A Study of the Effect of Pozzolana and Fibrous Materials on the Properties of Self-Compacting Concrete

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Abstract: Time, cost, and quality are three important factors that play a critical role in the construction industry. Any progress or development that improves these factors is welcomed by civil engineers. Self-compacting concrete, given its special properties, is one of these developments that can considerably affect the construction industry. The great advantages of self-compacting concrete have led to its extensive use throughout the world. These advantages can be briefly summarized as follows:

- Development of concrete structures in the world and the need for concretes with special properties
- Lack of need for specialized concrete workers, especially concrete vibrator workers
- Fast execution of concrete structures by facilitating concrete placement
- The ability to improve the mechanical properties of concrete
- The ability to execute light and heavy concrete structures and to choose small cross-sections or reinforced beams
- Development of precast concrete industries
- Being economical due to being less labor-intensive and time-consuming
- Beautiful surfaces of concrete structures
- Reduced noise pollution

Key words: Self-compacting concrete, pozzolana, nylon and polypropylene fibers, cullet, rice husk ash

INTRODUCTION

According to a study carried out in Sweden, 50% of the cost of concrete placement is related to the workforce. Thus, although using self-compacting concrete increases the cost of materials, but significantly reduces labor costs. In fact, in this type of concrete placement few but specialized and efficient workers are needed. Considering the high labor cost in Iran, reduction in labor cost will be greater than the cost of materials. Efficiency of self-compacting concrete can be defined with three important parameters:

- Filling ability
- Passing ability
- Stability

Only those concrete that have the above characteristics can be called self-compacting. Due to high fluidity of self-compacting concrete, there is a risk of segregation and thus use of super plasticizers and their adaptability with the type of concrete must always be considered. Sufficient amounts of aggregates (pozzolana or fibers) can be used to solve the problem of segregation in self-compacting concrete. The present article tries to examine the effects of pozzolana and fibers on self-compacting concrete (SCC) and to provide proper alternatives, while taking economic issues and type of structure into account.

1. Examining the performance of silica fume in SCC

The results of using silica fume with fixed water-to-concrete ratio in SCC suggest that increasing silica fume considerably improves plasticity and increases the liquidity of the concrete. However, the best way is to add 10% silica fume to SCC, since high levels of silica fume is not suitable for the hardened properties of SCC.

Using aggregates smaller than silica fume positively affects homogeneity of SCC and prevents its segregation. In addition, in the plastic state this also improves passing ability through grids and rebars. By increasing or decreasing the percentage of silicon in samples made with fixed diameter, slump diameter remains constant; however, in J-ring test, by increasing finer silica fume particles its passing ability through concrete increases, while passing time decreases.

A review of the experiments done on different samples indicates that increasing the percentage of silica fume has a more considerable effect on passing velocity through SCC than using finer silica fume particles. Moreover, using up to 10% of silica fume increases compressive strength of SCC, while using finer silica fume particles reduces its strength.

2. Examining the performance of synthetic pozzolana along with nano-silica particles in SCC

Pozzolana is a siliceous or siliceous and aluminous material that by itself has no viscosity, but can react with calcium hydroxide in the presence of water at room temperature and create compounds that are viscous (ASTM...
Standards: Pozzolanic materials include fly ash, slag, silica fume, and rice hush ash. Due to the poor performance of synthetic pozzolans, using nano-silica particles improves the performance of self-compacting concrete. Nano-silica particles are the most suitable materials in cement-based materials. This material has received much attention as a superpozzolan due to its high reactivity (Li, H., et al., 2004; Ji, T., 2005).

In mixing SCC gravel must be 40% of concrete volume and water-to-powder ratio is 0.9-1. Due to high water absorption of the pozzolan, water-to-powder ratio must be slightly higher. By increasing the amount of concrete replacement with pozzolan and nano-silica particles, liquidity of SCC decreases and its viscosity increases. The reason for this is the mechanism of reaction between nano-silica particles and the synthetic pozzolan. Nano-silica particles have a high specific surface area and numerous unsaturated bonds at the surface; thus, they attract water molecules around their surface (Senff, L., et al., 2009). Reduced liquidity and increased viscosity are the result of two main factors:

1. Pozzolanic particles, due to having a porous structure, have high water absorption capacity.
2. Higher specific surface area of pozzolanic particles and their finer and coarser particles compared to cement particles and leads to increased water absorption at the external surface of pozzolanic particles.

Therefore, by increasing pozzolanic and nano-silica particles, utilization of super plasticizers is inevitable. Nano-silica particles are used to increase the strength of pozzolana so that we can use greater amounts of pozzolana in making cement-based materials. This allows for improving compressive strength both at early and later ages.

Compressive strength of self-compacting concrete decreases with increasing levels of this pozzolan regardless of the presence or absence of nano-silica particles. It must be noted, however, that permeability of SCC improves in presence of nano-silica particles and its stability improves as a result of low levels of pozzolan replacement.

3. Examining the performance of SCC reinforced with rice husk ash

Rice husk ash (RHA) is a material with high pozzolanic reactivity that is used to improve the microstructure of the interfacial transition zone between the cement paste and the aggregate in self-compacting concrete. Okamura and Ozawa have proposed a simple mix-proportioning system assuming general supply from ready-mixed concrete plants (Skarendahl, A., Ö. Petersson, 2000). The coarse and fine aggregate contents are fixed so that self-compactability can be achieved easily by adjusting the water-to-powder ratio and super plasticizer dosage only.

Increasing the amount of rice husk ash replacement increases flexural strength and as a result water-to-binder ratio increases. Increased flexural strength in normal concrete samples is higher than self-compacting concrete. By increasing the amount of replacement, the effect of water-to-cementitious material ratio in SCC is higher than normal concrete.

4. Effect of polypropylene and nylon fibers on SCC

Different types of fiber, including steel, glass, natural, and synthetic fibers (cullet, nylon, polypropylene, and carbon), are used as reinforcement for creating stable and durable concrete for use in tunnels and underground structures. Due to the strong bond between polymeric fibers and concrete matrix, using fiber-reinforced concrete improves such structural properties as tensile and compressive strengths, impact resistance, resistance against thermal shocks and subsequent segregation, fatigue resistance, and ductility, thus increasing the durability of concrete matrix.

Among different types of fibers used for concrete reinforcement, there is an increasing use of synthetic fibers such as aramid, polyethylene, polyester, and especially polypropylene and nylon. Nylon-reinforced concrete has received much attention due to positive properties of fibers such as high resistance-to-weight ratio, accessibility, and relatively low price.

After initiation of the first crack, fiber-reinforced concrete creates bonds in different directions and prevent the propagation of the crack. The result is reduced width of cracks and formation of microcracks, which results in an operational and economical project.

The advantages of using polypropylene fibers include increased durability of concrete under hard environmental conditions, reduced cracks and bleeding, and corrosion resistance. The benefits of using nylon fibers include reduced fracture, crack control, and impact resistance. In general, the advantages of using fiber-reinforced concrete are as follows:

A. Better performance of the structure against earthquakes due to higher impact and fatigue resistance and lower weight of SCC compared to normal concrete
B. Reduced segregation of SCC during mixing, transportation, and pumping
C. Improved efficiency in conjunction with rebars
D. Alkali-resistance of fibers

Comparison of nylon and polypropylene fibers has shown that nylon fibers are better distributed in concrete than polypropylene fibers (which are the most widely-used fibers in fiber-reinforced concretes). Increasing the amount of nylon fibers in concrete reduces its efficiency. This reduced efficiency is due to the fact that compared to some synthetic fibers (e.g. polypropylene), nylon fiber has water absorbing capacity.
In many practical applications, using synthetic fibers in concrete is not to increase its compressive strength, rather to keep compressive pressure constant and increase other concrete properties such as crack control, tensile strength, and flexural strength (Mehdipour, I., A. Sangtarashha, 2009). Unlike steel fibers that have resulted in increased concrete resistance in some studies and reduced compressive strength in other studies, nylon fibers are reliable in terms of increasing compressive ability. Nylon-reinforced concretes have been shown to be more effective than polypropylene-reinforced fibers. The reason could be the high tensile strength and better distribution of nylon fibers in matrix compared to polypropylene fibers.

Non-metallic fibers such as polypropylene and glass reduce crack widths due to drying shrinkage of concrete at higher ages, and polypropylene is considered as the most effective fiber for controlling such shrinkage cracks. Although increasing the volume of non-metallic fibers significantly improves cracks, the concrete mix loses its efficiency and concrete placement problems arise. Increasing the amount of fibers does not necessarily reduce shrinkage strains, but it will be effective in controlling shrinkage of concretes with poor rheological properties (Mehdipour, I., A. Sangtarashha, 2009).

5. Examining the effect of glass fibers on the properties of SCC

High volume of cement paste in SCC leads to excessive shrinkage and reduced ductility such that it suddenly cracks after reaching the maximum load. Cracks caused by tensile stresses due to high levels of shrinkage strain can reduce the durability of concrete in the hardened state and the entire structure in the long run (Li, H., et al., 2004). Natural or artificial metallic fibers that have been randomly distributed in the mix can prevent the propagation of cracks by bridging the cracks and restraining tensile force (Ji, T., 2005). Also the cementitious mixtures of fiber-reinforced SCC have less water absorption capacity [4]. Research has also shown that fibers transform cracks into microcracks and control them, thus reducing the effect of chloride diffusion as compared to normal concrete (Miyazato, S., Y. Hiraishi, 2005; Sahmaran, M., et al., 2007).

Further, fiber-reinforced SCC has been used for many purposes due to its suitable viscosity, high liquidity, durability, stability, and such mechanical properties as shrinkage strain and compressive, tensile, and flexural resistance (Sangtarashha, A.,; Libre, N.A., et al., 2009). Excessive increase in the amount of fibers significantly decreases the workability of the mix (Sivakumar, A., and M. Santhanam, 2007). This usually increases the volume of air entrapped in the mix and thus reduces the resistance and operational life of the materials. Yield stress increases with the amount of fibers and thus liquidity decreases. Therefore, using an optimal amount of fibers in making fiber-reinforced SCC can lead to a workable and flowable mix that facilitates renovation and restoration operations.

Research has shown that increasing 6mm glass fibers, with 2-4% fiber content ratio, do not significantly affect the speed of the mix through the v-funnel. By increasing the amount of fibers to 5 volume percent, however, leads to blockage in the nozzle. Presence of 1 volume percent of 12mm fibers reduces speed through the nozzle by two times compared to the same amount of 6mm fibers, and increasing the amount of 12mm fibers leads to blockage in the nozzle of v-funnel.

Fibers with higher length-to-diameter ratio have greater ability to control shrinkage strains in the long term. Reduced compressive strength of the samples in the presence of fibers, which is due to the inherent poor performance of fibers against stress and the phenomenon of fiber balling in case of using excessive amounts of fiber, has made this characteristic a negative attribute and the amount of fibers must be adjusted to not only improve its workability and durability, but also prevent the dramatic decrease of compressive strength.

If only cement is used in self-compacting concrete, it will be expensive and the mix will be full of thermal cracks. Glass cullet that exists in fine and coarse powders is hard, angular, and fragile, and it does not absorb moisture compared to coarse gravel. Thus, the strength and liquidity of glass fiber reinforced concrete decreases with increasing amounts of cullet and also corrosion resistance decreases; on the other hand, it leads to water absorption. Glass reinforced concrete even exceeds the standard alkaline-silica reaction, but this effect can be counteracted by using low-alkaline cement and SCMs such as silica fume, metakaolin, and fly ash (Sangtarashha, A., et al.,).

Reactivity of glass depends on the size of the particles. Glass particles between 38-75mµ and larger than 75mµ have low or no pozzolanic properties. Compressive strength of concretes made with finer glass particles—i.e. less than 38mµ—is always better than similar samples with less than 75mµ glass particles, and finer glass fibers increase the strength of concrete in the long run. Increasing the amount of glass fiber reduces the weight of the concrete mix, for the specific weight of glass fiber is less than gravel or cement.

6. Examining the effect of LECA on the behavior of SCC

Using light expanded clay aggregate (LECA) increases compressive strength, but also increases instability. Considering the low water-to-cement range of LECA, using this filler is difficult and sensitive. Compressive strength of samples containing LECA is considerably higher than control samples. Samples containing LECA, if left static, quickly become paste-like and harden, but they can go back to their initial state once they are remixed. This attribute allows LECA-containing concrete to be used when speed of operation is of essence. High viscosity of samples containing LECA leads to bleeding in samples. Moreover, due to its long v-funnel time, it can hardly be called a self-compacting concrete.
Conclusion:
Self-compacting concrete (SCC) is an efficient and resistant concrete against instability or segregation. Many methods are applied to increase the efficiency of concretes, such as increasing the water-to-cement ratio, using super plasticizers, and, more commonly, using fillers. The advantage of using fillers is increased efficiency without any damage to the properties of SCC. Moreover, low cost, use of factory wastes, accessibility, and ability to be maintained for long periods of time are other advantages of fillers. The mixes proposed by the present research are listed below.

Concrete containing silica fume
- In places with highly compacted rebars and the need for high liquidity and low slump, such as bridge deck and dam spillways

Concrete containing synthetic pozzolan and nano-particles
- In situations where compressive strength, both at early and later ages, is required
- Using more pozzolan for it is economical

Concrete containing rice husk ash
- Improving mechanical properties after 60 days
- Need for high elasticity modulus
- Low cost due to less use of cement
- Availability of rice husk ash in Iran

Concrete containing polypropylene and nylon
- Efficiency in regions with highly compacted rebars, slabs, narrow cross-sections
- Massive concrete placement of structures that require fatigue resistance, such as heavy machinery foundations and parking pavement
- Application in repaired concrete with the ability to maintain shrinkage cracks in concrete floors or slabs

Concrete containing glass fibers
- In regions with chloride ion
- Alkali-resistance of the fibers
- No need for corrosion resistance
- Reduced water absorption

Concrete containing LECA
- When high resistance is needed in a short time
- For temporary structures with no complex rebar placement
- When speed is of essence

REFERENCES
ASTM Standards: C618 Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete.

