Application of “Ferroform™” to Concrete Pavement†

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Abstract:

Steel slag hydrated matrix “Ferroform™” is an environment-friendly material that consist of steelmaking slag as aggregate and ground granulated blast furnace slag as a main binder. Ferroform has the same strength and durability as concrete. It can be used as a substitute for cast-in-place concrete. This paper describes the application of Ferroform to RCCP (Roller Compacted Concrete Pavement), jointed concrete pavement and concrete pavement with sea water.

1. Introduction

Steel slag hydrated matrix “Ferroform™” is an environment-friendly material that was developed as a new use technology for steelmaking slag and is used as a substitute for concrete[1)]. Ferroform is produced by mixing steelmaking slag, which is formed as a byproduct of the steelmaking process in steel production, ground granulated blast furnace slag and water as essential materials, together with an alkali stimulant (cement) as necessary[2)]. Ferroform is produced with the same equipment as that used with conventional concrete production and has an extensive record of use in materials for port and harbor construction, including concrete secondary products such as JFE Steel’s “Marine Rock™, ” which is artificial stone substitute for natural stone, wave-dissipating concrete block (tetrapods) and the like.

Ferroform has also been used as a substitute for cast-in-place concrete in the construction on land at the steel works of JFE Steel by mixing with concrete-mixing equipment and transportation by agitator trucks, etc. Construction has been carried out by a variety of methods, particularly in construction of concrete pavement.

In the design of concrete pavement, flexural strength is generally specified in the pavement slab because bending stress is predominant in comparison with compressive stress.

In road pavement slabs with a high frequency of heavy vehicle traffic, such as a steel works, flexural strength of 4.9 N/mm^2 or higher is required. When converted to compressive stress, this is equivalent to 40 N/mm^2. On the other hand, in port and harbor construction materials, which are the largest application of Ferroform, the main strength level is compressive strength (design strength) of 10 N/mm^2 to 24 N/mm^2. Moreover, at an early material age, the rate of strength development of steel slag hydrated matrix is relatively slow, as hardening tends to be delayed in comparison with ordinary concrete using Portland cement. However, early opening to traffic is frequently demanded in highway construction. Therefore, in order to use Ferroform in pavement applications, concrete using Ferroform must have high strength, and must also show the specified strength after a short curing period.

These problems were solved by application of Ferroform to the Roller Compacted Concrete Pavement (hereinafter, RCCP), concrete mixed with seawater, etc. This report introduces examples of application of Feroform to concrete pavement as a cast-in-place applica-

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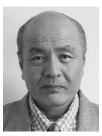
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tion using these construction methods.

2. Application to RCCP

2.1 RCCP Construction Method

RCCP is a pavement construction method in which extremely stiff consistency concrete (slump: 0 cm) with a low unit water content is spread by an asphalt finisher and compacted and finished with a vibratory roller and tire roller, etc[3]. Construction can be performed with the same equipment composition as that used with asphalt pavement, and a comparatively large volume of pavement construction can be carried out efficiently. Early opening to traffic is also possible, as initial strength is excellent. On the other hand, since this pavement has the disadvantages of poor finish of the pavement surface and poor runnabilities, in many cases it is used mainly in yards that are subject to heavy loading and similar applications. RCCP attracted attention as a construction method which makes it possible to produce a high strength, high density roller-compacted concrete slab with a low water content if large compacting energy is applied. As features of RCCP, the mix proportion contains a large amount of coarse aggregate and small unit amount of water, and the quality of the aggregate has a large influence on strength and workability.

2.2 Examples of Application of Ferroform™

RCCP using Ferroform™ was constructed at JFE Steel’s West Japan Works (Kurashiki). The construction area A=5 441 m^2. Since it was necessary to keep the road open to traffic while carrying out construction, early opening to traffic was demanded in this project. The concrete pavement specification in this project is shown in **Table 1**. Because this is a route which is used by heavy dump trucks, wheel loaders and other heavy vehicles, a pavement specification was a pavement thickness t=25 cm and design flexural strength σ_{bk}=4.9 N/mm^2 (equivalent to N_6 traffic classification). Proportioning strength was set at σ_{br}=6.2 N/mm^2 considering a margin for variations in compaction[4], and target strength for opening to traffic was set at 70% of proportioning strength.

Table 1 Pavement specification (RCCP)

Design flexural strength	$\sigma_{bk} \geqq 4.9$ N/mm^2
Proportioning strength	$\sigma_{br} \geqq (\sigma_{bk}+\sigma_p)\times p = 6.2$ N/mm^2 $\sigma_p = 0.8$ N/mm^2, p = 1.09
Target strength to open traffic	$\sigma \geqq \sigma_{br}\times 70\% = 4.4$ N/mm^2
Slump	0 cm
Degree of compaction	≧96%
Pavement thickness	t = 25 cm
Joint spacing	≦5 m

Table 2 shows a comparison of an example of the mix proportion when Ferroform is used to RCCP and the RCCP mix proportion for concrete of the same strength. The Ferroform is a high density material with a unit weight of 2 837 kg/m^{3}in comparison with the concrete RCCP (2 521 kg/m^3). Although the unit water content of the concrete RCCP is quite small, being 100 kg/m^3 (W/C=36%), the water content of the Ferroform mixture is even smaller, at 89 kg/m^3 (W/C=27%).

For an evaluation of consistency, the Marshall compaction test was performed. The compaction ratio was controlled to 96% or more. **Photo 1** shows a scene from the test and a typical test piece. Opening to traffic was decided by the flexural strength of site-cured specimens, and the target strength was achieved after curing for 7 days. **Figure 1** shows the strength property (flexural strength at different ages). **Photo 2** shows Ferroform being laid with an asphalt finisher, and **Photo 3**

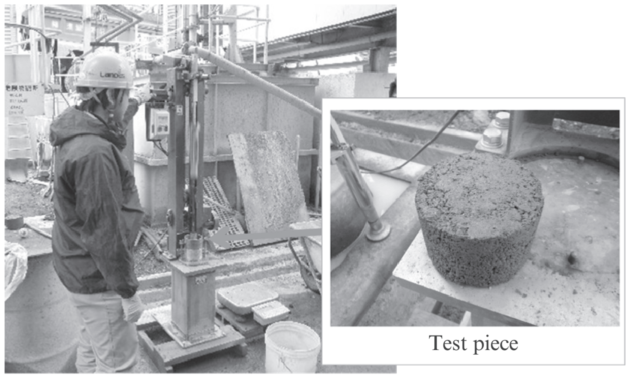

Photo 1 Compaction test

Table 2 Comparison of mix proportion between Ferroform™ and concrete

Type	Maximum aggregate size (mm)	Water-Binder ratio (%)	Unit weight (kg/m^3)							Admixture	Slump (cm)
			Water	Binder		Steel making slag		Aggregate:			
				NP	GGBFS	Fine	Coarse	Fine	Coarse		
Concrete	25	36	100	280	−	−	−	876	1 265	0.56	0
Ferroform	25	27	89	110	219	1 195	1 223	−	−	1.64	0

GGBFS: Ground granulated blast furnace slag NP: Normal portland cement

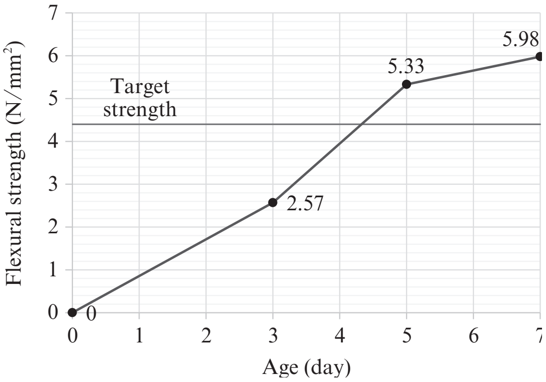

Fig. 1 Flexural strength at different ages

Photo 2 Laying Ferroform™ with asphalt finisher

Photo 3 Roller compaction

shows roller compaction. Construction is possible in the same manner as RCCP using concrete, and a pavement slab of similar quality could be laid with no difference in workability.

3. Application to Jointed Concrete Pavement

3.1 Jointed Concrete Pavement

RCCP is suitable for construction of large areas by using asphalt paving equipment such as an asphalt finisher, compaction roller, etc. Manual construction is suitable in cases where application of machine construction would be difficult or uneconomical due to the narrow construction width, small radius of curvature, small daily amount of construction, etc. However, material segregation, inadequate compaction, etc. are concerns when RCCP construction is performed manually.

On the other hand, construction methods for jointed concrete pavement include the set form method, in which concrete is poured in forms that have been set in advance, the slip form method, in which paving is performed by a machine that has the functions of feeding, compacting and forming the concrete, and others. Under construction conditions that are not suitable for machine construction, manual construction can also be performed appropriately. In case of machine construction of jointed concrete pavement, stiff-consistency concrete with slump of 2.5–5 cm is used. However, for a material suitable for construction by a concrete pump or manual construction, concrete with slump of 12 cm is used in consideration of workability.

The following describes application of Ferroform™ to jointed concrete pavement by manual construction for application to pavement under conditions where machine construction by RCCP, etc. would be difficult.

3.2 Examples of Application of Ferroform™

The roads in steel works are exposed to a condition of severe loading by work vehicles such as coil carriers, heavy dump trucks and the like. Deterioration is particularly fast at intersections due to the action of tire torsion. At intersections at JFE Steel’s East Japan Works (Chiba), construction is being carried out to replace asphalt pavement with concrete pavement, and a large quantity of Ferroform™ is being used in this work.

In construction of these intersections, it is necessary to divide the intersections into construction areas in order to maintain work vehicle traffic during the construction. As a result, the daily amount of work is small. In addition, manual construction is effective, as this work is not suitable for machine construction due to the small radius of curvature at the corners.

Table 3 shows the pavement specification when Ferrform is applied to jointed concrete pavement by manual construction at intersections with heavy traffic. Because these intersections are used by heavy vehicles, the pavement specification (equivalent to N_6 traffic classification) of pavement thickness t=25 cm and design flexural strength σ_{bk}=4.9 N/mm^2 was adopted, as in the example of application to RCCP presented

Table 3 Pavement specification (Jointed concrete pavement)

Design flexural strength	$\sigma_{bk} \geqq 4.9$ N/mm^2
Target strength to open traffic	$\sigma \geqq 4.9$N/mm^2
Pavement thickness	t = 25 cm
Joint spacing	$\leqq 5$ m

Table 4 Mixture proportion of Ferroform™

Maximum aggregate Size (mm)	Water-binder ratio (%)	Unit weight (kg/m^3)						Slump flow (cm)
		Water	Binder		Aggregate: Steel making slag		Admixture	
			NP	GGBFS	Fine	Coarse		
25	28.9	200	200	491	894	978	2.07	40±10

GGBFS: Ground granulated blast furnace slag NP: Normal portland cement

Photo 4 Slump test

Photo 5 Placing Ferroform™ by pumping

above. In general, if a concrete pavement can be cured to 70% of proportioning strength, there will be no problems in the development of the flexural strength of the concrete, even under repeated actions thereafter[5)]. Here, however, the target strength for opening to traffic was set at the design strength or higher, considering variations in the material, time change of consistency, etc.

An example of the mix proportion of Ferroform is shown in **Table 4**. In comparison with concrete, this is a high density material with a unit weight of 2 765 kg/m^3. For early opening to traffic, a large amount of binder (691 kg/m^3) was used in this mix proportion and the water-binder ratio was set at 28.9% so as to satisfy design strength with 7-day strength. Because variations and time change of consistency are large in comparison with general concrete, a slump flow of 40±10 cm immediately after mixing was specified, but due to time change, slump was 20 cm 1 hour after mixing. **Photo 4** shows the condition of a slump test 1 hour after mixing (consistency=21.5 cm).

Construction has been carried out by this method at 10 road intersections, etc. in JFE Steel's East Japan Works (Chiba), and results showing flexural strength of 4.9–6.9 N/mm^2 at a material age of 7 days were obtained, satisfying the target strength in all cases. Regarding workability, it is possible to select manual placing by chute or placing with a concrete pump. In both cases, construction was possible in the same manner as with ordinary concrete. **Photo 5** shows the placement of Ferrform by pumping.

4. Application to Concrete with Sea Water Mixing

4.1 Concrete with Sea Water Mixing

Slipping on concrete pavements occurs easily if the surface suffers wear, and chipping of the joint edges is a drawback in jointed concrete pavement and RCCP structures that include joints. Thus, a material with excellent wear resistance is advantageous. In RCCP, a high density material with a small unit water content having slump of 0 cm is placed by machinery. As a result, this is an excellent material in terms of wear resistance, cracking resistance and chipping resistance. In the case of manual placement of jointed concrete pavement, a high unit water content and cement content are used to secure the specified workability and strength, but as a result, the wear, cracking and chipping performance of this material is considered to be inferior to that of RCCP. Research by Obayashi Corporation revealed that initial strength development is accelerated and durability is improved by using sea water as the mixing water for concrete when using Portland blast-furnace slag cement[6)]. This behavior is thought to occur because the hydration reaction of ground granulated blast furnace slag is promoted by the effect of the chloride ions in sea water, and this results in fine, dense microstructure in the solidified material[7)]. On the other hand, based on research at JFE Steel, it was reported that Ferroform™ also has excellent wear and flexural fatigue characteristics in comparison with ordinary concrete[8)].

Table 5 Mix proportions of laboratory test

Type	Maximum aggregate size (mm)	Water-binder ratio (%)	Unit weight (kg/m³)								Slump flow (cm)
			Water		Binder		Aggregate: Steel making slag		Admixture		
					NP	GGBFS	Fine	Coarse	SP	AN	
1	25	31.6	Fresh water	180	207	363	1 347	735	5.97	−	50±10
2	25	31.6	Sea water	180	207	363	1 347	735	6.84	−	50±10
3	25	31.6	Sea water	180	207	363	1 347	735	6.84	13	50±10

GGBFS: Ground granulated blast furnace slag NP: Normal portland cement
SP: Super plasticizer AN: Special admixture for sea water mixing

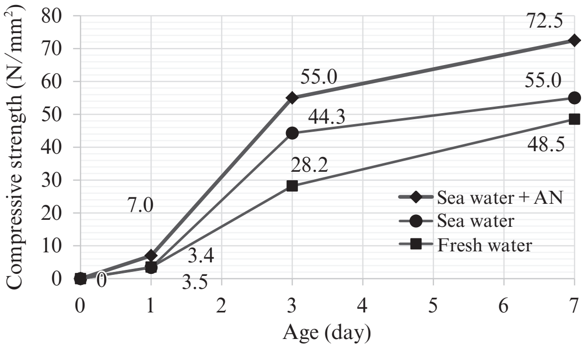

Fig. 2 Commpressive strength at different ages

Photo 6 Casting Ferroform™ pavement

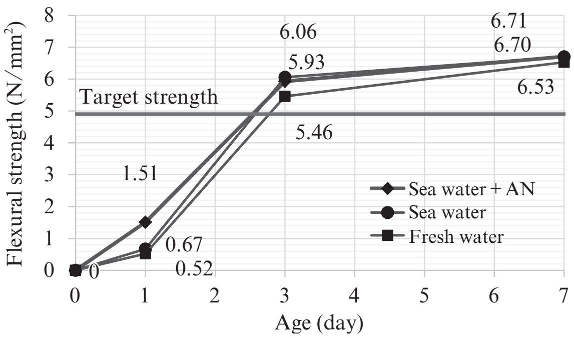

Fig. 3 Flexural strength at different ages

4.2 Examples of Application of Ferroform™

JFE Steel and Obayashi Corporation jointly studied a technology (Ferroform™ with sea water mixing) using sea water as the mixing water for Ferroform, and confirmed its practicality for use in pavement concrete. The pavement specification is the same as that of jointed concrete pavement in Table 3.

When studying the practicality of Ferroform with sea water mixing, an laboratory mixing test was carried out, and the Ferroform with sea water mixing was compared with Ferroform using fresh water (tap water)[9]. In sea water mixing, a sample using a special admixture for sea water mixing (AN) consisting mainly of calcium nitrite was also compared.

The mix proportions of the three above-mentioned cases used in the laboratory test are shown in **Table 5**. The results of tests of compressive strength and flexural strength by material age are shown in **Fig. 2** and **Fig. 3**, respectively. Compressive strength increased when sea water was used, and showed a further increase with the special admixture AN. On the other hand, the flexural strength of the mixtures using sea water and AN were slightly higher than that with fresh water until the age of 3 days, but the flexural strength of the three types was substantially the same at the age of 7 days. In a wear resistance evaluation of concrete by a raveling test, it has been reported that the material decrease by wear loss decreased as compressive strength increased[10]. Based on this, improvement of the wear resistance of pavement can be expected by using sea water, and a further improvement is possible by also using the special admixture AN.

Test construction using Ferroform with sea water mixing was carried out at a road on the grounds of JFE Steel's East Japan Works (Chiba). The pavement thickness t was 25 cm and the pavement area was approximately 1 000 m². The target strength was secured in this construction test with an actual plant, as flexural strength of 5.0–5.5 N/mm² at the age of 7 days was obtained with Ferroform with sea water mixing. The scene during casting work and the pavement after construction are shown in **Photo 6** and **Photo 7**, respectively. Workability was satisfactory, as construction was possible in the same manner as with conventional jointed concrete pavement.

Photo 7 Pavement after construction

5. Conclusion

Steel slag hydrated matrix "Ferroform™" is produced by using steel slag as the aggregate and ground granulated blast furnace slag as the binder. Pavement slabs using Ferroform were constructed by various construction methods at the steel works of JFE Steel, and the following results were obtained.

(1) Construction by the RCCP method was possible in the same manner as with general concrete pavement construction such as jointed concrete pavement, etc.

(2) The strength development rate of steel slag hydrated matrix at an early material age generally tends to be slower than that of ordinary concrete using Portland cement. However, by using the RCCP construction method, increasing the amount of binder and using sea water as the mixing water, opening to traffic is possible after curing for 7 days, even in the case of pavement slabs for heavy traffic with a design strength of 4.9 N/mm^2 and pavement thickness of 25 cm.

(3) The flexural strength of Ferroform with sea water mixing is similar to that with fresh water mixing, but because compressive strength with sea water mixing is higher, improved durability against wear is expected.

In the future, the authors plan to study expansion of the applications of Ferroform by examining this material as a substitute for fresh concrete not in only pavement, but also in various types of structures.

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