CHAPTER 2

LITERATURE REVIEW

2.1 GENERAL

In recent years, certain countries have considered the reutilization of waste materials as a new construction material as being one of the main objectives with respect to sustainable construction activities. This study focuses on reuse of recycled concrete aggregate and ceramic insulator wastes as coarse aggregate and fly ash as partial replacement for fine aggregate in lean concrete mix. The possible effects of aggregates such as recycled concrete aggregate, ceramic waste aggregate and fly ash upon lean concrete properties (mechanical and durability) have been discussed here. The detailed discussion on the results obtained from the research already conducted by various researchers are explained in this Chapter and the topics explained in this Chapter are:

- Properties of recycled aggregates
- Applications of recycled aggregates
- Properties of recycled concrete
- Effect of fly ash on properties of concrete

2.2 PROPERTIES OF RECYCLED AGGREGATES

Bairagi et al. (1990) studied the properties of recycled aggregates obtained by crushing M15 grade natural aggregate concrete and concluded that the grading curve of the recycled coarse aggregate as well as of the natural coarse aggregate do not differ appreciably except that former type of
aggregate possess lower specific gravity, higher water absorption capacity and significantly low resistance to mechanical action such as impact and crushing.

Environmental Council of Concrete Organizations (1997) provided standards for recycled aggregate and stated that the resistance to weathering of a recycled concrete aggregate usually is considered acceptable without running the sulphate soundness test if the concrete was durable in its previous life.

Annette R. et al. (2001) determined the mechanical properties of alternative materials (such as slate waste, limestone etc..) and concluded that many alternative materials performed as well as (or even better) than conventional materials. It was concluded that the stiffness and strength properties of the materials and mixtures were dependent on the coarsest particle size of the material and the amount of binder. It was also stated that the coarse materials had a higher stiffness than fine materials and required less binder to achieve a particular strength.

Florida Department of Transportation (FDOT) specifications recommended that Los Angeles abrasion loss should be less than 45% and Soundness by sodium sulphate test should be less than 15% for the use of recycled concrete aggregate as a base material in flexible pavements.

Nataatmadja (2001) investigated the performance of four recycled concrete aggregates obtained by crushing concrete with compressive strength ranging from 15 to 75 MPa. Based on the test results, it was concluded that the performance of the recycled concrete aggregate may be comparable to that of fresh base coarse aggregates. It was also stated that Ten Percent Fines test is suitable as an evaluation test for estimating the compressive strength of the parent material.
Shiou (2001) evaluated the physical and engineering properties of recycled concrete aggregate and developed specifications for the use of recycled concrete aggregate in pavement base course. Based on the results, it was recommended that Los Angeles abrasion loss should be less than 48% for the use of recycled concrete aggregate as a base material in flexible pavements. It was also recommended that the sodium sulphate test is not applicable for recycled concrete aggregate.

Sean Mulligan (2002) carried out Soundness test (Freeze/Thaw and Los Angeles abrasion) on recycled concrete material and reported that with respect to the Soundness test by Freeze/Thaw, recycled concrete material is not nearly as sound or durable as virgin aggregates (limestone and gravel) for particle sizes greater than or equal to the #4 sieve (4.75-mm sieve). It was also stated that with respect to the Soundness test by Los Angeles abrasion, recycled concrete material is not as sound or durable as virgin aggregates (limestone and gravel).

Amnon Katz (2003) investigated the properties of the recycled aggregates made from crushed concrete and reported that the properties of the recycled aggregates crushed at different ages were quite similar. It was also reported that the size distribution of the recycled aggregates was same for the various ages of crushing, as well as other properties such as water absorption, bulk specific gravity, bulk density, cement content and crushing value.

Microstructure of recycled aggregate prepared from the crushing of old concrete was studied by Amnon Katz (2004) and it was found that:

- Recycled aggregate is covered with loose particles that may prevent good bonding between the new cement matrix and the recycled aggregate.
• Old cement paste that remained on the natural aggregate was porous and cracked, leading to weak mechanical properties of the recycled aggregate.

Bekir et al. (2004) studied the properties of waste concrete aggregates obtained by crushing natural concrete specimens of having cylindrical compressive strength 14 MPa and it was reported that

• Specific gravity of waste concrete aggregates was lower than that of normal crushed aggregates due to the fact that there was a certain proportion of mortar over these aggregates.

• Water absorption ratio of waste concrete aggregate was found to be much higher compared with that of normal crushed aggregates and this was due to adhered mortar over these aggregates.

Marta et al. (2004) studied the effect of attached mortar content on the properties of recycled concrete aggregate and it was summarized that:

• Quality of recycled concrete aggregate is lower than natural aggregate quality, due to the mortar which remains attached to natural aggregate.

• Usual mortar content is about 23 to 44% for 8/16 mm fraction and 33 to 55% for 4/8 mm fraction. Generally, amount of mortar attached to fine fraction is higher than to coarse fraction.

• The main properties unfavourably affected by mortar content are absorption, density and Los Angeles abrasion.

• Recycled concrete aggregates with mortar content less than 44% are expected to have absorption lower than 8%.
- Recycled concrete aggregates with high mortar content seem to have higher sulphate and alkalis content.

- Fine fraction of recycled concrete aggregate has poor quality due to its higher mortar content and, it is not recommended to use fine recycled concrete aggregate for the production of new concrete.

- Original concrete quality also have influence on recycled concrete aggregate quality and generally, the lower the strength of the original concrete, the lower will be the quality of the recycled concrete aggregate.

- A solution to control recycled concrete aggregate quality for production of structural concrete could be to control original concrete, rejecting those concretes with compressive strength lower than 25 N/mm².

- Samples of coarse recycled concrete aggregate with high mortar content (more than 44%) or samples with a low mortar quality should be rejected.

### 2.3 APPLICATIONS OF RECYCLED AGGREGATES

Sagoe-Crengsil and Brown (1998) provided guidelines for specifying commercially produced recycled concrete aggregate for pre-mix concrete production based on product variability trials conducted by CSIRO. Based on product variability trials of commercially available recycled concrete aggregate, it was inferred that recycled concrete aggregate can be successfully used either as part or total coarse aggregate replacement in pre-mix concrete production for non-structural applications.
Khaled Sobhan and Raymond (1999) conducted experimental investigation to evaluate the performance of a cement stabilized recycled aggregate base course material under repeated flexural loads and from the results of the experimental investigation it was concluded that the recycled aggregate composite consisting primarily of waste materials has significant promise as a base course for highway pavements.

Majumder et al. (1999) conducted laboratory investigations for the evaluations of structural properties of cement treated low grade aggregates and concluded that the low-grade aggregates such as laterite and gravel can be effectively used as a road base or sub base by mixing them in suitable proportion with Portland slag cement and sand.

Khaled and Meheyd (2000) performed laboratory investigations to evaluate the performance of a cement-stabilized pavement base course material consisting of recycled concrete aggregate, ASTM Class C fly ash, and waste plastic (high-density polyethylene) strips obtained from post-consumer water and milk containers. From the experimental investigation, it was found that the unreinforced mixture containing 92% recycled concrete aggregate (by weight), 4% fly ash and only 4% cement achieved a compressive strength of about 5 N/mm$^2$, a split tensile strength of about 0.75 N/mm$^2$ and a flexural strength of about 0.95 N/mm$^2$, indicating a moderately strong stabilized base course material.

Price (2002) developed mix design specifications for low strength concretes containing recycled and secondary aggregates to encourage the use of recycled and secondary aggregates in low strength concrete applications in housing project. It was reported that the

- Recycled aggregate is limited to use in concrete with a maximum cube strength of 20 N/mm$^2$ and in only the mildest exposure conditions, whereas recycled concrete aggregate can
be used up to a characteristic cube strength of 50 N/mm$^2$ and in a wider range of exposure conditions.

- Recycled concrete aggregate is not generally permitted in concrete exposed to sea water, de-icing salts or severe freezing and thawing.

- Concrete containing recycled concrete aggregate is also generally restricted to use in non-aggressive soils.

Ramzi Taha et al. (2002) conducted laboratory evaluation of cement stabilized Reclaimed asphalt pavement (RAP) aggregate and Reclaimed asphalt pavement-virgin aggregate blends as base materials. From the results it was concluded that

- 100% Reclaimed asphalt pavement aggregate could be successfully utilized as a conventional base material if stabilized with cement.

- Reclaimed asphalt pavement aggregate seems to be a viable alternative to dense graded aggregate used in road base and sub base construction.

Taesoon Park (2003) conducted laboratory and field study to investigate the characteristics and performance of dry and wet recycled concrete aggregate as base and subbase materials for concrete pavement. It was reported that:

- Recycled concrete aggregate can be used as base and sub base materials, in place of crushed stone aggregate, for supporting a concrete pavement system.

- The compatibility of recycled concrete aggregate is the same as that of crushed stone aggregate and gravel aggregate.
Fouad M. Khalaf and Alan S. DeVenny (2004) conducted review on research works covering the use of demolished waste, especially crushed brick, as the coarse aggregate in new concrete. Review showed that most of the recycled aggregate has mainly been used as a sub base material or as a capping layer in road construction. It was reported that the recycled aggregate should be in a saturated surface-dry moisture condition before the commencement of mixing, because recycled brick aggregates have a high rate of water absorption and also informed that the recycled brick aggregates should be assessed for their moisture condition before use in concrete and, if necessary, the aggregate stockpiles should be sprayed with water to get the aggregate into a saturated surface-dry condition.

Sivakumar et al. (2004) conducted repeated load tests in a direct shear apparatus on crushed concrete and building debris and concluded that recycled construction wastes have significant shear strength and these materials could be utilized in various geotechnical applications. It was also stated that a careful consideration must be given to the suitability of these materials in civil engineering applications where the loading conditions are intensive.

Winston F. K. Fong et al. (2004) after conducting case studies discussed the latest application experience of using recycled aggregate in construction projects in Hong Kong and concluded that the recycled aggregates have been demonstrated to be able to produce quality concrete for structural applications. It was also stated that more research and development is needed to further promote the recycling concept and widen the scope of applications of recycled aggregates.

Oikonomou (2005) proposed a guidance of tests and limits of recycled concrete aggregate in order to be used as a basis for pilot and long
scale works where the use of recycled concrete aggregate can be estimated as more economic and friendlier to the environment.

2.4 RECYCLED CONCRETE PROPERTIES

Bekir and Nedim (1995) examined the various mechanical properties of concretes made with waste concrete aggregate (0, 30, 50, 70 and 100% replacement). It was observed that

- The density of concrete made with waste concrete aggregate (WCA) is lower than normal concrete.

- The workability of concrete made with WCA is low and could be explained by the high water absorption of WCA.

- As the amount of the WCA in the mixture is increased, the compressive strength is less and the modulus of elasticity is less than the normal ones at about 80%.

Zakaria and Cabrera (1996) conducted a laboratory study on the use of demolition bricks and artificial aggregates made from fly ash-clay as coarse aggregates to make concrete and concluded that

- Concrete of moderately high strength can be produced by using crushed demolition waste (brick) aggregates and at later ages, there is no significant difference between the compressive strength of artificial aggregate concrete and gravel aggregate concrete.

- High porosity is not necessarily indicative of lower compressive strength. At later ages, the brick aggregate concrete have relatively higher porosities than the gravel concrete mix.
- Use of crushed brick aggregates for concrete making is an adequate solution for regions where natural aggregates are scarce or demolition and/or industrial wastes are abundant.

Dhir et al. (1999) studied the effect of recycled concrete aggregate on strength development and durability properties on concrete and it was concluded that upto 30% replacement of coarse aggregate with recycled concrete aggregate has no influence on cube strength but this reduces with increasing recycled concrete aggregate content thereafter owing to increased quantities of attached paste.

Farhad Ansari et al. (2000) conducted a comprehensive study involving the use of recycled materials (such as crushed glass and recycled concrete aggregate) in Portland cement concrete and it was concluded that recycled concrete aggregate can be used for secondary applications and it possesses enhanced durability attributes in optimized, cementitious mixtures.

Padmini et al. (2001) investigated the use of coarse aggregate recycled from two types of low strength bricks in concrete making and studied the behaviour of such concrete. It was found that the density of brick aggregate concrete is 15% lower as compared to conventional concrete.

Sagoe-Crentsil et al. (2001) carried out performance tests to determine the fresh and hardened properties of concrete made with commercially produced coarse recycled concrete aggregate and natural fine sand. Test results indicate that

- Plant processing of recycled aggregate improves workability of concrete.
• There was no significant difference in 28-day compressive strength of concrete made with commercial recycled aggregate and natural basalt aggregate.

• In the period from 91d to 365d, there is no significant reduction in split tensile strength.

• Ratios of splitting tensile strength/compressive strength were found to be in good agreement with conventional values derived for concretes made with normal weight natural aggregates.

• Abrasion resistance of recycled aggregate concrete reduced by about 12% compared to basalt aggregate concrete.

Based on the results obtained from the performance tests carried out on recycled concrete aggregate (RCA) for use as a base material under hot mix asphalt pavements and as an aggregate in Portland cement concrete pavements, Abdol R. Chini et al. (2001) reported that

• The properties of RCA and concrete made with RCA obtained are consistent and within the range of values obtained by other researchers.

• The mechanical properties of RCA concrete decrease as the ratio of coarse RCA to virgin aggregate (VA) increase in the mix. Compared to VA concrete, the 100% RCA concrete was about 82% in compressive strength, 96% in tensile strength, 81% in flexural strength and 86% in modulus of elasticity for lab prepared samples.

• Despite having lower compressive strength than VA concrete, 100% RCA concrete had a 28-day compressive strength of 35 MPa, which is well above the target strength of 25 MPa.
Andrzej and Alina (2002) determined the mechanical properties of concrete made from recycled aggregate and compared with series of corresponding concrete made from new aggregates and derived the following general conclusions from the analysis of test results:

- Properties of original concrete have significant influence on mechanical properties of recycled aggregate concrete; it is possible to obtain recycled concrete with higher compressive strength than the original one.

- Mix design of recycled concrete is very similar to the procedure for concrete with natural (new) aggregate; corrections in water content are necessary to obtain proper workability but the changes in water/cement ratio may be relatively small.

- The replacement of fine fraction less than 2 mm in recycled aggregate by natural sand always changes for the better the properties of recycled concrete.

- Properties of recycled concrete may be significantly improved by admixtures of superplasticizers and silica fume, similarly to cases of concrete with natural aggregates.

Olorunsogoa and Padayachee (2002) investigated the performance of concrete manufactured with recycled aggregate (RA) using durability indexes (chloride conductivity, permeability, sorptivity) as indicators and it was reported that

- At a constant age of curing, water sorptivity of RA concrete increased with increases in the proportion of RA in the mixes. If mixes were cured for a considerable length of time, there may be little or no difference in the sorptivity values of concrete mixes for a given proportion of RA in the mix.
• Overall, durability quality of RA concrete reduced with increases in the quantities of RA that were included in a mix and, as expected, the quality improved with the age of curing and this is due to the fact that cracks and fissures created in RA during processing render the aggregate susceptible to ease of permeation, diffusion and absorption of fluids.

Padmini et al. (2002) determined the permeation characteristics (volume of voids, water absorption and sorptivity) of three strengths of concrete with a) recycled concrete aggregates and b) crushed brick aggregates and concluded that for a given strength, the volume of voids, water absorption and sorptivity of recycled aggregate concrete:

• reduces with increase in maximum size of aggregate used.
• increases with increase in strength of parent concrete from which the recycled aggregate is derived.
• is higher for brick aggregate concrete than for concrete produced with crushed concrete aggregate.
• the variation in volume of voids, water absorption and sorptivity between parent concrete and recycled aggregate concrete reduces with increase in strength of concrete.

Ryu (2002) evaluated the effect of recycled aggregate on interfacial property, permeability and strength characteristics of concrete in order to examine the relationship between the recycled aggregate and the performance of the hardened concrete and derived the following conclusions:

• The w/c ratio and quality of the recycled aggregate affect the permeability of the concrete. The permeability increases, as the water cement ratio increases and as adhesive strength of mortar of the recycled aggregate decreases.
• Although the strength characteristic of the concrete is not affected by the quality of recycled aggregate, when the w/c ratio of the concrete is high, it is affected by the quality of recycled aggregate when the w/c ratio of the concrete is low.

Amnon Katz (2003), tested the properties of the recycled aggregate and of the new concrete made from it, with nearly 100% of aggregate replacement, and found that the concrete made with 100% recycled aggregates was weaker than concrete made with natural aggregates at the same water to cement ratio. It was also found that the properties of aggregates made from crushed concrete and the effect of the aggregates on the new concrete (strength, modulus of elasticity, etc.) resemble those of lightweight aggregate concrete.

How-Ji Chin et al. (2003) conducted a series of experiments on concrete using recycled aggregate of various compositions from building rubble and found that the modulus of elasticity of recycled concrete was only about 70% that of normal concrete.

Nobuaki Otsuki et al. (2003) conducted an experimental study to examine the influence of recycled aggregate on strength, chloride penetration and carbonation of concrete and it was reported that

• The quality of recycled aggregate, in terms of adhesive mortar strength, affects the strength of recycled aggregate concrete when the water-binder ratio is low, however, the quality of recycled aggregate does not affect the strength of recycled aggregate concrete when the water-binder ratio is high.
• The chloride penetration and carbonation resistances of recycled aggregate concrete are slightly inferior to those of normal aggregate concrete and

• Improvements in strength, chloride penetration and carbonation resistances of recycled aggregate concrete can be achieved by using the double mixing method in the case of high water-binder ratio concrete.

Roumiana Zaharieva et al. (2003) compared the permeation properties of recycled aggregate concrete with those of a control concrete made with natural aggregate and it was concluded that in terms of durability, recycled aggregate concrete is significantly more permeable than natural aggregate concrete. The replacement of natural aggregates by recycled aggregates affects the quality of the concrete cover. Based on the criteria proposed in other studies, it was characterized the recycled aggregate concrete as of moderate quality rather than of poor quality. It was also mentioned that possible use of admixtures such as fly ash or silica fume could decrease significantly porosity and permeability of recycled aggregate concrete.

Senthamarai and Devadas (2003) carried out experiments to investigate the properties of M20, M25 and M30 grade concrete made with ceramic waste aggregate and drawn the following conclusions:

• Ceramic concrete is having better workability than conventional concrete.

• Compressive strength and flexural strength of ceramic concrete varies only marginal with conventional concrete.

• Split tensile strength of ceramic concrete is lesser than that of conventional concrete.
Arlindo Goncalves et al. (2004) analyzed the influence of the recycled concrete aggregates on durability related concrete properties and it was expressed that full replacement of natural aggregates by recycled aggregates leads to a decrease in concrete strength up to 16% and also lower performances to durability related properties mainly due to the higher porosity of recycled aggregates.

Properties such as slump, density, compressive strength, tensile strength, modulus of elasticity and drying shrinkage have been studied by Marta and Pilar (2004) in concretes with 20, 50 and 100% of recycled coarse aggregate and it was concluded that

- Fresh properties of recycled concrete are good when recycled aggregate is pre-wetting before using, avoiding workability loss produced when recycled aggregate is used in dry conditions.

- Compressive strength of recycled concrete is lower than compressive strength of a control concrete with the same dosage (equal water/cement ratio and cement content). Recycled concretes with a percentage of recycled coarse aggregate lower than 50% show decreases in the range 5 to 10%, while for concretes with 100% recycled aggregates, decreases ranged from 10 to 15%.

- Properties of conventional concretes and recycled concretes with the same compressive strength hardly change when less than 20% recycled coarse aggregate is used, except elasticity modulus, for which decreases until 10% can be found in recycled concretes.
• Effects that can appear when recycled aggregate content is increased until 50% are decreases of elasticity modulus that can reach values close to 20%.

• When the percentage of recycled aggregate is lower than 50%, tensile strength and drying shrinkage of recycled concrete is similar to conventional concrete with the same compressive strength.

• All properties of concretes with a 100% of recycled coarse aggregate are affected.

Roumiana Zaharieva et al. (2004) studied the frost resistance properties of concrete containing building waste recycled as aggregates and it was noted that the frost resistance of saturated recycled aggregate concrete is not satisfying and their use in structures exposed to severe climate is not recommended. It was also concluded that the main reason seems to be the high total w/c, inducing higher porosity and lower mechanical characteristics of recycled aggregate concrete as well as the frost resistance of recycled aggregate themselves.

Salomon M. Levy and Paulo Helene (2004) analyzed the properties such as water absorption, pore volume and carbonation of concrete mixtures containing fine and coarse recycled aggregates recovered from demolished masonry and concrete structures. It was reported that:

• Concrete made with recycled aggregates (20, 50 and 100% replacement) from old masonry or from old concrete can have the same fresh workability and can achieve the same compressive strength of concrete made by natural aggregates in the range of 20 to 40 MPa at an age of 28d.
• Minimum water absorption and total pore volume for the recycled aggregates concrete were observed at 20% replacement when using coarse recycled concrete aggregate and coarse recycled masonry aggregate.

• When the natural aggregate is replaced by 20% of the recycled aggregates from old concrete or old masonry, the resulting recycled concrete will likely present same and sometimes better, behavior than the reference concrete made with natural aggregates in terms of the properties studied (compressive strength, water absorption, pore volume and carbonation depth).

• Use of these concretes, can contribute to the preservation of the environment and can achieve the same final performance with probably less cost than ordinary concretes.

De Brito et al. (2005) conducted experiments to study the properties of fresh and hardened concrete (non-structural concrete) made with recycled ceramic hollow bricks fragments as aggregates. After analysing the test results, it was concluded that the recycling of ceramic waste from construction and demolition sites as coarse aggregates for the production of non-structural concrete is feasible. It was also concluded that

• The strength decreases as the quantity of ceramic aggregates in concrete increases, since they are lighter and less resistant than the primary stone aggregates.

• The decrease in compressive strength is higher than that in the flexural strength.
• The abrasion resistance of concrete made with ceramic recycled aggregates is higher than that of concrete made with limestone aggregates.

Jianzhuang Xiao et al. (2005) experimentally investigated the compressive strength and stress-strain behaviour of recycled aggregate concrete (RAC) with different percentages of recycled concrete aggregate (RCA) and it was concluded that

• The RCA replacement percentage (r) has a considerable influence on the stress-strain curves of RAC. For all cases from r = 0 to 100%, the stress-strain curves show a similar behaviour. The stress-strain curves of RAC indicate an increase in the peak strain and a significant decrease in the ductility as characterized by their descending portion.

• The compressive strengths including the prism and the cube compressive strengths of RAC generally decrease with increasing RCA contents. But the ratio of the prism compressive strength and the cube compressive strength is higher than that of the normal concrete.

• The elastic modulus of RAC is lower than that of the normal concrete. It decreases as the RCA content increases. For a RCA replacement percentage equals 100%, the elastic modulus is reduced by 45%.

• The peak strain of RAC is higher than that of normal concrete. It increases with the increase of RCA contents. For a RCA replacement percentage equals 100%, the peak strain was increased by 20%.
2.5 EFFECT OF FLY ASH ON CONCRETE PROPERTIES

Montgomery et al. (1981) conducted studies, aimed at identifying the mechanism or mechanisms whereby the incorporation of fly ash influences the strength of lean concrete mixes. It was stated that the fly ash particles provide well distributed and therefore convenient points within the paste for nucleation to occur and this leads to encapsulation of individual ash spheres by the cement hydration products. As the hydration proceeds around individual spheres, the outward growth leads to mechanical interlocking of the needles and plates. This enhanced interlinking aspect is thought to be fundamental to the strength imparting mechanism. It was also reported that the long-term strength is increased by a reaction which is presumably pozzolanic in nature and which starts to contribute at an age of about 10 to 12 weeks in the case of specimens cured in water at 20°C.

Dan Ravina (1986) investigated the effect of replacing 35 to 50 percent of cement by fly ash (Class C and Class F) on workability, water requirement, bleeding and setting time of lean concrete mixtures. It was concluded that in lean concrete, cement replacement by large amount of fly ash is highly beneficial and significantly improves the workability and substantially reduces the water requirement to attain a given consistency in concrete mixtures.

Dan Ravina and Mehta (1988) investigated the effect of replacing 35 to 50 percent of cement by fly ash (Class C and Class F) on the compressive strength of lean concrete mixtures. From the results, it was found that a concrete mix with 120 kg/m$^3$ cement and 180 kg/m$^3$ of Class F fly ash produced the designed compressive strength of 14 MPa in 75d curing and from the standpoint of economy and overall concrete performance, use of high fly ash concrete mixtures is worthy of consideration, particularly when high early strengths are not needed.
Malhotra and Painter (1989) conducted an investigation to determine the early-age strength and freezing and thawing resistance of concrete incorporating high volumes of ASTM Class F fly ash and it was reported that the

- Concrete incorporating high volumes of ASTM Class F fly ash has high density, satisfactory early age strength and high later age strength.

- Fly ash concrete has considerable potential for use in a wide variety of applications, including massive structural elements, tunnel linings, mat foundations and basement walls. However, indiscriminate use of this type of concrete is not recommended.

Tarun R. Naik (1994) evaluated abrasion resistance properties of concrete mixtures with 50 and 70% replacement of cement using ASTM Class C fly ash and drawn the following main conclusions based on the results obtained.

- Compressive strengths of high-volume fly ash concrete mixtures at 50 and 70% cement replacements were lower than the reference concrete containing no fly ash. However, the difference between strength gain of fly ash and no-fly ash concrete diminished with age.

- Concrete mixture having 50% cement replacement with fly ash attained sufficient strength required for structural applications.

- All the concrete mixtures used (0, 50 and 70% replacement of cement with fly ash), showed excellent abrasion resistance.
• In general, the no-fly ash concrete showed higher abrasion resistance during the accelerated testing relative to high-volume fly ash concrete mixtures. None of the concrete mixtures failed during the 30 min of abrasion. However, when time of exposure to abrasion was increased to 60 min, the high-volume fly ash concrete mixtures showed depth of wear in excess of 3 mm at an age of 28d. But at an age of 91d all the concrete mixtures exhibited excellent abrasion resistance when tested in accordance with the accelerated testing method proposed.

• Abrasion resistance of concrete was primarily influenced by its compressive strength.

• For a given concrete compressive strength range, irrespective of the amount of fly ash, the products of depth of wear and compressive strength was found to be constant.

Dan Ravina (1995) investigated the effect of Class F fly ash of marginal quality, as partial replacement of fine sand on the properties of green concrete and derived the following conclusions:

• Fly ash as partial replacement of fine sand increases the tensile strength of green concrete, at 2 to 4 h after mixing, by 25 to 40%.

• Fly ash as partial replacement of fine sand increases the water demand required to obtain the same consistency (slump) by about 10%.

Hiroshi Uchikawa et al. (1996) studied the hydration reaction, hardened structure and pore structure of concrete prepared by substituting various mineral powders (fly ash, slag, limestone and silicious stone) for part
of fine aggregate. Also investigated the physical properties of concrete and summarized the following:

- The mineral powder is uniformly distributed over the matrix part in concrete and it fills up the pores, prevents the materials from separating, reduces the size of the hydration reaction products and inhibits the deposition of Ca (OH)$_2$. As a result, the capillary pores as large as 50nm to 1μm in diameter are reduced and the formation of the transition zone is inhibited.

- In the concrete prepared by substituting mineral powder for part of fine aggregate, the large-sized capillary pore is mainly filled up with fly ash itself till the age of 28d in the same way as limestone and silicious stone powders and accordingly the pore size distribution shifts to the smaller side. C-S-H produced in the pozzolanic reaction at an age of 91d also contributes to densify the structure of concrete by filling up the pore.

- Compressive strength of the concrete prepared by substituting fly ash at an age of 91d differs by 10 MPa from those of concrete prepared by substituting limestone and silicious stone powders. The increase of strength may be mainly caused by the filling up of pores in concrete with the mineral powder, the prevention of the movement of pore solution to the aggregate and of the deposition of large-sized Ca(OH)$_2$, crystal on the surface of aggregate and the densification of the structure of the concrete in the case prepared by substituting slag and fly ash powders with pozzolanic reactivity by increasing the quantity of C-S-H.
Eleni Vassiliadou Churchill and Serji N. Amirkhanian (1999) examined the effect of coal ash (fly ash and bottom ash) when used as partial replacement of fine aggregate in asphalt concrete mixtures. From the experimental data it was concluded that substitution of fine aggregates by coal ash is technically feasible; however, utilization of coal ash in asphalt specimens decreased 24h tensile strengths. One factor that might have influenced this trend is the low unit weight of coal ash samples as compared with control samples. It was also recommended that the coal ash asphalt mixtures can be used in secondary roads with low traffic volumes, parking lots and drive ways.

Cengiz Duran Atis (2002) evaluated the influence of fly ash inclusion as partial replacement of cement (50 and 70%) on the abrasion resistance of high volume fly ash concrete for pavement application and made the following conclusions from the experimental investigation:

- The relation between abrasion value and the number of revolutions appears to be linear.

- The abrasion resistance of concrete is mainly dependent on the compressive strength of concrete. A general relation of a hyperbolic form provides a higher correlation.

- The linear approach to the relation between abrasion value and compressive strength is adequate and satisfactory for individual mixes.

- High volume fly ash concrete showed better abrasion resistance than normal Portland cement concrete, particularly at high compressive strengths.
There is no significant influence of using superplasticizer on the abrasion resistance of concrete.

Curing conditions have shown no significant influence on the general trend of the abrasion of concrete.

High volume fly ash concrete can be used in the field where high abrasion resistant concrete is required, provided that proper mix design is used and trials are carried out.

Tarun R. Naik et al. (2002) performed an investigation to establish the effect of the source and amount of fly ash (Class C) on abrasion resistance of concrete and it was reported that

- All fly ash mixtures exhibited substantially higher rates of strength gain as compared with the reference mixture.

- No definite trend could be established between properties of fly ash, concrete strength and abrasion.

- The effects of source of fly ash on concrete abrasion resistance followed the same general trend as that observed for compressive strength.

- The general trend of compressive strength data at both the 91d and 365d ages was similar to that observed at 28d.

- All mixtures with and without fly ash showed a high resistance to abrasion. Generally, depth of abrasion decreased with age and increased with time of abrasion or fly ash content. However, the 40% fly ash mixtures were as abrasion resistant as the fly ash-free mixture.
Beyond 50% fly ash content, abrasion resistance of the fly ash mixtures was slightly lower as compared with the reference mixture.

The depth of wear was inversely proportional to compressive strength; i.e., depth of wear decreased with increasing compressive strength.

Canan Tasdemir (2003) investigated the effect of mineral admixture (fly ash and silica fume) as partial replacement of sand and curing condition on the sorptivity of concrete and drawn the following conclusions from the results obtained:

- Mineral admixtures having high values of fineness and pozzolanic activity increase the compressive strength of concrete.
- Mineral additives with coarse particles cause the reduction in the strength of concrete.
- Since microfiller materials having fine particles fill both the interfaces and the bulk paste, hence, the sorptivity coefficient of concrete decreases.
- Microfiller materials with the low value of pozzolanic activity exhibit very little cementing value in laboratory conditions. However, under water-curing conditions, the cementing activity becomes apparent.

Camoes et al. (2003) studied the durability properties of low cost high performance fly ash concrete and concluded that it is possible to improve the durability properties of concrete by adding fly ash as cement replacement without having increased costs.
Cengiz Duran Atis (2003) carried out a laboratory investigation to evaluate the strength properties of concrete containing high volume fly ash (50 and 70% replacement of ordinary Portland cement) and from the laboratory results, it was concluded that

- High volume fly ash concrete attained satisfactory or higher compressive and tensile strength when compared to ordinary Portland cement concrete.

- High volume fly ash concrete becomes a possible alternative to ordinary Portland cement concrete used for road pavements applications and large industrial floors.

Rafat Siddique (2003) carried out experimental investigation to evaluate the mechanical properties of concrete mixtures in which fine aggregate (sand) was partially replaced with Class F fly ash. Fine aggregate was replaced with five percentages (10, 20, 30, 40 and 50%) of fly ash by weight and from the results, it was concluded that

- Compressive strength, split tensile strength, flexural strength and modulus of elasticity of fine aggregate (sand) replaced fly ash concrete specimens were higher than the plain concrete (control mix) specimens at all the ages. The strength differential between the fly ash concrete specimens and plain concrete specimens became more distinct after 28d.

- Compressive strength, splitting tensile strength, flexural strength and modulus of elasticity of fine aggregate (sand) replaced fly ash concrete continued to increase with age for all fly ash percentages.
• The maximum compressive, flexural and split tensile strength occurs with 50% fly ash content at all ages.

• At all ages, the maximum value of modulus of elasticity occurs with 50% fly ash content.

• Class F fly ash could be very conveniently used as partial replacement for fine aggregate in concrete.

Rafat Siddique (2003) determined the abrasion resistance of concrete proportioned to have four levels of fine aggregate replacement (10, 20, 30 and 40%) with Class F fly ash and drawn the following conclusions:

• Abrasion resistance of concrete was strongly influenced by its compressive strength, irrespective of fly ash content.

• Abrasion resistance was found to increase with increase in fly ash content as replacement of fine aggregate.

• Abrasion resistance was found to increase with the increase in age for all mixtures upto 40% replacement of fine aggregate with fly ash.

Cengiz (2003) carried out a laboratory study to evaluate the compressive strength, abrasion and porosity properties of concrete mixtures made with fly ash and normal Portland cement and it was reported that:

• Compressive strength increases, the abrasion volume of concrete decreases.

• Porosity increases, the abrasion volume also increases.

• Confirmed that strength alone cannot be used to predict the abrasion of concrete mixtures with different porosity values.
2.6 NEED FOR THE PRESENT STUDY

The necessity of utilization of recycled aggregates and industrial wastes in civil works is due to the great volume of waste materials generated in developed countries. Applications for fills and embankments, for road base and sub-base layers and as aggregate for concrete are some possible destinations of recycled aggregates and industrial wastes. Historically, because of the large volume of materials required for construction, pavements have been favorable structures for the recycling of a wide range of waste materials. Initially, this recycling was limited to the reuse of materials removed from previous pavement structures such as: recyclable asphalt pavement, recyclable Portland cement concrete and various base course materials. Recently, various other materials, not originating or historically associated with pavements, have come into use such as ceramic waste, tires, plastics, glass wastes etc.,

From the literature review, it was observed that the replacement of natural aggregates by recycled aggregates affects the durability properties of the concrete. To get significant improvements in the properties of the recycled concrete, particularly durability aspects, possible use of mineral admixture (fly ash) was selected. Since fly ash is one of the few waste materials and the use of fly ash is around 15 to 20% in India, an effort is made to increase its utilization by using it as partial replacement for fine aggregate in concrete. There is no detailed research has been done on lean concrete mix using both recycled aggregate and fly ash. Hence, a systematic study on the effect of fly ash on the properties of lean concrete using recycled aggregates is necessary.

2.7 OBJECTIVES AND SCOPE OF THE PRESENT STUDY

Many research studies were carried out on the use of recycled aggregates in concrete in an attempt to understand the properties of recycled concrete. However, most of the studies are focused on the mechanical and
durability properties of the standard and high strength concrete. Limited work was carried out on the understanding of the mechanical and durability aspects of the lean concrete. This research investigated the mechanical and durability properties of lean concrete made with recycled aggregates such as (i) recycled concrete aggregate made from building rubble, containing mainly waste concrete, (ii) ceramic waste aggregate made from ceramic wastes (collected from industries manufacturing ceramic electrical insulators) and partial replacement of fine aggregate with Class C fly ash collected from thermal power plant. Various tests are carried out to investigate the mechanical and durability properties of concrete. The objectives and scope of the present study are:

- To study the properties of recycled aggregates
  a) Recycled concrete aggregate b) Ceramic waste aggregate

- To study the properties of lean concrete made with recycled concrete aggregate/ceramic waste aggregate

- To study the effect of fly ash as partial replacement for fine aggregate on mechanical properties such as compressive strength, split tensile strength, flexural strength and modulus of elasticity of lean concrete made with recycled aggregates

- To study the effect of fly ash as partial replacement for fine aggregate on physical and durability properties such as voids, density, water absorption, water permeability, resistance to sulphate attack, water sorptivity and abrasion resistance of lean concrete made with recycled aggregates

- To study the performance of pavement constructed using lean concrete made with recycled aggregates and fly ash as base course
2.8 SUMMARY

The use of waste materials in the production of lean concrete has benefits in not only reducing the amount of waste materials requiring disposal but can provide construction materials with significant savings over new materials. This study is oriented towards utilizing recycled concrete aggregates and industrial wastes (ceramic wastes and fly ash) in the production of lean concrete.