IMPROVEMENT OF WEAR RESISTANCE OF CONCRETE SURFACE BY POLYMER IMPREGNATED CONCRETE AND ITS APPLICATTON TO URBAN BLOCK PAVING

Tadashi FUKUDA, Tohoku University
Iwao SATO, Sapporo City Office
Mitsuru KOMURA, Chichibu Cement Co., Ltd.
Tokihiro TSUDA, Chichibu Kenzai Hanbai Co., Ltd.

SUMMARY

The snowy and cold areas in Japan cover approximately 60 percent of its land. There in the snowy winter season, vehicles are equipped with studded tires, so the pavements tend to wear severely in the form of rutting. This has caused not only an increase in pavement repair cost but also various social problems such as obstruction to traffic due to erased markings, environmental pollution due to dust, etc., especially in urban areas.

Therefore, the author et al. have developed a concrete block having high resistance to wear by applying special treatment and has performed a field paving experiment. The method of giving wear resistance to concrete blocks consists in vacuum impregnating the surface with polymer to fill fine voids in the surface concrete and thereby to obtain wear resistant texture. The result of a laboratory test evidenced that this method was effective in improving wear resistance, therefore the author et al. applied it to a heavy traffic road in Sapporo, a snowy cold area. As a result, it was confirmed from a survey made after the lapse of two winters that the degree of wear of the polymer inpregnated blocks was very small. Further, the skid resistance and traffic noise were almost equal to those of conventional asphalt pavements.

1. INTRODUCTION

In the snowy and cold areas that cover approximately 60 percent of Japan, the roads have been suffering severe wear by studded tires and tire chains, with the result that the frequency of repair work and the repair costs have been increasing remarkably.

Since this wear has caused obstruction to traffic due to erased markings, and environmental pollution due to dust scraped off, etc., the problem of wear is becoming an important social problem especially in urban areas.

Therefore, the author et al, have developed a wear-resistant comcrete block whose surface was vacuum impregnated with polymer (referred to herein below as the "PIC blocks")

In November 1981, a road in Sapporo, a snowy cold area, was paved experimentally with them.

2. MANUFACTURE OF WEAR RESISTANT CONCRETE BLOCKS

As is apparent from past studies 1),2), 3),4), it is very important to increase the strength of concrete and to select wear resistant aggregates in order to improve wear resistance of concrete. Increasing the maximum size of aggregate is also effective in improving wear resistance. In this case, however, the unevenness of the road surface becomes greater with the progress of its wear, so there may arise a problem of noise pollution.

Further, the maximum size of aggregate is limited in the case of the concrete block.

Such being the case, possible methods of improving wear resistance are a) to increase the strength of concrete by using super water reducers, b) to perform special curing, for example, auto-clave curing; c) to increase the strength of concrete by impregnating with a polymer type material.

In fact, field application of those methods is complex and almost impossible. However, these methods are applicable to shop-made products.

Therefore, the author et al. conducted a series of laboratory experiments on these mechods, and as a result, a manufacturing method of wear resistant concrete blocks impreganted with polymer has been developed.

With this manufacturing method, the concrete block was dried in hot air, impregnated in a special tank and then steam cured at about 70 to 90 ℃ so that the material was hot polymerized to obtain a polymer impregnated concrete product. The monomer used as an impregnating agent was methyl methacrylate (Fig-1).

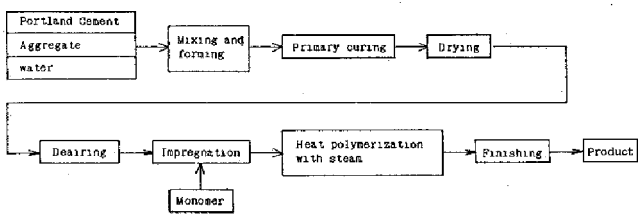

Fig. 1
Manufacturing process of PIC blocks

Table 1 Types of specimens used in wear tests

Classification	No.	Description
Asphalt concrete	1	Dense-graded asphalt concrete, Gmax=20mm As=5.2% M=1,190kg
	2	Fine-graded gap-graded asphalt concrete, Gmax=13mm As=7.2% M=740kg
	3	Surface course asphalt concrete, Gmax=20mm As=5.5% M=1,030kg
Cement concrete	4	conventional paving concrete block, w/c=26.2% σ=735kgf/cm² Ab=3.14%
	5	Road paving concrete, w/c=39.5% σ_b=49.9kgf/cm² Ab=3.90%
	6	Use of super-water-reducers, w/c=21% σ=855kgf/cm² Ab=2.05%
	7	Use of super-water-reducers, w/c=21% σ=1,092kgf/cm² Ab=1.60%
Polymer impregnated concrete	8	PIC impregnation 4.28%, curing in water, w/c=26.2% σ=2,248kgf/cm² Ab=0.16% D·F=99%
	9	PIC impregnation 2.70%, autoclave curing, w/c=21.0% σ=1,265kgf/cm² Ab=0.28% D·F=99%
Concrete using artificial aggregate	10	PIC impregnation 7.45%, curing in water, w/c=31.0% σ=1,624kgf/cm² Ab=0.31% D·F=99%
	11	PIC impregnation 8.79%, autoclave curing, w/c=30.0% σ=1,877kgf/cm² Ab=0.37% D·F=99%
	12	Use of special cement and super-water-reducers, w/c=25.0% σ=1,170kgf/cm² Ab=2.71 D·F=92%

M = Marshall slability Ab = Absorption D·F = Durability factor

3. LABORATORY TESTS FOR WEAR RESISTANCE OF PIC BLOCK

3.1 Test method

The types and properties of specimens used in wear tests are shown in Table 1. For comparison, asphalt concrete, conventional paving concrete and concrete using hard artificial aggregate were tested under the same conditions. Wear-tests were conducted using a rotary wear test machine with a chain-fitted wheel (Photo 1). The specimens used were 15 cm in short side, 20 cm in long side, 14 cm in width and 8 cm in thickness, and the test conditions were shown in Table2. The temperature in the laboratory during the test period was held in the range of 5 to 12 ℃, and water was sprayed to keep the specimens always humid during testing.

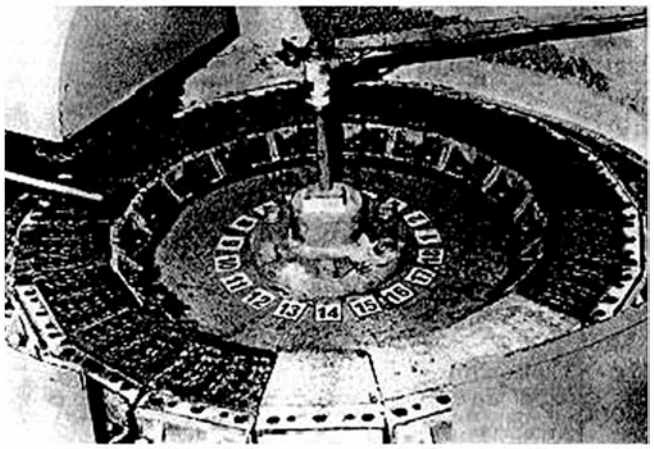

Photo 1 Rotary wear test machine

The chain-fitted wheel was applied to 100,000 passes after the wheel tires, i.e. not equipped with a chain, had been applied to 10,000 passes. The average depth of wear (mm) and the area of the worn section (cm²) were measured every 10,000 passes.
Here, the average depth of wear was defined as the value of the area of the worn section devided by width its.

Table 2 Test conditions

Test apparatus: Rotary wear test machine
Test temperature: 5-12℃ in wet condition
Speed: Tire = 30 km/hr. constant speed
Tire: Snow Star 4.00-8, pneumatic pressure = 2.2 kg/cm²
Wheel load: 50 kg

The rebound number by Schmide hammer was employed as a means of determining the wear resistance of the concrete block.
To measure this rebound number, the same specimens as used in the rotary wear tests were used. These speciemns were kept under a constant load of 50 kgf/cm² and the surface of each specimen was hit at 16 measuring points by Schmide hammer and its rebound number was determined 6) (Photo 2).

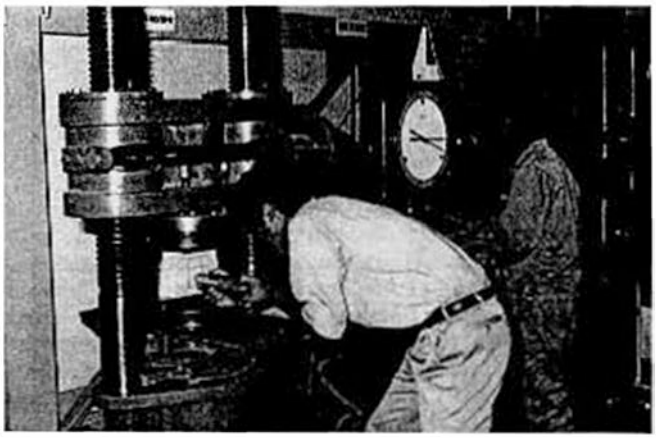

Photo 2 Measurement of rebound by Schmide hammer

3.2 Results

The relation between the number of passes of the chain-fitted wheel and the average depth of wear is shown in Table 3 and the cross sections of the tested specimens are shown in Fig. 2. It can be noted that the effect of the polymer impregantion of the block is more pronounced as the number of wheel passes increases. Namely, the average depth of the PIC block after 100,000 passes is about 1/5 that of asphalt concrete and 1/2 that of conventional paving concrete.

The relation of the compressive strength and the water absorption of concrete to the worn area is as shown in Fig. 3.

Table 3 Test results on the depth of wear and worn area

Type of specimen	Depth of wear 1)		Worn area	
	Average	Range	Average	Range
Dense-graded asphalt concrete conventional paving	10.0	6.2–12.6	10.2	6.7–12.2
Fine-graded asphalt concrete for cold districts	9.7	6.2–12.3	9.7	6.2–13.2
Surface course asphalt concrete for cold districts	9.5	6.0–11.2	9.4	6.0–10.4
Paving brock	7.0	3.6–8.9	6.8	3.8–8.6
Conventional paving cement concrete	4.3	2.3–5.6	4.3	3.3–6.1
Super-water-reducers curing in water	5.9	2.5–8.2	5.4	2.8–7.6
Super-water-reducers autoclave	5.4	2.4–6.6	5.0	2.2–6.3
PIC, Curing in water	2.2	0.9–3.4	2.1	1.0–3.4
PIC, autoclave curing	2.2	1.3–3.6	2.0	0.9–3.3
Artificial aggregate, PIC, curing in water	2.2	1.0–3.6	2.0	0.9–2.8
Artificial aggregate, PIC, autoclave curing	3.2	1.2–4.5	2.9	1.3–4.4
Artificial aggregate, special cement, super-water reducers	4.4	2.5–7.1	3.8	2.3–6.7

Note 1) : Average depth of wear in wheel track

In the case of using the same size of aggregate, the amount of wear exhibied a good correlation with the compression strength and the water absorption, i. The greater the compressive strength and the smaller the water absorption, the more the amount of wear decreases the rebound number by Schmide hammer shown in Fig. 4. Thus a high-degree of correlation between the rebound number and the amount of wear was obtained.

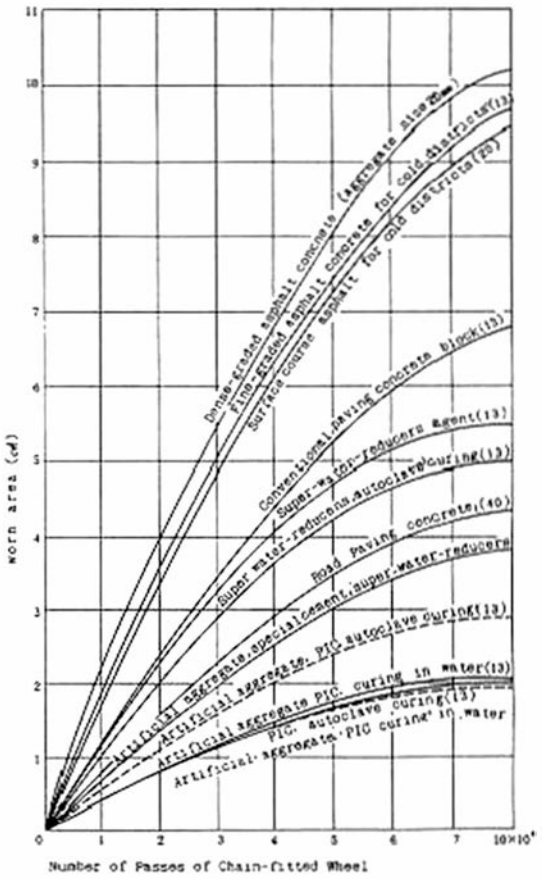

Fig. 2 Number of passes of chain-fitted wheel and worn area

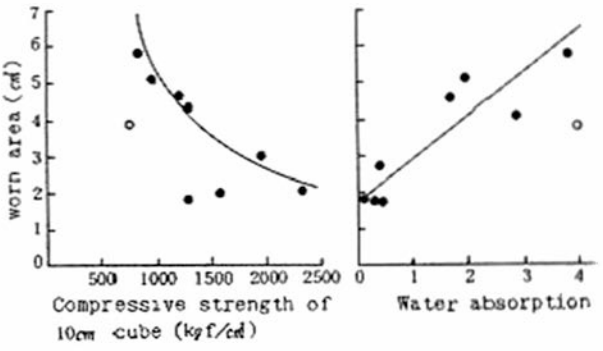

Fig. 3 Compressive strength of 10 cm cubic water absorption and worn area (Number of passes of chain-fitted wheel = 60,000)

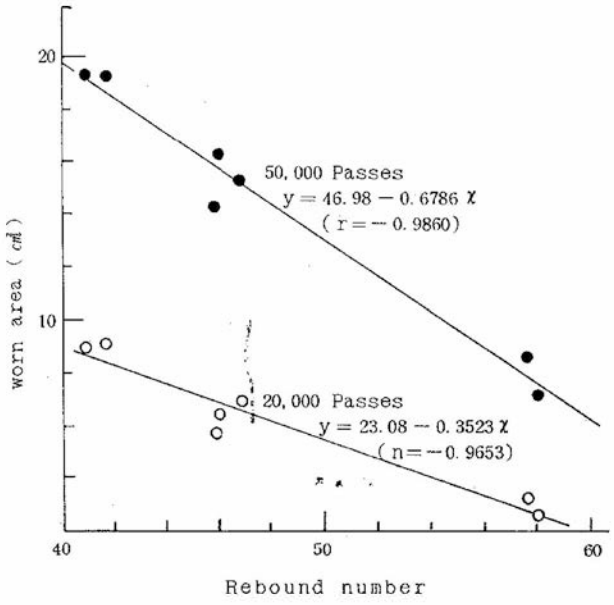

Fig. 4 Relation between rebound number and wear

4. FIELD TESTS WITH PIC BLOCK

4.1 PIC block

PIC blocks applied in the field were 8 cm in thickness. Tentatively the PIC blocks were composed of an 1 cm thick surface leyer of mortar and 7 cm thick base layer of aggregate of 10 mm in maximun size.

The compressive strength, the water absorption, the durability factor, the rebound number by Schmide hammer and the amount of wear are shown in Table 4. As seen from this table, the PIC block shows outstanding results compared with conventional concreate block.

Table 4 Properties of materials used

Type of block	compressive strength (kgf/cm²)	Water absorption (%)	Durability facton (%)	Wear (cm)			Rebound number
				Arerage	Max	Min	
Concrete block	724	3.2	96	7.9	12.5	2.0	37.0
P I C block	1,541	0.5	99	2.9	7.2	0.4	58.0

(1) Compressive strength was measured by overall loading test.

(2) 100,000 passes of chain-fitted wheel on rotary wear test machine.

(3) Constant load was set at 5.0 kgf/cm² when determining rebound number by Schmide hammer

4.2 Test pavement

In November 1981, a test pavement of 3 m in width and 70 m in length was constructed on one lane of the two-lane road on the bank of Toyohiragawa River in Sapporo.

The average 12-hour day time traffic volume in one direction is about 4,000 vehicles including 150 large vehicles, about 100 % of which are equipped with studded tires in winter. Therefore, the total number of vehicles passing this road in winter reaches about 800,000 during the 5-month period from mid-November to mid-April.

The section of the test pavement structure is shown in Fig.5. The upper 10 ~ 11 cm of the existing pavement was scarified followed by spreading a 3 cm sand layer over the scarified surface and laying concrete blocks on the sand layer.

According to plate bearing test the coefficient of bearing capacity was 48 kg/cm³ on the scarified surface of the existing road and 63 kg/cm³ on the surface of concrete block layer.

As a laying pattern of concrete blocks was adopted Heringbone bond as shown in Fig. 6. In laying concrete blocks, consideration was given to economy, so PIC blocks were laid only where vehicles run with high frequency and conventional concrete blocks where vehicles run less frequently. The cost per m² of the test pavement by such laying method was about 22 % higher than was in usual cases.

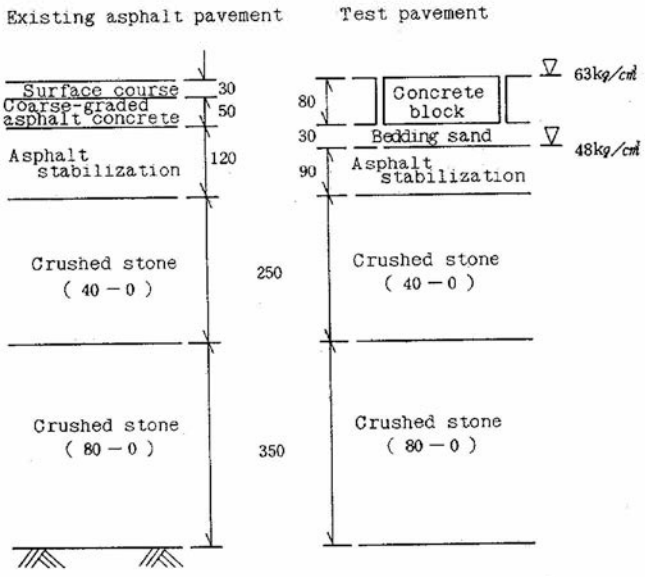

Fig. 5 Construction of test pavement

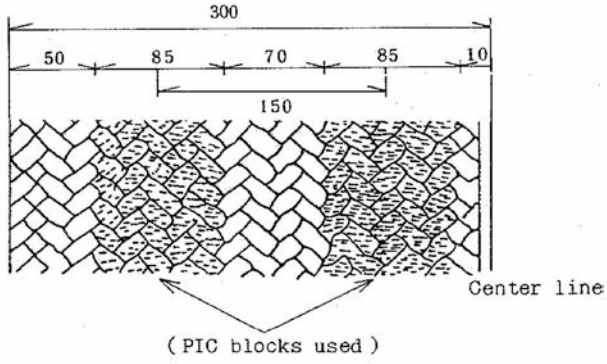

Fig. 6 Laying pattern



Photo 3 Test pavement profile being measured

4.3 Profile of the road surface

The profile of the road surface was measured by moving a gauge along a straightedge which was fixed at its both ends. Changes in the profile of the road surface after opened to traffic were measured at 8 points. The average values of the changes measured at each point are shown in Fig. 7. The average depth of rutting in the first winter (5 months after opened to traffic) was 2.6 mm. However, it was 0.6 mm after the lapse of next winter (18 months after opened to traffic) Namely, the depth of rutting in the road surface in the first winter includes the consolidation settlement of the sand layer largely and that in the second winter seems to be mainly due to wear of concrete blocks. This result is from 1/3 to 1/5 the amount of wear of the asphalt pavement adjacent to the test pavement.

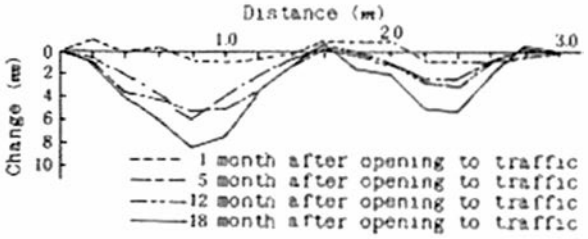

Fig. 7 Changes in profile

4.4 Skid resistance and traffic noise

The skid resistance test of the road surface was made by using a portable skid resistance tester specified in ASTM E 303-69. The results are shown in Table 5. As compared with the adjacent asphalt pavement whose skid resistance was measured for comparison, the PIC block pavement shows a somewhat lower value of skid resistance, but this value is not so low as to affect serviceability.

Noise measurements were made by running the same vehicles on the test pavement and the adjacent asphalt pavement. Noise meters were set at 4 m apart from running vehicle and 0.3 m in high. The results of measuring noise are shown in Table 5. As a result, the PIC block pavement shows a somewhat higher value than the asphalt pavement when the road surface is dry, but the reverse tendency is seen when wet. This result well agrees with data of noise measurements made by the author et al. in the past.

Table 5 Results of meausring skid resistance and noise

Item / Surface condition / Paving material	Skid resistance (BPN)		Noise (dB)		
	Dry	Wet		Dry	Wet
PIC block	70.4 (2.4)(1)	56.0 (2.2)	SP(2)	82.9 (2.5)	82.3 (2.8)
concrete block	-	-	ST	75.8 (2.4)	-
Asphalt concrete pavement	82.1 (4.2)	69.7 (2.0)	SP	80.7 (2.5)	84.8 (3.7)
			ST	73.7 (1.7)	-

(1) Given in parentheses are standard deviations.
(2) SP: Studded tire. ST: Summer tire.

5. CONCLUSIONS

The author et al. have developed a wear-resistant PIC concrete block and conducted tests to apply the PIC concrete blocks to road, especially in snowy and cold areas.

Since the concrete block is shop made, its properties are relatively easy to improve. Therefore, subjecting the concrete block to special treatment has made it possible to obtain high wear resistance.

Thus prepared wear resistant concrete blocks were laid in the test field. The results of investigation their performance may be summarized as follows:

1) By impregnating the surface of the concrete block with polymer to obtain high-strength concrete, it was possible to decrease the amount of wear. According to laboratory test data, the amount of wear of this high-strength concrete was about 1/5 that of conventional asphalt concrete

2) As a result of measuring the profiles of the test road, average wear of the PIC block was about 0.6 mm in one winter, about 1/3 to 1/5 that of the adjacent asphalt pavements.

3) The skid resistance and traffic noise of the PIC block pavement were almost equal to those of conventional asphalt pavements.

REFERENCES

1) Miwa, Hotta, Kaneko and Iida, Laboratory Experiments on wear Resistance of Concrete Pavement, Japan Highway Public Corporation's Test Report, 1972.

2) Reports on Test Paving of Kuriko Road with Concrete, 1977, 1978, 1979, Road Engineering Laboratory, Tohoku Universiry.

3) Winter Damage to Road Pavement, OECD Road Research Report, 1972.

4) Reports of 2nd European Symposium on Concrete Roads, 1973.

5) Fukuda, Tsuda and Komura, Study on Interlocking Paving Block with High Wear Resistance for Snow Chains, Review of the Thirty-Fourth General Meeting, of the Cement Association of Japan, 1980.

6) Suda, Yamanaka and Kodama, Relation Between Rebound Number by Schmide hammer and the Strength and Abrasion of Interlocking Block, 1983.

7) Iijima, Kojima and Sueyoshi, Winter wear of Asphalt pavements and its Estimation.

8) Tsuda, Komura and Takaura, Traffic Noise Characteristic of Interlocking Block Pavement, Pavement, Vol. 16, 1981.