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Fatigue resistance of double sealant composed of polyisobutylene sealant adjacent to silicone sealant

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HIGHLIGHTS

- Fatigue of double sealant joints was evaluated to achieve longer service life.
- Section dimension factors are proposed for predicting the fatigue resistance.
- The movement of each sealant affects the fatigue resistance.
- A larger total depth adversely affects the fatigue resistance.

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ABSTRACT

With the aid of current sealant technologies, a double sealant comprising adjacent silicone and polyisobutylene sealants may be used to enhance the durability of buildings. The inner silicone sealant is quite durable owing to its intrinsic properties, and covering it with an outer polyisobutlylene sealant prevents fouling due to silicone sealant. This study indicates that the fatigue resistance of double sealant joints is strongly correlated with both the total sealant depth and the movement intervention of each sealant. Furthermore, the proposed section dimension factors enable the design of sealants with appropriate section sizes through better prediction of the fatigue resistance.

1. Introduction

Long life building technologies (i.e., the use of durable materials) are key to the development of zero emission buildings. Organic materials generally deteriorate and foul over time, and when they are exposed, it is more important to consider the application of long life technologies [1]. In fact, in countries that frequently experience earthquakes and typhoons, such as Japan, buildings are designed with gaps between facade components to allow for movement. Such gaps are filled with sealants, the joints of which are exposed to the environment. This has necessitated the development of more durable sealant joints.

Sealant joints are designed for air/water tightness, the reliability of which can be enhanced by a double sealant. We discuss the innovation in this study. In a double sealant joint, the inner sealant is a silicone sealant, which has the best performance among sealants used for buildings. The outer polyisobutylene sealant, which is generally used for buildings, is considered to have the second best performance.

The disadvantage of a silicone sealant, in spite of its very good material properties, has been pointed out. A silicone sealant continues to produce a hydrophobic agent for more than 25 years. The released hydrophobic agent is thought to be dimethyl silicone, which originates from the production and hardening processes. The production utilizes dimethyl silicone as a dilution agent for adjusting the silicone polymer viscosity, whereas the hardening process might result in the production of a poorly reacted silicone polymer with a low molecular weight, some of which might be converted to dimethyl silicone. This hydrophobic agent is often called silicone oil, which is sticky and causes dust and dirt to easily

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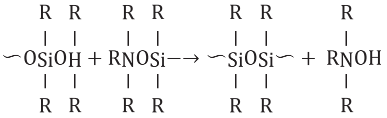
accumulate on the facade parts around the silicone joints [2]. This fouling problem caused by the exposure of silicone sealants restricts their use for glazing components in Japan [3] because they have the best adherence to glass, which is one of the materials with the poorest bonding properties. The double sealant joints discussed in this work prevents the fouling problem because the silicone sealant is used as the inner sealant and is protected by the outer polyisobutylene sealant. This covering enables the use of silicone sealant for every type of facade component and also ensures durability. Nonetheless, double sealant joints have the problem of low fatigue resistance. A conceptual illustration of the movement is shown in Fig. 1. The driving forces of the movement are temperature fluctuations, window pressure, and earthquake. It is obvious that suppression of the movements, especially compressive movements, may reduce the fatigue resistance. Fatigue and movement are important factors that affect the performance of sealant joints [4–6]. In the development of new building materials and solutions, it is very important to assess their durability, e.g., by carrying out accelerated climate ageing in the laboratory [7].

The purpose of this study was to investigate the fatigue resistance of double sealant joints. It has been pointed out that the fatigue resistance of a single sealant is affected by the sealant depth, with a greater depth producing higher inner stress [8,9]. However, to the best of the authors' knowledge, there has been no study on the fatigue resistance of double sealants. One method for the separate application of two sealants involves the use of a spacer or backup material between the sealants. However, poor workmanship in the application of the sealants and other unknown factors may result in reduction of the designed space between the sealants. An unsuitable backup material decreases the joint performance [6]. Issues of durability should thus be discussed by considering the worst situation in which there is no space between the two sealants in a double sealant joint. If the outer polyisobutylene sealant is broken by fatigue and there are cracks that pass through the outer sealant section, it may be impossible to prevent the occurrence of fouling due to hydrophobic agents produced by the inner silicone sealant. Further study is therefore required to investigate the fouling problem that occurs after failure of the polyisobutylene sealant.

2. Experimental

2.1. Materials

The tested sealants were the two-component silicone sealant (SR-2) and two-component polyisobutylene sealant (IB-2), which were produced by the same manufacture. There are different types of hardening processes for silicone sealants, and that of the tested silicone sealant is represented by the following:



$$\sim\mathrm{O}\underset{\underset{\mathrm{R}}{|}}{\overset{\overset{\mathrm{R}}{|}}{\mathrm{Si}}}\mathrm{O}\underset{\underset{\mathrm{R}}{|}}{\overset{\overset{\mathrm{R}}{|}}{\mathrm{H}}} + \mathrm{R}\underset{\underset{\mathrm{R}}{|}}{\overset{\overset{\mathrm{R}}{|}}{\mathrm{N}}}\mathrm{O}\underset{\underset{\mathrm{R}}{|}}{\overset{\overset{\mathrm{R}}{|}}{\mathrm{Si}}}- \longrightarrow \sim\underset{\underset{\mathrm{R}}{|}}{\overset{\overset{\mathrm{R}}{|}}{\mathrm{Si}}}\mathrm{O}\underset{\underset{\mathrm{R}}{|}}{\overset{\overset{\mathrm{R}}{|}}{\mathrm{Si}}}\sim + \mathrm{R}\underset{\underset{\mathrm{R}}{|}}{\overset{\overset{\mathrm{R}}{|}}{\mathrm{N}}}\mathrm{OH} \tag{1}$$

where R represent alkyl groups and ∼ represents silicone polymer units. The hardening process results in the production of hydroxylamine. Before the sealants were used to produce the samples, we applied a primer recommended by the manufacturer. All the materials used to produce the samples are quite popular building materials. The material properties of the tested sealants as presented by the manufacturer are given in Table 1. A 30% or 50% modulus indicates the stress when a sealant (height 50 mm, width 12 mm, depth 12 mm, and adhering to an aluminum alloy plate) is compressed or tensiled by 30% or 50% of the sealant width. The elongation is the ratio of the tensiled width (the elongated width minus the initial width) to the initial width (12 mm). It is apparent that SR-2 is harder and stretches better than IB-2.

2.2. Method

The fatigue test was conducted as illustrated in Fig. 2, in which the sample composition and dimensions are also shown. Three parameters of the fabricated samples were varied, namely, the sealant depth, sealant width, and adhesion boundary.

In an actual sealing work, a pre-applied sealant normally restricts the latter sealant, which also adheres well to the pre-applied sealant. Silicone sealant has poor adhesion, and other sealants generally do not adhere well to it when silicone sealant is used as a pre-applied sealant. It is therefore assumed in the general sealant technique that no other sealant type can adhere to silicone sealant. However, the tested IB-2 adheres to the tested SR-2. The adhesion boundary was therefore controlled by placing a polyethylene (PE) tape between the two sealants. The purpose of the tape was to prevent adhesion between the two sealants. In accordance with the specifications of the manufacturer, the two focus sealants were used on anodized aluminum plate components. SR-2 was first applied and the curing was carried out under two conditions. The first curing was done at 20 °C and 60% RH for seven days, and the second curing was done in an oven at 50 °C for seven days. After curing of the SR-2, IB-2 was applied. The SR-2 curing given above was then repeated for the complete system of SR-2 and IB-2. Subsequently, the fatigue load was applied to each sample at 20 °C and 60% RH. The fatigue loading was cyclic and each cycle consisted of sealant extension and shrinkage. The deformation length was 30% of the sealant width for both extension and shrinkage. The cyclic speed was varied from 0.08 Hz to 0.1 Hz. After every 2000 cycles of fatigue loading of each sample, the surfaces of the sealants were examined for cracks. It was obviously impossible to observe the boundary between the two sealants of the double sealant joint, and only the exposed sides were observed. When a crack was observed and its depth had increased to more than 2 mm, the number of fatigue load cycles was recorded and the test was terminated. The reason for setting the deformation of the expansion and shrinkage to 30% of the width was that the tested sealants were designed and produced to resist movements of up to 30% of their width.

The details of the fatigue tests of the double sealant samples are given in Table 2. Three samples of each sealant type were used, and each consisted of different combinations of SR-2 and IB-2. In addition to the double sealant joints, the single sealant joint was also tested for comparison of the fatigue resistances as shown in Table 3. All samples were fabricated by a skilled worker to minimize errors. The fabrication of the different samples lengthened the test duration to about 26 months. All the samples listed in Table 2 were not fabricated at the same time. The samples were gradually fabricated using experimental observations.

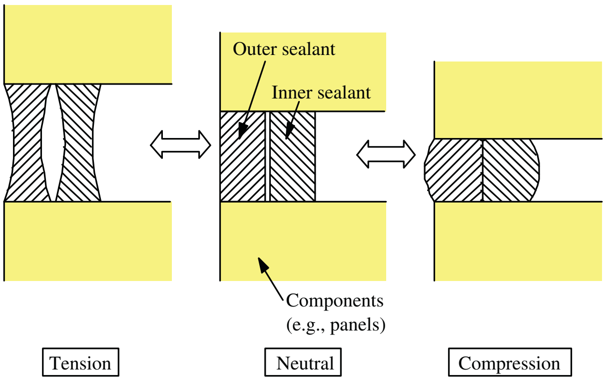


Fig. 1. Conceptual illustration of double sealant joint movements. Better durability is expected compared to a single sealant joint. However, the fatigue resistance may be poorer owing to the interaction between the sealant movements, especially under compressive loading.

3. Results and discussion

3.1. Single sealant samples

3.1.1. Observation of deformation and damaged parts

Examples of deformation in compression are shown in Fig. 3. Clear differences were observed under compressive deformation in terms of the dimension factor d/W of the single sealant samples where d represents the sealant depth, and W the width. When d/W was 0.3, the tested sealants buckled. The crack was observed close to the middle of the width, which is identified by the arrow in Fig. 3. This was due to the greatest elongation, which might produce the highest inner stress in the sealant section. For $d/W \neq 0.3$, the tested sealants exhibited two types of deformation in compression. In one deformation, both sides bulged outward, whereas one side bulged outward and the other pushed inward in the second deformation (i.e., the sealant assumed a bow shape as shown in Fig. 3). In both cases, there was cracking around the