International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056
Volume: 06 Issue: 05 | May 2019 www.irjet.net p-ISSN: 2395-0072

EXPERIMENTAL STUDY ON CRACK DETECTION AND DAMAGE INDEX IN CONVENTIONAL AND COPPER SLAG REPLACED CONCRETE USING SMART AGGREGATE

Aswathy S Kumar[1], S. Yamini Roja[2]

[1]PG student Department of Civil Engineering, Sri Ramakrishna Institute of Technology, Coimbatore-641010 , India
[2]Assistant Professor, Department of civil Engineering , Sri RamaKrishna Institute Of Technology,Coimbatore-641010 , India

---

Abstract - *Structural Health Monitoring (SHM) along with damage detection and assessment using sensors becomes essential in non-accessible Reinforced Concrete members since engineers often face the problem of detecting hidden damages. Smart sensing technologies including the applications of fibre optic sensors, piezoelectric sensors, magneto restrictive sensors and self-diagnosing fiber reinforced composites possess very important capabilities in monitoring various physical or chemical parameters. In particular, piezoelectric sensors and magneto restrictive sensors can serve both as sensors and actuators, which make SHM to be an active monitoring system. More recently, use of piezoelectric sensors is as an active sensing technology which is based on the measurement of electrical impedance and elastic waves. Based on electrical-mechanical transformation and mechanical-electrical transformation, piezoelectric materials exhibit simultaneous actuator/sensor behavior . In this study, voltage variation in conventional and copper slag replaced concrete is investigated using piezo electric sensors. Evolution of damages in a structure , as a quantitative manner can be identified using damage index equation. From this study, various parameters such as cracking of concrete , integrity of damage will be measured*.

Key Words: **Structural Health Monitoring, Crack Detection, Copper Slag Replaced Concrete, Damage Index**

1. INTRODUCTION

Recent development of various experimental approaches that prevent catastrophic failures and reduce cost of inspection in Reinforced Concrete infrastructures has been emerged from the necessity of real-time damage detection and Structural Health Monitoring (SHM) techniques. SHM aims to develop efficient methods for the continuous inspection and detection of various defects in Civil Engineering structural members. Even minor developing shear damage to deficient shear-critical RC elements, such as beam–column joints, short columns and deep beams, could be the cause of catastrophic collapse. Inaccessibility of portions of structures, presence of unseen hair cracks, as well as material deterioration of some parts of the structure can lead to whole structure failure or some of its elements. Early prediction of this damage could help in increasing their life time and prevent unexpected modes of failure. Therefore, health monitoring of vital structures by means of good nondestructive damage detection tools is crucial to maintain safety and integrity of these structures

1.1 OBJECTIVES

The preliminary objective of this research is to monitor the Structural health along with damage detection and assessment of its severity level in non-accessible Reinforced Concrete members using sensors. The main objective of the study is

(i) To identify the crack initiation in concrete structures.
(ii) To study the feasibility of smart aggregate in conventional and copper slag replaced concrete.
(iii) To identify the severity of damage using damage index expression

1.2 DAMAGE INDEX

A damage index is introduced to analyze the signals detected by the piezo electric patches. The damage index is defined as **DI** = $\frac{\sum_{i=1}^{n}|q_i A_h(i) - A(i)|}{\sum_{i=1}^{n} q_i\ A_h(i)}$ where **i** is the damage index, $\mathbf{A_h(i)}$ is the amplitude of the received signal in healthy state and **A(i)** is the amplitude of the received signal at damage state in frequency domain. The damage index defined by comparing the transfer function in damage state with that in healthy state was used in Gu et al.'s study . A coefficient or weight factor q_i is introduced here to the damage index to assign equal weights to all data points. q_i is defined as $\sum_{i=1}^{n} q_i = 1$

, $q_{i-1} A_h(i) - 1 = q_i \ A_h(i)$ When the damage index (DI) is close to 0, the concrete structure is healthy. Like all other DI definitions, this DI value also increases with the degree of damage: therefore, larger DI value implies more severe damage

2 METHODOLOGY

SHM aims to develop efficient methods for the continuous inspection and detection of various defects in Civil Engineering structural members. Even more, SHM is becoming extremely important in RC structures that are governed by shear mechanisms which lead to fragile and abrupt failure modes. Even minor incipient shear damage to deficient shear critical .RC elements, such as beam–column joints, short columns and deep beams, could be the cause of catastrophic collapse. Early prediction of this damage could help in increasing their life time and prevent unexpected modes of failure.

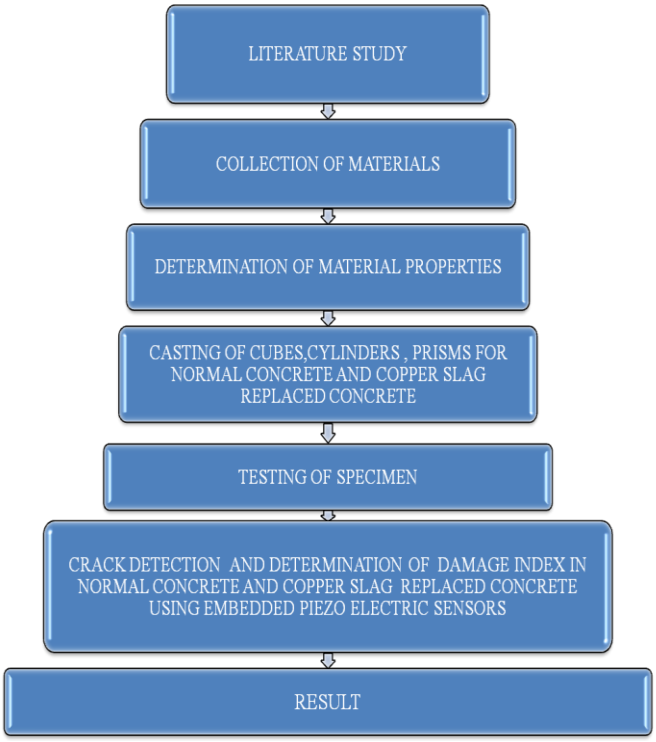

Fig -1 Flow chart for full project methodology

2.1 SMART AGGREGATE PREPERATION

Our Piezoelectric material for this project was Lead Zirconate Titanate (PZT). For this research, piezo electric patches (10mmx10mmx1mm) which is cheaply available , bought from local electronics shop at coimbatore. These patches were then soldered to a standard gauge electric communication wire was also local standard that was connected on the other end to a BNC connecter for connection for instruments such as an oscilloscope. The smart aggregate was first fabricated . It is formed by embedding a piezoceramic patch (10mm × 10mm × 1mm) with water-proof coating and lead wires into a small concrete block. The size of the small concrete block is 40mm × 25mm (diameter × height).

Fig -2 Smart Aggregate

2.2 REPLACEMENT OF FINE AGGREGATE BY COPPER SLAG

Copper slag is an irregular, black, glassy and granular in nature and its properties are similar to the river sand. Copper slag is a byproduct obtained during the matte smelting and refining of copper. In this project fine aggregate is replaced by copper slag to identify the response of piezo electric sensors in replacement of materials. Copper slag used is brought from " Ajith Associates", a copper slag dealer Malumachampatti , Coimbatore. Every ton of copper will generate approximately 2.2-3 tons of copper slag in a year.

2.3 SAMPLE PREPARATION AND TESTING PROCEDURE

The samples were prepared in accordance with the IS standard relevant to each test. In this project total 18 cubes of size 150x150x150, 18 cylinders of height 200mm and diameter 100mm , 18 prism of size 500x100x100 for Normal concrete, 20% copper slag replaced concrete, 40 % copper slag replaced concrete were casted by pouring mixed concrete into moulds. De molding of moulds was done after 24 hours of casting. The specimens were then kept for curing in curing tanks and they were tested after attaining age of 7and 28 days for compressive strength , flexural strength and split tensile strength. The smart aggregate was first fabricated and its schematic is shown in Figure 2. It is formed by embedding a piezoelectric patch (10mm × 10mm × 1mm) with water-proof coating and lead wires into a small concrete block. The size of the small concrete block is 40mm × 25mm (diameter × height). The strength test was conducted using testing machine. The real-time data acquisition system consists of an oscilloscope (Agilent DSO7034B), and a. BNC wires were used to connect the smart aggregate and the data recorder . The damage index of concrete was determined from the change in amplitude in the DSO.

Fig 3- Experimental set up for a cube with embedded patches

3 EXPERIMENTAL INVESTIGATION

3.1 GENERAL

A relationship between load , voltage and damage index was found from compressive, split tensile and flexural strength test. The voltage and damage index values of cube, cylinder and prism specimens for 7 and 28 days are shown below.

3.2 CONVENTIONAL CONCRETE

3.2.1 Damage Index of conventional concrete Cube cured For 7 Days

Table 3.1 : voltage and damage index values of cube specimen cured for 7 days

LOAD(KN)	VOLTAGE (mv)	DAMAGE INDEX
0	38.8	0
100	40	.03
200	48	.23
300	50.4	.298
360	74.4	.917
380	20	.484

3.2.1.1 Digital Recorded Signal At Each Load

The digital recorded signal at each load is shown in figures. Crack formation was identified by the change in amplitude of voltage signals

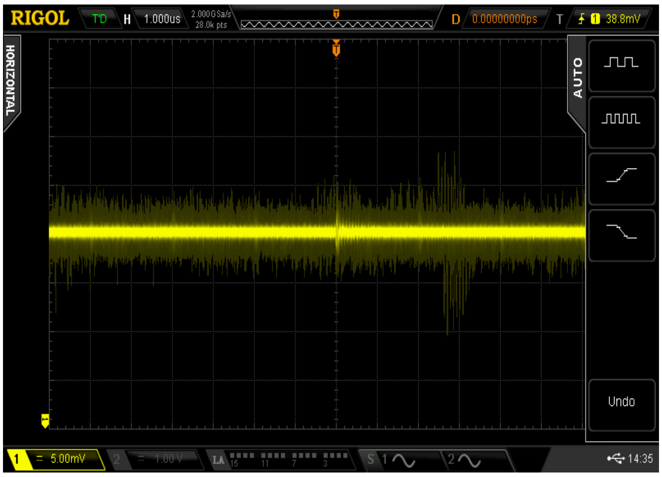

Fig 4 –Digital recorded signal at 0 KN load

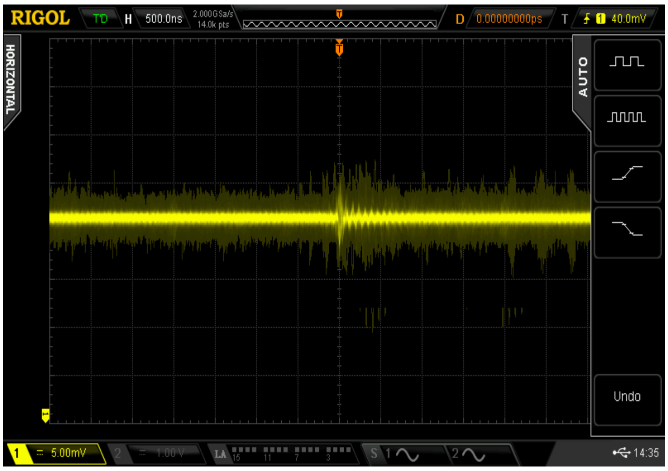

Fig 5- Crack initiation 100 KN load

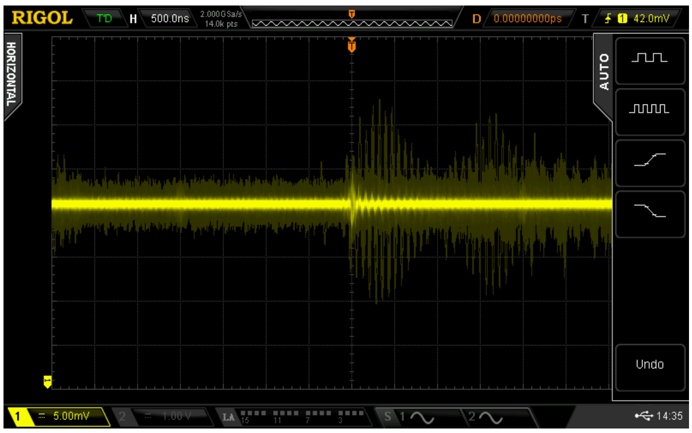

Fig 6 –Digital recorded signal of crack AT 200 KN load

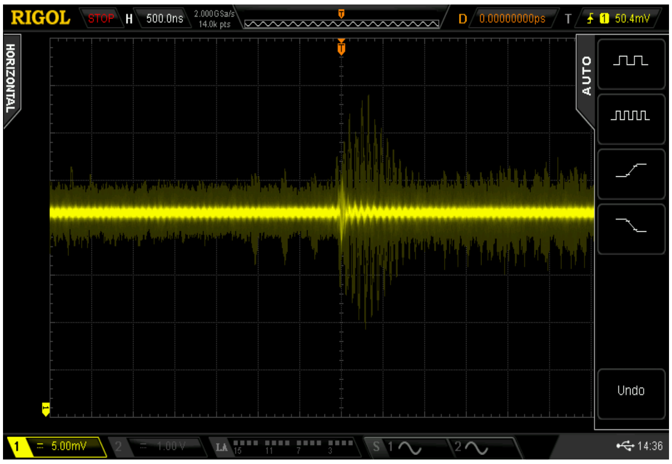

Fig 7- Crack propagated at 300 KN

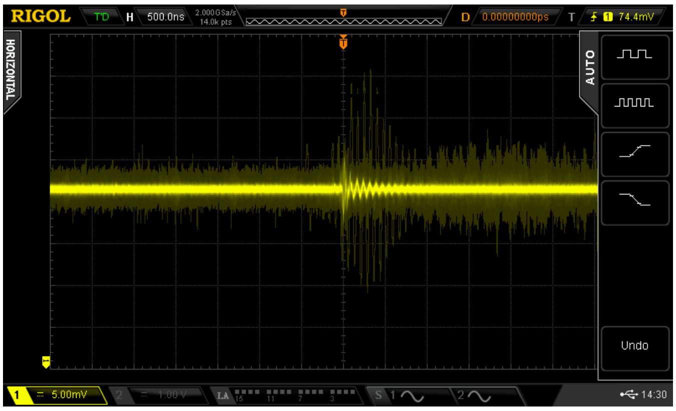

Fig 8- maximum damage at load of 360 KN

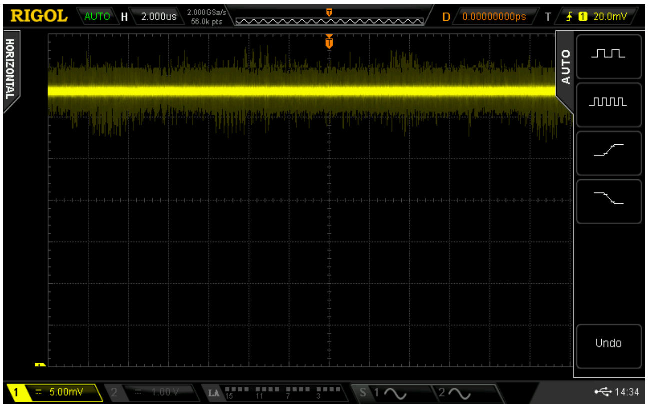

Fig 9- Digital recorded signal of specimen at failure for 7 days stage

3.2.1.2 Graphical Representation Of Load And Voltage

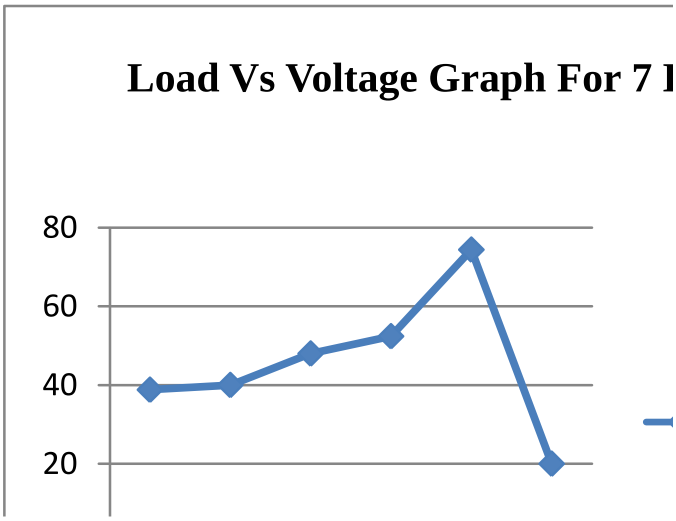

Fig 10 -Load Vs Voltage graph

The voltage variation at each load is measured using oscilloscope. As the load increases ,voltage also increases. Maximum voltage shift occurs at the load of 360 KN that means maximum damage occurs at that load and then the specimen breaks and there is a drop in voltage .

3.2.1.3 Damage Index

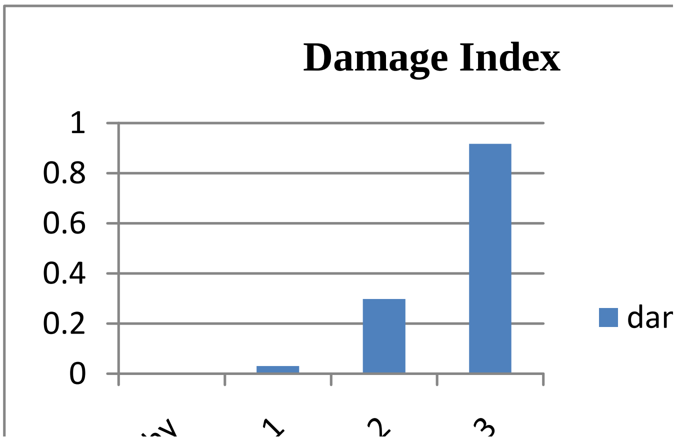

Fig 11- Damage index at different stages

Damage index of each load is calculated using the given equation. $\frac{\sum_{i=1}^{n}|q_i A_h(i) - A(i)|}{\sum_{i=1}^{n} q_i A_h(i)}$ When no load is applied the specimen is in healthy stage ,there is no damage in the specimen. As the load increases, integrity of damage also increases .The maximum damage occurs at the load of 360 KN and damage index on that load is .917

3.2.2 Damage Index of Conventional concrete Cube cured For 28Days

Table 3.2: Voltage and Damage index values of cube specimen cured for 28 days

LOAD	VOLTAGE	DAMAGE INDEX
0	58	0
100	65	.12
200	74.8	.28
300	82	.413
400	105.8	.824
480	63	.08

3.2.2.1 Graphical Representation Of Load And Voltage

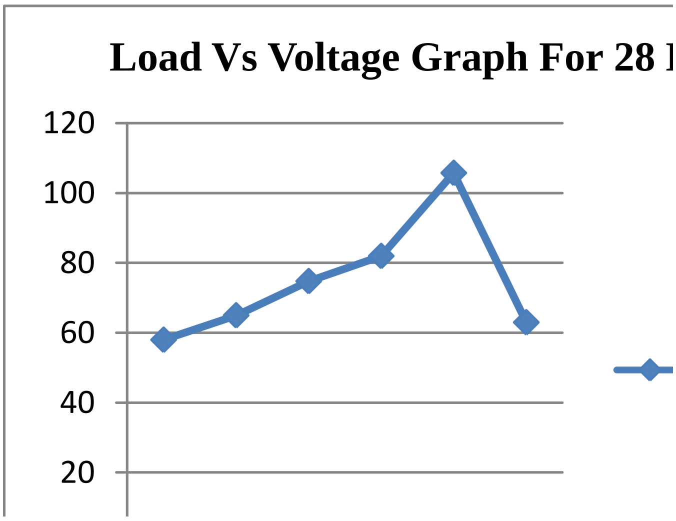

Fig 12- load Vs voltage graph for 28 days

The voltage variation at each load is measured using oscilloscope. As the load increases, voltage also increases. Maximum voltage shift occurs at the load of 400 KN that means maximum damage occurs at that load and then the specimen breaks and there is a drop in voltage.

3.2.2.2 Damage Index

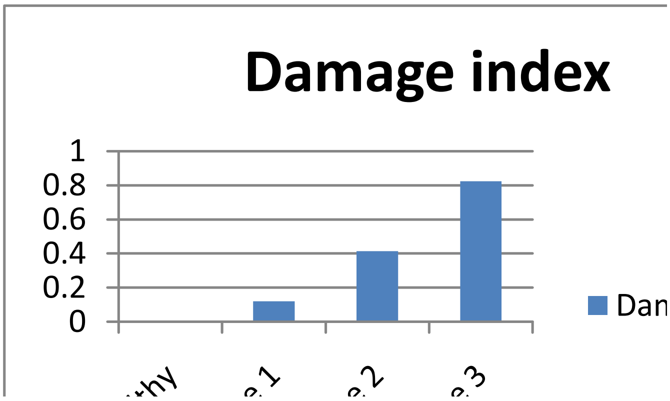

Fig 13- Damage index at different stages

Damage index of each load is calculated using the given equation $\frac{\sum_{i=1}^{n}|q_i A_h(i) - A(i)|}{\sum_{i=1}^{n} q_i A_h(i)}$. When no load is applied the specimen is in healthy stage ,there is no damage in the specimen. As the load increases integrity of damage also increases .The maximum damage occurs at the load of 400 KN and damage index on that load is .824

3.2.3 Damage Index of conventional concrete Cylinder cured For 28 Days

Table 3.3 : Voltage and Damage index values of cylinder specimen cured for 28 days

LOAD (KN)	VOLTAGE(mv)	Damage index
0	30	0
50	57	.9
70	45	.5

3.2.3.1 Graphical Representation Of Load And Voltage

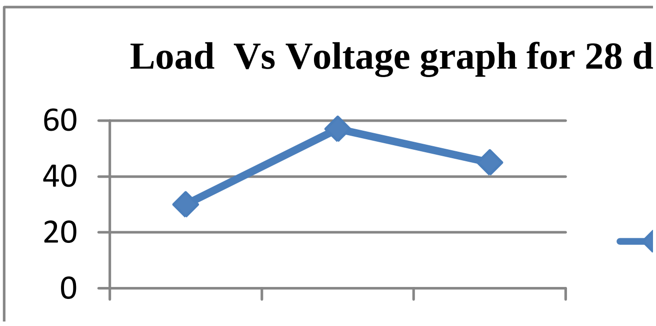

Fig 14- Load Vs voltage graph

The voltage variation in each load is measured using oscilloscope. As the load increases voltage also increases. Maximum voltage shift occurs at the load of 50 KN that means maximum damage occurs at that and then the specimen breaks, and there is a drop in voltage.

3.2.3.2 Damage Index

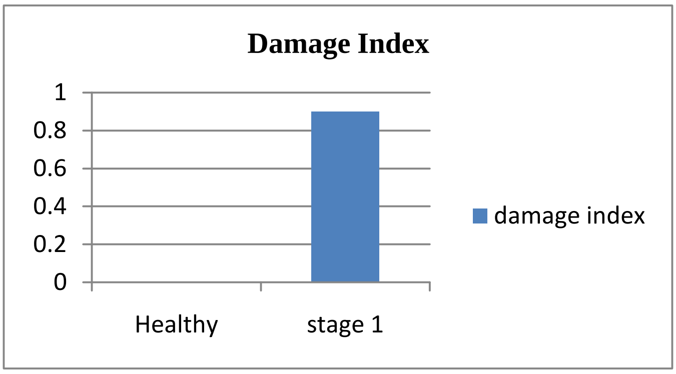

Fig 15- Damage index at different stages

Damage index of each load is calculated using the given equation. $\frac{\sum_{i=1}^{n}|q_i A_h(i) - A(I)|}{\sum_{i=1}^{n} q_i \; A_h(i)}$. When no load is applied the specimen is in healthy stage ,there is no damage in the specimen. As the load increases integrity of damage also increases The maximum damage occurs at the load of 50 KN and damage index on that load is .9

3.2.4 Damage Index of Conventional concrete Prism cured For 28 Days

Table 3.3 : Voltage and Damage index values of prism specimen cured for 28 days

LOAD	VOLTAGE	DAMAGE INDEX
0	50	0
7	4	.92

3.2.4.1 Graphical Representation Of Load And Voltage

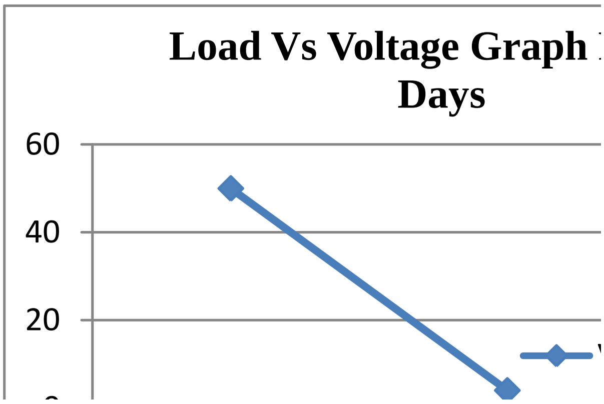

Fig 16- Load Vs voltage graph

The voltage variation in each load is measured using oscilloscope. when no load is applied the voltage was 50mv As the load increases failure of specimen occurs at 7KN load and there is a sudden drop in voltage occurred from 50 mv to 4mv. Maximum voltage shift occurs at the load of 7 KN that means maximum damage occurs at that load.

3.2.4.2 Damage Index

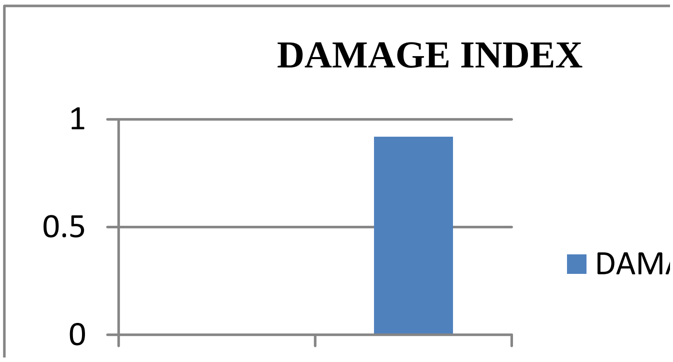

Fig 17- Damage index at different stages

Damage index of each load is calculated using the given equation$\frac{\sum_{i=1}^{n}|q_i A_h(i) - A(I)|}{\sum_{i=1}^{n} q_i \; A_h(i)}$. When no load is applied the specimen is in healthy stage ,there is no damage in the specimen. As the load increases integrity of damage also increases The failure of specimen occurs at the load of 7 KN and damage index on that load is .92

3.3 20 % COPPER SLAG REPLACED CONCRETE

3.3.1 Damage index of 20% copper slag replaced concrete cube cured for 7 days

Table 3.4 : Voltage and Damage index values of cube specimen for 7 days.

LOAD	VOLTAGE	DAMAGE INDEX
0	130	0
100	226	.65
200	236	.815
300	238.1	.831
400	250	.92
455	230	.67

3.3.1.1 Graphical Representation Of Load And Voltage

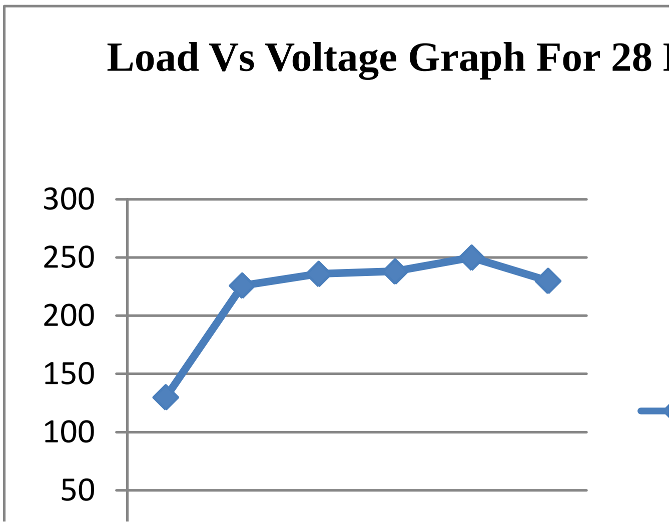

Fig 18- Load Vs voltage graph

The voltage variation in each load is measured using oscilloscope. As the load increases voltage also increases. Maximum voltage shift occurs at the load of 400 KN that means maximum damage occurs at the load of 400 KN and then the specimen breaks and there is a drop in voltage.

3.3.1.2 Damage Index

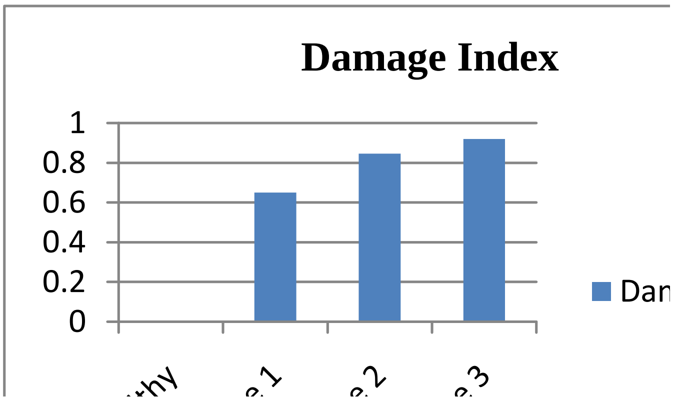

Fig 19- Damage index at different stages

Damage index of each load is calculated using the given equation $\frac{\sum_{i=1}^{n}|q_i A_h(i) - A(I)|}{\sum_{i=1}^{n} q_i \ A_h(i)}$. When no load is applied the specimen is in healthy stage ,there is no damage in the specimen. As the load increases integrity of damage also increases . The maximum damage occurs at the load of 400 KN and damage index on that load is .92

3.3.2 Damage index of 20% copper slag replaced concrete cube cured for 28 days

Table 3.5 : Voltage and Damage index values of cube specimen cured for 28 days

LOAD	VOLTAGE	DAMAGE INDEX
0	76.8	0
100	104	.354
200	119	.54
300	122	.588
400	126	.64
500	131	.70
600	132	.718
700	150.4	.958
720	118	.53

3.3.2.1 Graphical Representation Of Load And Voltage

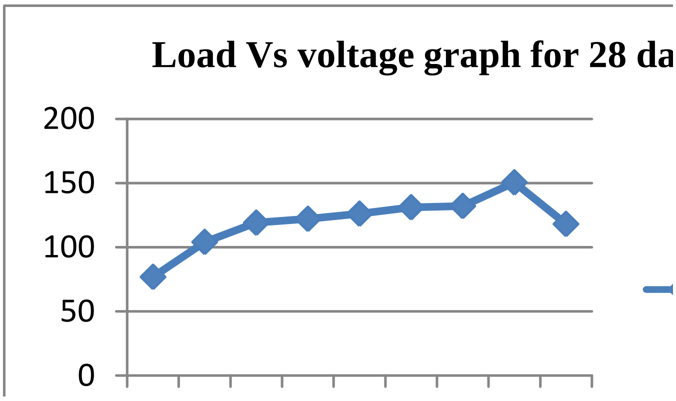

Fig 20- Load Vs voltage graph

The voltage variation in each load is measured using oscilloscope. As the load increases voltage also increases. Maximum voltage shift occurs at the load of 700 KN that means maximum damage occurs at the load of 700 KN then the specimen breaks and there is a drop in voltage.

3.3.2.2 Damage Index

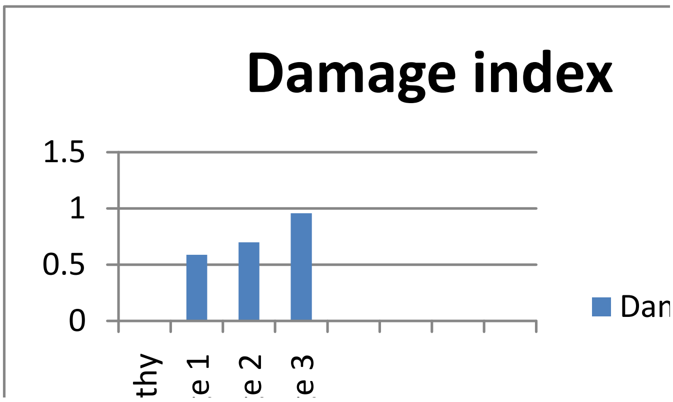

Fig 21 -Damage index at different stages

Damage index of each load is calculated using the given equation $\frac{\sum_{i=1}^{n}|q_i A_h(i) - A(I)|}{\sum_{i=1}^{n} q_i A_h(i)}$. When no load is applied the specimen is in healthy stage ,there is no damage in the specimen. As the load increases integrity of damage also increases The maximum damage occurs at the load of 700 KN and damage index on that load is .958

3.3.3 Damage index of 20% copper slag replaced concrete cylinder cured for 28 days

Table 3.6 : Voltage and Damage index values of cylinder specimen cured for 28 days

LOAD	VOLTAGE	DAMAGE INDX
0	40	0
50	73.5	.83
100	50.2	.25

3.3.3.1 Graphical Representation Of Load And Voltage

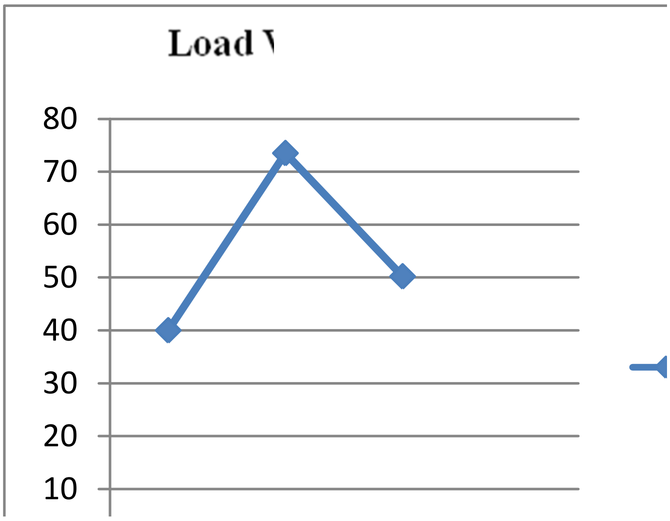

Fig 22 –Load Vs voltage graph

The voltage variation in each load is measured using oscilloscope. As the load increases voltage also increases. Maximum voltage shift occurs at the load of 50 KN that means maximum damage occurs at the load of 50 KN and then the specimen breaks and there is a drop in voltage.

3.3.3.2 Damage Index

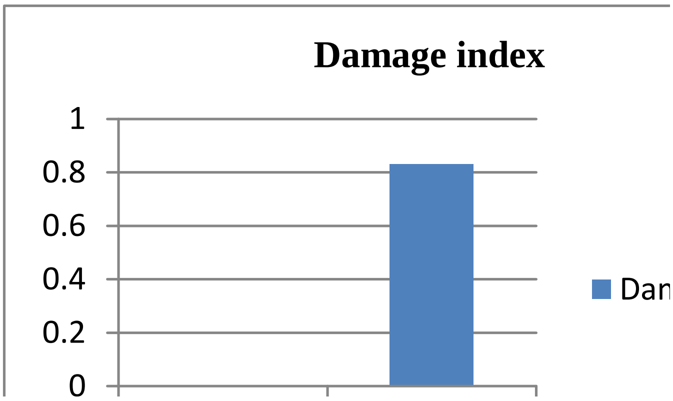

Fig 23- Damage index at different stages

Damage index of each load is calculated using the given equation $\frac{\sum_{i=1}^{n} |q_i A_h(i) - A(I)|}{\sum_{i=1}^{n} q_i\ A_h(i)}$. When no load is applied the specimen is in healthy stage ,there is no damage in the specimen. As the load increases integrity of damage also increases The maximum damage occurs at the load of 50 KN and damage index on that load is .83

3.3.4 Damage index of 20% copper slag replaced concrete prism cured for 28 days

Table 3.7 : Voltage and Damage index values of prism specimen cured for 28 days

LOAD	VOLTAGE	DAMAGE INDEX
0	120	0
10.8	10.56	.912

3.3.4.1 Graphical Representation Of Load And Voltage

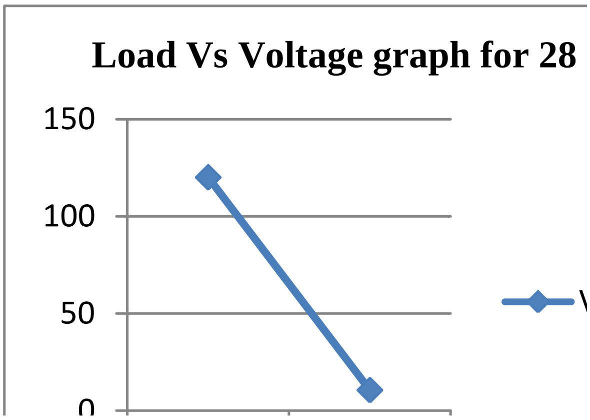

Fig 23- Load Vs voltage graph

The voltage variation in each load is measured using oscilloscope. when no load is applied the voltage was 120 mv . As the load increases failure of specimen occurs at 10.8 KN load and there is a sudden drop in voltage occurred from 120 mv to 10.56 mv. Maximum voltage shift occurs at the load of 10.8 KN that means maximum damage occurs at that load .

3.3.4.2 Damage Index

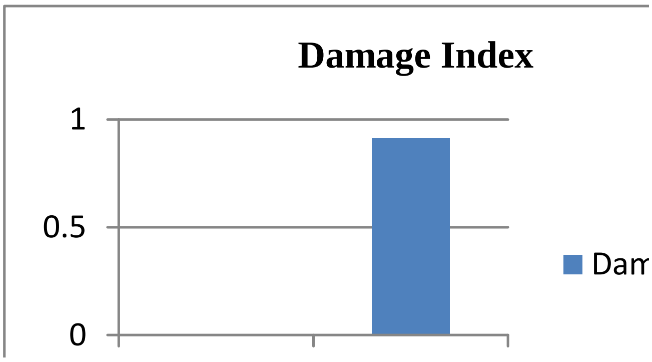

Fig 24- Damage index at different stages

Damage index of each load is calculated using the given equation $\frac{\sum_{i=1}^{n} |q_i A_h(i) - A(I)|}{\sum_{i=1}^{n} q_i\ A_h(i)}$. When no load is applied the specimen is in healthy stage ,there is no damage in the specimen. As the load increases integrity of damage also increases The failure of specimen occurs at the load of 10.8 KN and damage index on that load is .912

3.4 40% COPPER SLAG REPLACED CONCRETE

3.4.1 Damage index of 40% copper slag replaced concrete cube cured for 7 days

Table 3.8 : Voltage and Damage index values of cube specimen cured for 7 days

LOAD	VOLTAGE	DAMAGE INDEX
0	146	0
100	234	.6
200	236.2	.617
300	243	.66
400	247.5	.7
500	270	.84
560	240	.643

3.4.1.1 Graphical Representation Of Load And Voltage

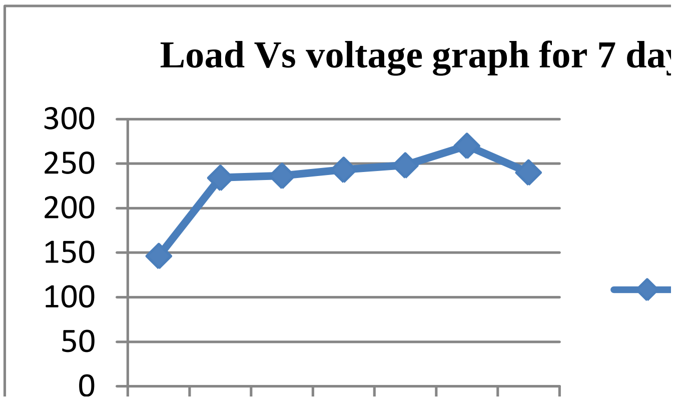

Fig 25- Load Vs voltage graph

The voltage variation in each load is measured using oscilloscope. As the load increases voltage also increases. Maximum voltage shift occurs at the load of 500 KN that means maximum damage occurs at the load of 500 KN and then the specimen breaks and there is a drop in voltage.

3.4.1.2 Damage Index

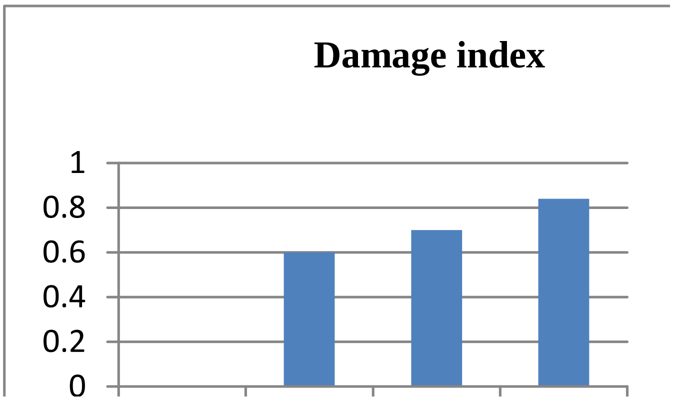

Fig 26- Damage index at different stages

Damage index of each load is calculated using the given equation $\frac{\sum_{i=1}^{n} |q_i A_h(i) - A(I)|}{\sum_{i=1}^{n} q_i\ A_h(i)}$. When no load is applied the specimen is in healthy stage ,there is no damage in the specimen. As the load increases integrity of damage also increases .The maximum damage occurs at the load of 500 KN and damage index on that load is .84

3.4.2 Damage index of 40% copper slag replaced concrete cube cured for 28 days

Table 3.9 : Voltage and Damage index values of cube specimen cured for 28 days

LOAD	VOLTAGE	DAMAGE INDEX
0	60	0
100	61.6	.026
200	64.4	.073
300	73.6	.22
400	75	.25
500	86.4	.44
600	99.6	.66
700	101.2	.686
800	115	.916
890	76.8	.28

3.4.2.1 Graphical Representation Of Load And Voltage

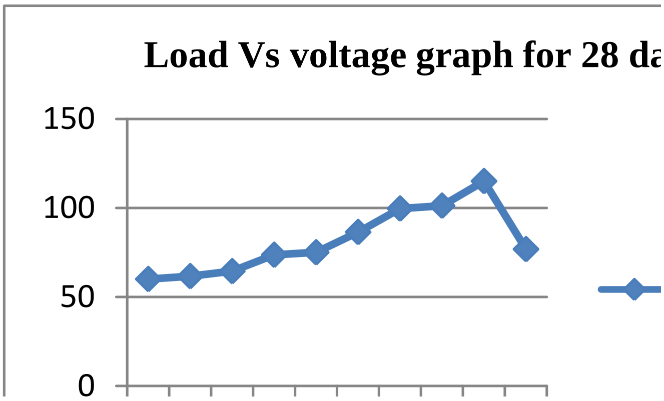

Fig 27- Load Vs voltage graph

The voltage variation in each load is measured using oscilloscope. As the load increases voltage also increases. Maximum voltage shift occurs at the load of 800 KN that means maximum damage occurs at the load of 800 KN and then the specimen breaks and there is a drop in voltage.

3.4.2.2 Damage Index

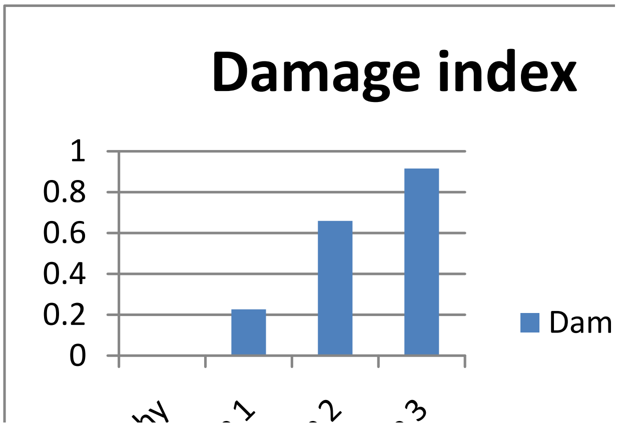

Fig 28 - Damage index at different stages

Damage index of each load is calculated using the given equation $\frac{\sum_{i=1}^{n}|q_i A_h(i) - A(I)|}{\sum_{i=1}^{n} q_i\ A_h(i)}$. When no load is applied the specimen is in healthy stage ,there is no damage in the specimen. As the load increases integrity of damage also increases . The maximum damage occurs at the load of 800 KN and damage index on that load is .916

3.4.3 Damage index of 40% copper slag replaced concrete cylinder cured for 28 days

Table 3.10 : Voltage and Damage index values of cylinder specimen cured for 28 days

LOAD	VOLTAGE	DAMAGE INDEX
0	30	0
50	56.2	.87
110	44	.46

3.4.3.1 Graphical Representation Of Load And Voltage

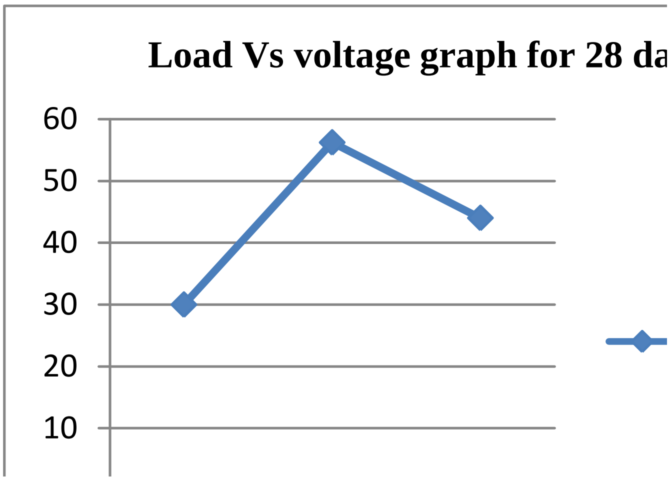

Fig 29- Load Vs Voltage graph

The voltage variation in each load is measured using oscilloscope. As the load increases voltage also increases. Maximum voltage shift occurs at the load of 50 KN that means maximum damage occurs at the load of 50 KN and then the specimen breaks and there is a drop in voltage.

3.4.3.2 Damage Index

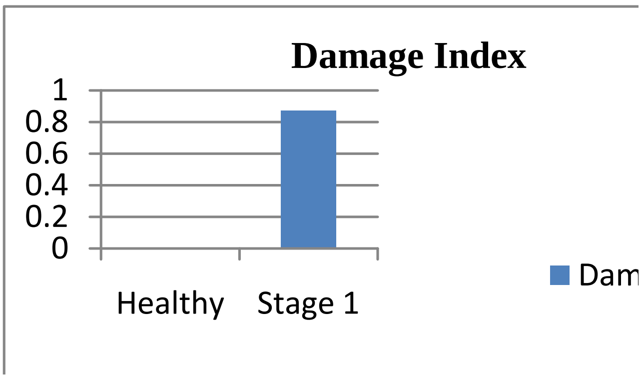

Fig 30- Damage index at different stages

Damage index of each load is calculated using the given equation $\frac{\sum_{i=1}^{n}|q_i A_h(i) - A(I)|}{\sum_{i=1}^{n} q_i \, A_h(i)}$. When no load is applied the specimen is in healthy stage ,there is no damage in the specimen. As the load increases integrity of damage also increases .The maximum damage occurs at the load of 50 KN and damage index on that load is .87

3.4.4 Damage index of 40% copper slag replaced concrete prism cured for 28 days

Table 3.11 : Voltage and Damage index values of prism specimen cured for 28 days

LOAD	VOLTAGE	DAMAGE INDEX
0	82	0
12.4	4	.95

3.4.4.1 Graphical Representation Of Load And Voltage

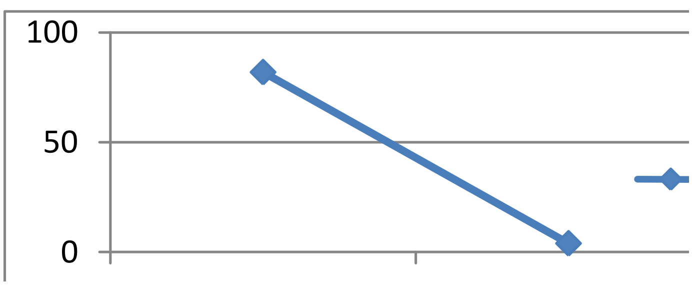

Fig 31- Load Vs Voltage graph

The voltage variation in each load is measured using oscilloscope. when no load is applied the voltage was 82mv As the load increases failure of specimen occurs at 12.4KN load and there is a sudden drop in voltage occurred from 82 mv to 4mv. Maximum voltage shift occurs at the load of 12.4 KN that means maximum damage occurs at that load .

3.4.4.2 Damage Index

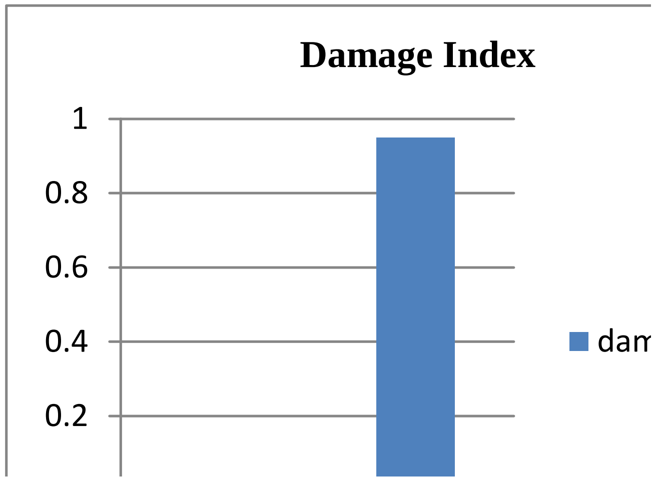

Fig 32- Damage index at different stages

Damage index of each load is calculated using the given equation $\frac{\sum_{i=1}^{n}|q_i A_h(i) - A(I)|}{\sum_{i=1}^{n} q_i \, A_h(i)}$. When no load is applied the specimen is in healthy stage ,there is no damage in the specimen. As the load increases integrity of damage also increases .The failure of specimen occurs at the load of 12.4 KN and damage index on that load is .95

4 CONCLUSION.

The damage of the structure is monitored using smart aggregate of size 40mmx25mm(diameter x height). A piezo electric sensor of (10mmx10mmx1mm) is embedded inside a small concrete block .The smart aggregate acted as transmitter. From the compressive strength test conducted on concrete specimen, the increase in strength of concrete from 7 to 28 days of curing is observed. The damage of concrete during compressive strength, split tensile strength and flexural strength test of concrete is observed at an interval of 100 KN load acting over the specimen. Voltage shift in each load is measured using oscilloscope. A linear relation ship between output voltage of piezo electric sensor and input load can be recognized. Severity of damage is analysed using a damage index equation. The signal amplitude received by a piezoelectric patch were recorded at four stages. Healthy stage (no crack is visible), stage 1 of damage (when a visible crack appears), stage 2 of damage (when maximum crack occurs), and stage 3 of damage(maximum crack reaches, severe damage) .From the experimental investigation following conclusions can be arrived.

- The concrete cube specimens of conventional concrete cured for 7 days and 28 days fails at loads of 380 and 480 KN respectively. The concrete cube specimen of 20% copper slag replaced concrete cured for 7 and 28 days fails at loads of 455 KN and 720 KN. But the concrete cube specimen of 40% copper slag replaced concrete cured for 7 and 28 days fails at loads of 560 KN and 89O KN. It is found that 40% copper slag replaced concrete specimen failed at an application of higher load comparing to other two. 40% copper slag replaced concrete has higher compressive strength than other two specimens for 7 and 28 days curing. 20% Copper Slag replaced concrete has higher compressive strength than conventional concrete.
- During split tensile strength test, the concrete cylinder of conventional concrete, 20% replaced concrete and 40% replaced concrete cured for 28 days failed at loads of 70KN,100KN AND 110 KN respectively. Here also 40% copper slag replaced concrete has high split tensile strength than other two.
- During Flexural strength test, the concrete cylinder of conventional concrete, 20% replaced concrete and 40% replaced concrete cured for 28 days failed at loads of 7KN,10.8KN AND 12.4 KN respectively. 40% copper slag replaced concrete has high Flexural strength than other two.
- The damage index value for conventional concrete cube specimen cured for 7 days and 28 days was found to be .917 and .824. Damage index value for 20% copper slag replaced concrete and 40% percent replaced concrete for 7 days and 28 days was found to be .92, .958 and .84 and .916 . This indicates that specimen is almost damaged at maximum load.
- Damage index value for all type of cylinders ranges from 0.8-0.9. This shows that tested cylinders has visible cracks.
- Damage index value for all types of prism ranges from 0.9 - 1. This shows specimen is completely damaged and unsafe for use.
- The embedded smart aggregate is feasible in conventional and copper slag replaced concrete and there is no negative effect on the strength of the concrete
- The crack initiation in concrete structures can be identified..
- Using this technique, identify the severity of damage using damage index expression. It has the potential to be applied to the health monitoring of *in situ* large-scale reinforced concrete structures at a very economical cost without using additional bulky equipment

REFERENCES

[1] K. P. Chong, "*Health monitoring of civil structures*," Journal of Intelligent Material Systems and Structures, vol. 9, no. 11, pp.892–898, 1999

[2] Minoru Kunieda, Keitetsu Rokugo.(2006) "*Recent Progress on HPFRCC in Japan Required Performance and Applications"* Journal of Advance Concrete Technology, *Vol **4**,* pp. 19 33

[3] Lim, Y. M., Li, V. C.(1997). "*Durable repair of aged infrastructures using trapping mechanism of engineered cementitious composites*" Journal of Cement and Concrete Composites, Elsevier 19(4), pp. 37 385

[4] P. L. Fuhr, D. R. Huston, M. Nelson et al., "*Fiber optic sensingof a bridge in Waterbury, Vermont*," Journal of Intelligent Material Systems and Structures, vol. 10, no. 4, pp. 293–303, 2000..

[5] J. Michels and J. Sena-Cruz, "*Structural strengthening with prestressed CFRP strips with gradient anchorage,"* Journal of Composites for Construction, vol. 17, no. 5, pp. 651–661, 2013.

[6]Li Z, Zhang D and Wu K (2002) "*Cement-based piezoelectric composites*" Journal of the American Ceramic Society, 85(2): 305–313.

[7] R. El-Hacha and M. Gaafar, "*Flexural strengthening of reinforced concrete beams using prestressed, near-surface mounted CFRP bars*," PCI Journal, vol. 56, no. 4, pp. 134–151, 2011.

[8] Qin L, Lu Y and Li Z (2010) "*Embedded cement-based piezoelectric sensors for AE detection in concrete*", Journal of Materials in Civil Engineering ASCE 22(12): 1323–1327.

[9] M. Quirion and G. Ballivy, *"Concrete strain monitoring with Fabry-P´erot fiber-optic sensor*," Journal of Materials in Civil Engineering, vol. 12, no. 3, pp. 254–261, 2000.

[10] Landis E and Shah S (1995) *Frequency-dependent stress wave attenuation in cement-based materials.* Journal of Engineering Mechanics ASCE 121(6): 737–743.

[11] Li Z, Li F, Zdunek A, Landis E and Shah S (1998) "*Application of acoustic emission techniques in detection of reinforcing steel corrosion in concrete*". ACI Materials Journal 95(1): 68–81.

[12] S. W. Lu and H. Q. Xie, *"Research of online monitoring technique for CFRP-strengthened RC beams with embedded fiber Bragg grating sensors*," Journal of Basic Science and Engineering, vol. 15, no. 3, pp. 387–394, 2007.

[13]Jun Zhang, Christopher K.Y. Leung, Yin Nee Cheung.(2006). "*Flexural performance of layered ECC-concrete composite beam",* Composites Science and Technology **66**, pp. 15011512

[14]Song G, Gu H and Li H 2004a "*Application of the piezoelectric materials for health monitoring in civil engineering: an overview*" (9th ASCE Aerospace Division Int. Conf.League city, Texas).

[15] D. Inaudi and S. Vurpillot, "*Monitoring of concrete bridges with long-gage fiber optic sensors,"* Journal of Intelligent Material Systems and Structures, vol. 10, no. 4, pp. 280–292, 2000..

[16] Song G, Gu H, Mo Y L, Hsu T T C, Dhonde H and Zhu R H 2004b "*Health monitoring of a reinforced concrete beam using piezoceramic materials*" (Proc.3rd European Conf.on structural control ,Vienna, july 2004)

[17]Bhalla S., Yang Y., Soh C.K. (2005) "*Structural Health Monitoring and Non-Destructive Evaluation of Concrete Structures using Piezo-Impedance Transducers"* (Proceeding of 4th International Conference on Smart Materials, Structures and Systems, July 28-30, Bangalore,) pp. SB 13-28