XV International Conference on Durability of Building Materials and Components
DBMC 2020, Barcelona
C. Serrat, J.R. Casas and V. Gibert (Eds)

Development of an Apparatus for Measuring the Load Acting on Joint Sealant when Movement Occurs

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Abstract. *The sealant that fills the joints of an exterior walls of building is subjected to weather loads, such as sunlight, ambient temperature, and rain, as well as a movement of the joints. As a result, the sealant gradually deteriorates under the combined deterioration factors of weathering and movement. Meanwhile, the results of a 15-year outdoor dynamic exposure test conducted in Japan using the methodology of ISO 11617 showed that the progress of damage varies greatly depending on the type of sealant and the stress relaxation rate. However, the mechanism of damage progression is unclear. In the present study, we focused on the load when the sealant moves and developed a load-measuring apparatus as the first step in clarifying the relationship between the progress of damage and the load. The load was measured at −20, 23, and 40 °C for test specimens with different stress relaxation rates, and it was confirmed that the developed load-measuring apparatus was able to measure the load correctly. Furthermore, it was shown that it is difficult for the stress of the sealant with a high stress relaxation rate to relax over time at low temperature but easy at high temperature, and the load increases when switching from the compressed state to the extended state.*

Keywords: *Joint Sealant, Load Measuring Apparatus, Joint Movement, Deterioration, Durability.*

1 Introduction

The sealant used for a joint of an exterior wall is affected by various environmental factors, such as ultraviolet rays, the air temperature, and rain, and is gradually degraded by movement of the joint. In Japan, in the 15 years since 1992, dynamic outdoor exposure tests were carried out at three locations having warm, subtropical, and cold climates using a variable sealant as defined by ISO 2014: 11617. It was found that most sealants deteriorated remarkably at the subtropical location where irradiation by ultraviolet rays was strong. However, for some sealants (having a high stress relaxation rate), the damage depth (Df value) near the adherend was more remarkable at the warm and cold locations than at the subtropical location as shown in Fig. 1. It was believed that this was due to the load that the sealant received when movement occurred.

However, few studies have clarified the damage to sealants in terms of the load they are subjected to during service life. Further, commercially available accelerated testing machines are either accelerated weathering or fatigue testing machines, most studies have been limited to either of them. In the case of a material, such as a sealant, in which deterioration progresses due to the combined action of the weathering and the movement, it is desirable to verify the durability by an acceleration test in which the weathering and the movement are simultaneously loaded.

In this study, as a first step to explain the mechanism by which deterioration is more intense in cold regions, we aim to develop an apparatus that measures the load applied to a sealant when both the weathering and the movement are combined. We fabricated prototype sealant with different stress relaxation rates and verified whether the load acting on the prototype sealant can be measured properly with a load-measuring apparatus.

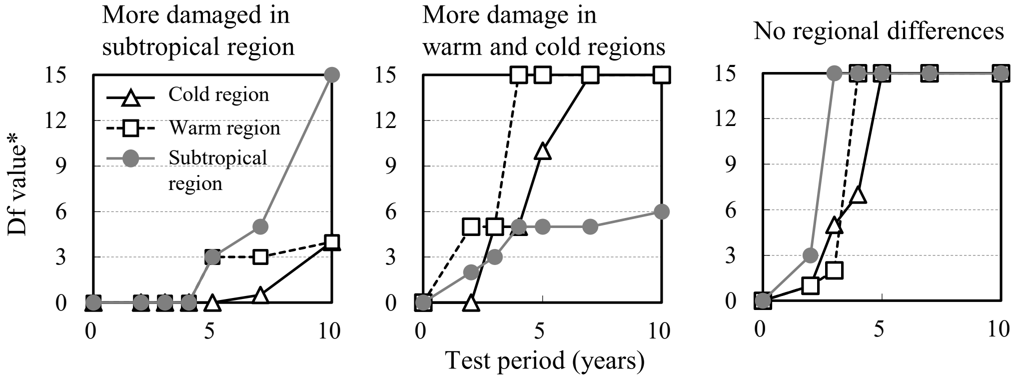

Figure 1. Example results of an outdoor dynamic exposure test.

2 Development of a Load-Measuring Apparatus

2.1 Load-Measuring Apparatus

To measure the load acting on the sealant when movement occurs, we developed a load-measuring apparatus as shown in Fig. 2. The ISO-type specimen shown in the figure is fixed to the load-measuring apparatus using a fixing jig. The portion of the specimen on the handle side is connected to a beam-type load cell, and the ball screw under the specimen portion is connected to the handle. When the handle is manually rotated, the specimen portion on the handle side moves horizontally, the sealant can be put into a compression or extension state, and the load generated in the sealant at that time can be measured by the load cell. A guide prevents displacement in the shear direction being applied to the specimen itself when movement is applied to the specimen. The dynamic outdoor exposure tests described above were carried out under various temperature conditions, and the temperature around the specimen could change. However, because the load cell is highly sensitive to temperature, the load cell is installed slightly away from the specimen so as not to be affected by temperature.

2.2 Prototype Sealant and its Stress Relaxation Ratio

As described above, sealants with high stress relaxation rates in the dynamic outdoor exposure test degraded greatly in a cold region. Two prototype sealants with different stress relaxation rates were therefore fabricated for testing in the present study.

The prototype sealants were two-component modified silicone sealants with different mixing ratios of the base material and curing agent. The sealants were intended to have almost the same moduli after standard curing but different stress relaxation rates.

To confirm that the intended sealants could be produced experimentally, test specimens of the

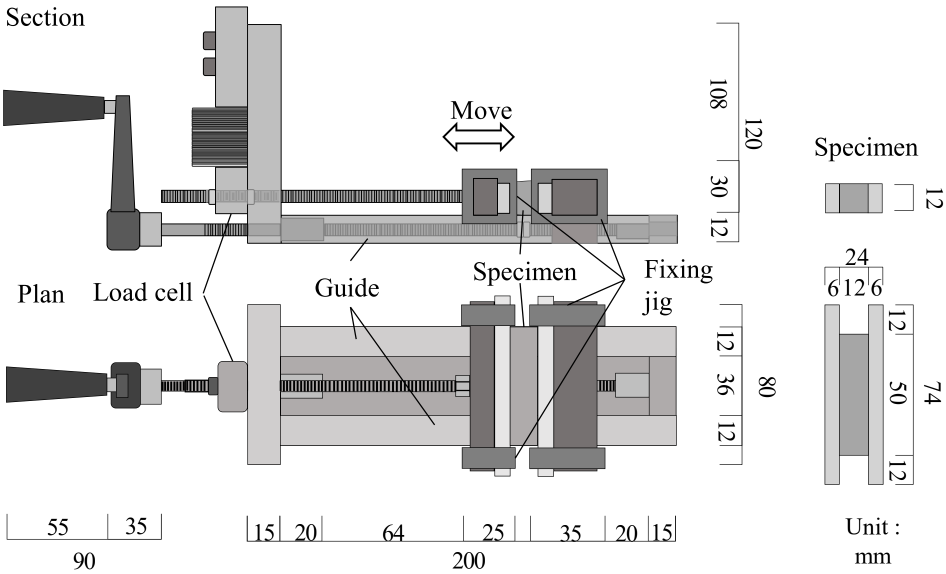

Figure 2. Load-measuring apparatus.

tensile adhesiveness test specified in JIS A 1439 were prepared using the prototype sealants (cured at 23 °C and 50% relative humidity for 7 days and at 50 °C and 50% relative humidity for 7 days, where the adherend was aluminum), and the stress relaxation rate was measured. Each specimen was attached to a tensile testing machine, the specimen width was extended by 30% (from 12 to 15.6 mm), and the stress was measured when the specimen was held for 18 hours in this state. The temperature was 23 °C and the tensile rate was 50 mm/min.

The temporal variation of stress is shown in Fig. 3 while physical properties, including the stress relaxation rate, are given in Table 1. The stress was a maximum when the specimen was extended by 30% and it lowered immediately afterwards. The stress did not decrease remarkably with time for specimen 1 having a low stress relaxation rate but lowered remarkably until 18 hours for specimen 2 having a high stress relaxation rate. Moreover, the moduli were almost the same, and it can be said that the aim of creating prototype sealants with almost the same initial modulus but different stress relaxation rates was achieved.

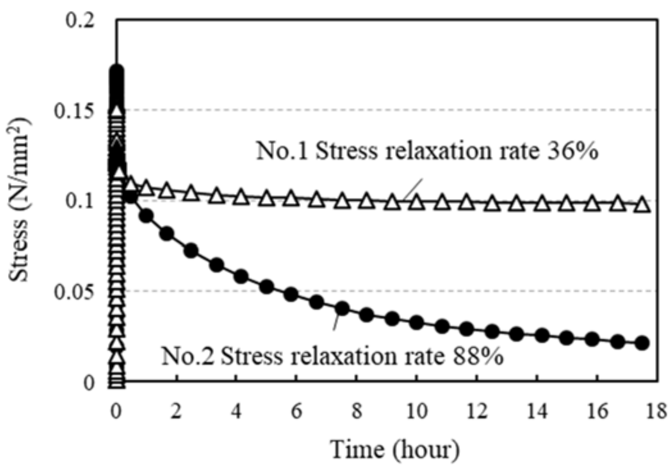

Figure 3. Temporal variation of stress.

Table 1. Physical properties of prototype sealant after standard curing.

Specimen	Stress relaxation rate*1(%)	Tensile adhesion*2		
		M_{50} (N/mm^2)	Tmax (N/mm^2)	Emax (%)
Specimen1	36	0.18	0.30	677
Specimen2	88	0.15	0.31	758

*1: Stress relaxation rate (%) = (Maximum stress -Stress after 18 hours) / MaximumStress × 100, Tensile speed 50 mm/min, Temperature of 23 ° C

*2: M 50: 50% modulus, Tmax: ultimate tensile stress, Emax: elongation at Tmax

2.3 Load-Measuring Procedure

To determine whether the load can be measured properly with the load-measuring apparatus, the joint width was compressed by 30% (from 12 to 8.4 mm) and held for 24 hours, and then extended by 30% (from 12 to 15.6 mm) and held for 24 hours, and the load was measured. The movement was realized manually as described above. The speed of movement was set to 50–100 mm/min with some variation.

As described above, there was more remarkable damage at the warm location and cold location than at the subtropical location in the dynamic outdoor exposure tests, and the present experiment was thus conducted taking the ambient temperature around the test specimen as a variable. The temperature conditions in the present experiment were set at three levels: a low temperature (−20 °C), normal temperature (23 °C), and high temperature (40 °C). The low-temperature condition was realized with a commercially available freezer, the normal-temperature condition with a constant-temperature and constant-humidity room, and the high-temperature condition with a box lined with insulating material and a planar heating element.

In cases of low and high temperature, only the temperature around the specimen was adjusted while the temperature of the load cell was kept constant. The test commenced after confirming that the internal temperature of the specimen was similar to the ambient temperature.

2.4 Test Results

Test results are shown in Fig. 4. For both specimens, the load peaked immediately upon movement but rapidly decreased immediately after and continued to decrease gradually with time. The decrease was remarkable for specimen 2 having a stress relaxation rate of 88% at normal and high temperatures. In other words, when the stress relaxation rate was high, the effect of temperature was strong, and the maximum load when switching to extension was large especially at high temperature. Furthermore, there was cohesive fracture during switching to extension at high temperature, and fracturing continued to progress even during holding in extension. The stress after 24 hours of compression had greatly relaxed, and it is thus considered that the sealant adapted to the compression state and the change due to the load generated in the next extension became large.

Table 2 shows the stress relaxation rate for extension. The stress relaxation rate at normal temperature (23 ° C) was slightly lower than that given in Table 1, which was measured by a tensile testing machine, because the specimen was extended after the compression state was maintained. However, the difference in the stress relaxation rate was clearly well measured by Table 2 shows the stress relaxation rate for extension. The stress relaxation rate at normal temperature (23 ° C) was slightly lower than that given in Table 1, which was measured by a tensile testing machine, because the specimen was extended after the compression state was maintained. However, the difference in the stress relaxation rate was clearly well measured by the developed load-measuring apparatus, and it is considered that the change in stress with time can be appropriately measured even if the temperature of the environment changes.

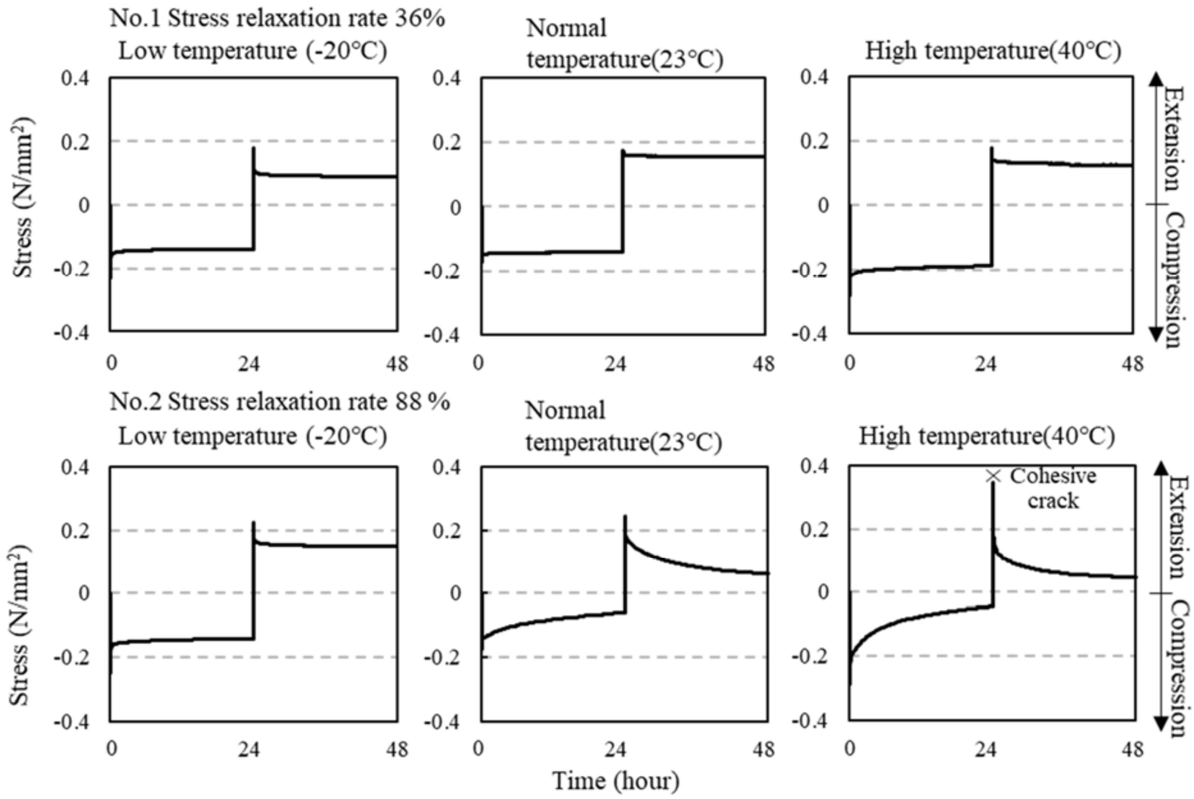

Figure 4. Temporal variation of stress.

Table 2. Stress relaxation rate measured by the load-measuring apparatus.

Specimen	Stress relaxation rate in extension as measured by the load-measuring apparatus *1 (%)		
	Low temperature(-20°C)	Normal temperature(23°C)	High temperature(40°C)
Specimen1	50	11	30
Specimen2	61	72	92

3 Conclusion

The main contributions of the present study are as follows.

- We have developed an apparatus for measuring the load on a sealant during movement. Although an apparatus can handle any deformation rate, any temperature environment, any speed, and any movement period, it is difficult to perfectly match the movement speed each time because it is manually operated at present. Therefore, it is planned to develop a load-measuring device for automatically generating a movement in the future.

- In order to verify the validity of the apparatus, we measured the load when 30% deformation was given at temperature (23 ° C), high temperature (40 ° C), and low temperature (-20 ° C) using two kinds of modified silicone sealants with different stress relaxation rates, it was found that the load gradually relaxed after compression and extension at normal temperature and high temperature but hardly relaxed at low temperature for prototype sealant with a stress relaxation rate of 88%. Meanwhile, the prototype sealant with a stress relaxation rate of 36% was hardly affected by temperature. The effect of temperature on the load can be measured using the load-measuring apparatus. It was shown that the effect of temperature on the load can be measured using the load-measuring apparatus.
- Although the purpose of this study was to develop of a load-measuring apparatus, our ultimate goal is to clarify the occurrence of sealant damage from the viewpoint of the load applied to the sealant. Therefore, in the future, it is planned to carry out repeated load measurement while applying other weathering such as ultraviolet rays by changing the type of sealant, stress relaxation rate, and deformation.

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