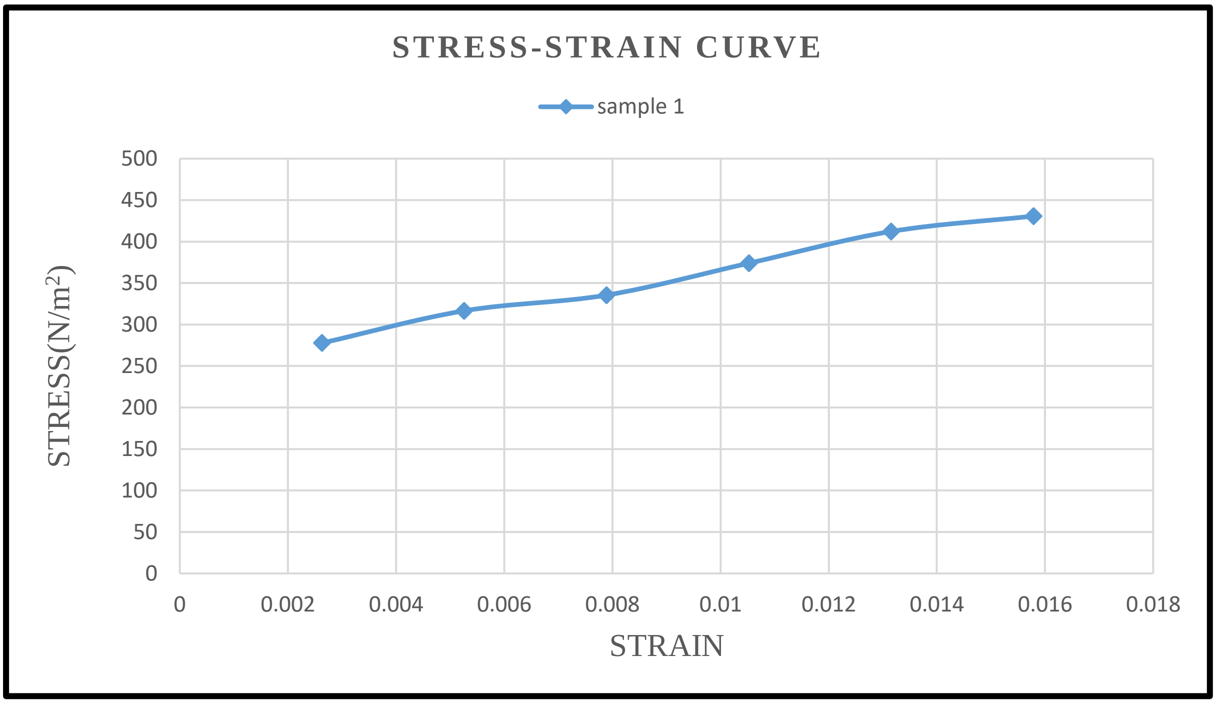


Figure A.4 Stress- strain curve for cement content 8% (28days curing)

UNCONFINED COMPRESSION TEST

CEMENT CONTENT 10% (3DAYS CURING)

TABLE NO A.11. Sample no 1 (3 days strength after 3days curing):

Proving ring	dial gauge	Strain	corrected area(cm^2)	comp. stress (N/m^2)
6	20	0.002631579	1137.102375	119.0552434
8	40	0.005263158	1140.110582	158.3214846
10	60	0.007894737	1143.134748	197.3783059
12	80	0.010526316	1146.175	236.2257072

TABLE NO A.12. Sample no 2 (7 days strength after 3days curing):

Proving ring	dial gauge	Strain	corrected area(cm^2)	comp. stress (N/m^2)
8	20	0.002631579	1137.102375	158.7403245
10	40	0.005263158	1140.110582	197.9018558
12	60	0.007894737	1143.134748	236.8539671
13	80	0.010526316	1146.175	255.9111828
15	100	0.013157895	1149.231467	294.4968092
17	120	0.015789474	1152.304278	332.8730157

TABLE NO A.13. Sample no 3 (14days strength after 3days curing):

Proving ring	dial gauge	Strain	corrected area(cm^2)	comp. stress (N/m^2)
7	20	0.002631579	1137.102375	138.897784
10	40	0.005263158	1140.110582	197.9018558
11	60	0.007894737	1143.134748	217.1161365
15	80	0.010526316	1146.175	295.2821341
16	100	0.013157895	1149.231467	314.1299298
17	120	0.015789474	1152.304278	332.8730157
19	140	0.018421053	1155.393566	371.0398021
20	160	0.021052632	1158.499462	389.521113

TABLE NO A.14. Sample no 4 (28days strength after 3days curing):

Proving ring	dial gauge	Strain	corrected area(cm^2)	comp. stress (N/m^2)
8	20	0.002631579	1137.102375	158.7403245
10	40	0.005263158	1140.110582	197.9018558
12	60	0.007894737	1143.134748	236.8539671
13	80	0.010526316	1146.175	255.9111828
15	100	0.013157895	1149.231467	294.4968092
18	120	0.015789474	1152.304278	352.4537813
21	140	0.018421053	1155.393566	410.0966234
22	160	0.021052632	1158.499462	428.4732243

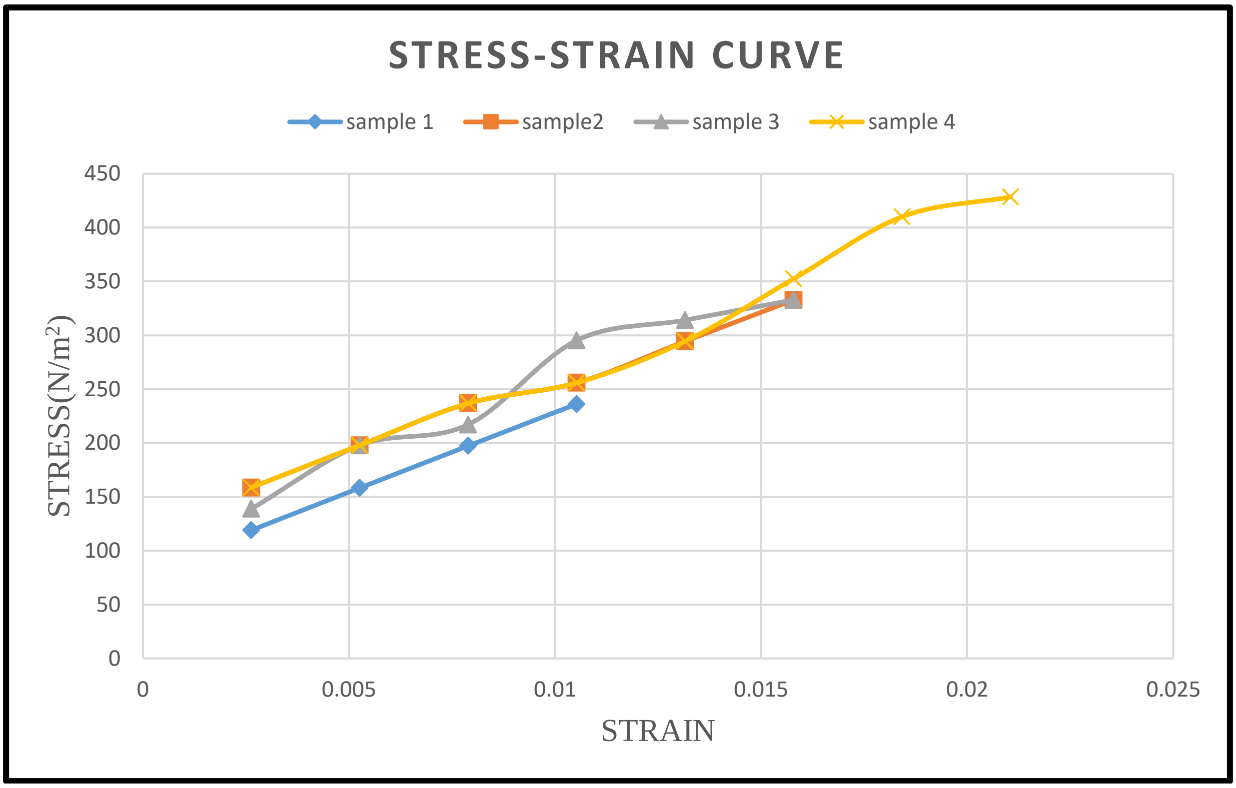


Figure A.5 Stress- strain curve for cement content 10% (3days curing)

UNCONFINED COMPRESSION TEST

CEMENT CONTENT 10% (7DAYS CURING)

TABLE NO A.15. Sample no 1(7days strength after 7days curing):

Proving ring	dial gauge	Strain	corrected area(cm^2)	comp. stress (N/m^2)
11	20	0.002631579	1137.102375	218.2679463
13	40	0.005263158	1140.110582	257.2724125
15	60	0.007894737	1143.134748	296.0674589
17	80	0.010526316	1146.175	334.6530853
18	100	0.013157895	1149.231467	353.3961711
20	120	0.015789474	1152.304278	391.6153125
21	140	0.018421053	1155.393566	410.0966234

TABLE NO A.16. Sample no 2(14days strength after 7days curing):

Proving ring	dial gauge	Strain	corrected area(cm^2)	comp. stress (N/m^2)
11	20	0.002631579	1137.102375	218.2679463
14	40	0.005263158	1140.110582	277.0625981
15	60	0.007894737	1143.134748	296.0674589
16	80	0.010526316	1146.175	314.9676097
18	100	0.013157895	1149.231467	353.3961711
20	120	0.015789474	1152.304278	391.6153125
22	140	0.018421053	1155.393566	429.6250341

TABLE NO A.17. Sample no 3(28days strength after 7days curing):

Proving ring	dial gauge	Strain	corrected area(cm^2)	comp. stress (N/m^2)
12	20	0.002631579	1137.102375	238.1104868
14	40	0.005263158	1140.110582	277.0625981
15	60	0.007894737	1143.134748	296.0674589
18	80	0.010526316	1146.175	354.3385609
21	100	0.013157895	1149.231467	412.2955329
23	120	0.015789474	1152.304278	450.3576094
24	140	0.018421053	1155.393566	468.6818553
25	160	0.021052632	1158.499462	486.9013913

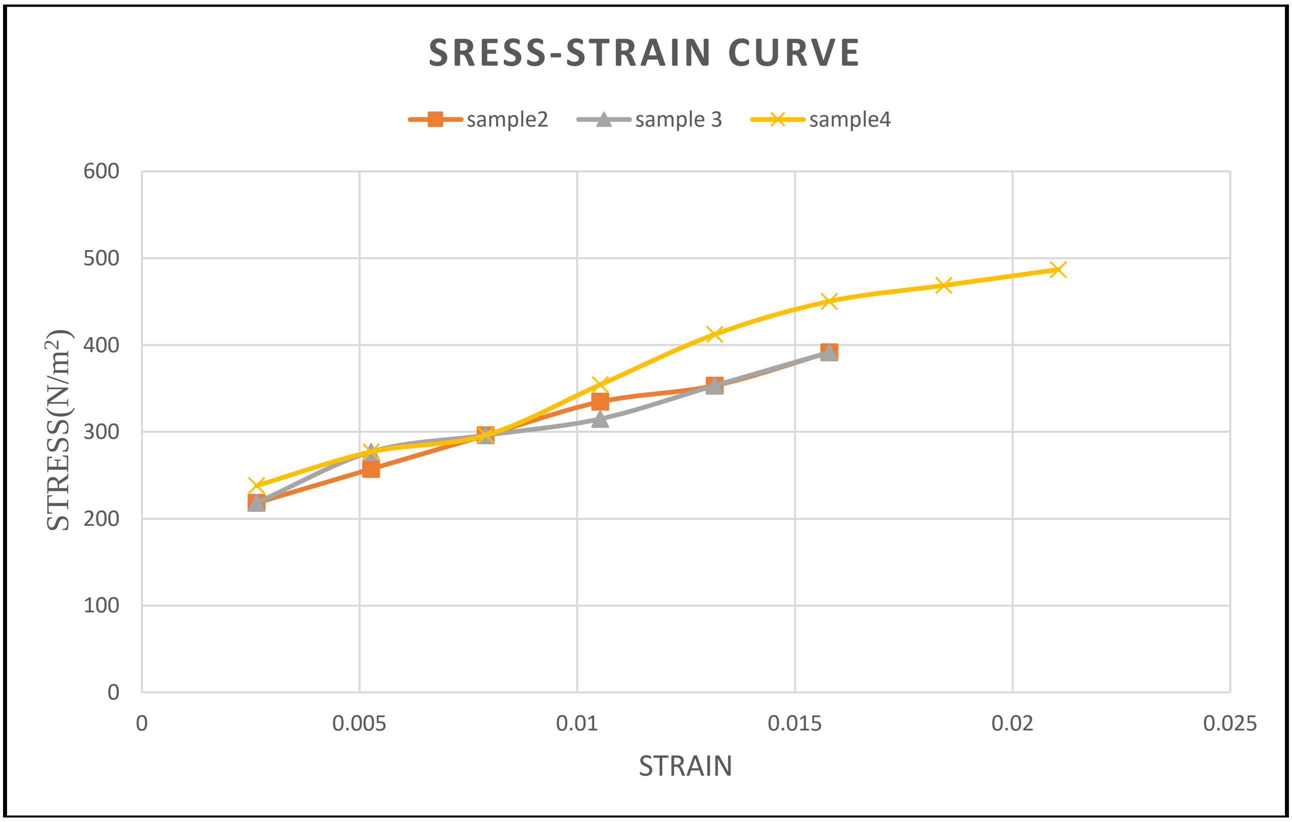


Figure A.6 Stress- strain curve for cement content 10% (7days curing)

UNCONFINED COMPRESSION TEST

CEMENT CONTENT 10% (14DAYS CURING)

TABLE NO A.18. Sample no 1(14days strength after 14days curing):

Proving ring	dial gauge	Strain	corrected area(cm^2)	comp. stress (N/m^2)
13	20	0.002631579	1137.102375	257.9530274
14	40	0.005263158	1140.110582	277.0625981
16	60	0.007894737	1143.134748	315.8052895
19	80	0.010526316	1146.175	374.0240365
22	100	0.013157895	1149.231467	431.9286535
24	120	0.015789474	1152.304278	469.938375
25	140	0.018421053	1155.393566	488.210266

TABLE NO A.19. Sample no 2(14days strength after 14days curing):

Proving ring	dial gauge	Strain	corrected area(cm^2)	comp. stress (N/m^2)
12	20	0.002631579	1137.102375	238.1104868
14	40	0.005263158	1140.110582	277.0625981
16	60	0.007894737	1143.134748	315.8052895
18	80	0.010526316	1146.175	354.3385609
20	100	0.013157895	1149.231467	392.6624123
23	120	0.015789474	1152.304278	450.3576094
24	140	0.018421053	1155.393566	468.6818553
26	160	0.021052632	1158.499462	506.3774469

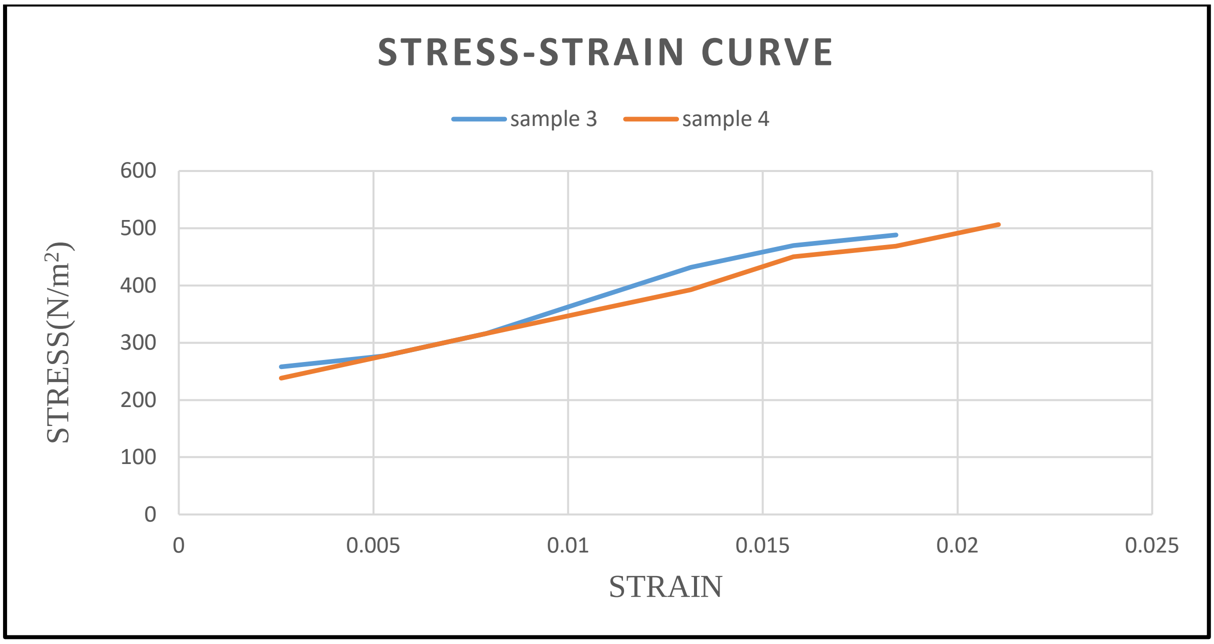


Figure A.7. Stress- strain curve for cement content 10% (14days curing)

UNCONFINED COMPRESSION TEST

CEMENT CONTENT 10% (28DAYS CURING)

TABLE NO A.20. Sample no 1(28days strength after 28days curing):

Proving ring	dial gauge	Strain	corrected area(cm^2)	comp. stress (N/m^2)
13	20	0.002631579	1137.102375	257.9530274
16	40	0.005263158	1140.110582	316.6429693
18	60	0.007894737	1143.134748	355.2809507
21	80	0.010526316	1146.175	413.3949877
22	100	0.013157895	1149.231467	431.9286535
23	120	0.015789474	1152.304278	450.3576094
26	140	0.018421053	1155.393566	507.7386766
27	160	0.021052632	1158.499462	525.8535026

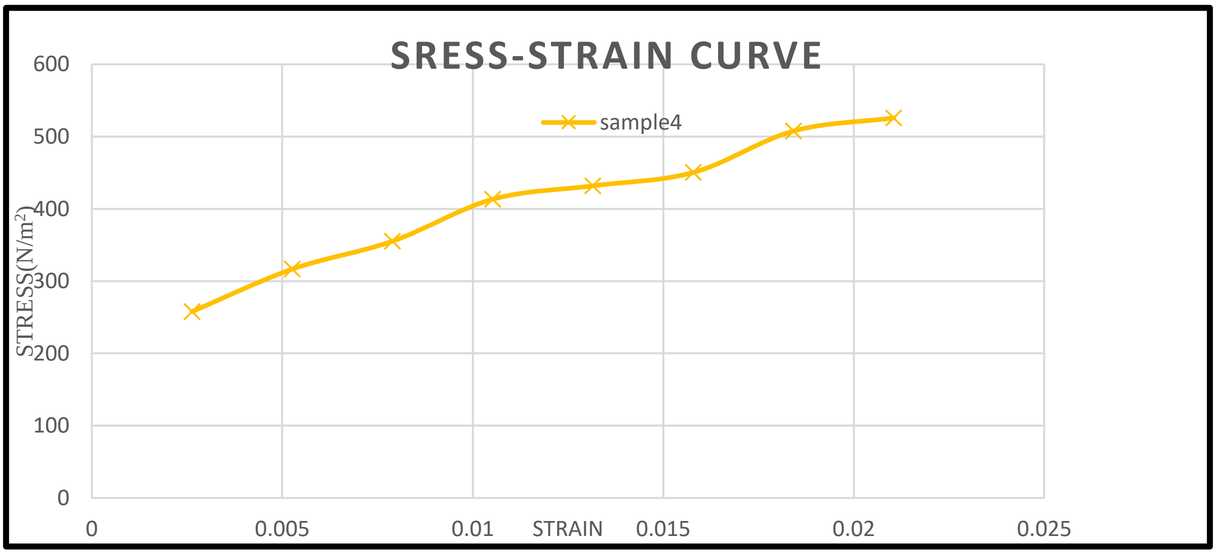


Figure A.8 Stress- strain curve for cement content 10% (28days curing)

UNCONFINED COMPRESSION TEST

CEMENT CONTENT 12% (3 DAYS CURING)

TABLE NO A.21. Sample no 1 (3 day strength after 3 days curing):

Proving ring	dial gauge	Strain	corrected area(cm2)	comp. stress (N/m^2)
5	20	0.002631579	1137.102375	99.21270284
7	40	0.005263158	1140.110582	138.5312991
9	60	0.007894737	1143.134748	177.6404753
11	80	0.010526316	1146.175	216.5402316
12	100	0.013157895	1149.231467	235.5974474

TABLE NO A.22. Sample no 2(7day strength after 3 days curing):

Proving ring	dial gauge	Strain	corrected area(cm^2)	comp. stress (N/m^2)
7	20	0.002631579	1137.102375	138.897784
10	40	0.005263158	1140.110582	197.9018558
12	60	0.007894737	1143.134748	236.8539671
14	80	0.010526316	1146.175	275.5966585
15	100	0.013157895	1149.231467	294.4968092
16	120	0.015789474	1152.304278	313.29225

TABLE NO A.23. Sample no 3(14day strength after 3 days curing):

Proving ring	dial gauge	Strain	corrected area(cm^2)	comp. stress (N/m^2)
7	20	0.002631579	1137.102375	138.897784
9	40	0.005263158	1140.110582	178.1116702
11	60	0.007894737	1143.134748	217.1161365
14	80	0.010526316	1146.175	275.5966585
16	100	0.013157895	1149.231467	314.1299298
17	120	0.015789474	1152.304278	332.8730157

TABLE NO A.24. Sample no 4(28day strength after 3 days curing):

Proving ring	dial gauge	Strain	corrected area(cm^2)	comp. stress (N/m^2)
10	20	0.002631579	1137.102375	198.4254057
12	40	0.005263158	1140.110582	237.482227
14	60	0.007894737	1143.134748	276.3296283
15	80	0.010526316	1146.175	295.2821341
16	100	0.013157895	1149.231467	314.1299298
18	120	0.015789474	1152.304278	352.4537813
20	140	0.018421053	1155.393566	390.5682128

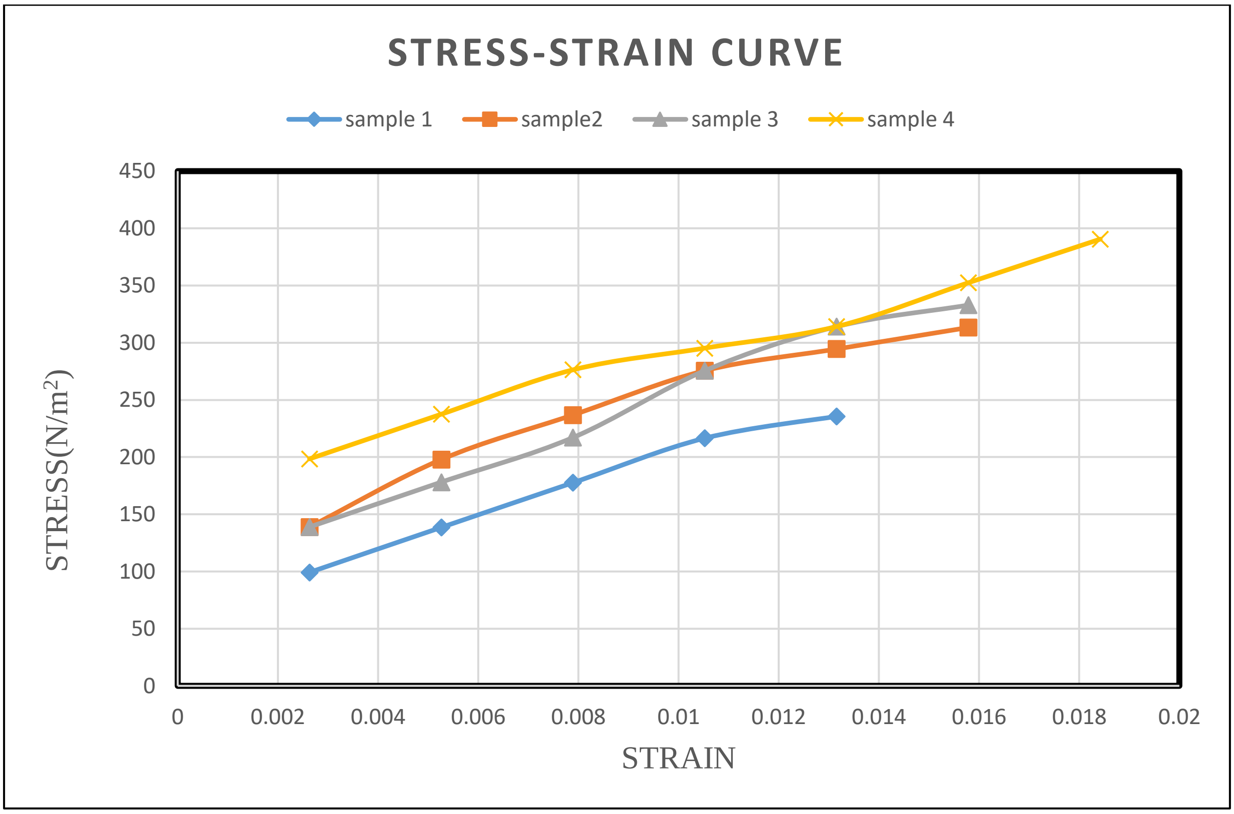


Figure A.9 Stress- strain curve for cement content 12% (3 days curing)

UNCONFINED COMPRESSION TEST

CEMENT CONTENT 12% (7 DAYS CURING)

TABLE NO A.25. Sample no 1(7days strength after 7 days curing):

Proving ring	dial gauge	Strain	corrected area(cm^2)	comp. stress (N/m^2)
8	20	0.002631579	1137.102375	158.7403245
10	40	0.005263158	1140.110582	197.9018558
13	60	0.007894737	1143.134748	256.5917977
15	80	0.010526316	1146.175	295.2821341
16	100	0.013157895	1149.231467	314.1299298
17	120	0.015789474	1152.304278	332.8730157

TABLE NO A.26. Sample no 2(14days strength after 7 days curing):

Proving ring	dial gauge	Strain	corrected area(cm^2)	comp. stress (N/m^2)
7	20	0.002631579	1137.102375	138.897784
9	40	0.005263158	1140.110582	178.1116702
12	60	0.007894737	1143.134748	236.8539671
15	80	0.010526316	1146.175	295.2821341
18	100	0.013157895	1149.231467	353.3961711

TABLE NO A.27. Sample no 3(28days strength after 7 days curing):

Proving ring	dial gauge	Strain	corrected area(cm^2)	comp. stress (N/m^2)
12	20	0.002631579	1137.102375	238.1104868
15	40	0.005263158	1140.110582	296.8527837
16	60	0.007894737	1143.134748	315.8052895
18	80	0.010526316	1146.175	354.3385609
20	100	0.013157895	1149.231467	392.6624123
21	120	0.015789474	1152.304278	411.1960782
22	140	0.018421053	1155.393566	429.6250341

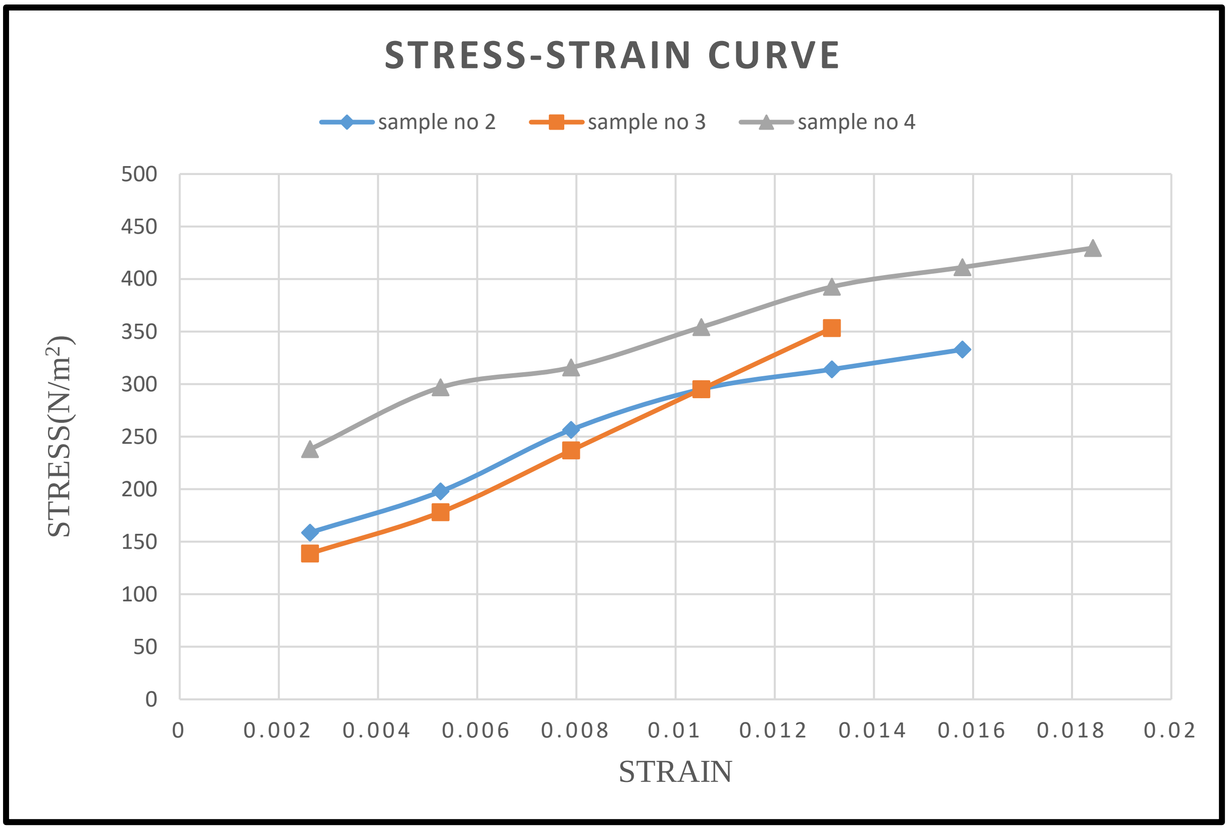


Figure A.10 Stress- strain curve for cement content 12% (7 days curing)

UNCONFINED COMPRESSION TEST

CEMENT CONTENT 12% (14 DAYS CURING)

TABLE NO A.28. Sample no 1(14 days strength after 14days curing):

Proving ring	dial gauge	Strain	corrected area(cm^2)	comp. stress (N/m^2)
8	20	0.002631579	1137.102375	158.7403245
10	40	0.005263158	1140.110582	197.9018558
12	60	0.007894737	1143.134748	236.8539671
14	80	0.010526316	1146.175	275.5966585
17	100	0.013157895	1149.231467	333.7630505
19	120	0.015789474	1152.304278	372.0345469

TABLE NO A.29. Sample no 2(28days strength after 14days curing):

Proving ring	dial gauge	Strain	corrected area(cm^2)	comp. stress (N/m^2)
12	20	0.002631579	1137.102375	238.1104868
15	40	0.005263158	1140.110582	296.8527837
17	60	0.007894737	1143.134748	335.5431201
20	80	0.010526316	1146.175	393.7095121
21	100	0.013157895	1149.231467	412.2955329
22	120	0.015789474	1152.304278	430.7768438
23	140	0.018421053	1155.393566	449.1534447

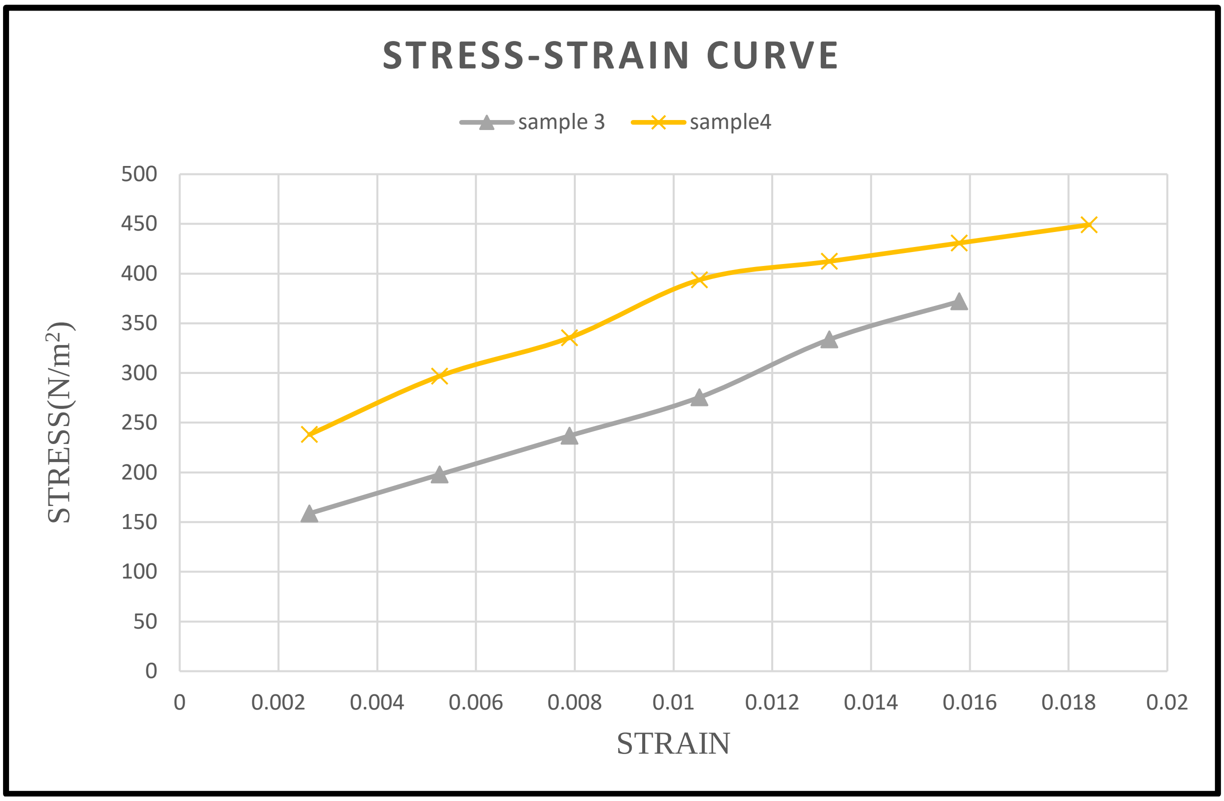


Figure A.11. Stress- strain curve for cement content 12% (14 days curing)

UNCONFINED COMPRESSION TEST

CEMENT CONTENT 8% (WITH CURING STRESS)

TABLE NO A.31. Sample no 1(3days strength after 3 days curing with curing stress)

Proving ring	dial gauge	Strain	corrected area(cm^2)	comp. stress (N/m^2)
4	20	0.002631579	1137.102375	79.37016227
6	40	0.005263158	1140.110582	118.7411135
8	60	0.007894737	1143.134748	157.9026447
10	80	0.010526316	1146.175	196.854756

1TABLE NO A.32. Sample no 2(7days strength after 7 days curing with curing stress)

Proving ring	dial gauge	Strain	corrected area(cm^2)	comp. stress (N/m^2)
10	20	0.002631579	1137.102375	198.4254057
14	40	0.005263158	1140.110582	277.0625981
18	60	0.007894737	1143.134748	355.2809507
20	80	0.010526316	1146.175	393.7095121

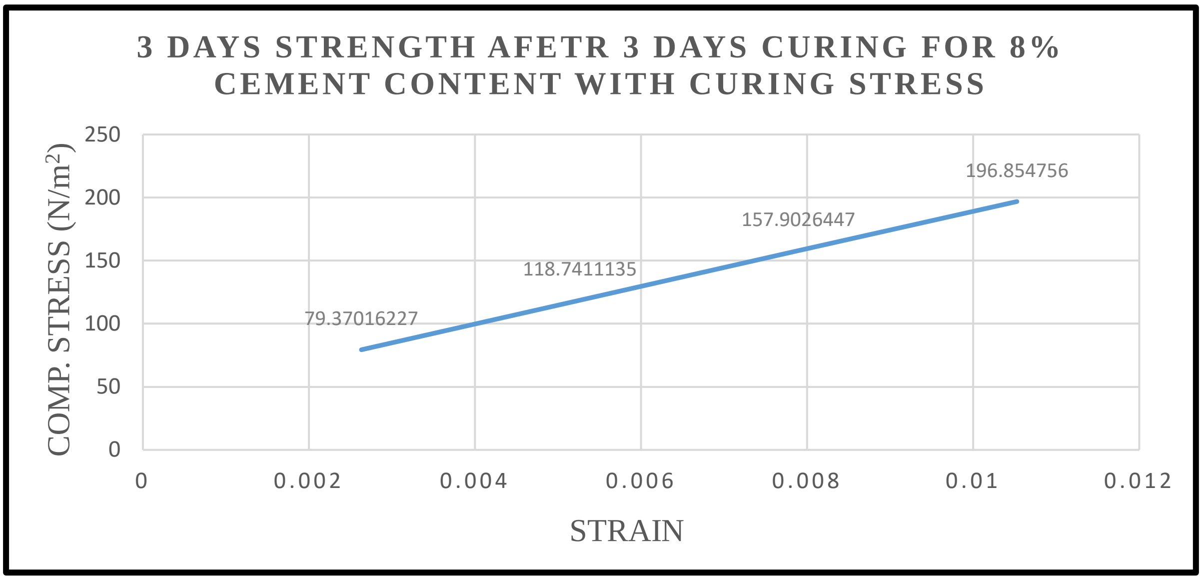


Figure A.13. Stress- strain curve for 8% cement content with curing stress.

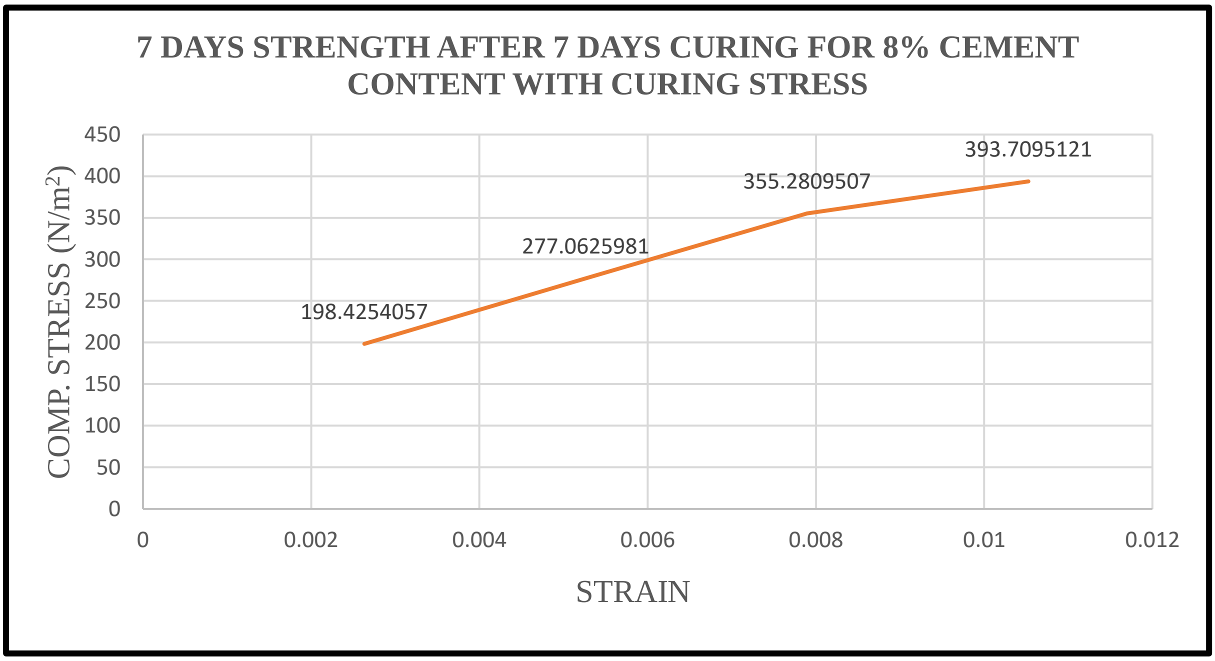


Figure A.14. Stress- strain curve for 8% cement content with curing stress.

UNCONFINED COMPRESSION TEST

CEMENT CONTENT 10% (WITH CURING STRESS)

TABLE NO A.33. Sample no 1(3days strength after 3 days curing with curing stress)

Proving ring	dial gauge	Strain	corrected area(cm^2)	comp. stress (N/m^2)
8	20	0.002631579	1137.102375	158.7403245
10	40	0.005263158	1140.110582	197.9018558
13	60	0.007894737	1143.134748	256.5917977
14	80	0.010526316	1146.175	275.5966585

TABLE NO A.34. Sample no 2(7days strength after 7days curing with curing stress)

Proving ring	dial gauge	Strain	corrected area(cm^2)	comp. stress (N/m^2)
12	20	0.002631579	1137.102375	238.1104868
14	40	0.005263158	1140.110582	277.0625981
16	60	0.007894737	1143.134748	315.8052895
18	80	0.010526316	1146.175	354.3385609
20	100	0.013157895	1149.231467	392.6624123
23	120	0.015789474	1152.304278	450.3576094
25	140	0.018421053	1155.393566	488.210266
27	160	0.021052632	1158.499462	525.8535026

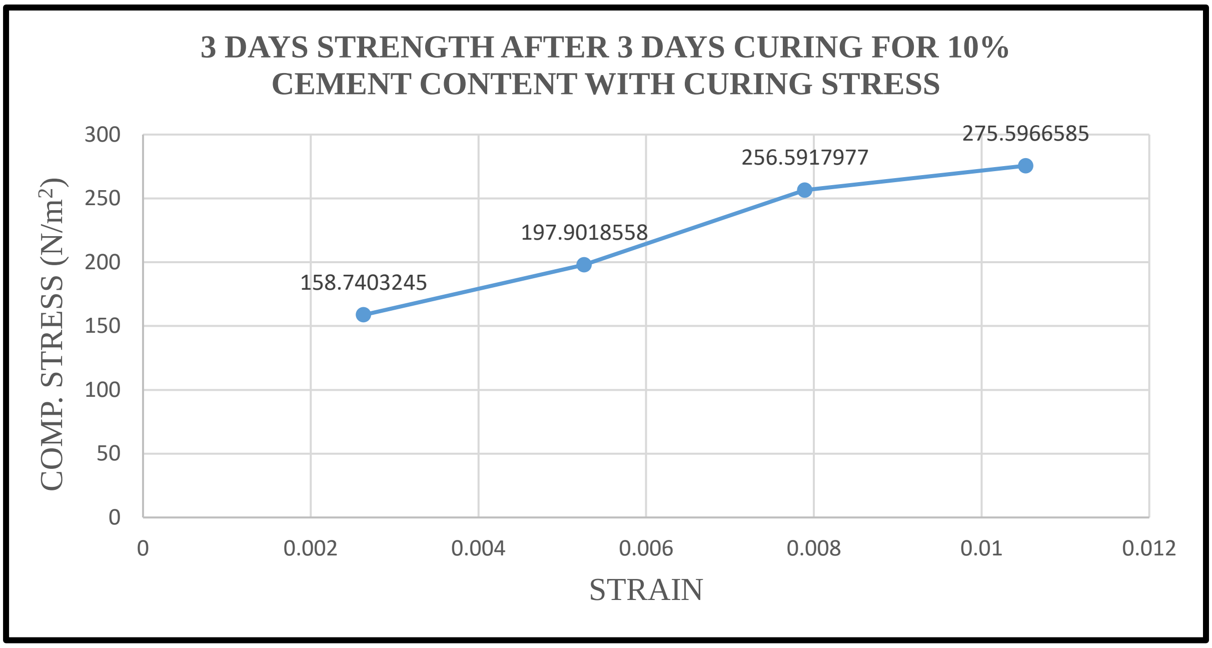


Figure A.15. Stress- strain curve for10% cement content with curing stress.

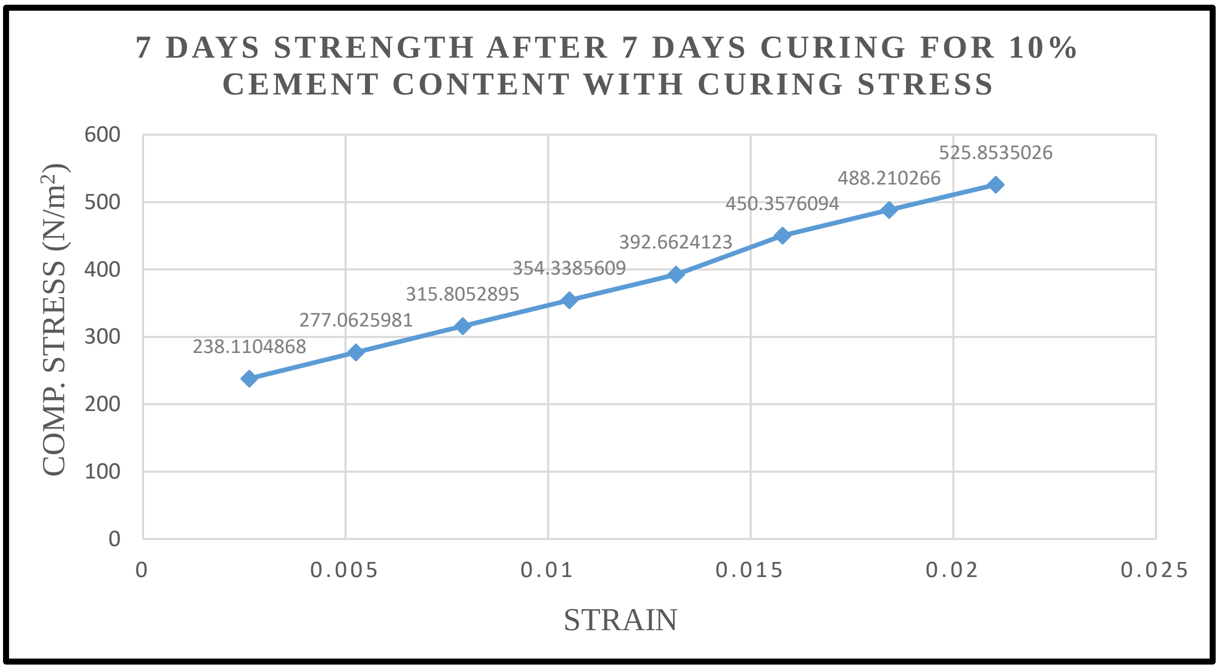


Figure A.16. Stress- strain curve for 10% cement content with curing stress.

UNCONFINED COMPRESSION TEST

CEMENT CONTENT 12% (WITH CURING STRESS)

TABLE NO A.35. Sample no 1(3days strength after 3days curing with curing stress)

Proving ring	dial gauge	Strain	corrected area(cm^2)	comp. stress (N/m^2)
6	20	0.002631579	1137.102375	119.0552434
8	40	0.005263158	1140.110582	158.3214846
10	60	0.007894737	1143.134748	197.3783059
13	80	0.010526316	1146.175	255.9111828

TABLE NO A.36. Sample no 2(7days strength after 7days curing with curing stress)

Proving ring	dial gauge	Strain	corrected area(cm^2)	comp. stress (N/m^2)
8	20	0.002631579	1137.102375	158.7403245
10	40	0.005263158	1140.110582	197.9018558
12	60	0.007894737	1143.134748	236.8539671
14	80	0.010526316	1146.175	275.5966585
16	100	0.013157895	1149.231467	314.1299298
18	120	0.015789474	1152.304278	352.4537813
20	140	0.018421053	1155.393566	390.5682128
22	160	0.021052632	1158.499462	428.4732243

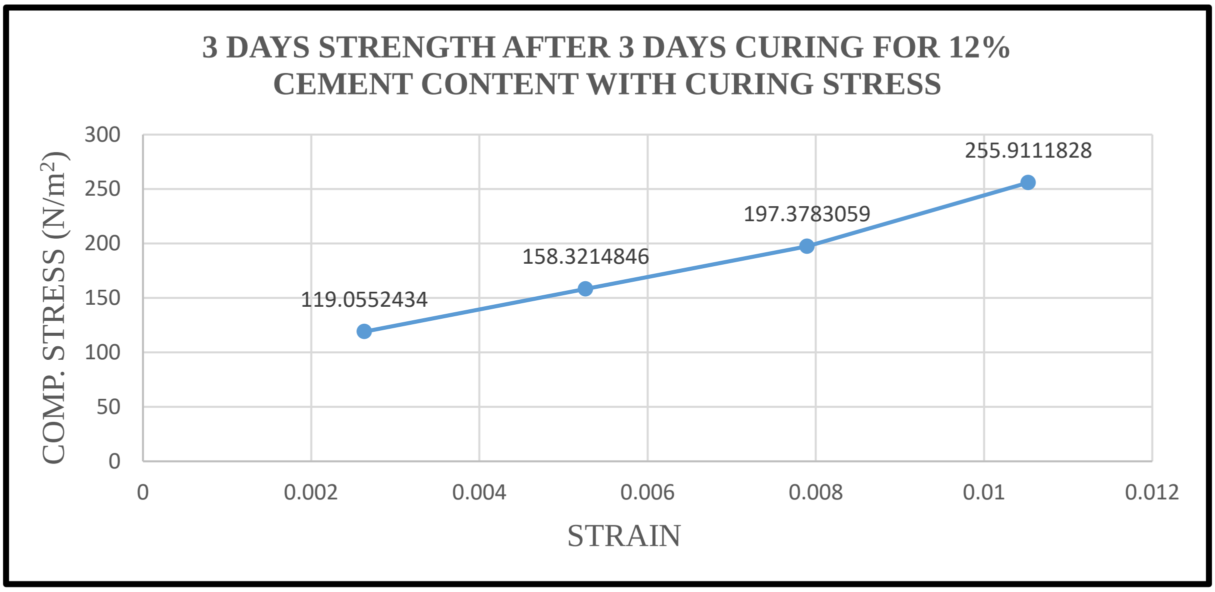
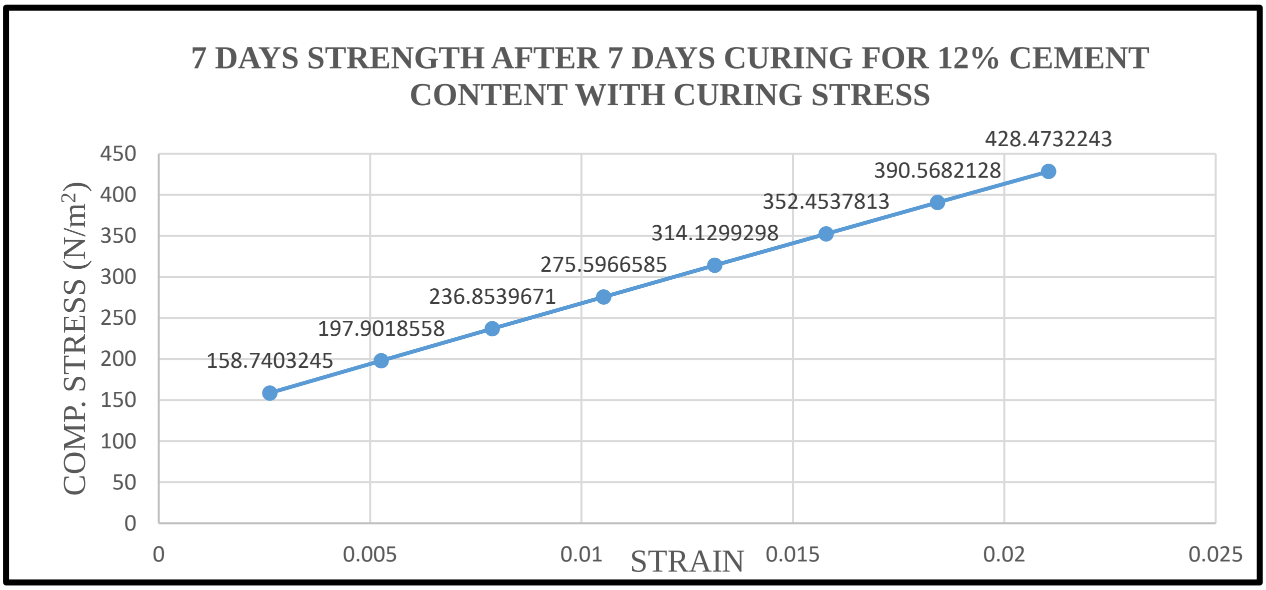


Figure A.17. Stress- strain curve for cement content 12% cement content with curing stress

Figure A.18. Stress- strain curve for cement content 8% cement content with curing stress



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