Quantification of Effect of Dynamic Movement for Weatherability of Construction Sealants

Noriyoshi Enomoto [1]
Kyoji Tanaka [2]

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ABSTRACT

Construction sealants are materials that ensure the waterproofing function of external joints of building, and the weatherabilty of sealant is a very important performance to sustain the functional performance of the joint. Sealant deterioration is a complex phenomenon influenced by factors such as joint movement and environmental agents whose intensity depends on the regional climate. Though many studies related to the weatherability of sealants have previously been completed, the evaluation of the surface degradation of sealants requires quantitative performance criteria. Prior to this study, a new type of test specimen was developed to assess the weatherabilty of sealants. The configuration of the test specimen is such that extension and of the joint can be applied continuously on a single specimen. For the quantitative evaluation of the surface degradation of sealants an equation based on the ISO 4628 assessment criterion was used. The approach adopted in this study for the quantitative evaluation of sealant degradations due to weathering thus included the new test specimen configuration and the ISO assessment method. The weatherability of sealants was considered to be composed of three factors: degree of degradation in the static conditions: increased rate of degradation due to joint movement, and: effects of environmental agents derived from the regional climate to which the sealant is exposed. In this study, eight sealants, commercially available in Japan, were subjected to a 4-year weathering test program carried out in the Yamanashi Prefecture, Japan. The exposure of sealants in this location was intended to exclude the effects of regional environmental factors on the degradation of the sealants. A functional equation is proposed that gives a surface degradation index of sealants subjected to static and dynamic conditions after a given exposure time. The following results were obtained in regard to the deterioration of sealants subjected to this weathering test program: silicone sealants did not deteriorate, though modified silicone sealants deteriorated slightly in static conditions. The degradation was greatly accelerated by adding joint movement. The degradation of polyurethane sealants was less influenced by joint movements as compared to the degradation of other types of sealant evaluated in this study.

KEYWORDS

Construction sealant, Out-door exposure, Weatherability, Dynamic transformation

[1] Product Development Dept., Sunstar Engineering Inc., Yamanashi, Japan, Phone +81 552845661, Fax +81 552827105,noriyoshi.enomoto@sunstar.com

[2] Structural Engineering Research Center, Tokyo Institute of Technology, Yokohama, Japan, Phone +81 459245329,Fax+81 459245339tanaka@serc.titech.ac.jp

1 INTRODUCTION

Construction sealant is the material used to maintain the waterproof and airtight functions over the long term, and the weatherability is an important performance criterion for maintaining these functions. Though the degradation of sealants in the outdoors proceed by UV irradiation, heat, water and many factors in general, the dynamic movement to which the sealant is exposed in actual joints accelerates the degradation. Many reports concerning outdoor exposure test employing testing device providing dynamic movements have been published, but there were usually large devices and only a limited number specimens could to be attached to them. [Matsumoto & Ono 1981][Koike & Tanaka 1983] This report presents information on the weatherability of construction sealants based on a newly developed test specimen [Enomoto & Tanaka 2006] that allows simultaneous exposure of the sealant to forced movement and outdoor environment.

2 TEST PROCEDURES

2.1 Sealants and Test Specimen

Eight commercially available sealants (see Table 1), typically used in Japan , conforming to JIS A 5758 [2004] and tested in accordance with JIS A 1439 [2004], were used to carry out the exposure test.
The configuration of the test specimen that enabled exposure of the sealant to continuous degrees of extension and compression in a single specimen is shown in Figure 1.

Table 1. Sealants tested.

Sealant	Mark	Physical Properties*		
		50%M (N/mm2)	Tensile Strenght (N/mm2)	Elongation (%)
2 part Silicone	SR-2	0.14	0.81	1170
2 part Polyisobutylene	IB-2	0.11	0.38	490
2 Part Modified silicone (General Purpose type)	MS-2(GP)	0.13	0.49	550
2 part Modified silicone (Stress Relaxation type)	MS-2(SR)	0.17	0.52	550
1 part Modified silicone	MS-1	0.12	0.51	800
2 part Polysulfide	PS-2	0.19	0.56	350
2 part Polyurethane	PU-2	0.11	1.15	790
1 part Polyurethane	PU-1	0.18	0.97	800

*Physical Properties : based on JIS A 1439

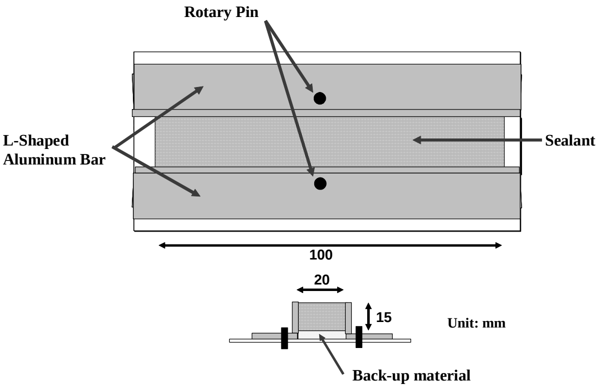


Figure 1. Test specimen.

2.2 Outdoor Exposure Conditions

The exposure test was carried out at one single site of Yamanashi Prefecture, located in central Japan. The choice of this exposure location permitted excluding variations in regional exposure factors. The exposure conditions and a summary of the weather at the exposure site are given in Table 2 and 3 respectively. The test specimen was exposed to both static and dynamic conditions, i.e. the static condition was without movement and the dynamic condition exposed the specimen to extension and compression cycle that were periodically reversed twice every week. The evaluation of surface degradation on the specimen was determined at four locations: i.e. for the static specimen, at ±0% movement amplitude, and: for the dynamic specimen, at ±1.5%, ±15% and ±25% movement amplitude as shown in Figure 2. The centre of the dynamic specimen was exposed to a movement of ±1.5% due to the gap between the rotary pin and the edge of the specimen.

Table 2. Exposure conditions

Location of exposure	Term of exposure	Direction/Angle	Interval of extension/compression exchange	Position of evaluation
Yamanashi Pref., Japan	2003.01.16 – 2007.01.15	South/30°	* Non (Static) * Twice/week (Dynamic)	* ± 0% * ± 1.5% * ± 15% * ± 25%

Table 3. Weather summary.

Temperature (℃)	Max.	40.4
	Min.	-7.8
	Ave.	15.2
Accumulated total solar radiation (0 ˚MJ/m2)		21,004
Accumulated precipitation (mm)		4,277

*Term: 2003.01.16 – 2007.01.15

[Extension/Compression: Non] [Extension/Compression : Twice/week]

Figure 2. Evaluation position of test specimen.

3 EVALUATION

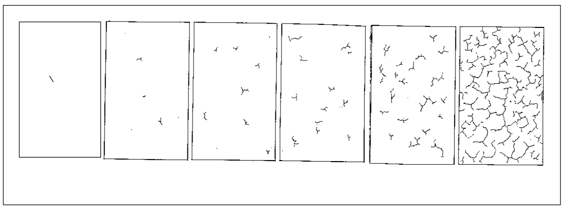
3.1 Determination of Degradation

The determination of the degradation was based on the rating scheme provided ISO 4628-4 [2003] with additional rating criteria introduced to determine the influence of minute cracks on the surface of the sealant. (see Table 4 – indicated by Italic letters, and Figure 3)

Table 4. Crack Rating index.

Rating	Quantity of cracks (Q)	Rating	Size of cracks (S)
0	None	0	*Not visible × 100 magnification*
0.5	*Trace*	*0.3*	*Only visible under magnification up to × 50*
1	Very few	*0.5*	*Only visible under magnification up to × 30*
2	Few	1	Only visible under magnification up to × 10
3	Moderate	2	Just visible with normal corrected vision
4	Considerable	3	Clearly visible with normal corrected vision
5	DEnse	4	Large cracks generally up to 1mm wide
		5	Very large cracks generally more than 1mm wide

*Italic letter : new added rating to decide minute cracks



0.5 1 2 3 4 5

Figure 3. Crack patterns for quantity.

3.2 Evaluation of Degree of Degradation

The degree of degradation (QS-value) was based on the product of the rating of quantity (Q) and Size (S) of cracks as provided Equation 1. The approximate relationship between the QS-value and the surface condition is indicated in Figure 4. The digital photo of the crack surface given in Figure 4 illustrates the effectiveness of the QS-value to assess the state of degradation of the sealant.

$$QS(t)=Q(t)\times S(t) \qquad (1)$$

where QS(t): QS-value after t months, Q(t): rating of Q after t months, S(t): rating of S after t months.

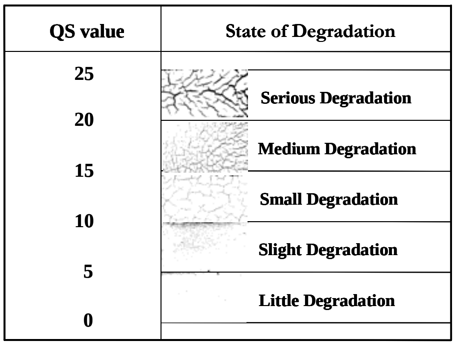


Figure 4. Surface degradation condition rating.

4 TEST RESULT

The changes in QS-value for the different sealants are provided in Figure 5. A summary of the test results is given below.

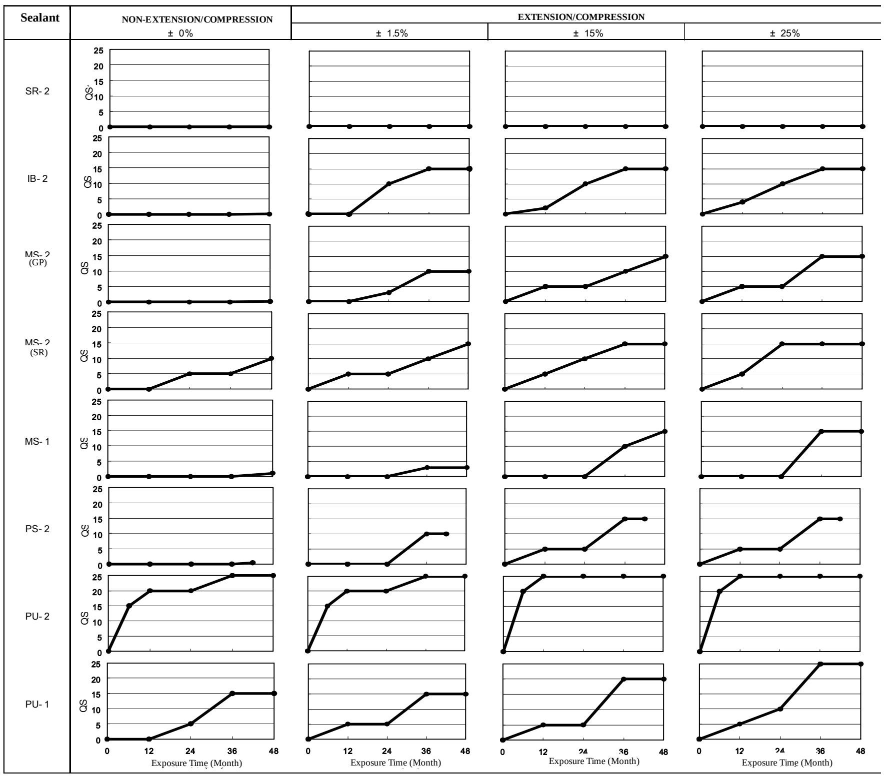


Figure 5. Changes of QS-value of sealants.

1) 2-part silicone sealants did not show degradation for any of the test conditions.
2) Though 2-part polyisobutylene, 2-part modified silicone (general purpose type), 1-part modified silicone and 2-part polysulfide showed a reduced rate of degradation in the static condition, the enforced movement in the dynamic condition accelerated the degree of degradation.
3) The degradation of 2-part modified silicone (stress relaxation type), 2-part polyurethane and 1-part polyurethane showed a gradual degradation with an increase in degree of movement.

5 DISCUSSIONS

5.1 Quantification of Degradation

A three dimension model (response surface) of the QS-value as a function of exposure time and extension-compression ratio was generated from the test results as shown in Figure 6.

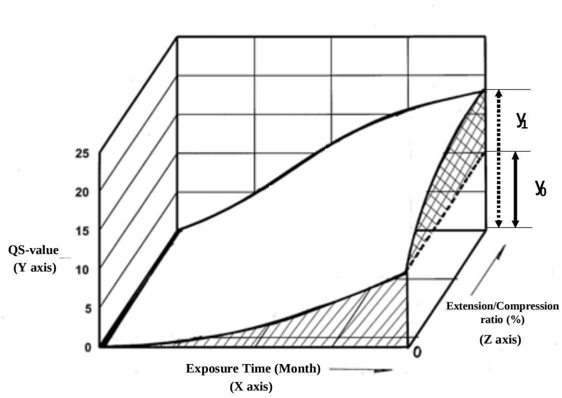


Figure 6. Response surface model of change in QS-value.

5.1.1 Degradation in Static Conditions

The change in QS-value with weathering in the static conditions is given in Equation 2.

$$QS_0(t)=a\cdot t^{b} \tag{2}$$

where, $QS_0(t)$: QS-value obtained from weathering in static conditions after t months; t: exposure months; a and b: constants.

5.1.2 Effect on Degradation due to Dynamic Joint Movement

When sealants as subjected to dynamic joint movement conditions, the equation for the acceleration of degradation due to movement is described in Equation 3. The relationship is derived from the response surface model given in Figure 6.

$$B=y_1/y_0 \tag{3}$$

where, B: coefficient of acceleration, y_0: QS-value on the static condition after t months, y_1: QS-value on the dynamic condition at the ε % of extension-compression ratio after t months.

From the model provided in Figure 7, the relation between the increased QS-value to that of y_0 induced by movement can be described by equation 4.

$$(y_1-y_0)/y_0=c\cdot \varepsilon^{d} \tag{4}$$

where, ε : extension-compression ratio, c and d: constant.

Substituting Equation 4 into Equation 3 yields Equation 5.

$$B = y_1/y_0$$
$$= (y_0 + y_0 \times c \cdot \varepsilon^{d})/y_0$$
$$= (1 + c \cdot \varepsilon^{d}) \qquad (5)$$

The change of value of $c \cdot \varepsilon^{d}$ for each year is shown in Figure 8. The parameters c and d are constants that were obtained from an average of each year.

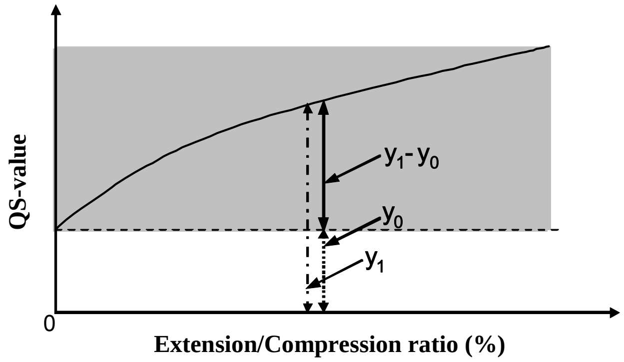


Figure 7. Model of QS-value change for movement.

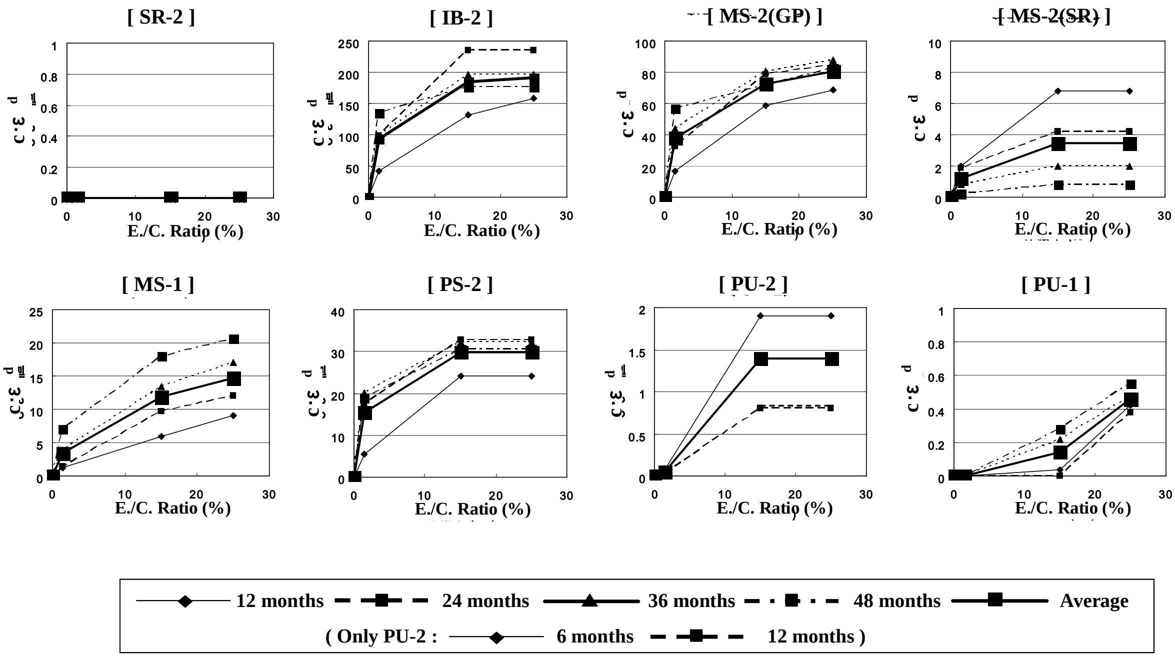


Figure 8. Change of $c \cdot \varepsilon^{d}$ value.

5.2 Proposal for The Equation of Degradation

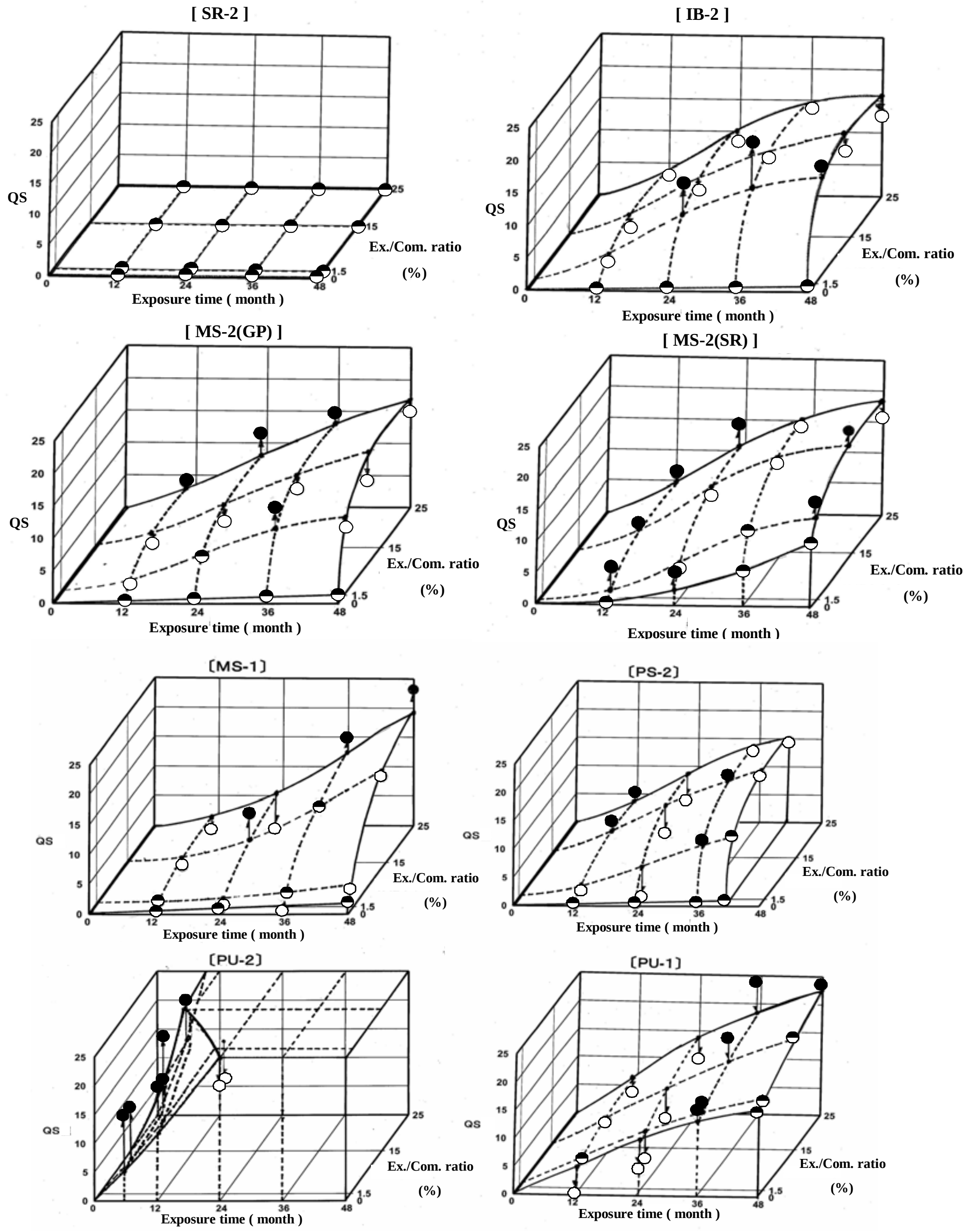
Based on Equation 2 to 5, the equation for the QS-value was expressed as shown in equation 6.

$$QS(\varepsilon \cdot t) = QS_0(t) \times B$$
$$= (a \cdot t^{b}) \times (1 + c \cdot \varepsilon^{d}) \qquad (6)$$

where, QS(ε ・ t): QS-value at ε % after t months, $QS_0(t)$: QS-value on the static condition after t months, t: exposure months, ε : extension-compression ratio, a,b,c and d: constant. The equation derived for each sealant is given in Table 5.

5.3 Comparison between Calculated and Observed Results

The relationship between QS-value and those calculated are shown in Figure 9.



● : observed ≧ calculated, ○ : calculated ≧ observed

Figure 9. Relationship of QS-value between observation and calculation.

Table 5. Equations of degradation for each sealant.

Sealant	**Equation for** $QS\ (\varepsilon \cdot t)$
SR-2	$QS\ (\varepsilon \cdot t) = (0\times t^{1.0})\times(1+0\times \varepsilon^{1.0})$
IB-2	$QS\ (\varepsilon \cdot t) = (0.002\times t^{1.0})\times(1+104\times \varepsilon^{0.2})$
MS-2(GP)	$QS\ (\varepsilon \cdot t) = (0.005\times t^{1.0})\times(1+40\times \varepsilon^{0.2})$
MS-2(SR)	$QS\ (\varepsilon \cdot t) = (0.005\times t^{1.9})\times(1+1.6\times \varepsilon^{0.3})$
MS-1	$QS\ (\varepsilon \cdot t) = (0.02\times t^{1.0})\times(1+4\times \varepsilon^{0.4})$
PS-2	$QS\ (\varepsilon \cdot t) = (0.01\times t^{1.0})\times(1+18\times \varepsilon^{0.2})$
PU-2	$QS\ (\varepsilon \cdot t) = (3.8\times t^{0.6})\times(1+0.4\times \varepsilon^{0.4})$
PU-1	$QS\ (\varepsilon \cdot t) = (0.7\times t^{0.8})\times(1+0.003\times \varepsilon^{0.9})$

6 CONCLUSIONS

1) The new rating criteria for determining minute cracks on the surface of sealants were an effective means to evaluate the degree of degradation of sealants.
2) The equation for the QS-value of the sealant products provides a reasonable relationship between experimental observations and the calculated index of degradation of sealants over the exposure period of this test program.

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