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A Proposal for the Application of Reinforcement Sheeting to Ensure Effective Use of Reclaimed Asphalt Pavement

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The aim of this research was to develop an improved recycled asphalt pavement by using reinforcement sheeting to decrease the shortcomings of reclaimed asphalt pavement (RAP), and take advantage of its merits. Evaluation tests showed that the use of reinforcement sheeting in combination with recycled asphalt mixture resulted in a paving material that significantly outperforms virgin asphalt mixture in rutting resistance, crack resistance and serviceability. Concern for the state of the environment has grown considerably in recent years throughout the world. Road construction is no exception to this. This report was submitted in the hope that the proposals it contains would contribute to further promotion and expansion of effective use of recycled asphalt mixture.

Key Words : *renewable material, recycled asphalt mixture, reclaimed asphalt pavement, reinforcement sheeting, environmental preservation*

1. INTRODUCTION

We live now in an age of extensive road maintenance and repair, resulting in a rapid increase in reclaimed asphalt pavement (RAP). While most RAP is currently reused in a limited way as recycled asphalt mixture, one would be hard pushed to say that RAP is currently being used in the most effective way.

While existing research has shown that RAP is superior to virgin asphalt mixture where rutting, raveling and delamination resistance is concerned, the most common method employed up to now to counter RAP's lower serviceability and crack resistance has been to add rejuvenating agents to binders to restore the penetrative properties of aged binder. However, the suitability and effectiveness of rejuvenating agents for the many binders used remains unconfirmed, and the risk that such agents may adversely affect recycled asphalt mixture's desirable attributes warrants reconsidering of the methods employed to reuse RAP.

The aim of this research was to look into the use of reinforcement sheeting to augment the shortcomings of RAP, and optimize its strengths. We sought to identify the type of sheeting most suited to the properties of recycled asphalt mixture, and performed a comprehensive evaluation of the effectiveness of reinforcement sheeting in improving the properties.

2. EVALUATION OF REINFORCEMENT SHEETING FOR ASPHALT MIXTURE

(1) Outline

Specimens combining an asphalt mixture with three different types of reinforcement sheeting were tested to determine and compare their serviceability and resistance to rutting and cracking, and the results were then considered to identify the type of sheeting offering the most promise when used with recycled asphalt mixture.

(2) Asphalt mixture and sheeting

The asphalt mixture utilized StAs60-80 asphalt mixture as identified in the Manual for Asphalt Pavement[1)] published by J.R.A. This is a dense graded virgin asphalt mixture with a maximum aggregate size of 13mm. Three types of reinforcement sheeting (A, B, and C) were used. These are the types most widely employed among those commercially available, but differ in both

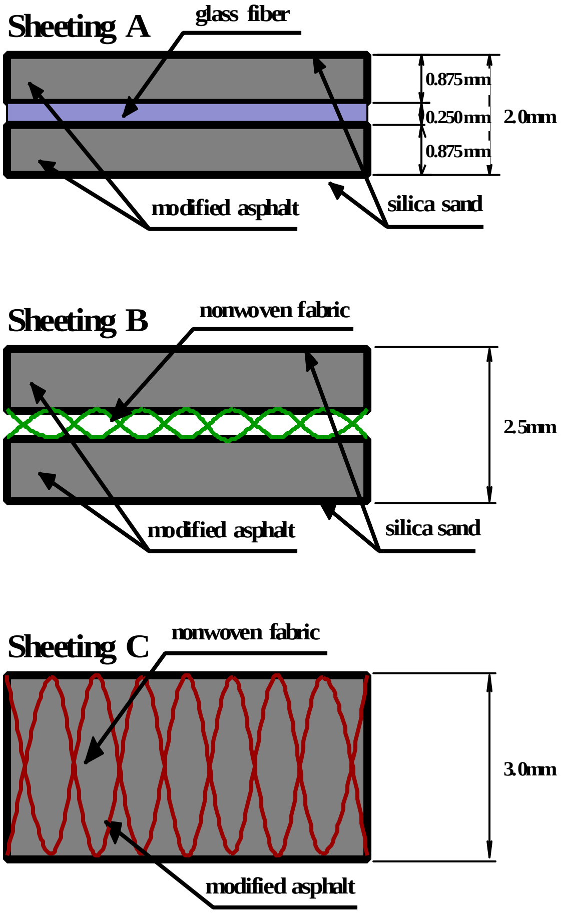

Figure 1 Compositions of sheeting

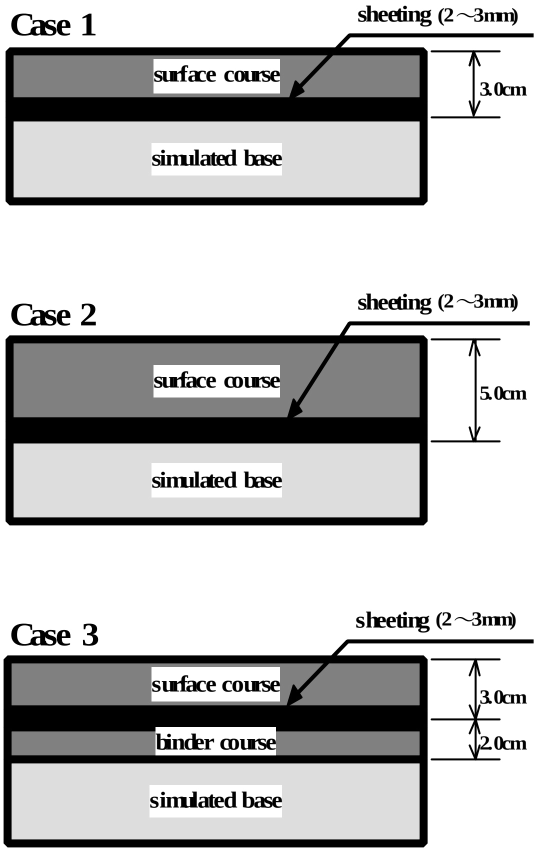

Figure 2 Specimen forms

Table 1 Names and compositions of test specimens

Test specimen name	Reinforcement sheeting
Type A	Sheeting A
Type B	Sheeting B
Type C	Sheeting C
Type D	none

properties and structure. **Fig. 1** shows the structure of the three types. Sheeting A[2), 3)], composed of a glass fiber fabric (polypropylene sheeting) coated on both sides with modified asphalt, is widely used to prevent reflective cracking in road maintenance and repair, and in new road construction. Its tensile strength is 68kN/m, and it has a high breaking strength and low breaking strain. Sheeting B and C, designed to prevent water seepage and cracking, are the most widely used sheeting incorporating nonwoven fabrics, and boast tensile strengths of 10-20kN/m. The fabric in Sheeting B is coated on both sides with modified asphalt, while that in Sheeting C is a nonwoven fabric impregnated throughout with modified asphalt. As shown in **Table 1**, we refer to the specimens as Types A, B, and C according to the types of sheeting they contain. A fourth test specimen containing no reinforcement sheeting, Type D, was also prepared.

(3) Evaluation of rutting resistance

Running tests adapted from wheel tracking tests[4)] were conducted to evaluate rutting resistance as well as the efficacy and desired position of the inserted reinforcement sheeting. Dynamic stability was calculated as in ordinary wheel tracking tests. Three different specimen forms (Cases 1, 2, and 3) were prepared for each specimen type, differing both in position of the inserted reinforcement sheeting (Sheeting A, B or C) and layer composition according to the major types of maintenance and repair works of actual roads, and tests conducted on each form. The layer structures of each specimen form are shown in **Fig. 2**. In Case 1, the reinforcement sheeting was laid over a simulated concrete base, after which a 3cm surface course of dense grade asphalt mixture was laid. In Case 2, a 5cm surface course of the same asphalt mixture was laid on top of the reinforcement sheeting, while in Case 3, a 2cm binder layer of dense grade asphalt mixture was first laid over the simulated base, followed by the reinforcement sheeting and then a 3cm surface course. As a follow-up evaluation of rutting resistance, designed to make a

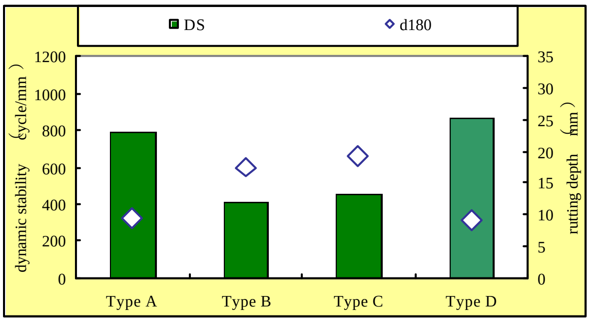

Figure 3 Case 1
DS, Rutting depth (180min)

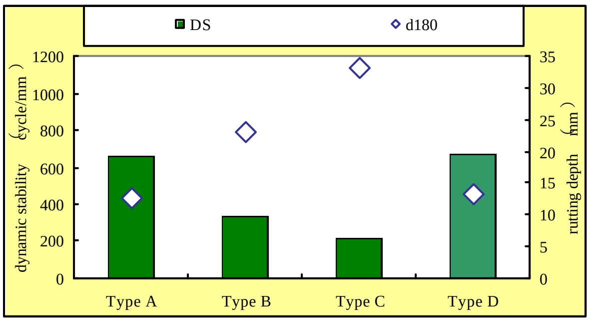

Figure 4 Case 2
DS, Rutting depth (180min)

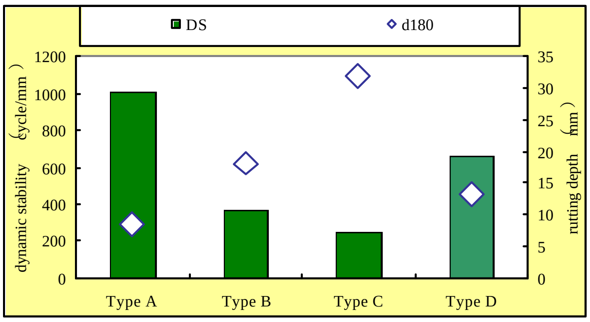

Figure 5 Case 3
DS, Rutting depth (180min)

clearer comparison of the effectiveness for plastic flow, we also compared rutting depth at the end of three-hour running tests. The dynamic stability and rutting depth after three hours (d_{180}) for all three specimen forms are shown in **Figs. 3**, **4** and **5**. In Cases 1 and 2, in which the sheeting base is a rigid concrete base, Type B and C specimens in particular displayed much reduced dynamic stability and increased rutting depth compared with the control specimen, Type D. We surmise that this is due to the influence of the adhesive properties of the sheeting at their interfaces, and of the extensibility of the sheeting themselves on the surface course. Likewise, with Type A the insertion of sheeting offers no advantage over Type D in Cases 1 and 2, suggesting that the positioning of the sheeting in these two cases is not suitable. However, Type A reinforcement sheeting sandwiched between two layers

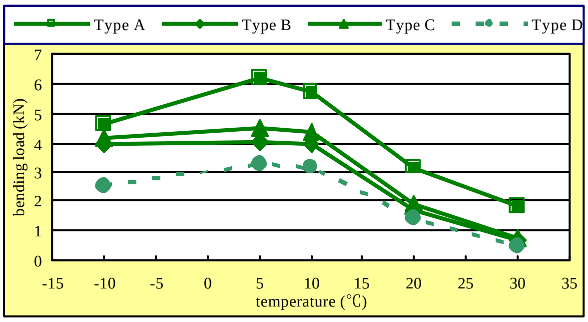

Figure 6 Bending load

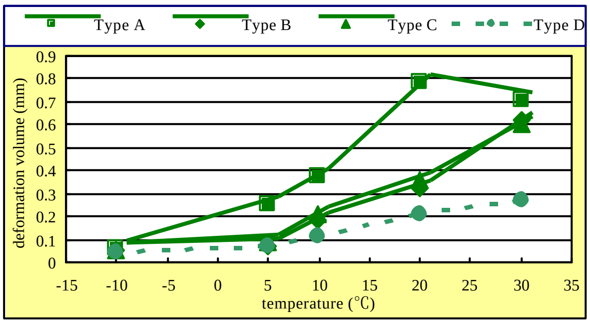

Figure 7 Deformation

of asphalt mixture, as in Case 3, yielded greater dynamic stability, and smaller d_{180} than Type D, suggesting that the insertion of Type A reinforcement sheeting has a positive effect on rutting resistance.

(4) Evaluation of crack resistance

The resistance of the reinforcement sheeting to cracking was evaluated through bending tests[4] conducted at -10°C, 5°C, 10°C, 20°C, and 30°C. The specimens used in these tests were 5cm×5cm×30cm pieces created by cutting up the specimens used in the wheel tracking tests (5cm×30cm×30cm). For the purpose of the tests, the reinforcement sheeting was inserted beneath the asphalt mixture layer. The relationship between temperature and bending load for Types A, B, C, and D is shown in **Fig. 6**, and the relationship between temperature and deformation at the breaking point is shown in **Fig. 7**. To help get a better grasp of the figures, a line has been drawn joining the test results for each specimen. At all tested temperatures, both bending load and deformability at the breaking point are higher when reinforcement sheeting has been inserted (Types A, B, C) than otherwise. Type A showed higher values for these parameters than Types B and C, and offered benefits in the high temperature range, where asphalt mixture has a natural disadvantage. Type A also showed almost twice the efficacy of Type D for bending load in the 5-10°C range, where the bending load is at a maximum. Overall, the tests showed that insertion of reinforcement sheeting is effective in boosting crack resistance, and that insertion of

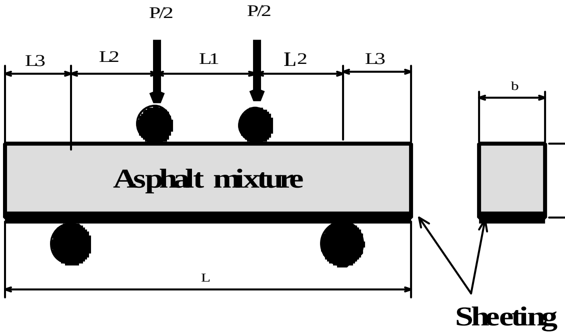

Figure 8 Fatigue test methodology

Table 2 Fatigue test conditions

test specimen dimensions (cm)	L=30、b=5、h=5
loading dimensions (cm)	L1=8、L2=8、L3=3
control method	loading control
load (kN)	1.59 (breaking load/2)
loading waveform	haver sine
frequency (Hz)	5
temperature (℃)	10、20
curing time	over 6 hours

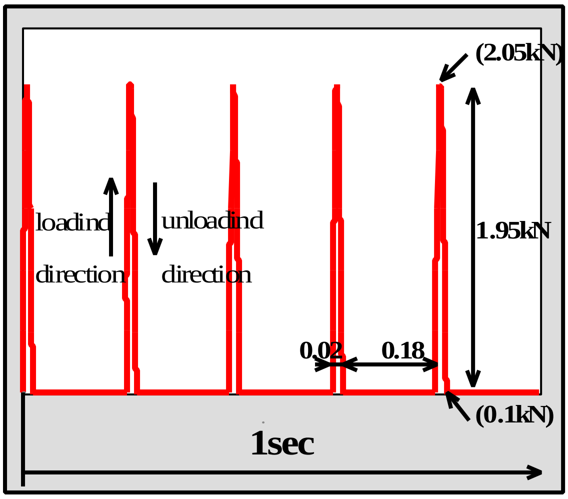

Figure 9 Waveform

Sheet A is particularly effective.

(5) Evaluation of fatigue resistance

As a way to assess the ability of reinforcement sheeting to enhance serviceability, the specimens were subjected to fatigue tests[5)]involving cyclic loading with a constant load. Since no established methodology is available for fatigue tests, the load was set at 50% of the bending load for the Type D control specimen at 10℃. The tests were conducted using the loading waveform at a 5Hz haver sine load with two-point loading, the

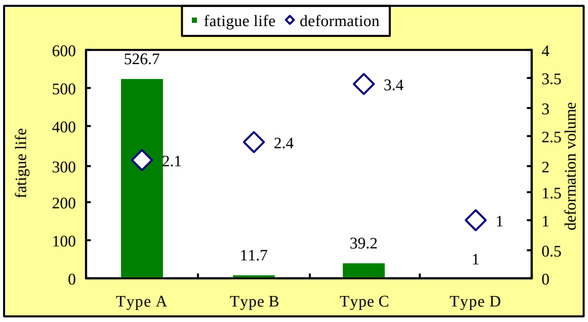

Figure 10 Fatigue life and deformation at 10℃

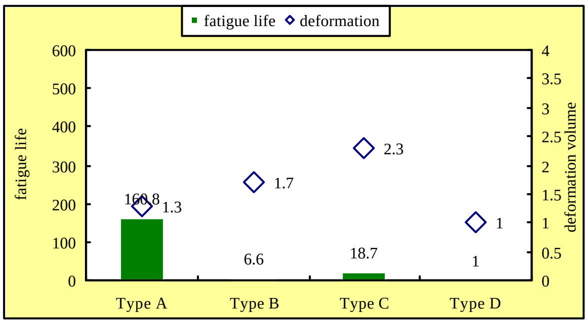

Figure 11 Fatigue life and deformation at 20℃

distance between the load points being one third of the total span. Test temperatures were 10℃ and 20℃. The methodology is illustrated in **Fig. 8**, while testing conditions are provided in **Table 2**, and details of the loading waveform in **Fig. 9**. As with the bending tests, the specimens used in these fatigue tests were 5cm×5cm×30cm pieces created by cutting up the specimens used in the wheel tracking tests, with reinforcement sheeting inserted beneath the asphalt mixture layer. Test results were subject to relative evaluation against the Type D control specimen, since the tests were conducted under special conditions. **Figs. 10** and **11** evaluate the fatigue life (number of cycles to failure) and deformation at 10℃ and 20℃, respectively, relative to Type D. For both temperatures, the insertion of the reinforcement sheeting increased the fatigue life. The benefit was particularly conspicuous for Type A, whose fatigue life was over 500 times that of the sheetless specimen. Overall, the fatigue tests showed that reinforcement sheeting is effective in increasing serviceability of the asphalt mixture, and that Type A is particularly effective.

(6) Overall evaluation

As an overall evaluation based on the above results, inserting Sheeting A is extremely effective. Type A specimen showed notably outstanding serviceability and crack resistance, and thus can be expected with much sureness to be effective when used with recycled asphalt mixture.

Table 3 Names and compositions of test specimens

test-piece name	RAP content	reinforcement sheeting (sheeting A)
V-N	none	none
V-A	none	inserted
R30-N	30%	none
R30-A	30%	inserted
R50-N	50%	none
R50-A	50%	inserted

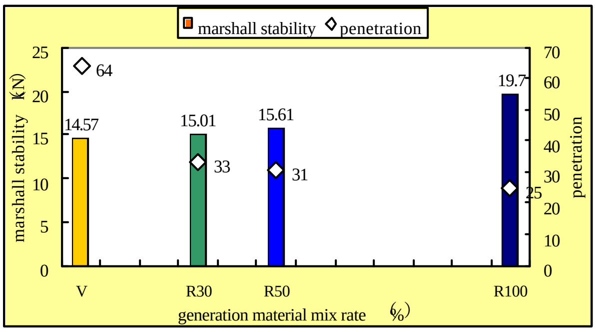

Figure 12 Marshall stability, Penetration

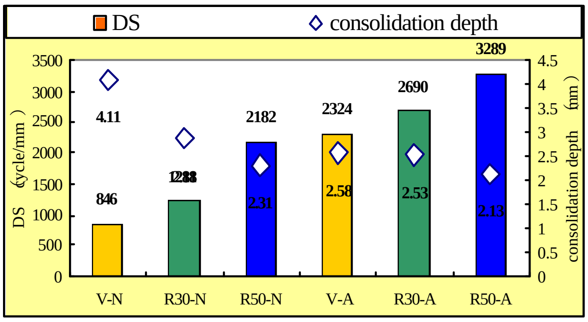

Figure 13 DS, Consolidation depth

3. EVALUATION OF THE EFFECTIVENESS OF REINFORCEMENT SHEETING WHEN USED WITH RECYCLED ASPHALT MIXTURE

(1) Outline

To evaluate the efficacy of reinforcement sheeting when used with recycled asphalt mixture, we conducted various tests using specimens of recycled asphalt mixture with Sheeting A[2),3)], which had proven to be so effective in the tests described above, in combination with two different recycled asphalt mixtures with a RAP content of 30% and 50% respectively.

(2) Test specimens

The specimens utilized the same StAs60-80 asphalt mixture with a maximum aggregate size of 13mm that was used in the above tests to compare virgin asphalt mixture and two kinds of RAP of different content proportions. To reproduce a similar degree of physical deterioration (penetration index) to that found in pavement actually in service, the RAP used in the recycled asphalt mixture was subjected to forced heat deterioration (7 days at 70°C), and then added to make up 30% and 50% mixtures respectively by weight. Sheeting A, the type that demonstrated outstanding effectiveness in the previously mentioned tests and boasts a high breaking strength and low breaking strain, was used for the asphalt reinforcement sheeting inserted beneath the asphalt mixture. Altogether six types of specimen were prepared for the various tests - virgin asphalt mixture with and without reinforcement sheeting (V-A and V-N respectively), and recycled asphalt mixtures containing RAP in 30% and 50% proportions, each with and without reinforcement sheeting (R30-A, R30-N, R50-A, R50-N). Test specimen names and details are provided in **Table 3**.

(3) Evaluation of the physical properties of the asphalt mixture

The stability of the asphalt mixtures (virgin asphalt and recycled) without sheeting was evaluated using the Marshall Stability Test[4)], and the penetration of the binder contained in the RAP assessed using the former Asphalt Properties Assessment Test described in the Plant Recycling Technology Guidelines[6)]. The same tests were also conducted on 100% RAP (R100) in order to confirm the similarity between RAP subjected to forced heat deterioration. Marshall stability and estimated penetration for the various mixes of RAP are shown in **Fig. 12**. Penetration decreases with an increase in RAP content, while Marshall stability shows a tendency to increase with RAP content, results that point to hardening due to deterioration of binder properties. It is known from previous studies that the penetration of naturally deteriorated binder tends to be between 25 to 35, and our tests confirmed that the penetration of the RAP we subjected to forced heat deterioration was of a similar level.

(4) Evaluation of rutting resistance

Wheel tracking tests[4)] were conducted to evaluate rutting resistance. Test methods and conditions conform to the Test Methods Handbook for Pavement. Dynamic stability and consolidation depth are shown in **Fig. 13**. Specimens containing RAP proved to possess greater dynamic stability, and smaller consolidation depth than respective virgin asphalt specimens in those both with and without sheeting inserted. Since this tendency becomes more conspicuous as the percentage of RAP content rises, we can infer that, as in the previously described tests, hardening due to deterioration of binder properties affects the rise in dynamic stability and the drop in consolidation depth. That the phenomenon was

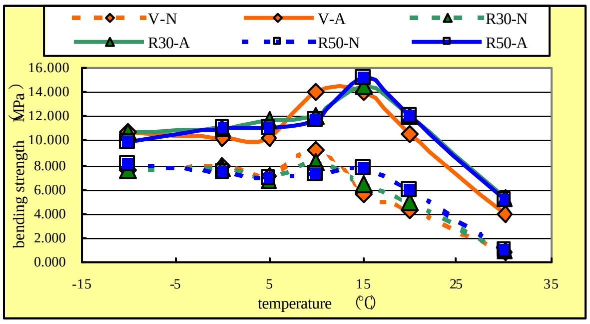

Figure 14 Bending strength

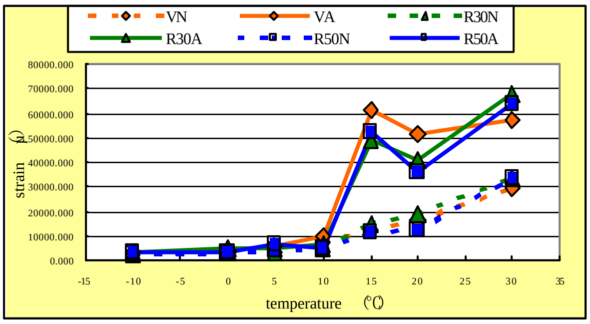

Figure 15 Strain

observed in specimens with sheeting inserted in both cases (V-A, R30-A, R50-A) confirms the effectiveness of the reinforcement sheeting used. Dynamic stability was greatest for R50-A, showing four times the dynamic stability and half the consolidation depth as the control specimen (V-N). Overall, our tests confirmed that RAP does indeed enhance rutting resistance, and that its performance can be further enhanced by the use of reinforcement sheeting.

(5) Evaluation of crack resistance

Bending tests[4] were conducted to evaluate crack resistance. The specimens used in these tests were 5cm×5cm×30cm pieces, as in the tests in **2.(4)**. Tests were conducted at -10°C, 0°C, 5°C, 10°C, 15°C, 20°C, and 30°C. The relationship between temperature and bending strength is shown in **Fig. 14**, and between temperature and bending strain in **Fig. 15**. To help better grasp the figures, a line has been drawn joining the test results for each specimen. For both sheetless specimens and those with sheeting inserted, the temperature at which maximum bending strength was achieved was 5°C higher for recycled asphalt mixture (15°C) than for virgin asphalt mixture (10°C). Except at a temperature of 10°C, where the bending strength for virgin asphalt mixture is maximized, the bending strength of the recycled asphalt mixture was higher than the virgin asphalt mixture. At 15°C, where the bending strength of the recycled asphalt mixture reached its peak, the value was 1.4 times greater than the virgin asphalt mixture. The recycled asphalt mixture also showed relatively lower strain with respect to bending strength. Considering that the tendency of recycled asphalt mixture's crack resistance was affected by the percentage of RAP content, we can assume these results were affected by properties of aged binders. Moreover the insertion of reinforcement sheeting enhanced the bending strength of recycled asphalt mixture, a property which has raised concern in the past, by 2,000 - 8,000Mpa, showing that the use of reinforcement sheeting is effective in improving crack resistance.

(6) Evaluation of serviceability

To evaluate serviceability, fatigue tests[5] were conducted for a relative evaluation of the fatigue cycle and the cumulative deformation. The tests were done at 10°C, using the same methodology and conditions as in **2.(6)**. The material constant (estimated resilient modulus) was calculated according to the following equation, using the tests' load and deformation measurements derived from the two-dimensional elastic analysis of deformation by Kuriyagawa[5] *et al.* The estimated resilient modulus was calculated for every five cycles.

$$E = \frac{p' \times L_1 \times (3L^2 - 4L_1^2)}{2h^3} \times \frac{F_v}{d} \qquad \text{(1a)}$$

Where,

E : elasticity modulus

P': P (load)/ 2b. (specimen width)

L : lower load point distance.

L_1: difference between lower and upper load point distances.

h : height of the test specimen.

d : measured displacement

F_v: coefficient of deflection

$$F_v = \frac{v}{d'} \qquad \text{(1b)}$$

Where v is two dimensional elastic analysis deformation, and d' is initial bending theoretical deformation

Fatigue life and cumulative deformation are shown in **Fig. 16**, and the relationship between number of loading and estimated resilient modulus in **Fig. 17**. The dots indicate the estimated resilient modulus at 100 cycles, the maximum and the breaking point. For sheetless specimens (V-N, R30-N, R50-N), fatigue life decreased as the percentage of RAP content increased, clearly showing a decrease in serviceability, which is a shortcoming of recycled asphalt mixture. For specimens with sheeting inserted (V-A, R30-A, R50-A), on the other hand, fatigue life increased significantly, and cumulative

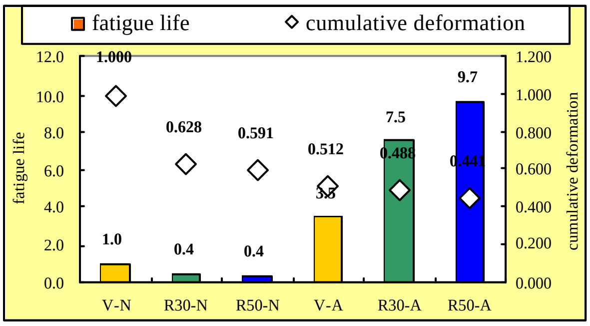

Figure 16 Fatigue life and cumulative deformation

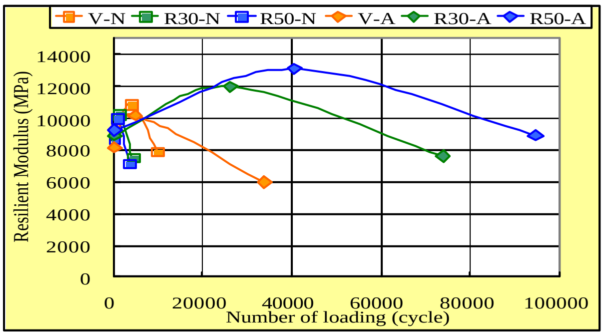

Figure 17 Resilient modulus

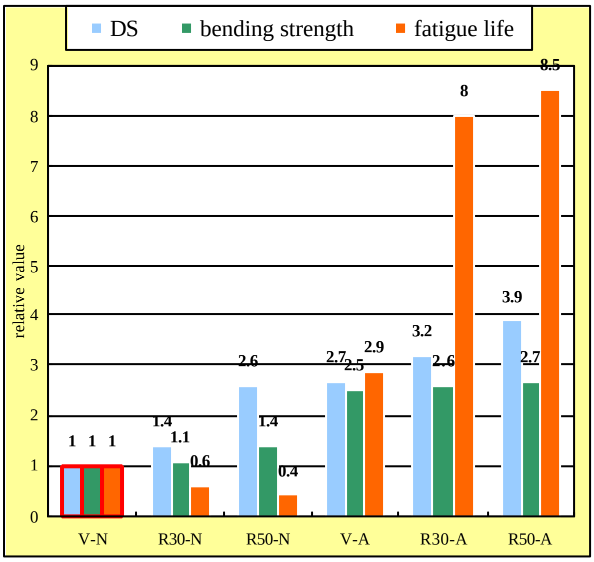

Figure 18 Overall evaluation

deformation dropped almost in proportion to the rise in the percentage of RAP content. Results for resilient modulus also point to the effectiveness of reinforcement sheeting on resistance to fatigue. It appears that insertion of reinforcement sheeting is instrumental in improving serviceability, the unreliability of which has been a major obstacle to the use of recycled asphalt mixture.

(7) Overall evaluation

The results of the above tests with respect to rutting, cracking and serviceability are summarized in **Fig. 18**.

Figure 19 Cutting bit

Figure 20 Milled pavement containing sheeting fragment

The tests demonstrated that both the addition of RAP and insertion of reinforcement sheeting are effective in enhancing resistance to rutting and cracking, and that reinforcement sheeting is able to radically improve serviceability. Reduced serviceability of pavement containing RAP has been a major stumbling block to the use of RAP, but with the insertion of the right type of reinforcement sheeting, it would appear that serviceability can become the major strength of recycled asphalt mixture.

Our results suggest that the use of reinforcement sheeting in recycled asphalt mixture offers hope for the construction of highly durable pavement and the expansion of the scope of applications for RAP, along with more possibilities for the effective use of RAP.

4. RECYCLING AND REUSE OF REINFORCEMENT SHEETING AND ASPHALT COMPOSITES

Consideration of the potential for recycling and reuse of asphalt pavement containing reinforcement sheeting is essential to any attempt to create a more ideal recyclable pavement. To research this, we prepared specimens incorporating Sheeting A, whose effectiveness was proven in **2.** and **3.** above, and, as a trial construction investigation, evaluated the ease with which the pavement could be milled and then sorted.

The influence of reinforcement sheeting on the milling of asphalt pavement containing such sheeting was tested out of concern that fragments of sheeting would adhere to and clog cutting bits, and otherwise adversely affect milling operations. **Fig. 19** shows the appearance of the cutting bits after milling, while **Fig. 20** shows a milled sheeting-asphalt composite. Our tests revealed that when an asphalt pavement containing Sheeting A is milled, the sheeting has no adverse effects such as adhesion of fragments to cutting bits and decrease in cutting speed. It was also confirmed that, using ordinary sorting techniques, it is possible to remove large pieces of sheeting and sort them fairly evenly. These results suggest that more concrete study is needed involving performance trials before RAP containing inserted reinforcement sheeting can be put to practical use as RAP.

5. CONCLUSIONS

There is a constantly growing demand in almost all industries for technology that contributes to the sustainable use of resources and protection of the natural environment, and in the field of road surfacing too, recycling technology is making steady advances, and is beginning to be applied in earnest. Our research focused on the use of reinforcement sheeting as a means of promoting the more effective use of RAP. The following is a summary of the conclusions we reached in each section.

1) From our tests on asphalt mixture specimens incorporating three different types of reinforcement sheeting, it became clear that Sheeting A in particular was effective in boosting resistance to rutting and cracking, and extending serviceability, suggesting that reinforcement sheeting could be used to improve performance of recycled asphalt mixture, and as such, open the road to new ways of putting recycled asphalt mixture to effective use.

2) The test results on the influence of reinforcement sheeting on recycled asphalt mixture showed that use of such sheeting could be very effective in resolving RAP's shortcomings. The performance of recycled asphalt mixture incorporating reinforcement sheeting surpassed that of virgin asphalt mixture by a large margin with respect to all of the properties tested.

3) Using specially prepared trial construction incorporating reinforcement sheeting, it was confirmed that ordinary milling techniques can be used for layer structures of asphalt pavement incorporating reinforcement sheeting.

Note that the tests described in this paper were conducted indoors, and there remain several issues that require further investigation. For the next stage, we hope to test the validity of our results to date by installing and investigating the performance of test sections in actual roads.

We should like to take this opportunity to express our heartfelt appreciation to Mr. Miysaka of Mitsui Chemicals, Inc. for his most generous cooperation in lending us his time and furnishing us with data.

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強化シートを用いた舗装発生材の有効利用に関する一提案

栗谷川裕造・加納陽輔・秋葉正一

本研究では，舗装発生材の短所を補い長所を活かす改善策として，強化シートを用いた工法に着目し，再生アスファルト混合物（以下，再生材）としての新たな有効利用方法を提案した．この結果，強化シートを適用することで流動抵抗性能，ひび割れ抵抗性能，供用性能において再生材が新材を大きく上回る性能が各工学的評価試験から確認された．近年，再生材が積極的に利用されている一方で,一般的に行われている添加剤を用いた再生方法に関しては各種のバインダーに対する適性や有効性等が未だ不明確である．以上のことを踏まえ，本提案による再生材の有効利用の促進および適用範囲の拡大を期待してこれを報告する．