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ABSTRACT

The proposed remover, which is made from Limonene and used in TSR method, is a transparent liquid and flows out or volatilizes easily if applied directly to sealed joints. Therefore, its effects, like swelling and softening, cannot be expected neither on vertical, horizontal nor oblique sealed joints within panels, sashes or glass. In order to overcome such shortcomings and engender required properties of removers, such as sagging resistance, wettability, dry rate, workability and removing task, the viscosity of the remover is improved through composition and mixing ratios, and swelling and softening of sealants are confirmed after being soaked in the improved remover. TSR method has taken shape through trials carried out on real buildings where the remover’s viscosity has been confirmed. These trials also allowed the evaluation of the cost for sealant renewal based on the used amount of the remover, the work efficiency and the selected procedure, and indicated that TSR method can decrease the life cycle cost and making it lower than the cost relative to the conventional method. This paper reports the procedure for improving the remover and the studies on its properties of swelling and softening in actual structures. The paper reports also the removal performance of sealants during the trials, as well as the calculation related to life cycle cost.

KEYWORDS

Sealant, Renewal, Sealant residuals, Gel, Remover, Life cycle cost.

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1 INTRODUCTION

An innovative sealing renewal method, named Thin Sealant Removal method (TSR method) have been developed. Contrary to conventional methods which cannot remove completely remaining thin layers of previous sealants that affect the water tightness reliability, this method can completely remove them. The companion paper (Part 1) concluded that Limonene made from oranges owns essential performance and is appropriate as a remover. However, because Limonene is a transparent liquid and flows out if applied directly to seal joints, its effect, like swelling and softening, can not be expected in a construction site. The purpose of this study is to improve the form of Limonene and provide it with required properties of a remover. This paper reports the improvement made on the composition and mixing ratio of Limonene in order to adapt a suitable viscosity. While the evaluation of softening effect of the improved remover by pulling test are reported in the companion paper (Part:1), herein life cycle cost of the TSR method based on trial installations is presented.

2 SUMMARY OF EXPERIMENT

2.1 Tested Materials

Some additives were mixed to Limonene to create gel-type and sol-type (paset-type) Limonene. The viscosity of gel-type and sol-type were intended to be applied to seal joints with a brush. The arranged Limonene was used in tests as a remover. Popular sealants were used for the test after curing them according to Japanese Industrial Standard (JIS) A5758 and A1439. The tested sealants are listed below.

1. Two-component silicone sealant (named SR-2)
2. Two-component poly isobutylene sealant (named IB-2)
3. Two-component poly modified silicone sealant (named MS-2)
4. Two-component poly polysulfide sealant (named PS-2)
5. Two-component poly urethane sealant (named PU-2)
6. One component silicone sealant (named SR-1)

2.2 Workability of Applying and Removing Test

In order to evaluate the workability of the remover containing Limonene by brush, and its effect on residuals of the previous sealant, the following procedure was applied.
1. Six removers which were arranged for gel-type and sol-type were produced by way of trials.
2. For test pieces, H shaped test pieces were prepared according to JIS A1439 as shown in Fig 1. After curing the test pieces according to the specified process in JIS A1439, the sealants were cut off leaving a thickness of 1 millimeter on the Aluminum alloy plate. SR-2 silicone sealant was chosen for the test because it showed the largest weight increase ratio after soaking it in Limonene (refer to the tests in Part:1). Fig 1 shows the sealant setup used in the test where the plane of the sealant was set vertically.
3. The trial remover was applied on the vertical plane of the sealant by a brush. An abundant weight of the remover was applied. Three grades were assigned to the applied weight and removing evaluated as good, not enough and bad.
4. After 3 hours, the remover was wiped off and the sealant was removed with a scraper as done in the tests in Part:1. When removing the sealant, a regular worker evaluated the workability according to the three-grades (good or not enough or bad) set in Part:1. The weight of the treated sealant was measured at five stages (A, B, C, D, E). Stage A was before applying the remover, stage B was just after applying the remover, stage C was after three-hour treatment, D was after wiping off the remover, and E was after removing residuals with a scraper. The maximum weight of the applied remover is evaluated as (B-A), the volatilized weight of the remover is evaluated as (C-B), the absorbed weight is evaluated as (D-A), Limonene content of SR-2 is evaluated as (D-A)/(E-A), the volatilized ratio is evaluated as (C-B)/(B-A), and the absorbed ratio is evaluated as (D-A)/(E-A).
2.3 Pulling Test

Fig 2 shows the form of the sealant test piece. Sealants with 2 millimeter thickness were cut into the form shaped as the No.3-dumbbell defined by JIS K 6251. The middle of the dumbbell shape was soaked in improved gel-type remover for a few hours and then pulled at the speed of 200mm/min. The maximum pulling strength was measured.

Figure 2. The form of the tested sealant for pulling test.

3 RESULTS AND DISCUSSION

3.1 Result of Workability of Applying and Removing Test

Table 1 shows the Result of the workability of the applying and removing test. Fig 3 shows the maximum weight of applied remover, volatilized ratio and absorbed ratio. For the conditions of Type A, the workability of applying the remover was very good, applied weight was large and slump was small. However, the workability of removing residuals was not enough because the volatilized ratio of the remover was large and the remover did not remain in the sealant for three hours. Moreover, Type A resulted in a dirty applying area as it dried due to a solid additive in type A. For Type B and Type C, it was difficult to apply them on the sealant with a brush and the applied weight was small. Therefore, the workability of applying the remover was bad. The workability of removing residuals was not enough. For Type D, workability of applying was good. However the slump was large, and it was easy to flow. Therefore, the workability of removing residuals was not sufficient. For Type E, it was hard to apply large weight onto the sealant. Therefore, the workability of applying remover was not sufficient. For Type F, it was easier to apply the remover onto the sealant with a brush compared to Type B and Type C, but still the workability of applying the remover was not satisfactory. However, the applied weight was appropriate. Slump and workability of removing residuals were good. As a general observation, it was easier to remove the sealant when the absorbed ratio (Limonene content of SR-2) increased. Our experimental results show that the optimum
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conditions which can achieve required workability of applying the remover and removing residuals are obtained when the gel viscosity is appropriately arranged to control slump. Based on the knowledge acquired in this test, the production and evaluation of the remover was done by way of trials. As a result, the appropriate composition and mixing ratios for the remover which is named TSR remover has been reached.

<table>
<thead>
<tr>
<th>Type</th>
<th>Form</th>
<th>Explanation</th>
<th>Workability Of Applying</th>
<th>Slump</th>
<th>Workability Of Removing</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Sol</td>
<td>This sample was similar to tooth paste.</td>
<td>○</td>
<td>○&lt;sup&gt;1&lt;/sup&gt;</td>
<td>△</td>
</tr>
<tr>
<td>B</td>
<td>Gel</td>
<td>This sample was gelatinous and tough (hard gel form).</td>
<td>×</td>
<td>×&lt;sup&gt;2&lt;/sup&gt;</td>
<td>△</td>
</tr>
<tr>
<td>C</td>
<td>Gel</td>
<td>This sample was gelatinous and very tough (hard gel form).</td>
<td>×</td>
<td>×&lt;sup&gt;2&lt;/sup&gt;</td>
<td>△</td>
</tr>
<tr>
<td>D</td>
<td>Gel</td>
<td>This sample was gelatinous grain whose diameter was about 1−3 millimeter (soft gel form).</td>
<td>○</td>
<td>△</td>
<td>△</td>
</tr>
<tr>
<td>E</td>
<td>Gel</td>
<td>This sample was similar to liquid (soft gel form).</td>
<td>△</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>F</td>
<td>Gel</td>
<td>This sample was gelatinous and soft (soft gel form).</td>
<td>△</td>
<td>○</td>
<td>○</td>
</tr>
</tbody>
</table>

※1 Slump was appropriate. But, it dried due to a solid additive in type A.
※2 It was impossible to evaluate slump because applying volume was small.

![Figure 5. Maximum weight of applied remover, volatilized ratio and absorbed ratio](image)

3.2 Result of Pulling Test

Fig 4 shows the relationship between the soaking time for TSR Remover and the maximum pulling strength which is measured by pulling a dumbbell test piece. The maximum pulling strength of major sealants decreases greatly after soaking for half an hour and continue decreasing gradually over another half an hour. Similar results were obtained when major sealants were soaked in Limonene (Part:1). Our experimental results showed that major sealants are softened by soaking them in the TSR remover.
4 TRIAL OF TSR METHOD

Pic 1 shows a trial process of the TSR method. Many trials were carried out on real buildings. The following results have obtained. TSR method can engender the required properties of swelling, softening and removing for major sealants except for PS-2 which contains lead as a hardening agent. Negative effects such as discoloring, swelling, or softening of the finishing materials around the joints are prevented by an appropriate cure. Given the work efficiency, the process of the TSR method have been defined (Fig 4). The Process of applying the Limonene remover is added to the conventional methods.

![Picture 1. Trial of TSR method](image-url)
Durability of sealants is worse in renewed buildings than in new buildings because of the remaining layer of the previous sealant that interferes between the adhering new sealant and the joint surfaces at renewal. In Japan, sealants maximum longevity on preventing water leaking is guaranteed for ten years in new buildings and seven years in renewed buildings. Because TSR method can remove all remaining thin layers and render joint surfaces conditions as those in new buildings, the maximum longevity on preventing water leaking for renewed sealants can be prolonged from seven years to ten years. Fig 5 shows the life cycle cost comparison between the TSR method and conventional method. The life cycle cost is calculated based on the used amount of the remover, the work efficiency and the selected procedure. The calculation is based on the following:
1. a ten-story apartment building.
2. a total floor area of 5,700 square meters.

Figure 5. Process of TSR method

5 CALCULATION OF LIFE CYCLE COST (LCC)
3. a floor height of 3.5 meters.
4. a total length of joints in the external wall of 15,000 meters.
5. a width of joints of 15 millimeters.
6. a depth of joints of 10 millimeters.
7. The Sealant used for Renewal is MS-2.
8. For the conventional method, the guaranteed maximum longevity on preventing water leaking is seven years.
9. For the TSR method, the guaranteed maximum longevity on preventing water leaking is ten years. Because the number of stages of the TSR method are more than the conventional method, in the beginning, the cost of renewal is higher. However, when looking at LCC over 20 years, the cost using the TSR method falls below the conventional method. This is because the TSR method can ensure performances equal to those of a sealant of a new building by removing the previous sealant completely. The LCC using the TSR method is less than conventional method which use grinder to remove previous sealant completely because the task to remove sealant and the work to cure are less in the TSR method.

![Figure 6. Life cycle cost of TSR method and conventional method (a ten-story apartment building)](image)

6 CONCLUSION

In order to solve problems in conventional sealant removal methods, the TSR remover have been developed and evaluated through experiments. The TSR remover was applied for trial and the effectiveness of the TSR method was evaluated. The LCC of the TSR method has fallen below the one of the conventional method because of the longevity of the implemented sealant and the higher watertight reliability of TSR method. To the best of the authors’ knowledge, at the time being this method is unsurpassed.
ACKNOWLEDGMENTS

The technical assistance of Sunstar Engineering Inc., Riken Industry.co.,Ltd and NIHON Building Engineering Inc. is acknowledged.

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