DEVELOPMENT OF FAST ACCELERATED SET CONCRETE APPLICATION FOR REPAIRING THE DETERIORATED REINFORCED CONCRETE DECKS

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Abstract

Many reinforced concrete bridge decks in the Hokuriku Expressway, hereinafter called as RC decks, have been damaged by deicing salt attack. The delaminated RC decks have been repaired by patching and applying the ultra rapid concrete. However, ultra rapid concrete application requires a special type of vehicle for mixing concrete, which results in the considerable increase of the total repairing cost of the RC decks. This paper describes the development of a rapid hardening concrete named Fast Accelerated Set Concrete, hereinafter called as FACET. FACET is mixed directly with calcium aluminates and sulfate powder in a mixer truck, and it can develop the compressive strength greater than 24N/mm^2 in 6 hours. In this research work, a total deck area of about 1,000m^2 is investigated to confirm the workability and the supply capacity of the FACET system. A cost-effective and easy supply system of FACET for repairing delaminated RC decks is furthermore proposed.

Introduction

These days, many RC decks in the Hokuriku Expressway have been damaged by deicing salt attack. The delaminated RC decks are normally repaired through the patch of concrete material. In order to reduce the influence on traffics and logistics on the expressway, a quick repairing method is always requested. As a result, the ultra rapid concrete, whose a unique characteristic is quick setting to reach the concrete compressive strength of 24N/mm^2 in 3 hours has been applied. The ultra rapid concrete requires to be mixed on the site by using a stationary type or portable type, as shown in **Fig. 1**. The mixing cost on the site of this material is normally ten times higher than that in the plant. A more cost-effective concrete material is therefore required. This paper presents the development of the supply system for FACET. This FACET is mixed directly with powder of the calcium aluminates and sulfate in a mixer truck and enables to develop compressive strength greater than 24N/mm^2 in 6 hours, whereas maintain cost performance.

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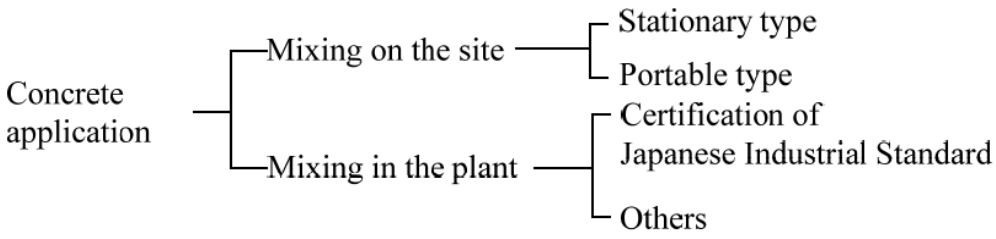


Fig.1 Concrete application types in Japan

The Problem in Repairing the Delaminated RC Decks

The Hokuriku Expressway began operating in 1970s. In winter season, deicing salts have been used on this expressway. The use of deicing salts have dramatically increased, as shown in **Fig. 2**, as a result of studded tires being banned in 1990 for heavy snowfall areas in Japan [1]. When the deicing salts (i.e. chloride ion) and water reach down the reinforcing bars, hereinafter rebars, an electrolytic action is started and causes the corrosion of rebars. As the corrosive particles build up, they expand against the concrete cover, eventually exceeding the tensile strength of the concrete. As presented in **Fig. 3**, this causes the horizontal cracks along the upper area of rebars, which results from the exceedance, can cause a delaminated area of concrete [2].

Delaminated RC decks are normally inspected by using the hammer tapping on the asphalt pavement, as given in **Fig. 4**. This inspection method is easy to be used and can detect fast the delaminated area. However, this method has low accuracy in estimating the area of delaminated RC decks, as addressed in **Table 1**. On the other hand, for the use of the conventional ultra rapid concrete application the good estimation of the repairing material volume is always require because if there is a mistake in the estimation of repairing area, mixing problem will occur, as depicted in **Fig.5**. Therefore, a development of a flexible supply system for the FACET is furthermore proposed.

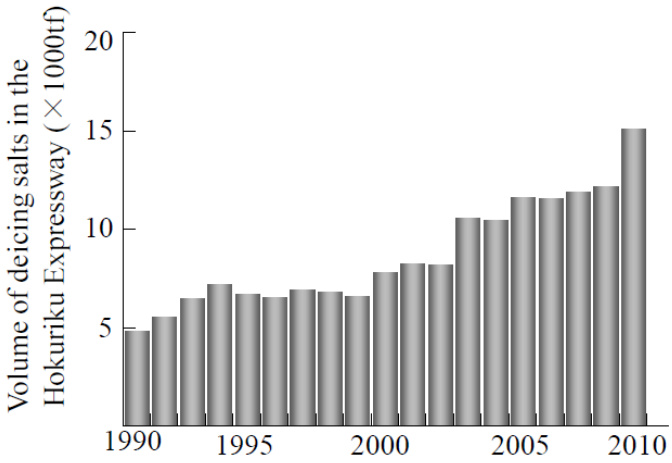


Fig.2 Volume of deicing salts in the Hokuriku Expressway

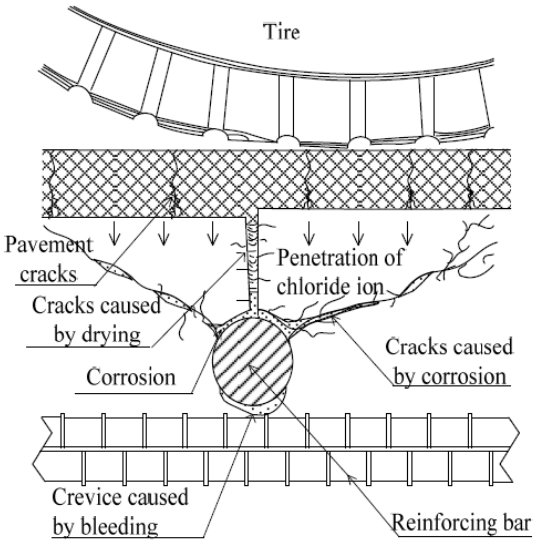


Fig.3 The delaminated RC decks caused by deicing

Table 1. Accuracy rate of hammer tapping

Method	Visual survey used on the concrete cores
Hammer tapping	88%

Fig.4 Typical investigation of RC decks

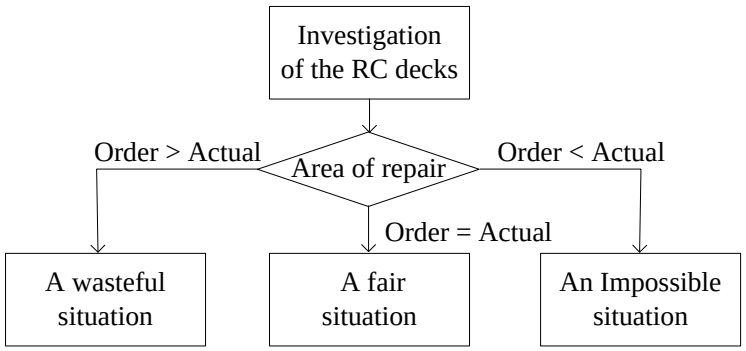


Fig.5 The problem of mixing concrete on the site

Characteristics of Facet

1. Outline

Mix of FACET applies a new manufacture concept. The ready mixed concrete, which doesn't harden yet, is supplied from a plant with a certification from Japanese Industrial Standard. FACET is made by mixing the ready mixed concrete with delaying agent solution, whose main chemical compound is called oxycarbonic acid, and then the powder of calcium aluminates and sulfate is added in a mixer truck. The typical mix proportion of the FACET is shown in **Table 2.** On the other hand, **Table 3** shows the comparison of FACET with the conventional ultra rapid concrete application. It shown from this table, the cost of using FACET is approximately half times cheaper than that of ultra rapid concrete. The mixing method of FACET also enables it to be a flexible supply system, which is expected if the repairing area is out of the estimation.

2. Material characteristics of FACET in fresh concrete condition

Fig. 6 shows the condition of the fresh FACET slump measured in accordance with the JIS A 1101. Because the FACET contains large amount of powder, the shape of slump measured is in viscosity condition. In addition, FACET has less bleed water on the concrete surface.

Fig.7 shows the measuring resistance of the penetration proctor in accordance with ASTM C 403. This result shows that the volume of delaying agent solution and temperature are influencing the setting time. Therefore, it is recommended that the material temperature should be measure and then an adjustment of the volume of delaying agent solution should be done to suit the concrete workable time.

Table 2. Typical mix proportion of the FACET (Unit: kg)

Water	Cement	Sand	Aggregate	Chemical admixture	Delaying agent		Admixing powder
					Chemical compound	Water	
168	350	744	1018	3.5	3.5	10	150

Table 3. Comparison of FACET with conventionally ultra rapid concrete application

	FACET Concrete	Ultra Rapid Concrete
Compressive strength	24 N/mm^2 in 6 to 12 hours	24 N/mm^2 in 3 hours
Starting of the mixed concrete setting time	More than 60 minutes	20 to 40 minutes
The place of mixing the concrete	In the concrete plant then add the powder on the site	On the site
Supplying ability	15 to 30 m^3/hour	15 to 30 m^3/hour
Price (×thousand yen)	120 to 180	250 320

Fig.6 The condition of FACET in accordance with slump test (JIS A 1101)

3. Material characteristics of FACET in hardening concrete condition

The compressive strength of FACET enables to be developed greater than 24 N/mm^2 in 6 hours and finally reached more than 70 N/mm^2 in 28 days, as shown in **Fig.8**. **Fig.9** shows the salt penetration depth of various concrete measured by Electron Probe Micro Analyzer ,hereinafter EPMA. The penetration of chloride ion in FACET is less than that in normal concrete. As a result, the high durability of FACET is confirmed.

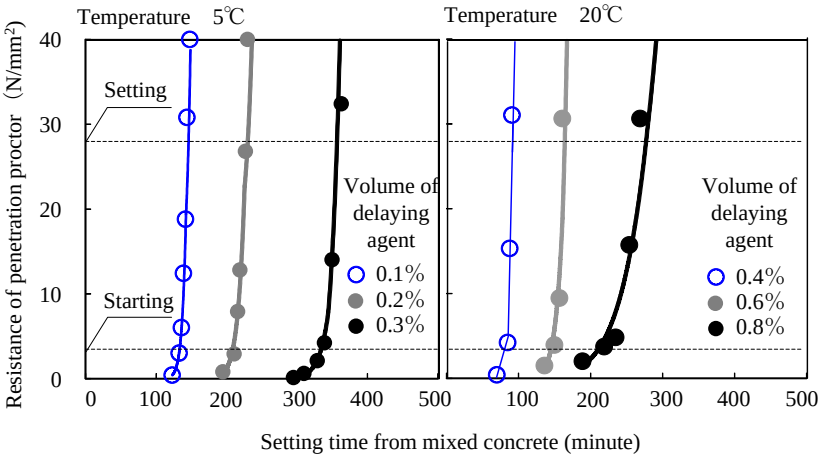


Fig.7 The measuring resistance of the penetration proctor of FACET

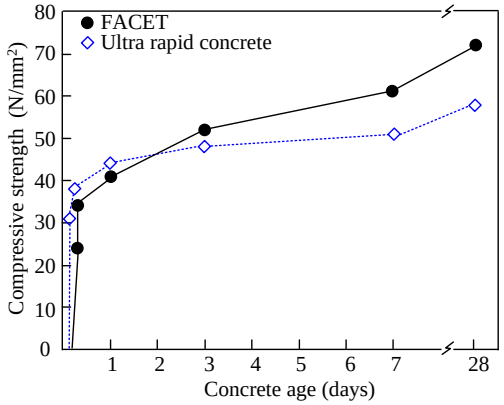


Fig.8 The compressive strength

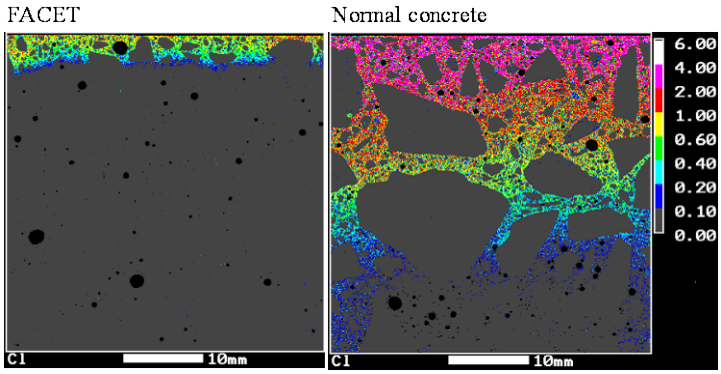


Fig.9 The salt penetration depth of various concrete measured by EPMA

Feasibility Test of Facet on the Construction Site

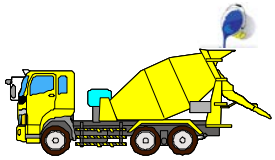
1. Feasibility test situation on the construction site

In order to repair the RC decks damaged by deicing salts in the Hokuriku Expressway, an experimental repair was performed on the total RC deck area of approximately 1,000 m^2. The production stages of FACET is shown in **Fig. 10**. First, as the concrete was brought to the construction site from the concrete plant by a mixer truck, the delaying agent solution was mixed with the concrete in high speed mixing for 15 seconds. Second, the fast accelerated admixture is added to the concrete mix in high speed mixing for 3 minutes. Before pouring the FACET, the degraded RC decks were removed with water jet, as shown in **Fig. 11**. Bleeding was not observed on the surface of the FACET. Therefore, it proves that a concrete with good quality was placed.

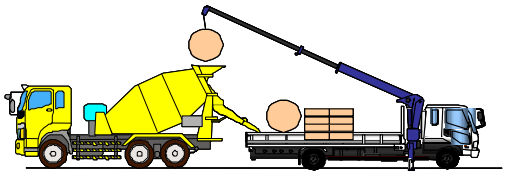
Furthermore, **Fig. 12** shows different curing method on the surface of the concrete which is resulting in different temperature of concrete. As shown in **Fig. 13**, the compressive strength of the concrete is gradually increasing. In addition, if the concrete surface is covered with a vinyl sheet the temperature of the concrete will be higher, especially at the early hours, compared with open-air curing, and the compressive strength will gradually increase over time by thermal insulation. Even though there are differences in the compressive strength before 6 hours on each curing method, but the compressive strength after 24 hours is almost the same.

2. The occurrence of initial cracks

The FACET can be effectively applied for repairing degraded RC decks. The experimental test of the repaired RC decks using FACET has been conducted for two years since 2012. However, only initial cracks with the average width of 0.2mm has been observe on about the area of 70m^2. Additionally, the initial cracks didn't form a directional cracks, as seen in **Fig. 14**. The crack densities are 3.3m/m^2 in the longitudinal direction, and 4.4m/m^2 in the lateral direction. It is noted that the grid density method counts the number of intersection and cracking grid lines drawn at 125mm intervals.



(1) Adding the delaying agent
（Mixing time is 15 seconds)



(2)Adding the powder(Mixing time is 180 seconds)

Fig.10 The addition of delaying agent solution and fast accelerated admixture

Fig.11 Removing the surface of RC decks with water jet

It is intended to quantify the crack density by dividing the total length of the grid. It therefore would be said that if FACET is applied the direction of crack can be detected easily.

Fig. 15 shows a schematic evaporation of water from the concrete surface and the effect of the presence or absence of curing sheet. The surface area of RC deck in contact with the outside air is large. Thus, the initial cracking is likely to occur due to moisture evaporation from the condensation, which happens before. Due to this reason, the concrete surface is covered with a curing sheet until the condensation of FACET ends. This method prevents the temperature change and moisture evaporation of rapid concrete, and therefore, becomes effective.

3. Experiments on the prevention of initial cracks in the FACET concrete

In order to prevent the occurrence of initial cracks on the surface of the FACET, the experiment of fresh concrete curing method and different troweling time have been performed. **Fig. 16** shows the sketch of the surface crack of the FACET concrete on a typical experimental condition. The specimens used in the experiment are 100mm thick with the size of 1320x840mm, and four specimens with the size of 560x350mm. In the case of applying the coating curing agent to the surface of the fresh concrete, the initial crack does not occur on the surface of the concrete. On the other hand, without applying the coating curing agent to the concrete surface, a countless fine cracks occurred on the surface of concrete. It turns out that it is important to prevent the moisture evaporation on the surface of FACET with a coating curing agent. Moreover, as a comparison without applying a coating curing agent, occurrence of an initial crack can be controlled by adjusting the right time to do troweling on the surface of concrete. There is a tendency that it is possible to remove the initial cracks, if the finishing of concrete surface is carried out at 60 to 90 minutes from mixing the FACET

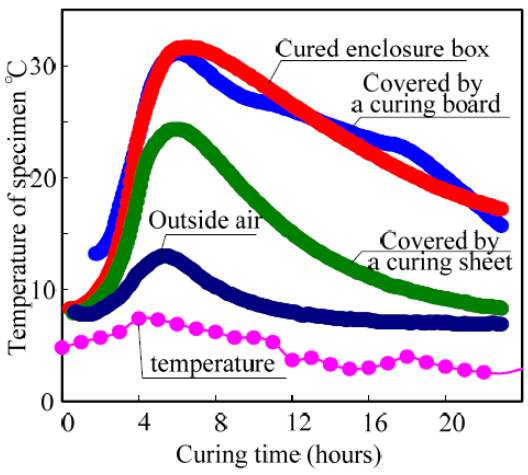


Fig. 12 The difference in the temperature change by different curing method

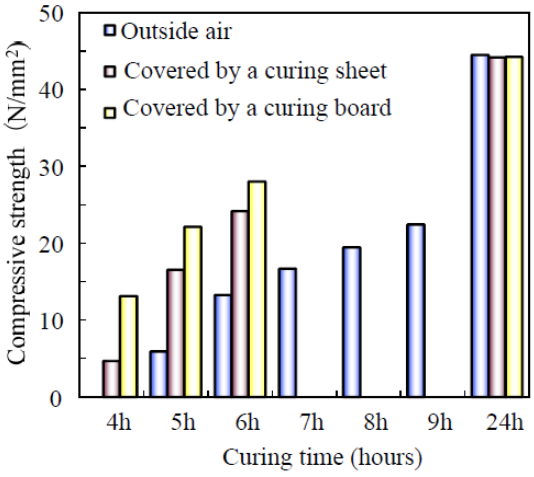


Fig.13 Changes in compressive strength due to temperature change

Therefore, when FACET is used for repairing RC decks, it is better to follow the following procedure. First the coating curing agent is applied and the surface of the concrete is tapped using the trowel. Then the curing method is conducted by covering a vinyl sheet on the concrete surface. This curing method will not make the hydration heat release rapidly by vaporization heat due to water evaporation of the concrete.

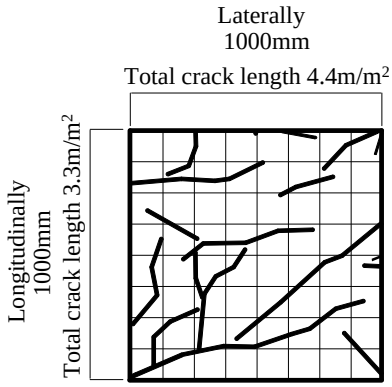


Fig.14 The initial cracks of FACET

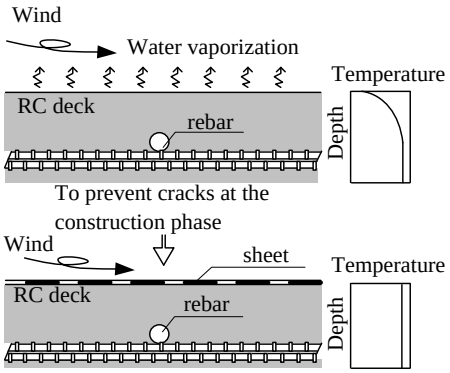


Fig.15 The reason of the concrete cracks

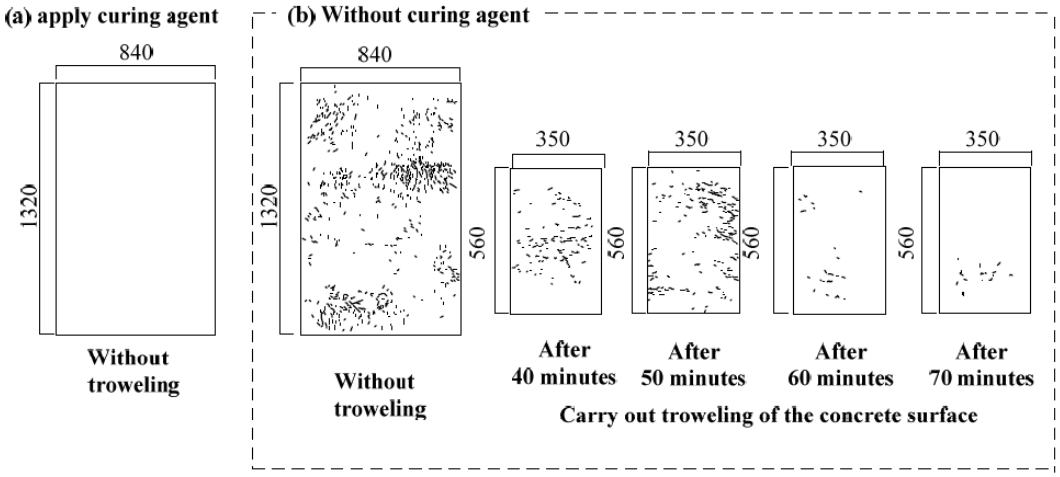


Fig. 16 The sketch of the surface crack of the FACET

Conclusions

This feasibility study confirmed the cost-effectiveness of the FACET. By adding the fast accelerated admixture and delaying agent solution in ready-mixed concrete, the practical application of the new concrete method is furthermore examined. The examination result confirmed that the proposed method can reduce up to half of the cost, in comparison with the use of the conventional ultra rapid concrete. As a result, the material cost of the repair concrete can be reduced significantly. The basic system of the material supply also can be developed from the ready-mixed concrete plant. This cost-effective supply system can cover the inaccuracy in the estimation of the delaminated RC decks, which is normally conducted by hammering.

Because FACET may have a little bleeding and tend to be influenced by the moisture evaporation of the concrete surface, it is suggested that the coating curing agent is applied to the concrete surface. Moreover, it is also proposed that the finishing of concrete surface is carried out at 60 to 90 minutes from mixing the FACET. This will prevent the occurrence of the initial cracks. In addition, it is important to cover the concrete surface with a vinyl sheet in order to prevent the hydration heat from releasing rapidly.

References

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[2] Y. Ishikawa, M. Aoyama, Y. Adachi and M. Nagai:"Damage assessment of reinforced concrete decks due to chloride-induced corrosion of reinforcing bars and fatigue, IABMAS, 2012.7