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PROPERTIES OF SUPER-TOUGH MIXED CONCRETE SUBJECTED TO HEATING AND REPEATED LOADING BY MOVING WHEELS DURING THE EARLY STAGE OF SETTING AND HARDENING

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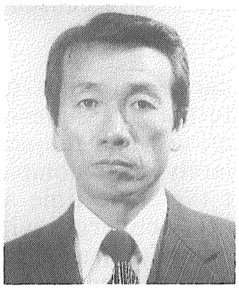

Toru YOSHIKANE

Super-tough concrete compacted with considerable vibration energy has properties which limit plastic deformation by external forces soon after compaction. During setting and early hardening, these properties can be taken by advantage of overlaying the hot-mixed asphalt concrete to form a composite pavement. The period of closure during pavement work can be reduced by opening the pavement to traffic without curing the concrete. In this study, it was confirmed that the flexure strength of such concrete develops rapidly through the hydration reaction, even if heating and repeated loading take place and the concrete is allowed no curing period.

Key Words *: fresh concrete, tough mixed concrete, composite pavement, repeated loading, heat action, quick execution method*

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1. PURPOSE

Regarding the highly vibration-compacted concrete obtained with a super-tough mixture (abbreviated HCC hereafter) and used as slab concrete, the general properties of both the fresh and hardened concrete have already been reported [1][2]. These earlier results, indicated that such concrete can be used for road pavements and similar applications as super-high strength concrete. Furthermore, even if normal Portland cement is used, it can be used as "one-day concrete", allowing traffic to use it within 24 hours of laying. However, with the increasing road mileage in Japan, repair work now surpasses new construction in terms of quantity and, as a consequence, there is a need to reduce losses such as time loss, economic loss, and others caused by traffic controls associated with pavement laying.

Given this background, the authors carried out this study for the purposes explained here. First, there is a need to demonstrate that the super-tough concrete reported previously does not suffer from plastic deformation when subject to any external load, as is the case with normal concrete, even immediately after compaction. Moreover, it must possess sufficient mechanical strength. At the same time an investigation was carried out to check whether it is possible to use this concrete with the composite pavement method used to ensure early opening of public roads, as shown in Fig. 1 and Fig. 2. With this method, the overlay of hot-mixed asphalt concrete is laid after only a short period of curing for the concrete. The effects of the resulting heating action, rolling action (rolling), and repeated loading caused by moving traffic on the occurrence of unevenness and cracking in HCC, the display of strength, and the hydration of cement were investigated through laboratory tests and full-size tests.

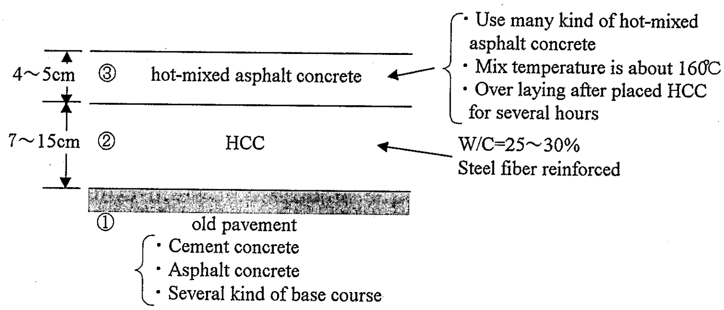


Fig. 1 Section of Construct HCC Composite Pavement

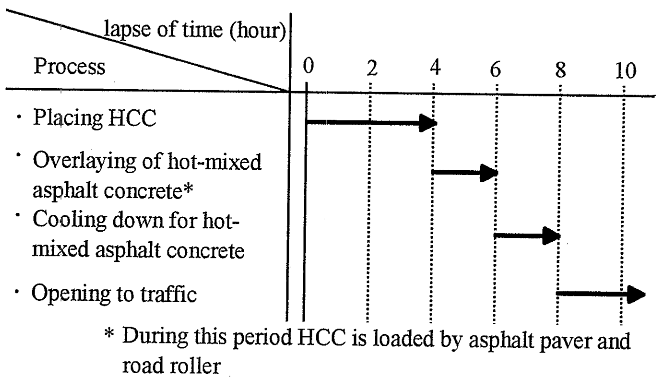


Fig. 2 Construction Process of Quick Construct HCC Composite Pavement

2. OUTLINE OF HCC

Although the fundamental properties and workability of HCC have been already reported [1][2], a brief outline is given here in order to provide a good background to this study.

HCC is positioned as an intermediate between conventional concrete called ordinary concrete in this report with a consistency expressed by the slump shown in Fig. 3 and which is high in plasticity and easily deformed by gravity, and roller-compacted concrete (RCC) with a consistency greater than 50 seconds in the modified VC Value. The consistency of HCC, expressed as a modified VC value, is in the range 10 to 40 seconds.

Regarding the properties of the fresh concrete, HCC intermediate between concretes in which the mortar forms a continuous phase similar to ordinary concrete, and those where the mortar is in a dispersed state and forms a discontinuous phase such as RCC. Accordingly, the coarse aggregate in HCC forms a core which the mortar coats. Furthermore, it has the distinctive feature of dumpling for each coarse aggregate particles.

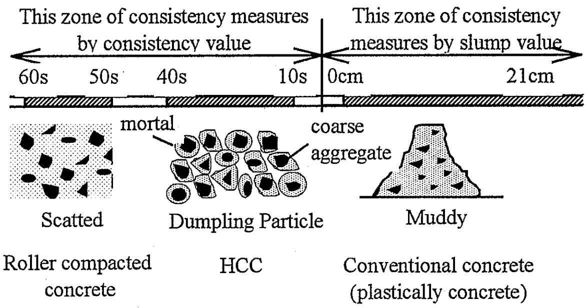


Fig. 3 Conception of Fresh Concrete

3. MATERIALS USED AND CONCRETE PROPORTION

3.1 Materials Used

The test results for the materials used in the experiments are shown in Table 1 and Table 2. Though not shown in the tables, the chemical mixing agent used for the concrete was the super-water-reducing and air-entraining agent FP 200S made by the FP company, while the steel fiber had a diameter of 0.6 mm and a length of 30 mm and was made by the BS company.

Table 1 Test Results of Aggregate

Kind	Classification	Producing district	Max. size	Absolute specific gravity	Water absorption	Fineness modulus	Solid volume percentage for shape judgment
Fine Agg.	sand	Machiya.R	5	2.52	1.6	3.05	-
Coarse Agg.	crushing sand stone	Yoro	20	2.63	0.55	6.7	58.8

Table 2 Results of Cement Test

Kind of cement	specific gravity	Blaine (g/cm^2)	Setting time (h : min)		Compressive strength(N/mm^2)		
			start	finish	3 days	7 days	28 days
normal Portland	3.15	3190	2:04～ 2:25	3:32～ 4:05	15.89	26.09	41.58

3.2 HCC Mix Proportion

The mix proportions used in the experiments are shown in Table 3. Moreover, concerning the difference in the proportion between 2 kinds of concrete, the quantity of the steel fiber reinforcement is 60 kg/m^3 in case of proportion I, and 100 kg/m^3 in case of proportion II. Therefore, the unit water content of proportion II is 5 kg/m^3 more than that of proportion I [2]. The former is measures for crack prevention to shrinkage control during the early period, and the latter is measures for reinforcement on flexure strength. The experiments were performed principally on proportion I, which is disadvantageous lower strength.

Table 3 Mix Proportion of HCC

Kind	W/C (%)	s/a (%)	Unit Value(kg/m^3)					Super Water reducer
			W	C*	S	G	SF	
I	30	45	130	433	828	1041	60	C×1.5%
II	30	45	135	450	810	1018	100	

* use normal portland cement
S; Fine Agg., G; Coarse Agg., SF; steel fiber reinforcement

4. LABORATORY EXPERIMENT

4.1 Preparation of Specimens and Loading Conditions

Three kinds of specimen were tested and compared under various experimental conditions, as follows.

① Specimens left as is after placing the HCC. (Left alone in the laboratory while other specimens are tested) (refer to Fig. 4)
② Specimens overlaid with hot mixed asphalt concrete 1~4 hours after the HCC is placed, then rolled and left alone. (refer to Fig. 4).
③ Specimens, prepared as in ② and then repeatedly loaded with moving wheels using the loading device shown in Fig. 5 from 4 to 7 hours after the HCC is placed and until 24 hours have passed.

These test conditions are shown in Fig. 4. The specimen identifiers shown in Fig. 4 are used as the symbols of the specimens by every combination of test conditions in the following experiment.

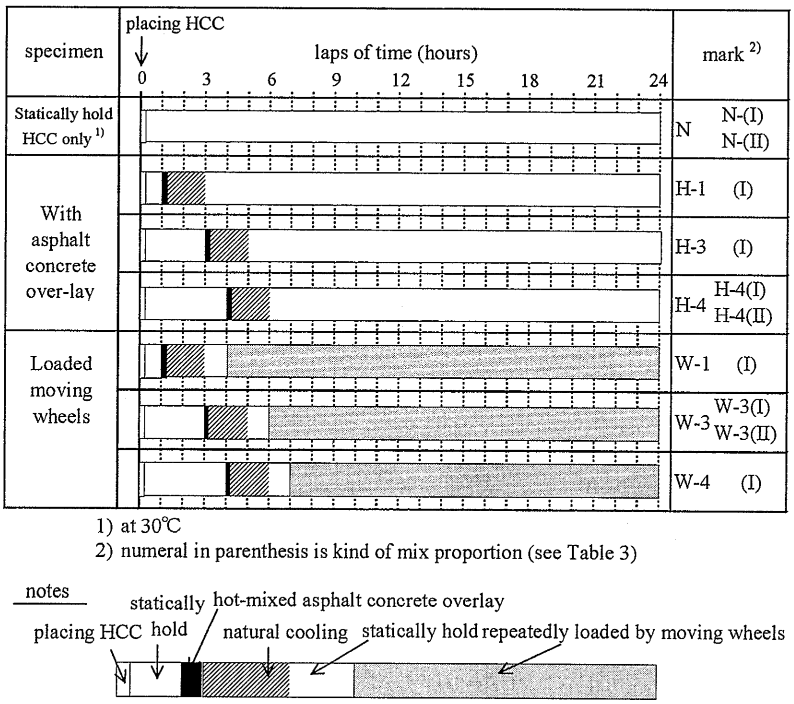


Fig. 4 Condition of Laboratory Test

The molding conditions of the specimens are as follows.

① Specimens: 30 cm × 30 cm × 10 cm (thickness) (thickness of HCC = 6 cm, thickness of asphalt concrete = 4 cm)
(However, in the case of the flexure tests, specimens are cut to a width of 10 cm and the asphalt concrete layer is removed.)

② Type of hot mixed asphalt concrete: maximum aggregate size = 13 mm; by type of the dense-graded asphalt concrete.

③ Temperature of the hot-mixed asphalt concrete when laid: 160°C.

④ Compaction of overlay: line load of 294 N/cm generated by roller compactor.

⑤ Method of repeated loading by moving wheels: wheel tracking test machine (refer to Fig. 5), with contact pressure of 0.63 N/mm^2 (about the same as the contact pressure of an actual truck tire)

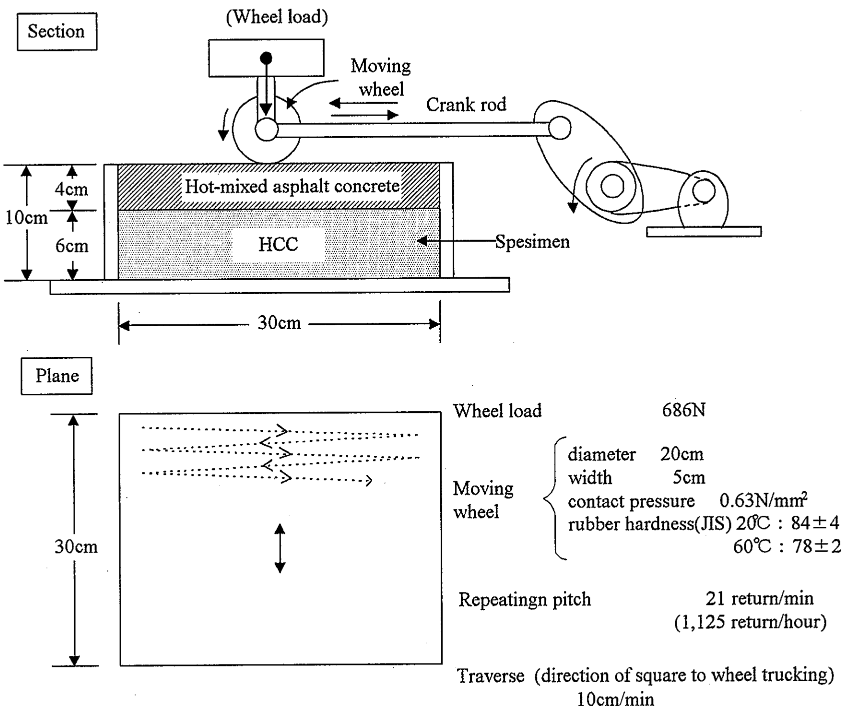


Fig. 5 Test Equipment for Repeatedly Moving Wheel Loading (Wheel Trucking Test Machine)

4.2 Heat Transfer When The Hot-Mixed Asphalt Concrete is Laid

The characteristics of heat transfer when the hot-mixed asphalt concrete is laid over the HCC one hour after placement are illustrated in Fig. 6. Whereas the temperature of the asphalt concrete when spread was 160°C, the surface temperature and central temperature of the asphalt concrete layer is already below 100°C 15 minutes later. Meanwhile, compaction of the asphalt concrete takes only several minutes. Further, the temperature at the interface between asphalt concrete and HCC is only 90°C just after the asphalt concrete is laid, quickly falling below 80°C several minutes thereafter. By the time 40 minutes have passed, it is less than 60°C, which is considered the maximum surface temperature reached by asphalt concrete in summer. After 2 hours, the temperature at the interface is 40°C, just 10°C or so different from ambient temperature.

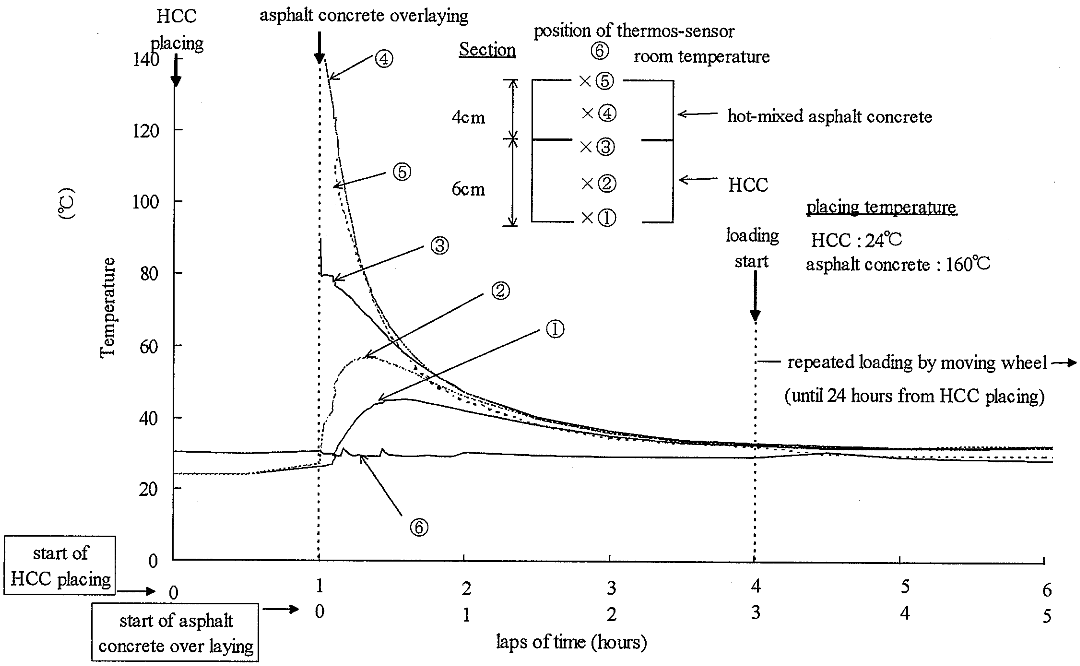


Fig. 6 Relation of Temperature and Laps of Time at Several Part of Specimen

As to why the HCC temperature in the vicinity of the interface does not rise up above 90°C , it is presumed that the larger specific heat of HCC compared to that of asphalt concrete, which contains no water, has an effect (in this case, the specific heat of HCC is about 0.26, and that of asphalt concrete is about 0.22; the former is about 20% higher than the latter.) At the point in time when the asphalt is laid, little of the water in HCC is in hydrate form and, accordingly, the contribution made to the specific heat by water, which accounts for more than 6% of the concrete mass (including water absorbed by the aggregate), is larger than that by the aggregate. In addition, the abrupt fall in temperature of the asphalt concrete when it comes into contact with HCC can be seen as resulting from the relatively coarse time interval (1 minute in this case) as well as from the influence of a water film at the contact surface.

Although the temperature difference between the upper and lower faces of the HCC layer fell to less than 20°C within 1.5 hours, the difference was somewhat greater in the shorter term. However, since setting of the cement has yet to begin at this point in time, or is little advanced, strength is not yet developed by the concrete and no thermal stress is caused by the temperature difference.

Table 4 Test Item and Property

No.	Objective	Method	Property
①	base	CBR Test method(penetration resistance)	CBR value
②	influence of heating and repeated loading action during the early stage	repeatedly moving wheel loading equipment (see Fig 5)	flexural strength
③	growing of crystal of cement hydrate	X-ray diffraction analysis	peak of calcium hydroxide
④	growing of crystal of cement hydrate	SEM photograph	condition of crystal of calcium hydroxide
⑤	Changing of hydrate space	measuring of pore size (mercury pressure injection)	pore size distribution

* the sample cutoff from after specimen flexural test

4.3 Experiment and Objectives

The influence of heating and repeated loading action during the early stages of HCC hardening on its strength development and hydration were investigated by carrying out the experiments shown in Table 4. The X-ray diffraction analysis(③), observation of scanning electron microscope (SEM) photographs(④),and measurement of pore size distribution (⑤) were carried out on test pieces removed from the specimens after the flexure tests for all prescribed ages in the repeated loading test with a moving wheel (②). They were tested immediately after removal. Test pieces from flexure test specimens which did not undergo heating and loading, were investigated using the same procedure.

5. RESULTS AND DISCUSSION

5.1 Penetration Resistance

Since the concrete is a super-tough mix, it is assumed that, just after compaction, it is in a state very close to the granular base required for pavements; this is when the post-compaction bearing strength of HCC is needed. To verify this, the CBR penetration resistance test was used to evaluate the changes in bearing strength with the passage of time. The characteristics of initial strength development by HCC have already been reported[1] and are shown in Fig. 7 for reference. As can be seen in this figure, the display of compressive strength starts around 3 hours after compaction and never really reaches 2 N/mm^2 even 6 hours after compaction. However, as shown in Fig. 8, the CBR values of both N-(I) and W-1(I) are 80% just after compaction, reaching 100% 2 hours afterward. Subsequently in the case of N-(I) when left to stand undisturbed, it reaches 200% at a time 6 hours after compaction. Further, in the case of specimen W-1(I) which was overlaid by asphalt concrete, the CBR value reaches about 350% in the same 6 hours after compaction. (The upper asphalt concrete layer was removed for this test.) Thus, HCC exhibits a considerably higher than conventional upper grade base materials used for road pavements, as shown in Fig 8. Moreover, it has a sufficiently high bearing strength even when compared with the CBR value of a normal asphalt concrete when opened to traffic. Furthermore, the CBR value is found to increase considerably as time passes. Based on these results, it can be concluded that HCC has adequate bearing strength to allow asphalt concrete to be overlaid immediately after it is placed. That is, it has ample bearing strength even before the cement begins to set. Even when its strength is not yet developed, it is strong enough to act as a work table for carrying out the overlay.

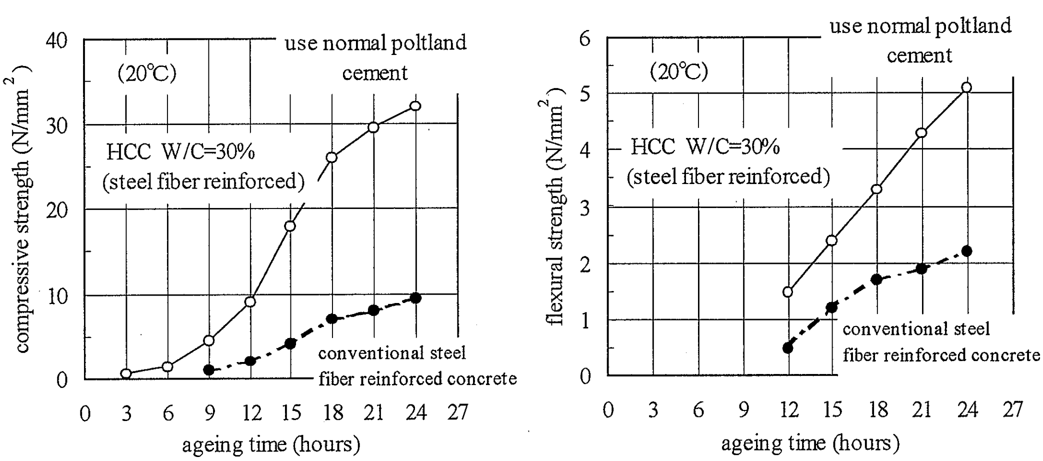


Fig. 7 Strength on First Age

5.2 Flexural Strength

The influence of heating and rolling action resulting from placing the overlay, and subsequent repeated loading by a moving wheel, on the hardening and strength development of HCC was examined and typical results are shown in Fig. 9. This figure shows the results for a case where the asphalt concrete was overlaid 1 hour after the placing of HCC, then repeated loading by the moving wheel was began 3 hours later. Concurrently, flexure tests were performed at all prescribed times. The results were subsequently compared with the test results for the case without heating and loading.

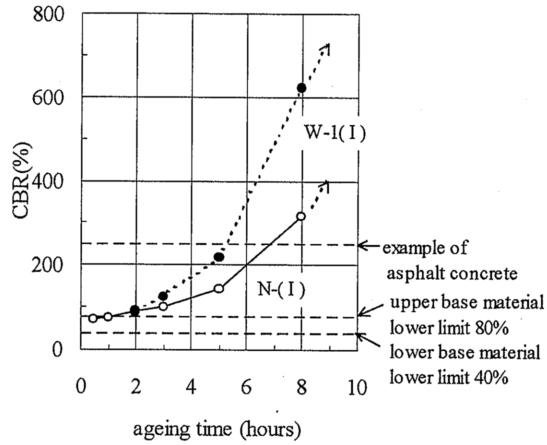


Fig. 8 Changing of CBR Value with the Laps of Time in the First Stage

According to Fig. 9, when compared to the specimen left untouched at 30°C after molding, the specimen, simply overlaid with asphalt concrete exhibited a flexural strength about 1 N/mm^2 higher, or some 20%, after 24 hours. Further, the one repeatedly loaded by the moving wheel was observed to increase in flexural strength by a further 1 N/mm^2, for a total increase of 30% compared to the untouched specimen. Moreover, similar flexural strength results from every combination of delay before the overlay and of time elapsed until loading by the moving wheel, as shown in Table 5. Also from these results, it was found that the tendency existed as same as in Fig. 9.

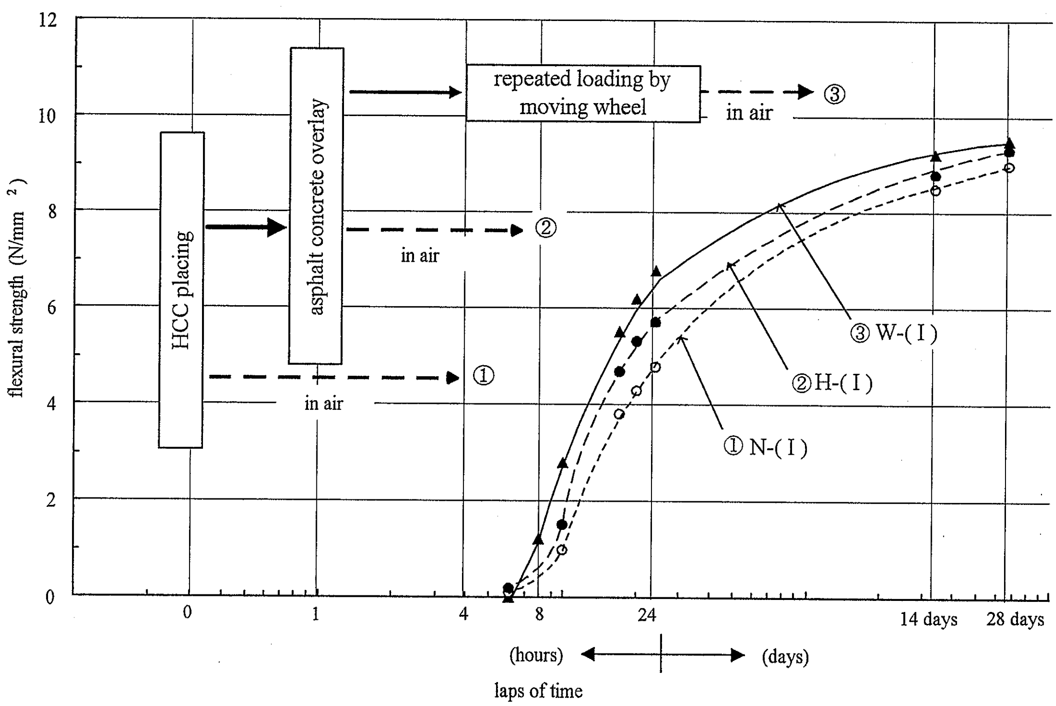


Fig. 9 Relation of Flexural Strength and Laps of Time

Table 5 Flexural Strength was Received Heating and Loading Action During First Hard Period

Mark 1)	Flexural strength (N/mm^2) (at 30℃ in air 2))		
	Ages		
	1day	14days	28days
N-(I)	4.8	8.5	9
N-(II)	5.5	9.4	10.6
H-1(I)	5.7	8.8	9.2
H-2(II)	6.2	9.2	9.5
H-3(I)	5.8	8.9	9
H-3(II)	6.4	9.8	10.7
W-1(I)	6.8	9.2	9.5
W-2(I)	6.3	9.3	9.6
W-2(II)	6.7	10.2	10.9
W-3(I)	5.8	8.8	9.2

1) rifer to Fig.4
2) holed same room with repeatedly loading test

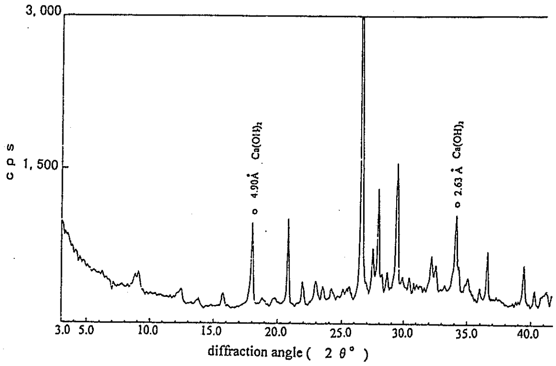


Fig. 10 Chart by X-ray Diffraction Analysis of Cement Hydrate in HCC

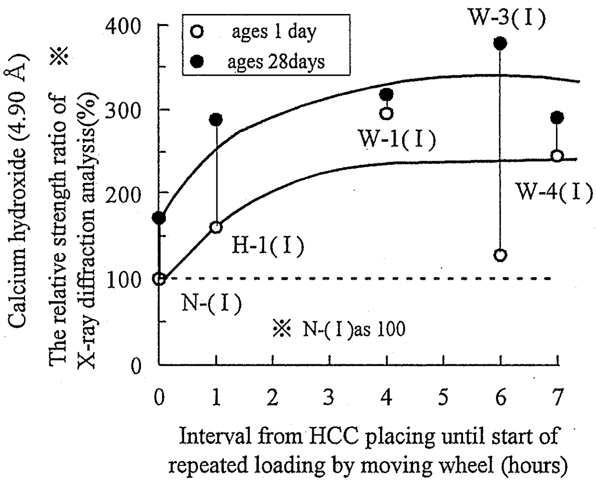


Fig. 11 Hydrate Changing of Repeated Loading by Moving Wheel

These results demonstrate that carrying out of the asphalt concrete overlaying soon after HCC molding has an effect on strength increase. It can thus be concluded that heating causes an acceleration of hardening, while the rolling action during the overlaying process has the effect of microscopic consolidating action before setting or as setting is about to start. Furthermore, since repeated loading by the moving wheel began when the temperature of the asphalt concrete layer was almost the same as the HCC layer, this loading also adds a similar consolidating action. With the HCC already compacted to a rate of density against theoretical density of more than 99% of its final rate of density after compaction, no volume change is caused by this microscopic consolidation after hardening.

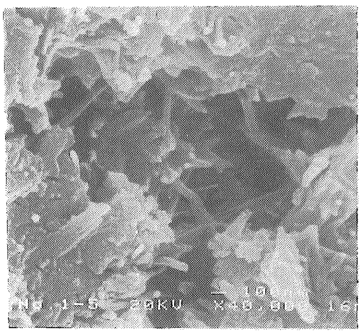
5.3 X-Ray Diffraction Analysis

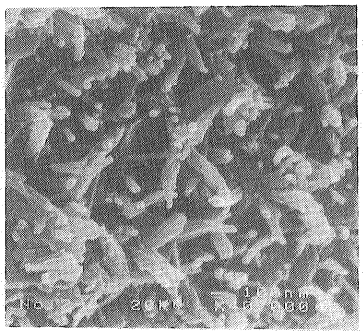
When using X-ray diffraction analysis, the reactions that take place during the initial stage of cement hydration (in the period several hours to several days), the strongest diffraction pattern is seen on interlayer distance at 4.90 Å and 2.628 Å from the crystals of calcium hydroxide[3]. An example for HCC is shown in Fig.10. Since no other distinguishing hydrate exists near 4.90 Å, it is believed that using this 4.90 Å pattern can be quantitatively effective to some extent[3]. To quantify it, values should first be obtained by generating a calibration curve based on a standard material (in this case, silica and calcium hydroxide) at various mixing ratios[3]. This is quite a complicated method, however, so a quicker method was adopted in this study. From the X-ray diffraction pattern of each test piece measured by 4000cps (count per second: referred to as CPS hereafter) setting full scale in the ordinate, the diffraction strength at 4.90 Å could be obtained and then by setting the strength of calcium hydroxide in case of N-(I) at 100, the relative strength ratio (%) of calcium hydroxide for each test piece could be expressed. The results are shown in Fig.11.

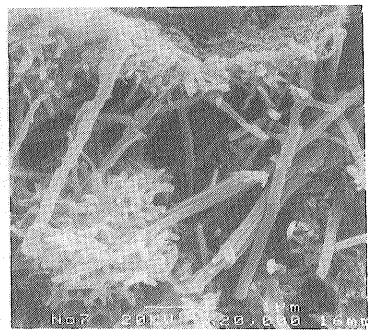
(1) Influence of overlaying asphalt concrete on hydration
Regarding the influence of the heating action of asphalt concrete and the rolling action of compaction on hydration, study from the relative strength ratio of calcium hydroxide to N-(I). Hydration becomes larger by about 70% both after 1 day and 28 days in the case of H-1(I). It is though that the development of calcium hydroxide crystals in the case of H-1(I) is advanced compared to that in the case of N-(I).
Based on these results, it seems that hydration is promoted when the consolidating action of heating and rolling is applied just after HCC compaction (in this case, 1 hour after compaction).

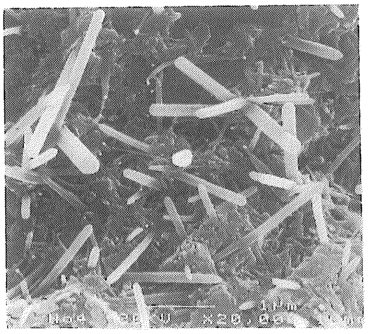
(2) Influence of repeated loading by moving wheel on hydration
In cases where heating and rolling action are applied during the initial stage and then repeated loading by the moving wheel is applied, the relative strength ratio of calcium hydroxide, which after 1 day in the case of W-3(I) is only 30% higher than that in the case of N-(I), is considerably higher after 28 days. Further, the overall trend indicates that the W group greatly exceeds even H-1(I) after 1 day, and is equivalent to the latter or exceeds it somewhat after 28 days.

In a consequence of these results, in cases then the overlay of the asphalt concrete is carried out after the compaction of HCC, and then, furthermore the repeated loading by the moving wheel is given from the time from 4～7 hours after the placing of HCC. It can be understood that hydration in this case is more developed compared to that in case of no loading.


N-(I) photographing magnification ×40,000


H-1(I) photographing magnification ×40,000


W-1(I) photographing magnification ×20,000


W-3(I) photographing magnification ×20,000

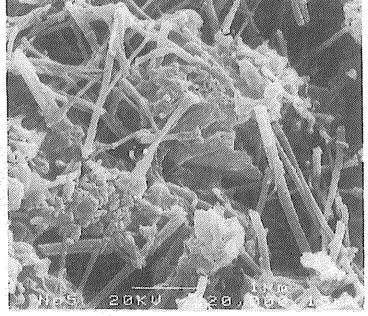

W-4(I) photographing magnification ×20,000

Photo 1 SEM Photographs (Age : 1day)

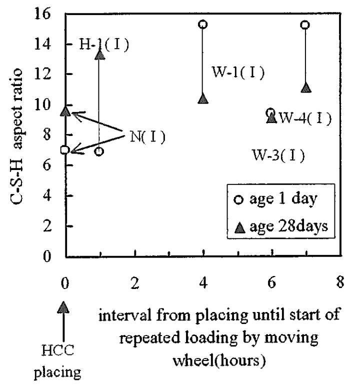


Fig. 12 C-S-H Aspect Ratio on Observation by SEM

5.4 Observation by SEM

Same of the SEM photographs are shown in Photo 1. From these photographs, it can be confirmed that the generation of C-S-H crystals (fibrous crystals) is greater in the case of H-1(I) compared to N-(I). In the case of the W group, together with increased generation of C-S-H crystals, distinctive growth of each crystal is observed. Concerning these fibrous crystals, the relation between aspect ratio, expressed as the ratio of length to diameter, and the time that repeated loading by the moving wheel began is shown in Fig.12. The aspect ratio after 1 day in the case of the W group is larger than that in the case of N-(I) and H-1(I), so the generation of crystals of the hydrate is greatly advanced. That is, heating and rolling action during the initial stage have the effect of accelerating the development of the hydrate. Reduction of the aspect ratio (the fibrous crystals become thicker) along with the development of crystals in the case after 28 days, is a general tendency of cement hydrates, and these phenomena are clear in the case of the W-1(I) and W-4(I) groups. Because the voids between the crystals become narrower with time and the crystals eventually overlap. Thus, even if the effect of heating and loading action resulting from the overlay and from the repeated loading by the moving wheel during initial setting and hardening is detrimental to HCC, acceleration of hydration over the short term is recognized, and this difference in hydration is not apparent to any great extent after 28 days.

5.5 Pore Size Distribution

The measurement results of the pore size distribution of each HCC specimen after 28 days are shown in Fig.13. To eliminate the influence of aggregate particles count in the test piece, the ordinate axis is expressed as the ratio of the pore volume concerned to the total volume of pores. According to this figure, the volumetric ratio of pores sized 30～50nm in the case of H-1(I), which was subjected to heating action and rolling action during compaction, is higher compared to N-(I), which was simply left in air at a temperature of 30℃. In the case of the W group, which deteriorated under repeated loading action by the moving wheel, the volumetric ratio of pores more than 100nm was lower, and in addition, whereas there was a tendency for higher volumetric ratio than in the case of H-1(I) at a pore size of 30～50nm, almost no difference was observed inside the W group. This demonstrates that differences in time between HCC molding and overlaying the asphalt concrete as well as in the time before repeated loading by the moving wheel have no influence on pore size distribution after 28 days.

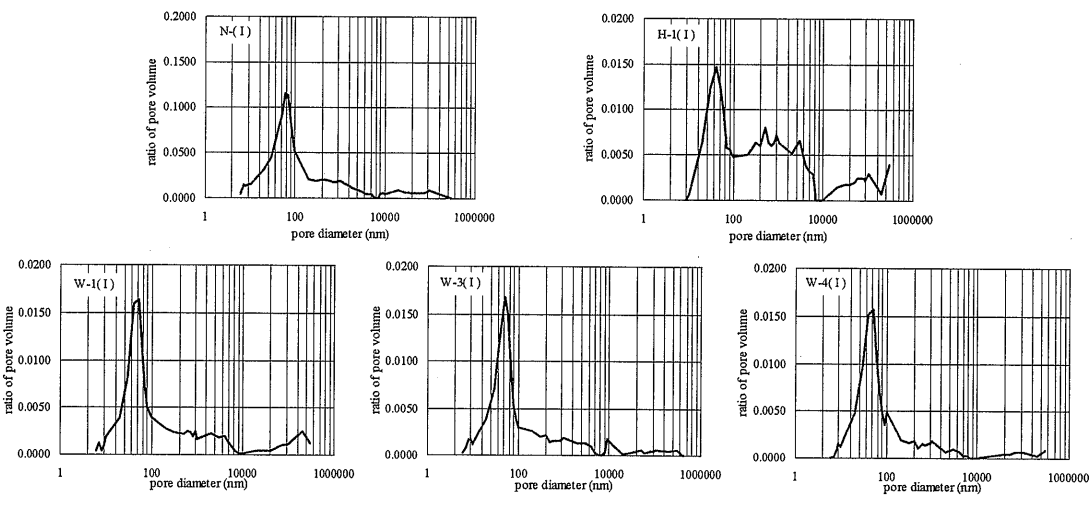


Fig. 13 Influence Pore Size Distribution of HCC by Heating, Rolling and Repeatedly Moving Wheel Loading (at 28days Ages)

The movement of the peak in the pore size distribution from the larger fraction above 100nm toward the smaller fraction within a range of 10～100nm like this is considered to contribute to the increase in concrete strength [5][6]. Based on the change in HCC pore size distribution shown in Fig.13, it is inferred that hydration is greater, though only a little, in cases when the asphalt concrete overlay and repeated loading take place during the initial stage of setting and hardening as compared with HCC left as is after compaction.

6. OUTLINE OF ACTUAL SIZE TEST

Test results described so for relate to laboratory tests on the after half-day open to traffic type composite pavement. Now full-size tests are described, including the execution of HCC and traveling tests by real automobiles, with the aim of investigating points 1-4 below.

① The possibility of spreading and rolling by laying the hot-mixed asphalt concrete at shortly after the execution of HCC

② The occurrence of deformation of the HCC surface, such as unevenness and cracking, caused by truck tires and paver crawlers when spreading the hot-mixed asphalt concrete

③ The occurrence of deformation and cracking on the HCC surface when the pavement is opened to traffic immediately after laying the hot-mixed asphalt concrete and leaving it to cool naturally

④ The bonding properties of the upper surface and lower surface of the HCC with the hot-mixed asphalt concrete later

6.1 Execution of Full-size Test

(1) Size and profile of work
The scale of the work and a sectional profile for the full-size test are shown in Fig.14.

(2) Conditions of work execution and test
The conditions of work execution and the test are shown in Table 6.

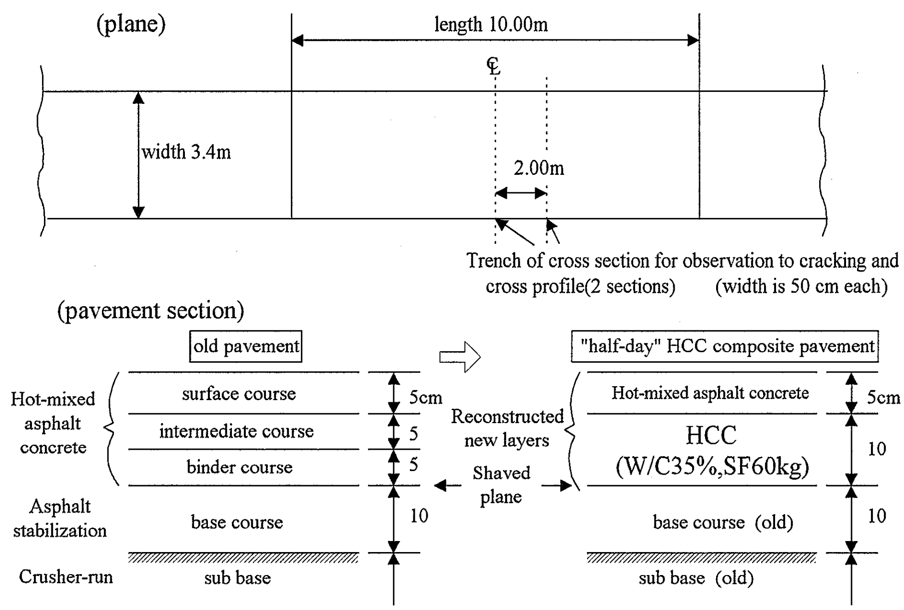


Fig. 14 Plane and Section Figure of Actual Size Test

6.2 Results and Discussion of Full-size Test

(1) Observations when overlaying hot mixed asphalt concrete
The behavior of the HCC was observed while carrying out of the overlay of hot-mixed asphalt concrete (refer to Photos 2 and 3) 4 hours after placing the HCC. During the work, the asphalt paver and dump trucks traveled over the HCC. As shown in Photo 4, no unevenness nor cracking occurred within the movement local of the dump trucks and asphalt paver.
This confirms that the higher CBR value after execution of the HCC, as shown in Fig.8, gives the HCC sufficient bearing strength to act as a support for the heavy machinery.

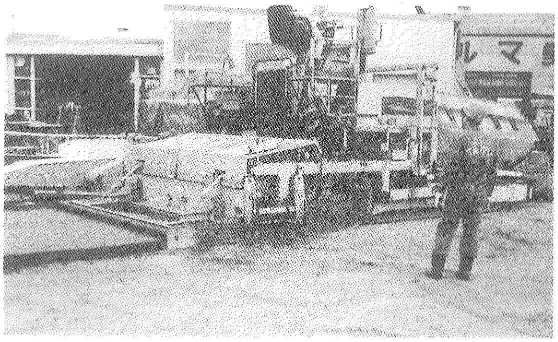
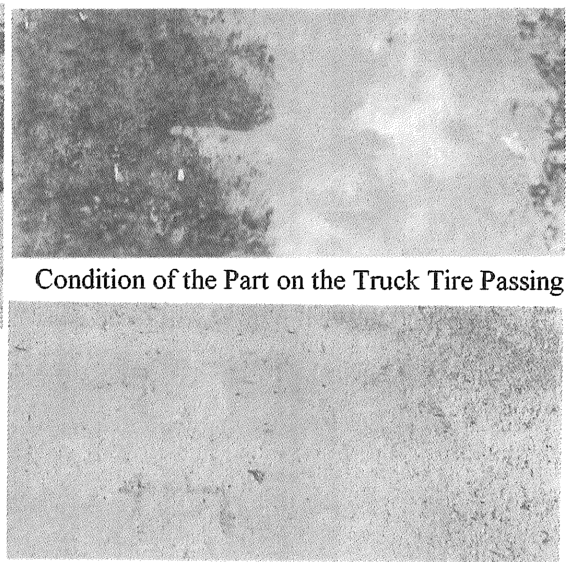


Photo 2 Placing Machine for HCC

Photo 3 Roller Compaction for Asphalt Concrete



Condition of the Part on the Truck Tire Passing

Condition of the Part on the Asphalt Paver Passing

there are dark spot by tire passing but was not observed uneven

Photo 4 Condition on Top of HCC at Part of the Truck Tire and Paver Passing in HCC Placing After Four Hours

(2) Temperature change after overlaying hot-mixed asphalt concrete
The change in temperature of each layer with time after laying the asphalt concrete can be seen in Fig.15. Repeated loading by trucks began when the road surface temperature fell below 40℃. This was about 2 hours after spreading the hot-mixed asphalt concrete, and 6 hours after placing the HCC.

(3) Influence of rolling during overlaying and repeated loading by subsequent truck movements
Two hours of repeated loading by trucks (refer to Photo 5) took place 2

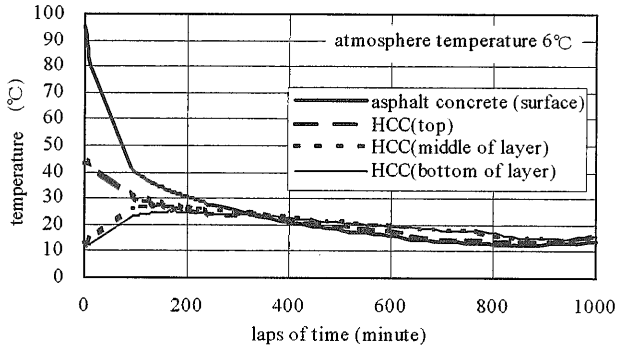


Fig. 15 Temperature Changing on Lap of Time at Each Pavement Section

hours after spreading and rolling the hot mixed asphalt concrete, as specified in Table 6. Two days later, cross trenches were excavated at the two sites shown in Fig.14, the asphalt concrete layer was removed, and the HCC surface was checked for flatness and cracking. These results are shown Fig. 16. According to Fig. 16, there was no change in flatness of the upper surface of the HCC after laying, after rolling out the hot-mixed asphalt concrete, and after repeated loading tests by trucks, and moreover there was no occurrence of flatness either.
The HCC removed after 2 days from the portion executed by the bonding prevention in the lower surface of the HCC and in the upper surface of the existing old asphalt stabilization layer was visually be checked (refer to Photos 6 and 7),but no cracking could be observed.

Photo 5 Traveling Test by Truck

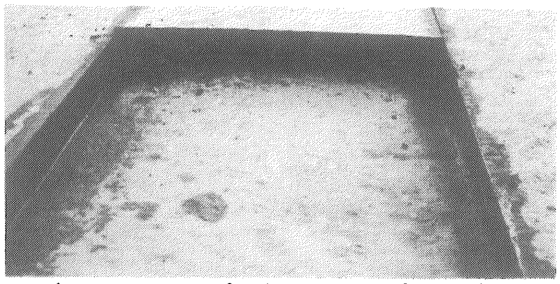


Photo 6 Top of HCC at Part of Trench Cut

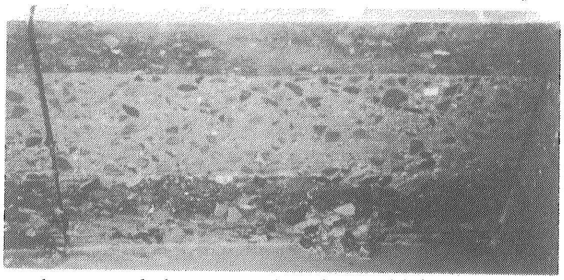

upper layer : asphalt concrete (overlay), middle layer : HCC
lower layer : asphalt stabilization

Photo 7 Section of Trench Part

Table 6 Conditions of Work Execution and Test

Work Execution	
Paving machine	HCC: Exclusive paver (refer to photo 2) Hot-mix asphalt concrete. : Conventional asphalt paver
Kind of asphalt concrete	Dense grade type asphalt concrete Spreading temperature : 160℃
Compaction machine for asphalt concrete	Primary compaction : macadam roller (total weight 98.1kN) Secondary compaction : tire roller (total weight 133.4kN)
Atmosphere temperature	6℃
Paving of asphalt concrete	Asphalt concrete spread after 4 hours since HCC placed
Repeatedly Loading by Moving Truck	
Live load	Large-size truck (twin axes ,axis load 88.2kN)(refer to photo 5)
Contact tire pressure	0.539 N/mm^2
Truck line	Coincided with both center of truck and pavement
Loading time	2 hours since 6 hours after HCC placed (15 sec/pass, total 480 passes)
Test and Observation	
Cross section profile	Trench cut and direct measured
Crack	Observation at trench on HCC surface
Flexural strength	By cut sample from placement place
Bonding strength	Measured by type (LPT-1500)* test equipment at each layers surface

* Research institute of architecture department in the ministry of construction

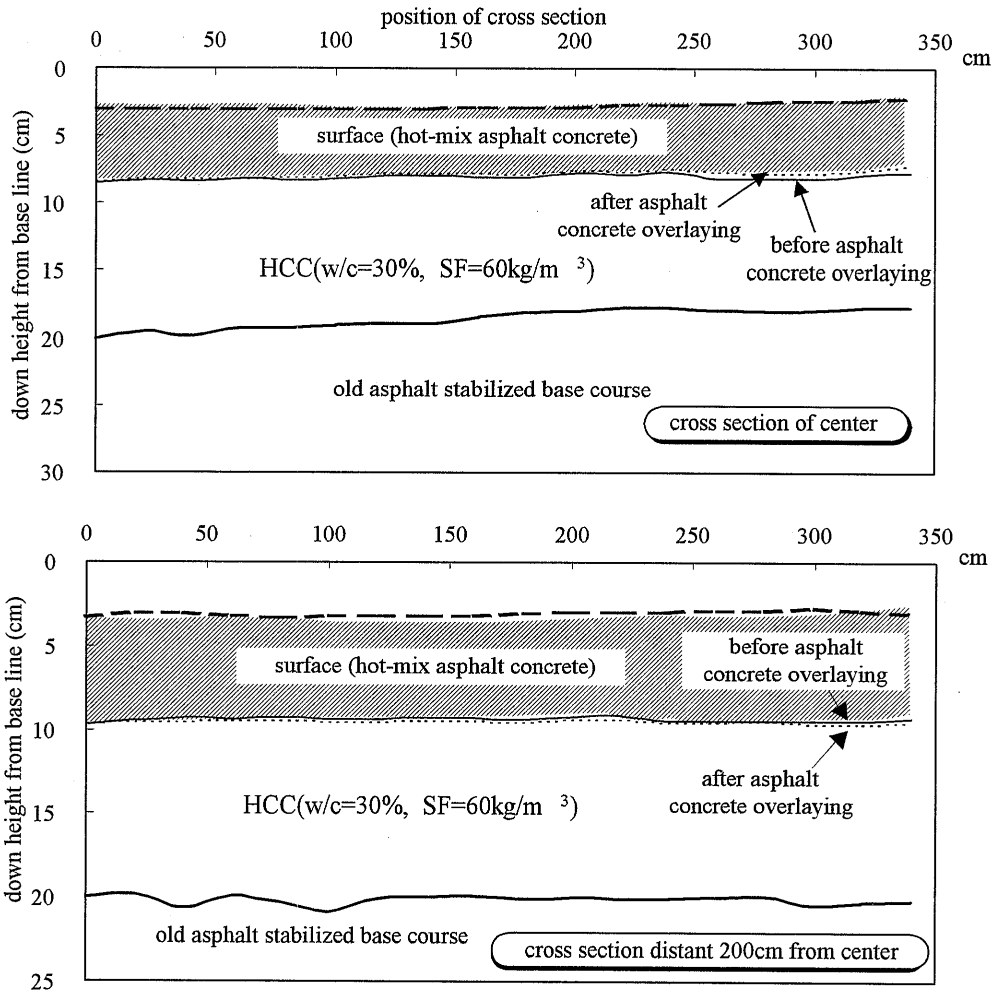


Fig. 16 Profile of Cross Section before and after Truck Wheel Traveling

(4) Bonding strength at upper and lower HCC surfaces

The bonding strength test results at interfaces between the hot-mixed asphalt concrete and the upper surface of the HCC and between the lower surface of the HCC and the existing old hot-mixed asphalt stabilization layer are shown in Table 7. The bond with the asphalt stabilization layer is somewhat weaker than that with the hot-mixed asphalt concrete. However, this difference derives from a difference in tensile strength of the asphalt concrete themselves, and it was confirmed that bonding was sufficient.

Table 7 Bonding Strength

Age (days)	Boundary plain between bottom of HCC and top of stabilized base course (N/mm^2)	Boundary plain between bottom of asphalt concrete and top of HCC (N/mm^2)
7	1.25	1.58
14	1.27	1.62
Tensile strength of conventional asphalt	0.8～1.3	1.2～1.6

* test at atmosphere temperature

(5) Flexural strength and density
The flexural strength of unloaded specimens and specimens taken from places subjected to heating and rolling action during the initial stage of setting and then to the repeated loading by trucks during initial hardening is shown in Table 8. In places subjected to repeated loading, strength is somewhat greater, this is similar to the tendency observed in the laboratory tests as shown in Table 5. The flexural strength in the full-size test is somewhat lower than the laboratory value, but this may be attributable to the low temperature of 6℃ when the full-size test was implemented, as well as to the fact that water curing was not carried out. In contrast the laboratory tests were carried out with water curing at 20±1℃. In addition, satisfactory results were obtained regarding the density of the cutoff of both specimens.

Table 8 Flexural Strength and Rate of Density by Cut Specimen from Placed HCC Layer

Age (days)	Flexural strength (N/mm^2)	
	Specimen A *1	Specimen B *2
7	7	6.5
14	8.5	7.8
Rate of Density *3	100.4	100.5

*1 the place was load by repeated traveling truck wheel
*2 the place was non loaded by truck wheel
*3 percentage of specimen density against theoretical density

7. CONCLUSION

The effects of heating and rolling action and repeated loading action by moving wheels on the hydration of concrete, the occurrence of unevenness and cracking, and strength development of HCC during initial setting and hardening were investigated. The following results were obtained.

7.1 From the Laboratory Tests

The CBR value expressing bearing strength immediately after spreading and compaction of the HCC concrete greatly exceeds that of the upper grade base material for the pavement. Moreover, strength increases rapidly during the early period (1～4 hours) after compaction. This demonstrates that HCC has sufficient bearing strength to form a platform for the laying of hot-mixed asphalt concrete.

When the HCC is subjected to heating action due to hot-mixed asphalt concrete and then rolling action soon (1～4 hours) after compaction, an increase in flexural strength is observed at 6 hours and thereafter. Flexural strength is the same after 28 days as in specimens undergoing no such heating and rolling action.
If the asphalt concrete is left to cool naturally to a temperature that makes automobile traffic possible, and then repeated loading by moving wheels takes place, flexural strength is seen to increase.

Tests based on X-ray diffraction analysis, SEM observations, and pore size distribution demonstrate that accelerated hydration takes place.

7.2 From the Full-size Tests

In order verify the laboratory test results, a full-size test was carried out. When the overlay of hot-mixed asphalt concrete was executed during HCC setting, and even when repeated loading by trucks took place during initial hardening, no unevenness or cracking was observed on the HCC surface. Furthermore, strength increase and other characteristics were similar to the results observed in the laboratory tests.

7.3 Summary

We have confirmed that HCC exhibits sufficient hydration and strength as super-tough concrete when spread and compacted, and then overlaid with hot mixed asphalt concrete 1～4 hours later. If it is subsequently left to cool naturally for 2～3 hours and then subjected to repeated loading by trucks, strength remains adequate. This demonstrates that HCC based an ordinary portland cement can be used as "half-day concrete" that can be opened to automobile traffic several hours after placing.

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