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The strength and durability of fiber-reinforced polymer cement mortars using UM resin

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ABSTRACT

A polymer cement mortar (PCM) has been widely used as the material of repair and restoration work for concrete structure. Such a PCM has advantages excellent in aspect of strength and durability. However a PCM usually induces an environmental pollutant. Therefore, there is a need to develop PCM as a repair and reinforcing material in consideration of environment. 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 a certain ratio. These are added in a certain percentage of PVA fibers, steel fiber and hybrid fiber mixed with PVA fiber and steel fiber in respectively to verify the effect of strength enhancement. The compressive, splitting tensile and flexural tests were performed in order to investigate the strength properties of the PCM reinforced fiber. In addition, the absorptivity and chemical resistance tests were conducted to determine the durability of proposed PCM. Experimental results showed that the durability and strength of proposed PCM using UM resin are improved in the comparison with general cement mortar. The usability of the UM resin PCM was confirmed as the reinforcing material to improve the durability of concrete structures exposed outside.

1. 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

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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 (Ohama 1981). 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.

The UM (Urethane Acrylate MMA resin) 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. The UM resin, eco-friendly resin was used as binding materials for polymer cement mortar. Also for the improvement of flexural strength, this polymer cement mortar was fiber-reinforced. In order to examine the durability according to use of resin, an experiment of absorption ratio and chemical resistance for polymer cement mortar depending on added amount of UM resin was performed. 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 durability and flexural strength. In addition, the mixing ratio was examined diversely, because the resin and fiber used in the fiber-reinforced polymer cement mortar are expensive and the performance or economic efficiency may drop with the effect not being represented properly.

2. EXPERIMENT

2.1 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. In order to confirm the durability performance of polymer cement mortar to which the UM resin, eco-friendly resin was added, an absorption test and chemical resistance test were performed. And as an experiment to investigate the basic characteristics of strength of fiber-reinforced UM polymer cement mortar, a compressive strength test, a splitting tensile strength test, and a flexural strength test were performed.

2.2 Materials used

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 1. The composition of the liquid UM resin is shown in Table 2. 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.

Table 1 The physical properties of fibers

	PVA	Steel
Diameter (mm)	0.04	0.50
Length (mm)	12	31.03
Tensile strength (MPa)	1,600	1,064
Elongation (%)	6	-
Young’s modulus (GPa)	37	-
Oil content (%)	0.8	-
Aspect ration (L/D)	-	62.06
Type	-	Hooked type

Table 2 The composition of the UM resin

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

Table 3 The composition of the UM resin

Type	Fiber type	Fiber content of total weight(%)	UM/W (%)	W (total)/C (%)	UM(resin)/C (%)
PCM	-	-	15	31.3	3.7
PCMFF1.0	PVA	1.0			
PCMFF2.0	PVA	2.0			
PCMSF1.0	Steel	1.0			
PCMSF2.0	Steel	2.0			
PCMHF1.0	Hybrid	0.5+0.5			
PCMHF2.0	Hybrid	1.0+1.0			
PCM	-	-	30	27.7	7.3
PCMFF1.0	PVA	1.0			
PCMFF2.0	PVA	2.0			
PCMSF1.0	Steel	1.0			
PCMSF2.0	Steel	2.0			
PCMHF1.0	Hybrid	0.5+0.5			
PCMHF2.0	Hybrid	1.0+1.0			
PCM	-	-	45	24.0	11.0
PCMFF1.0	PVA	1.0			
PCMFF2.0	PVA	2.0			
PCMSF1.0	Steel	1.0			
PCMSF2.0	Steel	2.0			
PCMHF1.0	Hybrid	0.5+0.5			
PCMHF2.0	Hybrid	1.0+1.0			
PCM	-	-	60	20.3	14.7
PCMFF1.0	PVA	1.0			
PCMFF2.0	PVA	2.0			
PCMSF1.0	Steel	1.0			
PCMSF2.0	Steel	2.0			
PCMHF1.0	Hybrid	0.5+0.5			
PCMHF2.0	Hybrid	1.0+1.0			
PCM	-	-	75	16.6	18.4
PCMFF1.0	PVA	1.0			
PCMFF2.0	PVA	2.0			
PCMSF1.0	Steel	1.0			
PCMSF2.0	Steel	2.0			
PCMHF1.0	Hybrid	0.5+0.5			
PCMHF2.0	Hybrid	1.0+1.0			

2.3 Method of experiment

For the mix 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 was 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. 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 3. In the table, 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.

2.3.1 Compressive strength test

A test-piece specimen was manufactured in dimensions of 50 mm × 50 mm × 50 mm in accordance with mix, and it was cured under the water for 28 days. A compressive strength test was performed on the manufactured test-piece specimen in accordance with the test method of KS L 5105, and thereafter the compressive strength was measured.

2.3.2 Flexural strength test

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.

2.3.3 Splitting tensile strength test

A circular test-piece specimen was manufactured in dimensions of φ 100 mm × 200 mm in accordance with mix, and it was cured under the water for 28 days. A splitting tensile strength test was performed on the manufactured test-piece specimen in accordance with the test method of KS F 2423, and thereafter the splitting tensile strength was measured.

2.3.4 Absorption test

A test-piece specimen was manufactured in dimensions of 40 mm × 40 mm × 160 mm in accordance with mix, and it was cured under the water for 28 days. An absorption ratio test was performed on the manufactured test-piece specimen in accordance with the test method of KS F 2459 and JIS A 1404, and thereafter the absorption ratio was measured.

2.3.4 Chemical resistance test

A test-piece specimen was manufactured in dimensions of 40 mm × 40 mm × 160 mm in accordance with mix, and it was cured under the water for 28 days. A chemical resistance test was performed on the manufactured test-piece specimen referring to the test method of KS M 5307 and ASTM C 267, and thereafter the weight change ratio was measured on the cured specimen after soaking for 28 days using 2% solution of hydrochloric acid and 5% solution of sulfuric acid (Kim 2006).

3. RESULT OF EXPERIMENT AND ANALYSIS

3.1 Results of durability test

3.1.1 Absorption ratio

Fig. 1 (a) represented the results of test on absorption ratio of polymer cement mortar. Absorption ratio has a significant effect on the durability of the structure. In most cases of ordinary cement mortar, the water penetrates into inside of the structures through the pores due to bubbles, capillary pores, gel pores, etc. and by an osmotic pressure action, etc. The water penetrated into the inside contains various harmful substances, providing the causes for corrosion of reinforcing bar, so the absorption ratio has a close relationship with the durability of structure. Polymer cement mortar reduces the quantity of pores into which the water can penetrate in a way that polymer particles or polymer films fill the internal pores like capillary pores and gel pores inside the structure.

Also, the polymer film plays a role to block the penetration of water from the outside having the waterproofing in itself. For this reason, the polymer cement mortar is often used as a waterproof material for interiors and exteriors, such as the walls, slabs, basements, bathrooms and water tanks, etc. of the structure much affected by the water, having an excellent waterproofing compared to the ordinary cement mortar (Depuy 1996). Absorption ratio and water permeability of polymer cement mortar differ slightly depending on the air content and type of polymer, and also differ greatly depending on the polymer cement ratio. However, in general, they show a big difference depending on the polymer cement ratio rather than on the air content and type of polymer, and it is known that as the polymer cement ratio increases, the absorption ratio decreases (Ohama 1973). It is because that the polymer dispersion represents the surface-active effect as the polymer is dispersed inside the non-hydrated cement complex, and because the resistance of complex against the air permeability and water permeability increases due to the fact that the polymer film with self-adhesiveness and adhesive property is formed as it is dehydrated and dried depending on the progress of cement hydration, sealing the micro pores in the complex (Soh, Park, Jo, and Lee 1991).

Likewise the existing studies, also in this study, the absorption rate is shown to drop according as the addition amount of UM resin increases. The polymer cement mortar with the addition of UM resin represented the drop of absorption ratio up to maximum 4.54 times as much as the ordinary cement mortar without the addition of UM resin.

3.1.2 Chemical resistance

Fig. 2 (a) and (b) represented the results of test on chemical resistance of polymer cement mortar. It can be seen that as the addition amount of UM resin increases, the acid resistance increases. The polymer cement mortar with the addition of UM resin represented the resistance effect of weight loss ratio up to maximum 2.98 times in the hydrochloric acid solution, and up to maximum 21.89 times in the sulfuric acid solution as much as the ordinary cement mortar without the addition of UM resin. As a result, it could be seen that the use of UM resin had a large effect on acid resistance. This is considered to be due to the fact that the formation of the polymer film reduces fine cracks on the surface of test-piece specimen, and the sealing effect of film increases the density, making the effect of resistance against acid resolution great. In addition, due to the formation of polymer particles and polymer film, the large pores inside the polymer cement mortar can be filled up. So it is considered that the decrease of whole pore amount and increase of micro pore amount have affected much influence on the improvement of durability (Ohama 1995).

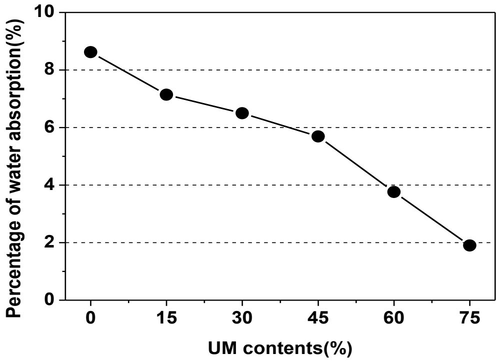
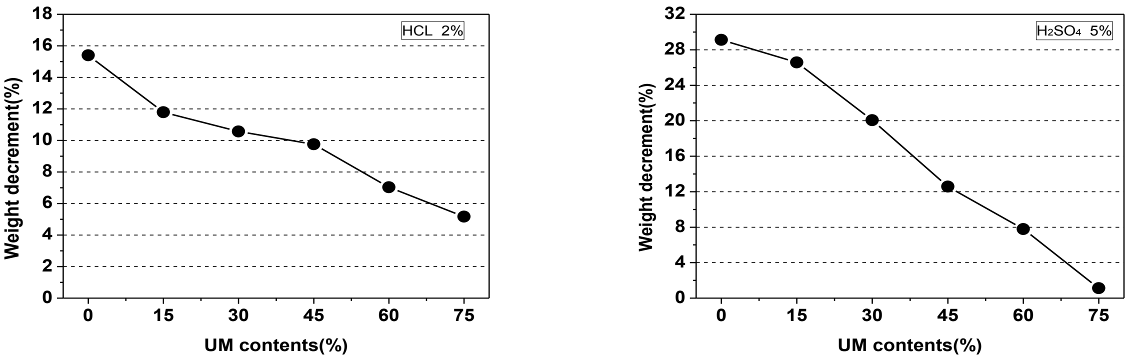
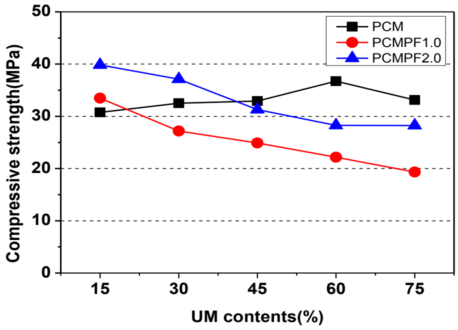


Fig. 1 Computational meshes for Gyeongju station

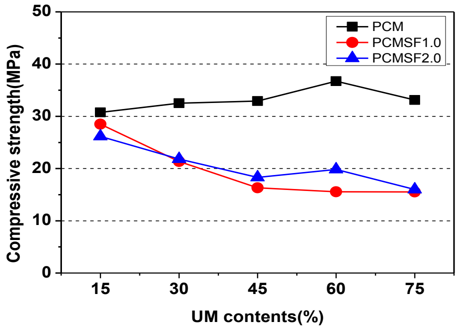


(a) HCL 2% (b) H_2SO_4 5%

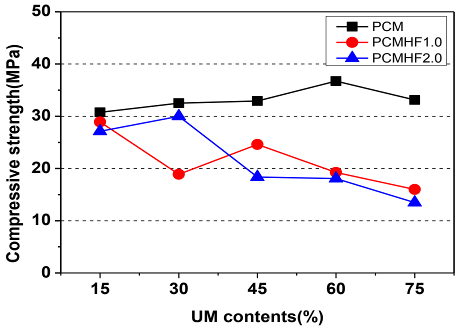
Fig. 2 Test results of chemical residence



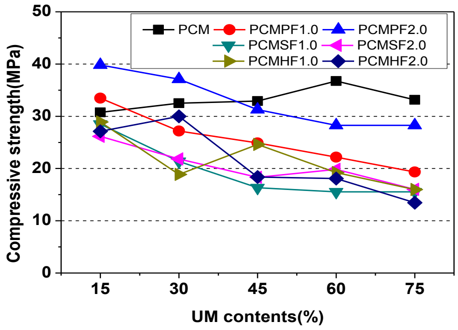
(a) PVA



(b) Steel

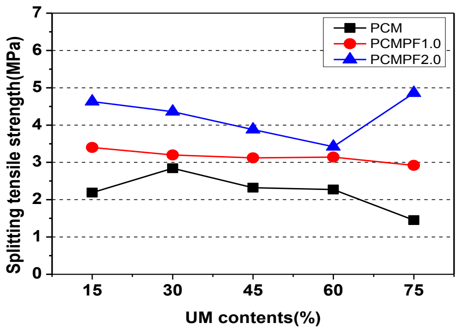


(c) PVA+Steel

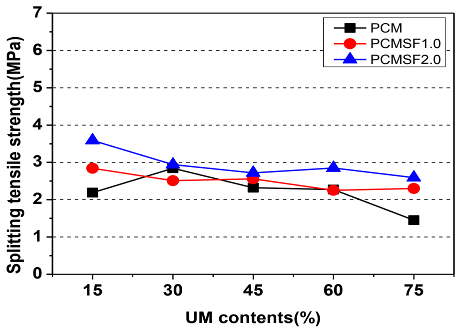


(d) Summary

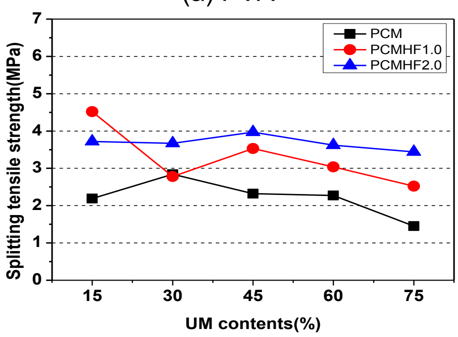
Fig. 3 Test results of compressive strength



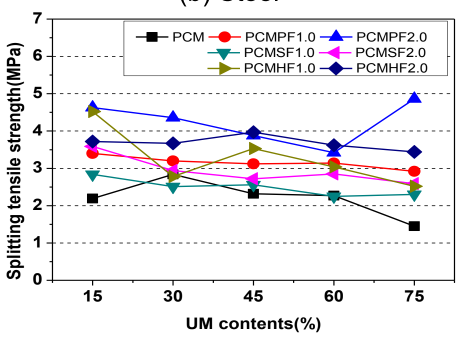
(a) PVA



(b) Steel

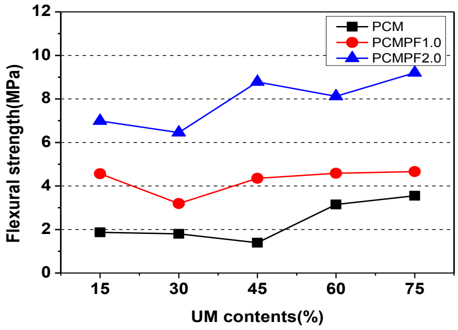


(c) PVA+Steel

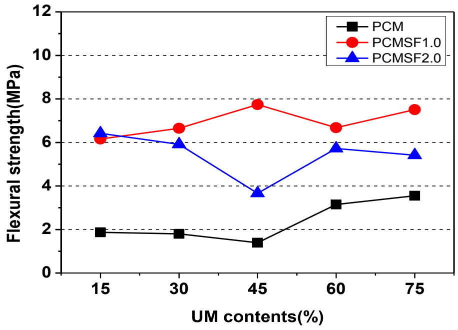


(d) Summary

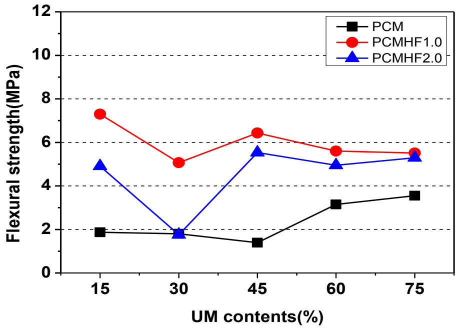
Fig. 4 Test results of splitting tensile strength



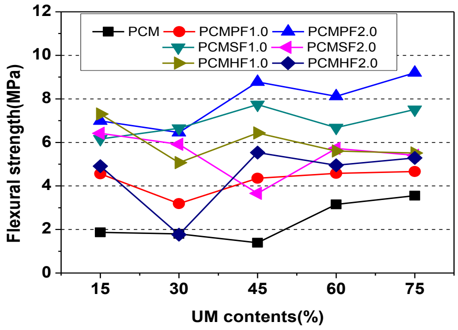
(a) PVA



(b) Steel



(c) PVA+Steel



(d) Summary

Fig. 5 Test results of flexural strength

3.2 Results of strength test

3.2.1 Compressive strength

Fig. 3 represents the results of test on compressive strength of fiber-reinforced polymer cement mortar depending on the UM content. In all specimens, it was represented that the compressive strength decreased generally as the UM resin content increased. Although it was expected that the compressive strength increased as the UM resin content increased due to the decrease of water-cement ratio (W/C), the compressive strength decreased generally as the UM resin content increased. Such decrease of compressive strength is considered to be due to the fact that the hydration of cement is delayed because the ion concentration of cement mortar in a liquid state is changed as a result of UM resin used. In addition, the compressive strength is also considered to have decreased due to the fact that the strength of cement hydrate bearing the compressive stress reduces, and the polymer film not having its own strength is formed and contains a large amount of moisture in a state close to wet gel, resulting in decrease of the adhesive strength between the cement hydrate and aggregates (Sekino 1996).

Fig. 3 (a), (b), and (c) represent the changes in the compressive strength depending on the fiber content. The PCMPF specimen containing only the PVA fiber shows relatively a big difference in the strength depending on the fiber content. In the specimen containing 15% and 30% resin content, the compressive strength increased due to the addition of fiber compared to the specimen without the addition of fiber. In the PCMPF specimen containing only the steel fiber and the PCMSF specimen containing both PVA fiber and steel fiber, it was represented that the strength tended to decrease as the resin content increased.

In Fig. 3 (d), the results of compressive strength depending on fiber type and content were compared generally. Among the specimens containing the fiber, it was represented that the PCMSF specimen containing only the PVA fiber had relatively the highest compressive strength. The PCMSF specimen and PCMHF specimen containing the steel fiber represented relatively lower compressive strength than the PCMPF specimen. Thus, the content of PVA fiber is considered to be relatively more sensitive to the results of compressive strength than the content of steel fiber. The improvement of compressive strength in cement mortar depending on the fiber reinforcement was not attained.

3.2.2 Splitting tensile strength

Fig. 4 represents the results of test on splitting tensile strength of fiber-reinforced polymer cement mortar depending on the UM content. In all specimens, it was represented that the splitting tensile strength decreased generally as the UM resin content increased. Reduction of splitting tensile strength is considered to have affected an adverse effect on the formation of cement matrix with a good quality bearing the splitting tensile strength due to the polymer film formed when the UM resin is added. However, in almost all specimens except the PCMSF specimen containing only the steel fiber, the splitting tensile strength increased more than the splitting tensile strength of PCM specimen regardless of the content of UM resin.

Fig. 4 (a), (b), and (c) represent the changes in the splitting tensile strength depending on the fiber content. In all specimens, the splitting tensile strength increased regardless of the content of UM resin as the addition amount of fiber increased. In case of PCMSF specimen, the splitting tensile strength has not increased so much. In the results of PCMHF specimen containing both PVA fiber and steel fiber, the increase of strength was not greater than the results of PCMPF specimen.

In case of PCMPF specimen, the splitting tensile strength increased relatively much as the addition amount of fiber increased. This is considered to be due to the fact that the effect of excellent control over cracks contributes to the improvement of performance in tensile strength on account of crosslinking effect of PVA fiber (Wang and Victor 2005), and in this experiment, PVA fiber is considered to have a great effect on improvement of tensile strength. In case of steel fiber, the increase of tensile strength depending on the addition of fiber was not greater than in case of PVA fiber. In Fig. 5 (d), the changes in splitting tensile strength depending on fiber type are compared generally. The PCMPF specimen and PCMHF specimen containing the PVA fiber represented relatively higher splitting tensile strength than the PCMSF specimen containing only the steel fiber. Thus the PVA fiber is considered to be relatively excellent as a reinforcement fiber to improve the splitting tensile strength.

3.2.3 Flexural strength

Fig. 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. If the stress affects the hardened cement paste, minute cracks easily occur. Minute cracks become the cause to weaken the flexural strength in ordinary mortar or concrete. Thus, the minute 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 (Ramachandran 1996). In all specimens with the addition of fiber, the flexural strength increased. This is considered to be due to the fact that the fiber caused interferences in control of minute cracks.

Fig. 5 (a), (b), and (c) 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 tend 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 crosslinking effect of PVA fiber (Wang and Victor 2005).

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 (d), 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.

4. 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.

1) Absorption ratio of the polymer cement mortar decreased as the amount of UM resin used increased. In addition, as the amount of UM resin used increased, the resistant force for chemical resistance was improved, causing the decrease in weight loss ratio.

2) The fiber reinforcement to improve the compressive strength of UM resin polymer cement mortar is not effective. At the time of fiber reinforcement, the control over decrease in compressive strength of polymer cement mortar incidental to the fiber reinforcement is considered to be possible based on the detailed study on interaction between used fiber and resin.

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

4) The polymer cement mortar using the UM resin and PVA fiber is considered to be available for use in order to improve the durability of concrete structures exposed to the outside because the waterproofing and chemical resistance are improved, and the performance of flexural and tensile strength increases. In addition, their usability as reinforcement materials to improve the flexural strength was confirmed.

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