Mechanical Properties of an Inorganic Oil Absorbent Hardener for Asphalt Pavement of Heavy Traffic Roads

Yutaka ANDO[1], Masaru YAMADA[2]

(*Received September 30,1996*)

Synopsis: This paper describes the mechanical properties of an inorganic oil absorbent hardener which absorbs a part of asphalt in asphalt paving mixtures at high temperature. The inorganic oil absorbent hardener improves the plastic flow resistance of asphalt paving mixtures without lowering workability and crack-resistance.

Key Words:asphalt pavement,rutting,inorganic oil absorbent hardener,dynamic stability

1. Introduction

Cracking and rutting are two major forms of injury to asphalt pavements. Following the recent advances in pavement structure thickness designing, the incidence of asphalt pavement cracking has decreased. However, rutting of asphalt pavements has not yet been prevented satisfactorily. The incidence of rutting has become higher than ever due to a recent increase in heavy vehicles and has become a serious problem [1] .

Asphalt mixtures are designed so that asphalt pavements will not easily undergo plastic flow deformation when exposed to wheel loads. However, if vehicles with large wheel loads pass repeatedly over an asphalt road in summer, when the road temperature rises up to around 60℃, deformities caused by plastic flow accumulate, resulting in rutting. Plastic flow of asphalt mixtures is caused by softening of asphalt. If improved asphalt, which remains highly viscous even at high temperatures, is used for asphalt mixtures, the plastic flow of the mixtures will decrease. However, as compared to ordinary asphalt, improved asphalt usually requires higher temperatures and stricter temperature control when it is used for paving. Furthermore, an increase in the viscosity of asphalt reduces the workability of asphalt mixtures. the flexibility and the stress relaxation, possibly leading to an increased probability of cracking, due to a decrease in the maximum endurable tensile strain. Therefore, the viscosity of asphalt can not be elevated without limitations.

We speculate that softening of asphalt mixtures at high temperatures is attributable to the response of the temperature-sensitive light oil contained in asphalt. Based on this view, the authors have attempted to absorb light oil in asphalt using a highly oil absorbent agent, for the purpose of preventing plastic flow of asphalt mixtures without reducing the workability and resistance to cracking. Through these attempts, we have devised an effective method of reducing plastic flow deformation of asphalt mixtures. With this method, a state shown in Fig.1 is effected by the use of an inorganic oil absorbent hardener to elevate the shearing resistance of asphalt mixtures and reduce the plastic flow deformation, while minimizing changes in the workability and resistance to cracking, by the use of asphalt with an ordinary viscosity. In more detail, voids of aggregates are partially filled with an oil absorbent hardener, so that the surrounding asphalt can be absorbed by it. In this way, excessive asphalt(especially light oil, which is likely to flow), known to be responsible for a decrease in the shear resistance of asphalt mixtures, will decrease. Thus, the shear resistance in the thus processed area will increase. The remaining areas

[1]Consulting Engineer, Sumitomo Osaka Cement Co., Ltd.
[2]Professor, Department of Civil Engineering

of the aggregates, not filled with the oil absorbent hardener, are free of the effects of the hardener and the asphalt in these areas retains ordinary viscosity, normal flexibility and normal stress relaxation.

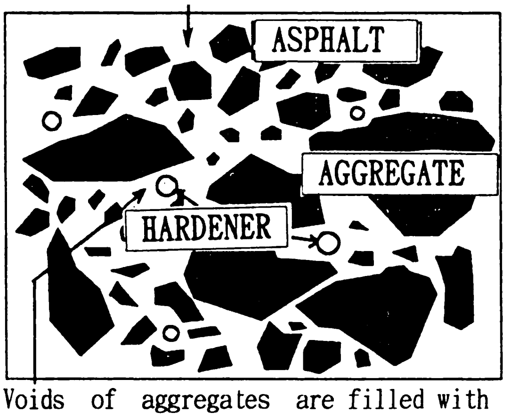
Plastic flow-resistant asphalt paving, using an oil absorbent hardener, can be characterized as follows:

1) Effects are manifested slowly ; no influence is placed on the properties of the asphalt mixture during its manufacture and spreading on roads ; temperatures need not be elevated for its use; and the asphalt mixture can be produced and used as simply as the ordinary asphalt mixture.
2) If the temperature remains elevated to around 60℃, a level likely to cause rutting, the oil absorbent hardener absorbs excessive asphalt, especially the light oil contained in asphalt [2] .
3) The resistance of the asphalt mixture against plastic flow is elevated by the addition of small amounts of an oil absorbent hardener, while an adequate percentage of the asphalt mixture remains free of the influence of the hardener and retains a high resistance against cracking.

This method of preventing plastic flow of asphalt mixtures, using an oil absorbent hardener, has been used in heavy traffic roads in many districts, especially in Osaka Prefecture and has shown effectiveness comparable to the use of resin-containing improved asphalt [3] . To date, this technique has been used for a total road area of about 7 million m² in Japan.

This paper will report on the effects of the oil absorbent hardener on the mechanical properties of heated asphalt mixture (especially the plastic flow and cracking resistance, as determined indoors by a wheel tracking test and a static bending test) with the oil absorbent hardener to improve plastic flow resistance.

The areas of the aggregates, not filled with the oil absorbent hardener, are free of the effects of the hardener.



Voids of aggregates are filled with the oil absorbent hardener, so that excessive asphalt which is known to be responsible for a decrease in the shear resistance of asphalt mixtures can be absorbed by the hardener. The shear resistance in the thus processed area will increase.

Fig.1 Effects of the oil absorbent hardener in the asphalt mixtures

2. Physical Properties of the Oil Absorbent Hardener

2.1 General physical properties

To achieve the effects mentioned above, an oil absorbent hardener, made of globular granules and assuming a polyporous form, was used. The polyporous form, i.e. the presence of many small pores, was adopted to allow gradual absorption of light oil (which is released from asphalt as the road temperature rises or as the road is heavily loaded with vehicles, causing plastic flow of asphalt mixtures), starting some time after mixing with asphalt (no absorption was recorded immediately after mixing), so that the workability of asphalt mixture may be unaffected.

Table1 shows the physical properties of the oil absorbent hardener, as determined by the standard test method stipulated for aggregates. The grain size of the oil absorbent hardener ranged between 0.3 and 5 mm. The hardener has a hardness comparable to general aggregates and has a high coefficient of water absorption.

Figs.2 and 3 show the distribution of pores in the oil absorbent hardener and river sand, respectively, as determined by a mercury porosimeter. The total pore volume of the oil absorbent hardener was about 10 times that of river sand. The arrangement of pores was more fine in the oil absorbent hardener than in river sand.

Table1 Physical properties of the oil absorbent hardener

Properties		Results	Method
Bulk specific gravity		2.225	JIS A 1109
Bulk specific gravity in saturated surface-dry		2.421	
Apparent specific gravity		2.759	
Water absorption(%)		8.7	JIS A 1110
Abration loss(%)		23.3	JIS A 1121
Stability(%)		1.7	JIS A 1122
Weight percent of passing sieves (%)	4.75mm	100.0	JIS A 1102
	2.36	72.5	
	1.18	34.0	
	0.6	3.5	
	0.3	0.3	

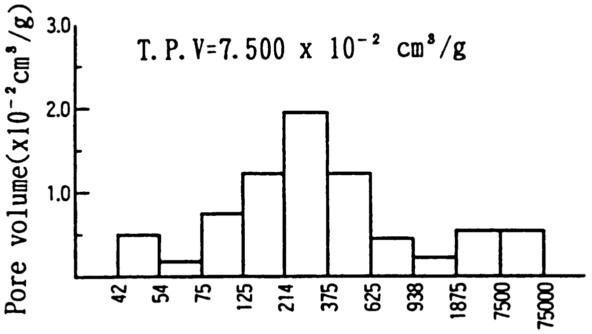


Fig.2 Pore distribution of the oil absorbent hardener

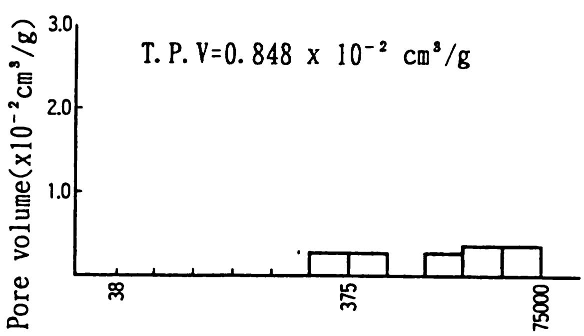


Fig.3 Pore distribution of rever sand

2.2 Coefficient of oil absorption of the hardener

An oil absorbent hardener, composed of particles with a size over 2.5mm, was mixed with the same amount (on a weight basis) of straight asphalt (60/80) at a temperature of 155℃. After cooling down to the room temperature, the mixture was kept at a temperature of 20, 40 or 60℃. After periods of time, the coefficient of asphalt absorption was measured. The mixture was again heated to 150℃, and the hardener was separated by sedimentation. According to the JIS method for testing the specific gravity and coefficient of water absorption of coarse aggregates (JIS A 1110), the asphalt on the surface of the hardener was wiped off with a benzene-containing cloth. The asphalt inside the hardener was then extracted, using a Soxhlet extractor. The coefficient of asphalt absorption was calculated using the following equation:

Coefficient of asphalt absorption (%) =

$$\frac{[(\text{pre-extraction weight of hardener}) - (\text{post-extraction weight of hardener})] \times 100}{(\text{post-extraction weight of hardener})}$$

Fig.4 shows the results of this measurement. The coefficient of asphalt absorption by the hardener became higher as the temperature, at which the mixture was kept, was elevated or as the mixture was kept for longer periods of time. The increase in the coefficient was greater at a temperature of 60℃ than at 20 or 40℃. At each temperature, the coefficient stabilized and reached an equilibrium after 14 days.

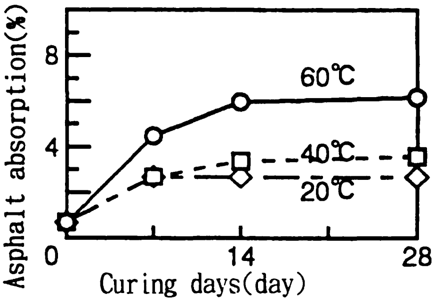


Fig.4 Coeffecient of asphalt absorption of the hardener

The coefficient of asphalt absorption was 0.7 % immediately after mixing. Assuming that the oil absorbent hardener is added to asphalt at a concentration of 6%, the amount of asphalt in voids of aggregates will decrease by about 0.04 % (= 6% x 0.07%). This amount of decrease is very small and unlikely to cause a decrease in the workability of asphalt paving. The coefficient of asphalt absorption after a 28-day exposure to a temperature of 60℃ was 6.2 %. Assuming that the oil absorbent hardener is added to asphalt mixtures at a concentration of 6 %, the amount of asphalt will decrease by 0.37 %. Thus, when asphalt mixtures containing this hardener are kept for long periods at high temperatures, the hardener is expected to absorb fairly large amounts of oil and thus contribute greatly to improving the plastic flow resistance of asphalt mixtures.

3. Optimal Hardener Addition Ratio

The optimal ratio of adding the oil absorbent hardener to asphalt mixtures was explored by a Marshall Stability test and a wheel tracking test, both of which were carried out according to the manual for pavement testing by Japan Road Association. Four asphalt mixtures were used for this study. Three of them were surface course materials, i.e. M-13 dense-graded asphalt concrete (OAC = 5.6%), M-20 dense-graded asphalt concrete(OAC = 5.3%) and fine-graded asphalt concrete (OAC = 6.8%). The other was a binder course material, i.e. coarse-graded asphalt concrete (OAC = 4.8%). Crushed hard stones and screenings, produced in Takatsuki, Osaka Prefecture, were used as aggregates. The type of asphalt used was straight asphalt (60/80). The optimum amount of asphalt, known for each asphalt mixture, was added to individual mixtures. The oil absorbent hardener was added to the asphalt mixtures in percentages between 0 and 10%.

3.1 Marshall stability test

Fig.5 shows the hardener addition ratio and the Marshall stability level of surface concrete materials containing the optimum asphalt content (OAC). The bulk specific gravity was used as the specific gravity of the hardener, when calculating the theoretical maximum density.

As can be seen from Fig.5, an increase in the hardener addition ratio resulted in a decrease in the density, an increase in the percentage of air voids and a decrease in the degree of saturation. When the hardener addition ratio was 10% or less, the percentage of air voids in each mixture was within the range recommended by the manual for asphlt pavement. The degree of saturation, however, tended to depart from the recommended range. The minimum addition ratio, causing the degree of saturation to digress from the recommended range, became smaller as the OAC decreased. When the hardener was added, the addition ratio satisfying the recommended range of the degree of saturation was 6 % at maximum in the case of M-20 dense-graded asphalt concrete and 8% at maximum in the case of M-13 dense-graded asphalt concrete.

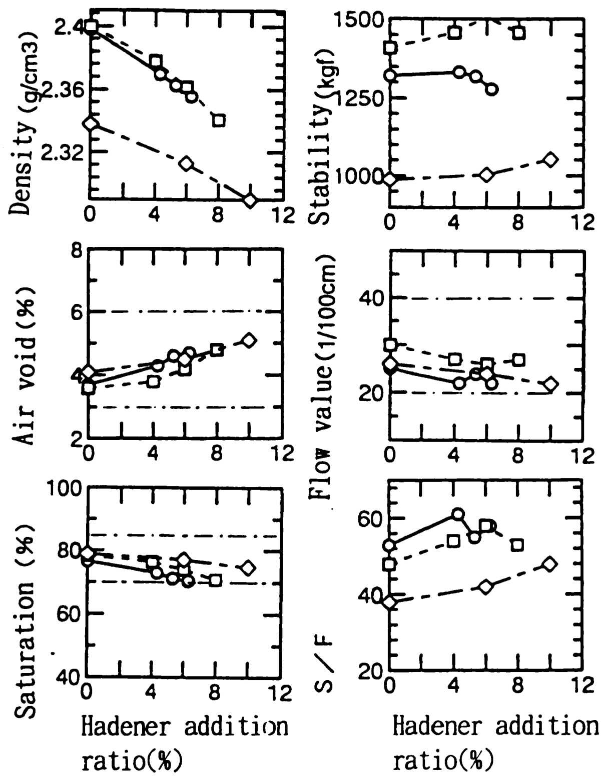
As the hardener addition ratio increased, the flow value (F) decreased, but the stability (S) remained almost unchanged, resulting in a tendency for S/F(an indicator of plastic flow resistance [4]) to increase. In the case of relatively asphalt-poor M-20 dense-graded asphalt concrete, the flow value tended to become smaller than the lower limit of the recommended range when the hardener addition ratio was over 8%.

In the case of coarse-graded asphalt concrete, each parameter of the Marshall stability test was within the recommended range when the addition ratio was 6 % or less.

3.2 Wheel tracking test

The results of the wheel tracing test of coarse-graded and M-20 dense-graded asphalt concrete, before and after a 2-week exposure to 60℃, are shown in Figs.6 and 7, respectively. The results of the same test of M-13 dense-graded and fine-graded asphalt concrete after a 2-week exposure to 60℃ are shown in Figs.8 and 9, respectively. In these figures, the amounts of asphalt indicate the percentage of asphalt's weight in the total weight of the mixture after the addition of the hardener.

When the dynamic stability before exposure to 60℃ was compared between the hardener-containing asphalt mixture and the hardener-free asphalt mixture, both of which contained the same amount of asphalt, the difference in the dynamic stability was small, and no evident effects of hardener addition were visible (Fig.6 and 7). The dynamic stability was dependent on the amount of asphalt contained. The stability increased linearly as the asphalt content decreased. The gradient of this change differed among different types of asphalt mixture. It was -500 passes/mm•%(asphalt) for the coarse-graded asphalt concrete and -1,000 passes/mm•%(asphalt) for the M-20 dense-graded asphalt concrete.



□----□ M-13 Dense-graded asphalt concrete
○——○ M-20 Dense-graded asphalt concrete
◇—·—◇ Fine-graded asphalt concrete

Fig.5 Marshall stability test results

When kept at 60℃ for 2 weeks (Figs.6 through 9), even the hardener-free mixtures showed an increase in dynamic stability as compared to the stability before exposure to 60℃, but the increase in this parameter became greater as the hardener addition ratio increased. This indicates that the addition of the hardener improves the plastic flow resistance of asphalt mixtures. The pattern of the curve representing the relationship between the asphalt content and the dynamic stability varied depending on the hardener addition ratio. For each type of asphalt mixture, the regression curve after exposure to 60℃ was linear or inwardly convex (convex towards the point of origin), similar to the curve depicted before exposure to 60℃, when the hardener addition ratio was small. As the hardener addition ratio became higher, the pattern of the regression curve for these mixtures changed from inwardly convex into outwardly convex. That is, when the amount of asphalt contained was too small or excessive, the dynamic stability of asphalt mixtures increased only slightly follow-ing the addition of the hardener, while the increase in the dynamic stability follow-ing the addition of the hardener tended to become greater in asphalt mixtures with an appropriate content of asphalt (i.e. when the asphalt content was close to the OAC).

These results suggest that whether or not the addition of the hardener is highly effective can be estimated from the pattern of the curve representing the relation-ship between the amount of asphalt and the dynamic stability. The addition of the hardener resulted in a marked increase in the dynamic stability when the hardener addition ratio was near the level at which the regression curve was outwardly convex. When the hardener addition ratio was increased from this level,

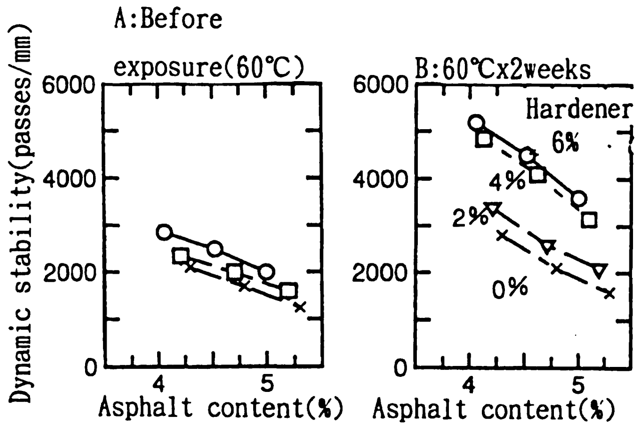


Fig.6 Wheel tracking test results of coarse-graded asphalt concrete

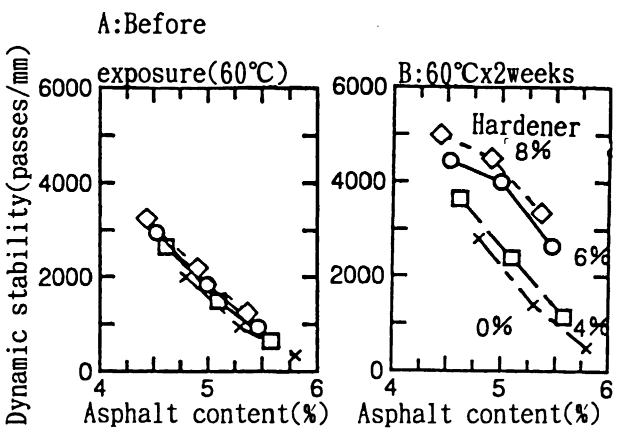


Fig.7 Wheel tracking test results of M-20 dense-graded asphalt concrete

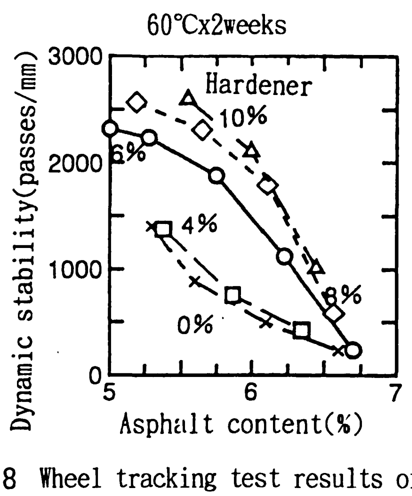


Fig.8 Wheel tracking test results of
M-13 dense-graded asphalt concrete

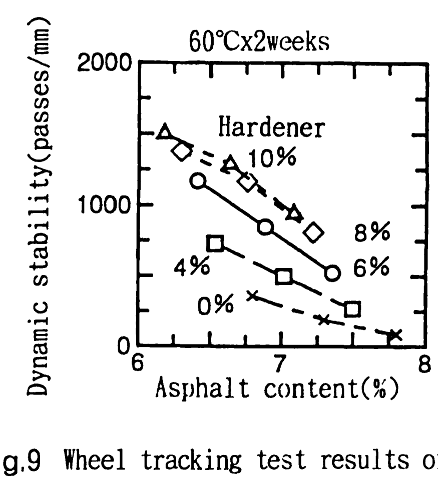


Fig.9 Wheel tracking test results of
fine-graded asphalt concrete

the dynamic stability was not markedly improved any more. This level of addition ratio was 4% in the case of coarse-graded asphalt concrete, 6% for M-20 and M-13 dense-graded asphalt concrete, and 8% for fine-graded asphalt concrete. At these levels of addition ratio, the parameters of the Marshall stability test satisfied the recommended ranges. These levels of addition ratio can be therefore viewed as optimum addition ratios.

4. Improvement in the Plastic Flow Resistance of Asphalt Mixtures Following the Addition of the Hardener

When the oil absorbent hardener was added to each asphalt mixture in a concent-ration of OAC ± 0.5% and the hardener-added mixtures were kept at 60℃ for 2 weeks, the dynamic stability of these mixtures was about twice or three times that of hardener-free mixtures which contained the same amount of asphalt.

Such an increase in dynamic stability seems to be attributable to a decrease in the amount of asphalt filling the voids of aggregates, primarily due to absorption of asphalt by the hardener. Since the percentage of asphalt absorbed by the hardener during the 2-week exposure to 60℃ was 6% (Fig.4), we deducted this percentage from the asphalt content to yield a modified asphalt content. Fig.10 shows the relation-ship between the modified asphalt content and the dynamic stability. For each type of asphalt mixture, the difference in dynamic stability at varying hardener addition ratios was considerably small. The dynamic stability was markedly elevated by the addition of the hardener. This difference in dynamic stability reflects the true effect of the hardener, probably attributable to selective absorption of the light oil by the hardener. At a given modified asphalt content, the dynamic stability did not change even when the hardener addition ratio was increased from the optimum addition ratio.

Regarding countermeasures against asphalt flow, the manual for asphalt pavement says that the

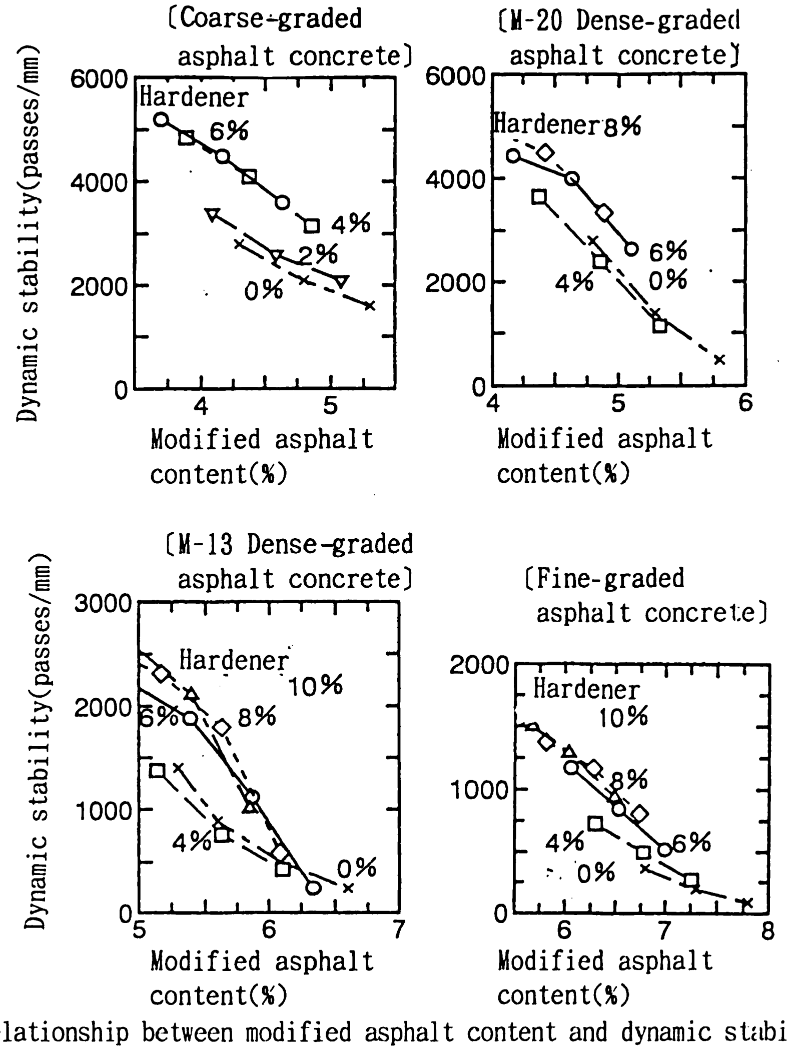


Fig.10 Relationship between modified asphalt content and dynamic stability(60℃x2weeks)

target DS (dynamic stability) is usually set over 1,500 passes/mm, taking into account the traffic, meteorological and economic conditions, but that it is often set over 3,000 passes/mm in places where heavy vehicles pass very frequently. When the asphalt content was about equal to the OAC and the hardener addition ratio was at the optimum level, a dynamic stability higher than the latter higher target(3,000 passes/mm) was recorded for two types of asphalt mixture (3,500 - 4,000 passes /mm by coarse-graded asphalt concrete, and 3,000 - 4,000 passes/mm for M-20 dense-graded asphalt concrete), while the dynamic stability of the M-13 dense-graded asphalt concrete (2,100 - 2,200 passes/mm) satisfied only the lower target (1,500 passes/mm). These results indicate that when measures are to be taken to prevent flow of asphalt in places where a dynamic stability over 3,000 passes/mm is required, it is desirable to use M-20 dense-graded asphalt concrete as a surface course material. The dynamic stability of fine-graded asphalt concrete was 1,000 - 1,200 passes/mm, which did not satisfy even the lower target.

Thus, the dynamic stability of asphalt mixtures varied depending on the type of asphalt mixture and the amount of asphalt contained. In the case of asphalt mixtures with a low OAC, high dynamic stability could be obtained even when the hardener addition ratio was low. In the case of asphalt mixtures with a high OAC, the dynamic stability did not satisfy the lower target (1,500 passes/mm) shown in the manual for flow resistant asphalt mixtures, even when the hardener addition ratio was high.

5. Static Bending Test of Asphalt Mixtures Containing the Hardener

A static bending test with two-point loading was carried out upon samples (30 x 30x 300 mm) to assess their cracking resistance. In this test, the failure strain and the bending strength were measured at temperatures between -20 and +20℃.

Bending characteristics were compared between various asphalt mixtures, including straight asphalt mixtures without additives, asphalt mixtures containing the oil absorbent hardener, and asphalt mixtures containing semi-blown asphalt or rubberized asphalt (binders often used to suppress the flow of asphalt mixtures). The asphalt mixture used in this test was M-20 dense-graded asphalt concrete (OAC = 5.2%). The hardener was added at a concentration of 6%. Fig.11 shows

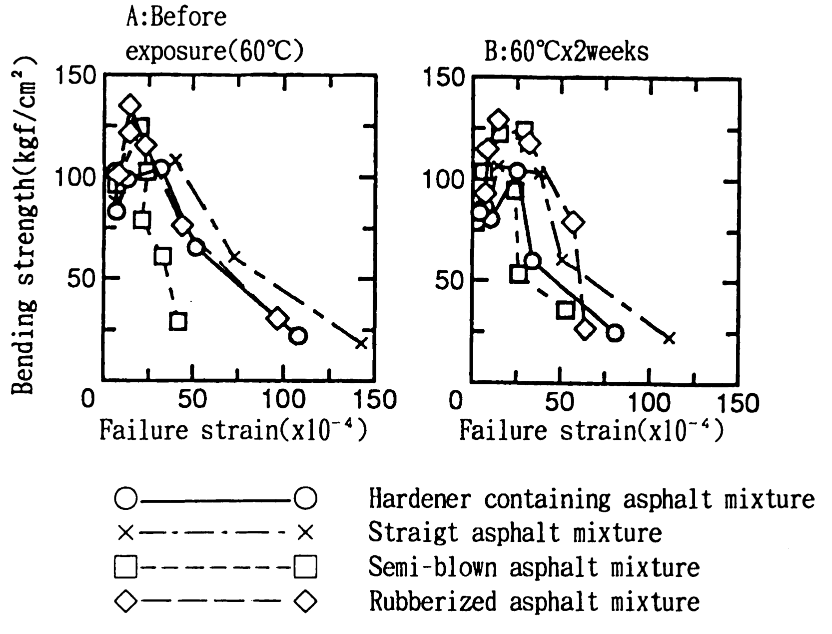


Fig.11 Static bending test results

the rupture line, representing the relationship between the bending strength and the failure strain, obtained from the test results from each test sample. High failure strain and bending strength throughout the asphalt mixture indicate that this mixture has an excellent resistance to cracking. Before exposure to 60℃, the semi-blown asphalt + rubberized asphalt mixture was superior to the hardener-free straight asphalt mixture in terms of the low-strain area (low temperature area). In terms of the high-strain area (normal temperature area), all asphalt mixtures with additives were inferior to the straight asphalt mixture without additives. Among others, the semi-blown asphalt mixture had a small failure strain for the normal temperature area. In terms of the rupture line, the following relationship was observed: straight asphalt › rubberized asphalt = oil absorbent hardener > semi-blown asphalt.

When the samples were kept at 60℃ for 2 weeks, the failure strain at normal temperature decreased, and this parameter of each asphalt mixture with additives tended to become closer to that of the semi-blown asphalt mixture. The rupture line of samples kept at 60℃ for 2 weeks showed the following relationship: straight asphalt > rubberized asphalt > oil absorbent hardener = semi-blown asphalt.

As shown in Fig.11, the rupture line of asphalt mixtures with the hardener was comparable to that of the semi-blown asphalt mixture and was not markedly superior to any of the other three mixtures in terms of cracking resistance. Therefore, the bearing capacity of the base and lower layers needs to be ensured not only when semi-blown asphalt mixtures are used but also when hardener-containing asphalt mixtures are used.

6. Conclusion

The authors have developed an inorganic oil absorbent hardener which manifests an oil-absorbing action in asphalt mixtures and elevates the plastic flow resistance of the mixtures when the temperature of asphalt-paved roads rise to around 60℃. The properties and major effects of this hardener can be summarized as follows:

1) The hardener assumes a polyporous form, made of granules with a diameter between 0.3 and 5 mm. It has a smaller specific gravity, a higher coefficient of water absorption and a similar hardness, as compared to ordinary aggregates.
2) The hardener absorbs asphalt little immediately after it is mixed with asphalt. If the mixture is then kept at high temperatures (about 60℃), the hardener absorbs about 6% of asphalt in the mixture at maximum.
3) The optimum hardener addition ratio, which reliably produces efficient improvement of the dynamic stability of asphalt mixtures, is 4% for coarse-graded asphalt concrete and 6% for M-20 and M-13 dense-graded asphalt concrete.
4) It is difficult to make fine-graded asphalt concrete resistant to flow by using the oil absorbent hardener.
5) The dynamic stability of asphalt mixtures containing the optimum ratio of the hardener was twice or three times that of hardener-free asphalt mixtures when the asphalt content was the same.
6) The cracking resistance of hardener-containing asphalt mixtures, as determined by the static bending test, was not satisfactorily high. It seems necessary to study this feature in more detail and to make appropriate modifications in designing the composition and structure of asphalt mixtures.

References

1. Iijima N, et al.:A round table talk on the current status and future perspectives of paving technology. Asphalt, Vol. 36, No.178, p1-25, January 1994.

2. Ando Y, Kubo H:The composition of asphalt absorbed by an inorganic oil absorbent hardener. Proceedings of 16th Japan Road Congress, p441 -442 , October 1985 in Japanese.
3. Mukumoto H, Ando Y, Furukubo K:Testing oil absorbent hardener-containing anti-flow pavement in actual roads. Proceedings of 19th Japan Road Congress, p380-381, October 1991 in Japanese.
4. Matsuno S, Tsukinari M, Sanada T: A test of the fluidity of asphalt paving mixtures. Proceedings of 9th Japan Road Congress, p151-152, October 1969 in Japanese.