Development of an Environment-friendly High-performance Asphalt Compound

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ABSTRACT: The Toho Gas Group has been studying (1) the methods of construction to minimize the amount of scraped soil and asphalt coming from gas pipe laying works, and (2) the development of technologies recycling industrial waste like scraped soil, asphalt and PE pipes. This time we have developed a high-performance pavement material enabling application not only to gas pipe laying but also to general road construction. A heated asphalt compound widely used for road repair work is carried to a small-scale construction site usually in an excess amount to prevent its temperature from dropping during transportation, which causes its unused part to be abandoned as waste. On the other hand, a normal-temperature asphalt compound suitable for small-amount use is unable to provide the strength as high as a heated compound, limiting its application only to temporary pavement. Under such circumstances we have worked on the development of a new asphalt compound that can be used in a small amount for a small-scale construction, hardening to give sufficient strength immediately after application. By combining a normal-temperature asphalt compound with a urethane resin binding agent consisting of a primary agent, a stiffener and a hardening promoter, we have developed a rapidly-hardening normal-temperature asphalt compound that maintains the characteristic elasticity of a normal-temperature asphalt and yet hardens quickly, giving the strength equal to or greater than a heated asphalt. The strength of this new compound gives Marshall Stability 20kN, higher than twice that of a heated asphalt compound, one day after its application. In addition we can reduce waste originating from construction works, and significantly curtail CO2 generation during its manufacturing process; an environment-friendly pavement material.

KEY WORDS: Normal-temperature asphalt, rapid hardening, regular repair, temporary repair, CO_2 reduction, environment, pavement material.

1. INTRODUCTION

The Toho Gas Group has been working on (1) the methods of construction to minimize the amount of scraped soil and asphalt coming from gas pipe laying works, and (2) the development of technologies recycling industrial waste like scraped soil, asphalt and PE pipes. This time we have developed a high-performance pavement material enabling application not only to gas pipe but also to general road construction. The developed pavement material not only decreases loss in its application to pavement, but also is an environment-friendly one drastically reducing CO_2 generated in its production process.

A heated asphalt compound widely used for road repair works (bone materials like crushed stones or sand is mixed with about 5% asphalt) has a character to harden due to temperature drop. Therefore, it must be used prior to its temperature drop after production, necessitating its transport from a production factory to an application site immediately before construction. Although the temperature drop of asphalt compound during transportation caused by heat release loss does not give a serious problem in a large-scale construction due to its large mass, the transport of little amount of asphalt for a small-scale construction causes asphalt hardening due to significant temperature drop, occasionally leading to inability to apply. Because of this, an asphalt compound transported to a small-scale construction site is usually more than necessary to maintain its temperature, which causes its unused part to be abandoned as waste.

On the other hand, a normal-temperature asphalt compound (asphalt is added oil components for use at normal temperatures), treatable in the form of packages, is appropriate for small-scale use, but is not as strong as a heated one due to oil components, limiting its use only to temporary pavement.

Under such circumstances we have worked on the development of a new asphalt compound that can be used in a small amount for a small-scale construction, hardening to give sufficient strength immediately after application. By combining a normal-temperature asphalt compound with additives (a urethane resin binding agent consisting of a primary agent, a stiffener and a hardening promoter), we have developed a rapidly-hardening normal-temperature asphalt compound that maintains the character of a normal-temperature asphalt and yet hardens quickly, giving the strength equal to or greater than a heated asphalt.

2. TARGET OF DEVELOPMENT

Our new asphalt is aimed to possess the following properties.

(1) It is as soft as an existing normal-temperature asphalt compound prior to application.

(2) It is as strong as a heated asphalt compound after application.

(3) It has rapid-hardening character, enabling a road open to vehicles transportation 1 hour after application.

(4) It can endure long-time storage, maintaining its performance unchanged for about two months after its manufacture.

3. ESSENTIALS IN DEVELOPMENT

(1) How to ensure the softness of an existing normal-temperature asphalt compound

A normal-temperature asphalt compound has the strength insufficient for regular repair, but is soft enough to provide easy application works, enabling long-time storage like 2-3 months. Thus our selected strategy has become (1) to use a normal-temperature compound as the basic material ensuring softness, for which we chose a temporary-repair normal-temperature asphalt compound from Toho Gas Techno Co (Trademark Toho CBA[1]).

Note 1: CBA means Cut Back Asphalt, the asphalt liquidized by mixing with volatile petroleum, which is the remnants from petroleum refinery resolved back into liquid by mixing with refined volatile part.

(2) Revelation of strength equivalent to a heated asphalt compound

Mixing Toho CBA with additives (an adhesive resin adding strength etc), we tried to reveal the strength and endurance equivalent to those of a heated asphalt compound. After studying the hardening pattern and type of each additive, we chose the additives that can reveal sufficient strength and endurance.

(a) Choice of hardening method: The hardening patterns of commercial additives are primarily classified into two types; normal- and high-temperature hardening types, as shown in Table 1. Out of these hardening patterns, we chose the hardening policy using normal-temperature hardening and addition of hardening agent.

(b) Choice of additives: Out of the additives of “adding hardening agent” type we studied the two additives shown in Table 2, excluding the ones containing environmental hormones. As a result, we chose a urethane resin adhesive (revealing strength due to reaction between primary and hardening agents) that can change strength and reaction rate at our disposal, and in addition has superiority in cost.

Table 1: Hardening Patterns of Additives and Result of Choice

Hardening Policy		Mechanism of Strength Origination	Features	Result of Choice
Normal-Temperature Hardening	Type of Hardening Agent Addition[2]	Reaction between Primary and Hardening Agents	(1) Easy to Control Hardening Rate (2) Easy Preservation in Packages	○
	Type of Solvent Desiccation[3]	Evaporation of Solvent	(1) Difficult to Control Hardening Rate (2) Solvent Evaporates during Storage	×
	Type of Damp Hardening[4]	Reaction with Water	(1) Difficult to Control Hardening Rate (2) Difficult to Preserve due to Absorption of Water in Air and Compound	×
Heated Hardening[5]		External Heating	(1) Heating Process in Necessary at Application Site (2) Randomness in Strength due to Non-uniform Heating	×

Note 2: Typical examples in Type of Hardening Agent Addition; Polyurethane resin adhesive, Epoxy resin adhesive, Phenol resin adhesive.

Note 3: Typical examples in Type of Solvent Desiccation; Natural rubber group adhesive, Vinyl acetate resin adhesive.

Note 4: Typical examples in Type of Damp Hardening; Polyurethane resin adhesive, Acrylic resin adhesive.

Note 5: Typical examples in Heated Hardening; Epoxy resin adhesive, Phenol resin adhesive, Polyurethane resin adhesive.

Table 2: Result of Choosing Additive

Evaluated Additive	Features	Result of Choice
Urethane Resin Adhesive	(1) Revealing sufficient strength (2) Reaction rate favorable (3) Low cost	O
Specific Phenol Resin Adhesive	(1) Revealing sufficient strength (2) Low reaction rate	×
Acrylic Resin Adhesive	(1) Revealing sufficient strength (2) Reaction rate favorable (3) High cost	×
Acrylic Copolymer Dual Emulsion	(1) Reaction rate uncontrollable	×

(3) Achievement of rapid hardening that enables traffic one hour after application

A urethane resin adhesive consists of 3 species (all liquid), *a primary agent, a stiffener and a hardening promoter*, revealing its strength by the reaction between the primary agent and the stiffener. Hardening rate can be adjusted by the amount of hardening promoter addition.

(a) Decision of mixing ratio among primary, stiffening and promoting agents

Since the strength revealed by a urethane resin adhesive depends upon the mixing ratio among the three agents, primary, stiffening and hardening promoting agents, it is necessary to acquire the relation between strength and mixing ratio, which is shown in Table 3. The experimental result gives the best performance for the mixing ratio (weight %) between primary and stiffening agents at 45-55%:55-50%.

Table 3: Dependence of measured hardening time and hardness on mixing ratio

No	Mixing ratio (weight %)		Result of measurement on characteristics	
	Primary	Stiffener	Hardening time (min) [6]	Hardness after hardening (compared with asphalt)
1	70	30	46	soft
2	60	40	23	hard
3	55	45	14	hard
4	50	50	14	hard
5	45	55	15	hard
6	40	60	16	hard
7	30	70	17	hard

Note 6: Hardening time = time for mixture convection to disappear.

In order to reveal the strength enough to be exposed to traffic one hour after application, another experiment is performed to give the relation between the amount of hardening promoter and the hardening rate, which is shown in Table 4. The result shows that the addition of 1% (weight % to the mixture of primary and stiffening agents) promoter reduces the hardening time down to 0.43 of the one without promoter, while 1.5% addition does down to 1/4. Thus a small amount of promoter can contribute to significant increase of hardening rate.

Table 4: Relation between the amount of hardening promoter and the hardening time

No	Mixing ratio (weight %)		Result of measurement on characteristics
	Primary+Stiffener	Promoter	Hardening time (min)
1	100.0	0.0	23
2	99.0	1.0	10
3	98.5	1.5	6
4	98.0	2.0	3

Based on such results, we decided the mixing ratio between primary and stiffening agents that can reveal necessary strength and the optimal mixing ratio of hardening promoter that can realize the strength enough to allow traffic one hour after application.

(b) Mixing with an asphalt compound

With regard to mixing primary, stiffening and promoting agents with an asphalt compound, premixed primary and promoting agents are added because they don't cause reaction. The most appropriate timing of addition is investigated in Table 5.

As a result the best method turned out: When a normal-temperature asphalt compound is manufactured, primary and promoting agents are added and packaged, before it is mixed with a stiffener at an application site. This method was chosen.

Table 5: Method of adding a urethane resin adhesive to an asphalt compound

Resin adhesive added to compound a priori		Resin adhesive added at application site		Features	Result of evaluation
Primary+ promoting agents (liquid A)	Stiffening Agent (liquid B)	Primary+ promoting agents (liquid A)	Stiffening Agent (liquid B)		
		○	○	(1) When Liquids A and B are added in turn, uniform dispersion of each is impossible (2) Mixing A and B, followed by its addition to compound, makes uniform dispersion difficult, due to reaction between A and B.	×
○			○	(1) A-priori mixing at the stage of manufacture necessitated by high viscosity of primary agent gives good dispersion. (2) It can reveal desired strength and rapid hardening.	**○**
	○	○		(1) Slight reaction of stiffener with water in air/ compound makes it difficult to maintain softness of compound (2) Stiffener has to be kept in a can separately. (3) Due to high viscosity of primary agent, on-site mixing makes dispersion difficult.	×

(c) Prevention of asphalt compound expansion

Since a stiffener reacts with water in an asphalt compound to generate CO_2, we encounter the problem of asphalt compound expansion after application. In order to avoid it, a method is discussed to absorb the generated CO_2 by adding an adsorbent inside the asphalt compound. It was discovered that the more adsorbent was added the less expansion we acquired, and yet an attempt to suppress the expansion of asphalt compound only by using adsorbent increased the amount of adsorbent, thereby incurring significant rise in cost.

Thus we studied an idea making it easier for CO_2 to escape from a compound by adjusting the grain size of bone materials and increasing its porosity, in order to reduce the amount of utilized adsorbent. It was speculated, however, that increased porosity gave reduction of contact area among bone materials, necessitating the increase of a urethane resin adhesive to maintain the strength. Therefore we obtained the relation between the porosity and the amount of a urethane resin adhesive necessary to maintain the strength, which proved that the porosity increase did not cause the rise of a urethane resin adhesive.

Consequently we succeeded in suppressing the expansion of an asphalt compound by increasing its porosity and adding a small amount of adsorbent.

(4) Confirmation of long-term storage

A normal-temperature asphalt compound usually stored in packages must maintain softness even after long-term storage, and reveal stable strength after application. Thus we conducted tests by storing it in a package for two months and applying it after opening the package, and confirmed that there were no problems in its softness and strength.

4. CHARACTER AND PERFORMANCE OF NEW ASPHALT

(1) Rapid hardening property

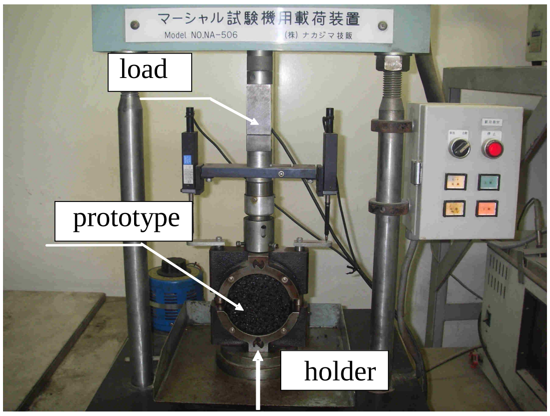
Usually a road that is paved by a heated asphalt compound is opened to traffic about one hour after application when the surface temperature has dropped down to below 50C. With regard to our high-performance asphalt, a normal-temperature asphalt compound premixed with primary and hardening promoter agents is mixed with a stiffener at an application site, inducing reaction between the agents and the stiffener to rapidly raise the strength of the asphalt compound. As a result the paved road can possess the strength sufficient to be open to traffic one hour after its application.

(2) High strength

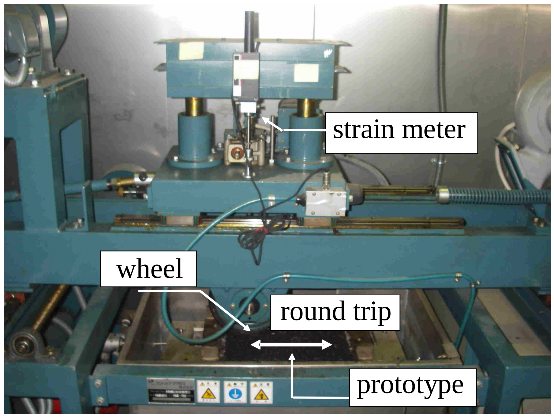
The strength of an asphalt compound is assessed by Marshall Stability[7] giving the breaking strength and Dynamic Stability[8] giving the anti-fluidity, shown in Asphalt Pavement Synopsis.

Note 7: Marshall Stability gives the breaking strength where the side of a cylindrical prototype of an asphalt compound (101.6mm dia., 63.5mm high) is clamped by two arc-shape holders, and is given a compression load in the diameter direction until the prototype is broken; the maximum load read by a measurement equipment (shown in Picture 1) is called Marshall Stability, which can assess the strength of a heated asphalt compound.

Note 8: Dynamic Stability is the number of round trips run by a wheel equivalent to the weight of a truck over a plate-shape prototype of an asphalt compound (300mm x 300mm x 50mm) until it undergoes a 1mm dip, giving its anti-fluidity. A measurement equipment is shown in Picture 2. Dynamic Stability assesses the strength of an asphalt compound used on heavy-traffic roads frequently run by trucks.



Picture 1: Marshall Stability Measurement



Picture 2: Dynamic Stability Measurement

It is stipulated in law that the standard value of Marshal Stability is 4.9kN for a heated asphalt compound. As shown in Figure 1, the value of our new compound "Katamaru-kun" reveals Marshall Stability 5kN after 1 hour and about 20kN after a day, followed by continuous rise caused by the reaction of resin, eventually reaching 30kN after 3 days.

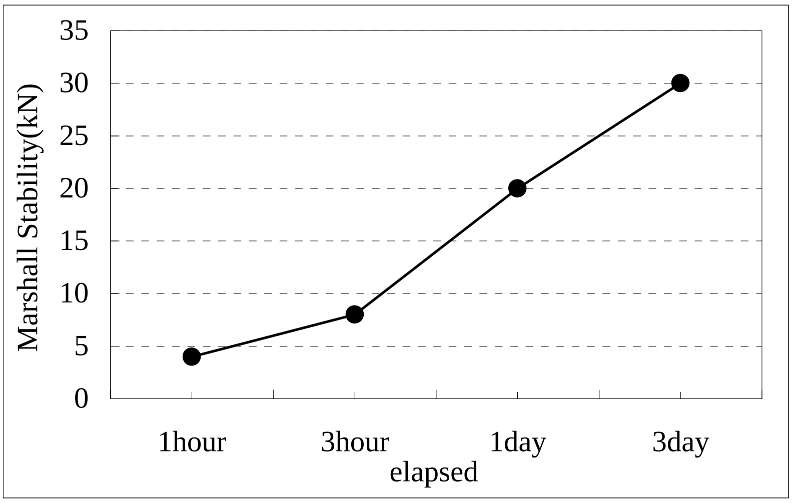


Figure 1: Marshall Stability of Katamaru-kun

It is also stipulated in law that the standard value of Dynamic Stability is 3000times/mm for an asphalt compound used on heavy-traffic roads (national roads frequently run by trucks). Dynamic Stability of our new compound gives 10,000times/mm even 1 day after its application. Thus it is concluded that our new compound "Katamaru-kun" has the strength equal to or higher than a heated asphalt compound.

(3) Excellent storage properties

After the elapse of two months in the form of packages, Katamaru-kun keeps the same softness and working efficiency as at the time of manufacture, showing no change in hardening rate and strength.

(4) Response to temperature variation of application environment

The hardening rate of a urethane resin reinforcement agent is influenced by the temperature of application environment. At low temperatures hardening reaction becomes slower. In this respect we tried to optimize the added amount of primary and promoter agents and the balance of bone materials grain size, depending upon the season, and confirmed that we could realize the strength enabling traffic to reopen one hour after application throughout the year.

(5) Effect of environmental load mitigation by Katamaru-kun

When manufacturing temperatures are compared between a commonly used heated asphalt compound and Katamaru-kun, the latter can be manufactured at a temperature about 60C lower than the former. Thus the amount of fuel for manufacturing our asphalt compound can be less, contributing to the reduction of CO_2 generation.

Since kerosene fuel is utilized for heating compounds in Toho Gas Techno Co., Ltd. the reduction of CO_2 is assessed in the following.

CO_2 generation (kg CO_2)[9] = M [used fuel (*l*)] × Q [exothermicity of kerosene (MJ/*l*)]
× K [CO_2 generation coefficient of kerosene (kg CO_2/MJ)],
where Q = 36.7 MJ/*l* and K = 0.0679 kg CO_2/MJ

Note 9: This equation is referred to "A guideline to calculate the amount of green-house-effect gases generated by industries", published by Ministry of Environment of Japan.

Since we can get the amount of fuel M from the fact that kerosene consumption for manufacturing 1ton of a heated asphalt compound is 9.7*l*, M = 9.7*l*/compound 1 ton.
Thus CO_2 generation becomes

$$\text{CO}_2 \text{ generation (kg CO}_2) = 9.7\ (l/\text{compound 1 ton}) \times 36.7\ (\text{MJ}/l) \times 0.0679\ (\text{kg CO}_2/\text{MJ}) = 24.1\ (\text{kg CO}_2/\text{compound 1 ton}) \quad (1)$$

On the other hand, to manufacture 1 ton of Katamaru-kun, 6.0*l* of kerosene is consumed, giving M = 6.0*l*/compound 1 ton. Then

$$\text{CO}_2 \text{ generation (kg CO}_2) = 6.0\ (l/\text{compound 1 ton}) \times 36.7\ (\text{MJ}/l) \times 0.0679\ (\text{kg CO}_2/\text{MJ}) = 14.9\ (\text{kg CO}_2/\text{compound 1 ton}) \quad (2)$$

Thus Eq.(1) – Eq.(2) gives the CO_2 reduction, 9.2kg CO_2/compound 1 ton, which is as high as 38.1% mitigation. Since annual production of Katamaru-kun is about 150ton, replacement from the previous heated compound to Katamaru-kun is lowering CO_2 generation by 9.2kg/ton x 150ton/year = 1,380kg CO_2/year at the time of manufacture.

5. WHERE AND HOW KATAMARU-KUN IS APPLIED

(1) Places for application

Katamaru-kun can be applied primarily to the following places:
①Regular repair in gas, water supply and drainage works
②Restoration of pavement accompanied by manholes replacement works (see Picture 3)
③Other small-scale pavements.

Picture 3: Application to a manhole:An example

(2) Methods of application

Methods of application are shown in Figure 2 for gas, water supply and drainage works.

6. CONCLUSION

A normal-temperature asphalt compound called "Katamaru-kun" has been developed the performance of which is superior or equal to a heated asphalt compound. Primary characters of Katamaru-kun can be itemized as:

①During application it is as soft as a conventional normal-temperature asphalt compound and easy to spread and flatten.

②About one hour after application it gets hardened, reveals strength and enables to be open to traffic.

③It shows excellent long-term storage properties, giving no performance mitigation.

Furthermore, it can be applied to small-scale pavement works, works far from a plant manufacturing a heated asphalt compound, and night works, for example, where supply of a heated asphalt compound is difficult.

Katamaru-kun has potential advantages to drastically mitigate CO_2 generation in the case of its increased application.

It is noted that this compound has been manufactured and sold by Toho Gas Techno Co., Ltd. since February 2004 under the trademark "Katamaru-kun mix", the improved version of which has been sold since February 2007 (see Picture 4).

Picture 4: Katamaru-kun mix. A package (30kg) contains primary and promoting agents, with a separate stiffener.

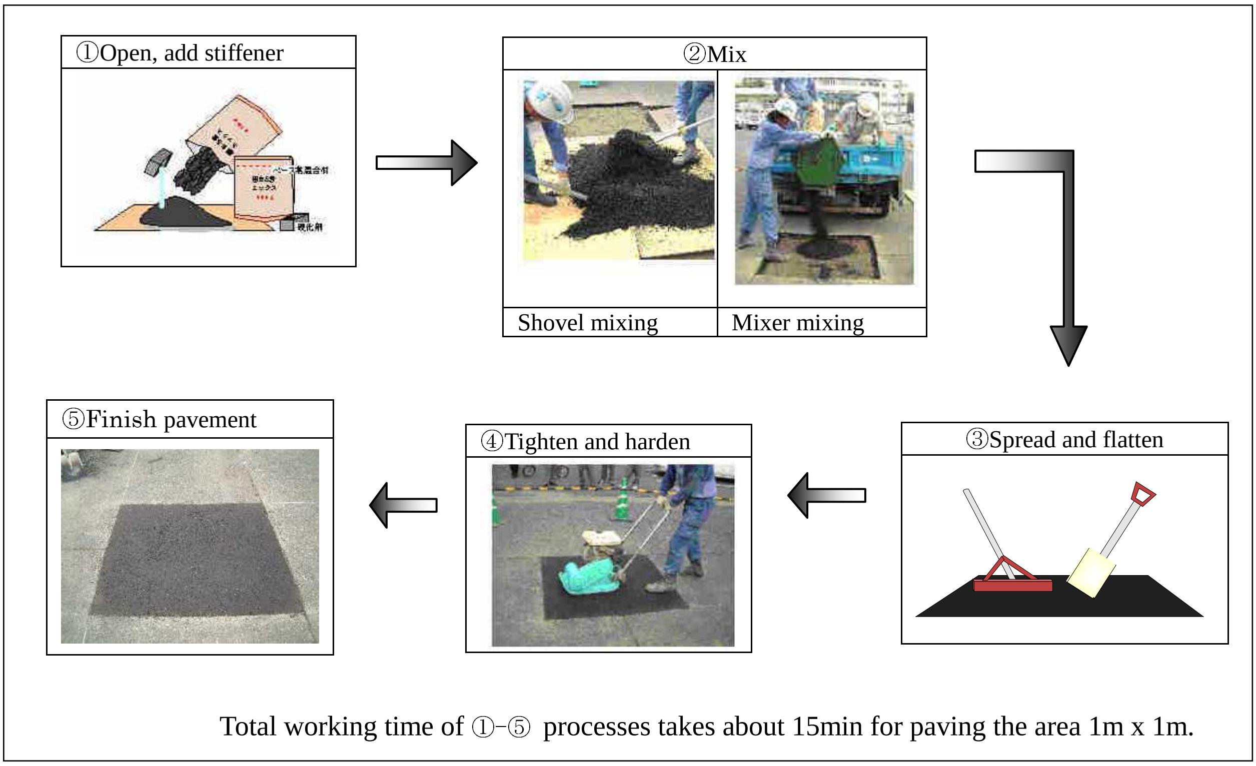


Figure 2: Method of application.

REFERENCES

Japan Road Association, 2005. *Asphalt Pavement Synopsis*, Japan.

Ministry of Environment, 2003. *A guideline to calculate the amount of green-house-effect gases generated by industries*, Japan