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REVIEW OF LITERATURE

2.1 General

A large number of studies have been published on the effects of low calcium (ASTM Class F) fly ash on the strength and durability properties of concrete (Berry and Malhotra, 1987, Sivasundaram et al., 1991). However, the available research on the high calcium (ASTM Class C) fly ash is very limited. Previous studies (Ellis Saravanos, 1995; Nasser and Lai, 1992), have studied the effect of using large volume of high calcium fly ash as replacement of Portland cement in the concrete. The effect of aggregate binder ratio on the engineering properties of high volume (ASTM Class C) fly ash concrete is very limited. Hence, in the present study variable percentages of Class C fly ash as replacement of Portland cement in combination with different aggregate binder ratio 1.50, 1.75 and 2.00, in order to produce medium to high strength concrete.

2.2 Effects of cementitious materials on the principal characteristics of concrete

The introduction of a cementitious material into concrete modifies the properties of the fresh and hardened concrete. When the water demand is increased, the situation can be partially or totally overcome by using some superplasticizer, but the extra cost of the superplasticizer will have to be taken into account when pricing the economical performance of the cementitious. The water demand is increased when silica fume and rice husk ash is added to the mix. This is due to the extreme fineness of particles of silica fume and diatomaceous earth due to the morphology of rice husk particles. It is difficult to be very specific about the water demand of natural pozzolan because there are different types.

The concrete containing some admixtures, it is often necessary to modify their dosage according to their carbon content. Usually carbon particles trap organic
molecules, diverting them from their intended action in the concrete mixture. The drawback of unburned carbon present in fly ashes is the variability of carbon content, which makes it quite tricky.

Generally, it is easy to maintain the slump of concrete containing cementitious materials for 1 hour to 1.5 hours because cementitious materials are less reactive than the Portland cement. In the case of slag, it can be necessary to add an amount of calcium sulphate that is roughly equal to that which was contained in the Portland cements that has been replaced, because slag consumes some $\text{SO}_4^{2-}$ ions when it starts reacting during the first hour and a halt following the introduction of water in the concrete mix (Saric-Corie and Aitcin, 2003).

In general, the early strength resistance of a concrete that consists of some cementitious materials are lower than that of a plain Portland cement concrete, except for silica fume. According to the reactivity of the cementitious material the decrease of the early and short term strength can be noticed until 7, 14 or 28 days. But in hot climates, where the concrete is placed at a high temperature, it is not significant disadvantage, because heat activates the reactivity of the cementitious materials. The concretes can be adjusted to the desired level, if the water cured adequately. It is primary important to note that the actual performance of a concrete containing cementitious material depends on the water availability because in order to see the pozzolanic reaction development.

The effect of fly ash in concrete consists of three types of aspects such as pozzolanic effect, micro aggregate effect and morphologic effect. Firstly the pozzolanaic effect states that, the unfixed $\text{Al}_2\text{O}_3$ and $\text{SiO}_2$ in fly ash can be activated by $\text{Ca (OH)}_2$ product of hydration of cement and produce more hydration gel. The hydration gel will fill the capillary pores in the concrete; it effectively conduces to
concrete strength. The second aspect is micro aggregate effect of fly ash states that, the micro beads in fly ash will disperse very well in concrete and produce densified concrete. The third one morphologic effect states that there are many more micro beads in fly ash are act as lubricating balls when incorporating in the fresh concrete. Duchesne and Berube, (2001) have clearly demonstrated that one of the best ways to fight potential alkali aggregate reaction is to use fly ash and slag, glassy fly ash and slag particles are activated by the rapidly soluble alkalis present in Portland cement (alkaline activation of glass). Carles-Gibergues, (1989) reported that, the slag and pozzolanic materials delay by several years the development of the alkalis aggregate reaction when accelerated tests are done at 38° C in perfectly saturated conditions.

2.3 Effects of Fly ash on Mechanical properties of concrete

2.3.1 Compressive strength

The strength of the hardened paste in the plain Portland cement concrete is not strongly dependent on the micro structure of the C-S-H at the atomic level. It has been suggested that the strength is determined by features at the mesolevel and the macro level. These parameters include total porosity, pore size distribution, presence of flaws in the system and the nature of the solid phase. The detrimental effect of the total porosity on the strength of any material has been recognized historically. Mindess, (1985) has been summerised the pore distribution of finer pores, the strength is improved.

The pozzolanic reaction of fly ash affects the formation of the hydration products in the hardened cement paste. The hydration products are influenced by the chemical composition of the fly ash and the ratio of the chemical reaction is dependent on the reactivity and particle size distribution of the fly ash. Since the pozzolanic reaction is time dependent the immediate effect of replacing cement with
fly ash is one of the delaying the hydration process and therefore the strength of the concrete develops in different rate. Slow rate of gain of strength is due to relatively slow pozzolanic action of fly ashes.

Mansur Sumer, (2012) has studied the variation of compressive strength with age for various fly ash replacements concrete mixtures at 28 and 90 days of curing. According to his results, the use of Class C fly ash improves the compressive strength of Class C fly ash additive concretes. He reported that Class C fly ash resulted to higher compressive strength. They observed that, there is 10% cement reduction by adding Class C fly ash improves compressive strength and this improvement increases with fly ash percentage.

Mucteba Uysal and Veysel Akyuncu, (2012) have showed experimental investigations of Class C fly ash instead of Class F fly ash with the same cement dosage and fly ash percentage. The concrete mixture C360C80 containing Class C fly ash attains highest compressive strength at 28 and 90 days.

Nath and Sarker, (2011) showed that the incorporation of fly ash in concrete decreased strength at the earlier age when compared with control concrete. They also showed that concretes with 30% fly ash have higher strength gain than those with 40% fly ash and the strength of fly ash concretes in both series developed at a higher rate than that of control concrete mix up to 56 days. They observed that, the strength increase after 56 days is very minimum in all the concrete mixtures.

Serdar Aydın et al., (2007) investigated the effects of ASTM Class C fly ash incorporation on mechanical properties of concrete. They reported that long-term strength values decreased significantly for concrete mixtures above 30% of fly ash replacement levels.
Oner, Akyuz and Yildiz, (2005) reported that strength of fly ash concrete increases with amount of fly ash until about 40% of cement and thereafter decreases with increasing fly ash fraction. Jingyi Zhu et al., (2005) showed that the 7-day strength of concrete containing Class C fly ash was maximum at 35% fly ash replacement, while Class F fly ash achieved maximum compressive strength at 25% cement replacement. The compressive strength of concrete cylinders containing Class C fly ash at 7 days is 27.6 N/mm² until the fly ash is above 65%.

Prinya Chindaprasirt, (2005) concluded that blended cement pastes containing the fly ash exhibited higher total porosity and capillary porosity than those of Portland cement paste and resulting in lesser compressive strength of the blended cement paste when compared with Portland cement paste. The blended cement pastes consists of classified fly ash resulted in higher compressive strength, lower total porosity and capillary porosity than those with the original fly ash.

Gettu, Gomes, Agullo and Josa, (1995) studied the mixture proportioning methodology of concretes with fly ash and showed that 7 and 91 days compressive strengths of over 50 N/mm² and 90 N/mm² respectively with 60% fly ash replacement levels. Vasundhara et al., (2004) showed that there is increase in compressive strength of normal mix with 40% fly ash as additional ingredient when compared with normal concrete. They noticed that, the strength decrease marginally in case of 50% and 60% fly ash additions in concrete mixes when compared with plain concrete mixes.

Rafat Siddique, (2004) observed that the use of high volumes of Class F fly ash as a partial replacement of cement in concrete decreased its mechanical properties at 28 days. Based on their experimental results, it was concluded that Class F fly ash
can be suitably used up to 50% level of cement replacement in concrete for use in precast elements and reinforced concrete construction.

Jiang, Zhenqing and Yiqun, (2004) reported that increase in strength with fly ash replacing fine aggregate; however, the rate of increase of strength decreases with increase of fly ash. The rate of gain of compressive strength of the mix prepared by use of fly ash and OPC, slower in the early stage but faster in the later stages as compared to those with OPC only.

Cengiz Duran Atis, (2003) was carried out to evaluate the strength and drying shrinkage properties of concrete containing high volume of fly ash ranging from 50% to 70% with variable water binder ratio varied from 0.28 to 0.34. He showed that 50% fly ash replacement concrete developed higher strength than OPC concrete at 28 days and the compressive strength of 70% fly ash replacement mixes developed lower than corresponding control mixes. He conclude that, 50% fly ash replacement mixes developed the marginal improvement in compressive strength compare with OPC concrete mixes at the age of one year. But, the fly ash 70% replacement mixes developed the strength 30-40% less when compared with other concrete mixes.

Naik. Singh and Hossain, (2003) performed an experiment for development of economical high strength self consolidating concrete containing high volume fly ash. Their experimental results showed that the use of high volume Class C fly ash in the self consolidating concrete drastically decreases the requirements for superplasticiser.

Li and Zhao, (2003) reported that, the strength of high volume fly ash concrete is less than that of concrete without fly ash up to 5 days. However, the strength of former was greater for 20% replacement of cement after 365 days. Cengiz Duran Atis, (2003) studied the abrasion resistance of high volume fly ash concrete.
His analysis of results showed that abrasion resistance increased as compressive strength increased.

Bouzouba et al (2001) reported that design of self compacting concrete is possible with incorporating the high volumes of Class F fly ash. They showed that 28 day compressive strength of 35 N/mm$^2$ was made with 50% replacement of cement by fly ash and with water to cementitious materials ratio of 0.45.

Poon, Lam and Wong, (2000) was carried out the properties of fly ash concrete with w/b ratio less than 0.30 with high volume of fly ash to produce the high strength concrete. They showed that, at w/b ratio of 0.24, the mix with 25% fly ash develop lower compressive strength at 3 and 7 days, but higher compressive strength at 28 and 90 days.

Tim Mitchell Borg, (1998) was made fly ash concrete mixes by varying the Class C fly ash to sand to coarse aggregate proportions. Each component was varied from 1 to 2 to 3 parts by weight in relation to other components. He reported that the unconfined compressive strength of fly ash concrete cylinder after 28 days of moist curing ranged from 10 N/mm$^2$ to 57 N/mm$^2$.

Elli Makrides-saravanos, (1995) studied the compressive strength of hardened concrete at ages of 5 hours following accelerated curing and also after 1, 3,7,14, 28, 56 and 91 days of standard curing. He observed that, initially, up to 14 days, the concrete which was prepared with 100% Portland cement developed higher strength than all of the concrete mixtures containing Class C fly ash as partial cement replacements. At the age of 91 days, the compressive strength of the concrete with 20% fly ash was 25% higher than that of control mixture. The compressive strength of the 30% and 50% Class C fly ash concrete mixtures followed a similar pattern and their 91-day strength was similar to that of control mixture.
Naik. Singh and Hossain, (1994) have developed mix proportions for paving roadway concrete with 20 and 50% Class C fly ash and 40% Class F fly ash replacements for Portland cement. They observed that, high volumes of Class C and Class F fly ash concrete mixtures can be used to produce good quality pavements in concrete with excellent durability properties. Compressive strength of fly ash concrete at 40% cement replacement was 8% more than that of normal concrete.

Malhotra and Ramezanianpour, (1994) studied the performance of concrete mixes with slag, fly ash and silica fume under four different curing regimes. The water-to-cementitious materials ratio was 0.5 for all mixtures, excepting for the high-volume fly ash mixture for which this ratio was 0.35. They reported that, the strength of concretes with fly ash was more sensitive to poor curing than the control concrete.

Sivasundaram and Mahlotra, (2004) reported that average compressive strength was 31.2 N/mm\(^2\) at 28 days and average strength at 91-days was 42.3 N/mm\(^2\). They found that at 28 days the compressive strength of fly ash concrete ranged between 70 and 90% of the control concrete. Naik, et al., (1995) investigated the effect of Class C fly ash on the abrasion resistance of concrete.

Feldman et al., (1990) showed the results are plotted as log (compressive strength) versus total porosity. The intercept at zero porosity on the strength axis increases with fly ash content, i.e. a given decrease in porosity gives a greater increase in strength, the greater the fly ash content of the mixture. Aggarwal, (1989) reported that strength of concrete made using 15-20% fly ash as partial replacement of cement, at the age of 90 days or above becomes comparable to the strength of the concrete made up of OPC only.

Sengul, (2005) studied the effect of partial replacement (0% to 70%) of cement by fly ash in concrete on its compressive strength and chloride penetration. He
reported that high volume fly ash concrete has decreased compressive strength at 28 days and the strength has improved at 56 and 120 days.

According to Neville (1996), the variability of fly ash makes it difficult to predict the exact outcome of strength developments. Testing is required for each specific fly ash type and percentage replacement for a given concrete. Table 2.1 shows the compressive strength values, over time, of the average of six type F and four Type C fly ashes. They are all having replacement levels of 25% fly ash. One control mix made with Portland cement is also shown. The pure Portland cement concrete has higher strengths than both fly ash types at all ages. Type C fly ash has higher compressive strength than type F, for most ages. This is because of type C fly ash usually gains strength sooner, is because it contains higher calcium levels (Malhotra, Neville, 1998).

Although, pure Portland concrete generally has higher strength values, relative to a similar one containing fly ash, the incorporation of fly ash can still provide a concrete with adequate strength (Siddique, 2004). The use of fly ash with the use of a superplasticzer to decrease the water cement ratio can have a greater compressive strength than to that of a pure Portland cement concrete.
Table 2.1 Compressive strengths for Portland Cements concretes and Portland Cement Concretes Made with 25% Class F and Class C Fly Ash Replacement

<table>
<thead>
<tr>
<th>Cementitious material</th>
<th>Compressive strength N/mm² at age (days)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Portland cement</td>
<td>12.1</td>
</tr>
<tr>
<td>Class F fly ash (25%)</td>
<td>7.1</td>
</tr>
<tr>
<td>Class C fly ash (25%)</td>
<td>8.9</td>
</tr>
</tbody>
</table>

2.3.2 Split tensile strength

Sahmoran et al., (2009) reported that the tensile strength of concrete, in which 40% of cement was replaced by fly ash, is slightly more than that of control concrete at 180 days. But it was observed to be slightly lower at 28 and 90 days. The increase in tensile strength was obtained for cement: fine aggregate: coarse aggregate proportion of 1:1.99:1.23 with water/binder ratio 0.35. In the above work, the variables were water/binder ratio, quantities of high/low lime fly ash, lime stone powder, coarse and fine aggregates.

Halit Yazıcı, (2008) showed the influence of fly ash content on splitting tensile strength. He observed that with increasing amount of fly ash content beyond 30%, splitting tensile strength also decreased for mixes containing cement was replaced at 30%, 40%, 50% and 60% with fly ash. However, for other mixes consists of cement replace with 10% silica fume improves the tensile strength at all fly ash replacement levels. He also reported that there is slight reduction in tensile strength at 40% and 50% fly ash level when compared with control concrete, splitting tensile strength of 60% fly ash concrete mixture is almost equal to the control concrete.
Antiohos et al., (2007) reported that for the case where fly ashes replaced 20% cement by weight, it is clear that the control concrete (no fly ash addition) performs better than every fly ash specimen up to 7 days of hydration. However, after the first two days, pozzolanic systems are starting to develop strength at a faster rate than the control. In fact after 28 days of curing, all fly ash samples are either approaching or outperform the no-fly ash mortar. At this age, the intermixture prepared with equal contributions from high-calcium and low-calcium ashes is the sample exhibiting maximum strength value. They noticed that fly ash blends with equal contributions from each Class C and Class F fly ash (50:50 ratios) were found to be the most effective for cement replacement. The tensile strength of concrete at 28 days was found to increase by 16.7% at replacement levels of 40% and 50% for water/cement ratios 0.40 and 0.50 respectively. The tensile strength was found to increase by 30% at 50% replacement level with 0.50 water/cement ratio at 91 days.

Siddique, (2004) observed that percentage increase in the splitting strength for the mixtures M-1 (0% fly ash), M-2 (40% fly ash), M-3 (45% fly ash), and M-4 (50% fly ash) was 5%, 43%, 46%, and 36%, respectively, in comparison with 28-day strength. It can be seen from these results the percentage increase in strength at 91 and 365 days with respect to 28-day strength was much more for fly ash concrete mixtures and control mixture M-1. This could be attributed to the pozzolanic action due to fly ash.

Cengiz Duran Atis, (2003) evaluated the strength and drying shrinkage properties of concrete containing high volume of fly ash ranging from 50% to 70% with water binder ratio ranged from 0.28 to 0.34. The split tensile strength of 70% fly ash concrete mixture was 35% lower than the strength of the control mixture at 7 and 28 days, but 10% higher at 7 days and 20% higher at 28 days for 50% fly ash concrete.
mixture. The fly ash content was varied between 30-70% and at all other cement replacement levels; the tensile strength was found to decrease at all the ages of curing.

Siddique, (2003) reported that the addition of fly ash as fine aggregate replacement increases the tensile strength upto 50% fly ash replacement level. In this work, the fly ash was used to replace the fine aggregate content. The replacement levels were 10%, 20%, 30%, 40% and 50% were adopted. The water/cement ratio was varied between 0.47 – 0.50 and cement content was kept constant at 390 kg/m³.

Bouzoubaâ et al., (2001) showed their results indicate that the use of high volume fly ash blended cement improves the splitting tensile strength of concrete, and this increase was due to an increase in the fineness of the fly ash and the laboratory produced cement in the blended cement resulting from the intergrinding of the two components.

### 2.3.3 Flexural strength

Ziad Biyasi et al., (1993) studied concrete mixes with various aggregate binder ratios and silica fume content. A decrease in the aggregate content seems to increase the permeability of silica fume concrete significantly. Their experimental results showed a fact that aggregates have a significantly lower permeability than cement paste.

Jiang et al., (2004) reported that the flexural strength of fly ash concrete at 40% cement replacement level was increased by 9% at 56 days. In this work, the variables were water/binder ratio, quantities of fine and coarse aggregates and replacement levels of fly ash. Fine aggregate: coarse aggregate ratio 1:1.69:3.13 having a water/binder ratio 0.40 were used.

Vasundhara et al., (2004) studied different fly ash replacement levels which were 10%, 20%, 30%, 40% and 50%. The flexural strength was found to increase by
16% and 25.5% at 28 and 365 days respectively at 50% replacement level with 0.50 water/cement ratio. It is reported that there is an increase in the strength 11.34% for 40% fly ash concrete when compared with plain concrete. They showed that marginal increase of 1.6% for 50% addition of fly ash and decrease of 8.76% for 60% fly ash addition compared with normal M 20 grade concrete.

Cengiz Duran Atis, (2003) has studied the strength and drying shrinkage properties of concrete containing high volume of fly ash ranging from 50% to 70% with water binder ratio ranged from 0.28 to 0.34. The mixtures containing 70% fly ash were lower than the strength of the control mixtures. The mixture containing 50% fly ash was higher than the control mixtures at 3 days of age and beyond.

Siddique, (2003) showed that flexural strength continued to increase with the increase in fly ash percentages at all age. He reported that the maximum flexural strength has been found to occur with 50% fly ash content at all ages. The experimental results showed that 4.3 N/mm² at 28 days, 5.2 N/mm² at 91 days, and 5.4 N/mm² at 365 days.

Bouzoubaâ et al., (2001) reported that the flexural strengths of the control concrete made with laboratory produced Portland cement (LPC) and the commercially available ASTM Type III cement were 6.3 and 6.7 N/mm² at 28 days.

Elli Makrides- Saravanos, (1995) studied the mixtures using a coarse/fine aggregate ratio of 1.22 and aggregate/binder ratio of 5.0. The Class C fly ash was used as partial replacement of Type 10 Portland cement at levels ranging between 10-60% by weight of the cementitious materials in the mixture. The aggregates work to arrest cracking when concrete is subjected to tensile and flexural stress and increase the flexural strength of the concrete.
2.3.4 Modulus of elasticity

The Young’s modulus of elasticity is a mechanical property that can control the behavior of concrete. However, unlike the measuring of the compressive strength which is quick and easy, direct measurement of the modulus of elasticity is time consuming and therefore, it is impractical.

Durán-Herreraa et al., (2011) reported that the fly ash substitutions of 15% increased the modulus of elasticity up to 8% in comparison with the reference concrete. For the range of fly ash substitutions studied in this work, the ACI equation to calculate the modulus of elasticity produces conservative estimates when compared with the values obtained through the ASTM procedure.

Raffat Siddique, (2004) has calculated the secant modulus for 33% of the maximum stress. Modulus of elasticity of concrete mixtures was determined at the ages of 28, 91, and 365 days. His results indicated that use of large proportion of fly ash reduced the modulus of the concrete compared to that of control concrete.

Vasundhara et al., (2004) reported that the modulus of elasticity values of concrete containing 50% fly ash are comparable to those of the control concrete and that no significant difference exists between these two concretes. They observed that there is a decrease in modulus of elasticity of fly ash added normal concrete mix about 2 to 4 percent when compared with plain concrete mix.

Siddique, (2003) reported that modulus of elasticity of fly ash concretes continued to increase with the increase in fly ash content. But, the rate of increase is becoming lesser with the increase in fly ash. This trend is more obvious between 40% and 50% replacement level. He also reported the maximum value of modulus of elasticity occurs with 50% fly ash content at all ages.
Bouzoubaâ et al., (2001) reported that the modulus of elasticity values at 28 days for the concrete made with blended cement and the concrete in which the Laboratory-produced Portland Cement (LPC) and the fly ash had been batched separately. They concluded that the reduction of modulus of elasticity values of mixture 1 were due to its high air content and low strength.

Makrides- Saravanos, (1995) was measured static modulus of elasticity was related to the ultimate compressive strength of concrete, at ages between 1 and 91 days. These measurements were performed for concrete containing 50% Class C fly ash and for the control mixtures. The static modulus of plain and fly ash concretes increased in the same direction as their compressive strength.

Baalbaki et al., (1991) have concluded the precise prediction of $E'_c$ of high strength concrete from its compressive strength is unreliable. In concrete incorporating high volumes of fly ash, it has been shown that the development of the modulus of elasticity increased with time following the same pattern is the compressive strength development (Sivasundaram, 1991). They reported values of 41.0 and 34.9 GPa at 28 days for concretes containing 545 and 359 kg/m$^3$ of cementitious material respectively. At 4 months the corresponding values for the modulus of elasticity increased to 45.2 and 38.9 GPa for the same concretes.

Feldman et al., (1990) showed the results of the modulus of elasticity plotted as log (modulus of elasticity) versus total porosity. As with the strength data, the higher the fly ash content, the greater the intercept at zero porosity. From theoretical consideration and practical experience it is determined that 50% or more cement replacement by fly ash, it is possible to produce sustainable, high performance concrete mixtures that show higher workability, higher ultimate strength and high durability.( Malhotra, 1999).
2.4 Chloride Mitigation

Chloride ions may penetrate into the concrete by absorption and capillary forces, diffusion through saturated or nearly saturated concrete and through cracks. Capillary movement is rapid method of transport in case of structures subjected to de-icing salts. Cady and Weyers, (1983) noticed that it is unlikely for water to penetrate that way, because mature concrete has a discontinuous pore system. The concrete holds water in the capillaries, which impedes the driving potential.

Cracking provides an easy pathway for chloride ions to penetrate the concrete cover and reach the reinforcing steel. Structural cracks are aligned perpendicularly to the main reinforcement and therefore, the access of chlorides to the steel bars is limited. These cracks are postponed parallel and directly above bars, and their development depends on the concrete cover, bar diameter, and slump of the concrete (Cady and Weyers 1983).

2.5 Rapid chloride penetration test

Mucteba Uysa et al., (2012) have conducted Rapid chloride ion permeability test on all the concretes containing fly ash and polypropylene fibres at different volume factions. They showed that 30% fly ash concrete mixture had the lowest chloride permeability, rated very low at 90 days among the mixtures had similar compressive strength values when compared with control concrete mixtures. The concrete containing Class C fly ash and Class F fly ash showed better performance when compared with control concretes. The concrete mix containing Class C fly ash performed better than Class F fly ash additive mixture with respect to chloride ion permeability.

Fledman et al., (1994) have investigated the Rapid chloride permeability Test and concluded that the test indicated changes in the pore structure and the resistivity of
the concrete specimens. Nath and Sarker, (2011) showed that total charge passed in the rapid chloride permeability test (RCPT) indicates the chloride ion penetration through the concrete. The fly ash concretes have shown better resistance at both the ages. Penetrability of reduced with the increase of fly ash in the mixtures. At 28 days of age, fly ash concretes achieved ‘Low’ level of chloride ion penetration in contrast to the ‘Moderate’ level of the corresponding control concretes. At 180 days, the chloride penetration level decreased to ‘Very Low’ for the fly ash concretes.

Vengata, (2009) has reported that addition of fly ash in high volumes considerably decreases the permeability of concrete even though the strength of fly ash concrete at 28 days is not encouraging. Suvimol Sujjavanich et al., (2005) concluded that high volume fly ash concrete has lower chloride permeability and has a tendency to minimize or cause no corrosion risk.

Ozkan Sengul, (2005) studied the effect of partial replacement (0% to 70%) of cement by fly ash in concrete on its compressive strength, brittleness index and chloride penetration. He reported that high volume fly ash concrete has decreased compressive strength at 28 days; strength has improved beyond 28 days and better resistance to chloride ions penetration. Naik et al., (2004) conclude that, the concretes made with 70 percent fly ash replacement had fairly coulomb reading early on at 60 days.

Mucteba Uysal Shaun Radomski, (2005) showed that high calcium fly ash concrete had much less coulombs passing through the specimen than the control concrete, but produces lower sulphate resistance. He reported that, high calcium fly ash concrete contains more sulphate susceptible hydration products than the sample containing 100% GU cement, since Rapid chloride penetration test results indicate more sulphate ions penetrating the control mortar bars.
Malhotra and Mehta, (2005) described high volume fly ash concrete with larger replacement of fly ash (greater than 30%) in cement as a beneficial practice for sustainable, durable and economic Concrete.

Poon et al., (2000) carried out the studies on the properties of fly ash concrete with w/b ratio less than 0.30 with high volume of fly ash to produce the high strength concrete. At the w/b ratio of 0.24, 45% fly ash replacement resulted in, 62% and 84% reduction in coulombs passed at 28 and 90 days. They also conclude that, with lower w/b ratio, the values of chloride diffusivity could not reduce further.

Makrides- Saravanos, (1995) have used Class C Fly ash as a partial replacement of type 10 OPC at level ranging from 20—60% by weight of cementitious materials. They used coarse/fine aggregate ratio of 1.22 and aggregate/binder ratio of 5.1 for several concrete mixtures. They noticed that, the presence of large volume of fly ash improved the sulphate resistance of hardened concrete.

Tarun Naik et al., (1994) reported Chloride permeability decreased with age. In this study all concrete mixtures except the 70% fly ash mixture at about 60-day exhibited moderate permeability in accordance with the ASTM C 1202 specification. The 50% fly ash concrete mixture showed lower permeability relative to the no-fly ash concrete at all ages. The 70% fly mixture also performed better than that of the no-fly ash concrete beyond 90 days of curing.

Malhotra, (1990) studied fly ash in concrete, with different types of fly ashes at replacements between 54 to 58 percent, all the mixtures showed good resistance to chloride ion penetration after 91 days. Malhotra and Ramezanianpour, (1994) studied the performance of concrete mixes with ground granulated blast-furnace slag, fly ash and silica fume under four different curing methods. The water binder of 0.5 was
adopted for all the concrete mixtures, excepting for the high-volume fly ash mixture for which this ratio was 0.3.

2.6 Mechanical properties of Polypropylene fibre Reinforced concrete

Hadi, (2007) was conducted a preliminary experimental program and indicated that the inclusion of polypropylene fibres to high strength concrete does not significantly affect the compressive strength of the concrete. Compared to concrete without fibres, the tensile strength was improved with all fibre additions. The compressive strength of the concrete just reached above the definition of high strength concrete for the concrete with 0.3% fibre content. He reported that, the test results of concrete without fibres, there was no significant improvement in compressive strength shown by adding fibres to the concrete mix.

Bentur et al., (1990) reported that the addition of polypropylene fiber and fly ash reduce the unit weight of concrete. They reported that, polypropylene fibre decreases the workability of concrete and compressive strength decreased with the increase of fly ash content. They reported that influence of polypropylene fiber on compressive strength and elastic modulus is found to be insignificant. They noticed that porosity, water absorption and sorptivity coefficient values have increased with the increase of fly ash content and fiber dosages for all mixtures.

Kukreja et al., (1989) reported based on experiments of three methods such as split tensile test, direct tensile test and flexural test, split tensile strength test was recommended for fibrous concrete. They reported that, increase in tensile strength and post cracking strength, toughness for fibrous concrete.

Tensile strength of SFRC was studied by Goash et al., (1989) and reported as inclusion of suitable short steel fibres increases the tensile strength of concrete even in low volume fractions. They found that, optimum aspect ratio was 80 and the
maximum increase in tensile strength was obtained as 33.14% at a fibre content of 0.7% by volume.

Suji, (2007) was used rectangular reinforced concrete beams of 1.8 m long with and without fibre at volume fractions of 0.1%, 0.2% and 0.3%. Moment carrying capacity of beams were arrived and compared with theoretical equations. She reported that the crack pattern remains same for all beams, but the crack width and length were reduced for fibre reinforced concrete beams.

Okan Karahan et al., (2005) reported the comprehensive study on the durability properties of concrete containing fly ash and polypropylene fibres. They observed form their results as the fly ash content increases the compressive strength decreases. The addition of polypropylene fibres in concrete, slightly improve in the compressive strength. At the age of 28 days, the modulie of elasticity of concrete containing 15% and 30% fly ash were comparable with the elasticity modulus of control concrete. They noticed that there is no significant effect of fly ash on the modulus of elasticity. The addition of 0.1% and 0.2% polypropylene fibres reduced the modulus of elasticity values.

Topcu and Canbaz, (2007) studied the effect of steel and polypropylene fibbers on the mechanical properties of concrete containing fly ash. They reported that addition of fibers provide better performance for the concrete, while fly ash in the mixture may adjust the workability and strength-loss caused by fibers, and improve strength gain.

Ravichandran et al., (2009) reported that the use of 80% steel fibres and 20% polyolefin fibres at each volume fraction gives optimum mechanical properties and hybrid fibre of 2.0% volume fraction with 80-20% steel-polyolefin combination has more significant effect on mechanical properties.
Qian et al., (2000) concluded that a certain content of fine particles such as fly ash is necessary to evenly disperse the hybrid fibres containing ultra-fine polypropylene fibres. The optimum dosage of polypropylene fibre was 0.15% under 400 kg/m³ cement and 100 kg/m³ fly ash in concrete.

Sivakumar et al., (2007) studied on mechanical properties of high strength concrete reinforced with metallic and non-metallic fibres. They concluded that steel fibres in concrete could be replaced to a small extent with polypropylene fibres. Wu Yao et al., (2003) studied on mechanical properties of hybrid fiber-reinforced concrete at low fiber volume fraction. From their study, it was shown that carbon fibers have high modulus and tensile strength; steel fibres have similar modulus to carbon fibers and with medium elongation and tensile strength, while polypropylene fibers have high elongation, low modulus, and tensile strength.

Mustafa Sahmaran et al., (2009) studied on hybrid fiber reinforced self-compacting concrete with a high-volume coarse fly ash and it was observed that, incorporation of high volume fly ash reduced the water requirement of a self compaction concrete mixture. The compressive strength reduction due to low pozzolanic activity of the fly ash was partially off-set by the use of smaller size steel fibers. As for the splitting tensile strength, the longer fibers with hooked ends were more effective in characterizing the tensile strength of concrete.

Balaguru and Khajuria, (1996) tested both normal and lightweight concrete with polymeric fibers up to about 4 lb/yd³. They found that the addition of fibers did not change the compressive strengths appreciably. Aulia, (2002) reported through testing a number of aggregates and mixes with polypropylene fibers that the use of 0.2 % polypropylene fibers alone resulted in the low influence on both the
compressive strength and modulus of elasticity of concrete. There was no difference between the compressive strength with and without fibers.

Banthia et al., (2007) reported that polypropylene fibers are highly effective in controlling plastic shrinkage cracking in concrete. They reported that, fibers reduce the total crack area, maximum crack width and the number of cracks. As fiber volume fraction increases, effectiveness of fibre reinforcement increases.

Ziad Bayasi and Jack Zeng, (2002) have conducted some experimental works on workability and mechanical strength properties. Fibrillated polypropylene fibres of length 12.7 mm and 6.4 mm at three volume fractions 0.1, 0.3 and 0.5% were used in concrete and workability properties such as slump, inverted slum cone, air content and mechanical strength properties such as compressive, impact and flexural behaviour were studied.

A study was carried out by Rami Haddad and Ahmed Asteyate, (2001) to predict the role of synthetic fibres such as polypropylene and nylon fibres in delaying steel corrosion cracks and improving the bond with concrete. Different length of polypropylene and nylon fibres with various volumes was mixed with concrete.

Wu Yao et al., (2003) have examined the mechanical behaviour of hybrid fibre reinforced concrete at low fibre volume fraction. Three hybrid composites such as polypropylene and carbon, carbon and steel and steel and polypropylene fibres were chosen and the mechanical properties such as compressive strength, split tensile strength, modulus of rupture and flexural toughness were ascertained. They reported that steel – polypropylene fibre combination gave slightly increased in compressive strength when compared to polypropylene fibre concrete.
Job Thomas and Ananth Ramasamy, (2007) carried some investigations on mechanical properties of steel fibre reinforced concrete. Three different strengths such as normal strength (35 MPa), moderately high strength (65 MPa) and high strength (85 MPa) concrete mixes were selected for this study. The mechanical strength properties and strain corresponding to peak compressive stress were studied. Based on 60 test data regression analysis is done and empirical relations were provided.

Experimental investigation and analytical modeling for flexural behaviour of reinforced fibrous concrete beams using synthetic fibres were performed by Suji and Natesan, (2007) and ultimate strength of steel fibre reinforced self compacting concrete beams were tested by casting 1.2m long reinforced concrete beams using self compacting concrete with steel fibres of three volume fractions of 0.25%, 0.5% and 0.75%. It is found that strength and ductility of fibre reinforced self compacting concrete specimens have increased substantially over conventional concrete.

Balaguru and Khajuria, (1996) have tested the splitting tensile strength of lightweight concrete with polymer fibers. The strengths were not appreciably different at 28 days; they were slightly higher at 7 days. However, the difference was not statistically significant.

Kao, (2005) found that moderate increases in tensile strength at early age with the addition of fibers, but long term there was no significant improvement. This is again primarily due to the low modulus of elasticity of the fibers. However, after cracking, the fibers come into play, and permit a greatly increased ultimate strain, though the load carrying capacity is decreased.

Bing Chen, Juanyu Liu, (2005) studied on contribution of hybrid fibers on the properties of the high-strength lightweight concrete having good workability. They concluded that for single fiber types, carbon and steel fibers can both enhance light
weight concrete and provide an increase in compressive and split tensile strengths at different levels.

Cengiz Duran Atis, Okan Karahan, (2003) studied on properties of steel fiber reinforced fly ash concrete and concluded that the unit weight of concrete increased uniformly with the increase in fiber content and decreased with the increase of fly ash content. They concluded that the behaviour of fly ash concrete is similar to that of Portland cement concrete when fly ash is added with steel fibres in 0.25% and 0.5% volume fractions.

Eswari et al., (2007) studied ductility performance of hybrid fibre reinforced concrete. The influence of fibre content on the ductility performance of hybrid fibre reinforced concrete specimens having different fibre volume fractions was investigated. They reported that, hybrid fibre volume fraction of 2.0% with 30-70 Polyolefin–Steel combine significantly improves the ductility performance of reinforced concrete specimens.

2.7 Durability and performance at high temperatures

The durability of thin sheets has been mainly evaluated. In thin sheet components, where the fibres are primary reinforcement. The polypropylene fibres are having high alkali resistant, and therefore would expect to retain in the highly alkaline matrix. Krenchel, (1998) observed a remarkable reduction in the flexural strength of high fibre volume (10%) composites when the temperature exceeded at 120°C. The elastic modulus will also reduced at high temperatures, but much more gradually reflecting the fact that this property is essentially matrix dependent.

Sivakumar et al., (2007) reported their experimental results of plastic shrinkage studies conducted on high strength silica fume concrete incorporating hybrid combinations of fibres.
Bayasi and Dhaheri, (2002) observed that continuous exposure to the temperatures in the range of 100-200°C led to reduction in the flexural strength and post-peak load bearing capacity of fibrillated polypropylene fibre concretes. Bentur,(1990) reported that the addition of polypropylene fiber and fly ash reduce the insignificant porosity, water absorption and sorptivity coefficient values increased with the increase of fly ash and fiber contents for all concrete mixtures.

2.8 Artificial Neural Networks

Artificial Neural Network (ANN) is computational system whose architecture and operation are inspired from our knowledge about biological neural cells (neurons) in the brain. They do however, model several aspects of information like combining and pattern recognition behavior of real neurons in a simple, but still in a meaningful way. ANNs can be used to learn and reproduce rules or operations from the given examples; to analyze and generalize from sample facts and make predictions from these; to memorize characteristics and features of given data; and to match or make associations from new data to old data in a variety of powerful ways (Flood and Kartam, 1994). The main feature of these networks is their adaptive nature, where ‘learning by example’ replaces ‘programming’ in solving problems. As long as enough data is available, a neural network will extract any regularity from it and form a solution. Another important feature of ANN is its essential parallel architecture that allows for fast computation of solution when these networks are implemented in customized hardware (Bandyopadhyay, and Chattopadhyay, 2007).

Artificial Neural Networks are advantageous when compared with conventional digital computing techniques. This is because of their special features like massively parallel processing, distributed storing of information, low sensitivity to error, their very robust operation after training, generalization adaptability to new
information (Schalkoff, 2002). Neural Networks are learn by examples. They can be trained with known examples of a problem to ‘acquire’ knowledge about it. Once appropriately trained, the network can be put to effective use in solving ‘unknown’ or ‘untrained’ instances of the problem.

Mohammed et al., (2002) have developed an Artificial Neural Network model to predict the behavior of fracture toughness and the tensile strength as function of micro structural applications. The developed model was to predict the best toughness properties in terms of inter-critical annealing temperature and marten site content, which could be used as partial tool for predicting the fracture toughness.

Ince, (2004) predicted the fracture parameters of concrete by artificial neural networks and compared the results of two-parameter model. In this investigation back-propagation feed-forward network was used. The author was developed ANN model with 22 data sets and tested with 18 data sets to validate the model. He concludes that the ANN can predict fracture characteristics with an accuracy which is widely acceptable for most design considerations.

Serkan Suba, (2009) has studied the application of artificial neural networks and regression techniques to predict the compressive and flexural tensile strength of mortars with various amount Class C fly ashes. In this model a multilayered feed-forward neural network with a back-propagation algorithm was used. They also reported that, compressive and flexural tensile strength values of mortars with different amount Class C fly ash can be predicted in a quite short period of time with tiny error rates by using the multilayer feed-forward neural network models when compared with regression techniques.

Akhmad Sryadi et al., (2010) have developed artificial neural net works for evaluating compressive strength of self compacting concrete. They selected six input
parameters and total of 250 different data sets of self compaction concrete were collected from ready mix plant and concrete lab. The Training data sets consist of 120 data entries and the remaining data entries are divided between the testing and validation sets. They reported that, the error for the training set was 1.74 % for the 120 training data sets at running time 43.890 seconds.

Paratibha Aggarwal et al., (2011) have compared the ANN prediction between the models developed to predict 28 days compressive strengths using neural network techniques. The back propagation neural net work was used to model both the problems those involved in nonlinear variables. The authors was used correlation coefficient for judging the performance of the model. They concluded that ANN is viable computational model for a wide variety of problems including prediction problem.

Artificial neural networks (ANNs) have been used to predict various strength properties of concrete. The main objective in building an ANN-based model is to train a specific network architecture using a comprehensive database to search for an optimum set of weights (connection strengths between its processing units) for which the trained ANN can predict accurate values of outputs for a given set of inputs from within the range of the training data. A neural network model requires no functional relationship among the variables, as is the case with most of other regression analysis techniques.

The main advantage of ANNs is that one does not have to assume an explicit model form, which is a prerequisite in the parametric approaches. Indeed, in ANN models, a relationship of a possibly complicated nature between input and output variables is generated by the data points. In comparison to parametric methods, ANNs can deal with relatively imprecise or incomplete data and approximate results, and are
less vulnerable to outliers. They are highly parallel, that is, their numerous
independent operations can be executed simultaneously (Haykin, 2001).

Vaishali G et al., (2013) have developed Genetic Algorithm based neural
network model for predicting the mechanical properties of High performance
concrete. They trained neural network model using 300 examples obtained from their
experimental values. They reported that the genetic algorithm based network model is
able to predict the mechanical properties of High performance concrete satisfactorily
with an accuracy of about 95%. They also reported that, genetic algorithm based
models can serve as a macro-mechanical model to predict the strength of high
performance concrete.

Dias and Pooliyadda, (2001) were used back propagation neural network
models to predict the strength and slump of ready mixed ordinary concrete as well as
high strength concrete. Basma et al., (1999) proposed a method for the prediction of
cement degree of hydration using ANN. Nehdi et al., (2001) has developed a neural
network model for performed foam cellular concrete. Their results showed that the
compressive strength of cellular concrete mixtures can be predicted much more
accurately by using ANN model.

Zong, Gung and Yun, (1999) have utilized an automatic knowledge
acquisition system, based on neural networks, to design concrete mixtures. They
proposed a method to predict 28-day compressive strength by using multi layer feed
forward neural networks.

Yeh, (1998) has developed a strength based Artificial Neural Network model,
which was found to be more accurate than the regression analysis. ANN model gave
the detailed effects of the proportions of each variable from the concrete mixtures.
Sudarsana Rao et al., (1997) have developed network model validation by observing the difference between the stress–strain paths obtained from finite element and artificial neural network for new interface shear strengths of ceramic matrix – composites (CMC). Their network model has been validated for two new interface shear strengths within the application domain of the network. The stress–strain response of CMCs with IFS values of 1200 MPa and 1400 MPa have been obtained from the trained network. They reported that, the stress–strain path for a number of new samples from the genetic algorithm/ back propagation neural network model can be obtained very quickly, with a significantly less computational efforts when compared with finite element model.

2.9 Concluding Remarks:

The literature survey reported that incorporating fly ash in concrete reduces the compressive strength at early ages but there is a drastic increase in the compressive strength at later ages. The early strength is reduced further if the percentage of replacement is increased. But, on the other hand when the percentage of replacement is increased the water/ binder ratio gets reduced, thereby, increasing the later age compressive strength. Also, it is observed that the later age strength of concretes having more than 40% replacement of cement by fly ash suffers adversely though water/ binder ratio is gradually reduced. For concretes with less than 40% replacement of cement, the characteristic strength at 28 days is on higher side. Whereas, for concrete with 40% replacement of cement, the 28 days compressive strength is at par with that of plain concrete. The concrete with more than 40% replacement of cement show lesser 28 days strength but gains better strength at 90days or later.
From the above literature review it can be concluded that studies on concrete containing the Class C fly ash are limited. Numerous research studies have been conducted on the strength development of concrete containing Class F fly ash as partial replacement of Portland cement. Therefore there is need to study the effects of Class C fly ash with and without polypropylene fibers at different volume fractions (upto 0.3%). The fibers are used to enhance the tensile properties of concrete such as split tensile strength and flexural strength. The water binder ratio 0.35, 0.4, 0.45 and 0.5 is used with variable aggregate binder ratio of 1.50, 1.75 and 2.00 to achieve the medium to high strength concrete. The effect of Class C fly ash as cement replacement on durability characteristics of concrete with and without polypropylene fibers is to be evaluated.