CHAPTER 2

LITERATURE REVIEW

2.1 HISTORICAL DEVELOPMENT OF SCC

The purpose for development of SCC is the social problem on durability of concrete structures that arose around 1983 in Japan. Due to a gradual decrease in the number of skilled workers in Japan's construction industry, a similar decrease in the quality of construction work took place. As a result of this fact, one solution for the achievement of durable concrete structures independent of the quality of construction work is the implementation of SCC. Development of the first practicable SCC by researchers Okamura and Ozawa, around 1986, at the University of Tokyo and the large Japanese contractors (e.g. Kajima Co., Maeda Co., Taisei Group Co., etc.) quickly took up the idea.

Bouzoubaa et al (2001) referred that researcher at the University of Tokyo, Japan, started in late 1980’s to develop SCC to be mainly used for highly congested reinforced structures in seismic regions. The reason behind developing this concrete is the concerns regarding the homogeneity and compaction of cast-in-place concrete within intricate highly reinforced structures, improvement of overall durability and quality of concrete etc., due to lack of skilled labor in Japan. In the early 1990’s there was only a limited public knowledge about SCC, mainly in the Japanese language. Concurrently with the Japanese developments in the SCC area, research and development continued in mix-design and placing of underwater concrete where new
Admixtures are producing SCC mixes with performance identical to the Japanese SCC concrete (e.g. University of Paisley / Scotland, University of Sherbrooke / Canada) as stated by Ferraris (1999).

A major limitation of SCC is that there is a lack of globally agreed upon test standards and mix designs. The contractors used their large in-house research and development facilities to develop their own SCC technologies. Each company developed their own mix designs and skilled their own staff to act as technicians for testing on sites their SCC mixes. Special applications such as underwater concreting have always required concrete, which could be placed without the need for compaction. A very important aspect is that each of the large contractors also developed their own testing devices and test methods as presented by Bartos (2000).

2.2 BASIC PRINCIPLES

SCC consists of the same components as in normal concrete, i.e., cement, aggregates, water, additives or admixtures. However, the high dosage of SP used for reduction of the liquid limit and for better workability, the high powder content as ‘lubricant’ for the CA, as well as the use of viscosity-agents to increase the viscosity of the concrete have to be taken into account. SP enhances deformability and with the reduction of W/P, segregation resistance is increased. High deformability and high segregation resistance is obtained by limiting the amount of coarse aggregate (CA). These two properties of mortar and concrete in turn lead to self-compactability limitation of CA content. Figure 2.1 shows the basic principles for the production of SCC.
2.3 METHODS FOR ACHIEVING SELF COMPACTION

SCC consists of powder (Cement + filler) in high volume rather than normal concrete; this can be normally achieved with replacement of CA from conventional concrete. This involves high deformability of paste or mortar and resistance to segregation of CA from mortar because concrete has to flow during confined zones and around obstacles like rebars. This in turn is achieved by limiting the aggregate content, using a low water-powder (W/P) ratio and use of a SP. The methodology is shown schematically given by Okamura and Ozawa (1995) as below in Figure 2.2.

**Figure 2.1 Basic principles for production of SCC (Dehn et al 2000)**

**Figure 2.2 Methods for achieving Self-Compactability**
SCC can be proportioned in several ways; however, in general two main technologies have been developed. In the first technology a SP is used in combination with a large quantity of fine materials. The second technology is based on the addition of a SP and a viscosity modifying agent (VMA). For mix based on the second technology, the yield strength; which is the amount of stress required initiating plastic deformation in a material, is controlled by the SP, while the plastic viscosity and segregation resistance is controlled by VMA. These viscosity agents can play the same role as that of fine particles in the first technology. SP improve deformability and with the reduction of W/P segregation resistance is increased. High deformability and high segregation resistance is obtained by limiting the amount of CA. These two properties of mortar and concrete in turn lead to self-compactability limitation of CA content. In this research, only powder type SCC is investigated due to its simplicity, economy and sustainability. Concrete is normally classified as SCC if the requirement for all three characteristics such as passing ability, filling ability and resistance to segregation is fulfilled.

2.3.1 Passing Ability

Passing ability is the ability of the concrete to flow though restricted spaces without jamming. This property is related to the maximum aggregate size and aggregate volume, and the L-Box test is the most common method used to evaluate this property. A visualization experiment conducted by Okamura (1997) showed that obstruction occurred from the contact among CA. As the distance between particles decreases, the potential for blocking increases due to particle collisions and the build-up in internal stresses. Decreasing the CA volume can reduce inter-particle interaction, and it has been shown that the energy required to initiate flow is often consumed by the increased internal stresses and CA. Hence, Okamura (1997) recommended that the aggregate content should be reduced in order to avoid blockage. The
relative displacement from the change in aggregate location causes shear stress in addition to compressive stresses, and in order to flow easily through the narrow spaces the shear stress should be minimized as proposed by Okamura et al (1999). As a result, the viscosity of the paste should be high enough to avoid the localized increases in the internal stress due to the CA particles approaching each other as discussed in Okamura et al (1999). The mechanism for achieving Self-Compactability is given in the Figure 2.3.

![Figure 2.3 Mechanism for achieving Self-Compactability (Okamura et al -1999)](image)

As concrete approaches and flows through narrow spaces, a difference occurs in the velocities of the aggregate and the relative location of the aggregate changes. This velocity difference results in the matrix preceding the aggregates through the space and hence the aggregate content is locally increased as new aggregate particles flow into the area and add to the remaining particles as stated by Noguchi et al (1999).
2.3.2  Filling Ability

Filling ability, or flowability, is the ability of the concrete to completely flow (horizontally and vertically upwards if necessary) and fill all spaces in the formwork without the addition of any external compaction. The flowability of SCC is characterized by the concrete’s fluidity and cohesion, and is often assessed using the slump flow test. Kennedy (1940) projected the “Excess Paste Theory” as a way to explain the mechanism governing the workability of concrete. Without the paste layer, too much friction would be generated as the aggregates moved and workability would be impossible. Nielsson and Wallevik (2003) designed SCC with decreased filling ability by only altering the paste composition while keeping the aggregate composition the same, and confirmed the theory that filling ability is primarily a function of the cement paste matrix.

2.3.3  Stability

Segregation is defined as the separation of CA particles from the mortar matrix during transporting, placement and setting of fresh concrete. There should be minimum segregation of the aggregates (both fine and coarse) from the matrix and little bleeding. One of the most important requirements for any self-flowing material is that the particles remain suspended while the material is at rest. Bleeding is a special case of segregation in which water moves upwards and separates from the mix. Bleeding is normal for concrete. But excessive bleeding can lead to a decrease in strength, high porosity, and poor durability particularly at the surface. Stability is largely dependent on the cohesiveness and viscosity of the concrete mixture, and reducing the free water content and increasing the amount of fines can increase cohesiveness and viscosity. A reduction of free water content has been shown to develop stability while decreasing inter-particle friction among solid particles as stated by Khayat et al (1999).
2.4 APPLICATION OF SELF COMPACTING CONCRETE

The development of SCC marks an important milestone in improving the product quality and efficiency of the building industry. SCC can also be used in situations where it is difficult or impossible to use mechanical compaction for fresh concrete, such as underwater concreting, cast in-situ pile foundations, machine bases and columns or walls with congested reinforcements. Recently, this concrete has gained wide use in many countries for different applications and structural configurations as stated by Bouzoubaa (2001). It can also be regarded as "the most revolutionary development in concrete construction for several decades". Originally developed to offset a growing shortage of skilled labour, it is now taken up with enthusiasm across the world for both site and precast concrete work. It has been proved beneficial economically because of a number of factors as given by Krieg (2003).

- Simple placement in complicated formwork and tight reinforcement
- Reduction in construction times, site manpower and noise pollution
- Higher and more homogenous concrete quality across the entire concrete cross-section especially around the reinforcement
- Concreting deep elements in single lifts
- Improved concrete surfaces, finishes, durability and bond strength
- Typically higher early strength of the concrete (formwork can be removed quickly)
- Higher moisture retention may aid curing
• Improved greater freedom in design
• Safe working environment

2.5 WORLD-WIDE CURRENT SITUATION OF SCC

SCC has already been used in several countries. In Japan, major construction projects included the use of SCC in the late '90s. Today, in Japan, efforts are being made to free SCC of the “special concrete” label and integrate it into day-to-day concrete industry production proposed by Okamura (1997). It is estimated that the daily production of SCC in the precast concrete industry in the United States will be 8000 m$^3$ in the first quarter of 2003 (around 1% of the annual ready-mix concrete). Research regarding the SCC is also carried out in Canada, few years after the concept was introduced in Japan. The introduction of the SCC in Europe is largely connected with the activities of the international association RILEM, France, particularly of its Technical Committee TC145-WSM on “Workability of Fresh Special Concrete Mixes” discussed by Dhir et al (1999). Housing and tunneling, as well as bridge construction for the Swedish National Road Administration were the main areas of use for SCC. In the Netherlands and Germany, the precast industry is mainly driving the development of SCC. SCC is used in many high-rise buildings, airport pavement, concrete-filled steel tubes, precast columns and beams. For example, Tao Jin (2007) was used C60 high strength SCC in the shear wall of Capital Airport. In the following, a summary of the articles and papers found in the literature, about the SCC and some of the projects carried out with this type of concrete, is presented.

2.6 USE OF SECONDARY RAW MATERIALS IN CONCRETE

Secondary raw materials (SRM’s) are defined in the literature by different ways like supplementary cementitious materials, fillers, fines and
powders depending upon their role in fresh and hardened state. These are less energy demanding materials, mainly industrial by-products. They may require little or no pyro-processing. They hold in themselves little or no cementitious value. They are available in finely divided form. Use of CRD and MSP in concrete represents a relatively new concept, several research studies have been conducted on some of the effects of these fines on the properties of concrete. Bonen et al (2005) stated that the large surface area of the filler fraction of the aggregate, the addition of filler may modify the rheological properties of fresh concrete to a great extent.

Generally, very fine particle are believed to increase the water requirement of concrete and therefore harmful to concrete. Mathematical particle packing theories, however, show the opposite. In concrete fine powder particles having binder and mineral powders fill the spaces between aggregate particles. The space remaining between fine powder particles is then filled with water and to a lesser extent with air also. For workability some excess water is needed for particle mobility. The main reason between practical experience and mathematical modeling is the flocculation of small particles. In mixes without plasticizer, fine particles are flocculated and cannot fill spaces of their own class size, which is why they often require more water. The first condition that must be met for high density is the use of SP to break flocculation and hence achieve uniform packing.

The consumption of calcite, the formation of carbo-aluminates, the accelerating effect on the hydration of $C_3A$, $C_3S$, the change in the CSH and formation of transition zone between the filler and cement paste, are all facts specific of the reactivity of MSP fillers. The addition of MSP as filler is a possibility to achieve this in the most satisfactory way. The resistance of concrete against pure and acid water is definitely increased by addition of filler materials in Portland cement. Fillers have been reported to accelerate the
cement hydration in some cases. Examples of increased compressive strength also exist. This is believed to be due to a general filler effect, i.e. that the cement hydration products may grow faster and become more evenly distributed in the presence of small mineral particles. In addition to the general filler effect, there might be chemical effects, in some cases pozzolanic reactions.

The alkali-silica reaction in concrete is known to result in cracking and overall expansion of structural elements. There are some examples in the literature indicating that the finest particles of alkali-reactive aggregates should not be considered dangerous in concrete. Some researchers have reported that filler particles below a critical limit, which has been reported to be in the order of 50 µm for some rocks, may give pozzolanic reactions, and consequently be beneficial. However, there have been reported cases where particles smaller than 20-30 µm give very fast and deleterious reactions. The use of fillers can considerably improve the transport properties and durability of concrete. However different dosages and combinations of supplementary materials can yield significantly different response.

2.6.1 **Crusher Rock Dust**

Crusher Rock Dust (CRD) fine aggregate could be an alternative of natural sand. It is a by-product generated from quarrying activities involved in the production of crushed CA. Quarry waste fine aggregate, which is generally referred as a CRD, causes an environmental load due to disposal problem. Hence, the use of CRD in concrete mix will reduce not only the demand for natural sand but also the environmental problem. In brief, the successful utilization of CRD will turn this waste material into a valuable resource. Unfortunately, limited research has been conducted to explore the effective utilization of CRD in concrete mix.
Al-Manaseer et al (1998) and Haque et al (1989) used Fly ash, slag, and limestone and siliceous stone powder in concrete mix as a partial replacement of river sand. As the properties are as good as the sand, the CRD are used as FA in the cement concrete. The introduction of modern, scientifically operated crushers proved better projection to CRD by utilizing the stone chips in the size range of 2 to 6mm, otherwise considered as waste marginal product as presented in Shetty (2002). The ordinary stone dust obtained from crushers does not comply with IS: 383-1979. Chitlange et al (2008) found that the presence of flaky, poorly graded and rough textured particles result in hash concrete for given design parameters. Use of CRD as a FA in concrete draws serious attention of researchers and investigators. Zain et al (1999) recommended that the CRD for production of high strength concrete compared to river sand. Mujtaba et al (2005) found higher content of dust in the aggregate increases the fineness and the total surface area of aggregate particles, where surface area is measured in terms of specific surface, i.e. the ratio of the total surface area of all the particles to their volume.

2.6.2 Marble Sludge Powder

In India the extractive activity of decorative sedimentary carbonate rocks, commercially indicated as “Marbles” and “Granites”, is one of the most thriving industries. Fines are generated in the ornamental stone industry during drilling, grinding, polishing, and sawing process. Marble Sludge Powder (MSP) is generated as a waste during the cutting and polishing of the marble. In all quarry operations fines are collected during the whole process chain by particle filter devices. Fines are removed from the material to be washed by wet sieving and/or separation in hydro cyclones. The outcome of this process is slurry highly loaded with a fine fraction of the appropriate rock type. This slurry is sometimes pumped directly into settling ponds where it
represents an environmental burden on the water and soil. Misra et al (2002) pointed out that, in India the amount of the MSP generated is very substantial being in the range of 5-6 million tones per annum. The heaps of this MSP acquire large land areas and remain scattered all around, spoiling the aesthetics of the entire region and have affecting the tourism and industrial potential of the state. Figure 2.4 represents the MSP generated during cutting and Figure 2.5 represents the MSP wastes dumped on road side.

Figure 2.4 Marble sludge generated during cutting

Figure 2.5 MSP wastes dumped on road side
Valeria Corinaldesi et al (2005) stated that the stone sludge generated during processing corresponds to around 40% of the dimension stone industry final product and this is relevant because dimension stone industry presents an annual output of 68 million tons of processed product. And they studied the physical properties of MSP and found it has a very high Blaine fineness value of about $1.5 \text{ m}^2/\text{g}$, with 90% of particles passing 50 $\mu\text{m}$ sieves and 50% under 7 $\mu\text{m}$. They used MSP as the replacement of sand and found that MSP performs better than the case of the marble powder used as the replacement of cement and 10% substitution of sand by the MSP provided maximum compressive strength at about the same workability. The hazardous dumping practices create a cruel danger on the environment, eco-system and health of the people. Prevention of landfill and a useful application of these rock powders would therefore constitute a great environmental benefit. Pratomo (2001) concluded that calcium or lime is main component of marble.

In conventional concrete, the introduction of high volumes of MSP to concrete mixes is limited due to its high fineness. Its corporation in excess amounts to fresh concrete increases the water demand, which has negative effects on the properties of fresh (longer setting times) and hardened concrete (low strength due to increased capillary porosity and loss of interface adhesion between cement paste and aggregate). In some cases, the cohesive content of MSP can increase depending on the clay veins embedded in marble rocks. From this point, the side effects of fine portion of MSP aggregates that spoil the concrete performance should also taken into account. However, these fines can be efficiently utilised as viscosity enhancer particularly in SCC applications. Thus, the successful utilisation of MSP in SCC could turn this material into a valuable resource. Brian Mitchell (2004) analysed the effect of addition of MSP with Portland cement modifies the relative content in hydrates as well as the microstructure. The MSP reacts with free $\text{Ca(OH)}_2$
to produce calcium silicate hydrate. Thus, the amount of binder is increased, which both increases the strength and reduces the permeability by densifying the matrix of the concrete.

2.7 APPLICATION OF EXCESS PASTE THEORY

In 1918, Abrams (1918) proposed a theory regarding reasonable mixing method for concrete. It is about the water and cement ratio and the proportion of CA. And about 20 or so years later, Kennedy (1940), proposed the “Excess Paste Theory”, which is essential to the understanding of the mechanism of the workability of fresh concrete. In the Figure 2.6, the left side model shows that the dispersion effect on aggregates closely contacted to each other, with void in between them.

![Figure 2.6 Dispersion effect on aggregates (Kennedy, 1940)](image)

If this model is fixed with cement paste, these closely packed aggregates are then separated by this thin film of cement paste around them, as the model on the right side shows. Also we could notice that the void is gone, filled up with cement paste. As we can see, adding cement paste will
change the interaction among aggregates. This is sort of a dispersion effect, i.e., aggregates are pressed away from each other. Without a film of cement paste around them, the movement between aggregates would generate much friction and make workability impossible.

### 2.7.1 The Computation Method for Excess Paste

Using the assumption of the two-phase flow theory, there is a good continuous grading of aggregates. To attain high workability on concrete, it is necessary to have a good spacing between the aggregates, as to minimize the friction between them. Figure 2.7(a) shows a concrete sample with a good spacing between the aggregates that are covered by cement paste. Then compact the aggregates, and squeeze out the excess cement paste surrounding them. A top layer with just the paste itself and below it a compact state of aggregates, with just enough cement paste to fill in the void space, as shown in Figure 2.7(b).

![Figure 2.7 Excess paste theory (Kennedy, 1940)](image)

This cement paste in between the voids is ‘compact paste’ ($P_c$) and the cement paste that wraps around the aggregates is the so-called ‘excess paste’ ($P_e$), which is calculated by subtracting $P_c$ from $V_p$, the total volume of paste, as shown by Equation (2.1). We can also calculate the thickness of the
excess paste (t_p) by just simply dividing the volume of the excess paste (P_e) by the total surface area of the aggregates (S_all), as shown in Equation (2.2).

\[ P_e = V_p - P_c \quad (2.1) \]
\[ t_p = \frac{P_e}{S_{all}} \quad (2.2) \]

### 2.8 MIX DESIGN

The basic components for the mix composition of SCC are the same as in normal concrete. However, Brian Mitchell (2004) stated that the importance of adding higher proportion of ultra fine materials and the inclusion of chemical admixtures, in particularly an effective SP in the SCC to improve the properties of fresh concrete. Ordinary and standard filler materials such as fly ash, limestone powder, blast furnace slag, silica fume and quartzite powder, MSP can be used in SCC mixture design too. A comparison of mix proportioning between SCC and NVC can be seen in Figure 2.8.

![Figure 2.8 Comparison of mix proportioning between SCC and NVC (Guerra M. Eddie - 2006)](image-url)
For both concrete types, the cement and water content is similar, however a decrease in CA content with a corresponding increase in fillers and sand is required in SCC in order to ensure high flowability without segregation. SCC design procedures are in general based on the two technologies mentioned above; however scientific theories and practical experiences have been proposed for SCC mixture proportioning too. ACI committee 237 R-04 (2007) has given guidelines for SCC mixture proportions, as seen in Table 2.1. Mortar fraction is defined as the product composed by cement, sand and water, while powder content includes all cementitious materials.

More recently, Su et al (2001) and Su and Miao (2003) developed an alternative method for composing SCC, henceforth referred to as Chinese Method. The Chinese Method starts with the packing of all aggregates (sand and gravel together), and later with the filling of the aggregate voids with paste. The method is easier to carry out, and results in less paste. This saves the most expensive constituents, namely cement and filler, and concrete of “normal” strength is obtained.

Table 2.1 Mix proportions given by ACI 237 committee

<table>
<thead>
<tr>
<th></th>
<th>28 to 32%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Absolute volume of CA</td>
<td>28 to 32%</td>
</tr>
<tr>
<td>Paste fraction (calculated on volume)</td>
<td>34 to 40% (total mixture volume)</td>
</tr>
<tr>
<td>Mortar Fraction (calculated on volume)</td>
<td>68 to 72% (total mixture volume)</td>
</tr>
<tr>
<td>Typical cement (powder content)</td>
<td>385 to 475 Kg/m³ (lower with a VMA)</td>
</tr>
</tbody>
</table>

This will also favour the technical performance of the concrete, as the largest possible volume of aggregate is advantageous in regard to strength,
stiffness, permeability, creep and drying shrinkage. The relation between packing and concrete properties is generally known, and usually a grading curve is selected for the aggregate as discussed in Neville (1995). Okamura and Ozawa (1995) have proposed a simple mix proportioning system for SCC, which will henceforth be referred to as Japanese Method. The coarse and FA contents are fixed so that self-compactibility can be achieved easily by adjusting the W/P ratio and SP dosage only. The method suggests that the gravel content in the concrete mix corresponds to 50% of its packed density, and that in the mortar the sand content corresponds to about 50% of its packed density as shown in Figure 2.9.

![Figure 2.9 Schematic composition of SCC (Okamura and Ozawa, 1995)](image)

In the Netherlands, and many other European countries, the Japanese Method has been adopted and used as a starting point for the development of SCC.

The mix design procedure of Japanese method is as follows:

- The CA content (all particles larger than 4 mm and smaller than maximum size of aggregate) is fixed in the range of 50
to 60% of the solid volume or 28 to 35% of the concrete volume or 700 to 900 kg/m³ of concrete.

- The FA content (all particles larger than 0.125 mm and smaller than 4 mm) is fixed in the range of 40 to 50% of the mortar volume.

- The W/P ratio is assumed in the range of 0.25 to 0.35 (by mass), depending on the properties of the powder (i.e. cement and filler having particles smaller than 0.150 mm).

- The SP dosage and the final W/P ratio are determined through trial mixes so as to ensure self-compactibility using U-flow, slump-flow and V-funnel tests. Target values are U-flow of 0 to 30 mm, slump-flow of 650 to 800 mm, and V-funnel time of 6 to 12 seconds.

A flow-chart describing the procedure for design of SCGC mix is shown in Figure 2.10. Self-compactability can be largely affected by the characteristics of materials and the mix proportion. A rational mix design method for SCGC using a variety of materials is necessary.

**Figure 2.10 SCGC Mix design procedure**
In this research Japanese Method proposed by Okamura and Ozawa, (1995) is adopted. The principal consideration of the Japanese Method is that the voids of the FA are filled with paste (cement, powder, water). The voids need to be filled with paste so that a workable fresh concrete is attained.

2.9 PREVIOUS RESEARCH WORK RELATED TO OUR STUDY

Zhu et al (2001) described SCC as a high performance material which flows under its own weight without requiring vibrators to achieve consolidation by complete filling of the formworks even when access is hindered by narrow gaps between reinforcement bars. Studies to develop SCC, including a fundamental study on the workability of concrete, were carried out by Ozawa and Maekawa (1989) at the University of Tokyo. They have done some research independently from Okamura, and in the summer of 1988, they succeeded in developing SCC for the first time. The year after that, an open experiment on the new type of concrete was held at the University of Tokyo, in front of more than 100 researchers and engineers. As a result, intensive research has begun in many places, especially in the research institutes of large construction companies and at the University of Tokyo. He completed the first prototype of SCC using materials already on the market. Other experiments carried out by Ozawa focused on the influence of mineral admixtures, like fly ash and blast furnace slag, on the flowing ability and segregation resistance of SCC. He found out that the flowing ability of the concrete improved remarkably when Portland cement was partially replaced with fly ash and blast furnace slag.

Fowler and Constantino (1997) recently presented an up-to-date review of research on different aspects of application of an increased percentage of fines in concrete that have either been performed in the last
couple of decades or are in progress in various locations across the globe. Research on mineral fines in concrete, has shown that in general, up to 15% of fines can be used in the FA without causing significant changes in the strength of the concrete. It is of some significance that most of these research efforts have focused the use of fines as a replacement for sand in concrete, rather than a replacement of cement.

A study was performed in Spain by Ramirez et al (1990), fines content varying from 5 to 25%, while holding the slump constant. Furthermore, they attempted to monitor the percentage of clay present in the fines using the sand equivalent test to keep the clay within the range of 0 to 4%. As a result of this study, they found that the compressive strengths were not affected by a replacement of sand with up to 25% fines, provided the fines contained 0% clay particles.

Nehdi et al (1996) recently completed another study on filler fines in concrete. They used limestone fines and silica fume to develop triple-blended cement. The concentrations of fines and silica fume were varied while everything else was kept constant. The results show that a triple-blend with 10% limestone fines and 10% silica fume was able to achieve higher compressive strength than normal concrete at 12 hours. The 28-day strength obtained using ordinary Portland cement was outperformed when a total of 20% fine powder by mass of cement compressing a combination of 10% limestone filler and 10% silica fume was used, yet at the same time, the concrete was more cost effective.

Siddarth Pareek (2001) observed that the important factors that influence the rheological behavior of CRD and MSP are the quality of the filler and its fineness. If the quality of CRD and MSP rock is good, rheology of the mortar or concrete remains unaffected. On the other hand, the presence of clay in CRD and MSP increases the water demand, thus negating the
beneficial effect of CRD and MSP filler. The fine particles of fillers have a favorable action; in the case of finely ground fillers, the water-reducing action is greater for W/C <0.40, though the effect may be opposite if clay is present.

Kliger et al (1990), however, saw no clear trend regarding the effect of carbonate addition on sulphate resistance. He rather concluded that sulphate resistance is not affected by carbonate additions but is primarily determined by C₃A content. He observed no clear trend for the effect of limestone addition on setting times. Similarly, in a series of tests conducted by him, he noted that the addition of filler fines appears to have little effect on the setting time where ground to more or less constant Blaine fineness.

Moir and Kelham (1989) reported that permeability to oxygen for a series of concrete made with cements with or without 5% or 25% fines slightly reduced due to the presence of limestone. Permeability is the key to durability of a porous material. Deterioration mechanisms involve the ingress of water and/or other harmful species (oxygen, carbon dioxide, chlorine, sulphate ions, acids etc.). Pore size is less important than the connectivity of the pore system. Further, extended curing reduced the permeability significantly. However, porosity and water sorptivity were similar for both the control and limestone cements.

Feldman et al (1992), examined Portland cement mortars exposed to NaCl and MgCl₂ solution, concluded that the moduli are reduced and expansions increased compared to controls exposed to Ca(OH)₂ solution. Chloride exposure is equally deleterious to the strength of mortars with or without limestone fillers. However, they noted that limestone filler is effective in protecting the steel from corrosion. As a matter of fact, concretes containing these CRD and MSP fines behave much the same as limestone fillers with respect to freeze-thaw and seawater resistance, and chloride diffusion properties.
According to Cochet and Sorrentino (1993), the strength gain achieved by using filler comes from (a) the water reducing effect of filler, (b) better use of hydraulic potential of clinker, and (c) optimization of quality of clinker at a given strength class. Furthermore, the optimum amount of filler in a concrete mixture depends on the maximum size of aggregate, grading of aggregate, mineralogical composition, and particle shape. Another French study Regourd (1976), focused on the particle size distribution and the chemical makeup of concretes when fillers are used. She reported that the substitution of fines serves to fill the gaps in the finer portion of the particle size distribution curve.

Jackson and Brown (1996) in comparing river sand versus CRD drew similar conclusions. They found that in most applications, use of a higher amount of fines in manufactured sand helps to improve workability, increase density, reduce w/c, and therefore achieve higher strength. Their experience, however, demonstrated that if the fines content exceed 10 %, plastic shrinkage is likely to occur; if the bleeding rate is lower than the evaporation rate, then this is quite possible. Furthermore, Jackson and Brown assert the importance of differentiating between fines representing the dust of fracture and naturally occurring fines that typically contain a high amount of clay. They attribute the beneficial properties of fines in concrete to its filler action, that is, fines help to reduce the voids and lubricate the CA particles without the need for additional water.

Daimon et al (1978) discussed as the fresh and hardened properties of superplasticized concrete has become active after the invention of sulfonated naphthalene formaldehyde (SNF) and sulfonated melamine formaldehyde (SMF) SP’s in the early 1970s. In the late 1970s and early 1980s, the concepts of “rheoplastic concrete” discussed in Collepardi (2001) and “flowing concrete” dealt in Banfill (1980) and Dhir et al (1983) emerged
to describe this self-flowing property of the fresh concrete. Evidence from the literature has showed that, in the early 1980s, such “flowing concrete” is not only limited in laboratory studies but is already available for practical applications. For example, a case study in Hong Kong in the construction of Tin Hau Station of the Mass Transit Railway has indicated that the concrete used for the construction required no vibration for consolidation as dealt in Sharpe et al (1985).

According to Neville (1995), there can be no unique relation because the modulus of elasticity of concrete is affected by the modulus of elasticity of aggregate and by the volumetric content of aggregate in the concrete. The broad relation between the modulus of elasticity and its compressive strength is well known but there is no agreement on the precise form of the relation. While the volumetric content of aggregate is easily calculated, the modulus of elasticity of aggregate is rarely known. Neville pointed out that, it is well known that the workability of a concrete mix can be improved by increasing the water content. However, with excess amount of water, the cement may not be capable of holding the mixing water. This would reduce the cohesion of the concrete and induce bleeding and segregation. Moreover, such increase in the water content would adversely impair the strength and durability of the hardened concrete resulting from the increased W/C as discussed in Powers (1968).

Khayat et al (1997) have concluded that compressive strength and modulus of elasticity were greater for SCC samples than those obtained from the medium fluidity conventional concrete. This research was conducted to evaluate the uniformity of in-situ mechanical properties of SCC used to cast experimental wall elements. Eight optimized SCC mix with slump flow values greater than 630 mm and a normal concrete with a slump of 165 mm were investigated. The SCC mix incorporated various combinations of
cementitious materials and chemical admixtures. The water-cementitious materials ratios ranged from 0.37 to 0.42.

Schindler (2007) evaluated the properties of SCC for prestressed members, also found a lower modulus of elasticity for SCC comparing ordinary and SCC concrete mix with similar compressive strength. However, Schindler indicated that although modulus of elasticity for SCC was found to be lower than that of conventional concrete, it generally slightly exceeded the modulus calculated using the equation given by ACI-318 (2005).

David Bonen Surendra and Shah (2005) also reported that the equations suggested by ACI Building Code for calculating the modulus of elasticity return reasonable estimates. In the study carried out by Schindler, the total aggregate volume in all SCC mix was almost the same, while the sand/total aggregate ratio by volume was varied, and cementitious materials such as silica fume, slag and fly ash were used in all SCC mix. The mixture proportions made by Schindler (Schindler 2007) were also designed to include a viscosity modifying admixture (VMA) with a maximum ratio of sand/aggregate by volume of 0.46. This limit was deemed sufficiently high for SCC designed specifically for prestressed concrete applications. The main concern was that a higher ratio of sand/aggregate might lead to decreased modulus of elasticity, as well as increased creep and drying shrinkage, these factors greatly affect prestress losses as well as member deflections.

Subramanian and Chattopadhyay Subramanian (2002) are research and development engineers at the ECC Division of Larsen & Toubro Ltd (L&T), Chennai, India. They have over 18 years of experience on development of SCC, underwater concrete with anti-washout admixtures and proportioning of special concrete mix. Their research was concentrated on several trials carried out to arrive at an approximate mix proportion of SCC,
which would give the procedure for the selection of a viscosity modifying agent, a compatible SP and the determination of their dosages.

Fernandez (2007) investigated the use of fly ash as replacement for FA in concrete and discovered that the compressive, tensile and flexural strength increase initially and reach a maximum value at 52% for both 7 and 28 days. Kulkarni (2005) investigated that the use of sawdust as replacement of FA in concrete. Clean Sawdust without a large amount of bark has proved to be satisfactory. This does not introduce a high content of organic material that may upset the reactions of hydration.

Olutoge (1995) investigated the physical properties of rice husk ash, sawdust and palm kernel shell found their bulk densities to be 530kg/m$^3$, 614kg/m$^3$ and 740kg/m$^3$ respectively and concluded that these materials had properties which resembled those of lightweight concrete materials. Palm kernel shell (PKS) is the hard endocarp of palm kernel fruit that surrounds the palm seed. It is obtained as crushed pieces after threshing or crushing to remove the seed which is used in the production of palm kernel oil. PKS is light and therefore ideal for substitution as aggregate in the production of lightweight concrete.