Development of Self-compacting Fibre Reinforced Structural Mortar for Concrete Repair

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Abstract. Self-compacting or self-flowing fibre reinforced mortar (FRM) is required for strengthening of structural concrete utilizing cementitious composites. In this study, high-strength FRM with self-flowing properties is developed using high volume (50\% by weight of cement) blended pozzolans and low-cost nylon fibre. A mixture of fly ash, slag and silica fume was used as blended pozzolan. Nylon fibre derived from conventional nylon rope was utilized as fibre in preparing FRM. Experimental results showed promising results in terms of strength. FRM with 2\% nylon fibre was achieved maximum strength, which is as high as 91.32 MPa in 28 days. However, inclusion of fibre causes a decrease of workability in the fresh state. Incorporation of nylon fibre also helped to bridge the crack and thus increase the tensile properties of mortar. Significant improvement was observed in the failure pattern of the specimens while incorporated with nylon fibres. Therefore, this type of FRM can be utilised for concrete repair.

1. Introduction
Concrete is the most popular construction materials in the modern world; more than 11.4 billion tons of concrete consumed annually worldwide. The high compressive strength of concrete had made it to be used for structural purposes. High stress concentration may cause a fracture of concrete due to its low tensile strength despite its high compressive behaviour. Therefore, unreinforced or plain concrete components require reinforcement since they are brittle and have low tensile strength which leads to cracking. Generally, humidity and temperature variation, overloading, change in usages are the typical causes of the cracks to happen [1].

Repair or strengthening of cracked or damaged concrete has becoming a challenge throughout the whole world [2]. Numerous materials have been studied and utilized for such activity. Epoxy and/or cement slurry injection to repair cracked concrete have been reported in some literatures [3]. Repair and strengthening of concrete structures using fibre reinforced polymer is very common nowadays [4-6]. Ferrocement has also been reported as low-cost strengthening material for concrete strengthening in several studies [1, 2, 7-10]. Fibre reinforced cementitious mortar (FRCM), also named textile reinforced mortar (TRM), is one of the promising inclusions the field of strengthening materials and techniques for concrete structural elements [11-13].

Ferrocement, TRM or FRCM are comprised of cement mortar and other reinforcing materials. ASTM C 219–03 defined Mortar as a mixture of finely divided hydraulic cementitious material, fine aggregate, and water [14]. Structural mortar is expected to resist some externally applied forces and provides strength. In strengthening application, it is expected that the mortar will also resist a part of loads.
Therefore, individual mortar component also needs to be reinforced with micro fibres for improved tensile properties.

Stainless steel or polypropylene fibres are the most common names in production of fibre reinforced mortar (FRM) [1]. However, these fibres are quite costly and thus not suitable for low-cost applications like in ferrocement or FRCM. Therefore, a low-cost fibre needs to be investigated for such low-cost applications in low-income or developing countries. This research is carried out to investigate the applicability of nylon fibre as a potential fibre to develop FRM for repair and strengthening applications.

2. Materials and methods

2.1. Materials

Locally sourced ordinary Portland cement (OPC) with blended pozzolans was used as binder material. OPC was replaced at 50% with a mixture of fly ash, silica fume and slag. The relative densities (specific gravity) of silica fume, fly ash and slag were 2.10, 2.25 and 2.85, respectively. Table 1 shows the percentages of pozzolans in the blended cementitious mixture.

River sand sieved through 1.18 mm sieve was as fine aggregate in the mortar mix, as used in cementitious material suggested ASTM. Specific gravity of sand was 2.60.

Conventional nylon rope available in the local market was used to derive nylon fibre. Fibre was derived by cutting it roughly into 0.5-1.0 cm in length. The diameter of fibre was nearly 0.4 mm. Figure 1 shows the fibre derivation process from nylon rope.

Municipal supply water supplied in the concrete laboratory was utilized for mortar mixing and later curing of specimens. Polycarboxylate-based superplasticizer that is commercially available in the local market was used in mortar mix to maintain high flowable properties.

2.2. Mortar Mix design

Mortar mix was designed on the basis of fine aggregate to binder ratio of 1.0. Blended cement with 50% blended pozzolans was used as cementitious binder. The blended pozzolan was produced from a mixture of 30% slag, 10% silica fume and 10% fly ash. Water to binder ratio was kept 0.25 to achieve high strength. To get the flowability, 6% superplasticizer (by mass of cement) was utilized. Control mortar did not contain nylon fibre; however, different proportion of fibre was used in FRM. Mortar mix proportions are presented in Table 1.
### Table 1. Mortar mix proportions.

| Mix Designation | Cement (kg/m³) | Sand (kg/m³) | W/C | Superplasticizer (% of cement) | Silica fume (kg/m³) | Fly ash (kg/m³) | Slag (kg/m³) | Nylon fibre (% of cement) |
|-----------------|----------------|--------------|-----|-------------------------------|--------------------|-----------------|--------------|--------------------------|
| CM              | 440            | 880          | 0.25| 6                             | 88                 | 88              | 264          | 0                        |
| FRM-0.25        | 440            | 880          | 0.25| 6                             | 88                 | 88              | 264          | 0.25                     |
| FRM-1           | 440            | 880          | 0.25| 6                             | 88                 | 88              | 264          | 1                        |
| FRM-2           | 440            | 880          | 0.25| 6                             | 88                 | 88              | 264          | 2                        |

2.3. Casting and curing

Mortar mixes were prepared in a Hobart mixer based on proportions given in Table 1. Extended mixing time was used to break the pozzolan and cement clumps occurred in the dry material in order to obtain a fluid mix, according to ASTM C 305 [18]. Once the mix was prepared, it was poured into standard size cube (50 mm × 50 mm × 50 mm) and cylindrical (50 mm diameter × 100 mm height) moulds. After pouring into moulds, all the specimens were wrapped with plastic foil paper to protect evaporation from the specimens’ surface. Specimens were de-moulded 24 hours after casting and kept under water in a plastic chamber placed inside the concrete laboratory until testing age. Figure 2 shows the casting and curing process of mortar specimens.

![Figure 2. Casting and curing process.](image)

2.4. Testing

After mixing, the fresh FRM is filled in a conical frustum shape Hägermann cone. Then, the Hägermann cone is lifted straight upwards to allow a free flow of mortar. After that, two diameters perpendicular to each other are determined and their average value is recorded as slump flow of FRM. Compressive strength was determined by crushing of mortar cube; however, tensile strength was measured by splitting of mortar cylinder under compression.

3. Results and discussion

3.1. Slump flow of FRM

Slump flows of the mortar mixes are reported in Figure 3. It shows that the mortar specimens without fibre achieved maximum slump flow of 195 mm. As expected, all fibre incorporated mortar shows lower slump flow. Lowest flow was observed in case of mortar specimen with 2% nylon fibre. Although the flow value of mortar with 0.25% and 1% fibre shows lower that of control specimens, it can be reasonably used for concrete repair work in filling narrow cracks.
3.2. Compressive strength of FRM
Compression strength test was conducted on cube specimens at 7 and 28 days in a compression testing machine. The results of compressive strength as obtained from experiment are presented in Figure 4. It shows that all fibre reinforced mortar achieved higher strength compared to control specimens at 28 days. However, specimen with 0.25% fibre could not attain higher strength at early age (7 days). Maximum strength at 28 days was observed in specimen with 2% nylon fibre, which is as high as 91.32 MPa. This strength is 18.4% higher than that of control specimens. Specimens with 0.25% and 1% nylon fibre achieved 3.5% and 15.3% higher strength compared to control mortar. Shannag & Mourad (2012) also obtained 15% increase in compressive strength while incorporating blended pozzolans in flowable mortar for concrete repair. Therefore, the developed FRM can be utilized for concrete repair and strengthening works.

3.3. Tensile strength of FRM
Although, most of the studies suggested to conduct direct tensile test, we have done splitting tensile test on cylindrical specimens due to the limitations in the laboratory facilities. Figure 5 presents the tensile strengths of different specimens obtained from experimental results conducted at 7 and 28 days. It shows that the nylon fibre incorporated mortar achieved higher tensile strength at 28 days. At 7 days, mortar with 0.25% fibre did not achieve higher strength compared to control specimens; but later at 28 days it achieved higher strength. This might be due to the incomplete pozzolanic reactions that cause a poorly developed interfacial transition zone. Maximum tensile strength was observed, as expected, in mortar
specimens with 2% fibre. Therefore, the developed FRM can be considered a good alternative for concrete repair and strengthening.

![Graph](image)

**Figure 5.** Tensile strength of FRM.

### 3.4. Failure patterns of FRM

Crack patterns of the tested specimens are shown in Figure 6 and Figure 7. As observed from these figures, specimens were all not broken or splitting apart after the compression or splitting tensile strength tests. The nylon fibres inside the specimen seemed to hold them together preventing it from breaking apart. The cylinder can be observed as just compressed a little bit but not split into two parts what observed in specimens without nylon fibres. This observation is in-line with the results of many studies done before [11, 15-16]. Therefore, it can be said that the nylon fibre is very effective to bridge the crack and thus can be used in flowable mortar to repair concrete.

![Images](image)

**Figure 6.** Failure pattern of mortar cubes; (a) control mortar, (b) fibre reinforced mortar.

![Images](image)

**Figure 7.** Failure pattern of mortar cylinders; (a) control mortar, (b) & (c) fibre reinforced mortar.
4. Conclusions
Based on the experimental results and analyses, following conclusions are made:
1. Workability of the fibre reinforced mortar is decreased with the increase of nylon fibre content in the mix. However, the workability is still within the acceptable range.
2. Compressive and tensile strengths are enhanced by the incorporation of nylon fibres. Specimens with 2% fibre showed maximum strengths compared to the control specimens.
3. Failure mode confirms that the nylon fibre is capable enough to bridge the cracks occurred during the experiments, thus contributes to the strength development of FRM.
Experimental results suggested that FRM incorporating nylon fibre can be used for concrete repair and strengthening. Although experiment shows promising results in case of nylon fibre incorporated cement mortar, detailed experiment is required before its practical application. Especially, the microstructure characterization and durability properties need to be investigated.

5. References
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