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Sealant aging and its correlation with facade reflectance

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HIGHLIGHTS

- Fatigue resistance of sealant joints is evaluated by experiments and FEM.
- Surface temperature of facades is calculated as a function of solar reflectance.
- A change of emissivity hardly changes surface temperature of the facade.
- Inner stress is calculated to evaluate fatigue damage for sealant joints.
- Facade solar reflectance should be made as high as possible.

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ABSTRACT

A highly reflective facade may enhance the durability of sealant joints. This study investigates that reflective facades reduce thermal movement loading to sealant joints due to less fluctuations of surface temperature, and therefore lower fatigue damage of sealant joints. Cumulative fatigue damage was calculated to less than 1.6% in the first year. This damage considering only the first year is not that large, however, serious fatigue damage would ensue from the accumulated deterioration of sealants during a longer period, e.g. 10–25 years. It is therefore recommended that the facade solar reflectance should be made as high as possible.

1. Introduction

Sealant joints are one of the most important parts of building facade components because they are designed for air and water tightness, which affects the energy efficiency and service life of a building. Particularly in countries that experience frequent earthquakes, such as Japan, sealant joints are indispensable to absorbing earthquake movements. This is in addition to thermal and wind pressure movements. In the facades of high-rise buildings, the total length of the sealant joints can be as much as several tens of thousands of meters. Incidentally, every sealant joint is damaged over time by aging factors such as ultraviolet rays, heat, rain, and moisture. It is therefore necessary to renew sealant joints at intervals of, for example, 10–20 years. The improvement of sealant durability is thus an important subject from the point of view of reducing maintenance requirements. Synnefa et al. suggested that one of the advantages of using reflective building materials was their longer lifespan owing to less daily surface temperature fluctuations [1]. It can thus be expected that the durability of sealant joints would be improved by the consequent reduced thermal movement when a reflective facade is used. This is because the infrared rays of solar irradiation are reflected. The reflective facade reduces the outermost surface temperature and thus reduces the thermal expansion of the exterior walls. The reduced thermal expansion consequently improves the durability of the sealant

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joints on the exterior walls owing to the reduced fatigue load on the sealant joints.

For example, in the design of a structural sealant glazing (SSG), the tensile strength reduction should be estimated from the initial value (i.e., non-aged value) because of aging factors [2], which affect the recommended tensile strength reduction factor. Regarding ultraviolet rays, heat, and water, a tensile strength reduction factor of 0.75 is recommended. Furthermore, when fatigue is considered, a tensile strength reduction factor of 0.3 is recommended. The SSG design method is not discussed in this paper, but it assumes that fatigue significantly affects the durability. The design method can generally be considered as the factor method and can be used to predict the service life of buildings [3,4]. It depends on the location and weather, which are used as the factors.

One method for achieving a reflective facade is the use of highly reflective materials for opaque parts of the facade. Highly reflective materials reflect more infrared rays and allow for the use of the desirable colors of conventional materials [5–7]. The installation of highly reflective materials is thus becoming increasingly popular, especially in relatively warm countries such as Japan. In warmer areas, a higher temperature on the surface of building materials is undesirable because it causes the heat island phenomenon and increases cooling requirements. Highly reflective materials are the key to maintaining lower temperature. In such areas, roofs and pavements with highly reflective coatings are desirable from an energy-saving point of view because good energy-saving effects occur on horizontal parts where the intensities of solar radiation incident are higher [8]. It may also be useful to install highly reflective materials on walls to mitigate the heat island phenomenon and reduce cooling energy. Walls with highly reflective materials have, however, not been thoroughly studied. Previous studies mainly focused on their energy-saving benefit [9,10] and experimentally demonstrated the aged reflectance that resulted from several years of exposure [11–13]. Field collection of data on aged reflectance has also been undertaken (e.g., [14]). Sleiman et al. proposed an accelerated aging method for predicting the solar reflectance of roofing materials after three years of exposure in some cities in the United States, taking soil and dust accumulation into consideration [15,16]. To the best of the authors' knowledge, no study has been conducted to investigate the durability benefit of higher reflectance. In such a study, it would be important to consider the reflectance change due to aging factors. Normally, the reflectance changes with time due to deterioration and dust or dirt that sticks to the surface. It is quite difficult to predict the accumulation of the dust and dirt except in an experimental work, although it is important to take the aging effect into consideration in walls with highly reflective materials. The present study revealed the difficulty of predicting the change in reflectance of walls with highly reflective materials or conventional materials. There has been no similar study on the relationship between a reflective facade and sealant durability. Furthermore, reflective facades are expected to become more popular through the use of highly reflective material technology.

The purpose of this study was to investigate how the durability of sealant joints can be improved by the use of reflective facades. The sealant fatigue resistance was evaluated by experiment and simulation, and it was found that the sealant fatigue resistance was connected to the sealant inner stress. Simulation was then used to demonstrate the surface temperature fluctuation by changing the facade solar reflectance assuming Tokyo, Japan, as the location. It was found that the sealant fatigue resistance was a function of the facade reflectance, which also affected the inner stress amplitude of the sealant resulting from surface temperature fluctuations. In this work, we also present the cumulative fatigue damage, which was used to investigate the effect of the reflectance. Only relatively new sealant joints were considered in this study, and further work is necessary to elucidate the effect of the facade reflectance on sealant durability, especially with regards to the fatigue resistance, taking several aging factors into consideration. In the development of new building materials and solutions, it is of particular importance to assess their durability by, for example, employing accelerated climate aging in the laboratory [17]. A robustness assessment should also be undertaken [18].

2. Methodology

The work comprised three parts, which corresponded to three typical types of two-component sealants, namely, polyisobutylene, modified silicone, and polysulfide. First, the fatigue resistances of the sealants were evaluated by fatigue tests. The inner stresses were also evaluated by simulations using the finite element method. The sealant fatigue resistance was then expressed as a function of the sealant inner stress.

Second, the temperature fluctuations in a day were demonstrated by simulation, assuming typical facade specifications and a Tokyo, Japan, location. The thermal movement was then calculated and defined in terms of both the thermal expansion ratio for the focus facade material and the simulated surface temperature fluctuation.

Third, we simulated the temperature fluctuations over a year. Miner's law was then used to express the annual cumulative fatigue damage to investigate the effect of the solar reflectance on the fatigue resistance of the sealant.

2.1. Sealant fatigue resistance evaluation

2.1.1. Fatigue test

The fatigue test was conducted to evaluate the sealant fatigue resistance. Fig. 1 illustrates the fatigue test setup. Table 1 gives the dimensions of the tested samples of the sealant. The two-component polyisobutylene sealant was mainly tested, and it was assumed that the sealant type affected the fatigue resistance. The other two sealant types were therefore tested to investigate the effect of the sealant type on the fatigue resistance. The other two component type sealants were modified silicone and polysulfide. These three types of sealants are popular facade components. Regarding the polyisobutylene sample used for the fatigue test, the width was set to 12 mm; only the depth was the variable parameter, and was it varied as 12, 18, 24, and 36 mm. Regarding the modified silicone and polysulfide samples, the depth and width were both set to 12 mm. Three samples of each tested sealant were prepared.

According to the specifications of the manufacturer, the sealant was used on aluminum plate components. After curing at 20 °C and 60% RH for 7 days, each sealant was further cured in an oven at 50 °C for 7 days. Thereafter, the fatigue load was applied to each sample at 20 °C and 60% RH. The fatigue load was cyclic, and each cycle consisted of extension and shrinkage of the sealant. The deformation distance was 30% of the sealant width (i.e., 3.6 mm) for both the extension and shrinkage. The cyclic speed was controlled between 0.08 Hz and 0.1 Hz. After every 2000 cycles of the fatigue loading of each sealant sample, it was observed for the occurrence of cracking on its surface using the crack inspection direction shown in Fig. 1. When a crack was observed and its depth exceeded 2 mm, the number of fatigue load cycles was recorded and the fatigue test was terminated. The reason why the magnitude of the expansion and shrinkage deformation was set to 30% of width was that the tested sealants were designed and produced to resist movements of up to 30% of their width. The cyclic speed and crack failure criteria were in accordance with Japanese industrial standards [19]. The fatigue testing of all the samples took about eight months.