Behavior of Flowable High Strength Concrete Repair Material for Sustainable Engineering Construction

By

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Abstract

Steel fibers in concrete is known for its potential ability to enhance the concrete material for increasing their flexural toughness, energy dissipation and have high impact resistance for many structural applications especially in building repairs and other civil engineering works. The use of steel fibers in flowable concrete would provide greater advantages in arresting cracks and enhancing their flexural rigidity of the composite material. Hence, such experimental investigation is significant in providing clear indication and understanding of their behavior and structural performance in engineering construction.

1. Introduction:

The steel fiber added concrete or mortar has been used to increase for the toughness, energy absorption capacity or the impact resistance in applications likes: slabs and floors, shell domes, rock slope stabilization, refractory linings, composite metal decks, seismic retrofitting, repair and rehabilitation of structure, fire protection coatings, concrete pipes….etc. **(Nataraja et al,2005)**.

The application of fibers in concrete was regarded very difficult in the past, due to insufficient workability of fiber reinforced mixtures. The development of superplasticizer has proven to offer significant improvement in application of fibers in concrete. Fibers can have rheological and mechanical synergistic effects, and the optimized fiber combinations can better increase mechanical performance while maintaining adequate flow or workability properties for fiber-reinforced flowable mortar and fiber- reinforced flowing concrete respectively. **(Nehdi &. Ladanchuk, 2004).**

The repair materials contribute to the mechanical strength of concrete structure and thus high fluidity is required to completely fill the cracks and pores. At the same time, a repair material is prone to minimum differential movement and must have an elastic modulus as close to that of concrete substrate as possible. Hence, a repair material with high fluidity and relatively higher compressive strength compared to concrete substrate is preferred. One of the greatest challenges facing the successful performance of repair materials is their dimensional behavior relative to substrate. Relative dimensional changes cause internal stresses within the repair material and within the substrate. High internal stresses may results in tension cracks, loss of load carrying capability and deterioration. Particular attention is required to minimize these stresses and to select materials that properly address relative dimensional behavior. **(Chin, & S.H .Jong ,2007)** .Therefore, this study aims to produce high strength flowing concrete and high strength flowable Mortar using different percentages of steel fiber and study the use of them as repair materials.

2. Literature review:

The literature review will describe the previous investigations concerning the main properties of the necessary materials to get flowable high strength concrete, beside that, the effect of using steel fiber with concrete mixes. Finally, the literature reviews deals with the repair materials.

2.1. Properties of superplasticized Concrete:

Superplasticizing admixtures act by causing the cement agglomerates to disperse; these admixtures are to be adsorbed on to cement particles, causing them to become mutually repulsive as a result of the anionic nature of superplasticizer.

The basic advantages of superplasticizers include:

1. High workability of concrete resulting in easy placement without reduction in cement content and strength.
2. High strength Concrete with normal workability but lower water content.
3. A Concrete mix with less cement but normal strength and workability.

The effect of superplasticizer on the properties of concrete has been investigated by many researchers. These admixtures can be added to concrete with a low-to-normal slump and water-cement ratio to make high-slump flowing concrete. Flowing concrete is a highly fluid but workable concrete that can be placed with little or no vibration or compaction while still remaining essentially free of excessive bleeding or segregation. The Following are a few of the applications where flowing concrete is used:(1) thin-section placements, (2) areas of closely spaced and congested reinforcing steel, (3) tremie pipe (underwater) placements, (4) pumped concrete to reduce pump pressure, thereby increasing lift and distance capacity, (5) areas where conventional consolidation methods are impractical or cannot be used, and (6) for reducing handling costs.

The addition of superplasticizer to a 75-mm (3-in.) slump concrete can easily produce a concrete with a 230-mm (9-in.) slump. Flowing concrete is defined by ASTM C 1017 as a concrete having a slump greater than 190 mm (71⁄2 in.), yet maintaining cohesive properties.

Setting time may be accelerated or retarded based on the admixture's chemistry, dosage rate, and interaction with other admixtures and cementing materials in the concrete mixture. Strength development of flowing concrete is comparable to normal concrete as shown in (Fig.1).Superplasticized concretes bleed significantly less than control concretes of equally high slump and higher water content. High-slump, low-water-content, superplasticized concrete has less drying shrinkage than a high-slump, high-water content conventional concrete; however this concrete has similar or higher drying shrinkage than conventional low-slump, low-water-content concrete. The effectiveness of the superplasticizer is increased with an increasing amount of cement and fines in the concrete. **(Steven et al ,2003)**

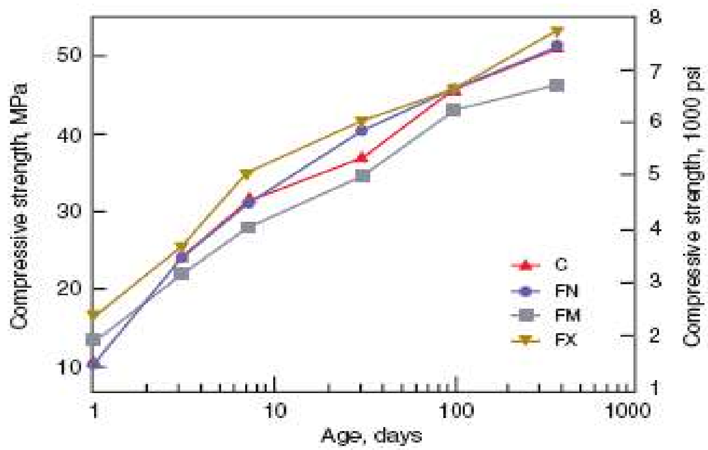


Fig.1. **Compressive strength development in flowing concretes. C is the control mixture. Mixtures FN, FM, and FX contain superplasticizers**

2.2 properties of pozzolan concrete:

Pozzalan or (Pozzolana) is an Italian word, named from Pozzuoli, the place near Naples where Pozzolan was first mined and used as cement during roman times.

Pozzolan- a siliceous or alumino- siliceous material that in finely divided form and in the presence of moisture, chemically react at ordinary room temperatures with calcium hydroxide released by the hydration of Portland cement to form compounds possessing cementitious properties. **(Neville,1995)**

Silica Fume:

Silica Fume is a recent arrival among cementitious materials. It is a by-product of the manufacture of silicon and ferrosilicon alloys from high purity quartz and coal in a submerged –arc electric furnace.

The beneficial effects of silica fume are not limited to its pozzolanic reaction: there is also a physical effect of the ability of the extremely fine particles of silica fume to be located in very close proximity to the aggregate particles ,that is, at the aggregate –cement paste interface. A contributing factor is the fact that silica fume, because its high fineness, reduce bleeding so that no bleed water is trapped beneath coarse aggregate particles. In consequence, the porosity in the interface zone is reduced, compared with a mix not containing silica fume. Subsequent chemical reaction of silica fume results in a still lower porosity in the interface zone which, in consequence, is no longer particularly weak, either in terms of strength or permeability. **(Neville,1995)**

(Yin & Shu 2003) Studied the effect of silica fume on the bond characteristics of steel fiber in matrix of reactive powder concrete (RPC), including bond strength, pullout energy. Various silica fume contents ranging from 0 % to 40 % were used in the mix proportions. Fiber pullout tests were conducted to measure the bond characteristics of steel fiber from RPC matrix. It was found that the incorporation of silica fume can effectively enhance the fiber–matrix interfacial properties, especially in fiber pullout energy. It was also concluded that in terms of the bond characteristics, the optimal silica fume content is between 20% and 30%, given the conditions of the experimental program. Comparing to that of the matrix without silica fume, the enhancement in pullout energy due to silica fume is more significant than that in bond strength. At the optimal silica fume dosage (30%), the pullout energy is increased by approximately 100%, whereas the bond strength is increased by 14%. The difference can be attributed to the different mechanisms of silica fume on pullout energy and on bond strength. The microstructure of fibers pulled out from high silica fume content matrix reveals a great amount of cementitious materials adhering to fiber surface. Consequently, the cementitious material contributes to the friction and resistance during the fiber pullout process. Therefore, the pullout energy is remarkably enhanced when a certain amount of silica fume content is incorporated.

2.3. The use of Steel fiber with Concrete:

Fiber reinforced concrete (FRC) may be defined as a composite material made with Portland cement, aggregate, and incorporating discrete discontinuous fibers.

Now, why would we wish to add such fibers to concrete? Plain, unreinforced concrete is a brittle material, with a low tensile strength and a low strain capacity. The role of randomly distributes discontinuous fibers is to bridge across the cracks reword some post- cracking “ductility”. If the fibers are sufficiently strong, sufficiently bonded to material, and permit the FRC to carry significant stresses over a relatively large strain capacity in the post-cracking stage. **(Colin,2001).**

The real contribution of the fibers is to increase the toughness of the concrete (defined as some function of the area under the load vs. deflection curve), under any type of loading. That is, the fibers tend to increase the strain at peak load, and provide a great deal of energy absorption in post-peak portion of the load vs. deflection curve.

When the fiber reinforcement is in the form of short discrete fibers, they act effectively as rigid inclusions in the concrete matrix. Physically, they have thus the same order of magnitude as aggregate inclusions; steel fiber reinforcement cannot therefore be regarded as a direct replacement of longitudinal reinforcement in reinforced and prestressed structural members. However, because of the inherent material properties of fiber concrete, the presence of fibers in the body of the concrete or the provision of a tensile skin of fiber concrete can be expected to improve the resistance of conventionally reinforced structural members to cracking, deflection and other serviceability conditions.

The fiber reinforcement may be used in the form of three – dimensionally randomly distributed fibers throughout the structural member when the added advantages of the fiber to shear resistance and crack control can be further utilized. On the other hand, the fiber concrete may also be used as a tensile skin to cover the steel reinforcement when a more efficient two – dimensional orientation of the fibers could be obtained. **(Colin,2001).**

(Steffen & Joost ,2001) Studied the effect of four types of steel fibers at different contents on workability of self compacting concrete (SCC), it was concluded that the flow behavior of fiber reinforced mixtures differs from that of plain (SCC).Qualitative observations indicated if a homogenous distribution was given, if a critical fiber content was surpassed, a stiff structure of the granular skeleton makes flow under concrete own weight impossible. It was also found that a considerable amount of fibers allowed self-compacting behavior and the mixture composition of the reference mixture composition of the reference mixture influences the maximum possible fiber content.

(Mohammadi et.al ,2006) studied the properties of plain concrete and steel fiber reinforced concrete (SFRC) containing fibers of mixed aspect ratio. The specimen incorporated three different volume fraction, 1.0 %, 1.5% and 2% of corrugated steel fibers and each volume fraction incorporated mixed steel fibers of size 0.6 x 2.0 x 25 mm and 0.6 x 2.0 x 50 mm in different proportions by weight and tested in compressive strength, split tensile and static flexural strength. A fiber combination of 65% 50mm+35% 25mm long fibers can be adjudged as the most appropriate combination to be employed in SFRC for all these tests, where a 59% increase in split tensile strength of fibrous concrete was observed with respect to plain concrete at a fiber volume fraction 2.0% . A 16% increase in compressive strength of fibrous concrete was observed with respect to plain concrete at the same fiber combination and volume fraction while the increase in the flexural strength was 88%.

(Ming et al 2005) Studied the use of reactive powder concrete (RPC) which contains steel fiber in its mix, as a repair material. They found that RPC displays excellent repair and retrofit potential on compressive and flexural strengthening with bonding RPC of 10 mm thick are about 200% and 150% more than those of normal strength concrete. The abrasion coefficient of RPC is about 8 times higher than that of normal strength concrete.

(Burak et al 2006) Studied the effect of steel fiber on surface wear resistance of self-compacting repair mortars. In this study, the optimum superplasticizer dosage and the maximum possible amount of fiber addition,which maintain the self-compactability and stability,was determined for mortars incorporating steel fiber. It was concluded that steel fiber have rheological and mechanical synergistic effects, and the optimized fiber-superplasticizer dosage combinations (156 kg/m^3 ,1% respectively) can better improve the wear resistance while maintaining adequate flow properties for fiber reinforced self-compacting repair mortar.

2.4. The use of repair materials:

Strengthening, maintenance and repair of concrete structures are becoming more recognized in the field of civil engineering. The Selection of the repair materials for concrete structures required an understanding of material behavior in the uncured and cured states in the anticipated service and exposure conditions.

(Hassan et al. 2000) Investigated the compatibility of using cementitious, polymer and polymer modified (PMC) repair materials. They concluded that the high shrinkage strain of cementitious repair mortars affected their compatibility with concrete and increased indirectly the permeability at the interface of the combined system, from the other side, the mismatch in the modulus of elasticity between concrete and the epoxy mortar used in this study reduced the load carrying capacity of the combined system. For the design of an efficient repair, it has been recommended that the repair materials should have greater modulus (> 30%) than the concrete substrate. **(Hassan et al 2000).**

(David et al 2005) Identified the characteristics of successful spall repair materials; tested a number of repair materials currently in use across the state; and compiled the information for use in a repair material selection process , 10 repair materials were selected for testing. Material types included three magnesium phosphates, one rapid setting hydraulic cement, three polyurethane polymers, one epoxy polymer, one thermosetting vinyl polymer, and one polymer modified bitumen. Tests for set time, compressive and flexural strengths, modulus of elasticity, shrinkage, Coefficient of thermal expansion (CoTE), and tensile bond strength were conducted at 40, 70, and 100 degrees F. Some conclusions had drawn from this study:

1. While testing the mechanical properties of each material, it was found that the different repair materials had very different stiffnesses. Accordingly the repair materials were grouped into three categories; rigid, semi-rigid, and flexible with magnesium phosphates representing the more rigid materials, and the polymer concretes representing the more flexible materials. Ultimate

compressive strengths could only be tested for rigid materials, and flexural strength could only be obtained from the rigid and semi-rigid materials.

2. Modulus of elasticity, shrinkage, and CoTE were the compatibility properties tested for each material. It was found that rigid materials like the magnesium phosphates had the highest values of elastic modulus, and flexible materials like the polymer concretes had the lowest values. In general materials with a low elastic modulus had a comparatively high CoTE value, while materials with a high elastic modulus had a comparatively low CoTE value. Shrinkage values were highly variable due to the wide range of material types and the amount of temperature change experienced while curing, but rigid materials experienced lower shrinkage values while semi-rigid and flexible materials experienced high shrinkage values.

3. Thermal cycling of simulated spalls produced no degradation of the repair materials. Tests for tensile bond values were taken from each of the repairs after cycling but results were variable partially due to the nature of the test and the varying bond surface. Certain types of rigid as well as flexible materials were found to bond well.

4. Spall repair materials to be applied in fields should be selected through the consideration and comparison of material acceptability and properties. The acceptability of material is determined based on whether the bond strength of a material satisfies the engineers' specified bond strength. Also, the materials can be ranked according to the following criteria derived from material properties: material cost, placeability, and overall utility. Overall utility includes consideration for future overlay operations and the ability of the spall repair material to bond to the overlay itself. The lower modulus repair material will not bond well to a concrete overlay, which should be given due consideration in this regard in the material selection process.

3. Problem statement:

Many structures especially those made of reinforced concrete have suffered severe degradation since their construction due to many environmental causes (deicing salts, Freezing and thawing, aggressive environment like earthquake…etc.) and drastically the increase of live loads. One of the major problems facing the civil engineers of today is "How to maintain and retrofit these structures?"

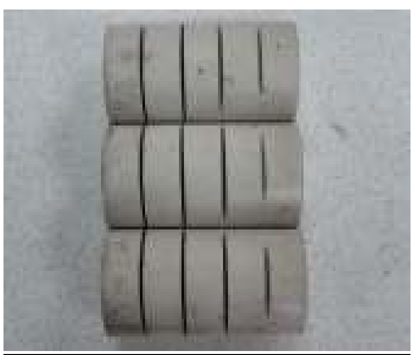
In many instances, epoxy resins are used as repair materials for the maintenance of concrete infrastructures, epoxy resins used as repair material, their prices are very expensive. In addition, thermal aging is accelerated when epoxy resins are exposed to the relatively high temperature and humidity in Malaysia, resulting in a drastic increase in maintenance cost for concrete structure .Hence, an alternative repair materials that is economical and posses good thermal resistance compared to epoxy resins are needed.

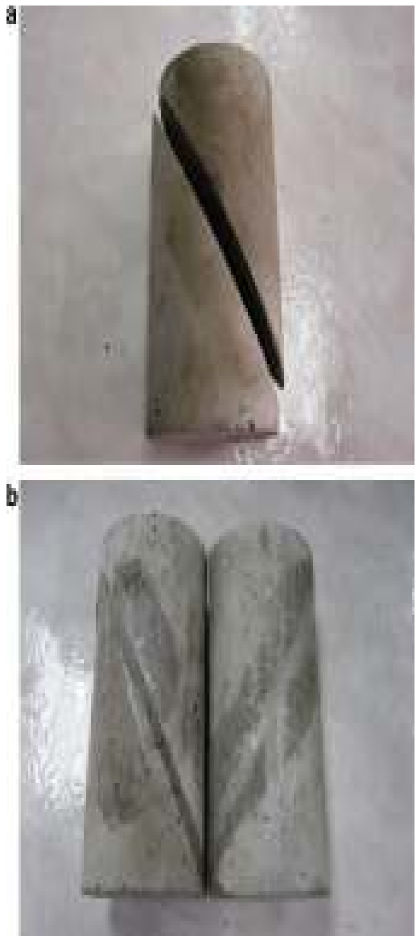
4. Research Objective:

The overall objective of this work is to study the importance of using steel fiber with high strength flowable mortar and high strength flowing concrete as repair materials that consider more beneficial than epoxy or polymer materials that also used for this purpose.

The measurable objectives are to:

- Determine the optimum percentage of silica fume as a partial replacement of cement.
- Characterize the high strength flowing concrete and high strength flowable mortar (without and with different percentages of steel fiber) by mechanical tests.
- Generate suitable models (combined system of a repair material and substrate concrete as shown in Fig.2) to use high strength flowing concrete and high strength flowable mortar as repair materials and study the properties of this combined system by mechanical tests.





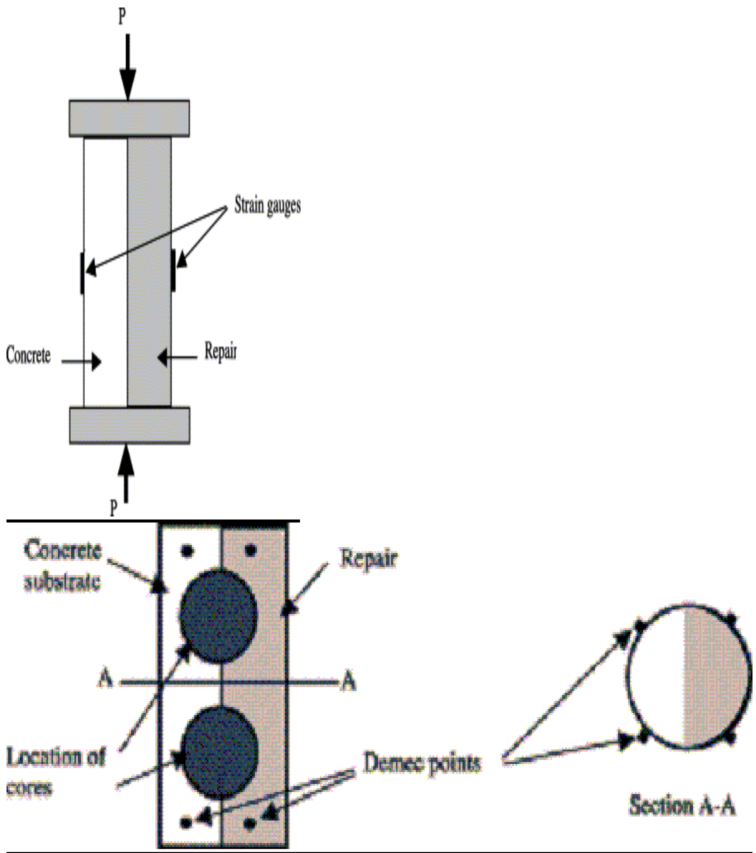


Fig. (2) Typical model of repair material and substrate concrete

5. Research Scope:

This research are achieved to study the effect of incorporating different percentages of steel fiber with high strength flowing concrete and high strength flowable mortar on the mechanical properties of them. Depending on these properties, the optimum mixes from each case of concrete and mortar mixes have selected to study the use of them as repair materials with substrate concrete and investigate the mechanical properties of this combined system.

6. Research Methodology:

This research divided into 4 Stages:

- Stage 1: Selection the optimum percentage of silica fume as a partial replacement of cement using Pozzolanic activity Index. (Fig. 3).
- Stage 2: Design high strength flowable mortar (without and with steel fiber) and do the mechanical required tests. (Fig. 4).

- Stage 3: Design high strength flowing concrete (without and with steel Fiber) and do the mechanical required tests. (Fig. 4).
- Stage 4: Select the optimum mix for each of the two cases (Mortar and Concrete) and do the mechanical tests required for the use of repair materials. (Fig. 4).

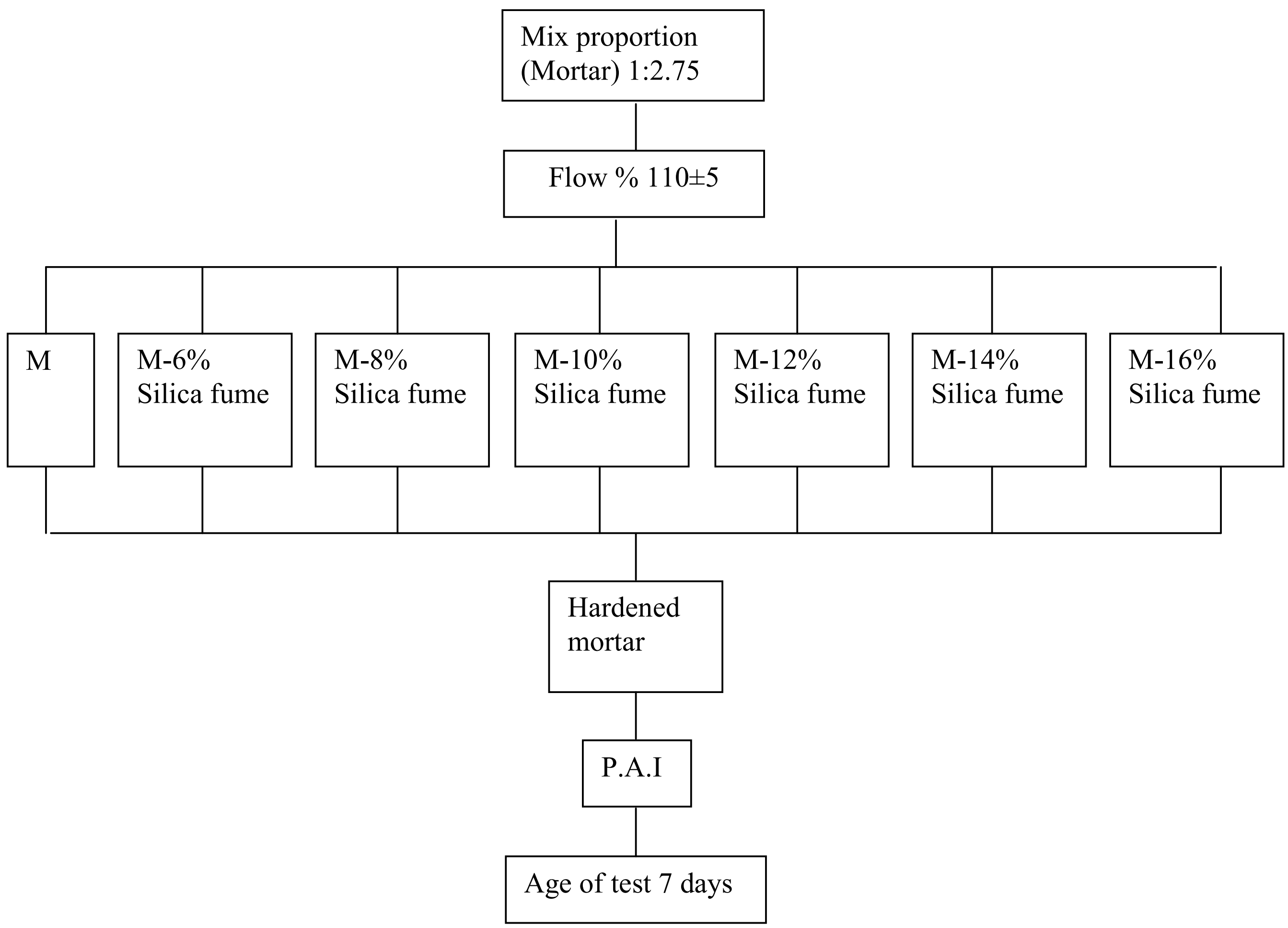


Fig. (3) Pozzolanic activity index using variable percentages of Silica fume as a partial replacement of cement

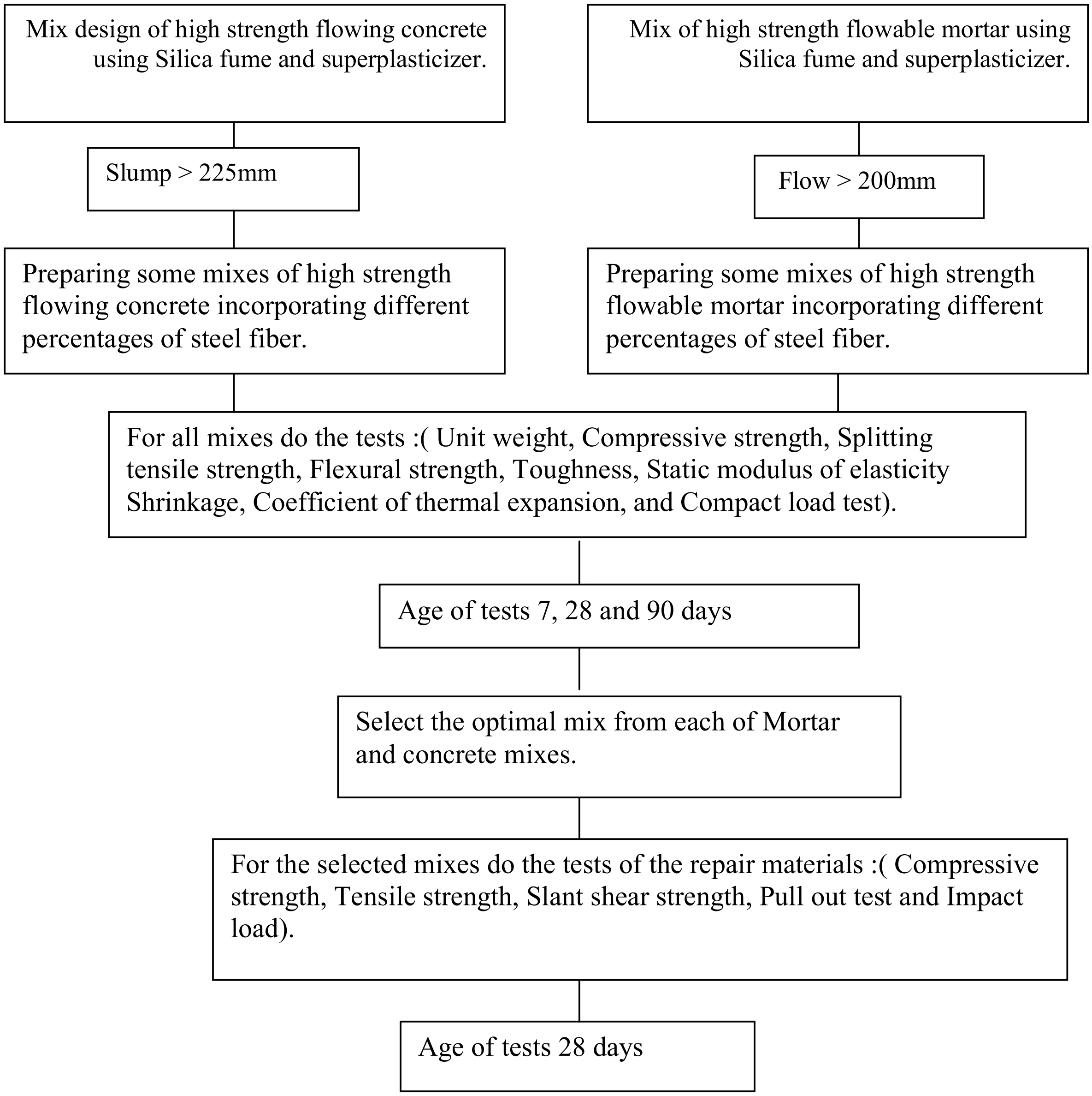


Fig. (4) Experimental Program for mix design development

Conclusions:

The study of flowable high strength concrete as repair materials should be evaluated from some of criteria required to understand the behavior of these materials in construction sites which need always to maintenance and repair the damaged construction members. There are some of matters should be taken into account for this type of study and these matters are:

- The experimental tests required to show the best performance of flowable high strength concrete can be done using the optimal percentages for each of silica fume as partial replacement of cement and steel fiber volume in the mix to give the properties of high compressive strength, high flexural toughness, and high of impact resistance but with low thermal expansion.
- The incorporating of coarse aggregate in the mix for the production of flowable high strength concrete could help in the perception the importance of the availability other suitable choice for a certain repair field.
- Adoption of some combined systems of repair materials with substrate concrete and/or steel bar reinforcement to achieve the lab tests is so much important in order to compare the tests results with the other repair materials (like epoxy) and perceive the bond action of this repair material (Flowable High strength concrete) in case of using it in repairing in site construction.

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