Chapter – 2

LITERATURE REVIEW
# CHAPTER – 2

## CHAPTER – 2: LITERATURE REVIEW

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2. LITERATURE REVIEW

2.1 GENERAL

Concrete is one of the important construction material used in the world in all engineering works including the infrastructure development at all stages. It has been used in construction sector for a long time and proved that, it is a cheap material and its constituents are widely available in nature. Due to wide spread usage and fast infrastructure development in all over the world, there is shortage of natural aggregates. The quality of concrete is determined by its mechanical properties as well as its ability to resist the deterioration. The mechanical properties are classified into two categories; they are short-term properties and long-term properties. Strength, elasticity modulus and bonding characteristics come under short-term (instantaneous) properties. Creep, shrinkage, fatigue and durability come under long-term properties. It’s a great opportunity for the concrete industry that they can save natural aggregate by replacing coarse aggregate with construction demolition waste and other waste materials like ceramic waste aggregates, granite waste aggregate and Cuddapah slab waste aggregate in the production of concrete.

The literature review presents the current state of knowledge and examples of successful uses of alternative materials in concrete technology, particularly the usage of ceramic waste aggregates in concrete composition. Ceramic waste aggregate is used in the concrete composite as coarse aggregate fraction and fine aggregate fraction in
non-structural and structural concrete. Many researchers were interested to study on industrial waste like ceramic and accumulation of such waste causes environmental pollution seriously. Ceramic industrial waste is one of the major sources of waste and accumulated waste at different ceramic industries like tiles, sanitary, insulators, and brick pots. Ceramic waste is generated due to many of its properties like brittle nature and composition.

A review of literature on physical, mechanical and durability properties of ceramic aggregates and mechanical, durability and structural properties of ceramic waste aggregate concrete are presented in this chapter. Aggregate is mixture of various sizes of stone particles with diameter more than 4.75 mm (retained on No 4 Sieve) usually classified as coarse aggregate, while less than 4.75 mm particles are classified into fine aggregate. Aggregates occupy 70-80% of total volume of the concrete. For this reason, aggregate characteristics, such as size, shape, texture, pore sizes and pore structure greatly influence the strength and durability characteristics of concrete.

2.2 CONSTITUENT MATERIALS IN CONCRETE

In recent decades, the usage of concrete has improved enormously and undergone modifications also. However, the basic constituents of conventional concrete are Ordinary Portland Cement (OPC), coarse aggregates, Fine aggregates and water. But in the present, infrastructure developers are intending to improve the quality of concrete without much difference of cost with little usage of chemical admixtures including super plasticizers, water reducing agents and air-
entertainers. The usage of pozzolonic materials into the concrete like fly ash, metakoline, granulated blast–furnace slag and silica fume is increased into the concrete. Apart from the above, there are many changes that have taken place in concrete technology. Relative changes are observed in cement production and different type of cement products introduced in the market like port land pozzolana cement, port land slag cement, high early strength cement and other products for use in different situations according to their requirement. Over the last decade research was focused on development of high-strength and high-performance concrete. The usage of various alternative fine and coarse aggregates in the production of concrete has been investigated including the partial substitution of recycled coarse aggregates, recycled fine aggregates. Stone dusts, robo sand, ceramic fine aggregate are being utilized for replacement of fine aggregate. Ceramic waste aggregates, Shahabad stones, Bethamcherla stone, granite stone etc, can be used for replacing the natural coarse aggregate. Normally, natural river sand is used as a fine aggregate in concrete production and natural potable water used for mixing of concrete.

2.3 PROFILE OF CERAMIC INDUSTRY IN INDIA

The waste generated by construction activity is estimated as 200 million tons in European Union. As per the data given by Spanish National Plan, construction and demolition waste is about 40 million tons. In European Union around 28% of waste is recycled, in Netherland 95% of the construction waste is recycled. In England and Belgium, recycling of waste is at 45% and 87% respectively.
India’s ceramic industry has begun during the British rule, with the demand for commodities, since then ceramic industry has grown to its present size, processing close to approximately 8,00,000 tons of ceramic tiles and 75,000 tons of sanitary sector. The unorganized sector has significant share of 55% in sanitary segment and 20% in ceramic tiles segment, especially this productivity came from Gujarat state. The market break-up of the organized sector is roughly 2,50,000 tons of floor tiles, 4,00,000 tons of wall tiles, and 68,000 tons of sanitary ware- commodes. The present growth rate of 8% is considered as lethargic but is expected to pick up in coming years. North and West India account for the bulk of ceramic sales of 35% each, while in south is fast catching up, though the institutional market still it is a largest segment. Retail markets, accounting for 45% of volumes are becoming instrumental to profit growth in the sector. Consumption for ceramic is primarily an urban occurrence and in rural areas generating only 20% of present demand.

2.4 CERAMIC PRODUCTS AND ITS EFFICIENCY

Ceramics can be defined as heat-resistant, nonmetallic, inorganic solids that are made up of compounds formed from metallic and nonmetallic elements [Mohd Mustafa Al Bkri Abdullah et al. (2006); Correia et al. (2006); and Senthamarai (2005)\textsuperscript{11, 12, 7}]. Although different types of ceramics can have different properties, in general ceramics are corrosion-resistant and hard but brittle nature. Most ceramics are good insulators, it can withstand high temperatures and have a crystalline
structure. These properties have led to their use in virtually every aspect of modern life.

Two main categories according to the usage are traditional and advanced ceramics. Traditional ceramics include objects made of clay and cements that have been hardened by heating at high temperatures. Traditional ceramics are used in dishes, crockery, flowerpots, and roof tiles. Advanced ceramics include carbides, such as silicon carbide, (SiC); oxides, such as aluminum oxide, $\text{Al}_2\text{O}_3$; nitrides, such as silicon nitride, $\text{Si}_3\text{N}_4$ and many other materials, including the mixed oxide ceramics that can act as superconductors. Advanced ceramics require modern processing techniques and the development of these techniques has led to advances in engineering. Ceramics can be excellent insulators, semiconductors, superconductors and magnets. Ceramic spark plug is one of the insulators, whose impact is large on the society. High voltage insulators make it possible to safely carry the electricity in large houses and business malls.

Ceramic waste is generated in two different categories according to the source availability of raw materials. The first one is developed by the structural ceramic factories, in this only red paste is supposed to use in manufacture their products such as bricks and roof tiles. Second one is produced from stoneware ceramics such as wall tiles, floor tiles and sanitary ware. Use of waste ceramic products in concrete composition has reduced the production cost of concrete [Cabral et al. (2009); Pacheco-Torgal et al. (2010); Hanifi Binici (2007)]$.^{13,14,15}$.
2.5 PHYSICAL PROPERTIES AND USES OF CERAMIC MATERIALS

For about centuries, ceramics were used by those who had little knowledge of their pore structure and its application. Today, understanding the crystalline of pore structure and properties of ceramics is making it possible to design a new kind of ceramics. Most of the ceramics are hard, chemically inert and refractory and these properties make ceramics attractive for many applications. Ceramics are used as refractory in furnaces and as durable building materials like bricks, tiles, cinder blocks, and other hard, strong solids. It was found that ceramic waste based concrete shows good workability and strength characteristics with a replacement of 20% ceramic waste for making the green concrete [Sharfuddin Ahmed and Obada Kayali (2010); Belen Gonzalez–Fonteboa (2012)\(^{16,17}\)]. Previous research suggested that more than 20% of replacement with ceramic waste coarse aggregate and fine aggregate shows decreased compressive strength of concrete [Eva Vejmelkova et al.(2012)\(^{18}\)].

They are also used as common electrical and thermal insulators in the manufacture of spark plugs, telephone poles, electronic devices. However, ceramics also tend to be brittle nature, a major difficulty with the use of ceramics is their tendency to acquire tiny cracks that slowly become larger until the material fails apart. To prevent ceramic materials from cracking, they are often applied as coatings on inexpensive materials that are resistant against cracks.
2.6 CHARACTERISTICS OF CERAMIC WASTE AGGREGATES

2.6.1 Classification of aggregates

Aggregates are classified into two groups based on its size, as coarse aggregate and fine aggregate. Size of the particle more than 4.75 mm size is treated as coarse aggregate and less than 4.75 mm size is treated as fine aggregate. A schematic classification of aggregate is projected in Fig. 2.1

![Classification of aggregates](image)

**Fig. 2.1: Classification of aggregates**

2.6.2 Density of aggregates

Aggregates are also classified in to three groups based on the unit weight of aggregate, for light weight of 1200 kg/m³, normal weight 1500 kg/m³ and heavy weight aggregates 2000 kg/m³. The bulk density of an aggregate gives valuable information regarding the shape size and grading of the aggregates. For a given specific gravity, the angular aggregate shows a lower bulk density. If the bulk density is more, filling
the void content with mortar becomes difficult and it is described in IS 2386(PARTIII)-1963. The density of normal concrete is 2200 -2600 kg/m³ and that of light weight concrete is around 2000 kg/m³.

Medina et al. (2012)⁹ studied on reuse of ceramic waste in recycled concrete and density of dry sample of gravel and ceramic waste was 2.63 and 2.39 kg/m³ respectively. Density of recycled concrete was substantially decreased with substitution of ceramic waste in concrete production. The density reduction was shown linearly with the correlation factor of 0.9143.

Nadwa Sadi Hassan (2011)²³ studied the effect of grading and type of coarse aggregates on strength and density of concrete. Dry unit weight of concrete observed with natural sand and natural gravel was 2369 kg/m³ and with natural sand and crushed ceramic waste was 2006 kg/m³. Ceramic aggregate was lighter and less resistance than natural aggregate, these two characteristics influenced the decrease of strength values.

Cabral et al. (2009)²⁵ found that the bulk density of natural, recycled concrete, recycled mortar and recycled brick ceramic was 1.44, 1.54, 1.44 and 1.46 kg/m³ respectively. Weakest results were obtained with replacement of natural coarse aggregate by coarse brick ceramic due to its specific gravity.

Pincha Torkittikul and Arnon Chaipanich (2010)²⁶ investigated the use of ceramic waste as fine aggregate in concrete composition. The density of concrete with 100% ceramic waste aggregate (CWA) was 2.31g/cm³, which was 0.07 g/cm³ lower with respect to controlled
concrete. These results obtained due to low specific gravity and density of CWA.

Medina et al. (2009)\textsuperscript{22} reported on use of ceramic wastes with 4 mm and lower size as fine aggregates in structural concrete and its density was 2.41kg/m\textsuperscript{3}. Compressive and split tensile strength values were increased due to lower fraction of ceramic waste usage into the concrete composition.

Paulo Cachim (2009)\textsuperscript{27} studied on concrete produced with crushed bricks as aggregate in new concrete making. Recycled aggregate was collected from ceramic industrial waste. The results clearly shown that, the density for recycled concrete was lower than the natural concrete, due to lower density of crushed brick aggregates.

Bazaz et al. (2006)\textsuperscript{28} reported on performance of concrete prepared with crushed bricks as coarse aggregate and fine aggregate. Percentage of ceramics in collected waste was 9\%. The dry density of crushed brick and natural aggregate was 950-1050 g/cm\textsuperscript{3} and 1500-1700 g/cm\textsuperscript{3} respectively, which influenced the mechanical properties of concrete.

Marcio et al.(2004)\textsuperscript{29}experimented on compressed stress, water absorption and modulus of elasticity of concrete made with recycled aggregate. Crushed ceramic blocks were used as coarse recycled aggregate in concrete fabrication. Specific density of aggregate was 2630 to 2310 kg/m\textsuperscript{3} for 0 to 100\% replacement. Up to the replacement of 20\%, Compression resistance and modulus of elasticity was equivalent with conventional concrete.
Padmini et al. (2001)\textsuperscript{30} reported on behavior of concrete with low-strength bricks as light weight coarse aggregate. The dry density of concrete specimens were 7-9 % lower than the controlled concrete. The density of hardened concrete decreased due to evaporation water content in brick aggregates.

**2.6.3 Size of the aggregate**

Usually in concrete making, for better grading purpose two different size of coarse aggregates are using. For reinforced concrete structures, according to the IS 456-2000\textsuperscript{(79)}, the maximum size of coarse aggregate used is 20mm. The maximum size of aggregate should not be more than one fourth of minimum thickness of the member. For the same w/c ratio, as size of the aggregate increases there is increase of compressive strength. According to IS383-1970\textsuperscript{(78)}, the particle size of fine aggregate is divided into four zones.

[Medina et al. (2012);, Sanchez et al. (2009);, Mohd Mustafa Al Bakri et al. (2008);, Hanifi Binici (2007); and Mohd Mustafa Al Bkri et al. (2006)\textsuperscript{9,94,32,17,11}] In previous research, they have chosen two different sizes of aggregate fractions (8 to 20mm) in their experimentation work. Concrete made with larger size of aggregate fraction presented higher vacuum and permeability. However the strength of concrete made with ceramic aggregate was low as compared with conventional concrete due to surface texture, water absorption, volume fraction and shape of the ceramic waste aggregate. There was a possible influence on concrete mix for easy to cast and finish with graded aggregates were preferred in their composition.
2.6.4 Shape and Texture of the aggregate

It is difficult to measure the exact shape of the aggregate which is preferred to use in concrete composition. The shape is also influenced by the type of crusher and condition of crusher. Angular shaped aggregate has superior quality than rounded as they exhibit better interlocking and greater surface area. Angular aggregates possessing well defined edges will help to improve the adequate locking, better bonding and prevent excessive deformation under loading. The angularity of aggregate can be estimated from the proportion of voids in sample compacted as prescribed in IS 2386(PART-I)-1963[^75].

Surface texture is the property, which influences the bond strength between the cement paste and aggregate. The surface texture of aggregate may be either polished or dull. This depends upon the hardness, grain size and pore structure of the rock. Visually ceramic waste aggregate has two clear distinguishable parts, one of its external with glaze and internal comprising with composition matrix. Based on the surface characteristics, IS 383-1970[^78] classifies the aggregate as glassy, smooth, granular, crystalline, and porous.

Medina et al. (2012)^9 studied on effective utilization of ceramic waste as recycled coarse aggregate. It was produced by crushing of sanitary ware and its shape curve of recycled ceramic aggregate was similar to the natural coarse aggregate. Irregular shape of aggregate was presented in the ceramic waste, resulted that superior surface area and better bonding was observed in experimentation.
Sekar et al. (2011) reported that surface texture of ceramic tile aggregate was found as smoother than the crushed aggregate, which influenced the strength characteristics by weak interfacial transition zone.

Mohd Mustafa Al Bakri et al. (2008) suggested that surface texture mineralogy affected the bond between ceramic waste aggregate and cement paste. Depreciation of strength was due to increase of stress levels on specimen at which micro cracking begun for failure.

Mashitah et al. (2008) concluded on recycling of homogeneous ceramic tiles used in the preparation of concrete block. The surface of ceramic tile aggregate was found as smooth, angular shaped and sharpen edges as compared with natural coarse aggregate. Flatter particles consumed more quantity of cement paste to generate better interfacial transition zone.

Jafar Bolouri Bazaz et al. (2006) reported that crushed clay brick aggregate had well defined edges and angular shape, which resulted high surface to volume ratio. The surface of the crushed brick was rough and porous, by which higher water absorption and significant reduction of strength observed in test results.

### 2.6.5 Specific gravity of aggregate

Specific gravity of cement and aggregates are useful in calculations of concrete mix design. Specific gravity of natural rocks varies between 2.6 to 2.80. Typical values for granite, sand stone and dense lime stone are 2.69, 2.65 and 2.60. The values of light weight and artificial aggregates are lower than normal and less than 2.50.
Sekar et al. (2011); Santhamarai et al. (2011); Pincha Torkittikul and Arnon Chaipanich (2010); VeeraReddy (2010); Baoshan et al. (2009); Shohei et al. (2009); Hanifi Binici (2007); Bazaz et al. (2006); Mohd Mustafa Al Bkri et al. (2006); and Senthamarai and Devadas Manoharan (2005). From the previous research and reported that, specific gravity of ceramic coarse aggregate varied between 2.2 to 2.56. These values were influenced the density of ceramic aggregate concrete.

### 2.6.6 Water absorption

Water cement ratio influences the workability of concrete, quantity of water for making good workability will depend on water content. Another important aspect for influencing the water absorption is “Porosity” of aggregates. Higher porosity present in aggregate will require higher water content to make good workable concrete. Few aggregates are highly porous and more absorptive based on the pore size and by means of that the water content is retained in aggregate for longer time. Porosity, permeability and absorption of aggregate influence the bond between aggregates and cement paste. Maximum value of water absorption for granite rock and lime stone is 0.5 and 1.0% respectively.

Medina et al. (2012) experimented and concluded that use of ceramic aggregate as recycled coarse aggregate in concrete was benefited and water absorption of ceramic aggregate and natural gravel was 0.55 and 0.23% respectively.
Pacheco-Torgal and Said Jalali (2011)\textsuperscript{16} studied the behavior of strength and durability of ceramic waste based concrete. Water absorption of ceramic coarse aggregate was higher than the natural aggregate. It can be assumed that the extra water content leads to better internal curing than the controlled concrete.

Santhamarai et al. (2011)\textsuperscript{10} conducted experimentation on concrete made with ceramic industry waste and its effect on durability of concrete. Similar behavior observed when concrete made with ceramic insulator waste and conventional concrete. Water absorption and penetration characteristic increased with increase of water cement ratio. This influenced the strength and durability characteristics of ceramic aggregate concrete.

Correia et al. (2011)\textsuperscript{13} reported the water absorption of recycled aggregate was more due to higher porosity of recycled coarse aggregate. Hence, there was a need of additional water quantity to make the good concrete composition.

Antonio Eduardo Bezerra Cabral et al. (2010)\textsuperscript{24} studied the water absorption of different recycled aggregates. Water absorption of natural, recycled concrete, recycled mortar and recycled brick ceramic was 1.22, 5.65, 9.52 and 15.62\% respectively. Higher water absorption was observed in case of recycled ceramic brick and which influenced the reduction of strength due to improper bonding.

Evangelista and de Brito (2010)\textsuperscript{38} reported on durability performance of concrete made with fine recycled concrete aggregates. Replacement with 30\% of recycled aggregate was shown 16.8\% increase
in water absorption and for 100% of replacement, 46% was increased. Thus, water absorption by capillarity was improved due to porous nature of the recycled concrete aggregates.

Shohei et al. (2009)\textsuperscript{37} suggested the effect of porous ceramic waste as an internal curing material on strength properties. The water absorption of ceramic waste was 8.58%. In concrete composition with addition of porous ceramic aggregate as an internal curing agent showed a substantial increase of finer pores.

Paulo Cachim (2009)\textsuperscript{27} studied on usage of recycled ceramic aggregate, collected from ceramic industrial waste. Water absorption of waste from two different sources was 15.81 and 18.91% respectively. The higher water absorption of ceramic aggregates influenced the workability of concrete. It was observed that in first 2 minutes, 75% of total absorption observed and after 5 min at least 91% of total absorption occurred.

Jafar Bolouri Bazaz et al. (2006)\textsuperscript{28} studied the performance of concrete produced with crushed bricks as aggregate. The water absorption of crushed brick and natural aggregate was 25-28% and 1-3% respectively. Water absorption of clay brick was about 12 times more than natural aggregate. Crushed brick had more surface area and highly porous nature due to mineralogical structure of brick, these two characters influenced the reduction of strength and durability.

Mohd Mustafa Al Bkri et al. (2006)\textsuperscript{11} experimented on concrete made with ceramic waste slabs. Different Ceramic wastes were collected from ceramic industries such as flower pots, tiles and sanitary
ware. Water absorption of ceramic waste aggregate and natural aggregate was 1.45 and 1.25% respectively.

Correia et al. (2006)\textsuperscript{12} studied on durability effect of concrete by using recycled ceramic aggregates. The water absorption either by immersion or capillarity increases regularly and significantly with the proportion of ceramic aggregates in the concrete mix. Therefore, eventual aggressive environmental agents, such as deleterious salts may easily penetrate into the concrete. Higher water absorption problem was partially solved with pre saturation of aggregates.

Marcio et al. (2004)\textsuperscript{29} concluded on crushed ceramic blocks that were used as coarse recycled aggregate in concrete. Water absorption of recycled aggregates increased with variance of 0.9 to 10.2% for replacement ranges from 0 to 100%. Damage occurred as micro level of the concrete and increased in the recycled aggregate due to porosity and lower resistance offered for path.

2.6.7 Bonding

Bond between aggregate particles and the cement matrix is a main module for strength aspect. Bonding is greatly influenced by the shape and texture of the aggregate and it directly influences the strength of the concrete. A better bonding is obtained by angular aggregates. Smooth texture characteristic which permits no penetration of surface particles by the paste is not conductive to good bond. Hence, softer porous and mineralogical heterogeneous will shows better results of bonding.
Santhamarai et al. (2011)\textsuperscript{10} suggested based on the experimental results that, Porosity of the ITZ (Interfacial transition zone) was increased in the ceramic waste aggregate. This was responsible for poor bonding between the aggregate and surrounding cement paste.

Belen Gonzalez Fonteboa et al. (2011)\textsuperscript{39} experimented and concluded on effect of recycled coarse aggregate on damage of recycled concrete. Mechanical properties of recycled aggregate concrete were reduced and development of cracks in interfacial transition zone was observed due to old cement paste and higher water cement ratio.

**2.6.8 Strength of Aggregate**

Strength of the material is defined as an ability to resist the stress against failure of the member. Strength of the concrete depends on the strength of the constituents, cement paste and also influenced by the bonding. Irrespective of the strength of the rock, if bonding and strength of the cement paste are poor, the strength of concrete is also poor. Strong concrete can't be prepared unless the usage of strong aggregates.

Sekar et al. (2011)\textsuperscript{33} reported on properties of ceramic aggregate, its crushing value, impact value and abrasion value were 27, 17 and 23\% respectively. These values were higher than natural stone aggregate values, thus strength of the ceramic waste aggregate concrete was influenced by strength of the ceramic aggregate.

VeeraReddy(2010)\textsuperscript{35} reported on impact value and crushing value of ceramic scrap as 18.2 and 24.7\% respectively. These values were
within the permissible limits according to IS 383-1970, hence it was safe to use as a coarse aggregate in concrete composition.

Senthamarai et al. (2005) concluded that ceramic waste can be effectively used as aggregates in concrete making, based on the strength of ceramic waste aggregate. The crushing value, impact value, abrasion values for ceramic scrap were 27, 21 and 28% correspondingly and for natural coarse aggregate 24, 17 and 20% respectively. Ceramic scrap does not have much variation with respect to the natural aggregates.

**2.6.9 Gradation of coarse aggregate**

Particle size and gradation of the aggregate have a significant effect on the behavior of a concrete mix, affecting its economy, workability and strength. The usage of larger sized coarse aggregates decreases the amount of cement paste required to suitable bonding between the particles. Conversely, the use of finer particles entails the use of more cement in order to maintain constant aggregate/cement ratio, which is at the same time decreases the workability of the concrete, even as it improves its finish.

Medina et al. (2012) reported that, for better grading two different sizes of aggregates were selected in experimentation work as 4 and 12.5 mm. It was observed that recycled aggregates had good grading curve with respect to natural aggregate.

Belen Gonzalez Fonteboa et al. (2012) reported on recycled aggregate of size 4-16 mm used in the concrete composition and
represented similar grading of curves for recycled aggregates and natural aggregates.

2.6.10 Abrasion

Abrasion value of coarse aggregate is determined by Los Angeles abrasion testing machine or Deval Abrasion testing machine, based on the IS 2386(PART IV) of 1963. The abrasive resistance of concrete is borne by the coarse aggregate, which protects the mortar against mechanical wear. Abrasion resistance is considered when the effect of binder addition is less critical than the strength of concrete.

Correia et al. (2011) investigated that the Los Angeles Abrasion coefficient of recycled concrete coarse aggregate (RCCA) was 41.5% and it was about 52% higher than natural coarse aggregate. The reason for lower resistance was due to adhered cement paste to the RCCA.

Turgut and Yahlizade (2009) studied on manufacture of concrete blocks with waste glass. Abrasion resistance was enhanced 15% with replacing of fine aggregate by 20% of fine glass (FG) but there was no significant effect on strength properties, when replaced with coarse glass (CG).

Jafar Bolouri Bazaz et al. (2006) studied on abrasion resistance offered by crushed brick as coarse aggregate and fine aggregate. Abrasion resistance for crushed brick and crushed concrete/cement mortar was 49.6 and 46.5% respectively.

Correia et al. (2006) concluded that the abrasion resistance of ceramic aggregates concrete showed even better than the reference concrete in their experimentation work.
2.6.11 Porosity of aggregates

Porosity of the aggregates is one of the main factors which influence the properties of both fresh and hardened concrete. The measure of voids exist in a solid particle is called porosity. It is expressed in percentage of total volume from 0-100%. Higher porosity of aggregates leads to lower strength and durability of concrete.

Medina et al. (2009) concluded that the total porosity of ceramic waste aggregate and natural aggregate was 0.32 and 0.23% respectively. A little higher porosity of ceramic waste was observed and it affected the strength of concrete but all properties of ceramic aggregate were well within the range of aggregates.

Fouad M. Khalaf and Alan DeVenny (2005) suggested on properties of new and recycled clay brick aggregates in concrete making. Out of seven only two recycled aggregates had higher porosity values than the crushed brick and granite aggregate. Due to the higher porosity of brick aggregates lower compressive strength values were observed.

2.7 PROPERTIES OF CERAMIC WASTE AGGREGATE CONCRETE

2.7.1 Mechanical properties of ceramic waste aggregate concrete

2.7.1.1 Workability

Workability of concrete is combined form of work, which consists of mixing, transportation, placing and enough compaction. Workability of concrete will be influence over different properties like shape, size, water absorption, roughness of aggregate, water cement ratios, aggregate binding ratio, grading of aggregate, porosity, and mix
proportion of concrete. Behavior of fresh concrete is measured by performing slump cone, compaction factor, vee-bee, flow table and Kelly ball tests. Slump test is used widely and universally, because the performance of test is simple, quick and cheap. Compaction factor test is also beneficial when the concrete sample is used in the pavements. Hence, both tests are preferred in field to resolve workability of concrete.

Medina et al. (2012)\textsuperscript{9} studied the workability of ceramic aggregate concrete according to EN 12350-2 and concluded that, soft consistency (6-9 cm) was observed due to the incorporation of ceramic recycled aggregates. An interesting point observed in reduction of slump was 5.3\% at 25\% replacement of aggregate. Linear reduction of workability has been observed by a coefficient of 0.9878, this was witnessed during the experimentation due to higher water absorption, shape, texture and porosity of recycled ceramic aggregate.

Parekh and Modhera (2012)\textsuperscript{43} reported on workability for recycled aggregates and slump test was reported based on IS 1199-1959(25). One of the most important point observed that, when recycled aggregates were used in larger percentage, more than 50\%, the concrete mix was less cohesive than those of natural aggregate concrete. The lack of cohesiveness of the concrete affected the mechanical and durability properties of hardened concrete.

Pincha Torkittikul and Arnon Chaipanich (2010)\textsuperscript{26} investigated on utilization of ceramic waste as fine aggregate within Portland cement and fly ash concrete composition. The particle size distribution of
ceramic waste was kept same that of sand. Workability of concrete was investigated according to the ASTM C 143 and clearly indicated the slump of concrete reduced with increase of ceramic waste aggregate. 110 mm and 5 mm slump values were observed with substitution of 50% and 100% of ceramic waste. In the analysis of test results, reason for decreased values was due to rough and angular nature of crushed ceramic aggregate.

Paulo Cachim (2009) examined the effect of recycled ceramic brick used in the concrete composition and it was procured from ceramic industrial waste. Size of the ceramic waste in concrete composition was varied from 2-16 mm and slump test conducted according to the NP EN 12350-2:2002. The average slump was 5 cm and 15 cm for W/C of 0.45 and 0.50.

Mohd Mustafa Al Bakri et al. (2008) studied on potentiality of recycled ceramic waste as coarse aggregate in concrete work. Size of the ceramic aggregate chosen for workability of concrete was 14-20 mm. Fresh ceramic waste coarse aggregate concrete was more workable than the conventional concrete. This was due to water absorption and smooth surface texture of ceramic waste coarse aggregate. The slump values ranged from 30-45 mm for ceramic aggregate concrete.

Senthamarai and Devadas Manoharan (2005) studied on ceramic waste aggregate concrete by replacing coarse aggregate by waste ceramics. Ceramic electrical insulators waste was used as a coarse aggregate in concrete mix. Fresh ceramic waste coarse aggregate concrete was more cohesive and workable than conventional concrete.
Water absorption and smooth surface texture of the ceramic aggregate influenced the workability characteristics. Slump test was conducted according to the IS 7320-1974, as the water cement ratio increases from 0.35 to 0.60, consequently slump was increased from 13 mm to 155 mm for ceramic aggregate concrete.

Ilker Bekir Topcu and Selim Sengel (2004) reported on properties of concretes produced with waste concrete aggregate (WCA). Slump test was performed according to the ASTM C 143-90. Based on the results, the workability of concrete decreased in parallel to an increase of 100% replacement by WCA, 15-20% of workability was decreased in above conditions. The reason for water absorption ratio of mortars over waste concrete aggregate was more.

2.7.1.2 Compressive and Split tensile strength

Testing of hardened concrete confirms the quality of concrete and workmanship. Test method should be simple, direct and convenient to perform. Compression test can be performed on cubes and cylinders to predict the compressive strength of concrete. It is to be known that a standard compression test specimen specifies the potential strength of concrete but not the strength of the concrete structure. For 20 mm maximum size of aggregate, the suggested cube specimen size is 150x150x150 mm and compressive strength is determined by ultimate load per unit area. Typical failure of specimens is represented in Fig.2.2.
Fig. 2.2: Typical compression failure of cube and cylindrical specimens

The size of the cylindrical specimen chosen for determining split tensile strength is 150x300 mm. Before testing of cylindrical specimen, it will be suitably capped. Usually cylindrical compressive strength is 75 to 85 % of cube strength. However it can be said that the cylinder is less affected by the end of restrains caused platens and hence it seems to give more uniform results than the cube specimen. So, the usage of cylindrical specimens in the research field to predict the compressive strength is more popularized. Tensile strength normally classified into two, they are direct and indirect methods. There is a little influence of aggregate on direct and indirect strength of concrete. Since it is difficult to apply uniaxial tension to a concrete specimen, hence, tensile strength is determined by indirect methods.

Split tensile method is well-known indirect method to determine tensile strength of concrete. The test consists of applying compressive line loads along the opposite generators of a concrete cylinder placed with its axis horizontal between the platens. Due to the applied line
loading a fairly uniform tensile stress is induced over nearly two-third of the loaded diameter as obtained from the elastic analysis. The magnitude of tensile stress (acting perpendicular to the line of action of applied compression) is $2P/\Pi DL$ (See Fig. 2.3).

Benito Mas et al. (2012)$^{45}$ studied on strength of mixed recycled aggregate, in which it had ceramic products as major component. A 15-18% decrease of compressive strength and split tensile strength was reported with replacement of 20 to 25%. The loss of strength was less for 90 days as compared with 7 and 28 days, when aggregate replaced with mixed fraction. Results were justified because of more porous structure of recycled ceramic aggregate.

Chandana Sukesh et al. (2012)$^{46}$ concluded according to the NP EN 12390-3; the usage of ceramic waste will solve several environmental problems and reported a minor strength loss due to pozzolanic reactivity in concrete.

![Fig.2.3: Typical cylindrical specimen for testing with proper packing](image)
Eva Vejmelkova et al. (2012)\textsuperscript{21} studied on application of waste ceramics as active pozzolana in concrete. The replacement of Portland cement by fine ceramic up to 20\%, compressive strength and bending strength was reduced by 10 and 3\% respectively. This was still acceptable for concrete regarding the strength aspects.

Sekar et al. (2011)\textsuperscript{33} studied compressive strength characteristics of ceramic aggregate concrete with ceramic insulator scrap. It was 16\% lower compressive strength and 11\% lower split tensile strength than the conventional concrete for 28 days. The reason of decreased mode was due to smooth surface texture of ceramic aggregates and poor bonding properties of the matrix with aggregates.

Siddesha (2011)\textsuperscript{8} studied on compressive strength and split tensile strength of concrete replaced with fine ceramic aggregates and the results obtained as a slight decrease of compressive strength and split tensile strength.

Nadwa Sadi Hassan (2011)\textsuperscript{23} concluded that Concrete mixes prepared with natural sand and uncrushed river gravel had max compressive strength as compared with other four groups of natural sand and crushed lime stone, crushed ceramic and crushed glass waste. The values were 32.17MPa, 28.43MPa, 21.1MPa and 13.3MPa. The main reason for decrease of compressive strength of ceramic waste aggregate concrete was higher water absorption, lighter and less resistance of ceramic aggregate respectively.

Fonteboa et al. (2011)\textsuperscript{39} studied on effect of recycled coarse aggregate on compressive strength of concrete and it was determined
by UNE-EN 12390-3:2009. Substitution of recycled aggregate by 20 and 50%, shown any difference but slight decrease of strength 5.6%, with replacement of 100% for w/c ratio of 0.65. Compressive strength declined to 2.4, 16.4 and 9.5% when replacement was 20, 50 and 100% for water cement ratio of 0.50. Similar decreased trend has been observed in Split tensile strength of recycled concrete also.

Niyazi Ugur Kockal and Turan Ozturan (2011)\textsuperscript{47} reported on durability of light weight concretes with fly ash aggregates. Based on the results, compressive strength, split tensile strength and modulus of elasticity of light weight aggregate concrete had lower than the conventional concrete due to higher permeable pore volume, water absorption and lower strength of light weight aggregate.

Antonio Eduardo Bezerra Cabral et al. (2010)\textsuperscript{24} experimented and concluded on four different aggregates, among these weakest results were obtained with brick ceramic as coarse aggregate. Compressive strength was reduced to 38% by replacement of 100% according to the Brazilian standards NRB 5739/07. Reduction behavior of compressive strength was due to angular shape of aggregate, which produced large amount of voids in the concrete section.

Pincha Torkittikul and Chaipanich (2010)\textsuperscript{26} investigated on utilization of ceramic waste as fine aggregate in concrete production. Compressive strength of concrete was increased to optimum value of 40MPa with 50% replacement, there after slowly declined to 38.5MPa with 100% replacement. A drop of strength due to angular shape of ceramic waste aggregate and it reduced the workability of concrete.
Thus the concrete was much more difficult to compact, there by lower compressive strength values were observed.

Veerareddy (2010) reported on replacement of ceramic scrap as coarse aggregate and replacing natural sand by stone dust in concrete composition. Compressive strength was arrived based on IS 516-1959. Compressive strength of conventional concrete was 33.93MPa and by replacing ingredients in different percentages, compressive strength of concrete declined gradually from 34.52MPa to 32.59MPa. Similar results were observed in split tensile strength also, in case of conventional; it was 3.25MPa and gradually reduced to 2.83MPa with respect to replacement percentages. 10 to 20% Replacement of coarse aggregate with ceramic scrap was the best option in concrete composition without affecting the strength values.

Farid Debieb et al. (2010) studied on mechanical and durability properties of concrete using contaminated recycled aggregates. Strength of recycled concrete was lower than natural concrete, as for compression strength it was 40% less, for split tensile strength 19% less and for elasticity modulus 38% less as compared with reference concrete due to greater capacity of water absorption and porosity of recycled aggregates.

Cabral et al. (2009) reported the performance of red ceramic recycled aggregate concrete. It was observed that recycled aggregate used as coarse aggregate in concrete composition had a negative effect and the recycled coarse aggregate exercised a large influence than fine aggregate in strength aspect.
Paulo Cachim (2009) experimented with crushed brick as aggregate in concrete production and waste was collected from ceramic industrial dump. Natural aggregate was replaced by crushed ceramic bricks up to 15%, no reduction of strength, there after decrease of compressive strength observed and test was performed according to the NP EN 12390-3:2003. Similar strength values were observed in split tensile strength also. Reduction of strength was due to porosity and strength of the brick ceramic. Based on the results, application of brick aggregate concrete was recommended in low demanding structural applications.

Mohd Mustafa Al Bakri et al. (2008) reported on the potentiality of recycled ceramic waste as coarse aggregate in concrete composition and its 7 days compressive strength values of ceramic aggregate concrete was ranges from 4 to 19MPa.

Mashitah et al.(2008) investigated on recycling of homogeneous ceramic tiles for the production of concrete block. The strength of the concrete block determined as per IS 516-1959, it was lower as compared with control concrete and it lies within a range of 41.1–48.8MPa. Strength of concrete decreased with higher substitution and less interaction among the aggregates.

Ivana Kesegic et al. (2008) reported an overview of results on concrete made with recycled clay brick as an aggregate. The loss of compressive strength as compared with natural concrete for recycled crushed brick aggregate and crushed tile was 23.8 and 32.7%
respectively. This can be attributed due to the higher water absorption of recycled clay brick.

Etxeberria et al. (2007) deliberated on influence of the amount of recycled coarse aggregate and production process on properties of recycled aggregate concrete. Crushed concrete was used as a recycled coarse aggregate and substituted four different proportions in concrete. Due to better water absorption capacity of recycled aggregate (crushed concrete), it must be saturated before use. Concrete made with 100% recycled coarse aggregate shows 20-25% lower compressive strength than conventional concrete with the same effective w/c ratio and same quantity of cement.

Hanifi Binici (2007) reported on effect of crushed ceramic (CC) and crushed basaltic pumice (CBP) as fine aggregates on concrete mortars. Replacement of fine aggregate by crushed ceramic and CBP at 40, 50 and 60% in concrete composition had higher compressive strength than control specimens because of additive type of ceramic. It can be observed that, there was an increase in strength with increase of CC and CBP percentages and obtained maximum value at replacement of 60%.

Mohd Mustafa Al Bkri et al. (2006) experimented on ceramic waste concrete slabs. Ceramic waste was collected from industries such as flower pots, tiles and sanitary ware. Compressive strength of ceramic concrete waste slab varied from 15 to 30MPa, which was Poorer than the conventional one.
Correia et al. (2006)\textsuperscript{12} studied concrete strength and durability effect by usage of recycled ceramic aggregates. The rate of increase of replacement percentage in concrete composition, compressive strength decreased, it varied from 23.3MPa to 13.0MPa. Similar trends observed in split tensile strength also as it varied from 3.5MPa to 2.60MPa.

Mohd Mustafa Al Bakri et al. (2005)\textsuperscript{95} studied on concrete made with ceramic waste and quarry dust aggregate. Experimentation focused on strength of concrete with ceramic waste as coarse aggregate and quarry dust as fine aggregate. The compressive strength of ceramic waste aggregate concrete rages from 15-30MPa and these values were lower than conventional concrete.

Senthamarai and Devadas Manoharan (2005)\textsuperscript{7} studied on ceramic electrical insulators waste as a coarse aggregate in concrete. The compressive strength varies from 51 to 30MPa and split tensile strength was 4.5 to 3.2MPa with varied water cement ratios. This strength was about 3.8% and 18.2% lower than the conventional concrete.

Seung Burm Park et al. (2004)\textsuperscript{51} reported on studies on mechanical properties of concrete containing waste glass aggregate. Compressive strength decreased as compared with plain cement concrete as 99.4, 90.2 and 86.4% respectively. The declination of compressive strength was due to adhesiveness between surface of the glass aggregates and the cement paste. Emerald glass was replaced as a fine aggregate in concrete composition of 30\%, resulted a tensile
strength loss of 96.6%. When replacement was 50 and 70%, tensile strength loss was 90.8 and 85.0% respectively.

Marcio et al. (2004)\textsuperscript{29} studied the effect of compressed stress, water absorption and modulus of elasticity on concrete made with recycled aggregate. Crushed ceramic block was used as coarse recycled coarse aggregate. The compression resistance and modulus of elasticity are equal with natural coarse aggregate by replacing recycled aggregate of 10 and 20% but results are far less when replacement was 40%. Reason for decreased mode was due to compression resistance, water absorption and specific gravity of ceramic waste aggregate.

Nuran Ay and Mevlut Unal (2000)\textsuperscript{96} experimented on usage of waste ceramic tile in cement production. Reduction in compressive strength was 38.4MPa to 32.2Mpa, when replacement was 25 to 40% respectively.

\textbf{2.7.1.3 Young's Modulus}

Modulus of elasticity is determined with cylindrical specimen under uniaxial compression and measuring the deformations with dial gauge fixed at gauge length of 20 cm. To get the original deformation, observed dial gauge readings are divided by two. Observations are recorded to establish relation between stress vs strain. The modulus of elasticity of concrete is determined in arbitrary manner of peculiar and complex behavior of stress-strain relationship. The elasticity modulus of concrete is designated in various ways and these can be illustrated on the stress-strain curve, they are initial tangent modulus, tangent modulus and secant modulus. In case of concrete, since no part of the
graph is straight, the modulus of elasticity is found out with reference to the tangent drawn to the curve from the origin, this is referred as initial tangent modulus. It will give satisfactory results only at low stress values. For higher stress values it does not specified the ideal values, it may mislead the picture. Normally experimental results are picked up for determining the initial tangent modulus or secant modulus of concrete.

Belen Gonzalez Fonteboa et al. (2012)\textsuperscript{20} experimented with recycled aggregate as one of the composition in concrete making. Based on the experimental results, it was detected that considerable decrease of young’s modulus observed as 18.0 and 29.2% respectively, with replace of 100% recycled aggregate at water cement ratio of 0.65 and 0.50. The reason for decrease of Young’s modulus was due to adhered mortar and impurities within the concrete section.

Correia et al. (2011)\textsuperscript{13} investigated on concrete made with recycled coarse aggregate and performed the experimentation according to the LNEC E-397. A drop of 35.1% observed in the modulus of elasticity, for 100% replacement with recycled coarse aggregate at thermal exposure of 800°C. The declination was due to consistent ambient temperature for which highest reduction occurred. Elasticity modulus was affected by high temperatures and this can be associated with high level of cracking observed in the concrete specimen.

Fonteboa et al.(2011)\textsuperscript{39} studied on effect of recycled coarse aggregate on damage of recycled aggregate concrete. The value of longitudinal and transverse modulus of elasticity was decreased with
improve of percentage replacement. For water cement ratio H-0.65, modulus of elasticity was decreased by 4.7, 10.9 and 18.5% respectively. For H-0.50, values were 3.8, 14.9 and 29.2% respectively. Decreased tend witnessed due to presence of mortar adhered to the recycled aggregate.

Bezerra Cabral et al. (2010)\textsuperscript{24} studied with different groups of aggregates, among those deprived result was obtained with red ceramic (brick ceramic) aggregate as coarse aggregate in concrete. Coarse recycled brick resulted 44\% of reduction in elastic modulai with replacement of 100\%. Author pointed out on elasticity of concrete was reduced mainly due to the properties of recycled coarse aggregates and subjective on all mechanical properties. Such behavior can be explained that ceramic brick contain high water absorption and more porous nature.

Paulo Cachim (2009)\textsuperscript{27} studied on behavior of concrete prepared with ceramic brick aggregate and witnessed poor modulus of elasticity of concrete. Ceramic brick aggregate concrete had lower modulus of elasticity than conventional concrete and this was due to the higher water absorption of ceramic aggregate. Concrete made with ceramic brick aggregate was used into the low demanding structural applications.

Debieb and Kenai (2010)\textsuperscript{48} concluded the reuse of crushed ceramic brick as coarse aggregate in new concrete production. Modulus of elasticity of crushed brick concrete was 30-40\% lower than the natural concrete.
Senthamarai and Devadas Manoharan (2005) studied on effective recycling of ceramic waste aggregate into concrete work. Ceramic electrical insulator waste was used as a coarse aggregate in concrete making. Modulus of elasticity of ceramic concrete was 22.2 to 16.1 GPa for different water cement ratios from 0.60 to 0.35 and it was 13.6 to 2.4% lower than the conventional concrete. Ceramic aggregate influenced the mechanical properties of ceramic aggregate concrete.

Jianzhuang Xiao et al. (2005) reported on mechanical properties of concrete primed with recycled aggregates and tested under uniaxial loading system. The elastic modulus of recycled aggregate concrete was 45% lower with replacement of natural aggregate by 100% recycled aggregates. The main reason for reduction was due to different elastic modulus of recycled aggregates and stress–strain curve of recycled aggregate concrete was same as with the natural aggregate concrete.

Marcio et al. (2004) reported on coarse recycled aggregates originated from concrete waste and ceramic blocks as coarse aggregate in concrete production. As the percentage replacement was increased, modulus of elasticity was decreased from 40 GPa to 33 GPa.

2.7.1.4 Flexural strength

Influence of coarse aggregate on flexural strength of concrete is higher due to usage of extra angular crushed aggregate than the rounded aggregate. The reason for this is effective bonding between the cement paste and crushed aggregates. The values of the modulus of rupture (Extreme fiber stress in bending) depend on dimensions of the
beam and approach for application of loading. According to IS 516-1959, the standard size of the specimen 150x150x700 mm over a centre to centre support of 600 mm is used to perform the modulus of rupture of the concrete section. Typical test performance has been shown in the Fig.2.4.

Eva Vejmelkova et al. (2012)\textsuperscript{21} studied the recycling of waste ceramics as active pozzolana in concrete production. The replacement of Portland cement by fine ceramic up to 20%, the bending strength was reduced by 3%. When replacement exceeded to 20%, more effect on compressive strength than bending was observed.

Sekar et al. (2011)\textsuperscript{33} studied on strength characteristics of ceramic waste aggregate. Decreased trend was witnessed in flexural strength of concrete made with ceramic aggregate concrete. Flexural strength of ceramic scrap concrete and conventional concrete was 16.9MPa and 17.133MPa respectively.

Fig. 2.4: Third point loading plat form
Siddesha (2011)\textsuperscript{8} reported that the flexural strength of concrete with replacement by fine ceramic aggregate in composition, represented slight decrease with increase of fine ceramic fraction.

Veera Reddy (2010)\textsuperscript{35} concluded that the effect of coarse aggregate replacement with ceramic scrap and stone dust as fine aggregate in concrete composition. The modulus of rupture for conventional concrete and ceramic aggregate concrete was 4.98MPa and 4.40MPa respectively. Mode of declination of 12\% was due to smooth texture of ceramic aggregate and improper bonding between the cement paste and aggregates.

Ivana Kesegic et al. (2008)\textsuperscript{49} stated that the research was carried out on recycled clay brick as coarse aggregate. Pre saturated crushed brick and crushed tiles were used in the experimentation work and flexural strength of concrete made with crushed brick micro-concrete and crushed tiles micro concrete was 6.63MPa and 6.01MPa respectively, these were lower than natural concrete as 10.1MPa. Flexural strength of concrete was decreased about 34\% due to the original strength of the brick.

Senthamarai and Devadas Manoharan (2005)\textsuperscript{7} concluded on ceramic waste aggregate was used as ingredient in new concrete composition. Flexural strength of ceramic concrete was 6.9MPa to 4.70MPa for varied water cement ratios from 0.5 to 0.60\%. This strength was about 6\% lower than conventional concrete composition.

Seung et al. (2004)\textsuperscript{51} reported on mechanical properties of concrete containing waste glass aggregate in new type of composition.
The test method was performed according to KS F 2408 and flexural strength loss was 96.8, 88.7 and 81.9% with replacement of 30, 50 and 70% of waste glass aggregate.

Ilker Bekir Topcu and Selim (2004)\textsuperscript{44} studied on properties of concrete produced with waste concrete aggregate. Flexural strength of concrete decreased from 2.65 to 2.30MPa, with respect to increase of substitution of waste concrete aggregate from 0 to 100%.

Nuran and Unal (2000)\textsuperscript{96} experimented on reuse of waste ceramic tile in cement production. Bending strength of mortar was reduced with replacement of cement by waste tile. Reduction was 7.1MPa to 6.2MPa with replacement of 25 to 40% respectively.

2.7.1.5 Shear strength

Different methods are used to determine the shear strength of concrete section. It is the resistance of one layer with respect to other during slip at common surface of contact. There is a question that, two planes failing simultaneously in double shear doesn’t happen in reality and however shear strength is calculated in this manner. There exists no standard reliable and simplified method for shear strength of concrete specimens using compressive testing machine. Shear failure will be occurred due to brittle nature in concrete structures. Following examples in concrete structural failure related to shear loading are bridge deck punching shear, corbel failure, anchor bolt pull out and segmental bridge shear key failure. Fig 2.5 is representing the shape, size and position of the reinforcement in shear mould.
Fig. 2.5: Shear mould with reinforcement

Ghorpade G. Vaishali and Sudarsana Rao (2012) reported on strength and permeability characteristics of fiber reinforced high performance concrete with recycled aggregate. Based on the experimentation, shear strength of all steel fiber reinforced high performance concrete mixes was superior than glass fiber reinforced high performance concrete and Polypropylene fiber reinforced high performance concrete. Maximum value of shear strength was arrived at 1% of fiber volume for all three types of fibers used.

Belen González Fonteboa et al. (2007) experimented on shear strength of recycled concrete beams. Recycled aggregate was collected from real demolition debris and used in concrete mix with fraction of 4 to 12 mm. Based on the results, the behavior of each specimen without shear reinforcement exhibited an initial flexural crack at the centre and subsequent flexural cracks away from that section. When the applied
load was increased, one of the flexural cracks extended into diagonal crack near one of the support. After formation of the diagonal crack, brittle failure occurred. Specimens with shear reinforcement proved the same crack pattern as the same without shear reinforcement until the formation of diagonal cracks. Little difference was observed in the structural behavior of the concrete beams in terms of both deflections and ultimate load, difference was only in the analysis of cracking.

2.7.2 DURABILITY CHARACTERISTICS OF CERAMIC WASTE AGGREGATE CONCRETE

Durability is one of the important properties of concrete because it has ability to resist against chemical and withstand against weathering actions and abrasion. Among all other materials used in the building structures, concrete is the best part of a durable material. A durable material helps the environment by conserving resources and improving the quality of structure. Different concretes require diverse degree of durability depending on the exposure condition and properties desired. About 40% of structures require maintenance within 10 years of life span because of corrosion to the reinforcement, improper maintenance of structure, improper quality aggregates and poor concreting practices in construction. The durability of concrete influence by permeability due to ingresses water into concrete section, carbonation, sulfates, chlorides, acids and other deleterious substances. Durable waste material can facilitate the environment by conserving resources to the future generation, reducing the quantity of waste and environmental impact of repair and replacement. According
to Alexander et al. (1999) ranges of index values for concrete durability is tabulated in Table 2.1.

<table>
<thead>
<tr>
<th>Durability Class</th>
<th>Oxygen Permeability Index (OPI) (log scale)</th>
<th>Sorptivity (mm/sqrt (h))</th>
<th>Chloride conductivity (s/cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Excellent</td>
<td>&gt;10.0</td>
<td>&lt;6.0</td>
<td>&lt;0.75</td>
</tr>
<tr>
<td>Good</td>
<td>9.5 – 10.0</td>
<td>6.0 - 10.0</td>
<td>0.75 - 1.50</td>
</tr>
<tr>
<td>Poor</td>
<td>9.0 – 9.5</td>
<td>10.0 – 15.0</td>
<td>1.50 – 2.50</td>
</tr>
<tr>
<td>Very poor</td>
<td>&lt;9.5</td>
<td>&gt;15.0</td>
<td>&gt;2.50</td>
</tr>
</tbody>
</table>

2.7.2.1 Chloride permeability

The most common cause of corrosion to the reinforcement is due to the high chloride concentration. As per the IS456-2000, chloride resistance depends on concrete permeability and thickness of cover provided to the reinforcement. The chloride resistance of the concrete section depends on porosity of concrete in terms of pore size, pore distribution and inter connectivity of the pore system. If concentration of chloride ions exceeds the amount, which may possibly react with some components of hydrated cement paste and remaining free chloride ions shall lead to initiate the corrosion process. The amount of chlorides permitted in concrete is limited to acid soluble chloride contents of 0.40 and 0.8 kg/m³ for pre-stressed and reinforced concrete works. Permeability of chloride according to the ASTM C-1202 is tabulated in Table 2.2.

Ghorpade.G. Vaishali and Sudarsana Rao (2012)\textsuperscript{53} concluded on Strength and permeability characteristics of fiber reinforced high performance concrete with recycled aggregate. Chloride ion
permeability was increased for recycled coarse aggregate and recycled fine aggregate with added glass fibers in to the concrete composition due to higher water absorption of recycled aggregate.

**Table 2.2: Permeability as per ASTM C-1202**

<table>
<thead>
<tr>
<th>Charge (coulombs)</th>
<th>Permeability</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt;4000</td>
<td>High</td>
</tr>
<tr>
<td>2000-4000</td>
<td>Moderate</td>
</tr>
<tr>
<td>1000-2000</td>
<td>Low</td>
</tr>
<tr>
<td>1000-100</td>
<td>Very Low</td>
</tr>
<tr>
<td>&lt;100</td>
<td>Negligible</td>
</tr>
</tbody>
</table>

Fernando Pacheco Torgal and Said jalali (2010)\textsuperscript{16} concluded on the behavior of concrete produced with ceramic powder and ceramic aggregate as fine and coarse aggregates in concrete composition. Chloride ion diffusion in concrete with coarse ceramic aggregate has been observed good promising results.

Senthamarai et al. (2011)\textsuperscript{10} reported effect of ceramic waste aggregate concrete on durability property and conducted on chloride ion permeability of ceramic aggregate concrete. Average charge passed through two cells of ceramic waste aggregate concrete and conventional concrete was 4908 and 2650 coulombs respectively for water cement ratio of 0.50. Penetration characteristics increased with increase of water cement ratio due to water absorption and pore structure of the ceramic aggregate.

Jongsung sim and Cheolwoo Park (2011)\textsuperscript{54} studied on resistance against chloride ion penetration of recycled aggregate concrete with
varying amount of fly ash and fine recycled aggregate. The recycled fine aggregate concrete for the structural member had sufficient resistance to the chloride permeability. Resistance can be controlled better by adding fly ash content. The reason for this was addition of supplementary cementitious materials like fly ash.

Mukesh Limbachiya et al. (2011)55 studied on use of recycled concrete aggregate in fly-ash concrete composition and with addition of recycled coarse aggregate in the concrete composition either fully or partially. Inclusion of fly ash in recycled coarse aggregate concrete was observed slightly improve the resistance against the chloride permeability.

Martin et al. (2011)56 studied the characterization of recycled aggregate from construction and demolition waste for concrete making. Several recycled aggregates have chloride content below 0.05% but certain ceramic material had high values of chlorides and sulfates. Few authors suggested that, chloride content of recycled aggregates can be reduced by immersing it into water before use.

Evangelista and de Brito (2010)38 reported on durability of concrete made with fine recycled concrete aggregates. In the performance of chloride permeability, it increases to 12% when replacement was 30% and it enhanced to 33.8%, when replacement was 100%, the reason for improvement chloride permeability due to higher porosity of recycled aggregate than natural aggregates.

Hanifi Binici (2007)17 reported the effect of crushed ceramic and basaltic pumice as aggregates on properties of mortars. The chloride
penetration depth for crushed ceramic at 60% resulted less than the controlled concrete specimens. Based on the test results, when the replacement of crushed ceramic increased, subsequently chloride permeability was decreased due to the size of the crushed ceramic used in the concrete composition was 4-16mm.

Nobuaki Otsuki et al. (2003)\textsuperscript{57} studied on influence of recycled aggregate on interfacial transition zone and strength. For the same water binder ratio, chloride penetration and carbonation depths of recycled aggregate concrete were slightly more than the normal aggregate concrete. This was due to aged interfacial transition zone and adhesive mortar to the recycled aggregate which promotes the permeability.

Wee et al. (1999)\textsuperscript{58} studied on influence of aggregate fraction in the mix on the reliability of the rapid chloride permeability. For a given pre curing period, an increase in W/B ratio promoted the amount of charge passed through the plain cement concrete and mortar specimens. The depth of chloride penetration increased with increasing period of immersion in salt solution. Plain cement mortar specimens were high resistance against the chloride penetration than the plain cement concrete specimens.

\textbf{2.7.2.2 Acid attack}

Most of the acid solutions are disintegrate the concrete depending upon the type and concentration of acid. No Portland cement is resistant against the attack by acids. In damp condition, sulfur dioxide (SO\textsubscript{2}) and carbon dioxide (CO\textsubscript{2}) as well as other fumes
present in the atmosphere to form acids. This attack the concrete by dissolving and removing a part of the hydrated cement paste and leaves a soft and weak mass. This form of attack is encountered in industrial structures. In general, the degree of attack increases as the acidity of the acid increase. Generally attack observed when the pH value is less than 6.5 and the attack will be more severe when the pH value is lower than 4.5. The rate of attack also depends on the ability of hydrogen ions to be diffused through the cement gel (C-S-H) after (Ca (OH)₂) has been dissolved and leach out.

Girardi and Di Maggio (2011)⁵⁹ proposed on resistance of concrete mixtures to the cyclic sulfuric acid exposure. In which, six concrete pipes were casted according to the EN standards, Chemical test was conducted as cyclic immersion in sulfuric acid solution with pH value of 2, the specimens showed a constant decrease in mass. The mass loss was due to the reaction of the acid solution with the alkaline substances in the concrete.

Milica et al. (2011)⁶⁰ experimented on durability effect of sulfur concrete in various aggressive environments. A mass loss of 20% after 60 days was observed for all samples prepared with ordinary port land cement concrete. On the other hand, sulfur concrete specimens were prepared with sulfur, aggregate and various fillers with talc and micro silica, which do not shown any substantial change in strength concept and mass loss due to applied filler. Apparent porosity was increased for sulfur concrete samples exposure to the HCl a bit lower than in H₂SO₄·
Saravan kumar and Dhinakaran (2010)\textsuperscript{61} studied the effect of acidic water on strength, durability and corrosion of concrete. NaCl was mixed to the water at 10, 20 and 30\% directly with pH value of 7.1. It was observed as the compressive strength of concrete reduced irrespective of grade of concrete, the rate of reduction was 28 to 36\% at 7 days age and the value of reduction of 28 days was 14 to 24\% for M 20 grade of concrete. However the reduction of compressive strength was 6 to 14\% for M 25 grade and 2 to 10\% for M30 grade of concrete. Regarding the split tensile strength, the diminution of strength was 12\% for M20 grade, 2 to 7\% for M25 grade and 19\% for M30 grade concrete.

Girardi et al. (2010)\textsuperscript{62} studied on resistance of different types of concrete to cyclic sulfuric acid and sodium sulfate attack. The disruption caused by sulfate expansion and reduction of thickness in sulfuric acid due to mass loss.

Said et al. (2010)\textsuperscript{63} reported the behavior of self compacting concrete under sulphuric and hydrochloric acid attacks with influence of pozzolona. Self compacting concrete with lime stone filler addition at 30 and 50\%, specimens lost their cube shape when exposure to the 5\% concentrated HCl solution.

Soon-Do Yoon and Yeon-Hum Yun (2008)\textsuperscript{64} studied on chemical durability of glass–ceramics obtained from waste glass and fly ash, specimens were immersed into 20 ml acid solution to a period of 48 hrs and tested the compressive strength values before immersion into the HCl, which varied between 236.4 to 279.7 MPa and after immersion in
acid, values were 192.1 to 248.6 MPa. Bending strength was 72.8 to 94.9 MPa before immersion in acid and after immersion it was 55.3 to 72.6 MPa. Mechanical strength of concrete was not influenced by temperature but exposure of acid solution influence the strength.

Murthi and Siva Kumar (2008) reported on acid resistance of ternary blended concrete. The specimens were exposure to the water with 5% concentration of H$_2$SO$_4$ and HCl, the degree of deterioration appeared to be slightly lower for 5% HCl than 5% H$_2$SO$_4$ for plain cement concrete (PCC) specimens. The mass loss for 28 and 90 days cured M20 grade concrete PCC specimens was 19.6% and 16.1% respectively. Deterioration was due to acid diffused into concrete structure, destroy the cement gel paste forming soft and soluble gypsum, which reacted with C$_3$A and formed ettringite.

Kejin Wang et al. (2006) reported on damaging effects of deicing chemicals on concrete materials. CaCl$_2$ with or without corrosion inhibitor exhibited the mass loss and strength loss associated with salt crystallization and precipitation.

Pengfei Huang et al. (2005) studied on influence of HCl corrosion on the mechanical properties of concrete. Based on the experimental results, the diffusion coefficient of chloride ion decreased with increase grade of concrete and implied that the normal strength concrete show greater mass loss caused by HCl. Based on the test results, strength loss increased with increase of HCl concentration. Mass loss of the normal concrete was more serious than that of high strength concretes.
Hill et al. (2003) conducted on experimental study of combined acid and sulfate attack of concrete. By visual verification of samples after 6 months, deterioration of specimen was more when exposure to the acidic solution than sulfate solution. Sulphate and acid attack started at edges of the specimen and moved towards corners. Greatest deterioration samples occurred on surface of the samples.

Kilinckale (1997) studied on the effect of MgSO₄ and HCl solutions on the strength and durability of pozzolana cement mortars. Mortar specimens were exposure to 5% concentration of MgSO₄.7H₂O and in HCl (pH-2). Silica fume, rice husk ash, blast furnace slag, and fly ash as pozzolana in cement mortars at 20%. Higher weight loss was observed when the mortars exposed to HCl.

2.8 CLOSURE

With reference of previous research, properties of ceramic waste aggregate and its applications in concrete have been studied. Following conclusions are drawn from the review of literature.

1. Ceramic aggregate is an appreciated and appropriate concrete material for substitution into new concrete composition based on physical and mechanical properties.

2. It is generated from construction and demolition waste and ceramic industries. It is difficult to dump into yards due to its unique characteristic like brittleness. It is not biodegradable, so waste is growing up day by day. Substitution of coarse aggregate by ceramic waste aggregate into concrete composition is one solution for diminishing of ceramic waste.
3. Mechanical properties of ceramic aggregate are similar to the natural aggregate and its behavior is similar but not same. Water absorption, crushing value, impact value, and abrasion values are higher than natural coarse aggregate and lower by specific gravity and bulk density.

4. Mechanical properties of ceramic aggregate concrete decreases with increase in replacement of natural aggregate by ceramic aggregate.

5. When coarse aggregate is substituted with ceramic waste aggregate, compressive strength, split tensile strength and flexural strength of ceramic waste aggregate concrete are lower as compared to the conventional concrete but fine aggregate is replaced by ceramic sand, compressive strength has been increased.

6. Durability of ceramic aggregate concrete shows better than the conventional one when size of the fraction is 4-12mm.

7. Inclusion of ceramic waste aggregate into concrete composition is one of one of the appreciable consequence in construction activity.

8. By inclusion of ceramic waste into concrete, proper effective utilization of ceramic waste can be achieved and to avail the quality of aggregates to the future generation.

9. Though lot of research is carried out in bits on the effect of ceramic waste aggregate on the properties of concrete, there is no detailed and systematic study on workability, strength and
durability aspects. Hence, there is need to conduct detailed investigation with locally available ceramic waste aggregate.

10. Production cost comparison is required for natural and ceramic waste aggregates because of feasibility study on usage of ceramic waste aggregates into the concrete composition.