HIGHLY DURABLE LIGHT-COLORED EPOXY RESIN ASPHALT COMPOUND FOR PAVING TUNNELS IN COLD SNOWY AREAS

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ABSTRACT

In cold and snowy areas of Japan, most trucks use tire chains to ensure safe driving. However, the chains cause such severe rutting of the pavement in narrow and crowded tunnels that the pavement may need to be repaired after 1 to 2 years for asphalt concrete pavement and 3 to 4 years for durable concrete pavement.

For highway tunnels that are exposed to such severe conditions, we have developed a light-colored epoxy resin asphalt compound and have applied it to roads.

The epoxy resin asphalt compound is characterized by 1) having a grading of stone matrix asphalt, 2) using a mixture of petroleum resin and epoxy resin at a ratio of 65 to 35 as the binder, 3) containing ceramic aggregates (13 to 5 mm) and vegetable fibers to increase durability, and 4) using white pigment to produce a light color.

A follow-up survey showed that the pavement constructed using the light-colored epoxy resin asphalt compound has retained its light color, suffered little rutting, and has remained in a good service condition for almost 10 years. The compound was shown to produce highly durable pavement.

1. INTRODUCTION

In Japan, which extends north and south and has a steep topography, the climatic and traffic conditions vary greatly depending on the area, and so the performances required of highway pavement vary accordingly. In many areas, pavement is exposed to very severe conditions.

This paper describes a method for controlling the rutting of pavement in tunnels located in cold snowy areas. In one of such tunnels, deep rutting of about 30 mm was formed on the pavement in 3 to 4 years due to vehicle tire chains even though the pavement was high-strength steel-fiber-reinforced high-early-strength concrete, and the pavement needed to be reconstructed.

Light-colored epoxy resin asphalt compound (“CERAM”) was used to repair the pavement, and has shown good serviceability. This paper describes the characteristics of CERAM.

2. CERAM

2.1 Overview

CERAM is composed of the materials shown in Table 1. Major characteristics are the use of white ceramic aggregates and a specific binder, which is a mixture of petroleum resin bitumen and epoxy resin. The compound has a grading of stone matrix asphalt (SMA) to improve the resistance against abrasion and flow. The combined gradation is shown in Table 2 and Fig. 1.

Table 1 - Materials and purposes of use

Materials	Target effect	Contents
Aggregates	—	Crushed stone, natural sand, stone dust
Special aggregates	Light color, abrasion resistance	White ceramic aggregates
Binder	Light color, abrasion resistance	Petroleum resin bitumen: 65%, epoxy resin: 35%
Pigment	Light color	White pigment
Vegetable fibers	Abrasion resistance	Amount added: 0.3% of the mixture

Table 2 - Combined gradation of CERAM

Aperture (mm)	19.0	13.2	4.75	2.36	0.6	0.3	0.15	0.075
Percentage passing (%)	100.0	98.7	34.5	25.0	19.1	15.7	13.7	12.0

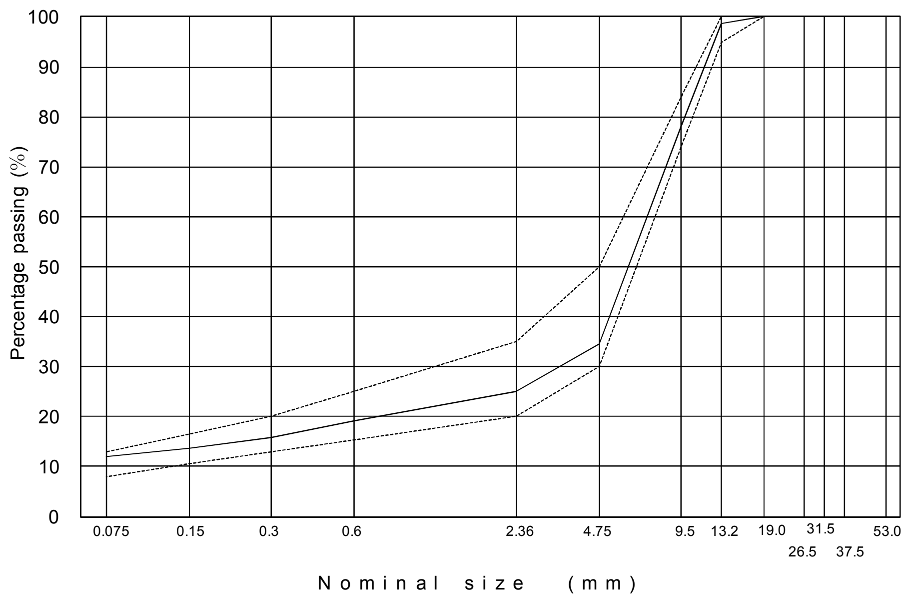

Figure 1 - Combined gradation of CERAM

2.2 Mix design test

The percentage of aggregates and the amounts of binder and other materials were determined by the Marshal test. The amount of binder was determined so as to achieve a void ratio of 3%. In the Marshal test, the specimens were cured for 1 week at 60ºC in order to measure the ultimate strength of the hardened epoxy resin. The target Marshal stability of CERAM after curing was at least 30 kN, which is five times larger than that of ordinary stone matrix asphalt (6 kN) used in Japan.

2.3 Checking performances (flow resistance, abrasion resistance, and light color)

The performances were investigated by conducting the Japanese wheel tracking test and labeling test and measuring luminosity.

2.3.1 Flow resistance

Flow resistance was evaluated by determining the dynamic stability (number of passes/mm) in the Japanese wheel tracking test (Photo 1). Figure 2 shows the dynamic stability values of ordinary straight asphalt concrete, concrete and CERAM. Larger values mean higher flow resistance and reduced rutting. Figure 2 shows that CERAM has much better dynamic stability than ordinary asphalt concrete although it was slightly lower than that of concrete pavement.

Photo 1 - Wheel tracking test

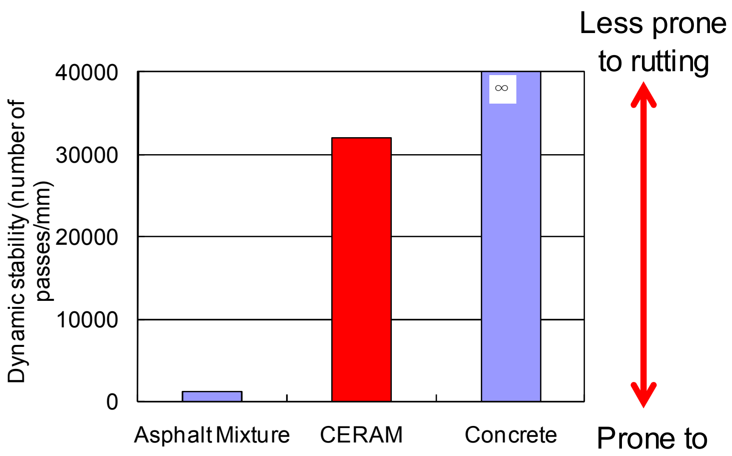

Figure 2 - Flow resistance

2.3.2 Abrasion resistance

In Japan, abrasion resistance is evaluated by conducting the labeling test (Photo 2). The test is usually performed at a test temperature of −10ºC for a duration of 90 minutes, but we tripled the duration to 270 minutes in order to emphasize the difference. Figure 3 shows the abrasion of straight asphalt concrete, concrete and CERAM. Smaller abrasion values mean better abrasion resistance and less rutting. The figure shows that CERAM is more abrasion resistant than ordinary asphalt concrete and concrete.

Photo 2 - Labeling test

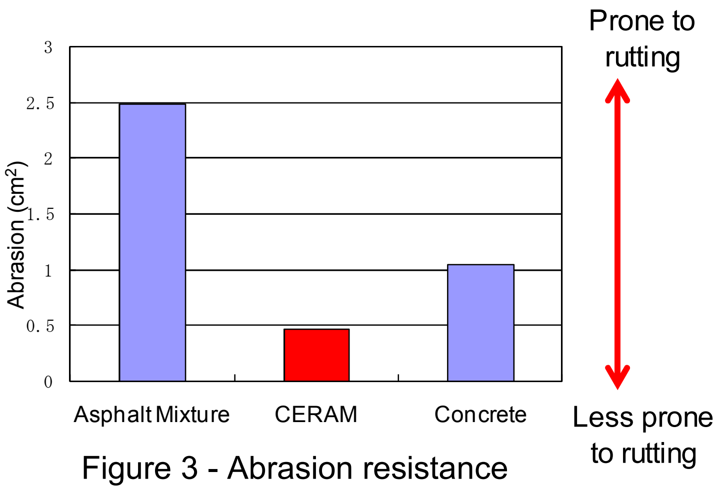

Figure 3 - Abrasion resistance

2.3.3 Luminosity

The light color was evaluated by measuring the luminosity with a colorimeter (Photo 3). The luminosity is shown in Fig. 4 for asphalt concrete, concrete and CERAM. Lower values mean darker color, and larger values mean lighter appearance. The figure shows that CERAM is lighter than asphalt concrete and as light as concrete.

Photo 3 - Measuring luminosity

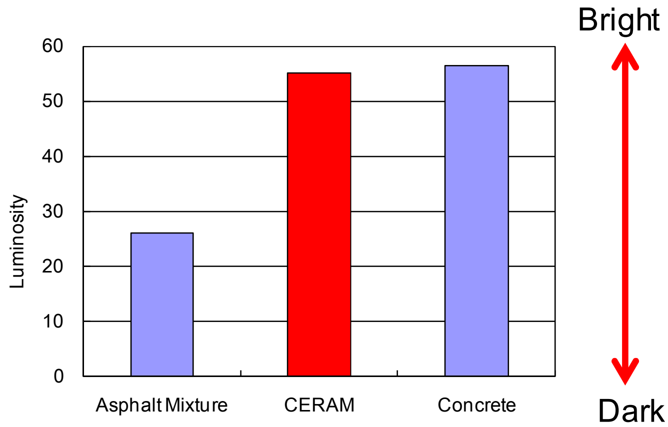

Figure 4 - Luminosity

2.4 Changes of performance by outdoor exposure

The strength of CERAM, which contains epoxy resin, changes as the resin hardens. Because the luminosity was suspected to be changed by ultraviolet rays, a specimen was prepared and exposed to outdoors to check the changes in performance. The specimen was prepared in November (early winter) when resins harden most slowly in Japan. The tests were conducted 1, 3, 7, 30, 60, 120, 240, and 260 days after the preparation. The results are described below.

2.4.1 Changes in Marshal Stability

The changes in Marshal Stability are shown in Fig. 5. The stability was almost constant until Day 7, increased gradually thereafter, and reached 30 kN on around Day 180 (equivalent to the stability value for the specimen cured at 60ºC for 1 week in the mix design test).

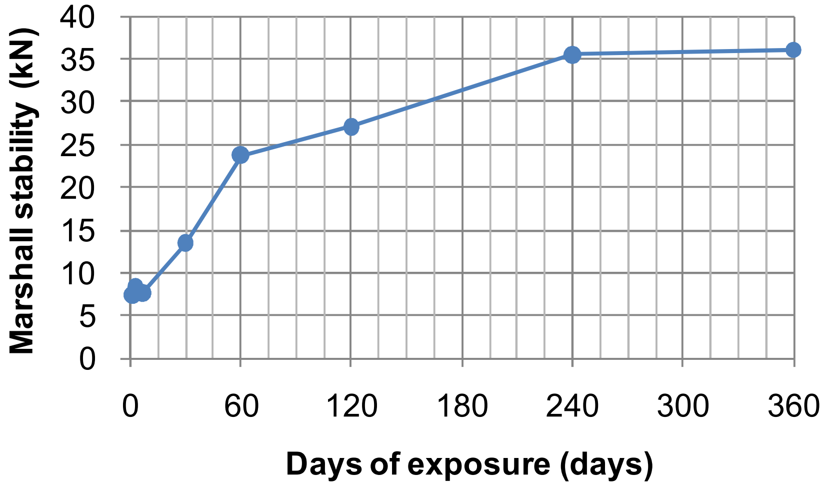

Figure 5 - Changes in Marshal stability

2.4.2 Changes in flow resistance

Figure 6 plots the changes in dynamic stability in the wheel tracking test, which shows flow resistance. As shown, the dynamic stability was almost constant until Day 7, gradually increased thereafter, and stabilized at about 60,000 passes/mm on about Day 120 (60,000 passes/mm is the upper limit of the test; measurement is impossible above this).

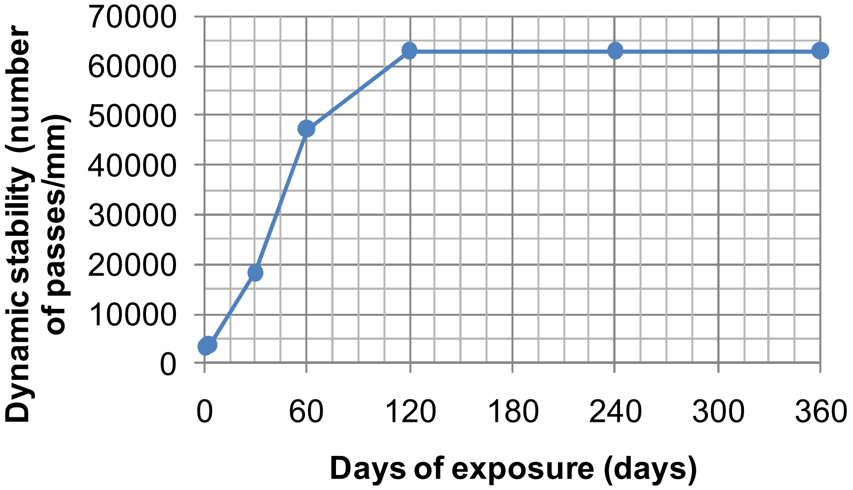

Figure 6 - Changes in dynamic stability

2.4.3 Changes in abrasion resistance

The changes in abrasion during the labeling tests are shown in Fig. 7. As shown, the abrasion varied between 0.4 and 0.7 cm^2 until Day 120 and stabilized thereafter at around 0.4 cm^2. The variation may be attributable to the non-uniformity of the specimen and/or the instability until it completely hardened. Because all values satisfied the criterion in Japan, which is to not exceed 1.3 cm^2, the variation was unlikely to constitute a problem.

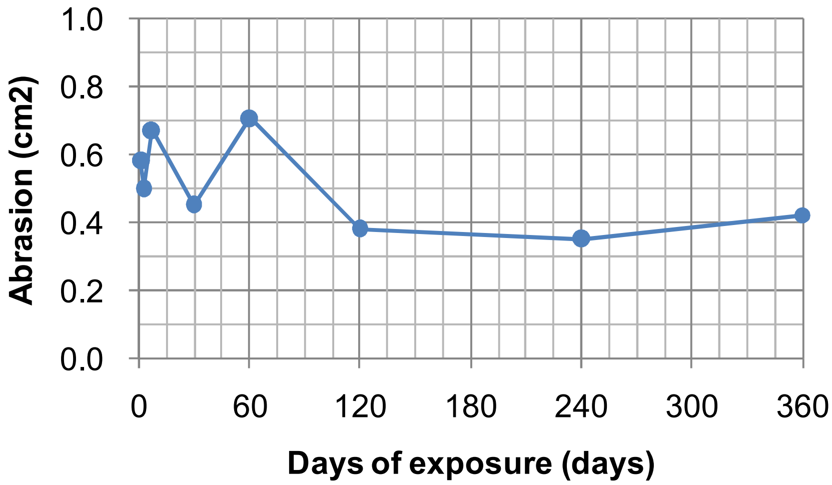

Figure 7 - Changes in abrasion

2.4.4 Changes in luminosity

The changes in luminosity measured with a colorimeter are shown in Fig. 8. As shown, the luminosity was almost constant at about 58 until Day 30, increased by 10 to 67 on Days 120 and 240, giving a lighter appearance, and decreased to 65 by Day 360, which meant that the pavement became slightly darker. For CERAM, luminosity tended to increase during the first year of construction.

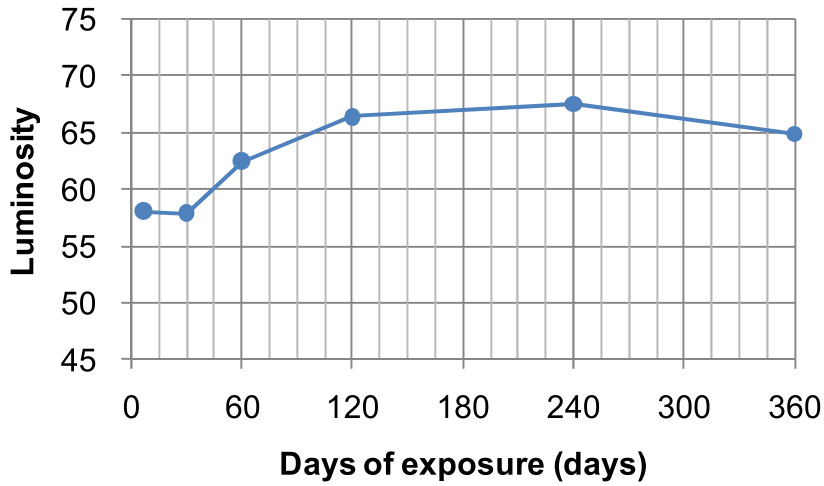

Figure 8 - Changes in luminosity

3. ACTUAL PRODUCTION AND IN-SITU CONSTRUCTION

3.1 Points to note during production and construction

CERAM is produced and applied in almost the same manner as ordinary asphalt concrete pavement. It is produced in an asphalt plant, and is spread and compacted using an asphalt finisher and a roller. Because special materials such as epoxy resin are used, thermostatic tanks and measuring tanks must be installed in the asphalt plant (Photo 4) and an exclusive-use inlet must be installed on the wall of the mixer (Photo 5).

Epoxy resin may not harden sufficiently in the presence of water. Materials other than water need to be used to prevent sticking during rolling compaction.

Photo 4 - Thermostat and measuring tanks for epoxy resin

Photo 5 - Inlet of epoxy resin

3.2 Site of test construction and CERAM construction

CERAM was used to pave a tunnel on National Highway Route No. 13, which passes under the Kuriko Pass (Photo 6). The pavement in the tunnel is prone to rutting because:
1) the paved width is as narrow as 3.25 m/lane, and so wheels always pass over the same

tracks,
2) the mean daily traffic volume is large with 9,000 vehicles a day (with trucks accounting for 50%), and
3) many vehicles use tire chains in winter because the highway passes through mountains.
As mentioned above, rutting exceeds 30 mm in just 3 to 4 years.

CERAM was produced and constructed at the site. Views of the production and construction are shown in Photos 7 and 8, and views after CERAM construction are shown in Photos 9, respectively.

Photo 6 - Tunnel of CERAM construction
(before CERAM construction)

Photo 7 - Mixing and laying CERAM

Photo 8 - Spreading

Photo 9 - Completed CERAM pavement

4. DURABILITY AND LIFECYCLE COSTS

4.1 Durability

The CERAM pavement was monitored for 10 years, and the changes in rutting are shown in Fig. 9. The rutting on CERAM during the 10 years was only about 30 mm, while high-strength steel-fiber-reinforced high-early-strength concrete suffered rutting exceeding 30 mm in about 4 years.

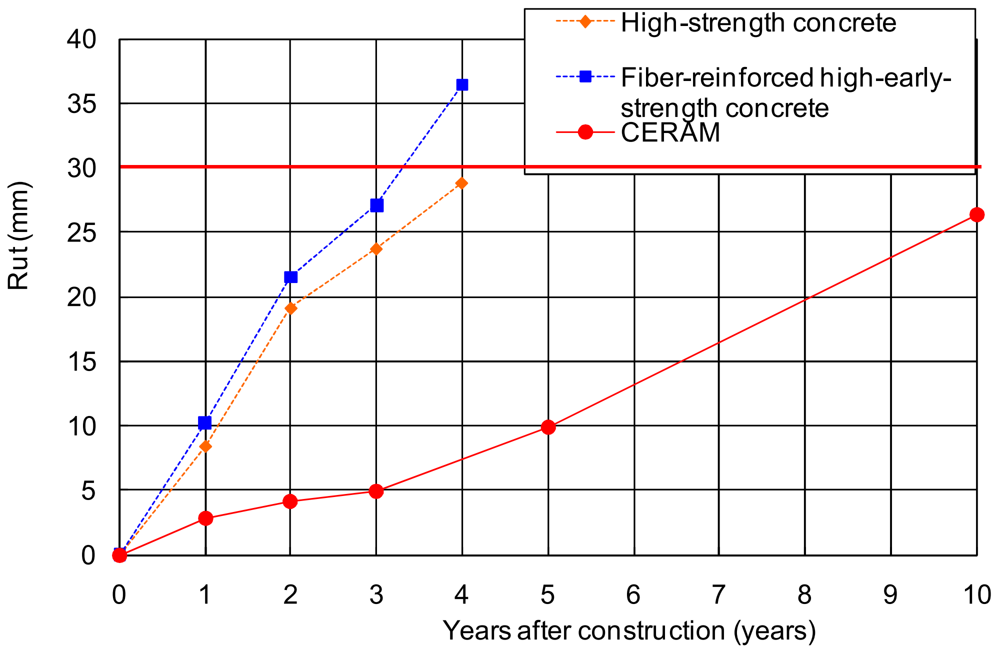

Figure 9 - Results of follow-up survey

4.2 Simple lifecycle cost estimates

CERAM is more resistant to rutting than concrete, but uses more expensive materials and thus the initial cost is higher. According to approximate figures of actual construction costs in Japan, the construction cost of CERAM is 2.2 times higher than that of ordinary concrete pavement (thin-layer concrete pavement costs 45% that of CERAM). However, CERAM lasts longer than concrete. The lifecycle costs of concrete pavement and CERAM were estimated only from the construction costs by assuming lifespans of 4 and 10 years, respectively, and are shown in Table 3. As shown, CERAM is advantageous compared to concrete. The actual advantage in lifecycle cost should be larger than the figures shown because CERAM also reduces the cost of restricting traffic during pavement reconstruction and lost benefits to users.

Table 3 - Cost comparison

Paving material	0 years	4 years	8 years	10 years
CERAM	1	1	1	1
Thin-layer concrete	0.45	0.90	1.35	1.35

CONCLUSIONS

CERAM is much more durable than ordinary asphalt mix and can produce more durable pavement than concrete under certain conditions. A series of indoor tests and a follow-up survey showed that CERAM effectively increases the resistance to abrasion. Although the construction cost of CERAM is high, which may discourage its use, it is highly advantageous in terms of lifecycle cost over 10 and 20 years. We recommend using it for paving highway sections exposed to severe conditions. The main characteristics of CERAM are summarized below:

1) CERAM has several dozen times greater flow resistance and abrasion resistance than ordinary asphalt mix.
2) It has at least double the abrasion resistance to tire chains compared with concrete.
3) The color is as light as concrete.
4) The initial strength is sufficiently high for service, but it reaches the ultimate strength in about 120 days.
5) It is produced in an asphalt plant and constructed using asphalt finishers and rollers as with ordinary asphalt.
6) Like asphalt concrete pavement, it can be opened to traffic after construction as soon as it has cooled down.

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