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# The Flexural Strength of Fiber-Reinforced Polymer Cement Mortars Using UM Resin

Min Ho Kwon, Woo Young Jung, Hyun Su Seo

***Abstract*—**A polymer cement mortar (PCM) has been widely used as the material of repair and restoration work for concrete structure; however a PCM usually induces an environmental pollutant. Therefore, there is a need to develop PCM which is less impact to environments. Usually, UM resin is known to be harmless to the environment. Accordingly, in this paper, the properties of the PCM using UM resin were studied. The general cement mortar and UM resin were mixed in the specified ratio. A certain percentage of PVA fibers, steel fibers and mixed fibers (PVA fiber and steel fiber) were added to enhance the flexural strength. The flexural tests were performed in order to investigate the flexural strength of each PCM. Experimental results showed that the strength of proposed PCM using UM resin is improved when they are compared with general cement mortar.

***Keywords*—**Polymer cement mortar (PCM), UM resin, Compressive strength, PVA fiber, Steel fiber.

## I. Introduction

THERE occur a lot of environmental contamination problems like acid rain, etc. according as the air pollution increases due to industrialization recently all over the world. The problems of poor performance in concrete structures such as degradation of concrete structures due to harmful substances in the atmosphere and acid rain, etc. and deterioration of concrete structures due to long-term use, etc. become social issues. There has been rapidly increased the interest in maintenance and reinforcement of structures and the materials for maintenance and reinforcement domestically and overseas. Polymer cement mortar is excellent in durability performance like anti-chemical property, chemical resistance, water tightness, etc. compared to ordinary cement mortar. On account of characteristics like these, the amount of use is on an increasing trend in accordance with performance requirements for the materials for maintenance and reinforcement of structures, covering materials or finishing materials to protect the structures [1], [2]. Accordingly, in recent years the studies on polymer cement are actively under way by researchers. However, most of previous studies were concentrated on the characteristics of polymer types and amount of use. And also various studies on the development of eco-friendly construction materials are under way. Because the studies on eco-friendly polymer binding materials in consideration of environment or fiber-reinforced polymer cement mortar are currently insufficient, it is necessary to make a study on development of materials for maintenance and reinforcement in consideration of environmental issues.

Urethane Acrylate MMA resin (UM resin) is a water-soluble resin harmless to the human body, and is used for the manufacture of artificial teeth, artificial joints, and contact lenses, etc. In addition, it is a non-toxic flame retardant, not discharging any poisonous gases in case of fire. This UM resin is faster in hardening time compared to other existing resins and is not sensitive to temperature. In addition, when used at normal temperature, it does not generate any harmful gases that occur in the existing resins. This study intended to determine the possibility of development of eco-friendly maintenance and reinforcement materials to increase the durability for concrete exposed to outside under flexural and tensile forces [3]. The UM resin, eco-friendly resin was used as binding materials for polymer cement mortar. For the improvement of flexural strength of polymer cement mortar, an experiment was performed with the addition of PVA fiber and steel fiber. The experiment was intended to provide a basic data for the development of maintenance and reinforcement materials eco-friendly with a high performance and superiority in flexural strength.

## II. Experiment

### *A. Summary of Experiment*

In this study, the polymer cement mortar with a high durability was mixed using the UM resin, eco-friendly resin. For the improvement of strength, this polymer cement mortar was fiber-reinforced. As a basic study for manufacture technology and utilization of fiber-reinforced polymer cement mortar, the added amount of resin, fiber types and characteristics depending on added amount were reviewed. For the study, the UM resin was used as resin, and the PVA fibers, steel fibers were used as fiber, respectively. The ratio of cement (C): standard sand, the materials used in experiment was 1:1, and the ratio of (water (W) +UM resin (UM)) / C was fixed at a constant 35%. Out of 35% which is the ratio of W+UM, the ratio of added liquid UM resin was replaced for mixing by increment of 0%, 15%, 30%, 45%, 60%, and 75%, respectively. For reinforcement of fiber, PVA fiber, steel fiber and hybrid fiber (PVA fiber + Steel fiber) were added in each specimen by 1% and 2% of weight ratio, and the results were compared with one another. For curing after mixing, the water curing was performed, and the curing time for each test specimen was based on 28 days. And as an experiment to investigate the basic characteristics of strength of fiber-reinforced UM polymer

M. H. Kwon and H. S. Seo are with the Department of Civil Engineering, ERI, Gyeongsang National University, 900 Gajwadong, Jinju, 660-701, South Korea (phone: +82-55-772-1796; fax: +82-55-772-1796; e-mail: kwonm@gnu.ac.kr).

W. Y. Jung is with the Department of Civil Engineering, Gangneung-Wonju National University, 120 Gangneung-Daehangno, Gangneung, Gangwon 210-702, South Korea (e-mail: woojung@gwnu.ac.kr).

cement mortar and a flexural strength test was performed.

*B. Used Materials*

In this study, the UM resin, eco-friendly and water-soluble resin was used as well as the water. The UM resin is an eco-friendly resin with the advantage that it is faster in hardening time compared to other existing resins and the rapid construction is available due to not being sensitive to the temperature of construction site at the time of construction. Also, the smell does not occur when working, ensuring the excellent usability. The fibers used to reinforce the strength are PVA fiber manufactured by K company in Japan, and the hook-type steel fiber manufactured by H company in our country, and their physical properties are shown in Table I. And Fig. 1 shows the shape of the fibers. The composition of the liquid UM resin is shown in Table II. As the cement used for mortar mix, the 1st class, ordinary-type Portland cement (density: 3.15g/cm3, power degree: 3,302 cm2/g) was used in accordance with the provisions of the KS L 5201. As fine aggregates, Joomoonjin (in Korea) standard sand was used in accordance with the provisions of the KS L 5100. In addition, in order to prevent the separation of materials that may occur in the process of mix and improve the fluidity, the water-reducing agent and thickener were used, and also in order to remove the large bubbles that are created in the process of mix, anti-foaming agent was added. For the last thing, the water supplied from water service not containing oil, acids, organic impurities, turbid water, etc. was used as the mixing water.

*C. Method of Experiment*

For the mixing test of fiber-reinforced polymer cement mortar, an electric mixer with the nominal capacity of 40L was used. For the mix of polymer cement mortar, KS F 2476 (method of test for polymer cement mortar) was referred. After the dry mixing had been performed for 30 seconds in a state that cement and standard sand were put together, the UM resin was mixed with the mixing water for 2 minutes. After the addition of each fiber, in order to exclude the separation of materials, fluidity, large bubbles that are created in the process of mix, admixtures were added, and thereafter it was agitated for 1 minute and 30 seconds. It took 240 seconds for a total mixing time [4]. A stopwatch was used to record the exact mixing time. The blending amount of UM resin was increased constantly in its weight ratio of the liquid UM resin against the mixing water. The mixing related to experiment is shown in Table III. In the Table IV, W (total) refers to the amount of water after the water contained in the liquid resin and the mixing water is summed up, and the UM (resin) refers to the weight excluding the water contained in the liquid UM. A test-piece specimen was manufactured in dimensions of 100 mm × 100 mm × 500 mm in accordance with mix, and it was cured under the water for 28 days. A flexural strength test was performed on the manufactured test-piece specimen in accordance with the test method of KS F 2408, and thereafter the flexural strength was measured.

## III. Result of Experiment and Analysis

Figs. 2-5 represented the results of test on flexural strength of fiber-reinforced polymer cement mortar. In case of PCM specimen, it could be confirmed that as the addition amount of UM resin increases, the flexural strength was improved as a rule. In general, the hardened cement paste is combined mainly by the weak Van der Waals force caused by calcium-silica-hydrate and calcium hydroxide [5]. If the stress affects the hardened cement paste, micro-cracks easily occur. Micro -cracks become the cause to weaken the flexural strength in ordinary mortar or concrete. Thus, the micro-cracks created when the flexural strength occurred by the addition of the polymer in cement mortar are considered to be filled up by the polymer film and polymers, and have affected the improvement of flexural strength [6]. In all specimens with the addition of fiber, the flexural strength increased. This is considered by the fiber having affected control of the micro-cracks.

TABLE I
THE PHYSICAL PROPERTIES OF FIBERS

| Specification | PVA | Steel |
|---|---|---|
| Diameter | 0.04 mm | 0.50 mm |
| *Length* | 12.00 mm | 31.03 mm |
| *Tensile strength* | 1,600 MPa | 1,064 MPa |
| *Elongation* | 6 % | - |
| *Young's Modulus* | 37,000 MPa | - |
| Oil Contents | 0.8 % | - |
| Aspect ratio (L/D) | - | 62.06 |
| *Type* | - | Hooked type |

TABLE II
THE COMPOSITION OF THE UM RESIN

| MMA (Methyl Methacrylate) | PMMA (Polymethyl Methacrylate) | BA (Butyl Acrylate) | Water |
|---|---|---|---|
| *56%* | 7% | 7% | 30% |

TABLE III
THE FIBER CONTENTS OF SPECIMENS

| Type | Fiber type | Fiber content of total weight |
|---|---|---|
| PCM | - | - |
| PCMFF1.0 | PVA | 1.0% |
| PCMFF2.0 | PVA | 2.0% |
| PCMSF1.0 | Steel | 1.0% |
| PCMSF2.0 | Steel | 2.0% |
| PCMHF1.0 | Hybrid(PVA+Steel) | 0.5%+0.5% = 1.0% |
| PCMHF2.0 | Hybrid(PVA+Steel) | 1.0%+1.0% = 2.0% |

TABLE IV
THE COMPOSITION OF THE UM RESIN

| UM / W | W(total) / C | UM (resin) / C |
|---|---|---|
| 15% | 31.3% | 3.7% |
| 30% | 27.7% | 7.3% |
| 45% | 24.0% | 11.0% |
| 60% | 20.3% | 14.7% |
| 75% | 16.6% | 18.4% |

(a) PVA fiber (b) Steel fiber

Fig. 1 Shape of the fibers

Figs. 2-4 represent the changes in the flexural strength depending on the fiber content. In case of PCMPF specimen, the flexural strength increased greatly as the addition amount of PVA fiber increased. In particular, the flexural strength was represented the biggest at 75% UM resin content and 2% PVA. Due to the addition of PVA fiber, the flexural strength was improved greatly. In addition, taking into consideration the fact that as the UM content is large, and the addition amount of PVA fiber increase, the flexural strength tends to increase, the PVA fiber is considered to have an excellent effect on the improvement of flexural strength. This is also considered to be due to the fact that the effect of excellent control over cracks contributes to the improvement of performance in flexural strength on account of cross linking effect of PVA fiber [7].

In case of PCMSF specimen, as the addition amount of steel fiber increases, the flexural strength was measured relatively small. This is considered to be due to the fact that when mixing, the formation of solid cement matrix is difficult because the separation of materials like the phenomenon of fiber ball or fiber sinking, etc. occurs so often in steel fiber. It is thought to be necessary to consider the use of admixtures more carefully. The characteristics of steel fiber are also considered to be the effect of PCMHF specimen results. Like the results of PCMSF specimen, the results of PCMHF specimen also represented small flexural strength as the addition amount of fiber became large. As the content of resin increases, the content of fiber is considered to have no great effect on the flexural strength.

In Fig. 5, the changes in flexural strength depending on fiber type are compared generally. The PCMSF specimen and PCMHF specimen containing the steel fiber represented the decrease in flexural strength as the addition amount of fiber increased. In addition, the increase of resin content was not effective for the improvement of flexural strength. In case of PCMPF specimen with the addition of only the PVA fiber, as the addition amount of fiber increased, the flexural strength increased greatly. In addition, the flexural strength also increased according as the resin content increased. Seeing these results for reference, the PVA fiber is considered to be excellent as a reinforcement fiber to improve the flexural strength.

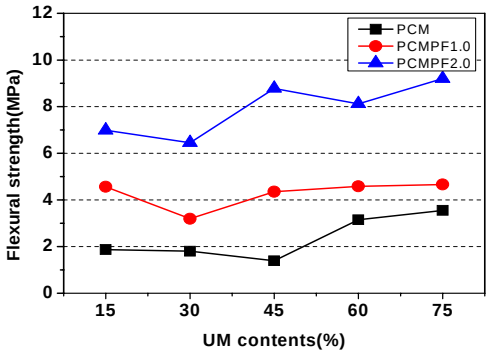


Fig. 2 Test results of flexural strength with PVA fiber

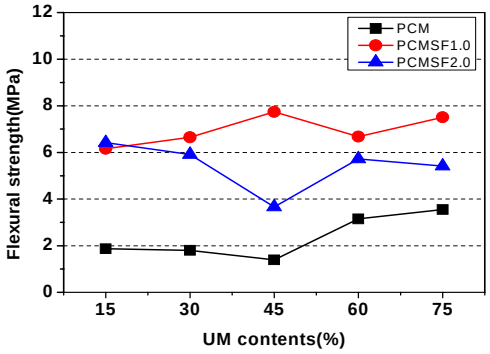


Fig. 3 Test results of flexural strength with Steel fiber

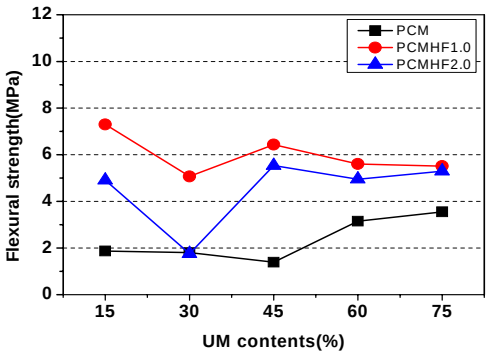


Fig. 4 Test results of flexural strength with PVA and Steel fiber

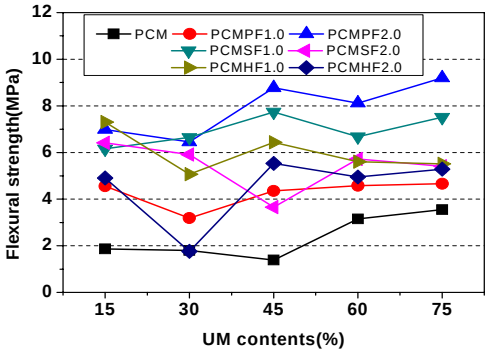


Fig. 5 Test results of flexural strength with all specimens

## IV. Conclusions

This study intended to assess the possibility of development of maintenance and reinforcement materials with a high durability using the polymer cement mortar to use the UM resin, eco-friendly resin. In addition, as a result of comparative analysis on improvement effect for characteristics of strength in the fiber-reinforced polymer cement mortar using the UM resin through experiments, the following conclusions were derived.

The flexural strength was increased in an experiment of fiber reinforcement to improve flexural strength of UM resin polymer cement mortar. For reinforcement of flexural strength, the PVA fiber was more effective than steel fiber.

## Acknowledgment

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