EFFECT OF PARTIAL REPLACEMENT OF FINE AGGREGATE WITH CERAMIC WASTE ON MECHANICAL AND DURABILITY PROPERTIES OF CONCRETE

A thesis submitted in fulfilment of the requirement for the award of degree of

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Submitted by

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DECLARATION

I, Gurpreet Singh hereby declare that the work which is presented in this thesis report entitled **"Effect of partial replacement of fine aggregate with ceramic waste on mechanical and durability properties of concrete"** in fulfilment of requirement for the award of degree of **Master of Engineering** in **Structures,** submitted at **Civil Engineering Department, Thapar Institute of Engineering & Technology(Deemed to be University), Patiala,** is an authentic record of the work carried out under the guidance of **Dr. Heaven Singh, Assistant Professor, Department of Civil Engineering, Thapar Institute of Engineering & Technology , Patiala** from January 2018 to June 2018. The matter presented in this has not been submitted either in part or full to any other university or institute for the award of any other degree.

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CERTIFICATE

This is to certify that the above statement made by the student concerned is correct and true the best of my knowledge and belief.

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ABSTRACT

In India, the manufacturing sector produces a large amount of industrial waste every year and this waste generated from industries have continued to increase due to continued exploitation and use of resources . This waste consists of about a million tons of ceramic waste. India accounts for over 6% of total global production. Globally India is ranked 3rd in world in consumption. So similarly waste generation after consumption of these tiles is also of huge amount and is disposed on large area. Due to large scale construction and infrastructure development, natural sand is getting depleted from rivers quite fast. Hence, finding a substitute or an alternate material for fine aggregate is very important. So both problems of dumping of broken ceramic tiles and finding an alternate to fine aggregate can be solved by using ceramic waste powder in concrete.

In the present experimental study ceramic waste powder has been used as partial replacement of fine aggregate in concrete. Ceramic waste (CW) was used as fine aggregate in the varying ratios of 10, 15 and 25% as the total weight of fine aggregate. In all, 4 mixes, i.e. CM (Control Mix), CW10%, CW15% and CW25% of M25 grade of concrete were prepared. These mixes were tested for workability of fresh concrete, compressive strength, split tensile strength and durability properties like water permeability, rapid chloride permeability test (RCPT) and sulphate attack.

It was observed that the workability of fresh concrete was affected on ceramic waste addition and as we increased the content of ceramic waste in concrete , workability deteriorates. Concrete made with ceramic waste powder as fine aggregate showed an increase in compressive strength and split tensile strength at 7 and 28 days up to 25% replacement and 15% replacement of fine aggregate respectively.

Durability properties of concrete were investigated. It was concluded that in general, the addition of ceramic waste improved the durability properties of concrete. However, increase in the water penetration depth was observed with an increase in content of ceramic waste. However, the ceramic mix concrete gave better resistance to sulphate attack as compared to control concrete. In case of chloride penetration, ceramic mix concrete performed way better than control concrete as chloride penetration decreased to low level from moderate on replacement of fine aggregate with ceramic by 25% as compared to control concrete. In all, it was concluded that from the strength and durability considerations, 25% of ceramic waste by weight of fine aggregates provides the best performance for the mixes tested under this study.

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CHAPTER 1
INTRODUCTION

1.1 GENERAL

Waste generated from industries have continued to increase because of continued exploitation and use of resources . Which has led to cause serious problems like health illness, land pollution, air pollution etc. all over the world. Side by side giving rise to depletion of natural resources as well. One of the ways to optimize the problem is to utilise the waste generated by industries. Demolition and construction waste contribute 75% of waste world wide. One of the waste from construction industry is ceramic waste. It is estimated that around 30% of daily production of ceramic in the ceramic industry goes to waste. A recent PWC report says ceramic tiles industry in India has grown by approx 11% between 2013-2014 and expected to reach up to a size equivalent to Rs 301 billion by 2016, growing at a 15% CAGR. Globally India is ranked 3rd in world. India accounts for over 6% of total global production. Similarly waste generation after consumption of these tiles is also of huge amount and is disposed on large area.

Waste from tiles only cause pollution and is not used effectively anywhere rather than its one or two most common uses like in flooring of houses, walkways, gardens etc. as a ground material. So ultimately waste ceramic tiles are either stored in fields of factories or disposed on large lands because of their low economical values. This all can be saved by recycling the same to save our resources and money.

As we know fine aggregate is major constituent of concrete and play an important role in construction industry. But due to frequent exploration of sites, problems like floods have caused trouble in India.

Moreover chemical composition of ceramic waste seems to make a suitable concrete mix when used in partial replacement of fine aggregate. Waste from ceramic tiles is hard, durable, highly resistant to physical, biological and chemical degradation forces. Using ceramic waste as replacement of fine aggregate in concrete will not prove to be economical but will also prove good for environment.

Fig 1.1 shows ceramic tiles damaged and broken in pieces at one of the site.

Fig 1.1 Ceramic broken tiles

Ceramic industries comprise of following sectors:

Refractory materials, Technical ceramic, Sanitary ware, Wall and roof tiles, Bricks and roof tiles and ceramic material used for ornament and domestic purposes. (A Jual at al, 2010).

Different types of ceramic based upon different procedures of manufacturing from where ceramic waste is obtained are presented in the flow chart given in **Fig. 1.2 .**

Types of Ceramic waste :

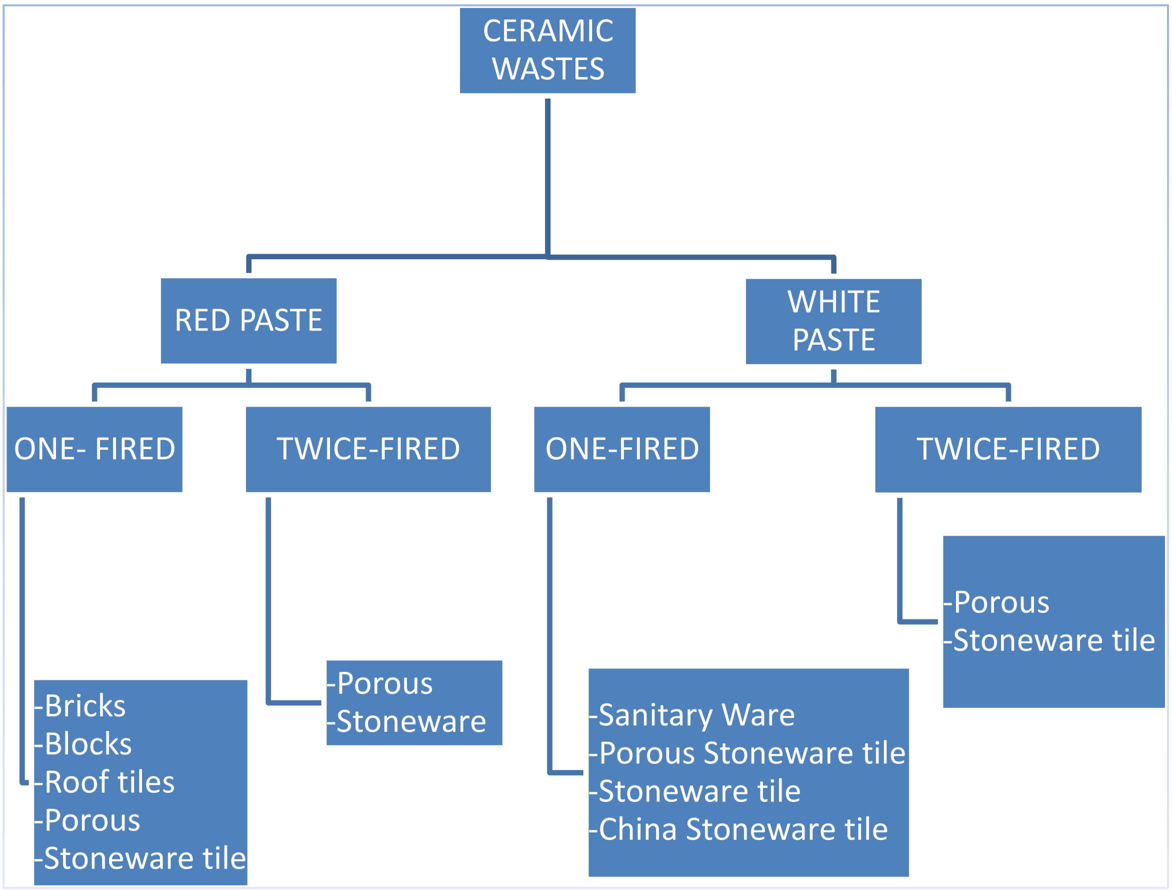

Fig 1.2 Ceramic Waste types

1.2 CERAMIC

Ceramic tile is made by natural material sintered at high temperature taking care of not using any harmful agents in making.

A ceramic is an inorganic non-metallic solid which comprises of metal, or metalloid atoms held in covalent and ionic bond. Ceramic are generally made by taking different mixes of powder, earthen elements, clay and water and then shaping them into required forms as desired. After shaping, it is fired in a kiln. Then the material is used for making earthen ware, sanitary ware, building material such as tiles.

There are three basic categories of ceramic depending on at what temperature it is fired and what type of clay is used:

- Earthen ware
- Porcelain
- Stone ware

1.3 CERAMIC WASTE

Consumption of ceramic tiles is not appropriate. Huge amount of waste is generated while using ceramic tiles on construction site and that is called ceramic waste. Ceramic waste is generally a material of porous nature which acts as a wet curing medium in hydration of cement paste and decreases the shrinkage which is autogenous.

So far in some of the studies, ceramic tile aggregate is also used as in replacement for coarse aggregate as it is hard, have a considered value of gravity , roughness at one side and other side smooth surface . But to investigate and explore the use of ceramic waste as in replacement of fine aggregate this study was done. This experimental study was done by checking and comparing its mechanical and durability properties with that of reference concrete.

Apart from this, other reasons of using ceramic waste as replacement of fine aggregate in concrete:

- It conserves natural resources and space acquired by land filled disposal is reduced.
- It is cheap and eco friendly.
- A ceramic tile waste comprise of raw material like quartz, feldspar and clay, which promote pozzolanic reactivity. This has been confirmed by using ceramic waste powder from ceramic roof tiles. (Lavat AE et al [13])
- Its chemical composition shows that it is rich in SiO_2 compound which is one of the factors responsible of imparting strength in concrete.

So in this study, mechanical and durability properties of concrete mix made by replacing ceramic waste with fine aggregate in three percentages other then the reference concrete were tested and compared.

Hence the affect of the same was investigated and studied on basis of some standard parameters.

Ceramic waste in broken tile form is crushed to fine powder form by different means (In this study los angeles abrasion testing machine is used for the same. Broken Tiles were brought from a local tiles store and were broken further into small pieces and were crushed under impact of steel balls present in machine. Machine was rotated for a specific period till the powder form is nearly achieved. Crushed pieces were then sieved to get required amount of fine powder).

Ceramic waste generally looks whitish in colour as shown in **Fig. 1.3.**

Fig 1.3 Ceramic waste

1.3.1 Why use concrete tile waste?

Ceramic waste is a waste product which comes from tile industry which is now being explored as a substitute for fine aggregate in concrete. This step is taken mainly due to following reasons:

1) Other than river sand in India there is none other primary source for the construction industry than fine aggregate. But as it is a non renewable natural resource, it is depleting factor due to growing demands of infrastructure development in this era. Construction and infrastructure projects are increasing at an alarming rate in India as it is one of the developing nations of world. Construction of high storied buildings, smart city developments, dams etc all over the country has lead to exploitation of river sand causing a large cut down of the area of natural river beds. Which makes the daily price hiking of natural fine aggregate side by side causing its depletion. This needs to be controlled. So now need of the hour is to find a alternative for river sand to avoid its depletion.

2) Huge amount of waste is generated while using ceramic tiles which leads to pilling up of large lands causing health hazards.

3) Various researches have given an idea to find out use of ceramic waste by exploring ceramic waste of having pozzolanic nature and having constituents which are able to impart

strength in concrete. The texture and nature of particles of ceramic waste also tend to have a similar impact on that of required substitute for fine aggregate.

1.3.2 PHYSICAL PROPERTIES OF CERAMIC WASTE

Mostly the particle shape of ceramic waste is irregular in nature. The colour of ceramic waste in powdered form is generally white. The fineness modulus of ceramic waste generally lies in range from 3.4-3.8. The specific gravity of ceramic waste material varies from 2.2 to 2.5. A detailed discussion of chemical and physical properties of ceramic waste used in this research study is presented in Chapter 3.

1.4 ORGANIZATION OF THESIS

1st chapter provides introduction to production and general properties of ceramic waste. Its environmental need and relevant importance in field of construction is discussed in this chapter.

In chapter 2 the existing research studies and literature on effect of ceramic waste in concrete as in replacement of fine aggregate is highlighted. Scopes and objectives of present study are also laid out.

In chapter 3 the experimental program carried out for this study is discussed in detail. Codel recommendation and procedures for various durability and strength tests are also discussed in this chapter.

Chapter 4 gives the result of experimental testing on concrete specimens having ceramic waste as partial replacement for fine aggregate. Results discussed and conclusions drawn from the study are discussed in this chapter.

In chapter 5 conclusion of this study is memorised for future research work recommendations are provided.

CHAPTER 2

LITERATURE REVIEW

2.1 GENERAL

From the past decades, due to urbanisation a boom in infrastructure and construction industry has taken place which resulted in increased usage and production of construction and building material in India. Similarly due to this tile industry also went on to higher production of tiles which side by side increased its wastage right from the time of making till the time of finishing. Which at last resulted in large piles of land dumping causing hazardous effects. So utilising and recycling this waste is the only option left. It is seen from recent researches that this ceramic waste can be used as replacement of fine aggregate in concrete. In the following section a review of such research studies is given in detailed form. It is categorised on basis of mechanical and durability properties of concrete.

2.2 COMPRESSIVE STRENGTH

Pincha Torkittikul et al (2010) studied the utilization of ceramic as fine aggregate within Portland cement and fly ash concretes. He did research on mechanical properties of concrete made by replacing ceramic with fine aggregate (FCA). He used ceramic waste aggregate as sand replacement at 0%, 10%, 20%, 30%, 40%, 50% and 100%. Effects of CWA replacement on compressive strength was seen at 7, 14and 28 days. The result showed that concrete having CWA as replacement of fine aggregate gave higher compressive strength then normal reference concrete. He concluded that 50% of fine ceramic aggregates is an optimum replacement ratio so as to maintain equivalent or nearby compressive strength as that of reference concrete.

G. SivaPrakash et al (2016) did experimental study on partial replacement of sand by ceramic waste in concrete of M25 grade. To analyse compressive strength, he cast samples with 10%, 20%, 30%, 40 %, 50% replacement of fine aggregate using ceramic and then tested it for period of curing of 7 days, 14 days and 28 days. According to his research compressive strength was achieved upto 30% replacement of ceramic waste with sand beyond which addition of ceramic resulted in reduced strength of concrete

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Salman Siddique et al (2017) studied the influence of ceramic waste on compressive strength of concrete. In this study, natural sand was replaced with different percentages of ceramic waste from 0, 20, 40, 60 and 100 and mixes were prepared with three water cement ratios that is 0.35, 0.45, 0.55. Compressive strength parameter was examined to check the effect of ceramic aggregate in concrete. Compressive strength of these mixes was checked at 28 days and compared with the control concrete mixes. At 28 days, 20% ceramic mix concrete has the highest compressive strength. At 28 days, increase was seen in mixtures of C series between 0 and 15.8%, 4.3 and 26.0%. For series E and 12.1% for series D. According to him higher compressive strength of concrete series having ceramic waste gives intimation of using it successfully as fine aggregate.

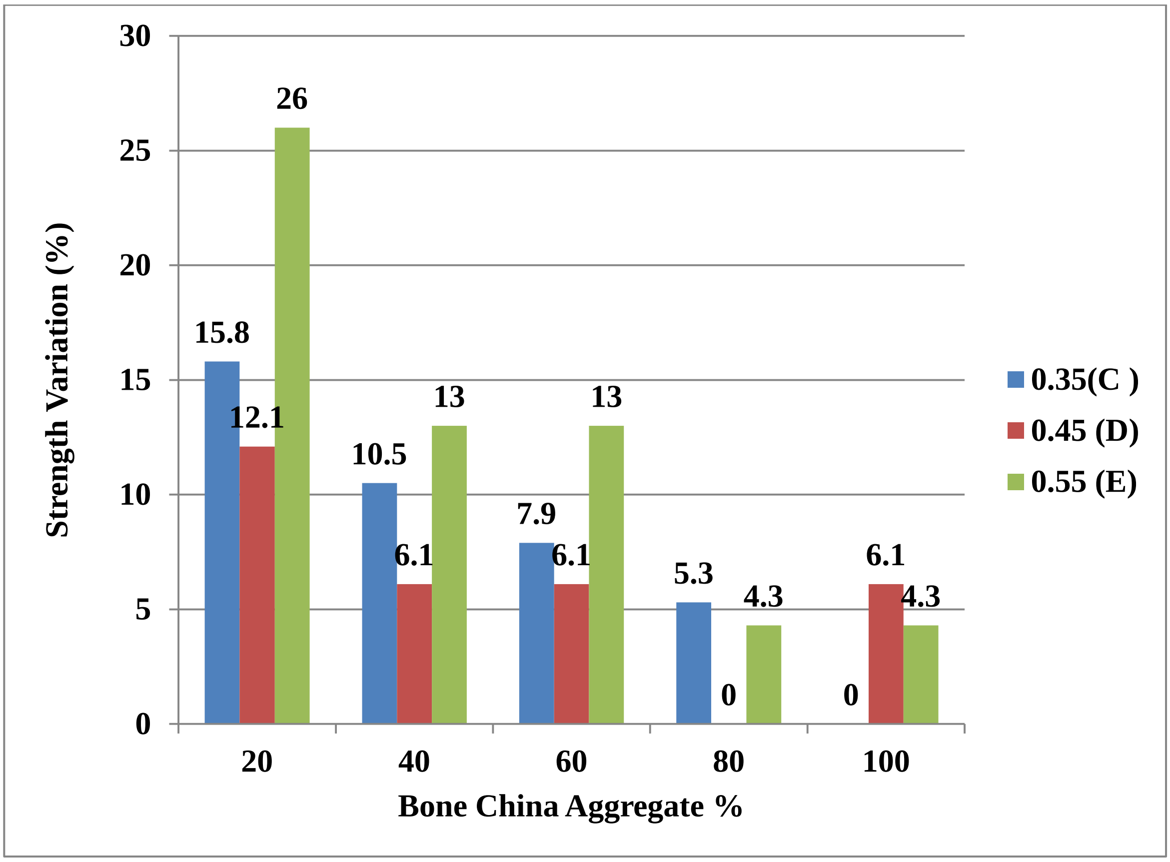

Fig 2.1 Compressive strength variation V/S Ceramic aggregate content in concrete

Fernando Pacheco et al (2010) examined compressive strength and durability properties of ceramic wastes based concrete. In this experimental study, a number of concrete mixes were made possessing mean target compressive strength of 30MPa using concrete waste in replacement of fine aggregate. Concrete made by using ceramic waste as fine aggregate was assessed on basis of compresive strength on age at 7, 14, 28, 56 and 90 days of curing. Results obtained indicated that compressive strength is higher for mixes with ceramic waste as replacement of fine aggregate than control concrete with normal aggregates. Specifically according to him strength was higher for mixes with ceramic beyond 14 days of curing.

A. V Alves et al (2014) did research study on mechanical properties of structural concrete with fine recycled ceramic aggregates. His objective was to examine the effect of recycled ceramic aggregates which were obtained from crush sanitary ware and bricks on compressive strength of concrete. He did his study by replacing ceramic aggregate with 0%, 20, 50% and 100% of fine aggregate and then comparing the result of its compressive strength with conventional reference concrete. The purpose of his research was to make a concrete with mean cube compressive strength of 37MPa. Testing was done at 7, 28 ad 56 days. According to him compressive strength when compared with reference concrete decreases with incorporation of fine aggregates at all ages of test. At 7, 28 and 56 days loss in strength was 49.8%, 42.5% and 34.9% as relative to the reference concrete, this was due to increase of effective W/C ratio with replacement ratio which lead to decrease in percentage of strength.

Paul O. Awoyera et al (2016) did an experimental study on characterisation of ceramic waste aggregate concrete. The compresive strength of hardened concrete samples having CFA (Ceramic Fine Aggregate) was tested and compared with normal reference concrete at an interval of 3, 7, 14 and 28days. A 1:2:4 concrete mix was adopted in this research work in which batching was wholly conducted by weight. 108 concrete cube samples were made including samples having ceramic waste in replacement of fine aggregate (CFA) with content of 0%, 25%, 50%, 75% and 100%. Results show that control concrete development early strength at 3 and 7 days than ceramic mix concrete, but at 14 and 28 days compressive strength of CFA increased and become higher than that of reference concrete. Upto 22.1% it remained increasing with increase in substitute aggregate till total of 100% substitution. This sort of positive result was thought to be due to affect of high water absorption of ceramic waste in accompliance with the pozzolanic activity of micro particles ceramic combined along with cement compounds.

Hiroshi Higashiyama et al (2012) explained the parameters of compressive strength and resistance to chloride penetration of mortars using ceramic waste as fine aggregate. In this study a constant water cement ratio of 0.5 by weight was choosen and partially replacement of ceramic powder by 10%, 20% and 30% was done. Compression testing was done at 7, 28 and 91 days of curing. Compressive strength of ceramic mix concrete increased up to a percentage level of 20% with respect to conventional concrete.

Salman Siddique et al (2018) studied the strength and impact resistance properties of concrete containing fine bone china ceramic aggregate. In this research he examined mechanical properties and impact resistance of concrete by replacing ceramic aggregate with fine aggregate. 18 mixes were prepared with 3 water binder ratio i.e. 0.35, 0.45 and 0.55. Replacement of fine bone china aggregate with fine aggregate was done at 0%, 20%, 40%, 60%, 80% and 100%. Compressive strength of concrete mixes was examined at 7, 28, 90 and 180 days of curing. Inducing fine bone china aggregate in place of fine aggregate resulted in increase of compressive strength. After 180 days of curing the specimens containing 100% replacement gone the highest compressive strength due to pozzolanic behaviour of fine bone ceramic aggregate. This was said to be also due to better quality Calcium silicate hydrate which lead to origin of a good interfacial transition zone specially in mixes which had ceramic aggregate. Specimens containing 60% replacement of ceramic aggregate gone highest compressive strength in the 28 days curing period system. He concluded that pozzolanic behaviour of fine bone ceramic aggregate was mainly responsible for strength enhancement in concrete structure. Due to which concrete with increased content of fine bone ceramic aggregate achieved maximum compressive strength for both long term and standard curing.

Hanifi Binici (2006) studied the effect of crushed ceramic and basaltic pumice as fine aggregate on concrete mortar properties. He examined suitably of ceramic waste as a possible substitute to be used in replacement of conventional fine aggregates. He did experiments to find out compresive strength of ceramic mix concrete and to compare the same with compressive strength of reference concrete mixes. On each side three cube samples were used for testing of compression strength at 7, 28, 90 and 365 days of curing. Replace was done at 0%, 40, 50% and 60% replacement level respectively. He concluded that during whole year compressive strength of all concrete mixes having ceramic as fine aggregate kept increasing. Though, at 60% fine aggregate replacement maximum strength took place at all ages of curing.

A. Gonzalez-Corominas et al (2014) did research on properties of high performance concrete made with recycled fine ceramic and coarse mixed aggregate. Fine Ceramic Aggregate (FCA) were used in replacement of natural sand by 15% and 30% and Coarse Mixed Aggregates (CMA) were used in replacements of 20%, 50% and 100% of natural coarse aggregate so as to produce a high performance concrete (HPC). Effective W/C ratio of

0.285 was used in production of all concrete mixes. Compressive strength was done at stage of 7 and 28 days of curing. Other than conventional concrete all other recycle concrete mixes a high compressive strength except than concrete made with 100% replacement of mixed coarse aggregate with possessed 10% lesser strength. The to low early age compressive strength was considered to be due to poor quality of aggregate. Whereas fine ceramic aggregate concrete possessed higher early compressive strength due to its early high absorption capacity and high specific surface of fine aggregate. Conclusion drawn from studies explain that due to pozzolanic reactions compressive strength of FCA concrete was higher than that of normal referral concrete.

Salman Siddique et al (2018) did his study on durability properties of Bone China Ceramic Fine Aggregate Concrete (BCCFA). In this BCCFA was replaced partially with fine aggregate by 0%, 20%, 40%, 60%, 80% and 100%. Water to binder ratio was kept at 0.35 constantly. Total of six mixes were prepared where CC stands for refrence concrete and CCX refers to concrete having BCCFA in which X stood for the percentage replacement of fine aggregate. Compressive strength of BCCFA concrete was found and compared with that of referral concrete after 28 days of curing. It was seen that compressive strength was higher for BCCFA concrete than normal concrete de to fact that BCCFA mix concrete provided rich cement gel aggregate behaviour. It was also known as BCCFA exhibited pozzolanic behaviour when in concrete due to the presence of SiO_2 , CaO and Al_2O_3 observed BCCFA release the extra water present in the fresh mix helping in the formation of denser CSH gel which led to the provision of curing effect giving rise to higher compressive strength of BCCFA mix concrete. Due to these reasons compressive strength of BCCFA concrete mix was higher than normal concrete at all levels of reference.

Table 2.1 Comparison of compressive strength of mixes tested by various researchers

Author				28-day Compressive Strength (MPa)						
	CM	CW 10%	CW 15%	CW 20%	CW 30%	CW 40%	CW 50%	CW 60%	CW 80%	CW 100 %
Pincha Torkittikul et al (2010)	42	43	-	44	46	49	50	-	-	46
G. Sivaprakash et al (2016)	27.5	26.5	-	26	25.4	25.3	25.1	-	-	-
Salman Siddique et al (2017)	-	-	-	26	-	13	-	13	4.3	4.3
Fernando Pacheco et al (2010)	40	-	-	-	-	-	-	-	-	45
A. V. Alves et al (2014)	46.2	-	-	31.2	-	-	30.7	-	-	26.6
Paul O. Awoyera et al (2016)	24	-	-	-	-	-	25	-	-	29
Hiroshi Higashiyama et al (2012)	49.4	-	-	51.2	-	53.1	-	55.1	52.6	56.9
Salman Siddique et al (2018)	39	-	-	40	-	45	-	47	43	44
Hanifi Binici (2006)	25	-	-	-	-	27	31	35	-	-
A.Gonzalez-Corominas et al (2014)	102.09	-	109.70	-	109.06	-	-	-	-	-
Salman Siddique et al (2018)	31.33	-	-	33	-	35.65	-	38.33	36.33	33.33

2.3 SPLIT TENSILE STRENGTH

G. SivaPrakash et al (2016) did experimental study on partial replacement of sand by ceramic waste in concrete. To investigate mechanical properties i.e split tensile strength samples were prepared with 10%, 20%, 30%, 40%, 50% replacement of sand by ceramic waste. For all the experimental study M25 grade concrete was considered. Testing was done on two test specimens for each proportion of percentage mixes and tensile strength was measured at age of 7, 14 and 28 days of curing. It was seen that tensile strength samples with ceramic waste as replace was higher than the tensile strength of normal concrete. This increase was upto 30% replacement level. Tensile strength at 14 days of 10%, 20% and 30% replacements showed consistency in achieving required range. Further increase in addition of ceramic waste resulted in decrease in strength.

Salman Siddique et al (2018) investigated strength and impact resistance properties of concrete containing fine bone china ceramic aggregate (BCCA). In his research he investigated mechanical properties of concrete by replacing ceramic aggregate with fine aggregate at 0%, 20%, 40%, 60%,80% and 100% in which 18 mixes were prepared with three water binder ratio i.e. 0.35, 0.45 and 0.55. Series of mixes were named as A for 0.35 ratio, B for 0.45 and C for 0.55. Split tensile strength was examined on 150mm cubic specimen following IS5816:1999. It was performed after 28 days of curing. Results showed that split tensile strength of fine bone china ceramic aggregate mix concrete on 100% replacement with natural sand increased by 26.49%, 40.617% and 37.33% for series A, B and C of water binder ratio respectively.

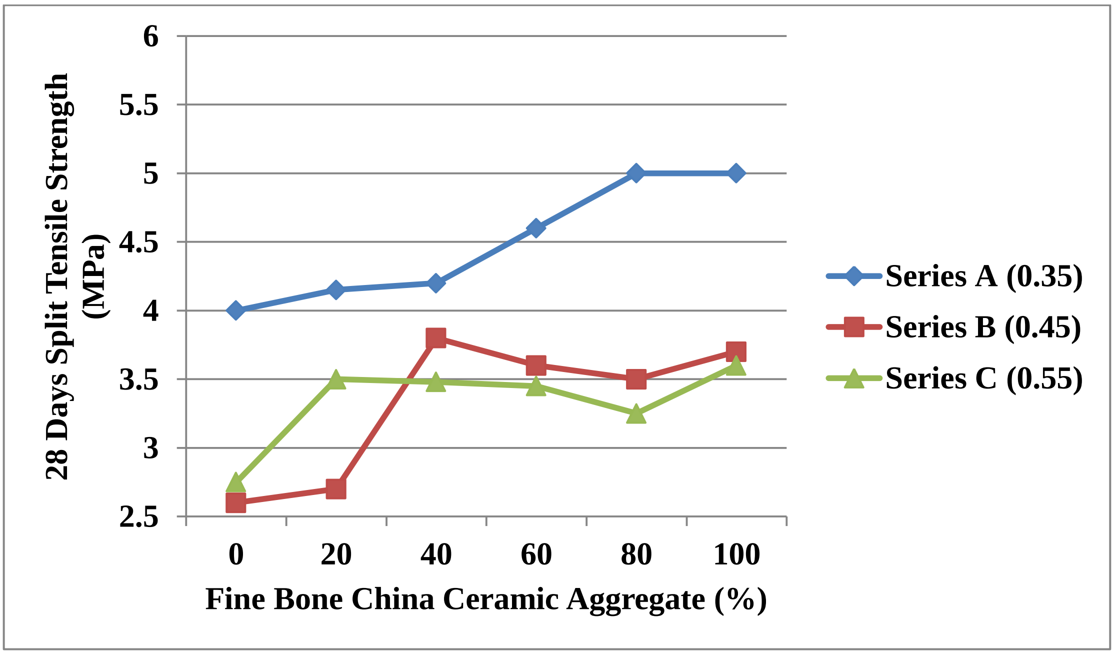

FIGURE 2.2 28 days TENSILE STRENGTH OF VARIOUS CONCRETE MIXES

A. Gonzalez-Coraminas et al (2014) did research on Properties of high performance concrete made with recycled fine ceramic and coarse mixed aggregates. Natural sand was replaced by Fine Ceramic Aggregate (FCA) by 15% and 30% and coarse aggregates (CMA) were used by 20%, 50% and 100% as replacement of natural coarse aggregates so as to produce a High Performance Concrete i.e. HPC. Water cement ratio of 0.285 was used as affective w/c ratio for performance of all concrete mixes. Split tensile strength of prepared samples was determined and was compared to the conventional concrete. Concrete mixes with FCA achieved equal or higher splitting strength to these of reference concretes after the end of 28 days of curing. Coarse mix aggregate ceramic concrete dropped in split tensile strength from 10% to 20%. Use of coarse ceramic aggregate created a negative affect where a use of fine ceramic aggregate created a positive effect.

Salman Siddique et al (2018) studied permeability properties of Bone China Ceramic Fine Aggregate Concrete (BCCFA). BCCFA was replaced partially with fine aggregate by 0%, 20%, 40%, 60%, 80% and 100% in which water to binder ratio was kept at 0.35 constantly. Total of six mixes were prepared in which X stood for percentage replacement of fine aggregate. Splitting tensile test was carried on these specimen and average of three 150mm cubes was taken after curing of 28 days. This strength was then compared with control concrete. Concrete having BCCFA showed higher splitting tensile strength than the normal concrete. It promoted the generation of stable and higher phased CSH gel which created strong microstructure leading to increase in splitting tensile strength. Splitting tensile strength for 0%, 20%, 40%, 60%, 80% and 100%. BCCFA mixed concrete was 3.99 MPa, 4.14MPa, 4.25MPa, 4.68MPa, 5.03MPa, 5.05MPa respectively which shows it increase with increase in percentage level of replacement.

A. V. Alves et al (2014) did hid study on mechanical properties of structural concrete with fine recycled ceramic aggregates. He examined the effect of recycled ceramic aggregate obtained from sanitary and bricks on split tensile strength of concrete in which ceramic aggregates were replaced by fine aggregate i.e. natural sand by 0%, 20%, 50% and 100%. Concrete with ceramic aggregate was tested and compared to control concrete after 28 days of curing. Mix with recycled Brick Ceramic (BC) as replacement upto 50% saw a relative loss of 5.7% to reference concrete and it was expected that mix with 100% replacement of ceramic aggregate would undergo maximum loss in tensile strength as compared to control concrete. Reason for this strength decrease was increase in paste porosity due to increase in replacement ratio.

Paul O. Awoyera et al (2016) investigated Characterisation of ceramic waste aggregate concrete. Splitting tensile strength of hardened concrete samples having CFA (Ceramic Fine Aggregate) was tested and compared with normal reference concrete at 3, 7, 14 and 28 days of curing in which 1:2:4 concrete mix was adopted. CFA replacement was with content of 0%, 25%, 50%, 75% and 100% by fine aggregate in concrete. It was examined that between 14 and 28 days of curing CFA mixed concrete developed adequate split tensile strength yielding results as 2.8N/mm^2 and 3.6 N/mm^2. Studies have shown that usage of ceramic fine aggregate causes well refinement of pores which simultaneously increase capillary pores volume and decreases macro pores volume in the pore system. However, some studies based on using ceramic sanitary ware contradicts the results of studies in which ceramic wall tiles waste is used. This variations in results could be due to difference in conditions adopted when ceramic products are produced.

2.4 WORKABILITY

Salman Siddique et al (2017) studied the Influence of ceramic waste on fresh properties and compressive strength of concrete. In this experiment study, natural sand aggregate was replaced with different replacements of ceramic waste varying from 0%, 20%, 40%, 60% and 100% in which three different waste cement ratios were taken i.e. 0.35(C), 0.45(D), 0.55(E). To maintain workability of concrete mix in a particular range super plasticizer dose was monitored closely. Target completion value greater than or equal to 0.90 was considered. Super plasticizer dosage was increased with an increase in amount replacement of bone china aggregate in mix. In concrete fine particles increase on as a whole after incorporation of bone china ceramic fine aggregate which resulted in decrease of workability as surface area increased. Due to presence of semi closed or closed pores in microstructure of BCCA, water absorption by aggregate took place as a result, which gave rise to reduction of free water needed for lubrication of particles. Presence of P_2O_5 increase the water need in concrete mixes. However BCCA has only 10.99% P_2O_5 due to which BCCA controls excessive water absorption in concrete. When percentage of BCCA increases in concrete, P_2O_5 also increases which causes low workability.

Pincha Torkittikul et al (2010) studied the utilization of ceramic waste as fine aggregate within Portland cement and fly ash concretes. He did hid search on mechanical properties of concret made by replacing ceramic with fine aggregates at replacement of 0%, 10%, 20%, 30%, 40%, 50% and 100%. Workability of mortars having ceramic waste as fine aggregate reduced on flow of mortar decreased significantly with increase in content of ceramic waste aggregate. The flow was approximately 116mm, decreasing by 39.2% as compared to reference mix. When there was 100% replacement of fine aggregate slump value come close to zero which means incorporation of ceramic as fine aggregate reduce workability.

Salman Siddique et al (2018) did hid study on Durability properties of bone china ceramic fine aggregate concrete (BCCFA). In this experiment study considering water to binder ratio as 0.35 constantly, BCCFA was replaced partially with fine aggregates. Higher water absorption properties of BCCFA has negatively affected the work ability of fresh concrete. As particles of BCCFA are angular in nature, higher inter particle friction in created which resulted in decrease of workability.

A. V. Alves et al (2014) did his experimental study on Mechanical properties of structural concrete with fine recycled ceramic aggregate. He examined the affect of recycled ceramic aggregate obtained from crushed sanitary ware and bricks on different properties of concrete. Total of seven concrete mixes were made in which same aggregate size gradation was used so as to perform valid comparison.

TABLE 2.2 Tests Results of fresh concrete: slump (h) and bulk density

Composition	**h(cm)**	**Bulk Density (Kg/m^3)**
RC	**12.3**	**2352.7**
BC20	**12.3**	**2303.1**
BC50	**13.4**	**2250.8**
BC100	**11.6**	**2167.4**
SWC20	**12.0**	**2248.3**
SWC50	**11.6**	**2221.7**
SWC100	**11.6**	**2154.6**

Table 2.2 shows slump test results and effective and apparent water cement ratios for each mix made. Accordingly it shows that workability of concrete is negatively affected in which recycled ceramic aggregated are incorporated. This can be overcome by changing the apparent W/C ratio. Due to percentage increase in replacement water/cement ratio also had to

be increased, even that all the mixes produced had a target interval of slump within (12.5 ± 1 cm). For concrete mixes having fine recycled brick aggregates, water cement ratio was increased in order to obtain equivalent workability as workability of conventional concrete. This can be obtained due to high water absorption characteristics of ceramic aggregates. The migration of water to water is mainly implied by this property. Resulting in reduction of water quantity which contribute to workability. For the mixes with sanitary ware aggregates as replacement of fine aggregates the result was unexpected. To reach the target slump , a much needed increase in affective W/C ratio was expected despite the low water absorption of aggregates. Accumulation of water at interface between coarse aggregate and fine recycle aggregate took place due to this property because of presence of liquid bridges present in between. However according to this study there is no explanation to this result in literature.

Paul O. Awoyera et al (2016) investigated Characterization of ceramic waste aggregate concrete. Considering 1:2:4 ratio mix concrete with Ceramic Fine Aggregate (CFA) was prepared in replacement of fine aggregate by 0%, 25%, 50%, 75% and 100%. Workability of every mix was measured by slump test. The results of CFA 25%, CFA 50%, CFA 75%, CFA 100% vary from medium to high workability, in which range of slump varies from 80 to 120mm. Samples of this slump range according to BS8500 fall in SS2 and SS3 categories which are suitable for cast in-situ hard standing slab and simple strip floating.

2.5 DURABILITY PROPERTIES

2.5.1 Rapid Chloride Permeability Test (RCPT)

Hiroshi Higashiyama et al (2011) studied Compressive strength and resistance to chloride penetration of mortars using ceramic waste as fine aggregate. In this study resistance of mortars to chloride penetration was determined by : X ray fluorescence spectrometry and by 0.1N silver nitrate solution spray. After spraying 0.1N silver nitrite solution, it can be seen that mortars containing ceramic waste aggregate have less chloride ion penetration depth than mortar made of fine aggregate, the difference in both was in sufficient. According to some studies, chloride penetration is entirely based on porosity of cementitious matrixes at hardened state. Mortars containing ceramic waste aggregate has lower pore volume than that of fine aggregate mortar. Depth of penetration of mortars with ceramic waste aggregate were half of that mortar made with sand at three month immersion. Apparent chloride diffusion of mortar made of ceramic significantly decreased as compared to mortars made of sand.

Fernando Pacheco et al (2010) explained Compressive strength and durability properties of ceramic waste based concrete. In this study a concrete with partial replacement of ceramic aggregate performed better than reference concrete having normal aggregates concerning chloride diffusion. The results of chloride diffusion confirms good performance of concrete made by ceramic waste aggregates.

Hanifi Binici (2006) studied effect of crushed ceramic basaltic pumice as fine aggregate on concrete mortar properties. According to investigation of this study, chloride penetration depth increased as crushed ceramic percentage is decreased. Chloride penetration depth for mixes with ceramic concrete of 60% replacement was less than other mixes. As percentage of additives increased by 40% to 60% chloride penetration depth reduced significantly while on other side chloride penetration depth was slightly affected by other additives. Chloride penetration depth was considerably greater for specimens in which no additives were used i.e. control specimen. So therefore penetration depth reduces when percentage of CC was increased. For higher strength concrete specimens general trend of results was observed after 6 months immersion test. However according to some studies this method was good for normal and low strength concretes where chloride depth difference was large. This indicated that in concrete use for fine ceramic concrete increased chloride penetration resistance.

A. Gonzalez – Corominas et al (2014) investigated the Properties of high performance concrete made with recycled fine ceramic and coarse mixed aggregates. At 28 days, resistance to chloride ion penetration decreased as recycled Ceramic aggregate content is increased. The conventional concrete showed highest resistance to chloride penetration and as per classification based on this it was at very low risk to corrosion. Concrete with 15% of FCA obtained similar level risk control concrete with 30% FCA achieved low risk to corrosion. After 180 days, mixes produced by replacing FCA showed highest resistance to penetration of chloride. 35% reduction in total charge passed from 28 to 180 days in ceramic concrete took place. However in concrete RC I5-FCA and RC-30 FCA 52% and 70% reduction of total charge took place respectively. Therefore increase in resistance to chloride penetration FCA mix concrete was highest.

2.5.2 Water Permeability

Fernando Pacheco et al (2010) studied about Compressive strength and durability properties of ceramic waste based concrete. Permeability performance like water permeability of ceramic mixed concrete was assessed. Different ceramic mixes gone different water permeability. White Stoneware Once Fired (WSOF) have lower permeability and as due to their lower strength index, micro structure is not so dense which results in reduction in water permeability. This may be attributed to hydration of unreacted particles during test

Salman Siddique et al (2018) investigated Durability properties of bone china ceramic fine aggregate concrete. An increase of 23.5% in average value of water penetration in concrete specimens having 100% BCCFA was seen. According to study reports of other researchers, the rise in depth was observed in each specimen having BCCFA mix concrete. This happened due to angularity and toughness of particles of BCCFA which leads to greater voids which cause high penetration. Due to presence of pores of varying size (2.5mm - 10mm) in CSH gel, no influence is made by such micro pores under normal condition on water permeability properties of concrete. Discoloration effect can also be caused by these pores on application of pressure by creating a channel of pores filled with water which is observed after the samples split into two. These channels of water filled pores can cause increase in depth of water penetration by making it higher. Similarly BCCFA mix concrete result in denser CSH gel which makes surface area large, promoting higher water penetration depth.

CHAPTER 3

MATERIAL TESTING AND EXPERIMENTAL PROGRAM

3.1 GENERAL

The various test conducted during this study are discussed in this chapter. It also explains details of various test conducted on ceramic waste modified concrete in its fresh as well as hardened state. To check the effect of replacing ceramic waste with fine aggregate experimentation is done with help of particular specialized testing. In this experimentation study, procedure followed for all the tests was in accordance with relevant codes. It is explained in following steps:-

1) Basic tests like Consistency test and setting time for cement and various properties of material to be used in concrete are checked which includes , checking the specific gravity for coarse and fine aggregates.

2) Design of trial mixes of M25 grade for checking of adequate compressive and splitting tensile strength of normal concrete with OPC- 43 at 3, 7 and 28 days respectively.

3) Design of 4 concrete mixes i.e. (mix with 0% ceramic waste) control mix, mix with 10% ceramic waste + 90% fine aggregate, mix with 15% ceramic waste + 85% fine aggregate, mix with 25% ceramic waste + 75% fine aggregate. Mixes were design with reference of IS 10262:2009.

4) For workability, slump was measured for fresh concrete in both control and mixed forms and effect of ceramic waste on fresh concrete properties was checked and noted.

5) Then, specimens were cured for definite time required for specific tests.

6) After the time interval of curing, all the samples were tested to check and calculate strength and durability properties of concrete in hardened form. (check fig. 3.1)

7) Micro Structural Analysis – SEM(Scanning electron micrograph) analysis was done to identify various phases in concrete. Difference of phases in control mix and that of ceramic waste modified mix was studied.

8) Analysis and investigation of results and conclusion. (refer chapter 4 and 5)

Figure 3.1 shows various tests performed on concrete mixes in this study

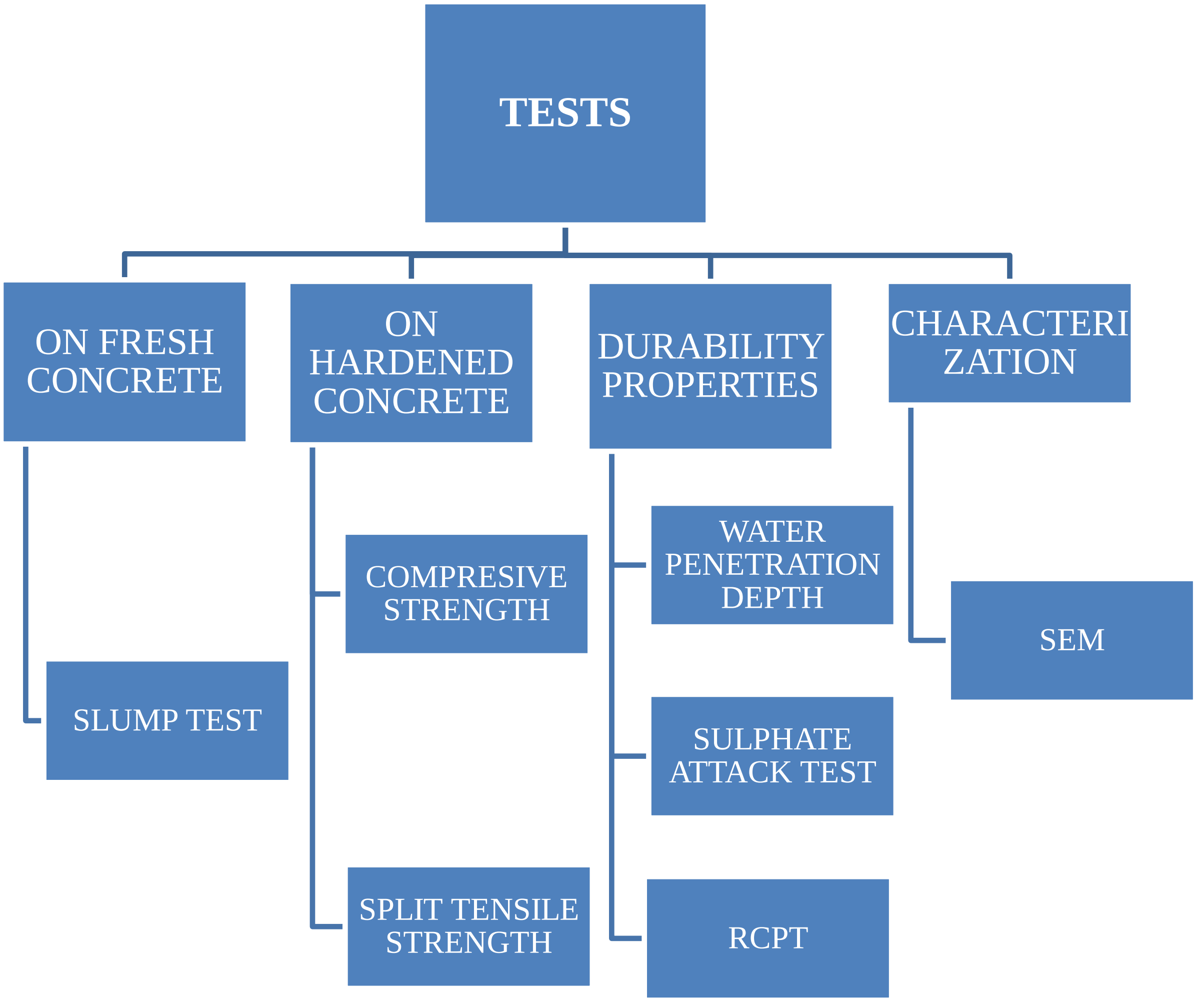

Fig 3.1 Experimental tests performed on concrete mixes in this study

3.2 MATERIAL TESTING

3.2.1 Cement

Cement used in this study was of OPC-43 grade. It was manufactured by Ambuja. Properties of cement were confirmed by IS8112:1989. Setting time and consistency were determined with reference from IS 4031:1988. Test performed are given in detailed form in **Table 3.1** and **Table 3.2.**

3.2.1.1 Cement Consistency

This property is measured using Vicat apparatus with procedure of IS 4031 (Part-4) 1988. A part was made using 500gm cement. It was placed in Vicat's apparatus, which consists of a 10mm diameter plunger which is standard. Plunger was made to penetrate in mix after leveling the top surface of mould. Different water content values were taken on basis of which various trails were performed. That water content when the penetration of plunger is between 5mm to 7mm from bottom of apparatus, is taken as standard consistency of cement.

3.2.1.2 Setting Time of Cement

Setting time of concrete was determined by Vicat's apparatus with procedure of IS4031 (Part-5) :1988 in with cement paste was made with water as 0.85 times water required for standard consistency of concrete. After placing the paste in the mould it was leveled from top end. A standard needle of diameter 1mm was moved in the mould and the process was repeated until it became unable to move beyond 5mm from bottom. The time at which water added to cement till the time of which plunger failed to go beyond 5mm was recorded as time of initial setting also known as initial setting time.

Final setting time is the time when water is added to cement to the time when annular ring (which is used in place of needle) is unable to make an impression on surface of paste.

3.2.1.3 Chemical Characterization

Characterization of cement and chemical analysis in accordance with IS 8112:1989 provided by Ambuja Cement. Details of which are given in Table 3.1 and 3.2

Table 3.1 Physical properties of cement

Physical properties	**Test results**	**Specification (IS 8112:1989)**	**Test procedure**
Fineness	8%	10% (Maximum)	IS 4031(Part 1):1996
Soundness(mm)	1	10 mm(Maximum)	IS 4031(Part 3):1988
Standard Consistency (%)	26	-	IS 4031(Part 4):1988
Setting time (min)			IS 4031(Part 5):1988
Initial setting time	120 min	30 (Minimum)	
Final setting time	470 min	600 (Maximum)	
Specific gravity	3.06	3.15	IS4031(Part 11):1988

Table3.2 Chemical properties of Cement

Particular	Test results	Specification as per IS 8112:1989	Test Procedure
$Al_2O_3/F_{e2}O_3$	1.30	0.66 (Minimum)	BIS:4032:1989
Insoluble residue (% by Mass)	1.60	2.00 (Maximum)	
Magnesia (% by Mass)	0.96	6.00 (Maximum)	
Sulphuric Anhydride (% by Mass)	2.39	3.00 (Maximum)	
Total loss on ignition (% by Mass)	2.94	5.00 (Maximum)	
Total chlorides (% by Mass)	0.022	0.05 (Maximum)	

3.2.2 Fine aggregate and ceramic waste

3.2.2.1 Specific gravity and water absorption

In this procedure for both fine aggregate and ceramic waste 500gm sample is taken and is tested by using Pycnometer according to IS 2386 (Part 3):1963 to find out specific gravity.

Formulas for calculating gravity and water absorption are given as follows:-

Specific gravity = d / {a-(b-c)}

Water absorption = {100*(a-d)} /d

a = Weight of saturated surface by samples of sand or ceramic waste, gm

b = Weight of Pycnometer containing samples of sand or ceramic waste and filled with water, gm

c = Weight of Pycnometer filled with water alone, gm

d = Weight of oven dried sample of sand or ceramic waste, gm

3.2.2.2 Particle size analysis

Samples of ceramic waste and fine aggregate were oven dried for 24 (±) 1 Hr at 100^0C. After then they were taken out and left for cooling at room temperature. Set of sieves from 4.75mm, 2.36mm, 1.18mm, 600mm, 300mm, 150mm, 90mm and pan of 4.75mm from top and bottom were taken and 1000gm of each sample was sieved through these set of sieves. **Table 3.3** and **3.4** shows the test results.

Table 3.3 Particle size analysis of fine aggregates

Sieves	**Weight Retained**						
	Sample1	**Sample 2**	**Sample3**	**Mean value**	**% weight retained**	**Cumulative % retained**	**% passing**
4.75	39.5	42.1	45.6	42.52	4.252	4.252	95.748
2.36	162.5	171.7	152	162.77	16.277	20.538	79.5
1.18	241	241.6	227	237.61	23.761	44.289	55.711
600	167.5	155	159.5	161.41	16.141	60.43	39.57
300	332	313.3	312	320.9	32.09	92.5	7.5
150	52	72.5	91.5	72.3	7.23	99.73	0.27
Pan	1.5	2	4.5	2.7	0.27	100	0

Fineness modulus of sand = (4.252+20.538+44.289+60.43+92.5+99.73)/100= **3.22**

Table 3.4 Particle size analysis of ceramic waste

Sieves	**Weight retained(gm)**	**%weight retained**	**Cumulative % retained**	**% passing**
4.75	18	1.8	1.8	98.2
2.36	167	16.7	18.5	81.5
1.18	107.5	10.75	29.25	70.75
600	46	4.6	33.85	66.15
300	57	5.7	39.55	60.45
150	266	26.6	66.15	33.85
Pan	335	33.5	99.65	0.35

Fineness modulus of ceramic waste - (1.8+18.5+29.25+33.85+39.55+66.15+99.65)/100= 2.89

Table 3.5 and **Table 3.6** shows physical properties of fine aggregate and ceramic waste respectively

Table 3.5 Physical Properties of Fine Aggregates

Fineness Modulus	**3.217**
Specific Gravity	**2.544**
Grading zone	**2^{nd}**

Table 3.6 Physical Properties of Ceramic Waste

Specific Gravity	**2.40**
Fineness Modulus	**2.8875**
Water Absorption	**2.5 %**

Table 3.7 Chemical Properties of Ceramic Waste

Chemical Composition	**Percentage (%)**
Silicon dioxide (SiO_2)	**60.9**
Aluminum Oxide (Al_2O_3)	**19.80**
Calcium Oxide (CaO)	**4.21**
Potassium Oxide (K_2O)	**5.195**
Iron Oxide (FeO)	**3.745**
Titanium Oxide (TiO_2)	**1.56**
Sodium Oxide (Na_2O)	**1.70**
Magnesium Oxide (MgO)	**2.87**

Table 3.7 shows ceramic waste chemical composition which shows ceramic being rich in silica content.

3.2.3 Properties of coarse aggregates

Coarse aggregate of maximum 20mm size was used. Apart from that 10mm coarse aggregates were also used. Fineness modulus of coarse aggregates is found out with the help of specific test and procedures.

Particle size analysis of coarse aggregates was also determined and the results are given below in **Table 3.8.**

Table 3.8 Particle size analysis of coarse aggregates

IS sieve	Wt. retained	% retained	% passing	Cumulative % retained
80	0.00	0.00	100.00	0.00
40	0.00	0.00	100.00	0.00
20	3650	36.5	63.5	36.5
10	5190	51.9	11.6	88.4
4.75	1160	11.6	0.00	100
2.36	0	0.00	0.00	100
1.18	0	0.00	0.00	100
600 μ	0	0.00	0.00	100
300 μ	0	0.00	0.00	100
150 μ	0	0.00	0.00	100
Pan	0	0.00	0.00	100

Sum 724.9

Fineness Modulus =7.25

3.3 Specimen casting and Mix design

As per guidelines of IS 10262:2009, M25 control mix was designed. The mix was designed for a 28 day target compressive strength of 31.6 N/mm^2 .

Some design detail input of mixes are as follows:-

- Nominal size of coarse aggregate -20mm,10mm
- Exposure = mild

- Target 28 days compressive strength = 31.6 N/mm^2.
- 28 days characteristic strength = 25 N/mm^2.
- Degree of control = good
- Grade designation = M25
- Type of cement = OPC 43
- Water cement ratio = 0.43

Some of mixes were prepared by hand mixing and some mixes were prepared by help of mixture of capacity of $0.06m^3$. Ceramic waste, cement, coarse aggregate, fine aggregate were mixed after weighing until uniformity in color is obtained. Water was added in two shifts in machine mixing and aggregates were mixed in dry state. Mixing is stopped when uniform color is achieved. Moulds of different shapes were taken according to need of testing and were oiled properly before filling them with specimens. After 24 hr's of time, moulds were opened and specimens were taken out and immersed in water for prior curing of the samples as per relevant testing procedures.

Fig 3.2 Curing and casting of Test specimens

3.4 EXPERIMENTAL TESTING DETAILS

3.4.1 Workability

It is generally measured using slump test. Workability is performed in accordance with IS 1199:1959. In this slump test is done in which fresh concrete is poured in slump mould in which compaction of that concrete is done uniformly. After this procedure slump mould is lifted up vertically upwards. It is removed very slowly. After that difference in the peak point and deformed concrete and highest point of mould is calculated by means of a scale. This value is known as slump of concrete.

Fig 3.3 Slump Measurement

Number of tests were performed for finding effects on different properties of concrete. In which tests were carried out after specific number of curing days as per requirement of definite property.

The total no. of specimen made and age of testing is given under **Table 3.9.**

Table 3.9 Name of tests performed and Age of testing

NAME OF TEST	AGE OF TESTING	TOTAL NUMBER OF SPECIMENS TESTED
Compressive Strength	7 and 28 days	24 cubes (3 specimens for each mix for 7 and 28 days of curing)
Split Tensile Strength	28 days	12 cylinders (3 for each mix for 28 days) (150mm*300mm)
Sulphate Resistance	56 days	12 cubes (3 for each mix for 56 days)
Water Permeability	7 and 28 days	24 cubes (3 for each mix for 7 and 28 days)
RCPT	28 days	12 cylinders (100mm*200mm) 3 for each mix for 28 days

3.4.2 Hardened Concrete : Strength Properties

3.4.2.1 Compressive Strength

Resistance of concrete to load of compression is defined as compressive strength. CTM (Compression Testing Machine) was used in this test with IS 516:1959 having a capacity of 2000kN. Pace of 5 kN/Sec was set as loading rate without any shock until when load starts decreasing till the moment when no more load can be applied to concrete. Maximum load applied is calculated and compressive strength is calculated by following formulas:-

Compressive strength = Peak load (Failure) / Cross sectional area of sample

Fig 3.4 shows CTM machine which is used for compression testing and Fig 3.5 shows compressive strength testing in which specimen is kept under loading in CTM machine.

Figure 3.4 CTM **Fig 3.5 Specimen under loading**

3.4.2.2 Split Tensile Strength

Tensile Strength of concrete is measured by means of split tensile method in accordance with IS 5816:1999 on Compression testing machine (CTM) having capacity of 2000kN. Samples used in this test method are of cylindrical shape with diameter of 150mm and height of 300mm. In this test specimens are placed under the plunger in direction along the diameter. Loading rate was fixed at 2kN/sec pace. Peak load was noted and split tensile strength was calculated by following formulae :-

$$\sigma = 2P/ \pi dl$$

where, σ = Split tensile strength (N/mm^2)

P = Applied load at failure (N)

d = Diameter of cylinder (mm)

l = Length of cylinder (mm)

Fig 3.6 Testing of cylinder in CTM for Split tensile strength

3.4.3 Hardened Concrete : Durability Properties

3.4.3.1 Water Permeability Test

Durability of concrete is studied and checked out on the basis of various parameters, one of which is water permeability test. In this test we find permeability of concrete when a constant water pressure s applied on sample. This test is performed after 7 days and 28 days of curing in accordance with IS 3085(part 7): 1963. It is performed on cube specimens of size 150mm*150mm*150mm. In this test whole machine consists of three permeability cells, a pressure regulator which is used to adjust pressure, two pressure gauges with pressure varying from 0-15 kg/cm^2 and 0-20 kg/cm^2 respectively . This apparatus is used to find out permeability in which first gauge measures the input pressure and second gives the test pressure. Water pressure of 0.5 N/mm^2 is applied over specimen with help of air compressor for about 72 hours after oven drying the sample at 100^{0}C for about 24 hours. After 72 hours sample is taken out and is split from middle line by putting it in diagonal position in CTM. Penetration of water depth is marked and noted.

Apparatus of water permeability test and specimen after splitting apart is shown below in **Fig 3.7** and **3.8** respectively.

Fig 3.7 Water Permeability apparatus

Fig 3.8 Specimen broken into two parts for measuring water penetration depth

3.4.3.2 Sulphate Resistance

There can be mainly three sources from where sulphate attack can occur which are: soil, ground water ad sea water. The severity of attack is known from the factor from which sulphate is available for ingression in concrete. Sulphate attack can result in mass loss, any form expansion or loss in compressive strength of concrete. It is performed in accordance with ASTMC 1012-15. Measurements like weight of specimen and initial length of specimen were taken after curing of 28 days. After that specimens were immersed in sodium sulphate solution of specific concentration for 28 days. This is done to check affect of suphate attack on concrete specimen. After 28 days of immersion in solution, specimen are taken out and compressive strength test was performed on specimen by using CTM and readings were noted. So the change in compressive strength of specimen after immersing them into solution is taken as intimation of sulphate resistance of concrete specimen.

It is calculated as:-

Change of compressive strength(%) = $[(s_1-s_2)/s_1]*100$

Where;

S_1 = Average compressive strength of concrete after 28 days.

S_2 = After 28 days, average compressive strength of specimen after immersion in Na_2SO_4 solution.

Fig3.9 Specimens placed in tank for Sulphate attack

3.4.3.3 RCPT (Chloride Permeability)

Chloride intrusion can lead to corrosion and reduction in strength. It is one of the major attacks most of the structures have to bear during lifetime. Concrete surface contains pores which are responsible for ingression of chloride ion. To find out this ingression , Rapid chloride penetration test is performed in accordance with ASTMC 1202-10. 100mm diameter with 200mm length concrete cylinders are cut from middle to take out 50mm thick with 100mm diameter sections. These sections obtained from one cylinder are tested for different percentages and ages. It consists of passing electric charge through these sections to check their ability to resist that specific charge. In this apparatus one end of specimen is immersed in solution of sodium hydroxide (.3 N NaOH) and other end in solution of sodium chloride (NaCl)(3%). For 6 hr's, charge is passed and on basis of this, specimen resistance to chloride is interpreted with codal values.

As per guidelines of ASTMC 1202-10.

Table 3.10 Standard values for Chloride Penetration

CHARGE PASSED (COLUMBS)	Chloride Ion Penetration
<100	Negligible
100-1000	Very Low
1000-2000	Low
2000-4000	Moderate
>4000	High

Fig 3.10 RCPT Apparatus

3.4.4 Scanning Electron Microscopy (SEM)

SEM helps in characterization of microstructure of concrete. Micro structure of concrete consists of aggregates, CSH gel, Calcium hydroxide, ettringite and monosulphate and interfacial transition zone. So with the help of scanning electron microscopy we can study compositional as well as topographical analysis of concrete. This includes study of structures and helps in determining shapes of compounds like for an example ettringites appear to be objects like crystals like needle with no branches.Platy crystal, elongated crystal and blocky mass crystal are among many shapes in which CaOH may appear. This study of structural details of compounds is the helping key for finding and analysing factors which effect the durability and mechanical properties of concrete.

In this procedure, core of the concrete is explored and broken chip from that concrete core is observed under micrographs. To make the sample electrically conductive it is coated with gold and the SEM images of the sample are taken in next mode. In secondary mode primary beam electron with electro sample takes place. The image of the surface of sample in itself formed by the help of secondary electron. Then energy dispersive spectroscopy is used for performing chemical analysis of sample.

Fig 3.11 Gold plating of sample for SEM

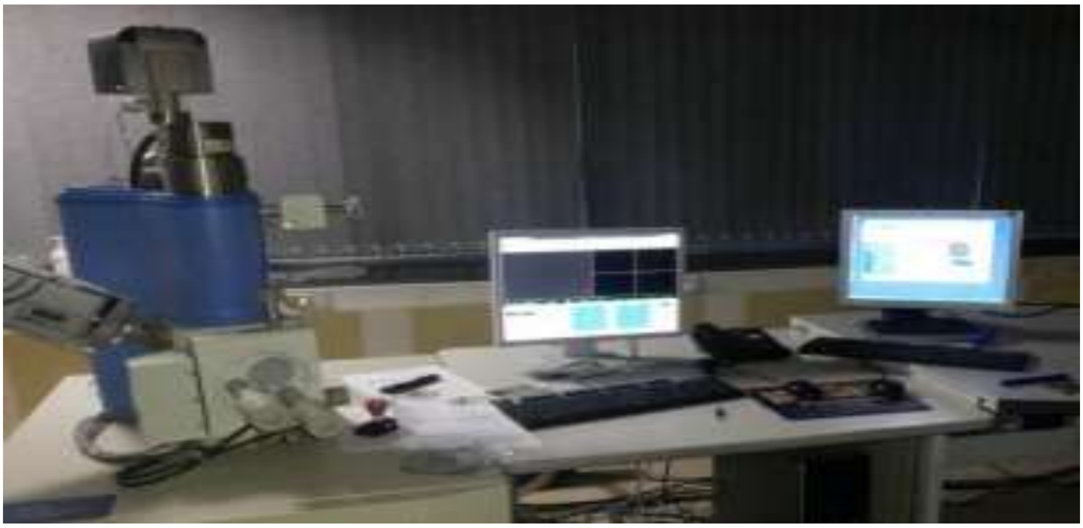

Fig 3.12 SEM Apparatus

CHAPTER-4

RESULTS AND DISCUSSIONS

4.1 GENERAL

Results of the experimental study are presented in this chapter. In the previous chapter, we discussed the various experimental tests that were conducted to find change in strength and durability properties of concrete on replacing ceramic waste with fine aggregate. Under that section properties studied were compressive strength, splitting tensile strength , rapid chloride penetration test, water permeability test and sulphate attack . The results obtained are discussed in detail in this section and the effects of ceramic waste in concrete are analysed.

4.2 Properties of Fresh Concrete

4.2.1 Effect on Workability

Property which refers to ease in which concrete can be mixed, compacted, transported, placed and finished is called workability. There are two parameters i.e consistency and homogeneity which play main role in accounting workability. It is assessed on basis of slump test . So test was conducted on fresh concrete incorporating ceramic waste as fine aggregate and slump was measured. The values of slump are presented in **Table 4.1**.

Table 4.1 Slump values

Mix	Ceramic waste as fine aggregate(%)	Slump (mm)
CM(control mix)	0	80
10% ceramic waste (cw)	10	60
15% CW	15	40
25% CW	25	30

It can be observed that slump of concrete mix with o% to 25% replacement decreases with increase in content of ceramic waste . As slump value for control mix is 80mm which further decreases to 30mm at 25 % replacement level . This represents a significant decrease of about 62.5% as compared to control mix. Trends are plotted in **Fig 4.1.**

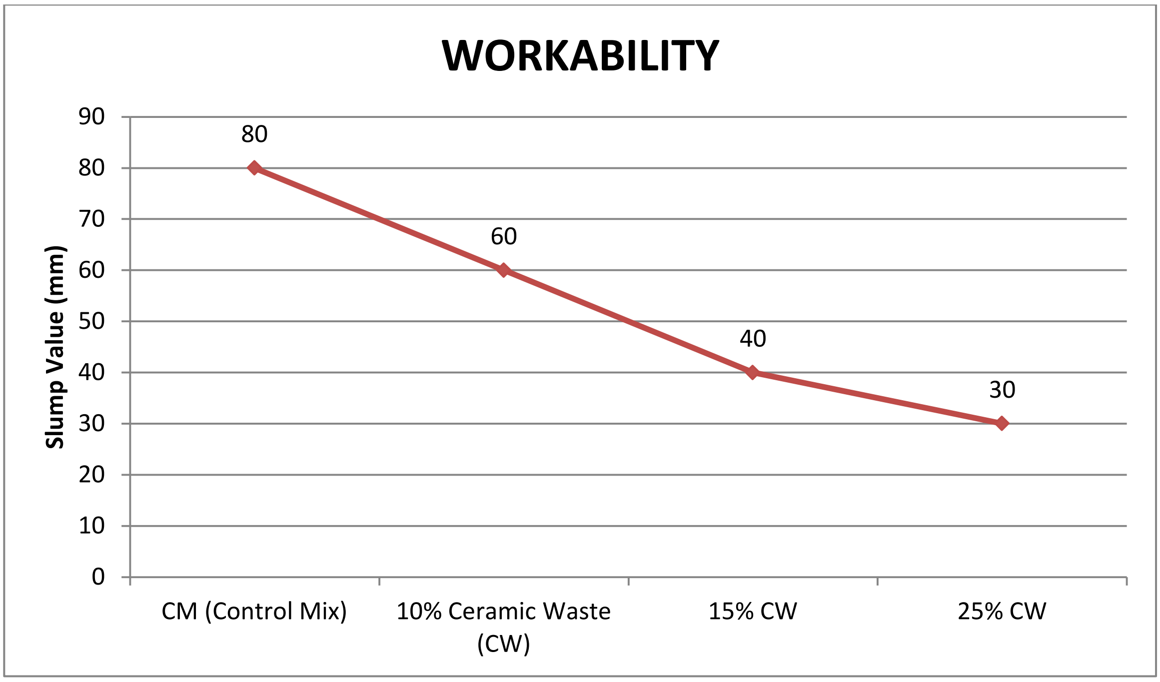

Fig 4.1 Slump value

Fig 4.2 Ceramic waste (25%) **Fig 4.3 Ceramic waste (0%)**

The possible main reason due to which decrease in workability is seen with an increase in replacement of ceramic waste is the nature of particles of ceramic waste which possess high water absorption characteristics as compared to normal river sand. Which as a result decreases the availability of free water which otherwise serves the purpose of a lubricant. This in fact decreases the workability .Similarly due to this flowability of concrete is also affected.

Salman Siddique et al (2018) also studied effect of ceramic waste as replacement of fine aggregate on workability of concrete and reported decrease in workability with an increase in replacement level.

Pincha Torkittikul et al (2010) also used ceramic waste in replacement of fine aggregate and observed that workability decreased with an increase in replacement level of ceramic waste and concluded high absorption characteristics of ceramic waste as a reason behind this .

4.3 Hardened Concrete: Strength Properties

4.3.1 Compressive Strength

In this study one of the most important parameters of mechanical properties i.e compressive strength was tested and effect of ceramic waste on concrete mixes with (0%,10%,15%,25% replacement of fine aggregate) on compressive strength at age of 7 and 28 days was noted and analyzed. The values are presented under **Table4.2.**

Table 4.2 Variation of Compressive strength of different mixes

Replacement %age of ceramic waste (CW)	7 days compressive strength (MPa)	7 days average Compressive strength (MPa)	28 days compressive strength (MPa)	28 days average Compressive strength (MPa)
O% CW	25.2	23.26	26.4	27.8
	22.4		29.0	
	22.2		28.0	
10% CW	21.8	20.73	27.4	25.53
	21.0		22.6	
	19.4		26.6	
15% CW	25.0	25.46	28.4	28.93
	24.6		31.4	
	26.8		27.0	
25% CW	29	27.46	38.2	34.3
	28.2		32.4	
	25.2		32.4	

Based on these results increasing/decreasing graph is plotted to simplify the trends.

The same is shown in Fig 4.4

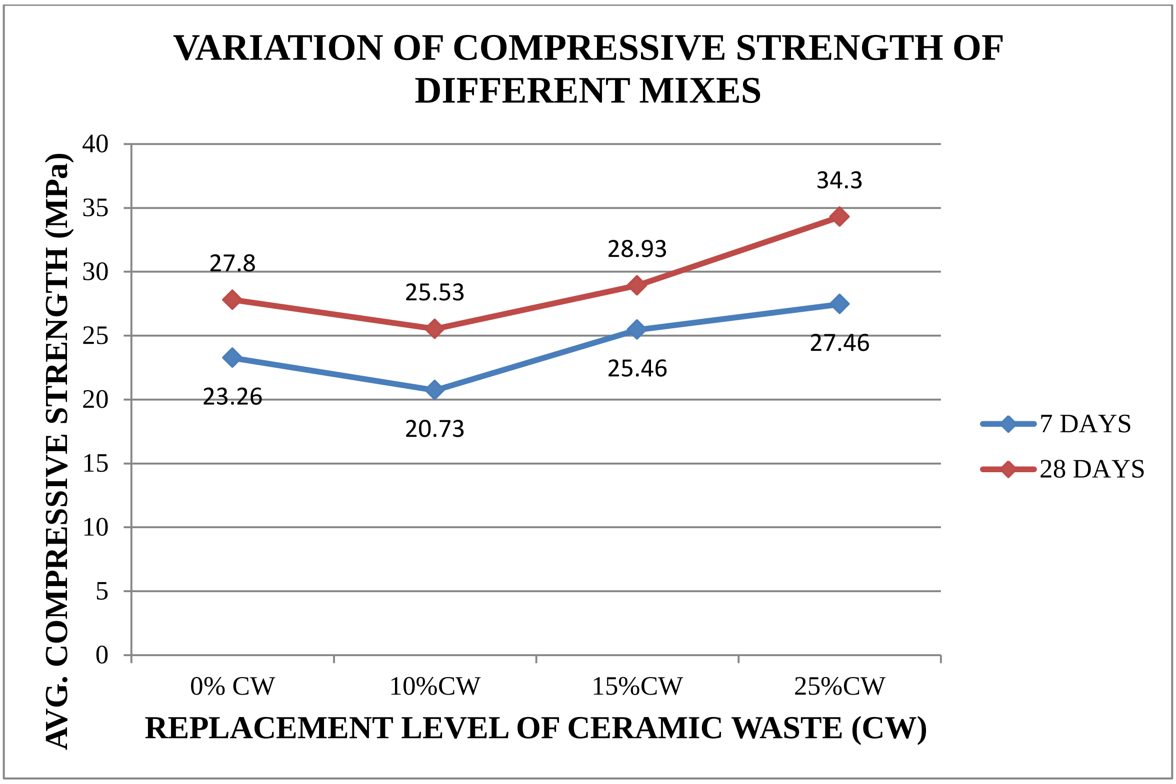

Fig 4.4 Variation of Compressive strengths of different mixes after 7 and 28 days

According to values obtained, **7 days** compressive strength of concrete mixed with 25% waste ceramic showed **15.30 %** increase in strength as compared to normal reference concrete with 0% ceramic. Which indicated that with increasing content of ceramic in substitution of fine aggregate, compressive strength increases. **After 28 days** compressive strength of concrete with 25% ceramic undergoes **18.95 %** increase than strength of normal concrete with 0% replacement. Which is a marginal increase. This increase in compressive strength is supposed to have taken place due to four reasons. One of which being pozzolanic character of ceramic waste which results in increased pozzolanic reactivity promoting better microstructure and interfacial transition zone characteristics which lead to creation of dense formation of hydration products simultaneously. Second reason is that due to higher early absorption capacity and higher specific surface of ceramic particle , water gets restored and that presence of water allows adequate hydration of cement through internal curing. Which therefore results in increased compressive strength. Third reason is only due to fine particles of ceramic which acts as a filler to promote denser matrix than normal concrete giving larger compressive strength values. Fourth one is due to presence of high content of silica in ceramic waste which is much responsible for incorporating high strength to concrete.

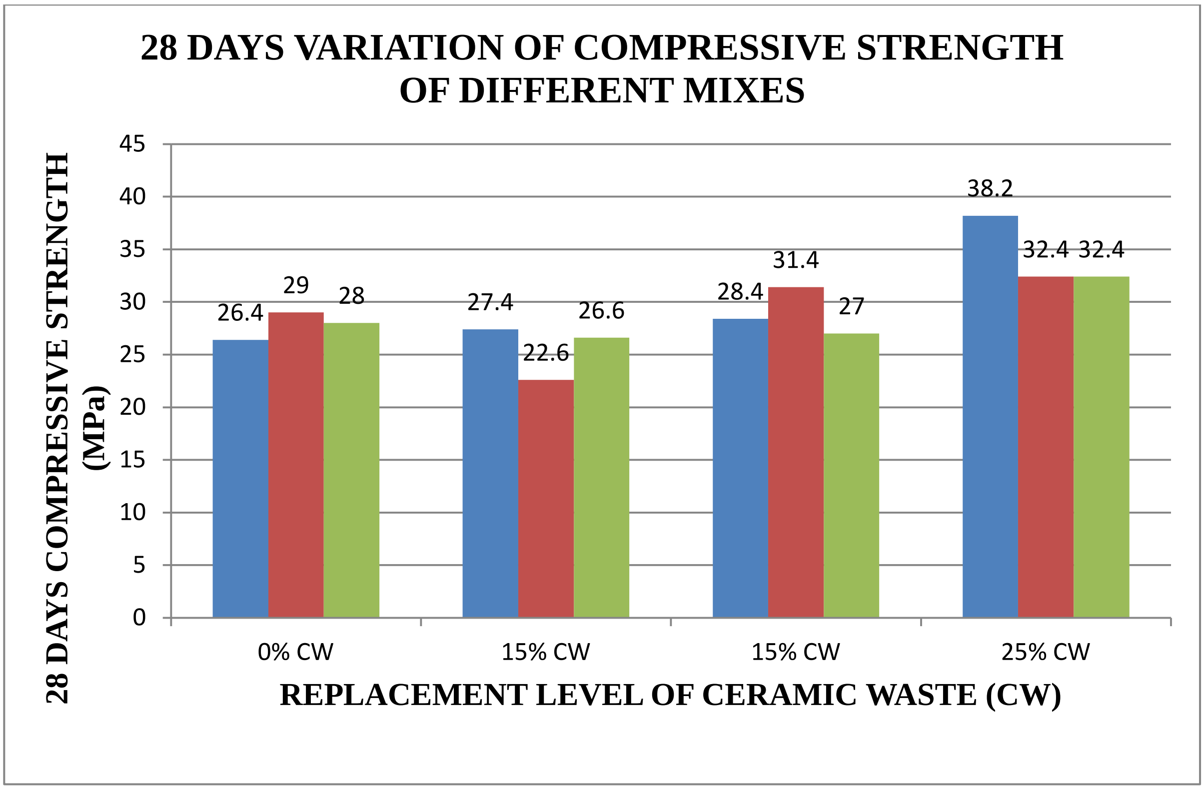

Fig 4.5 Trends of all 12 cubes after 28 days (compressive strength)

Pincha Torkittikul et al (2010) did investigation on ceramic concrete and reported surface texture of ceramic particle as a reason for higher compressive strength as grip between paste and aggregate at interfacial zone gets improved when a rougher texture fine aggregate is used, thereby leading to an increase in compressive strength.

Salman Siddique et al (2017) concluded that ceramic powder posseses fine particles which act as a filler in matrix and hence give rise to a denser matrix which results in increased compressive strength of concrete.

Paul O. Awoyera et al (2016) studied effects of ceramic waste on compressive strength and concluded that pozzolanic activity of ceramic micro particle is hugely responsible for gain in strength as it promotes the formation of hydration products and also acting as a grip to the paste hence giving rise to a better microstructure.

4.3.2 Split tensile strength

Flexural and shear parameters of concrete are analysed with the help of split tensile strength test. Testing was done with help of CTM after 28 days of curing on both control concrete and ceramic mix concrete .12 cylinders of 300*150 mm were tested among which 3 were control,3 were of 10% ceramic,3 of 15 % ceramic and last 3 of 25 % ceramic .Values obtained were noted and are presented under **Table 4.3.**

Table 4.3 Split tensile strength values

Type of mix	28 days Split tensile strength (MPa)	28 days average Split tensile strength (MPa)
CM (control mix) 0% ceramic	1.86	2.63
	2.92	
	3.11	
10 % ceramic waste	2.36	2.69
	3.32	
	2.39	
15 % ceramic waste	3.207	2.805
	3.11	
	2.10	
25% ceramic waste	2.29	2.43
	2.73	
	2.27	

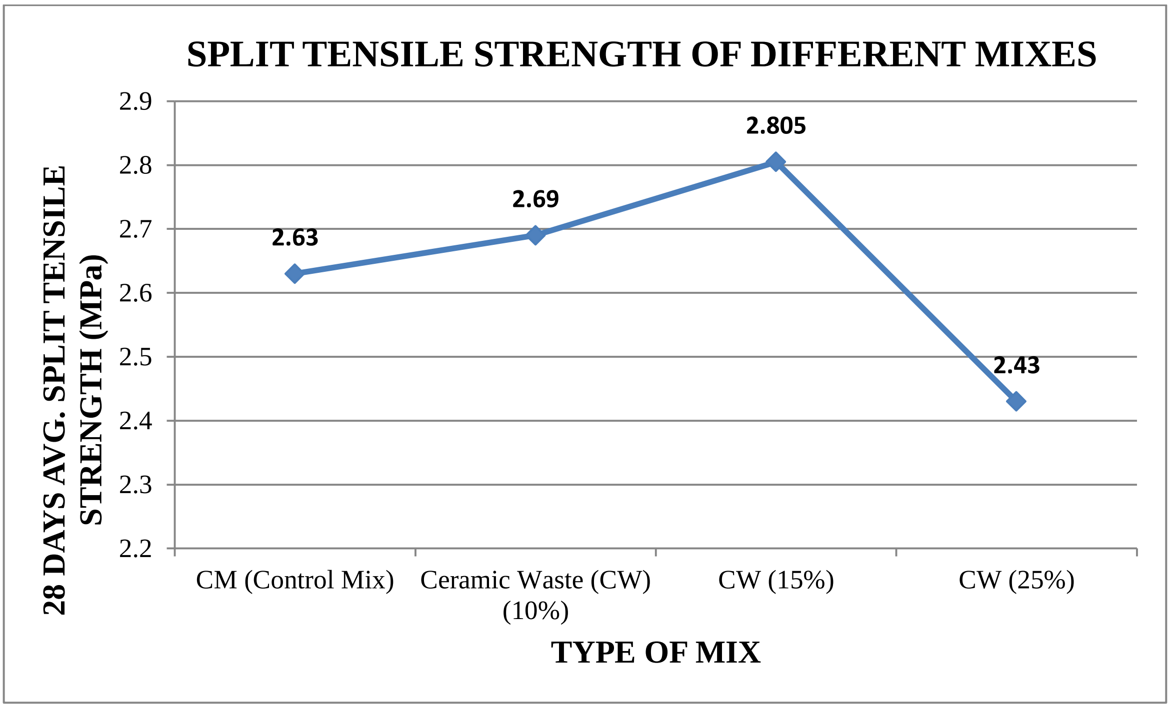

Fig 4.6 Based on same values graph is plotted to show trends in more simplified form

As per actual values given in table 4.3 , it can be seen that split tensile of concrete mix increased on increasing content of ceramic up to 15% beyond which i.e at 25% replacement split strength started declining . Maximum tensile strength was achieved at 15% replacement level. Strength increased with **2.2 %** and **6.2 %** on replacement with **10%** and **15%** of ceramic content respectively as compared to that of normal concrete. So this brings to a conclusion that on increasing the content of ceramic waste up to an optimum level of 15% , split tensile strength of concrete can be increased. This increase mainly happens due to high silica content of ceramic waste and its pozzolanic behavior which results in improved mortar-aggregate interface and densification of concrete matrix.

A.Gonzalez-Corominas et al (2014) also concluded that concrete made with fine ceramic aggregate achieved higher splitting tensile strength to that of normal concrete.

Salman Siddique et al (2018) also reported higher split tensile strength with increase in content of ceramic waste due to pozzolanic behavior. He concluded the reason for this increase being denser microstructure of fine bone china ceramic aggregate concrete which helps in enhancing the tensile capacity of the concrete matrix and hence improves the tensile strength of the specimen.

4.4 Hardened Concrete: Durability properties

4.4.1 Water Permeability

Durability of concrete is checked and acknowledged after investigating and testing on various parameters. One of these parameters is permeability of concrete which is explored by water permeability test. Which usually takes 72 hours or 3 days roughly. It is tested in accordance with IS 3085 (part7):1963. In this test water is applied at 10-15 kg /cm^2 pressure for 3 days and after that specimens are split apart into two pieces to check the penetration of depth of water ingression. In this study values which are taken after testing are presented under **Table 4.4** which shows the penetration depth of water in samples with and without ceramic waste.

Table 4.4 Test results: Water Permeability

Mix	**Depth of Penetration of Water(cm)**
Control mix	1.8
Ceramic waste (CW) (10%)	2.1
CW (15%)	2.2
CW(25%)	2.5

Based on these results graph is plotted between depth of penetration of water in cm and level of replacement of ceramic waste. It can be seen in Figure 4.7

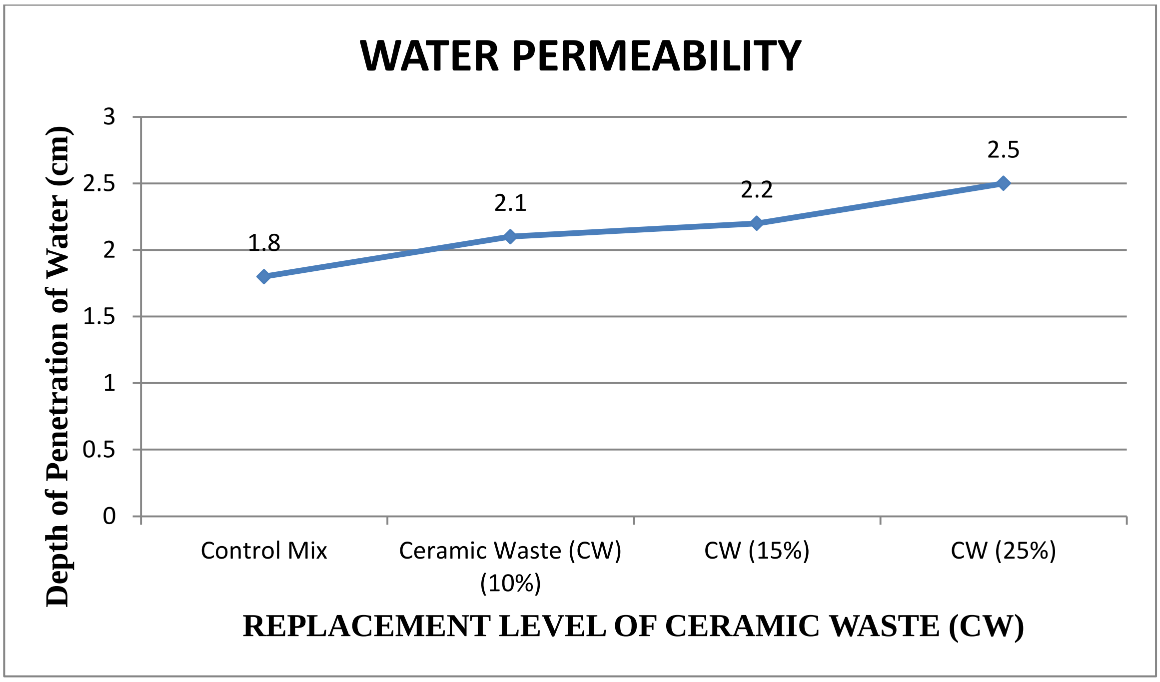

Fig. 4.7 Plot showing permeability trend

So according to obtained results, depth of water penetration increases by 28 % in specimens having 25% ceramic waste as compared to that of control mix . It is observed that as the ceramic percentage replacement level is increased in concrete, penetration depth increases. This happened due to the fact that CSH gel contains ipores which are of varying sizes i.e (2.5-10nm). Such micro pores have no effect or influence on permeability properties of concrete under normal conditions. But when pressure parameter comes into picture , its application can influence the pore structure and make permeability worse by generating a channel of water filled pores causing a discoloration effect, which can be seen after splitting of samples.

Similar effect can be seen in SEM images of control concrete and concrete with 25% replacement.

Fig 4.8 and 4.9 shows 1000x images of pore structures of control concrete and ceramic mix concrete respectively

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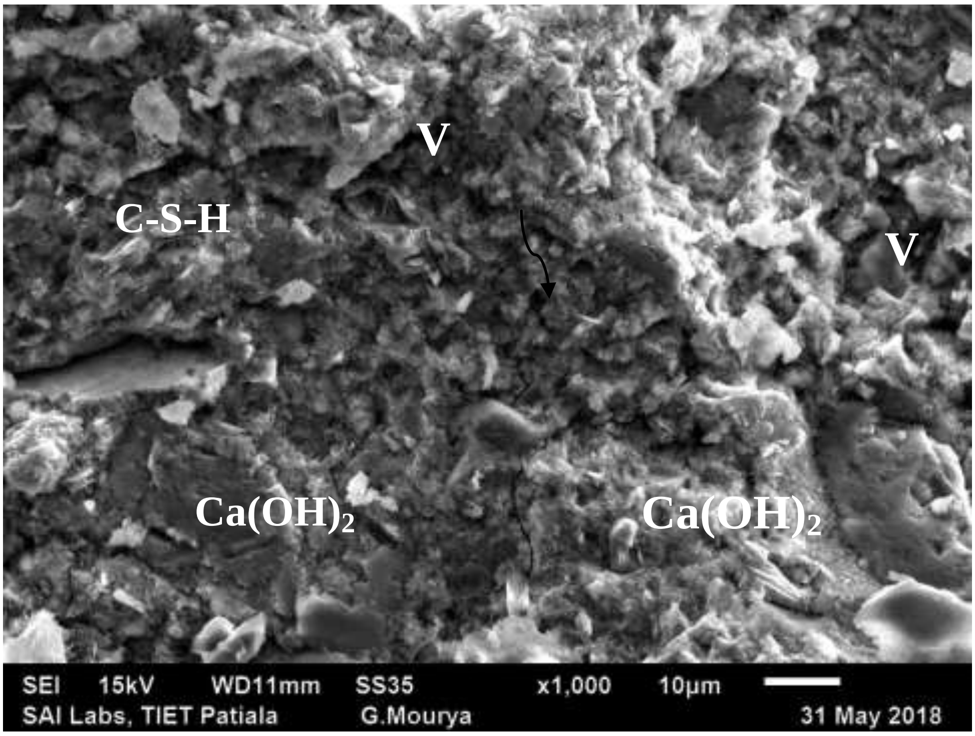

Fig 4.8 SEM of control concrete

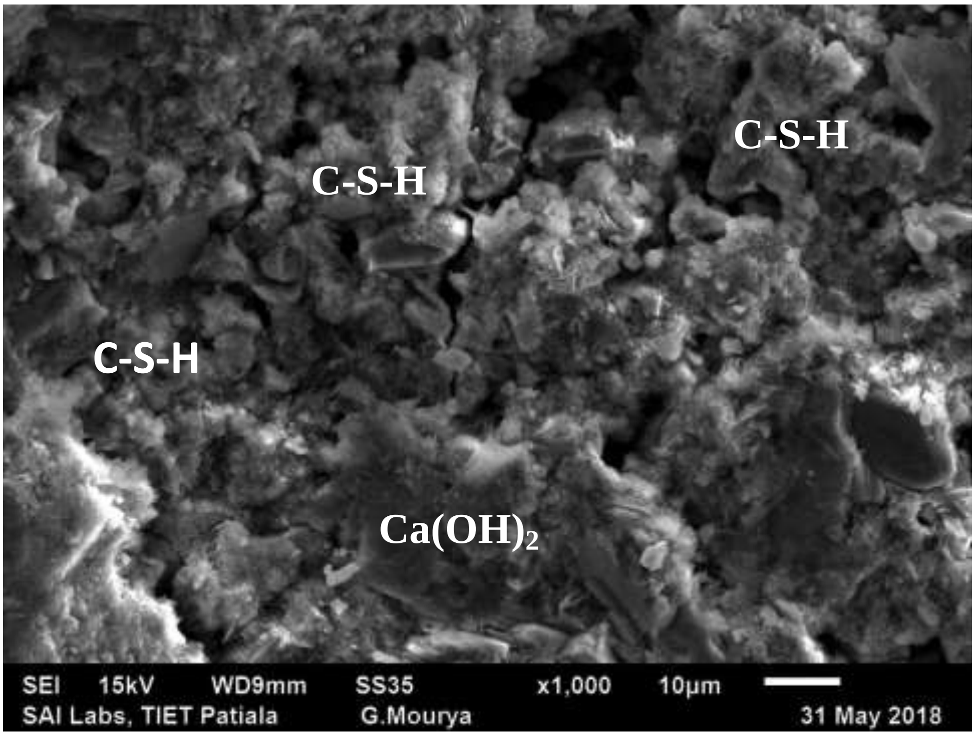

Fig 4.9 SEM of 25% ceramic waste concrete

4.4.2 Sulphate attack

This test was performed in accordance with ASTMC 1012-15. In this specimens were immersed in sodium sulphate solution of 5% for 28 days after period of 28 days of curing. After immersion period specimens were checked and loss in weight was noted so as to check the effect of ceramic waste in concrete and to compare that values with those of normal concrete after and before sulphate attack. Compressive strength test was performed on specimens and readings were noted. 12 specimens were tested and results of same are shown under **Table 4.5.**

Table 4.5 Sulphate Attack test results

Mix	28 days Compressive strength (N/mm^2)	28 days Avg. Compressive strength (N/mm^2)
CM 0%	**34.84**	**34.89**
	37.36	
	32.48	
Ceramic waste (CW) 10%	**30**	**31.58**
	31.51	
	33.24	
CW (15%)	**38.17**	**37.28**
	39.00	
	34.69	
CW (25%)	**41.58**	**39.97**
	38.11	
	40.24	

In Table 4.6 Comparison of 28 days Compressive strength of cube before and after sulphate attack is shown:

Table 4.6 Compressive strength before and after sulphate attack

Mix	Compressive strength before attack (N/mm^2)	Compressive strength after attack (N/mm^2)
CM 0%	**27.8**	**34.89**
Ceramic waste (CW) 10%	**25.53**	**31.58**
CW (15%)	**28.93**	**37.28**
CW (25%)	**34.3**	**39.97**

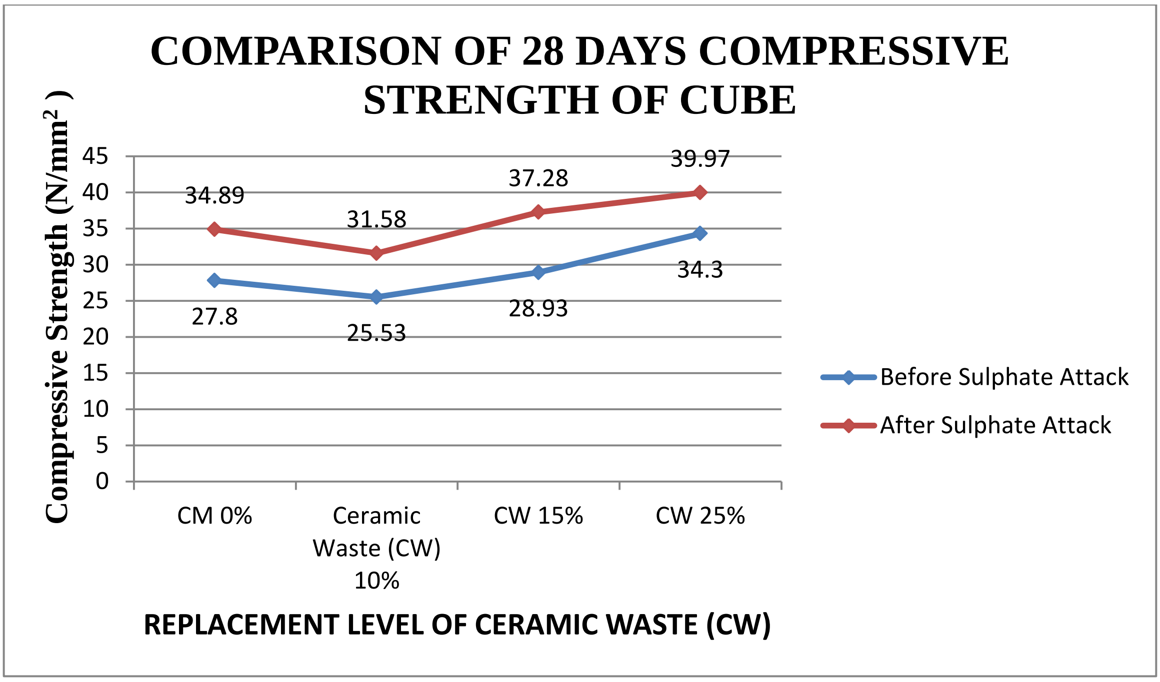

Fig.4.10 Similar trends are plotted for compressive strength

From **Fig 4.10** it can be observed that 28 days compressive strength of concrete cubes having ceramic waste in replacement of fine aggregate increases with an increase in content of ceramic waste after sulphate attack as compared to that of control concrete . Compressive strength undergoes 12.70% increase on 25% replacement of ceramic waste as compared to control concrete after sulphate attack. An increase of 6.41 % in compressive strength was seen after replacing 15% ceramic waste with fine aggregate as compared to that of control mix. This brings to a conclusion that even after sulphate attack with an increase in %age replacement of ceramic waste with fine aggregate 28 days compressive strength increases. This nature of concrete was due to ceramic waste intrusion which made concrete resistive to attack. It was seen that beside sulphate attack on cubes there was a very little change in their dimensions as well as weights . Increase in compressive strength that has taken place was only due to 56 days of maturity of concrete. This brought us to a conclusion that ceramic waste enhances the durability of concrete making ceramic concrete more resistive to attacks like sulphate.

4.4.3 Rapid Chloride Penetration Test (RCPT)

Rapid chloride penetration test was performed in accordance with ASTMC 1202-10 to check the chloride intrusion and charge passed in control concrete and ceramic mix concrete. Charge was passed through specimens for 6 hours. Comparison of total charge passed was done between different concrete mixes and is presented in **Table 4.7**

Table 4.7 Rapid Chloride Penetration Test Results

Mix	Charge passed (coulombs)	Average charge passed (coulombs)	Chloride ion penetration	Average chloride ion penetration
CM (control mix)(0%)	2362	2394	Moderate	Moderate
	2887		Moderate	
	1933		Low	
Ceramic waste CW (10%)	2185	1864.3	Low	Low
	1886		Low	
	1522		Low	
CW (15%)	1494	1495.3	Low	Low
	1497		Low	
	1495		Low	
CW (25%)	941	1044	Very Low	Very Low
	1056		Very Low	
	1136		Low	

According to results obtained from present study and as presented under **Table 4.7** chloride ion penetration in control mix after 28 days is moderate and it decreases along with increase in content of ceramic waste on replacement with fine aggregate. As Chloride ion penetration becomes low from moderate on 10% replacement level and decreases to Very Low from Low level on 25% replacement. Charge passed from mix having 25% ceramic waste decreased by 56.39% than the normal control mix having fine aggregate. So this summarizes the fact that concrete gets more durable if fine aggregate is replaced by ceramic waste as chloride penetration varies from moderate to very low level on 25% replacement level respectively. Now this type of behavior of concrete has resulted is due to finer particle structure of ceramic which has led to reduction in pores. With an increase in content of ceramic waste this reduction kept on increasing making concrete less permeable and hence increasing its durability.

Fernando Pacheco-Torgal et al (2010) also concluded the similar behavior of ceramic particle structure which led to reduction in pore volume similarly making concrete more durable and resistive.

4.5 Microstructure analysis using SEM studies

As mentioned in the previous chapter, SEM analysis was performed to check the effect of using ceramic waste as fine aggregate on concrete. All 4 mixes were taken after 28 days of concrete hardening and were crushed into small chips after removing coarse aggregates. Components like CSH gel, calcium hydroxide, ettringite, voids etc can be seen in ceramic micrographs in which ettringites appear to be needle like structures, calcium hydroxide as hexagonal blocky crystal structures and CSH gel as short needle-like form structures.

Specimens were then studied and observed under Scanning Electron Microscope(SEM). SEM images for various mixes are shown in **Fig 4.11, Fig 4.12, Fig 4.13, Fig 4.14.**

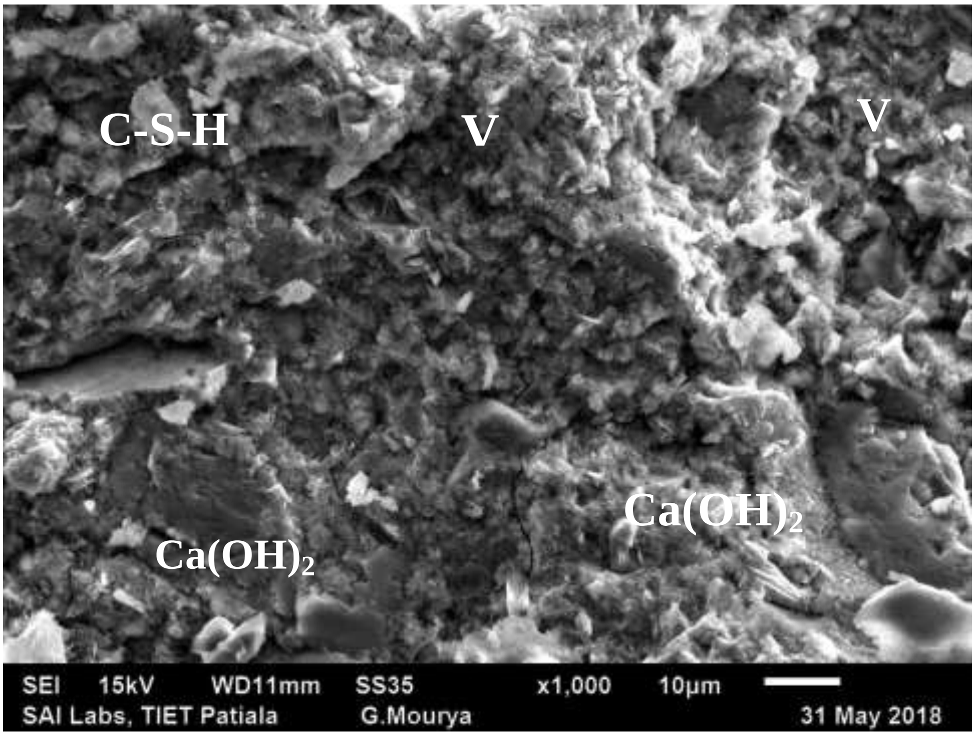

Fig. 4.11 SEM image of Control concrete

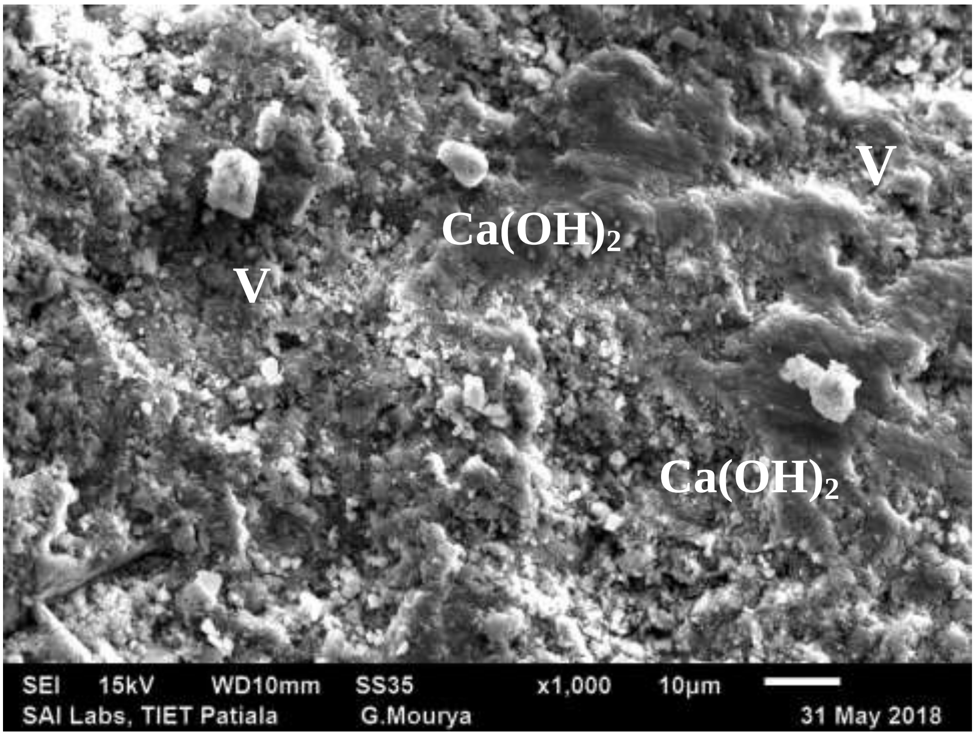

Fig.4.12 SEM image of 10% Ceramic mix concrete

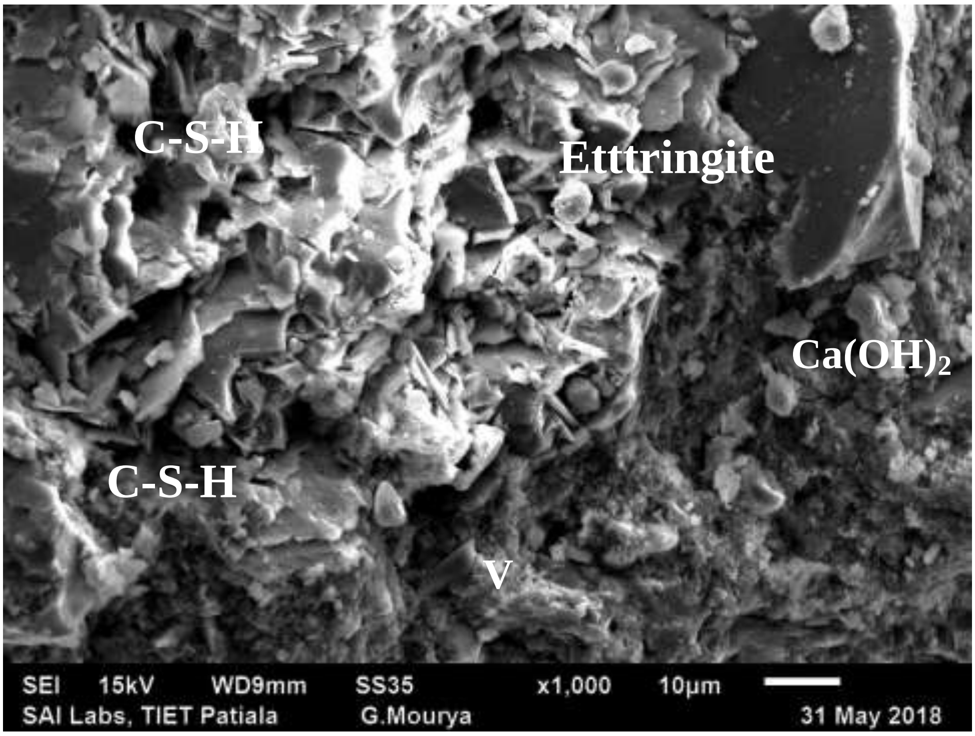

Fig.4.13 SEM image of 15% Ceramic mix concrete

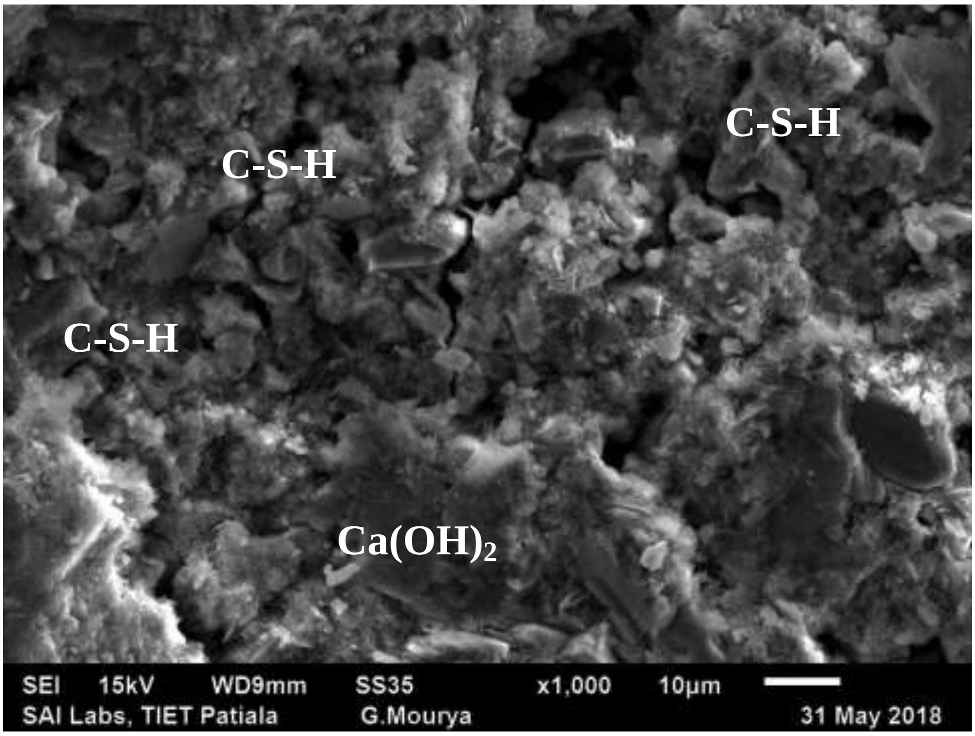

Fig.4.14 SEM image of 25 % Ceramic mix concrete

After analyzing SEM images at different magnifications of various mixes some points were made for structural description of the same:

- Main components observed in various mixes under scanning electron microscope were
  Calcium-silicate-hydrate gel ,calcium hydroxide, ettringite and voids.
- It can be observed in **Fig 4.11** in control concrete mix, structure is not so dense but after ceramic incorporation till 25%, concrete microstructure densifies as seen in **Fig.4.14.** this has happened due to filling of voids by finer particles of ceramic waste.
- Presence of constituents like silica and calcium in ceramic waste gave rise to C-S-H gel and calcium aluminate hydrates which present less porous structure in **Fig 4.13**
- Some morphological differences like enhancement in well formed crystal structure were also observed in C-S-H gel in ceramic waste concrete than in control concrete.
- Due to this morphological change ,as seen in **Fig 4.13 .**C-S-H gel grew more compact and granular in lateral ages which appeared to be layered at early stages in 25% ceramic mix concrete.
- Reduction in voids is observed in 25% mix micrographs due to efficient filler effect of ceramic aggregates as compared to that of fine aggregates.

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CHAPTER-5

CONCLUSIONS

5.1 GENERAL

The present research study was done to examine the effect of using ceramic waste in replacement of fine aggregate on various Mechanical and Durability properties of concrete. Ceramic waste (CW) was added at 0%, 10%, 15% and 25% replacement levels of fine aggregates (river sand). The effect of this replacement on compressive, splitting tensile strength and durability properties such as water permeability, resistance to sulphate attack and Rapid Chloride Penetration Test was examined. SEM studies were also performed on the ceramic waste material and concrete specimens for the micro-structural analysis of concrete.

The following are the main conclusions of this study:

5.1.1 Workability

- Decrease in the slump value was observed on increasing ceramic waste content in the concrete. Slump value was decreased from 80mm to 30 mm on replacing 25% of ceramic waste powder with fine aggregate as compared to control concrete. This may be attributed to the high water absorption characteristics of ceramic waste which decreases the availability of free water and hence affects the flowability and decreases the workability.

5.1.2 Mechanical Properties

- At both 7 and 28-days, the compressive strength was observed to increase with increase or rise in ceramic waste content in the concrete even at 25% replacement of fine aggregate. At 7 days, maximum increase was 15.30% which was at 25% replacement level and after 28 days, maximum increase was of 18.95% at 25% replacement level as compared to normal concrete. So thereafter increase in the strength was observed on increasing the content of ceramic waste. This was mainly attributed to fine particle size of ceramic waste and presence of high silica content in ceramic composition.
- The split tensile strength of concrete did not show any significant increase beyond 15% replacement level on incorporation of ceramic waste as replacement for fine aggregates. Split tensile strength values for mixes with 15% replacement level rise with 6.2% increase in strength as compared to normal concrete. This was the

maximum increase which took place on 15% replacement level .Beyond this level i.e at 25% replacement strength started decreasing. So the increase in strength up to 15% level was because the density of CW modified mixes increased in all cases due to the densification of concrete caused by pozzolanic action of ceramic waste (CW)

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5.1.3 Durability Properties

- The depth of penetration in water permeability test showed increase with increase in content of ceramic waste. This happened after application of pressure on samples which influenced the pore structure which led to generation of a channel of water filled pores, hence making permeability worse.
- In Rapid Chloride Penetration Test, chloride ion penetration in control mix after 28 days came to be moderate and it decreased along with increase in content of ceramic waste on replacement with fine aggregate. Chloride ion penetration became low from moderate on 10% replacement level and further decreased to Very Low from Low level on 25% replacement. Charge passed from mix having 25% ceramic waste decreased marginally by 56.39% than the normal control mix having fine aggregate. So this summarizes the fact that concrete gets more durable if fine aggregate is replaced by ceramic waste. This type of behaviour of concrete was resulted due to finer particle structure of ceramic which led to reduction of pores in concrete.
- The Resistance to sulphate attack was the only test where no change happened on ceramic mix concrete samples and these samples performed better than normal mix concrete. After 28 days of curing and 28 days of sulphate attack, concrete cubes were tested for compressive strength. Increase in compressive strength took place even on 25% ceramic mix concrete samples which clarifies that no damage was done to ceramic mix samples even after sulphate attack making ceramic mix concrete more durable and resistible to these types of sulphate attacks

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Based on the results of this experimental study, 25% replacement of sand by Ceramic Waste is recommended as the optimum replacement percentage in concrete mixes from both strength and durability point of view.

5.2 RECOMMENDATIONS FOR FUTURE STUDIES

The following are some proposed areas of research for future studies in this field:

- In multi-storeyed high rise buildings, generally high strength concrete is preferred for use. Ceramic waste incorporated concrete has been successfully experimented in giving greater strength than normal concrete. Thus use of ceramic waste in such mixes needs to be studied thoroughly.

- The addition of ceramic waste in place of fine aggregate has proved in giving better resistance to sulphate attacks and showing low rapid chloride penetration, which may result helpful to be used in structures like industries where buildings are susceptible to these types of attacks. Hence improving the durability of structures.
- The addition of ceramic waste in place of fine aggregates on the fire resistance of concrete and corrosion resistance of concrete mixes is still a completely unexplored area.
- These days, bridge construction and highway is the major area of thrust in infrastructural development in India. The roads in India being subjected to high temperatures during the summer days and low temperatures during winters need to be made more resistant for the same to avoid early damages. These temperature variations may affect roads resulting in additional fatigue in the roads. This effect of temperature variations needs to be explored for ceramic waste incorporated mixes.

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