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INFLUENCE OF FREEZING AND THAWING CONDITIONS AT INITIAL AGE ON THE STRENGTH DEVELOPMENT OF MORTARS

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ABSTRACT: Agricultural irrigation canals are widespread across Japan and extensively used in productive farming. There is an urgent need to extend the service life of these facilities to reduce their maintenance cost. Therefore, the purpose of this study is to experimentally explore the effect of low-temperature history on the long-term strength of polymer cement mortar, especially during the early stage of the mortar's life, thus, 3 days of age. In this study, two types of polymer cement mortar were used: powdered ordinary polymer cement mortar and powdered fast-hardening polymer cement mortar, thus 100P and 100PS respectively. The experimental results indicate that the compressive strength analysis of the polymer cement mortar is lower than the standard cured, whenever the initial curing process was subjected to rapid temperature changes (-10ºC to 5ºC) every 3 hours; subsequently, its purpose of extending the service life of agricultural canals cannot be fulfilled. We again noted that the compressive strength of the specimens subjected to low temperature during the initial curing period does not show positive strength on the 91st day, and depending on the timing of the repair work, the waterway may lack sufficient compressive strength. Finally, under a constant low-temperature environment where freezing and thawing do not occur (-10 ºC), the fast-setting polymer cement mortar shows sufficient strength up to 91 days. The results from this work will provide a reference to experimentally clarify the effect of low-temperature history on the long-term compressive strength of typical polymer cement mortar.

Keywords: Compressive strength, Polymer cement mortar, Concrete, Freezing, and Thawing

1. INTRODUCTION

The first canals were built between the Middle Ages and the Renaissance to harness the driving force of water [2]. Their development during the 18th and 19th centuries aimed to address the growing need for water in Mediterranean farming. Canals have aided the development of irrigated agriculture since the late 1800s, allowing for increased production, increased crop surfaces, and the introduction of new crops [3].

Agricultural water use, as the largest form of water use, accounts for 70% of the total water consumption in the world and is a vital part of the social water cycle, and even in regions with relatively abundant water resources, the agricultural water demand cannot be met completely [4, 5]. Intense water resource exploitation and utilization have resulted in severe changes in natural hydrological cycle processes in many agricultural watersheds [6-8].

Agricultural water utilization facilities, thus concrete canals in Japan were mainly constructed between the end of World War II and the period of rapid economic growth, and nearly 80 years have already passed. There is an urgent need to extend the service life of these facilities and reduce their cost.

As a result, irrigation canal scheduling is critical for achieving high crop yields and improved water use efficiency while lowering environmental impact. Several issues have arisen as a result of rising temperatures affecting the use of mortar and concrete in recent years, posing a significant danger to their performance [9]. Concrete made of ordinary Portland cement has disadvantages such as slow hardening, large shrinkage, weak tensile and flexural strengths, lack of water tightness, and weak chemical resistance, although it also has some advantages, such as easy manufacturing and application in construction and high compressive strength [10].

To overcome the disadvantages of ordinary cement concrete and mortar with Portland cement, researchers have attempted over the last 60 years to develop a new type of concrete and mortar using a polymer that demonstrates excellent performance [10, 11]. Today, various polymers are being tested to improve cement's properties as a binder; this new concept of concrete or mortar has better physical properties and durability than ordinary cement concrete and is termed polymer-modified concrete/mortar or polymer cement concrete (PCC)/mortar (PCM).

Agricultural open waterways are scattered throughout Japan [12]. Whenever there is a deterioration in the agriculture canal even if the deterioration is of the same kind, it may be difficult to repair them using the same repair material due to various conditions such as environmental conditions, usage conditions, and location within the waterway [13]. In addition, agricultural irrigation canals are often conducted during the off-season, that is winter as shown in Fig. 1, and the possibility of construction failure caused by low temperatures is considered to be high. Damage caused by frost expansion is a primary concern when designing concrete structures in cold-weather regions [14-16].

Measuring the early age strength of mortar is important since it has a direct impact on the progress of a building project. In most cases, it is the governing parameter in the speed of the construction. Both time and temperature are crucial elements in the strength development of mortar. It may also have an impact on the safety margins for progressing to the next stage of construction. The structural engineer is likewise concerned with strength, to determine whether certain elements have gained sufficient strength to carry the next flow load. The mortar compressive strength improves as the microstructure of the specimen develops with time. The curring regime to be adopted can also affect the strong growth in mortar.

The combined effect of time and temperature can be used to study the strong growth of the cement mortar. The age of mortar has a significant effect on strength. On the other hand, the temperature history during the curing process of mortar can affect strength growth.

Many types of cement have been created to ensure concrete's long-term resilience in a variety of environments. However, it has not been possible to find a complete solution to the problem of concrete durability in the cement composition: the main mechanical and physical properties of hardened concrete, such as strength, shrinkage, permeability, weathering resistance, and creep, are influenced by factors other than the cement compoeven thoughact that the cement composition determines the rate of strength gain to a large extent [17].

Fig. 1 Workers repairing a deteriorated river canal in Kochi.

Ordinary portland cement concrete has a range of benefits, including low costs, high compressive strengths, and flexibility in fabrication and casting, but its durability concerns are gaining more attention these days, as the majority of concrete structures are experiencing performance degradation[18, 19].

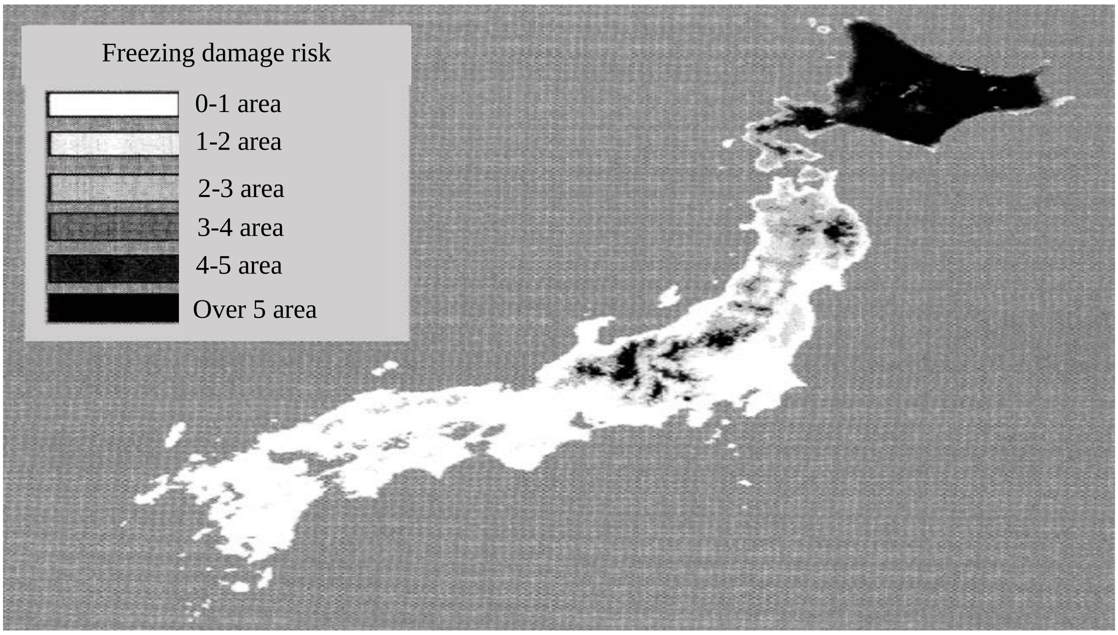

Fig. 2 Map of Japan showing freezing damage risk.. *Source:*[1]

Concrete performance is affected by a variety of factors, including material composition, curing schemes and temperatures, hazard species, harsh conditions, and external loads [20].

Furthermore, concrete durability in freezing and thawing temperatures is a complicated phenomenon. Surface scaling and internal cracking are signs of concrete deterioration caused by freeze-thaw cycles as shown in Fig. 3 [21, 22]. The freezing and thawing of water with deicing salt in porous buildings causes significant damage and necessitates significant financial investments in their repair and/or replacement [23]. This deteriorating process has been extensively explored, and as a result, many theories and criteria for evaluating the resilience of concrete subjected to F-T cycles utilizing accelerated tests have been proposed [23, 24]. Freeze-thaw deterioration is categorized as physical damage. The mechanism of frost damage of cementitious materials was initially described by T.C. Powers, based on hydraulic and osmotic pressure theories [15].

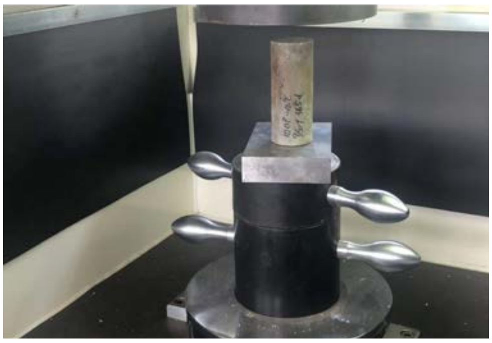

Fig. 3 Compressive test setup of the specimen

Therefore, in this study, we focused on the cracks in the concrete canal walls of agricultural canals as one of the aging problems of agricultural water utilization facilities.

2. Research significance

The purpose of this study was to experimentally elucidate the effect of low-temperature history on the long-term strength of polymer cement mortar, especially during the early stage of the mortar's life up to 3 days of age. Secondly, to experimentally clarify the effect of low-temperature history on the long-term compressive strength of polymer cement mortar. It also aimed to build analytical models for predicting concrete compressive strength for 7, 28, 91, and 365 days.

3. MATERIALS AND METHODS

2.1 Materials

This experiment was conducted in Japan, Kochi prefecture as shown in Fig. 2 above. The map shows freezing damage risk in japan, thus area marked with 0-1 have lower freezing damage risk whereas areas marked 4-5 has a high freezing damage risk. In this study, two types of polymer cement mortar were used: powdered ordinary polymer cement mortar and powdered fast-hardening polymer cement mortar. The former will be referred to as 100P and the latter as 100PS. A CF 1033 table vibrator was used to level and release existing air in the mortar. A mortar mixing machine was used to mix the cement, water, and, sand to control air bubbles that are entrained in the process of mixing. A cube mould with a size conforming to IS: 10080-1982 was adopted for casting [26]. Also, a concrete compression testing machine was used to measure the compressive strength employed in the fracture test at the final material age as shown in Fig. 3. This work was completed in line with ASTM C109/C109M standards [27].

2.2 Methods

Firstly, grease was applied inside the plamold for easy removal of the made mortar. A 4kg of each polymer cement, thus 100PS and 100P was measured using the electronic balance in the cement mixing machine. The water-cement ratio was the value recommended by the manufacturer, with a pH value of 7.

Furthermore, the plastic mould was thoroughly cleaned using oil. The made specimen was immediately placed on the vibrating machine by holding it in the position by clamps provided on the machine to release entrapped or existing air in the mortar. We further filled the cube mould with the entire quantity of mortar using a suitable hopper attached to the top of the mould and vibrate it for 2 minutes at a specified speed of 12000±400 per minute to achieve full compaction [25]. A total of 120 mortal samples were prepared, which were subsequently subdivided, thus based on the properties of cement mortar used. Nine mortar specimens were tested on each of these ages.

After the compaction process, the moulded specimen was kept in a place with a temperature of 27±2° and relative humidity of 90% for 24 hours. At the end of the 24 hours, the specimen was removed from the plamond plastic mould and immediately stored in an incubator capable of providing arbitrary low-temperature history. This was used to provide low-temperature levels up to 3 days of material age as shown in table 1.

The minimum temperature was set at -10ºC and the maximum was set at +5ºC. The reason why the minimum value of the low temperature was set to -10°C is that it is the lowest temperature in cold regions in Japan, and the maximum value of the temperature history was set to +5°C based on the assumed daily difference.

The curing conditions of mortar specimens were all standard water curing and it was cured by wet sac under laboratory conditions. The temperature history of the specimens during curing was set at 20°C (hereinafter referred to as control), which was recommended by the manufacturer, as the standard condition. The curing condition was observed for 7, 28, 91, and 365 days respectively.

All specimens were further removed from the water only at the testing time. The measured compressive strength of the cubes was computed by dividing the maximum force applied to the cubes during the test by the cross-sectional area calculated from the section's mean dimensions and expressed to the closest 0.5 N/mm2 as shown in Equation (1) and(2).

$$IICompressive\ Strength\ \frac{Load}{Cross\ Sectional\ Area} \qquad (1)$$

$$F = \frac{P}{A} \qquad (2)$$

The compressive strength of cement is calculated MPa.

In general, freezing and thawing effects on hardened concrete cause volume expansion and contraction, which are the failure mechanisms in freezing damage. However, the effect of freezing and thawing immediately after casting on the long-term strength of cement hydrates has not yet been clarified. The test results were the average of the three specimens.

Table 1 below shows the temperature differences, duration, and the number of cycles for a cement mortar in an incubator.

4. RESULTS AND DISCUSSION

Firstly, comparing the normal strength development characteristics of 100P and 100PS, it can be read that the compressive strength increases with time for both. However, the strength development characteristics were different, with the compressive strength of 100PS being greater at 7 days of age, but showing little change at 91 days of age.

To investigate the effects of freezing and thawing (freeze-thaw) cycles, the specimens were subjected to a low-temperature history of -10°C for 3 days during initial curing as shown in Fig. 7. The compressive strength of 100P was small (10.0 kN) at 7 days of age, and only about half of the compressive strength of the control specimen (20.0 kN) was shown in Fig. 4. On the other hand, the difference between 100PS and the control specimen was minimal, and the strength of 100PS was about 3.7 times higher than that of 100P under the same condition as shown in Fig. 5.

Table 1. Experimental design for freeze-thawing for 3days.

Temperature (ºC)	Duration	Cycle
Standard 20ºC		
-10ºC	3 days	Keep in an incubator for 3 days at a controlled temperature of -10ºC
-10 ºC +5 ºC	12 hours, 3 days	+5ºC for 12 hours and -10ºC for 12hours (a cycle a day)
-10 ºC +5 ºC	6 hours, 3 days	+5ºC for 6 hours and -10ºC for 6 hours (4 cycles a day)
-10 ºC +5 ºC	3 hours, 3 days	+5ºC for 3 hours and -10ºC for 3 hours (9 cycles a day)

Furthermore, as shown in Fig. 4 and Fig. 5, not much difference ware recorded for 100P and 100PS polymer cement mortars compared to the control specimen at 28 days of mortar age. This may be due to the constant temperature adopted during the initial curing process for 3 days of the mortar life.

At 91 days of age, the average compressive strength of both types of specimens for Fig. 7 was 22.9 MPa, which was the least recorded among the specimens at the same mortar age. Both types of specimens that underwent freeze-thaw at 12 and 6-hour pitches showed an increase in strength with time, but the average compressive strength was lower in both conditions.

For the specimens subjected to freeze-thaw at a 3-hour pitch, both specimens showed relatively high compressive strength up to the 7th and 28th day, but the compressive strength on the 91st day was lower than the compressive strength on the 28th day as shown in Fig. 8.

It was confirmed that 100PS, which is a fast curing type, has a larger initial strength development rate. According to the manufacturer's measurement, the compressive strength of 100P was higher than that of 100PS even at the age of 7 days. One possible reason for this is that the manufacturer recommended a water-mortar ratio (water/polymer cement mortar,

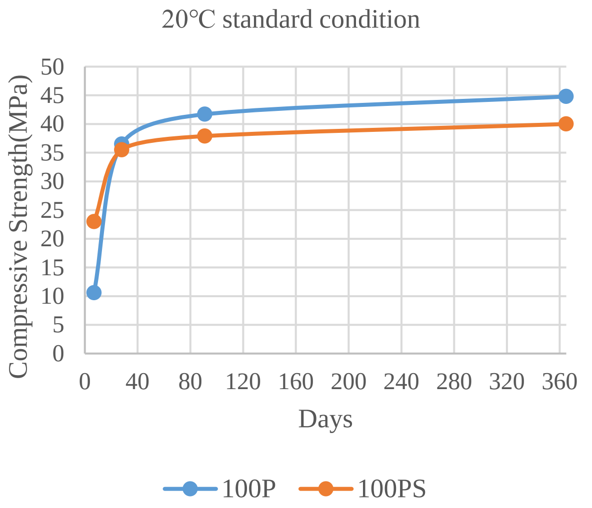

Fig. 4 20 ºC standard condition in water

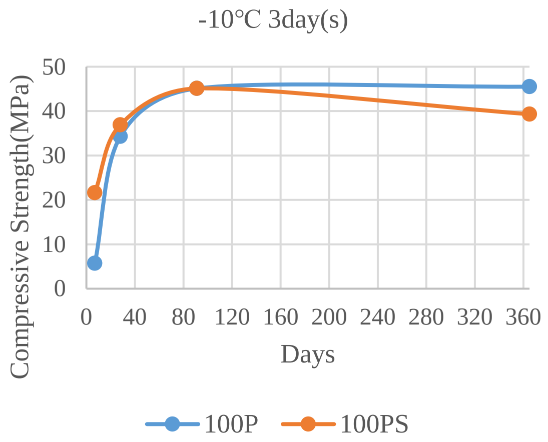

Fig. 5 Compressive strength of -10ºC for 3 days

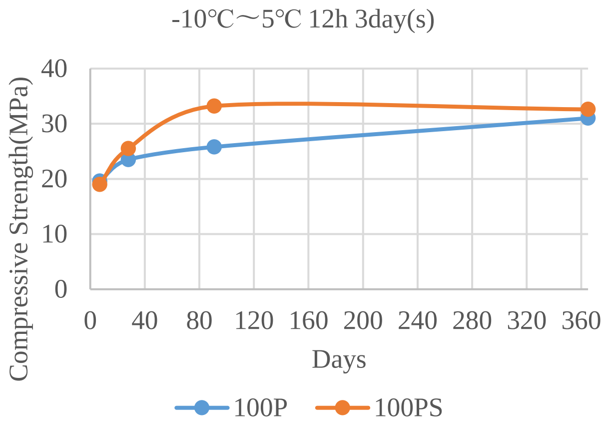

Fig. 6 Compressive strength of -10ºC~5 ºC for 3 hours

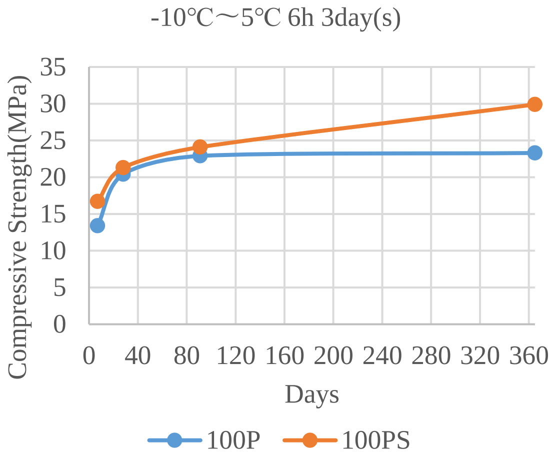

Fig. 7 Compressive strength of -10ºC~5 ºC for 3 hours

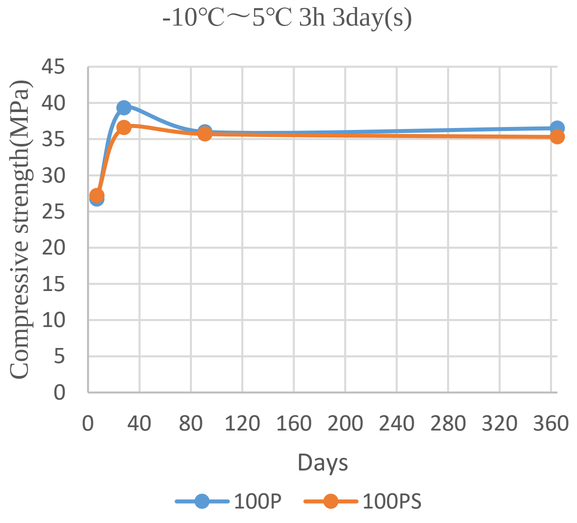

Fig. 8 Compressive strength of -10 ºC~ 5 ºC for 3 hours

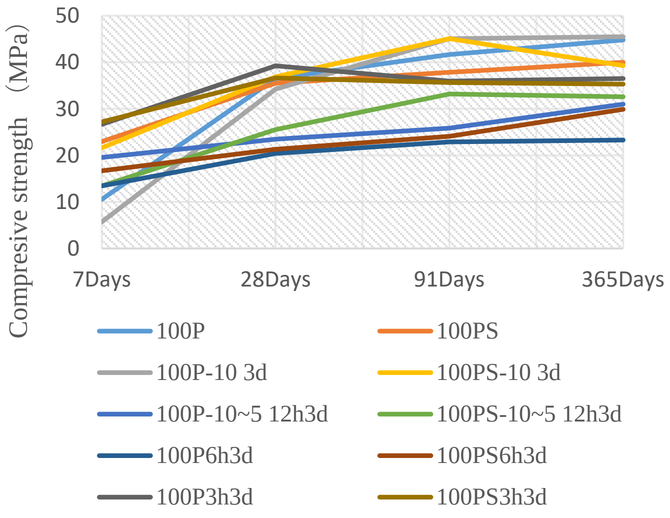

Fig. 9 Variation of compressive strength and age

weight %) in the range of 15.6~17.2% for 100P and 16~18% for 100PS.

In this study, the amount of water used for both is unified and set at 17%, which falls within the common range and may have caused the difference between the strong expression in this experiment.

We also confirmed that the freeze-thaw effect during the initial age of the specimens hurt the compressive strength, which was due to the increase in the volume of water in the specimens caused by freezing and the destruction of the hardened parts by fine cracks due to the hydration reaction. This suggests that the compressive strength of the specimens was not sufficient due to the increase in the volume of water in the specimens caused by freezing and the destruction of the hardened parts by fine cracks due to the hydration reaction.

The decrease in compressive strength at 91 days was caused by freeze-thaw action more times than the specimens with 12-hour and 6-hour pitches, indicating that freeze-thaw action after casting hurts long-term strength development, even for the mortars subjected to this study. From Fig. 9, it can be seen that 100PS showed the highest compressive strength on the 91st day recording 45.1 MPa but showed a significant decline in compressive strength at 365 days recording 39.3 MPa. Subsequently, the 100P mortar specimen which underwent freezing for 3 days at 10ºC, developed the highest compressive strength of 45.5 MPa at the age of 365 days but recorded the lowest strength at 7 days as shown in Fig. 9. However, it should be noted that variations in mixed proportions do influence these trends to some extent.

5. CONCLUSION

In this study, we focused on two types of polymer cement mortar, one of the inorganic repair materials, in the cold climate of Japan, where the temperature sometimes drops below 0°C. The influences of curing time at different ages on the development of strength for various curing temperature histories were investigated. The following experimental results were obtained by confirming the compressive strength of polymer cement mortar subjected to various low-temperature histories.

First, if the initial curing process is subjected to rapid temperature changes every three hours, the compressive strength tends to drop, and the purpose of extending the service life of agricultural canals cannot be fulfilled.

Secondly, the compressive strength of the specimens subjected to temperature changes during the initial curing period does not develop easily on the 91st day, and depending on the timing of the repair work, the waterway may be used without sufficient compressive strength.

Finally, under the low-temperature environment where freezing and thawing do not occur, the fast-setting polym_er cement mortar shows sufficient strength up to the 91st day.

Fig. 10 A well repaired irrigation canal in Kochi

We encourage further studies into the water-cement ratio and also the temperature history by adopting different curring conditions and to ascertain any improvement in the compressive strength of the cement mortar specimens.

6. ACKNOWLEDGEMENT

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