

## **ON-SITE NON-DESTRUCTIVE TEST FOR SEALANTS**

Non-destructive test for sealants

M.Y.L. CHEW

School of Building and Real Estate, National University of Singapore, Singapore

Durability of Building Materials and Components 8. (1999) *Edited by M.A. Lacasse and D.J. Vanier*. Institute for Research in Construction, Ottawa ON, K1A 0R6, Canada, pp. 825 – 834.

© National Research Council Canada 1999

### **Abstract**

In recent years, the deterioration of sealants has attracted much attention in conjunction with the construction industry's increasing use of large panel curtain walls. Although sealants are relatively inexpensive, they constitute a major function in a building's life cycle. Effective sealants are important in contributing to successful watertightness and energy efficiency of the building envelope. The high cost of energy for heating and air-conditioning is causing serious consideration of good building sealants. The long term financial impact of poor sealants on the cost of keeping the building comfortable is now being calculated by building owners. Currently in the local scene, most sealants in high rise buildings are reaching the limit of their life span. Generally, sealants for cladding wall applications have a warranty period of 13 years or less. Reports have shown that many building in the city area are anticipated in the next few years, to engage in repair or replacement of sealants in the building facade. This paper discusses the development of an on-site non-destructive testing technique to assess the performance of sealants on building facades. Tests were carried out on various generic types of high performance sealants subjected to natural and artificial weathering. Results were compared with those from the conventional laboratory tests including elasticity, compression, adhesion and cohesion.

Keywords: elastic recovery, sealants, compressibility, test method, experiment, test device, correlation

## 1 Introduction

The evolution of modern architecture depicts an increasing trend of curtain walling construction. This trend is complemented by the usage of elastomeric sealants such as silicones, polysulphide and polyurethane. These polymers allow for more design creativity and are expected to accommodate mechanical vibration, thermal movement, expansion and contraction stemming from weather variances. The integrity of a building is thus maintained by the elastomeric properties of sealants that prevent water and air infiltration, thereby warranting a watertight and airtight envelope.

In the case of determining the durability and performance of new sealants, the conventional testing techniques stipulates that the sealants must be statically cured for a period of 28 days before the tests are to be conducted. This approach seems to suggest that all sealants fail from weathering, ignoring the fact that failure may actually occur before the sealant has a chance to cure. In practice, sealants that are installed on-site, do not “enjoy” the luxury of being statically cured in a fixed position, before experiencing undue stress caused by movements. They are subjected to dynamic curing rather than static curing and occurrences of premature failures are highly possible. This highlights the concern that conventional control tests conducted may be meaningless if sealants were to fail before they are put to service. It is thus important to monitor the in-service performance of sealants regularly especially during the initial stage after application (Margeson, 1992; Matsumoto, 1992, Beech & Beasley, 1992; Klosowski, 1978, Panek and Cook, 1984). To achieve that, a reliable on-site, non-destructive diagnostic technique is needed.

This paper gives an overview of a research project looking into the feasibility of developing an in-situ non-destructive diagnostic technique for the assessment of sealants based on elastic recovery and compressibility.

## 2 Methodology

The project was broadly divided into three main sections with their respective experiments as follows:

Section I	<u>Development of Conceptual framework</u>
Experiment 1 -	Semi-destructive elastic recovery test method versus ASTM D412 test method.
Experiment 2 -	In-situ non-destructive elastic recovery test method versus standard resilience test.
Experiment 3 -	In-situ non-destructive elastic recovery test method - horizontal and vertical orientated
Experiment 4 -	Semi-destructive elastic recovery test method versus in-situ non-destructive elastic recovery test method
Experiment 5 -	Investigation into the in-situ compressibility test
Experiment 6 -	Investigation into the correlation between compressibility with elastic recovery and Shore A hardness

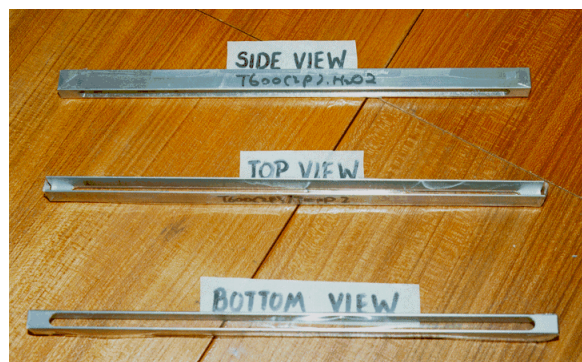
Section II Assessment of the reproducibility, repeatability, sensitivity and reliability on in-situ non-destructive elastic recovery test device

- Experiment 7 - The significance of the shape of the detector
- Experiment 8 - The significance of the size of the detector
- Experiment 9 - The significance of the restoring time
- Experiment 10 - The significance of the type of substrate
- Experiment 11 - The significance of temperature
- Experiment 12 - The significance of moisture content
- Experiment 13 - The significance of air-void
- Experiment 14 - The reproducibility of the in-situ non-destructive test device
- Experiment 15 - The repeatability of the in-situ non-destructive test device

Section III Applicability of in-situ non-destructive elastic recovery test device

- Experiment 16 - The effect of curing on the elastic recovery of sealant
- Experiment 17 - The applicability of compressibility test
- Experiment 18 - Adhesion and cohesion of sealant

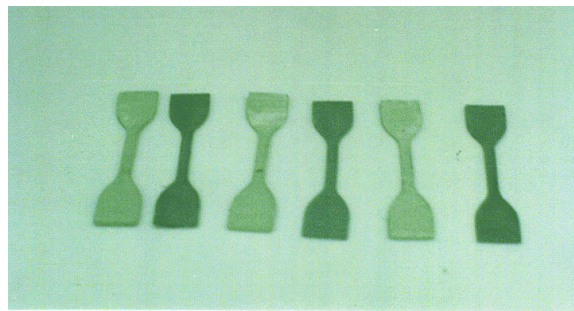
Five generic types of high performance sealants were evaluated which were chosen to represent the wide range of materials available in the market. These were one part silicone (1S), one part polysulphide (1P), one part polyurethane (1U), two-part polysulphide (2P) and two part polyurethane (2U). Experiments were conducted on the sealants that were exposed to various simulated weathering conditions such as water immersion at 25°C and 70°C, heat aging at 70°C and QUV weatherometer. Three main types of sealant specimens were fabricated i.e.:



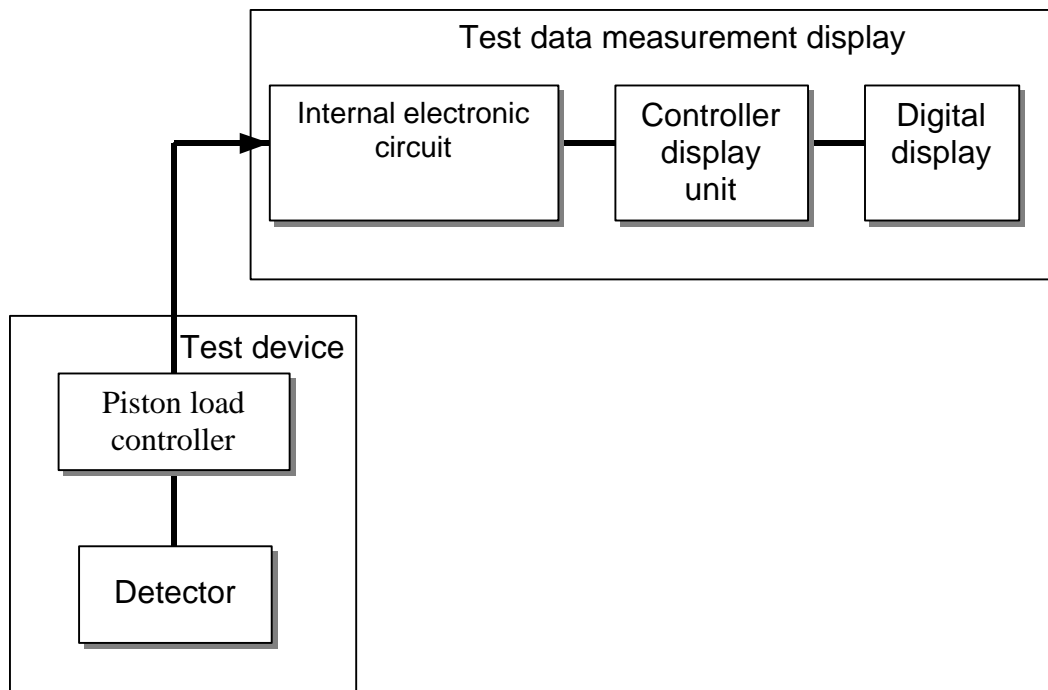
**Fig. 1: Aluminium mould of dimension 30mm (length) x 15mm (height) x 10 mm (width) that resembles the “as-built” sealants used in joints of buildings**



**Fig. 2: H-joint configuration sealant specimens with different types of substrates i.e. glass, mortar and aluminium prepared similar to that of ASTM C719-93**



**Fig. 3: Dumbbell shape according to ASTM D412**



**Fig. 4: A schematic diagram of the in-situ non-destructive test device**

### 3 Results and Discussion

The results are broadly summarised in Tables 1 and 2 in the following pages.

In the first section, a semi-destructive elastic recovery test device was developed based on the principle of ASTM D412 test method. Sealants were cast in aluminium moulds to simulate the actual sealant joints on-site. This semi-destructive elastic recovery test method involved the modification of a standard laboratory test ASTM D412 for elastic recovery of sealant into an on-site diagnostic technique. The evaluation and correlation of the existing laboratory testing technique (ASTM D412) with the semi-destructive elastic recovery test method were carried out. Good correlation was achieved. The project extended on to the development of an in-situ non-destructive elastic recovery test device (Figure 4). Special attention is dedicated to the simulation of real life situation such as the shapes and dimensions of the mould and the plane of testing when conducting the experiments. Results derived from the test device were correlated with the standard resilience test both vertically and horizontally as well as with the semi-destructive test method. Good correlation was achieved in various aspects. Further enhancements and improvement such as the inclusion of testing facilities for compressibility and visual assessment were incorporated. The compressibility test has also been correlated with the elastic recovery and Shore A hardness.

In the second section of the development work, laboratory experimental studies were carried out to assess and evaluate the significance of various factors that might affect the reliability and sensitivity of the test device. Among the factors investigated were the shape of detector, size of the detector, types of substrates, restoring time, temperature variation, moisture content variation and the compactness/air-void. The reproducibility and repeatability of the test device were also investigated.

The viability of the test device was evaluated using statistical analysis on data derived from in-situ non-destructive elastic recovery tests in which the degree of correlation among different sets of experiments was determined. In addition, attempts were made to establish the relationship between the various tests on high performance sealants.

The third section looked into the application aspects such as the effect of the curing process. Curing is very crucial to the development of strength, movement capability and elastic recovery material. Inferences from the experiment will thus serve as a primary indication and guideline to be utilised as a benchmark for the industry. It is apparent from the results that silicones and two part sealants are superior in term of cure rate, as compared to one part polysulphide and polyurethane, engendering them to be more desirable for sealing joints which are subjected to high movement stress immediately upon installation.

The compressibility test used to assess hardness and detect voids in sealants, in terms of applied force, was also investigated. The test device has shown to be reliable in detecting voids and measuring hardness in terms of applied force. The compressibility test has been shown to be more superior than Shore A hardness test device in terms of sensitivity and consistency.

**Table 1: Development of in-situ non-destructive elastic recovery test device**

Test methods		Plane of orientation test		Sealant	Linear relationship equation	R <sup>2</sup>
Y	X	Vertical	Horizontal			
ASTM D412	Semi-destructive	-	-	simulated	$y = 0.1116x + 85.346$	0.8237
Non-destructive	Resilience test	-	Horizontal	Fresh	$y = 0.9847x - 6.2599$	0.9665
Non-destructive	Resilience test	-	Horizontal	Fresh	$y = 0.8735x - 3.182$	0.9343
Non-destructive	Non-destructive	Vertical	Horizontal	Fresh	$y = 0.8842x + 2.3878$	0.9646
Non-destructive	Non-destructive	Vertical	Horizontal	simulated	$y = 1.0858x - 10.229$	0.9702
Non-destructive	Semi-destructive	Vertical	-	simulated	$y = 0.6159x + 33.565$	0.8375
Elastic recovery	Compressibility	Vertical	-	Fresh	$y = -0.0414x + 94.485$	0.0013
Elastic recovery	Compressibility	Vertical	-	simulated	$y = 0.0245x + 76.07$	0.0003
Shore A hardness	Compressibility	Vertical	-	Fresh	$y = 1.1175x + 14.53$	0.5764
Shore A hardness	Compressibility	Vertical	-	simulated	$y = 0.606x - 7.7815$	0.8257

**Table 2: Evaluation and correlation of linear relationship equations on the assessment of the reliability of the in-situ non-destructive elastic recovery test device**

Assessment	Factors		Plane of orientation test		Sealant	Linear relationship equation	R <sup>2</sup>
	(X)	(Y)					
Shape of detector	Pellet	Ball	Vertical	Horizontal	Simulated	$y = 0.8865x + 10.059$	0.8732
	Pellet	Ball	Vertical	-	Simulated	$y = 0.8839x + 12.53$	0.86
	Pellet	Ball	-	Horizontal	Simulated	$y = 0.8972x + 6.8472$	0.8847
Shape of detector (Sensitivity)	Pellet	Ball	Vertical	Horizontal	Simulated	$y = 0.8958x + 2.9416$	0.8695
	Pellet	Ball	Vertical	-	Simulated	$y = 0.8765x + 4.136$	0.8306
	Pellet	Ball	-	Horizontal	Simulated	$y = 0.9205x + 1.3972$	0.9027
Size of detector	10mm pellet	5 m pellet	Vertical	Horizontal	Simulated	$y = 0.8189x + 17.294$	0.9102
	10mm pellet	5 m pellet	Vertical	-	Simulated	$y = 0.7836x + 20.8$	0.9006
	10mm pellet	5 m pellet	-	Horizontal	Simulated	$y = 0.8533x + 13.897$	0.9239
Size of detector (Sensitivity)	10mm pellet	5 m pellet	Vertical	Horizontal	Simulated	$y = 0.8089x - 1.1077$	0.8892
	10mm pellet	5 m pellet	Vertical	-	Simulated	$y = 0.7562x - 1.9314$	0.887
	10mm pellet	5 m pellet	-	Horizontal	Simulated	$y = 0.8724x - 0.3424$	0.9157
Restoring time	20 s	5 s	Vertical	Horizontal	Simulated	$y = 0.9503x - 0.0703$	0.928
	40 s	5 s	Vertical	Horizontal	Simulated	$y = 1.0113x - 7.0493$	0.9214
	60 s	5 s	Vertical	Horizontal	Simulated	$y = 0.9859x - 7.7902$	0.8986
Restoring time (Sensitivity)	20 s	5 s	Vertical	Horizontal	Simulated	$y = 0.8951x + 2.103$	0.8711
	40 s	5 s	Vertical	Horizontal	Simulated	$y = 0.9405x + 3.7278$	0.8654
	60 s	5 s	Vertical	Horizontal	Simulated	$y = 0.8834x + 4.1333$	0.812
Substrate types	aluminium	glass	Vertical	-	Curing	$y = 0.9745x + 1.4942$	0.9829
	mortar	aluminium	Vertical	-	Curing	$y = 0.9792x + 2.3686$	0.9607
	mortar	glass	Vertical	-	Curing	$y = 0.9625x + 3.2764$	0.9595

**Table 2, cont'd: Evaluation and correlation of linear relationship equations on the assessment of the reliability of the in-situ non-destructive elastic recovery test device**

<b>Assessment</b>	<b>Factors</b>		<b>Plane of orientation test</b>		<b>Sealant</b>	<b>Linear relationship equation</b>	<b>R<sup>2</sup></b>
Temperature of sealant	30°C - 70°C		Vertical	-	Fresh AS101(1U)	$y = 0.0512x + 89.579$	0.063
	30°C - 70°C		Vertical	-	Fresh SIU (1S)	$y = -0.0466x + 101.13$	0.2058
	30°C - 70°C		Vertical	-	Fresh T600(2P)	$y = -0.0502x + 100.91$	0.0977
	30°C - 70°C		Vertical	-	Fresh T1 (1P)	$y = 0.348x + 46.061$	0.285
Moisture content of sealant	Variation in moisture content (%)		Vertical	-	Fresh PE (1P)	$y = 24.596x + 64.34$	0.7033
			Vertical	-	Fresh AS101(1U)	$y = 0.2447 + 94.796$	0.0046
			Vertical	-	Fresh NI525(1U)	$y = 3.1019x + 84.838$	0.3393
			Vertical	-	Fresh BF (1U)	$y = 0.7294x + 68.897$	0.1938
			Vertical	-	Fresh BBS (1S)	$y = -0.0711x + 100.02$	0.0042
			Vertical	-	Fresh T600(2P)	$y = -0.3973x + 96.73$	0.0175
Air-void	Full compactness	air-void	Vertical	-	Simulated	$y = 1.021x - 0.6694$	0.9708
Reproducibility	Device 1	Device 2	Vertical	-	Curing	$y = 1.1504x - 9.7828$	0.9269
Repeatability	Testing 1	Testing 2	Vertical	-	Simulated	$y = 0.9727x - 1.7854$	0.8598

The failure of building sealants in an active joint is usually manifested by cohesive failure in the sealant or adhesive failure between the sealant and substrates or both. Thus, another aim of the applicability studies was to examine and correlate the three performance parameters of high performance sealant that is elastic recovery, cohesion and adhesion when subjected to accelerated weathering. Laboratory studies based on cyclic movement (Hockman Cycle ASTM C719-93) were conducted. In the cyclic movement studies, mortar substrates H-joint configuration sealant specimens were fabricated and subjected to cyclical simulations up to 5 cycles. The conditions consisted of water immersion at 25°C followed by oven treatment at 70°C and 10 cycles of alternate compression and extension joint movement in a compression-extension cyclic machine. Upon completion of the cyclical simulation, elastic recovery was measured and the magnitude of the cohesive and adhesive failures were determined and evaluated. Analysis was rendered to examine the relationship of elastic recovery performance with cohesive and adhesive failures of the various generic sealants. The relationship was traced through five cycles of laboratory testing and subsequently correlation was drawn to affirm the reciprocity among the parameters. A correlation was established to evaluate the relationship between the three parameters, i.e. cohesion, adhesion and elastic recovery.

#### **4 Conclusions**

In the development framework of the in-situ non-destructive elastic recovery test device, correlation of results derived using different elastic recovery test methods i.e. ASTM D412, semi-destructive elastic recovery test method, in-situ non-destructive elastic recovery test method, standard resilience test and compressibility test were established. A wide range of different generic types of sealants was tested to ensure that the works might be applicable to a broad range of sealants subjected to different degree of weathering.

The test device was subsequently evaluated for its reliability, sensitivity and the extent to which it would be influenced by factors such as shape of detector, size of detector, restoring time, types of substrates, temperature variation, moisture content variation, compactness and air-void.

The significance of curing on the performance of sealants has been investigated. The in-situ non-destructive elastic recovery test device has been shown to be useful on the monitoring of the physical curing process of various generic sealants. Works are still being undertaken to determine the long term curing characteristics of the sealants to establish the benchmark that can be used when assessing the state of sealants on-site.

Compressibility test has been shown to be a parameter for determining air-void/compactness. The test has been shown to be more superior than Shore A hardness test device in term of sensitivity and consistency.

In the cyclical movement studies, the effect and extent of both the cohesive and adhesive failures on the performance of elastic recovery of sealants were examined. The results have shown no correlation between adhesive failure and elastic recovery. However, good correlation was found between cohesive failure and elastic recovery of the sealant. Critical elastic recovery of the sealant can be determined through the study of cyclical movement. Melting and softening may also cause low elastic recovery regardless of the extent of the cohesive failure.

## 5 References

- Margeson, J. (1992) The Effect of Movement During Cure on Sealant Strength Development, *Science and Technology of Building Sealants*, Sealants, Glazing and Waterproofing, ASTM STP 1168
- Matsumoto, Y. (1992) The Effect of Building Joint Movements on Outdoor Performance of Sealants During Their Cure, *Science and Technology of Building Sealants*, Sealants, Glazing and Waterproofing, ASTM STP 1168
- Beech, J. and Beasley, J. (1992) Evaluation of Cure and Durability Aspects of Building Sealants, *Science and Technology of Building Sealants*, Sealants, Glazing and Waterproofing, Vol. 2, ASTM STP 1200, 1992
- Klosowski, J.M. (1978) Durability of Building Materials and Components, *Proceedings of the First International Conference*, ASTM
- Panek, J.R. and Cook, J.P. (1984) Construction Sealants and Adhesives, Wiley Interscience Publication, New York

