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16. Abstract

Project 0-187 task 15 continued investigative efforts of project 1371. The project completed laboratory tests including relaxation tests, bond-strength tests, and fatigue tests for various sealant materials, and also established a field test site of a variety of joint sealants to monitor performance. The researchers constructed a material behavior model based on finite-deformation viscoelasticity as a function of temperature, deformation, and age effects. They studied the correlation between natural and artificial weathering and proposed a sealant performance model. Based on this model, this report provides a procedure for estimation of the service life of a sealant in concrete pavement joints. Material and pavement engineers can use this procedure for design and maintenance purposes. This report also proposes a specification and a test protocol for joint sealant materials, which incorporate performance prediction procedure. The proposed guidelines can be verified and refined through continuous observation of the field test sections. The researchers of the project expect that application of the research products from this project will lead to an improved sealant selection process and reduced maintenance cost for concrete pavements.

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# EVALUATION OF JOINT SEALANTS OF CONCRETE PAVEMENTS

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# IMPLEMENTATION STATEMENT

The findings of this project will have an important bearing on the design, selection, and maintenance procedure of the joint sealants. A procedure for determination of the service life of a joint sealant in the concrete pavement is proposed based on various models developed in project 1371 and this project, namely, the material behavior model, the bond strength model, and the performance model. The procedure can be used by the highway agency to properly design and select joint sealants for a given climate and traffic condition. Necessary laboratory tests to support the procedure are specified in the proposed specification and test protocol for the sealant materials used in concrete pavement joints. It is hoped that the results obtained from the study and the guidelines provided will reduce the distress levels in concrete pavement caused by poor sealant performance and help reduce rehabilitation costs.

# DISCLAIMER

The contents of this report reflect the views of the authors who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official view or policies of the Texas Department of Transportation (TxDOT) or the Federal Highway Administration (FHWA). This report does not constitute a standard, specification, or regulation.

# ACKNOWLEDGMENT

Appreciation is extended to the Texas Department of Transportation and the Federal Highway Administration for the financial support provided under study no. 0-187-15. This report presents the results of the study.

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# SUMMARY

Project 187-15 is a continuation of project 1371 "Evaluation of Joint Sealants." Investigation under this project included completion of relaxation tests of selected joint sealant materials for concrete pavements at different temperatures, deformation levels, and ages and the establishment of a field test site which consisted of a variety of joint sealant materials near Liberty, Texas, on SH 90. The project included a test program that included relaxation tests of specimens of sealant materials after naturally or artificially aged to establish the equivalency of the natural weathering and accelerated weathering achieved in the laboratory. Laboratory bond-strength and fatigue tests were previously completed in project 1371.

Based on these tests, a material behavior model and a sealant performance model have been proposed. These models have led to a procedure for estimation of the service life of a joint sealant material in concrete pavements. Engineers can use this procedure to estimate the service life for design and maintenance purposes. This procedure requires some material properties, including bond strength and relaxation modulus. As a result of the laboratory evaluation process for sealant materials, a specification and test protocol for joint sealant in concrete pavements is proposed based on the behavior and performance models. Continuing field observation of the test sections near Liberty, Texas, on SH 90 will further verify and improve the procedure. Sealants of different geometries were installed in the test sections to study effects of sealant geometry on the sealant service life.

Improved sealant selection and reduced maintenance cost for concrete pavements is expected upon application of the proposed material behavior and performance models, the proposed specification and test protocol, and the proposed procedure for estimation of service life of the joint sealant.

# CHAPTER 1 INTRODUCTION

This report documents investigation of concrete pavement joint sealants which began with project 1371 "Evaluation of Joint Sealants." The purpose of the continued investigation is to propose specification and test protocol for joint sealants in concrete pavements based on characterization of selected material properties. The report documents the procedure for estimation of the service life of a sealant joint sealant material and its application to specification development..

Laboratory material tests are reported in the final report of project 1371 [1], but additional laboratory tests were conducted by the researchers under this project. Sealant performance in the field test section established near Liberty, Texas, was observed. This field test section should be monitored from time to time to verify the proposed specification and test protocol and improve the life prediction model.

Joints play an important role in the performance of jointed and continuously reinforced concrete pavement systems. Accordingly, concrete slabs move with a certain level of freedom under traffic, temperature, and moisture changes. Slab movements (which occur at the joint) reduce slab stresses and resulting pavement distresses. Conversely, when the pavement slabs move, the joint sealant can undergo extensive deformation (both compressive and tensile), which may eventually cause failure of the sealant. In addition, exposure to various climatic and solar radiation levels may tend to deteriorate the sealant material. Therefore, joint sealants judiciously selected (based on appropriate performance models) should provide better performance than those which are not.

There are many different joint sealant materials, each of which can be classified as a material of low modulus whose behavior is time-dependent. The elastic modulus of a sealant material changes with time upon loading. This phenomenon results in sealant materials exhibiting creep and relaxation characteristics. Such materials are also referred to as viscoelastic materials. Tests conducted in this project have shown that behavior of each tested sealant is not only time-dependent, but also strain-, temperature-, and age-dependent.

In the current documented test procedures of the Texas Department of Transportation (TxDOT), which were revised in 1982, Test Method Tex-525-C "Testing Concrete Joint

Sealers" [2] adopts ASTM D 545 [3] and ASTM D 994 [4] to test poured concrete joint sealers. These tests determine some physical and mechanical properties of the sealant material that may provide some reference for evaluation purposes. The departmental material specification D-9-6310 (1992) [5] establishes requirements for concrete sealants based on results of these tests. However, these tests only concern properties of a sealant immediately after placement. It was evident in this project that consideration of long-term sealant behavior and environmental conditions must be taken into account to achieve full characterization of the sealant. Very few previous research efforts on joint sealants have characterized behavior of the largely deformable sealant under repetitive loading relative to long-term effects of aging due to solar radiation and moisture effects. Neither did these studies provide a failure criterion. In order to establish a complete test procedure for evaluating various concrete joint sealant materials available in the current market, it was of interest to develop the necessary tools such that performance of the sealant in service can be predicted with the data from the tests conducted in the materials laboratory.

Researchers undertook several different laboratory tests conducted in the course of this project. These tests include relaxation tests at different temperature, deformation and age levels, adhesive strength tests, and fatigue tests. Material samples were naturally weathered and artificially aged in a Weather-Ometer®. An attempt was made to establish the local equivalency between artificial aging and natural aging. Based on these tests and theoretical models, material behavior (or relaxation) and material performance (or failure criterion) were characterized in a model format, from which the service life of the sealant under varying traffic and climatic conditions could be predicted.

Researchers conducted a field study to examine the performance of sealants under field conditions in project 1371. A special field section was established in this project where different sealants were placed in transverse joints of a rehabilitated jointed concrete pavement system. Long-term observations of these test sections documenting the joint sealant performance should prove to be very useful in future study.

As a result of this research effort, a new modified specification and a new test protocol were developed which include the measurement of sealant bond strength as well as relaxation behavior. Each of these is documented in the attached appendices.

This report consists of five chapters. Chapter 2 gives a brief description of the field test site investigation and performance survey results. Chapter 3 includes summaries of further laboratory tests conducted under this study. Following the test results, Chapter 4 gives the analysis of the experimental data and provides a material behavior model. Chapter 5 presents the efforts to investigate the correlation between natural and artificial weathering. Chapter 6 provides the procedure for estimation of the service life of the joint sealant based on the proposed performance model under the standard conditions. An example of using the procedure is also demonstrated in the chapter. Chapter 7, the last chapter, presents the project conclusions. Appendices A and B present the proposed specification and test protocol for joint sealants in concrete pavements, respectively. Appendix C provides the joint sealant survey form used to collect information pertaining to joint sealants in concrete pavement from various TxDOT districts. Appendix D shows thirty figures for details of the relaxation test results for a sealant material.

# CHAPTER 2 FIELD STUDY

## INTRODUCTION

This chapter covers the initial results of joint sealant performance surveys performed at a field test site established near Liberty, Texas. The test section was established to monitor the behavior of various joint sealants under actual field conditions. The purpose of the field test was to better understand joint sealant material behavior, to monitor and calibrate material performance models, and ultimately to verify the procedure for estimation of service life of a joint sealant, and refine and improve sealant specifications and test protocols. The proposed service life estimation procedure of a joint sealant in a concrete pavement based on the material behavior and performance models is discussed in Chapter 6. The implementation of these models is encompassed within the specification and test protocol for the joint sealant as proposed in Appendices A and B.

## ESTABLISHMENT OF FIELD TEST SECTION

A field test site was established to evaluate several combinations of joint sealant types and joint geometries under actual field conditions. It should be possible to use the results of these field sections, in conjunction with the results from laboratory investigations done in project 1371 and this project, to fulfill the purpose of validating and advancing the behavior and performance models, the specification and test protocol, and the service life estimation procedure for joint sealant materials used in concrete pavements.

### Test Site Location

The Beaumont District volunteered a test site on SH 90, west of Beaumont near Liberty, Texas. The test section begins at FM 1413 and continues for 5.8 km (3.6 miles) in the eastbound direction. The pavement at this site is a jointed reinforced concrete pavement (JRCP) with expansion joints located on 18.44 m centers. No control joints are located in this pavement. Figure 1 shows the layout of the test sections.

*Factorial Experiment*

The proposed field test plan was simple in that it entailed the use of only two primary variables, joint sealant type and joint geometry. Ten joints for each combination of joint sealant type and joint geometry were included. Provision was made for three extra joints for each material to serve as practice joints for the construction crews performing the work, thus resulting in a total of thirteen joints for each material. These three extra joints should not be monitored in the evaluation of the material performance. Therefore, a total of 312 (6x4x13) transverse joints were used to establish the test section. Both lanes of the two-lane highway were used for the test section. The following is a description of the primary variables and their levels in the experimental layout.

**Materials :** Two hot applied thermoplastic sealants, three cold applied thermoplastic sealants, and one two-part, thermosetting sealant were installed in this experiment. These sealants were selected based on laboratory test results, and they include:
Hot Applied Thermoplastic Sealants

- Durafill 3405; Polymeric Rubber with Asphaltic Resin
- Solarite KM-1166; Elastomeric Modified Asphalt

Cold Applied Thermoplastic Sealants

- Dow Corning; 888 SL (Self-Leveling)
- Crafco; Road Saver Silicone Sealant (SL)
- Kengo Sealer; Single component asphalt based latex

Two-Part Thermosetting Sealant

- Percol Joint Sealant; (this material is a two-part polyurethane)

*Traffic Flow* ←

| US 90 | | | | | | |
|---|---|---|---|---|---|---|
| Section 1 | Section 2 | Section 3 | Section 4 | Section 5 | Section 6 | Section 7 |
| Dow 890 SL | Crafco 903 SL | Kengo | Crafco RoadSaver | Durafill | Dow 890 SL | Crafco 903 SL |

→ *Traffic Flow*

Geometries of Joints used in Sections

**SECTION #1 and 6 DOW CORNING 890 SL**

| Joint Geo.#1 | | Joint Geo. #2 | | Joint Geo. #3 | | Joint Geo. #4 | |
|---|---|---|---|---|---|---|---|
| 13 Joints | | 13 Joints | | 13 Joints | | 13 Joints | |
| 6 Primed | 7 Unprimed | 6 Primed | 7 Unprimed | 6 Primed | 7 Unprimed | 6 Primed | 7 Unprimed |

**SECTION #2 and 7 Crafco 903 SL**

| Joint Geo.#1 | | Joint Geo. #2 | | Joint Geo. #3 | | Joint Geo. #4 | |
|---|---|---|---|---|---|---|---|
| 13 Joints | | 13 Joints | | 13 Joints | | 13 Joints | |
| 6 Primed | 7 Unprimed | 6 Primed | 7 Unprimed | 6 Primed | 7 Unprimed | 6 Primed | 7 Unprimed |

**SECTION #3 Kengo**

| Joint Geo.#1 | Joint Geo. #2 | Joint Geo. #3 | Joint Geo. #4 |
|---|---|---|---|
| 13 Joints | 13 Joints | 13 Joints | 13 Joints |

**SECTION #4 Crafco RoadSaver 231**

| Joint Geo.#1 | Joint Geo. #2 | Joint Geo. #3 | Joint Geo. #4 |
|---|---|---|---|
| 13 Joints | 13 Joints | 13 Joints | 13 Joints |

**SECTION #5 Durafill**

| Joint Geo.#1 | Joint Geo. #2 | Joint Geo. #3 | Joint Geo. #4 |
|---|---|---|---|
| 13 Joints | 13 Joints | 13 Joints | 13 Joints |

**Figure 1.** Schematic Test Site Layout.

**Joint Geometry:** The width of these joints varied slightly depending on the condition of the existing joints. Figure 2 shows the various levels of joint geometry used.

The objective of this experiment was to test the performance of the joint sealants themselves and not the long-term concrete slab performance resulting from the effectiveness of the sealant. The latter is beyond the scope of this study. The exception to this may be in terms of joint spalling resulting directly from the presence or absence of the joint sealant after traffic has been applied.

Joint sealant performance parameters include:

- Spalling of concrete at the joint,
- Extrusion of joint sealant material,
- Intrusion of joint sealant material,
- Adhesive or cohesive sealant failure, and
- Cracking in joint sealant.

Selected co-variables of the experiment include:

- Time of year of sealant placement,
- Temperature of concrete at placement,
- Joint width at time of placement,
- Temperature of sealant at placement, and
- Traffic level (two levels: inside vs. outside lane).

## Field Test Site Installation

The field test site consisted of a re-sealing project covering two lanes where each sealant material was placed in a sector or group of consecutive transverse joints extending across both lanes as previously indicated. The centerline longitudinal joint was also sealed. Prior to placing the new material, cleaning of existing joints was done. This consisted of removing the existing joint sealant material followed by sandblasting and cleaning the joint with compressive air.

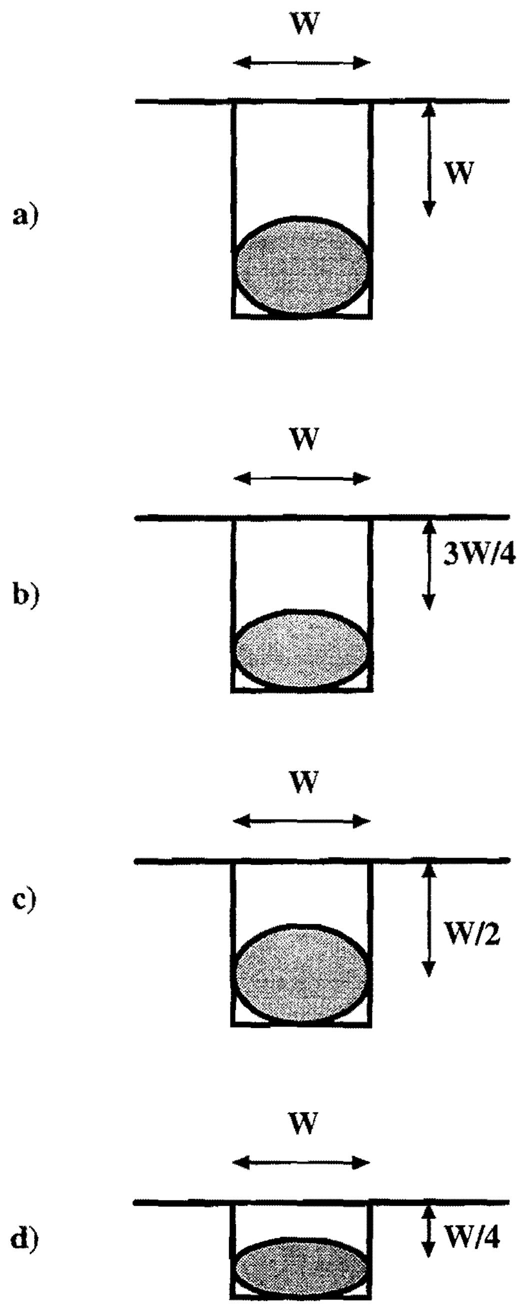



FIGURE 2. Joint Geometries Employed at Test Section.

*Dow Corning 890-SL Installation*

This material was placed during hot, sunny, humid weather conditions. The ambient temperature was 35 to 40 °C. After placement of the backer rod, certain joint faces (if designated) were primed. The material was recessed just below the surface of the joint. The self-leveling property of the sealant gave the material a smooth finish; however, because of the slight slope of the pavement, it also allowed for the sealant to run out at the ends of the joint wells. For areas of heavy spalling at the ends, the material tended to pool, making it necessary to apply additional sealant for these joints.

A special type of installation, referred to as a split sealant, was also completed. A split sealant consists of two backer rods, the first of which was placed as normally specified while the second (9.525 mm diameter) was embedded within the body of the joint sealant. In order to facilitate placement, the sealant material was placed in two lifts or layers. A certain amount of time must expire for surface curing to prevent the 9.525 mm backer rod from floating to the upper surface. Examination of the one-day cured Dow Corning 890-SL material revealed that it was very soft and mushy. Piercing the very thin cured surface layer showed that under the surface the material was uncured. This was a concern since it was observed that small aggregates had pierced into the layer under traffic pushing the uncured sealant to the surface.

*Crafco 903-SL Silicone Sealant Installation*

This sealant is a single compound, self-leveling silicone sealant, that was placed under similar conditions as the Dow Corning 890-SL material. The split sealant type installation was also performed with this material.

*Kengo Sealer Installation*

The Kengo material installation went very fast due to its low viscosity and the fact that, according to the manufacturer, no preparation other than removing the old backer rod was necessary. It was so fluid that, in the absence of a water tight seal between the backer rod and the slab, most of the material would have leaked out of the joint well. Even though the Kengo would set in approximately 20 to 30 seconds, it still caused the backer rod to float to the top. A problem observed with this material was that the traffic immediately pulled out the backer rods from the joints.

*Durafill and Crafco Road Saver Installation*

These hot poured joint sealant materials were applied using the manufacturer's provided instructions. The Percol joint sealant and Solarite sealant were not installed due to lack of supply of material at the test section.

**Bubbling**

A phenomena that occurred in most installations, except in the Kengo, was bubbling at the sealant surface. The hot poured materials, Durafill and Crafco Road Saver, exhibited bubbling almost immediately out of the applicator. The silicone sealants would produce bubbles after a period of time, approximately five to 15 minutes after placement. Different mechanisms as to the cause of the bubbling were explored. One of the material representatives claimed that it was due to slicing the closed-cell, gas-filled backer rod since the tools the workmen used to lay the backer rod could easily puncture the rod. However, after placing and pouring over sufficient length of visibly ripped backer rod, no bubbles were present. This test was conducted on many joints of different geometries with different sealant materials. It was observed that some of the ripped backer rods did produce some bubbling; however, it was also observed that backer rods that did not have any visible tears produced bubbles as well. Another possibility was that the applicator, as it was being dragged along the backer rod, was entrapping air behind it. This was negated when three joints were poured where the wand was held in the air and produced just as many air pockets. A sufficient amount of material was poured straight from the applicator into a cup to see if the bubbles existed before placement. This was apparently not the case since the bubbles were formed only at the surface. The entire phenomenon was unusual, since samples poured in the laboratory did not display this characteristic.

The future survey at the test site should include visual observation, checking for adhesion, cohesion, sealant pull out, exposed backer rod, etc. Falling weight deflection (FWD) testing should also be conducted to monitor the joint performance relative to load transfer and joint opening.

## FIELD SURVEY AND JOINT SEALANT PERFORMANCE

The test section was evaluated on December 14, 1995, to record the performance of various joint sealants. The right lane at the test site was closed down, and a detailed inspection of the joints was carried out. During this survey, the condition of sealant and the joint well were observed. Falling weight deflection (FWD) tests were also carried out. The following section discusses the performance data recorded and presents a summary of FWD data as well as sealant performance to date.

### Performance Data Collected

To assist in systematically recording the field performance data in a consistent and logical manner, joint seal field survey forms were prepared. The two parts of these survey forms are shown in Figures 3 and 4. Part I of the survey form is used to record the pertinent information of the joints being surveyed and also includes a distress identification reference. Three severity levels for each distress type were identified and referenced in part I (Figure 3). Part II of the survey form (Figure 4) was used to graphically record the observed distresses.

One form was used for each section which had ten joints. The joints were surveyed a foot at a time, and distress types were recorded on both sides of the joint well (i.e., approach and leave sides). The distress manifestations included:

- Adhesion loss,
- Cohesion loss,

# Joint Seal Field Survey Form

Date Surveyed: ___/___/___ Date Accepted: ___/___/___

State Contact: ____________________ Phone: ____________

District: __________ County: __________ Highway: __________

CSJ: ____-____-____ Nearest RM: __________ Direction: __________

Nearest City: ______________ Sealant Type/Class: ______________

Location Description: ________________________________________

______________________________________________________________

______________________________________________ Total Length: ______

Lane Number: _____ Slab Width: ________ Slab Length: ________

Air Temp: ______°F Pavement Temp: ______°F Time: ____:____

PCC Thick: ________in Subbase Thick: ________in Subgrade Type: ______________

Notes: ________________________________________________________

______________________________________________________________

______________________________________________________________

Distress Identification Reference:

| Distress Number - Type | Low Severity | Medium Severity | High Severity |
|---|---|---|---|
| A - Adhesion | Still tight to side, bond lost at top only. | Full depth loss of bond but opening < 1/16". | Opening ≥ 1/16" |
| C - Cohesion | Small crack in sealant. | Crack in sealant ≤1/8" | Wide crack in sealant. |
| I - Intrusion | Somewhat difficult to penetrate. | Difficult to penetrate, may be stones embedded. | Sealant dried and cracked. |
| M - Missing | Less than 2"/foot. | Between 2" - 4"/foot. | More than 4"/foot. |
| P - Partial Depth Spall (joint remains sealed) | Cracks outside of joint, not yet broken. | Spalled but broken pieces still attached. | Spalled pieces missing. |
| S - Full Depth Spall (joint no longer sealed) | Spalled pieces still attached. | Less than 4"/foot missing. | More than 4"/foot missing. |
| E - Extrusion | Less than 2"/foot pushed above joint. | Between 2" - 4"/foot. | More than 4"/foot. |
| F - Faulting | Less than 1/8". | 1/8" - 1/4". | More than 1/4". |

**FIGURE 3.** Joint Survey Form, Part I.

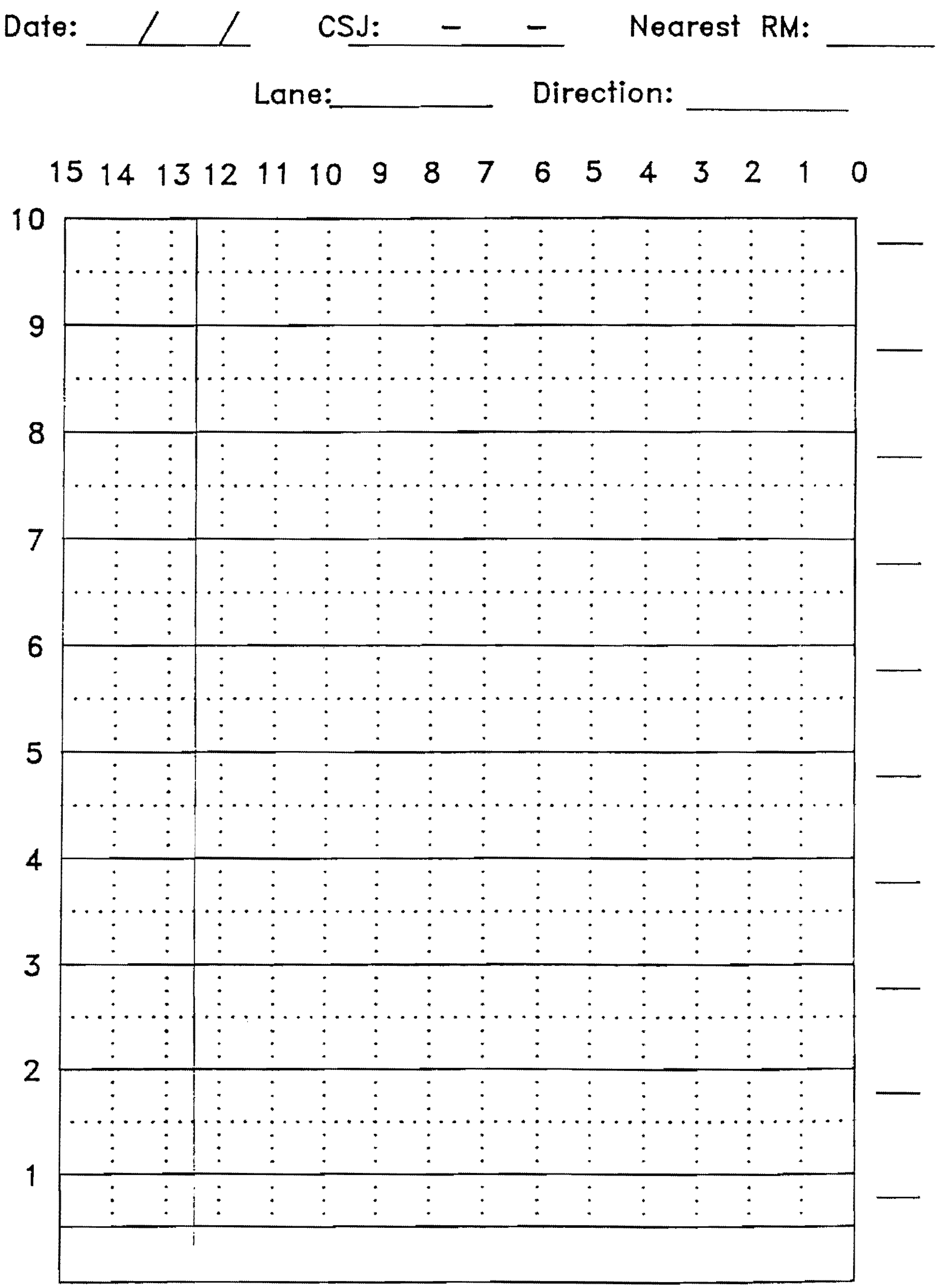



**FIGURE 4.** Joint Survey Form, Part II.

- Intrusion,
- Missing sealant,
- Partial depth spall,
- Full depth spall, and
- Extrusion.

## INITIAL OBSERVED PERFORMANCE

The loss of adhesion to the concrete was the most common form of distress observed in the field. This was particularly true for the hot applied joint sealants. Figure 5 shows the adhesion loss observed at various test sections, which are specified by the section number (Figure 1) and sealant geometry number (Figure 2). For example, the symbol of S3-2 in Figure 5 designates a section within Section 3 as shown in the test site layout (Figure 1). The number 2 in the symbol indicates that joints in the section used Geometry 2, which is shown in Figure 2. As seen from the plot, silicone sealant had an overall better performance compared to other types of joints.

Section three, which was installed using Kengo joint sealant, had the poorest performance. This behavior was expected, since most of the material had drained into the shoulders leaving behind empty joint wells during installation. It was also observed that the hot poured sealants were also prone to intrusion.

### Deflection Testing

A FWD (falling weight deflectometer) test program was carried out to record the load transfer efficiency across the joints. The testing equipment is a trailer-mounted FWD weighing approximately 6,670 N (1,500 lb). The impulse force is created by dropping masses. The load, measured by a transducer, is transmitted to the pavement through the load plate having a radius of 150 mm (5.9005 in). Deflections are measured by using velocity transducers mounted on a bar that is lowered simultaneously with the load plate to the

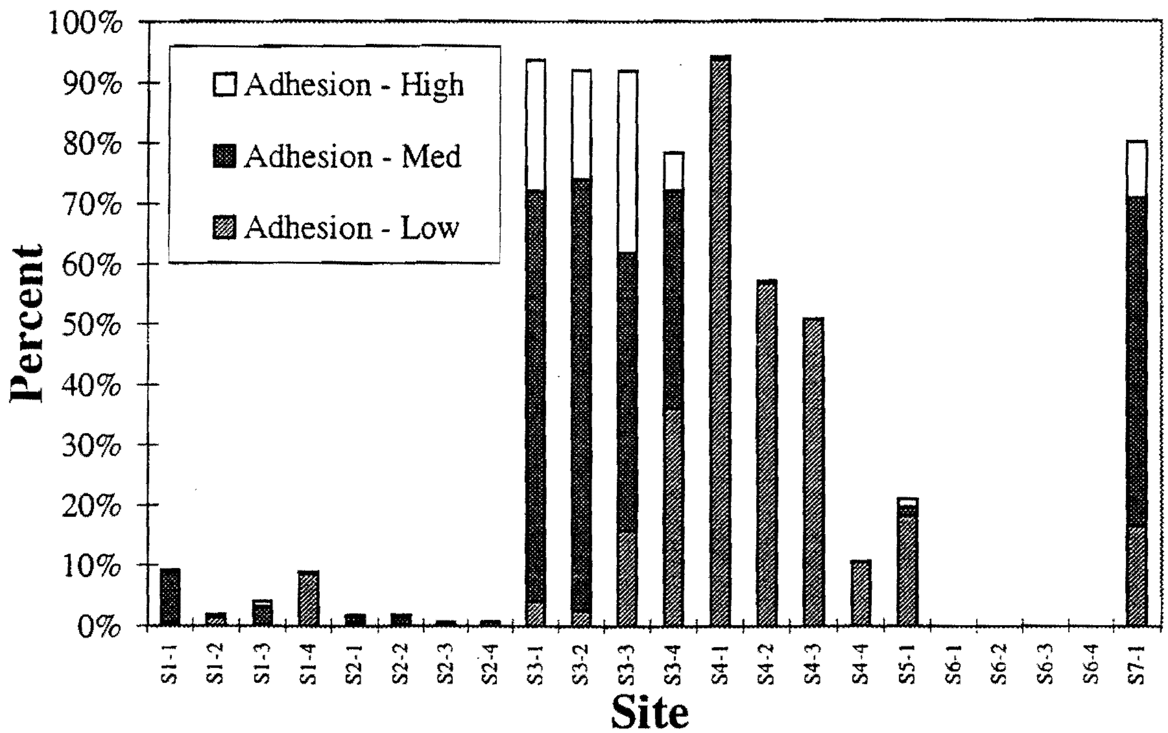



**FIGURE 5.** Adhesion Loss for Various Test Sections.

pavement surface. The results of FWD field measurements are described in terms of the load plate deflection ($D_0$), the load transfer efficiency (LTE), and the effective stiffness ($E_c$) at the joint. The LTE is equal to the change in deflection on the unloaded side of the joint divided by the change in deflection on the loaded side of the joint. The effective stiffness $E_c$ is determined from the Westergaard solution for slab-on-grade deflections at an interior load position.

To study the effect of pavement temperature, the FWD test runs were carried out once in the morning and then repeated in the late afternoon. The morning test was carried out until approximately 11:30 a.m. on an overcast day. No significant change in the ambient temperature was observed during this test session. The afternoon session was carried out over the same joints and a comparison made. Figure 6 illustrates the LTE plot, across each joint in the test site. For comparison purposes, both the morning as well as the afternoon test results are plotted in Figure 6. As seen from the LTE plot, the transfer of load across the joints was excellent. Morning and afternoon sessions did show some difference. These data will be useful as a reference for future evaluation of the in-place joint sealants.

FWD tests were also carried out at the center of the selected slabs in each section. These data can be used to back-calculate the elastic layer modulus of underlying layers and also to determine the deflection basin along the length of the test section. A continued effort should be made to survey and record the FWD test data for future reference. These data can be effectively applied to evaluate the influence of joint sealants on pavement performance. Continual monitoring of the changes in LTE across a joint over a long period can reveal the benefits of joint sealants in improving the pavement joint life as well as sealants' effectiveness. As an additional note, there are many factors that affect the actual response of slabs to FWD loading, such as pavement temperature, which can affect measured deflections due to slab curling and warping over the course of the day. To minimize variability due to this effect, FWD tests should be carried out under the same environmental and seasonal conditions.

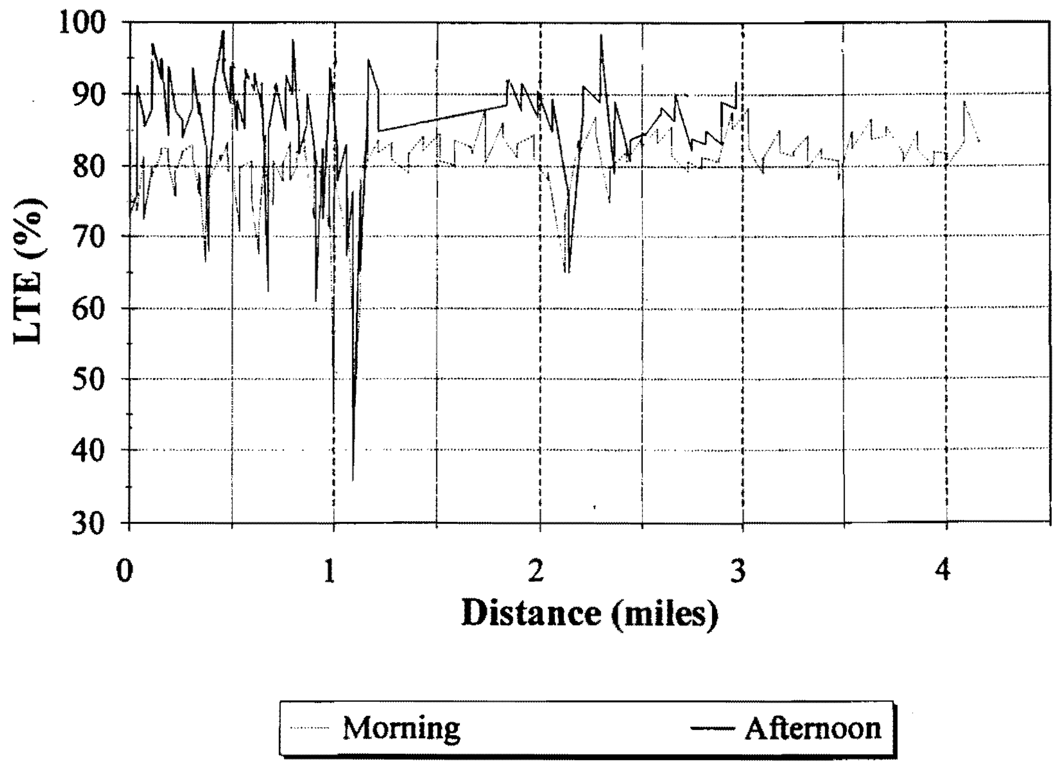



**FIGURE 6.** Load Transfer Efficiency Along the Test Site.

## JOINT SEALANT SURVEY AMONG DISTRICT ENGINEERS

During the course of this project, joint sealant survey forms were sent to various TxDOT district pavement management engineers to procure information pertaining to use of joint sealants in their concrete pavements. The researchers were interested in knowing what kind of joint sealants were most often used and their performance levels. The specific information sought included:

- Brand name of sealants used in recent past,
- Their performance rating (s) (on a scale of 1 to 5),
- Mode of failure, if any, and
- Maintenance and other pertinent information.

### Survey Form

A survey form was developed to procure the above mentioned information from district pavement engineers. This joint sealant survey form (provided in Appendix C) was sent to all the TxDOT district offices. The survey form had listed the sealants used in project 1371 and this project. Due to rapid development in the sealant industry and constant change in sealant formulation, only information pertaining to sealants less than eight years old was requested.

Sealants that did not survive beyond six months were rated *poor* while those surviving more than five years without failure were rated *excellent.*

## FINDINGS

Figure 7 illustrates the performance rating of various joints sealants as obtained from the survey. Generally, the silicone-based sealant performed better than the asphaltic sealants (hot poured). It was also found that the districts relied on their experience and used a sealant that had worked best in the past. None of the asphaltic-based sealant was rated excellent. There was one instance where a silicone-based sealant was rated poor. Upon further investigation, it was found that this particular sealant was not properly installed at the time of sealing and hence rapidly failed.

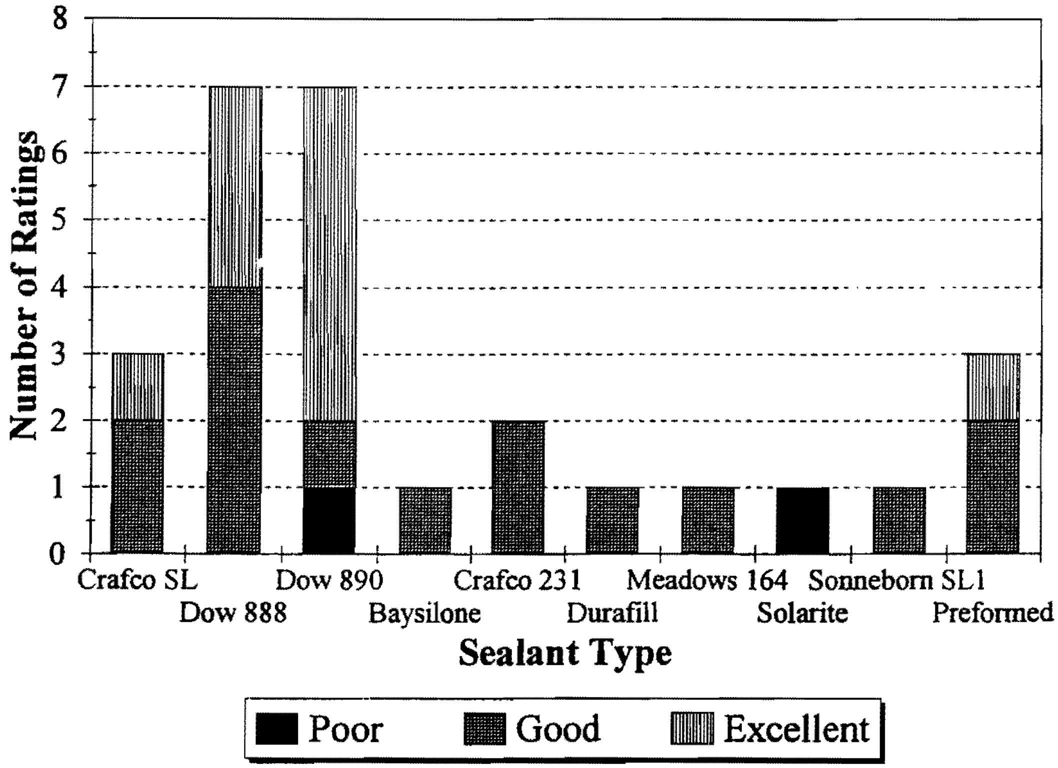



**FIGURE 7.** Performance Rating of Various Sealants from TxDOT District Survey.

# CHAPTER 3 LABORATORY TEST PROGRAM

## INTRODUCTION

One of the benefits of the laboratory testing conducted in project 1371 and this project was the development of specification and test protocols for joint sealants in concrete pavements to evaluate the sealant material performance, which was based upon material models for estimation of the service life of a joint sealant (Chapter 6). As a result of the laboratory tests, as well as the field observations conducted in project 1371 and this project, new specification and test protocols in Appendices A and B were developed which should be validated under field conditions. Sealant evaluation was carried out relative to the material relaxation, bond strength and performance models for various sealant materials. Most of these efforts were developed under project 1371. Results of these tests, as well as detailed laboratory setup and theoretical background involved in synthesizing the data, can be found in the final report of project 1371 [1]. More relaxation tests of fresh specimens and artificially aged specimens were performed under this project. All the relaxation tests of fresh and artificially aged specimens of various joint sealant materials are summarized and reported in this chapter and Chapter 4. Under this project, relaxation tests of specimens of many sealant materials were conducted after naturally or artificially aging in order to understand the equivalency between effects of natural and artificial weathering. This equivalence is discussed in Chapter 5. Also, relaxation tests of preformed sealants were conducted. For readers' convenience, relaxation test procedures and related theoretical background are repeated briefly in this chapter and Chapter 4, although they have been addressed in the final report of project 1371 [1].

## TEST MATERIALS

Today, there are numerous varieties of sealants available on the market for joints in concrete pavements [6, 7]. Many are either silicone-based, urethane, or asphaltic in nature. Silicone sealants can be found in either self-leveling or non-sagging form. To distinguish between different materials, they are classified according to Item 433 of Texas Department of

Transportation's Standard Specifications for Construction of Highways, Streets and Bridges, 1993 [8].

The materials selected covered a wide range of material classification. A brief description of the materials used in the laboratory test programs follows.

1. *Crafco Roadsaver:* This is an asphaltic-based material, which is hot applied.
2. *Crafco 903-SL:* It is a cold-applied, one-part low modulus silicone rubber. The material is packaged in a cartridge container which is extruded with a hand-operated caulking gun.
3. *Dow Corning 888:* It is a cold-applied, one-part low modulus silicone rubber. The material is packaged in a cartridge container which is extruded with a hand-operated caulking gun.
4. *Dow Corning 890-SL:* It is also a cold-applied, one-part low modulus self-leveling silicone sealant. The material is packaged in a cartridge container which is extruded with a hand-operated caulking gun.
5. *Durafill 3405:* This is a hot-applied asphaltic-based material, which is specially formulated to be heat stabilized for direct-fired heaters.
6. *Fox Industries FX-570:* It is a two-component polymeric joint sealant. The two components are mixed in a proportion as provided by the manufacturer. The manufacturer provided smaller convenient packages for this study which were thoroughly mixed to produce a caulking gun grade material.
7. *Percol Joint Sealant:* It is a two component polyurethane joint sealant. The two components are mixed in equal proportion with the aid of an air-pressure-operated caulking gun. The material is packed in such a manner that while extruding, the two components are mixed in the nozzle specially provided for it. The material sets quickly, and its curing time is about ten minutes with a pot life of up to two minutes.
8. *Solarite KM-2780:* This is a hot-poured rubber-asphalt sealant which incorporates a minimum of 20% crumb rubber tire stock uniformly dispersed.
9. *Delastic Preformed Neoprene Seals:* This a preformed compression seal manufactured by D.S. Brown in various configurations.

Table 1 below describes the materials used in the laboratory for evaluation and their classification according to TxDOT Standard Specifications [8]. Since sealant materials of Classes 1 and 4 demonstrate similar mechanical properties, and so do those of Classes 2 and 7, we group Classes 1 and 4 as Type 1, Classes 2 and 7 as Type 2. Correspondingly, Class 5 is Type 3; Class 3 is Type 4, and Class 6 is Type 5. We designate Type 6 for new materials that cannot be classified in Types 1-5. For the definitions of types of sealant materials, please refer to Appendix A.

**Table 1.** Classification of Joint Sealants Studied.

| Joint Sealant | Classification (Item 433) | Type (Appendix A) |
|---|---|---|
| D. S, Brown Preformed Seal | **Class 6** | **Type 5** |
| Crafco RoadSaver 230 | **Class 3** | **Type 4** |
| Crafco 903 SL | **Class 5** | **Type 3** |
| Dow Corning 888 | **Class 4** | **Type 1** |
| Dow Corning 890 SL | **Class 5** | **Type 3** |
| Durafill | **Class 3** | **Type 4** |
| Fox Industries FX-570 | **Class 1** | **Type 1** |
| Percol Joint Sealant | **Class 2** | **Type 2** |
| Solarite | **Class 3** | **Type 4** |

## PREPARATION OF TEST SPECIMENS

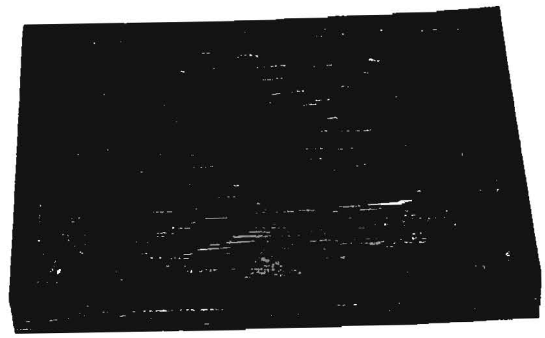
When available, the test specimens used in the experimental study were prepared according to the ASTM standard requirements. Following sections discuss the preparation techniques used for preparing relaxation, bond strength, and fatigue test specimens.

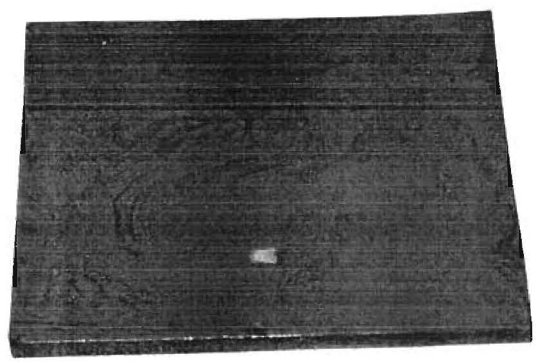
**Relaxation Specimen**

Relaxation tests were conducted in the uniaxial tension mode, and at present there is no standard to specify test specimen geometry. There is little information in the literature regarding the size and shape effects. Due to the mode of testing and traditional usage, a rectangular-shaped test specimen was chosen for the test.

All the specimens were prepared from the material obtained from the same cartridge container to preserve consistency among the specimens. The sealant specimens for relaxation tests were prepared in a 300 mm x 230 mm x 6.35 mm wooden mold as shown in Figure 8(a). A plastic sheet coated with a thin layer of silicone lubricant placed at the bottom of the mold prevented adhesion between the material and the mold. The curing time for the material varied according to the manufacturer's recommendations. All curing was done at 25 °C temperature and 50% relative humidity. Once the curing was accomplished, the sheet of the cured sealant material (Figure 8(b)) was removed from the mold, and 6.35 mm wide strips were cut using a band saw (Figure 8(c)). Consequently, strips of a cross-sectional area of 12.7 mm x 6.35 mm were obtained. These strips of material were then tested to characterize the unaged sealant material. The relaxation test specimen had a gauge length of 50.8 mm and 25.4 mm of grip length on each end. To securely grip the test specimen without pinching, 3 mm thick plywood strips measuring 6.35 mm wide and 25.4 mm long were glued on opposite sides of each end of the specimen (Figure 8d).

The remaining uncut sheet of the sealant material was then placed in the Ci65A Atlas Weather-Ometer® for accelerated aging [9]. The material was artificially aged by exposing it to weathering cycles for at least 2000 hours in 500-hour intervals. Strips of the aged materials were cut from the sheet of the material at the end of every 500-hour interval for the preparation of test specimens. Use of the Atlas Weather-Ometer will be discussed at the end of this chapter.





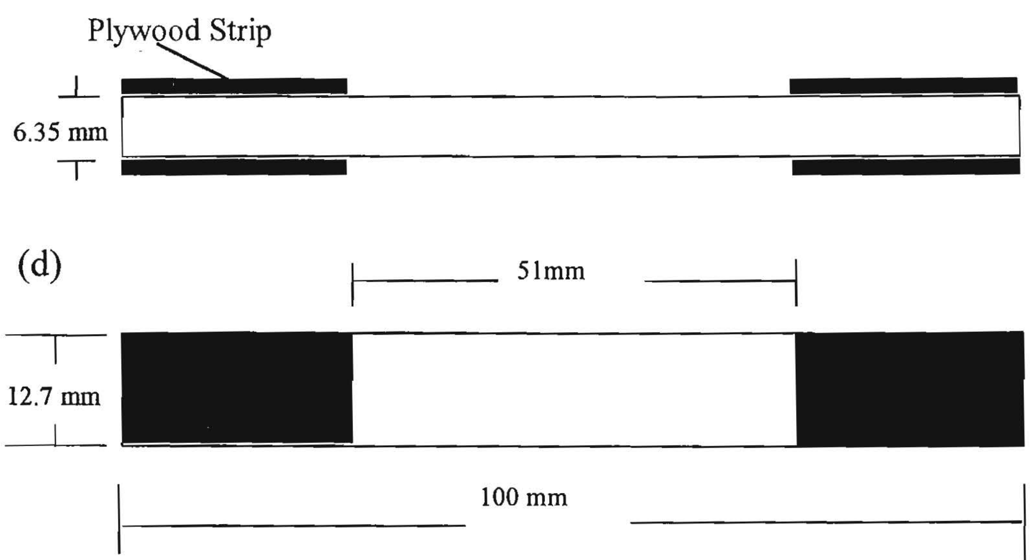



**Figure 8.** Relaxation Specimen (a) Specimen Mold, (b) Cured Sheet of Material, (c) Specimen Strips, and (d) Test Specimen.

## TEST PROCEDURES

Standard test procedures were followed to conduct the test program when available. Unfortunately, there are not many standard specifications for testing joint sealant materials pertaining to the scope of this research. Therefore, the tests were either conducted based on the literature review or a standard specification available for a similar material for a similar purpose. The following section discusses the test procedures used to conduct various tests on the sealant material specimen prepared.

### Relaxation Test

Researchers used stress relaxation tests to investigate and characterize the time-dependent properties and aging effect of joint sealants. Accordingly, a test specimen was instantaneously stretched to a predetermined unit extension level and maintained at that unit extension level. The decaying magnitude of the load with time in the test specimen was recorded and was used for determining the viscoelastic parameters.

All the dimensions of the specimen were measured and recorded before setting it up for the test. All the relaxation tests were carried out on an Instron machine, model 4505. A 690 N load cell was used to record the load, and the data was automatically acquired using Instron data acquisition software. All the specimens were stretched at a constant rate of 50.8 mm/minute to the desired unit extension levels. This applied displacement rate of 50.8 mm/minute met the specification of ASTM D 2991 [10]. Field studies of pavement joints in the past have shown that joint sealant materials can experience a large amount of joint opening and closing. In an attempt to encompass the wide range of movements that may be experienced by a concrete pavement joint sealant in the field, six different levels of unit extensions were used. These levels varied from 5, 10, 30, 50, and 100% of the original gauge length (50.8 mm). The unit extension level of 30% was later dropped for test temperatures other than 25 °C. This was done for each level of age, generally at 500 hours of exposure, in the Atlas Weather-Ometer, apart. There were generally five age groups up to 2000 hours of exposure. Crafco 903 SL (Table 1) was also studied for additional age level of 2500 hours of exposure. The above combinations of unit extension levels and age levels were repeated at five different test temperatures, namely, -25, 0, 25, 40 and 60 °C. Tables 2 and 3 summarize aging exposure time and temperatures used for the relaxation tests of different joint sealant materials.

## VISCOELASTIC MATERIAL MODEL

A joint sealant response depends not only on the temperature but also the deformation and its age. To characterize effects of deformation, age, and temperature, a relationship similar to one proposed by William, Landel, and Ferry [11] (usually referred as the WLF equation) is used. The WLF equation was originally proposed to relate the effect of temperature to the effect of time on relaxation modulus, based on a great deal of experimental evidence. The relationship proposed in this investigation converts the factors of deformation, age, and temperature to the factor of time:

$$E_R \equiv E_R(E, A, T, t) = E_R(E_0, A_0, T_0, \tau) \tag{1}$$

$$\tau = \frac{t}{a(E, A, T)} \tag{2}$$

where,

| | |
|---|---|
| $E_R$ | = relaxation modulus, |
| t | = reduced time, |
| a(E, A, T) | = material shift factor, |
| E | = unit extension, |
| A | = age, |
| T | = temperature, |
| $E_0$ | = reference unit extension, |

**Table 2.** Relaxation Test Performed for Various Temperature Levels.

| Material Type | Temperature Level (°C) | | | | |
|---|---|---|---|---|---|
| | -25 | 0 | 25 | 40 | 60 |
| Crafco 903 SL | ✓ | ✓ | ✓ | ✓ | ✓ |
| Dow Corning 888 | ✓ | ✓ | ✓ | ✓ | ✓ |
| Dow Corning 890 SL | ✓ | ✓ | ✓ | ✓ | ✓ |
| Percol Joint Sealant | | | ✓ | | |
| Fox Industries FX-570 | | | ✓ | | |

**Table 3.** Relaxation Test Performed for Various Age Levels.

| Material Type | Age Level (Hours of Exposure) | | | | | |
|---|---|---|---|---|---|---|
| | 0 | 500 | 1000 | 1500 | 2000 | 2500 |
| Crafco 903 SL | ✓ | ✓ | ✓ | ✓ | ✓ | |
| Dow Corning 888 | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Dow Corning 890 SL | ✓ | ✓ | ✓ | ✓ | ✓ | |
| Percol Joint Sealant | ✓ | ✓ | ✓ | ✓ | ✓ | |
| Fox Industries FX-570 | ✓ | ✓ | ✓ | ✓ | ✓ | |

$A_0$ = reference age, and

$T_0$ = reference temperature.

The material shift factor, a(E, A, T) can be separated into three distinct factors, namely, time-deformation, time-age, and time-temperature shift factor as:

$$a(E, A, T) = a_E(E) \cdot a_A(A) \cdot a_T(T) \tag{3}$$

It is found that the time-deformation shift factor, $a_E(E)$, the time-age shift factor, $a_A(A)$, and the time-temperature shift factor, $a_T(T)$, can be well described in the form as:

$$\text{Log } a_E(E) = \frac{-K_1(E - E_0)}{K_2 + E - E_0} \tag{4}$$

$$\text{Log } a_A(A) = \frac{-K_3(A - A_0)}{K_4 + A - A_0} \tag{5}$$

and

$$\text{Log } a_T(T) = K_5(T - T_0) \tag{6}$$

where,

$a_E(E)$ = time-deformation shift factor,

$a_A(A)$ = time-age shift factor,

$a_T(T)$ = time-temperature shift factor,

$K_1$, $K_2$ = material constants determining the deformation effect,

$K_3$, $K_4$ = material constants determining the age effect, and

$K_5$, = material constant determining the temperature effect.

To determine the relaxation modulus from laboratory tests, the following equations were used to convert the unit extension into Cauchy stress (or true stress) and finite strain [1]:

$$\sigma(t) = \frac{P(t)}{A(t)} = \frac{P(t)L(t)}{W_i T_i L_i} \qquad (7)$$

$$E_{11} = \frac{1}{2}(\Lambda^2_{(1)} - 1) \qquad (8)$$

where

$\sigma(t)$ = Cauchy stress (or true stress) at time t,

P(t) = load at time t,

A(t) = deformed cross-sectional area at time t,

$W_i$ = initial width of the test specimen,

$T_i$ = initial thickness of the test specimen,

$L_i$ = initial length of the test specimen,

$E_{11}$ = the tensile strain in the load direction, and

$\Lambda_{(1)}$ = $L(t)/L_i$ = stretch.

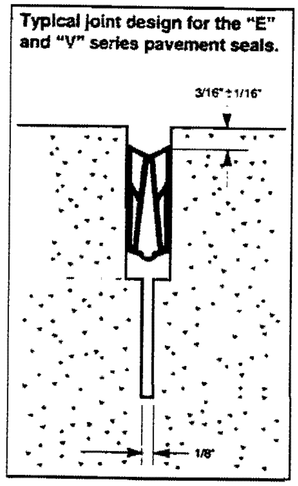
Relaxation modulus is then obtained as

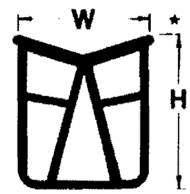
$$E_R = \frac{\sigma(t)}{E_{11}} \qquad (9)$$

Note that $\Lambda_{(1)} - 1 = [L(t)- /L_i]/L_i$ is referred to as unit extension.

## PREFORMED JOINT SEALANT

Delastic preformed neoprene seals supplied by D.S. Brown Co. were evaluated in the laboratory. Two preformed compression seal models viz., V-687 and V-812 as shown in Figure 9 were tested. These seals are used to prevent the entry of harmful and damaging particles and moisture into a concrete pavement joint. This is achieved by exerting a constant compressive force on the joint reservoir wall while allowing the concrete pavement to move because of temperature and moisture changes. These V-series models are generally used for sealing joints in concrete pavements.




| Model | Nominal Width (W), mm | Nominal Height (H), mm |
|---|---|---|
| V-687 | 17.46 | 20.64 |
| V-812 | 20.64 | 23.81 |

**Figure 9.** Preformed Compression Seal Models V-687 and V-812.

## Weathering

Samples of the preformed joint sealant were artificially weathered to study the effect of aging on the seal behavior. A number of 150-mm-long strips were cut from the roll supplied and were subjected to artificial weathering in the Atlas Weather-Ometer. These were exposed along with other joint sealants such as silicone and asphalt-based sealant. The specimens were placed in the mold and were exposed only from the top. These samples were tested in compression relaxation mode at different levels of weathering, namely 0, 1000, and 2000 hours.

### Test Specimen and Procedure

The test specimens measured 76 mm in length and were obtained by cutting off the ends of the 150-mm-long strips. This was primarily done to remove the ends of the strips which might have been exposed to radiation from the sides. The test specimens were supported by thin plywood strips on both ends to prevent any slipping while they were compressed to the desired level. The plywood strips were not glued to the test specimen because of the compressive nature of the test.

Two levels of compressive strains, 15 and 30% were used in the study. For each age level, the specimens were compressed to the desired strain level at a rate of 52 mm/min and held constant in that position with time. The load required to maintain the deformation was measured and recorded to study the relaxation behavior. The test and measurement were accomplished using the Instron model 4505 test system.

## ACCELERATED WEATHERING (AGING)

Joint sealant materials were subjected to repeated exposure to accelerated weather cycles in the Atlas Ci65A Weather-Ometer® system (Figure 10) [9]. The Ci65A Xenon Weather-Ometer® has a controlled irradiance Xenon exposure system. It reproduces and accelerates the degradation process of the specimen by controlling parameters including black panel temperature, dry bulb temperature, humidity, light, and water spray. The weather cycle, as shown in Table 4, was 120 minutes long and consisted of 60 minutes of light exposure only, followed by 40 minutes of light exposure and water spray, and finally a dark period of 20 minutes. The term "cycle" is defined as the total time for all exposure conditions to be repeated. The samples were placed horizontally inside the apparatus as shown in Figure 10. The radiant energy is provided by a single water-cooled-xenon-arc lamp whose filtered spectral output closely simulates natural sunlight (Figure 11). ASTM Standards, D 4798, "Standard Test Method for Accelerated Weathering Test Conditions and Procedures for Bituminous Materials (Xenon-Arc Method)" [12], and G 26, "Practice for Operating Light-Exposure Apparatus

(Xenon-Arc Type) With and Without Water for Exposure of Nonmetallic Materials" [13] were used to successfully weather the test samples.

The temperature, moisture, and radiation conditions provided by the Atlas Weather-Ometer are different from those in nature. (Figure 12 compares spectral distributions of natural sunlight and the radiant rays in the Atlas Ci65A.) Efforts were made to determine the equivalency of the natural and artificial wearthering , which will be discussed in Chapter 5.

**Table 4.** Operating Cycle of the Exposure.

| Test Conditions | Time, min |
|---|---|
| Light only (60 °C ± 3 °C black panel temperature) | 60 |
| Light with spray | 40 |
| Dark | 20 |
| A complete cycle | 120 |
| Total cycle time (12 complete cycles) | 24 h |

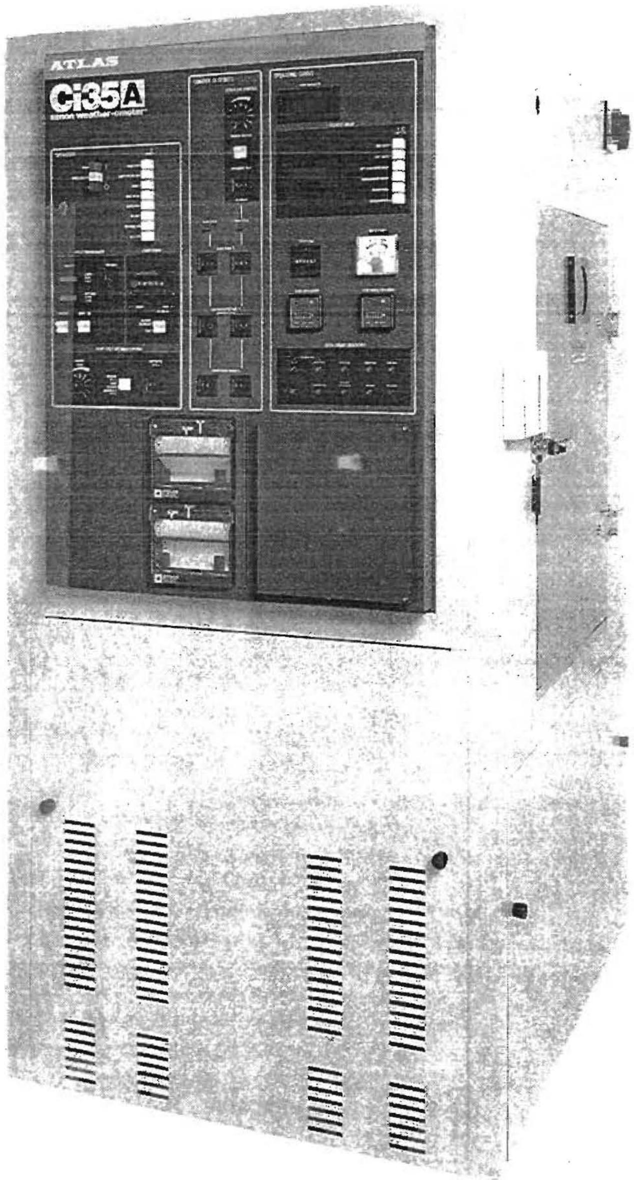



**FIGURE 10.** Atlas Ci65A Xenon Weather-Ometer®.

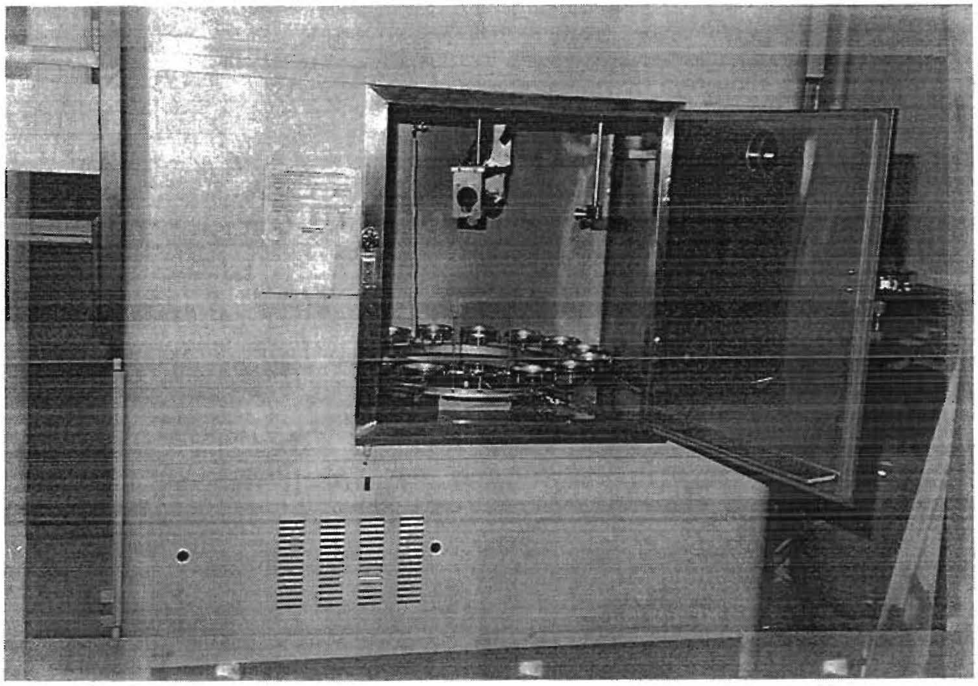


**FIGURE 11.** Test Samples in Atlas Ci65A Xenon Weather-Ometer®.

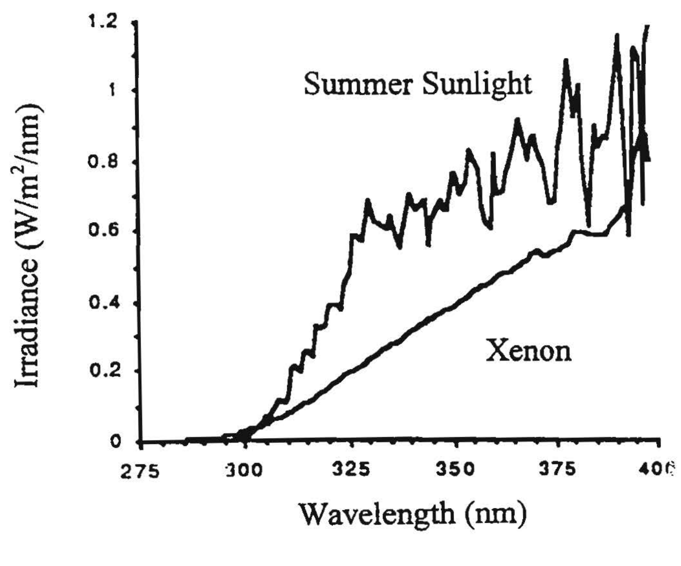



**FIGURE 12.** Comparison of Spectral Distribution of Natural Sunlight and Atlas Ci65A.

# CHAPTER 4 ANALYSIS OF EXPERIMENTAL DATA

## INTRODUCTION

This chapter presents the analysis of experimental data obtained from relaxation tests under different conditions. The analysis of the relaxation test results, as well as the bond and fatigue test results, forms the basis of the specification and test protocol listed in Appendices A and B. The bond and fatigue tests have been previously described in the final report of project 1371 [1].

## MATERIAL MODEL

Due to their apparent viscoelastic nature, stress relaxation tests were employed to investigate the time-dependent properties and aging characteristics of joint sealants. In the relaxation test, the sample was brought to a predetermined unit extension level and held indefinitely. The decaying load to maintain the given unit extension level was recorded using the Instron data acquisition system. These data were then converted into a relaxation modulus using finite strain and true stress definitions.

Up to six different levels of unit extensions namely 5, 10, 20, 30, 50 and 100%, five levels of age, namely 0, 500, 1000, 1500, and 2000 hours of exposure time, and five different temperature levels, namely -25, 0, 25, 40, and 60 °C, were used in this study. Relaxation modulus curves were successively normalized to account first for deformation, then for age, and finally for temperature. As a result, a master relaxation modulus curve was obtained, in which factors of deformation, age, and temperature are converted to the factor of time by three shift relationships. These relationships are combined to form *material shift factors* (Equations 3-6).

All the relaxation modulus curves obtained for Crafco 903 SL (Table 1) are plotted in Appendix D. Data for Dow Corning 888, Dow Corning 890 SL, Percol joint sealant, and Fox Industries FX-570 have been shown in the final report of project 1371. For Percol joint sealant and Fox Industries FX-570, relaxation tests were conducted only at room temperature (25 °C), and the temperature dependence was not measured due to time and budget constraints. To maintain the clarity of explanation, only Crafco 903 SL will be discussed in the following sections. But the results for other materials are provided where appropriate.

### Time-Deformation Shift Factor, $a_E(E)$

Relaxation modulus curves measured for various unit extension levels are shown in Figures 44-63 of Appendix D for the material Crafco 903 SL. These relaxation modulus curves were normalized for deformation. This was achieved by horizontally shifting the individual curves to superimpose them on a chosen reference unit extension level. In this study, a unit extension level of 5% was chosen as the reference level, $\varepsilon_0$. Accordingly, all the curves were shifted to the right to form a smooth curve. The amount of shifts for each unit extension level was recorded. The time-deformation shift factors, $a_E$ (E) for Crafco 903 SL are shown in Figure 64. Figures 65-69 show the resulting curves for all temperature and age levels. For convenience, all these curves normalized for unit extension are displayed on the same plot for each temperature level.

Using the shifts required to generate a master curve, the time-deformation shift relationship, $a_E(E)$, in the form of Equation 4 was deduced for each material. The material constants, $K_1$ and $K_2$ , of time-deformation shift relationships, $a_E$ (E), were obtained as a minimum error fit, as shown in Table 5. The solid line in Figure 64 is the fitted curve (Equation 4) is found to be a good fit to the observed data.

### Time-Age Shift Factor, $a_A(A)$

Figure 70 of Appendix D collectively illustrates the relaxation modulus curves normalized for all age levels obtained under five different temperature levels. The effect of exposing the specimen to UV radiation, temperature, and moisture is clearly evident from these figures. As expected, the material became stiffer with age, and the modulus increased with each exposure level. As proposed, the effect of age was normalized by forming yet another master curve.

**Table 5.** Time-Deformation Shift Constants.

| Joint Sealant | $K_1$ | $K_2$ |
|---|---|---|
| Dow Corning 888 | 10.66 | 109.12 |
| Dow Corning 890 SL | 6.36 | 72.52 |
| Crafco 903 SL | 9.63 | 49.10 |
| Percol Joint Sealant | 5.62 | 29.04 |
| FX 570 | 7.66 | 27.31 |

This time, the unaged level (zero hours of exposure) was chosen as the reference age, and the curves in Figures 65-69 were moved horizontally to the left. These shifts are plotted in Figure 71. Equation 5 was used to describe the relationship between age and the time-age shift factor.

The fitted relationship is plotted in Figure 70 of Appendix D along with observed values of the time-age shift factors for each material. The new normalized relaxation modulus curves are thus obtained, which have been normalized for deformation and age. For convenience, all these curves are shown together for different temperatures in the same figure. The time-age shifts constants, $K_3$ and $K_4$, obtained for all the materials tested are tabulated in Table 6.

**Table 6.** Time-Age Shift Constants.

| Joint Sealant | $K_3$ | $K_4$ |
|---|---|---|
| Dow Corning 888 | 3.79 | 888.00 |
| Dow Corning 890 SL | 12.11 | 13700.00 |
| Crafco 903 SL | 102.97 | 35230.00 |
| Percol Joint Sealant | 4.69 | 1082.00 |
| FX 570 | 6.54 | 686.65 |

### Time-Temperature Shift Factor, $a_T(T)$

Figure 72 shows the relaxation modulus normalized for deformation and age effects. As can be seen from the plot, these curves can be shifted one more time to form a "final" master relaxation modulus curve for the material. A temperature of 25 °C was chosen as the reference temperature, and the curves were shifted to the right or left accordingly. Figure 73 shows the plot of time-temperature shift factors. Equation 6 for the time-temperature shift factors was used to fit a curve and determine the material constants. Table 7 provides the values of $K_5$ for the material tested. Figure 56 shows the final master relaxation modulus curve obtained for Crafco 903 SL after normalizing for unit extension, age, and temperature dependence.

**Table 7.** Time-Temperature Shift Constants.

| Joint Sealant | $K_5$ (T < 25 °C) | $K_5$ (T > 25 °C) |
|---|---|---|
| Crafco SL 903 SL | 1.884 | 0.01237 |
| Dow Corning 890 SL | - | - |
| Dow Corning 888 | - | - |

## ANALYTICAL MATERIAL MODEL

A model for pavement joint sealants can be developed reliably if an appropriate material model representing the behavior of the material is incorporated. The constitution of silicone and polymer sealants is such that it displays a viscoelastic behavior. These materials are neither pure elastic solid nor pure fluid. Their response lies somewhere in between these two extremes. The constitutive equation, which relates the response of the material to external displacements, can be developed from relaxation modulus curves. The viscoelastic behavior can be represented by various combinations of springs and dashpots [14-16]. A linear spring element represents instantaneous elasticity and instantaneous recovery, whereas, a dashpot represents the viscous nature of the material. These basic units can be arranged in various combinations to represent a particular material response. For this study, the Generalized Maxwell model in parallel was chosen to represent the sealant behavior as it can accurately predict the time-dependence of stress associated with a prescribed strain variation. This model is also easy to incorporate in finite element analysis.

**Generalized Maxwell Model**

The Maxwell model consists of linear spring and linear viscous dashpot elements connected in series. In the generalized Maxwell model in parallel, Maxwell units are connected in parallel with a single spring element, shown in Figure 13. This model represents instantaneous elasticity, delayed elasticity with various retardation times, stress relaxation with various relaxation times, and viscous flow. The generalized Maxwell model in parallel can be used to predict stress associated with a prescribed strain variation more accurately since the same strain is applied to each individual element. The resulting stress is then simply the sum of the individual contributions of each Maxwell unit. The relaxation modulus, $E_R$, for a generalized Maxwell model in parallel is given by:

$$E_R(\tau) = E_0 + \sum_{i=1}^{n} E_i \, e^{\frac{-E_i \tau}{\eta_i}} \qquad \textbf{(10)}$$

where

$E_R(\tau)$ = relaxation modulus,

$E_i$, $\eta_i$ = modulus and viscosity of ith Maxwell unit, and

n = the total number of the Maxwell units.

The above equation is generally written in the following form for convenience:

$$E(\tau) = E_0 + \sum_{i=1}^{n} E_i \, e^{-\frac{\tau}{\zeta_i}} \qquad \textbf{(11)}$$

where

$\zeta_i = \eta_i / E_i$ = relaxation time for ith Maxwell unit.

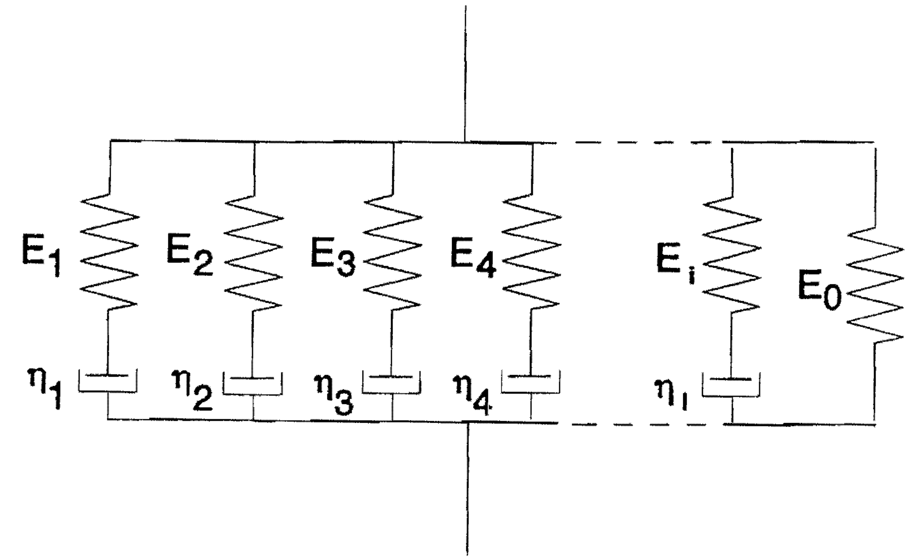



**Figure 13.** Generalized Maxwell Model.

The relaxation moduli of a viscoelastic material is determined from stress relaxation tests. Once the "master relaxation modulus" curve normalized for the deformation, age, and temperature effects is obtained for a material, a generalized Maxwell model can be fitted to the experimental data. There are different numerical techniques to obtain parameters for the Maxwell model that make the master relaxation modulus curve fit the experimental data. One method would be to minimize the square error between the measured relaxation modulus data and analytical representation, i.e., generalized Maxwell model (Equation 11). Another common method is to equate the experimental data and analytical representation at several points. This matching procedure is called the collocation method.

The range of variation of a single exponential function is approximately one decade, and if several exponentials with widely separated relaxation times are added together, it results in the staircase-type function. However, if the time constants are selected close together, the exponentials blend together to form a smooth curve. It is clear that these times should not be separated by more than a decade.

The two sets of unknown coefficients, $E_i$ and $\zeta_i$, were determined by using the collocation technique. This was easily done by solving Equation 11 for an arbitrarily chosen set of relaxation times ($\zeta_i$'s) for each Maxwell unit. Once the $\zeta_i$'s are fixed, Equation 11 reduces to a set of simple equations which are solved simultaneously to obtain the modulus values. Tables 8-12 list the values of relaxation time used for each material and the corresponding modulus ($E_i$) values obtained from the solution. Once the relaxation modulus for each unit was obtained, the corresponding coefficients of viscosities were calculated using the following relationship:

$$\eta_i = \rho_i E_i \tag{12}$$

In Figures 14-18, the master relaxation modulus curves obtained from the laboratory tests and the one described by fitted Generalized Maxwell Model in parallel are plotted for each material. As seen from the figures, the fitted model provides an accurate and reliable fit to the laboratory curves.

**Table 8.** Coefficients of Generalized Maxwell Model for Crafco 903 SL.

| Element # | Modulus (psi) $E_i$ | Coefficient of Viscosity $h_i$ (psi-sec) | Log Relaxation Time $t_i$ (sec) |
|---|---|---|---|
| 0 | 16.674 | - | - |
| 1 | 0.8 | 1.6E-3 | 2E-03 |
| 2 | 1.531 | 3.06E-2 | 2E-02 |
| 3 | 1.537 | 3.07E-1 | 2E-01 |
| 4 | 0.804 | 1.6 | 2E+00 |
| 5 | 0.852 | 1.7E+1 | 2E+01 |
| 6 | 0.7 | 1.4E+2 | 2E+02 |
| 7 | 0.64 | 1.38E+3 | 2E+03 |
| 8 | 0.94 | 1.88E+4 | 2E+04 |
| 9 | 0.519 | 1.04E+5 | 2E+05 |
| 10 | 0.902 | 1.8E+6 | 2E+06 |
| 11 | 0.631 | 1.26E+7 | 2E+07 |
| 12 | 0.795 | 1.6E+8 | 2E+08 |
| 13 | 0.667 | 1.334E+9 | 2E+09 |
| 14 | 0.358 | 7.16E+9 | 2E+10 |
| 15 | 0.673 | 1.35E+11 | 2E+11 |
| 16 | 0.358 | 7.16E+11 | 2E+12 |
| 17 | 0.698 | 1.396E+13 | 2E+13 |

**Table 9.** Coefficients of Generalized Maxwell Model for Dow Corning 888.

| Element # | Modulus (psi) $E_i$ | Coefficient of Viscosity $h_i$ (psi-sec) | Log Relaxation Time $t_i$ (sec) |
|---|---|---|---|
| 0 | 16.674 | - | - |
| 1 | 7.59 | 1.52E-01 | 2E-02 |
| 2 | 16.918 | 3.384 | 2E-01 |
| 3 | 33.585 | 67.17 | 2E+00 |
| 4 | 29.622 | 5.92E+02 | 2E+01 |
| 5 | 33.807 | 6.76E+03 | 2E+02 |
| 6 | 10.776 | 2.152E+04 | 2E+03 |
| 7 | 5.019 | 1.004E+05 | 2E+04 |

**Table 10.** Coefficients of Generalized Maxwell Model for Dow Corning 890 SL.

| Element # | Modulus (psi) $E_i$ | Coefficient of Viscosity $h_i$ (psi-sec) | Log Relaxation Time $t_i$ (sec) |
|---|---|---|---|
| 0 | 2.27 | - | - |
| 1 | 1.965 | 3.93E-1 | 2E-01 |
| 2 | 7.343 | 1.468 | 2E+00 |
| 3 | 11.67 | 2.334E+02 | 2E+01 |
| 4 | 4.272 | 8.544E+02 | 2E+02 |
| 5 | 0.807 | 1.614E+03 | 2E+03 |
| 6 | 0.605 | 1.21E+04 | 2E+04 |

**Table 11.** Coefficients of Generalized Maxwell Model for Percol Joint Sealant.

| Element # | Modulus (psi) $E_i$ | Coefficient of Viscosity $h_i$ (psi-sec) | Log Relaxation Time $t_i$ (sec) |
|---|---|---|---|
| 0 | 23.4 | - | - |
| 1 | 9.776 | 1.96E-2 | 2E-03 |
| 2 | 5.246 | 1.05E-1 | 2E-02 |
| 3 | 0.65 | 1.3 | 2E-01 |
| 4 | 4.019 | 8.04 | 2E+00 |
| 5 | 2.339 | 4.67E+1 | 2E+01 |
| 6 | 2.502 | 5.0E+2 | 2E+02 |
| 7 | 2.635 | 5.27E+3 | 2E+03 |
| 8 | 2.375 | 4.75E+4 | 2E+04 |
| 9 | 1.178 | 2.36E+5 | 2E+05 |
| 10 | 3.284 | 6.34E+6 | 2E+06 |
| 11 | 3.261 | 6.32E+7 | 2E+07 |

**Table 12.** Coefficients of Generalized Maxwell Model for FX-570.

| Element # | Modulus (psi) $E_i$ | Coefficient of Viscosity $h_i$ (lb/in$^2$-sec) | Log Relaxation Time $t_i$ (sec) |
|---|---|---|---|
| 0 | 50.674 | - | - |
| 1 | 19.878 | 0.03976 | 2E-03 |
| 2 | 37.899 | 0.75798 | 2E-02 |
| 3 | 36.902 | 7.3804 | 2E-01 |
| 4 | 42.941 | 85.882 | 2E+00 |
| 5 | 0.464 | 9.28 | 2E+01 |
| 6 | 63.342 | 1.27E+3 | 2E+02 |
| 7 | 10.349 | 2.07E+4 | 2E+03 |
| 8 | 32.051 | 6.41E+5 | 2E+04 |
| 9 | 5.051 | 1.01E+6 | 2E+05 |
| 10 | 20.965 | 4.19E+7 | 2E+06 |
| 11 | 11.24 | 2.25E+8 | 2E+07 |
| 12 | 11.169 | 2.24E+9 | 2E+08 |
| 13 | 4.663 | 9.33E+9 | 2E+09 |
| 14 | 14.112 | 2.82E+11 | 2E+10 |

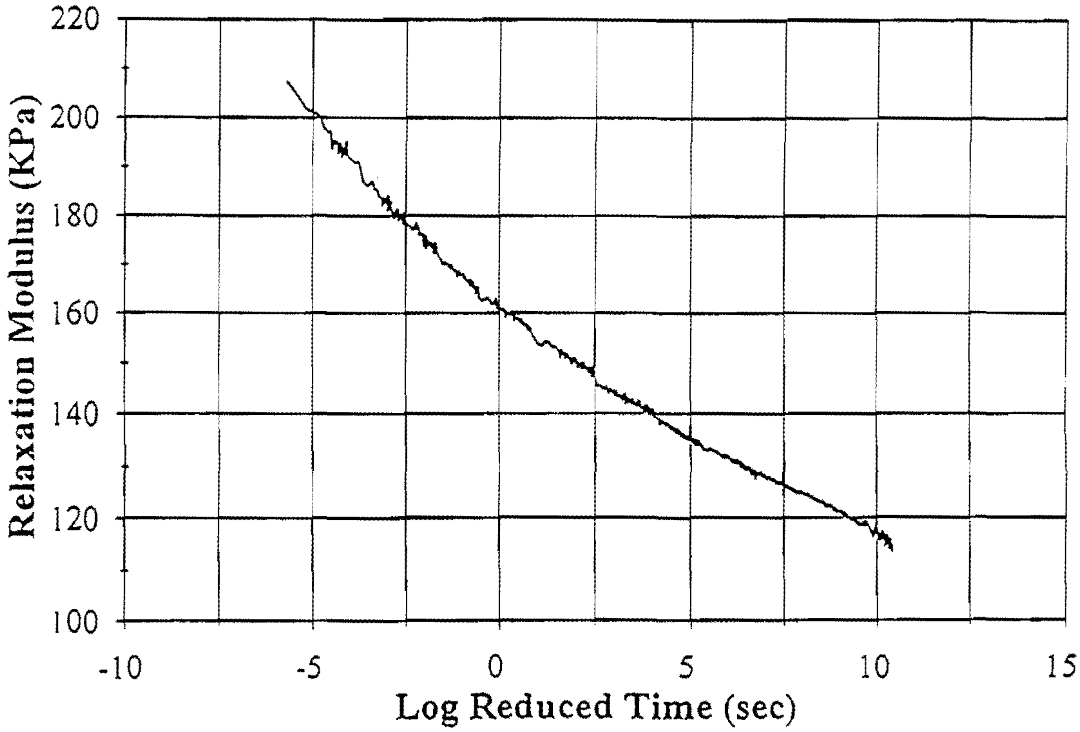



**Figure 14.** Master Relaxation Modulus Curve and Fitted Generalized Maxwell Model for Crafco 903 SL.

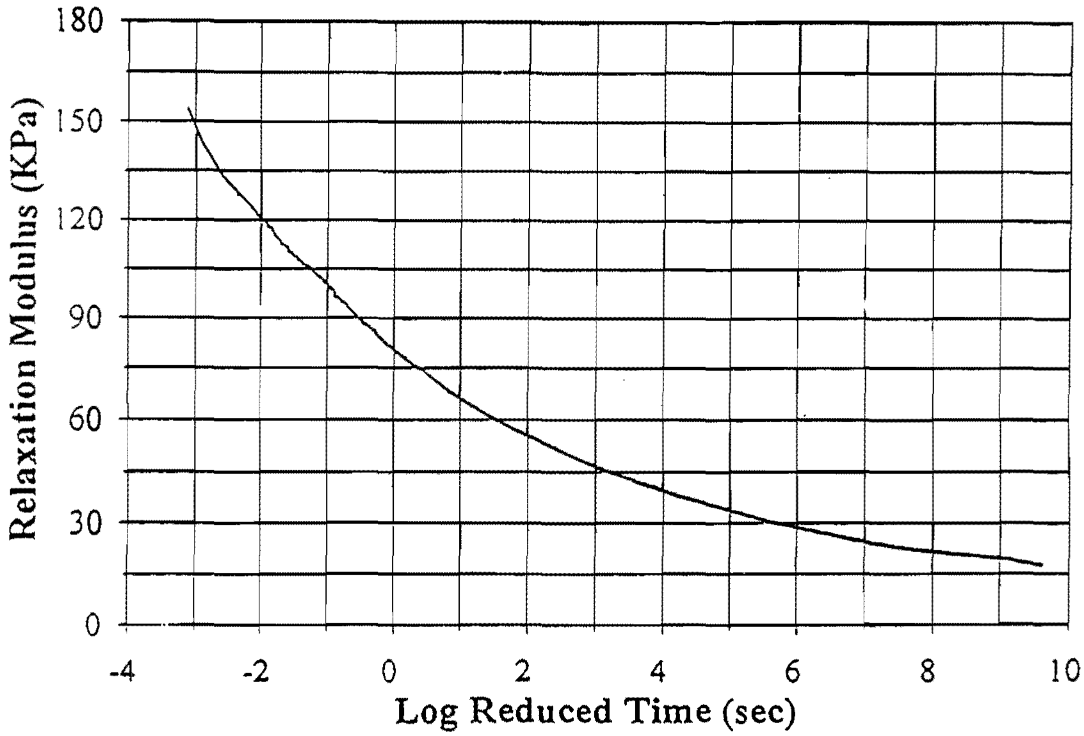



**Figure 15.** Master Relaxation Modulus Curve and Fitted Generalized Maxwell Model for Dow Corning 888.

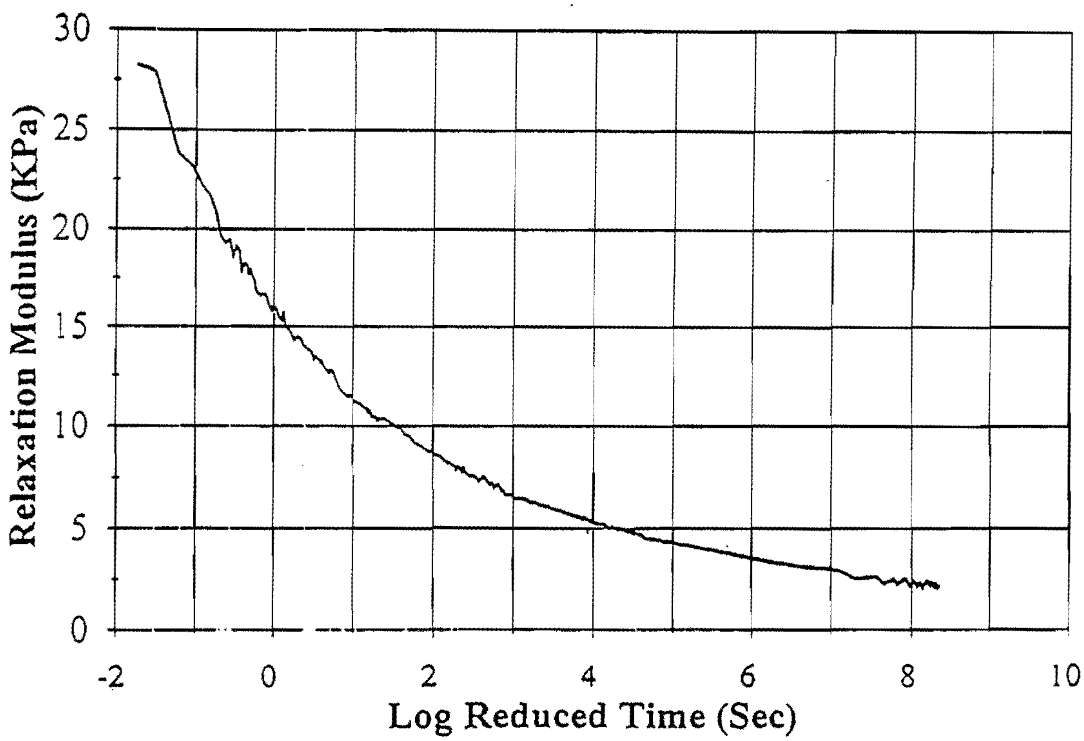



**Figure 16.** Master Relaxation Modulus Curve and Fitted Generalized Maxwell Model for Dow Corning 890 SL.

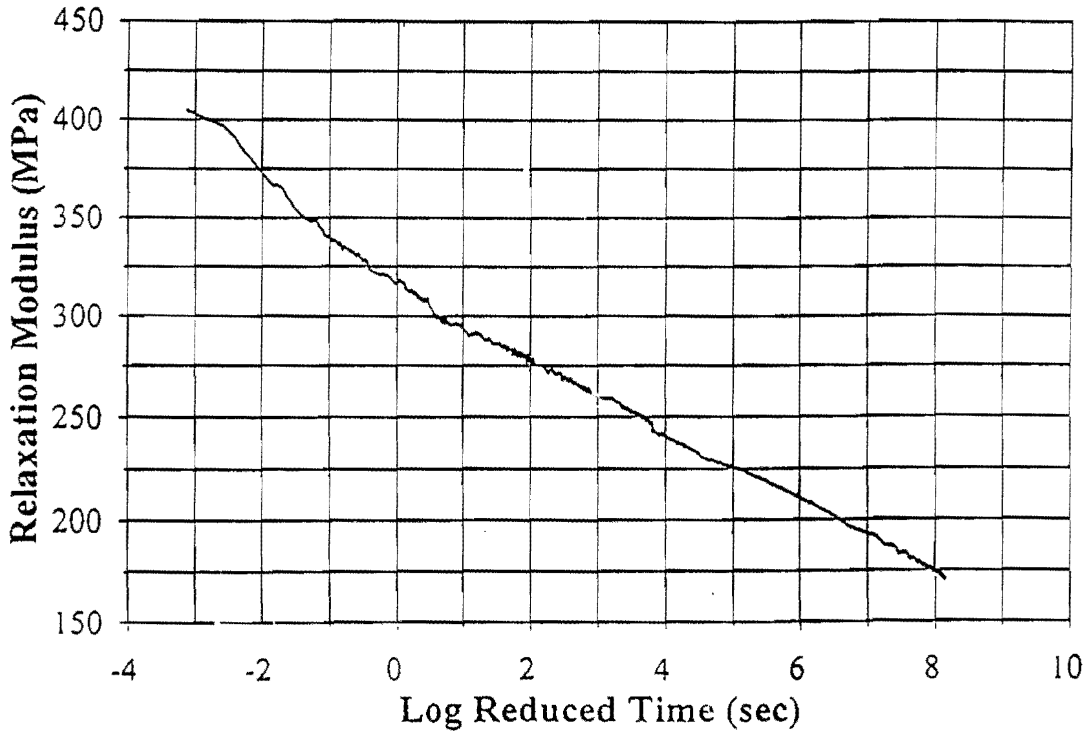



**Figure 17.** Master Relaxation Modulus Curve and Fitted Generalized Maxwell Model for Percol Joint Sealant.

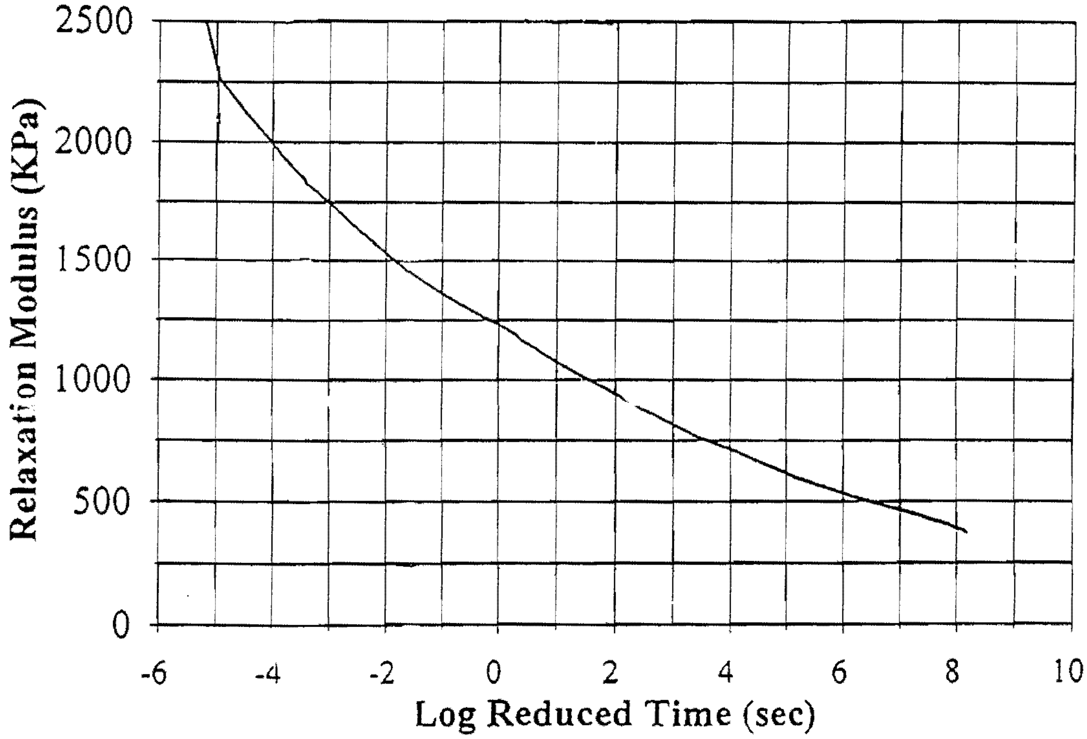



**Figure 18.** Master Relaxation Modulus Curve and Fitted Generalized Maxwell Model for Fox Industries FX-570.

## PREFORMED JOINT SEAL TEST RESULTS

For preformed joint seals, the test duration was consistent with the other relaxation tests performed on silicone and polymer sealants. Figures 19-22 show the decaying modulus with time. It should be noted that the stiffness of this type of seal is a "structural" stiffness since the 'modulus' refers to the overall rigidity of the seal and not elastic modulus of the material. These figures clearly show that the stress relaxation occurs in the seals. With time, the preformed compression seal loses its compressive reaction for the same amount of deformation. The extent of this compressive loss will greatly affect the performance and service life of the sealant. A preformed joint seal will be effective in field only if it maintains a certain amount of compressive reaction on joint reservoir walls.

The effect of aging was also apparent from these figures. The seal structure hardened and became stiffer with greater levels of exposure. The amount of increase in modulus is large enough to warrant its inclusion in the design process. As seen from the plots, aging caused the modulus to increase, and this upward shift between two ages was generally constant with time. This behavior was clearly displayed in all tests except for model V-812 at 30% compression. The implication of this behavior is that a master curve can be generated to normalize the effect of aging and strain by simply shifting the curves horizontally.

Equations similar to those proposed to normalized temperature, deformation, and age in silicone sealant can be also used for preformed compression seals. To develop these master curves and to determine the shift factors, a more rigorous test program involving different test temperatures should be explored and its effects characterized.

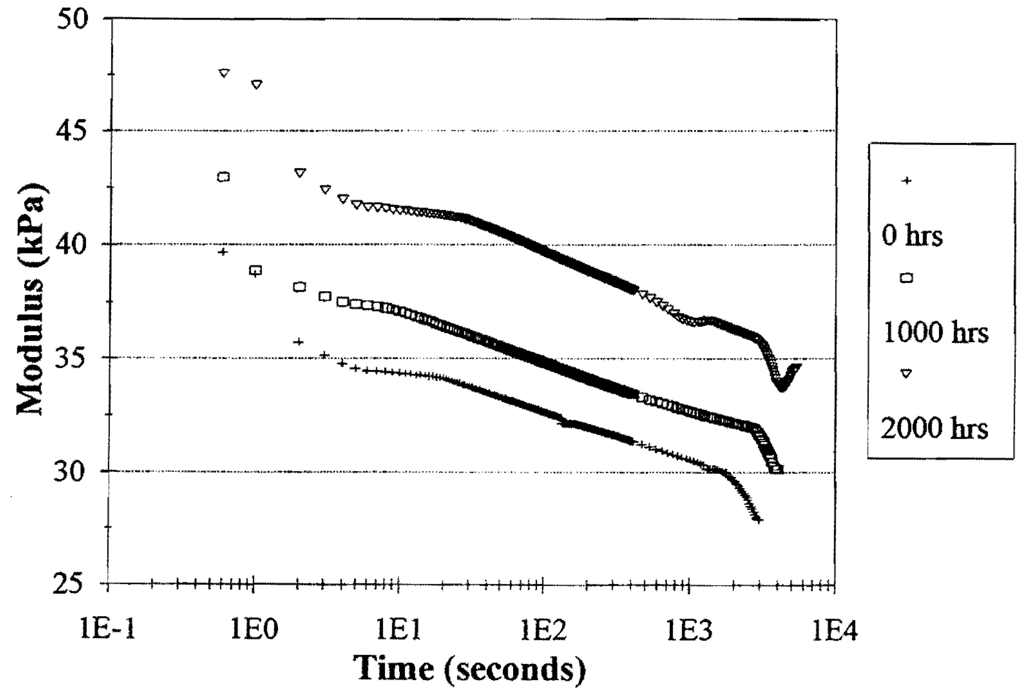



**Figure 19.** Relaxation Modulus for Seal V-687 at 15% Strain Level.

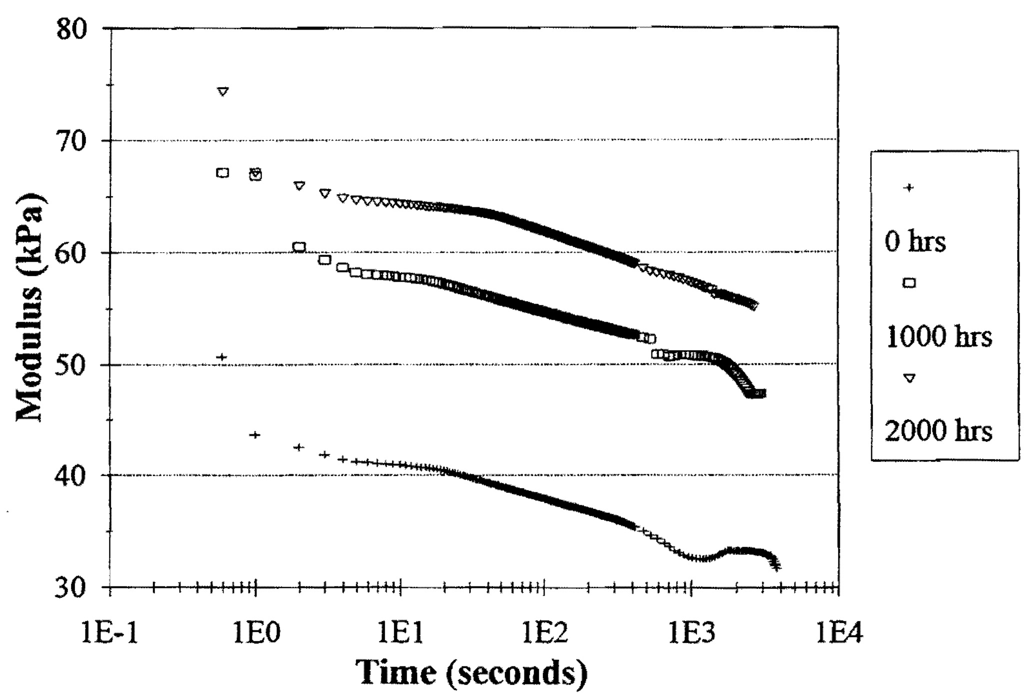



**Figure 20.** Relaxation Modulus for Seal V-687 at 30% Strain Level.

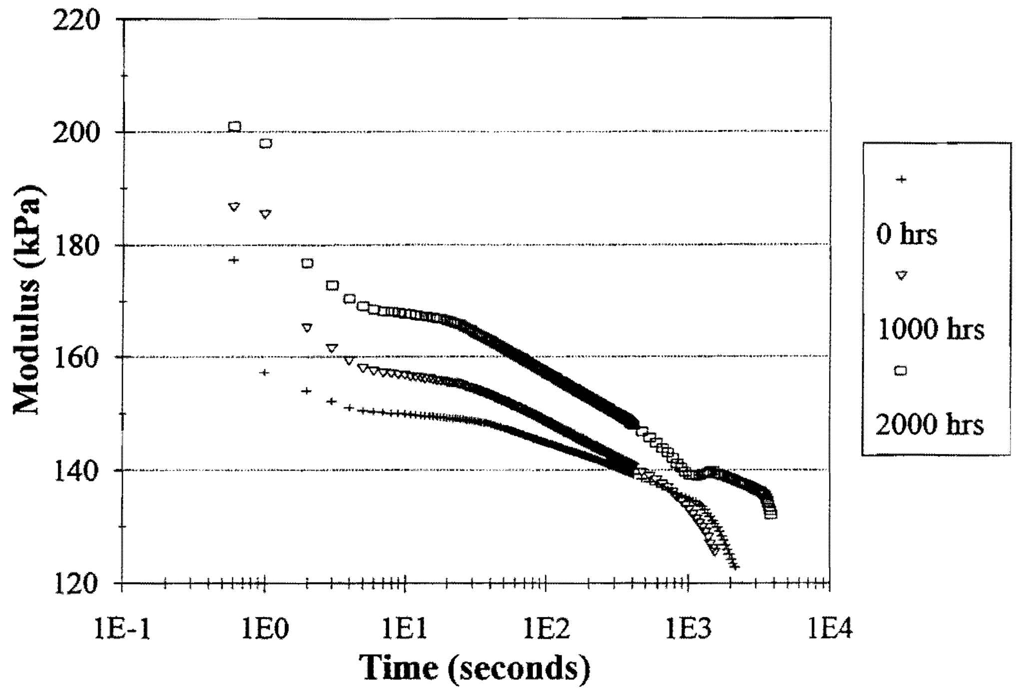



**Figure 21.** Relaxation Modulus for Seal V-812 at 15% Strain Level.

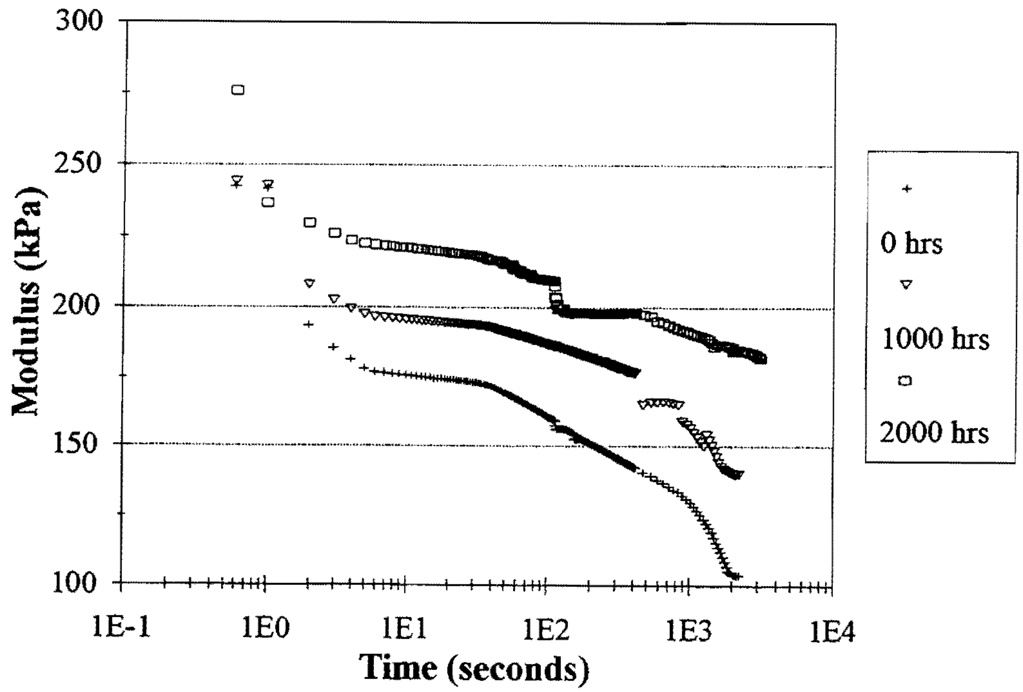



**Figure 22.** Relaxation Modulus for Seal V-812 at 30% Strain Level.

# CHAPTER 5 CORRELATIONAL STUDY OF ARTIFICIAL AND NATURAL WEATHERING

## INTRODUCTION

In service, a joint sealant is exposed to the natural environment. The environmental factors include:

- sunlight (UV radiation and heat radiation),
- ambient heat conduction, and
- precipitation, drainage, and moisture transfer.

Heat from the infra red portion of natural sunlight causes the temperature of the exposed body of the sealant to rise above ambient temperature while ultraviolet light of wavelengths between 280 and 400 nm, which makeup only about 6% of the total solar radiation received by the earth's surface, is largely responsible for the degradation of material. Presence of water or moisture may lead to macroscopic swelling of the sealant upon absorption. Water may also lead to the hydrolysis of chemical bonds within the sealant's polymeric matrix and manifest itself in the loss of adhesion. Thus, it is generally observed that the light, moisture, and heat combine synergistically in the natural environment to cause photochemical and mechanical changes in joint sealants [18].

These environmental factors listed above vary widely, even at the same geological location. In contrast, artificial weathering provides stable conditions. Radiation intensity, temperature, and moisture content in the artificial weathering chamber are controlled. Consequently, the artificial weathering chamber cannot completely simulate the natural weathering because of the complexity of the environmental factors. It is obviously important to understand how artificial weathering is correlated to natural weathering. The methodology used in this project is to correlate the relaxation modulus of the specimens weathered in these different ways because a series of relaxation tests conducted in project 1371 and this project have given equivalency among effects of temperature, deformation, and artificial aging on the relaxation modulus (Chapters 3 and 4).

## ARTIFICIAL WEATHERING

An Atlas Weather-Ometer® Ci65A was used to artificially weather the sealant specimens. Atlas Ci65A reproduces and accelerates the natural degradation process. The radiant energy in Ci65A is provided by a single, water-cooled xenon arc lamp whose spectral output closely simulates natural sunlight.

Samples were artificially aged and tested in the laboratory following the procedure shown in Chapter 3. The results of this test will be utilized to generate a correlation between artificial and natural weathering.

## NATURAL WEATHERING

For the purpose of correlating the two kinds of weathering, the joint sealant specimens were subjected to natural weathering according to ASTM G7 [17] specifications. The exposure site was located in College Station, Texas. Molded sheets of sealant material measuring 300 mm by 110 mm and 12.7 mm thick were placed on the rooftop on a plane surface at an angle of 5° facing the equator. Test specimens were cut from these sheets at periods of 2, 6, 12, 24, and 52 weeks and tested in the laboratory. These samples were subjected to the relaxation test regime.

The sealants subjected to natural weathering include Dow Corning 888 and 890SL, Crafco 903 SL, Crafco RoadSaver 231, Durafill 3405, Solarite KM, FX-570, and D.S. Brown Company's Preformed pavement joint seals model V687 and V812.

## SOLAR DATA

The solar data pertaining to the test period were obtained with the aid of the Meteorological Department of Texas A&M University. The weather station located nearby is capable of recording the ultra violet radiation, temperature, and wind speed, and downloads relevant data every five seconds via a modem. The solar ultraviolet radiation (UV) recorded every five seconds by the weather station was cumulatively added to obtain total radiation received for the appropriate time durations. The intensity of total UV radiation, plotted in Figures 23-26, was reasonably close to the one indicated by the general UV radiation contour maps.

## CORRELATION BETWEEN NATURAL WEATHERING AND ARTIFICIAL AGING

The relaxation tests conducted on these specimens are used to correlate natural and artificial aging for individual materials. Tests revealed that the different materials react differently to natural weathering. With controlled artificial weathering as the reference, some materials degraded faster than others. The researchers concluded that the correlation between the natural and artificial weathering is material-dependent. This is not surprising because different mechanisms prevail in degradation of different sealant materials [18].

It has been shown that a sealant material becomes stiffer after artificial weathering (Chapter 4). Similarly, natural weathering increases the relaxation modulus of the sealant material. Since there was considerable noise in the load records of the relaxation tests of naturally exposed specimens at unit extensions of 5% and 10%, relaxation test results at the unit extension of 30% are reported herein. Figures. 27-29 show relaxation moduli of Crafco 903 SL, Dow Corning 888, and Dow Corning 890 SL after weathering. In these figures, discrete marks indicate the relaxation moduli of artificially weathered specimens, while continuous curves (either solid or dashed) represent the relaxation moduli of naturally exposed specimens. It is easily seen that, in the sense of material stiffening, four weeks' natural exposure is equivalent to 1000 hours artificial weathering for Crafco 903 SL; four weeks' natural exposure is equivalent to 2200 hours artificial weathering for Dow Corning 888, and four weeks natural exposure is equivalent to 1000 hours artificial weathering for Dow Corning 890 SL; Material dependence of the correlation between the natural and artificial weathering is obvious.

It is usually expected that artificial weathering facilities accelerate the weathering process because these facilities provide more UV radiation than sunlight, and UV is usually taken as the primary cause of polymer degradation. The tests conducted in this project indicate that this point of view needs to be rectified. Although the spectrum of the UV

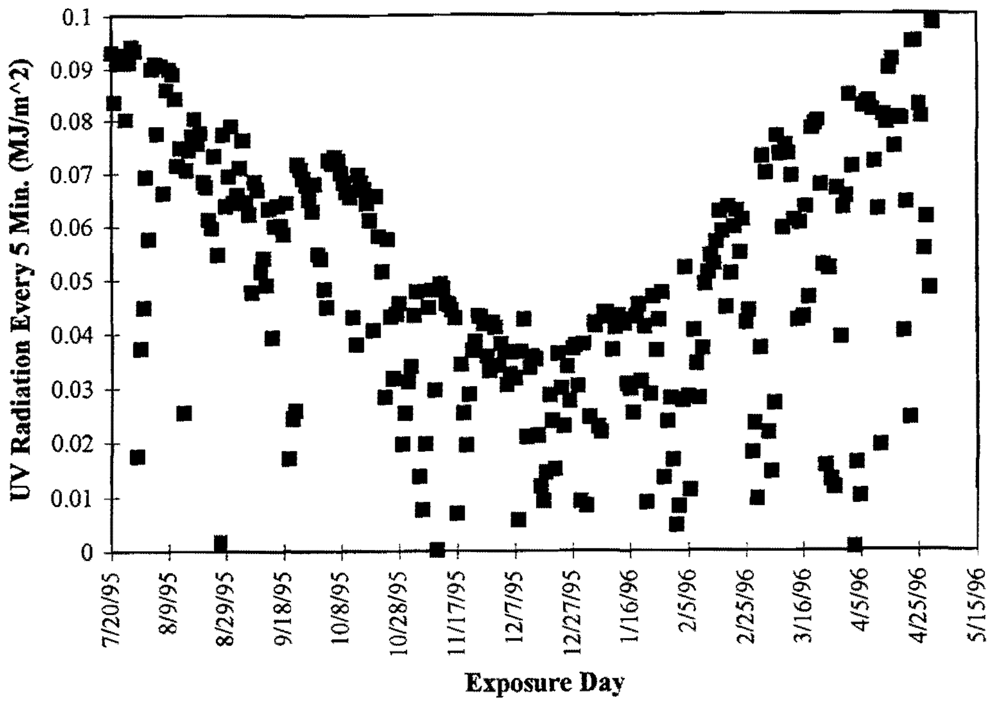



**Figure 23.** Solar Radiation Observed at the Exposure Site Weekly.

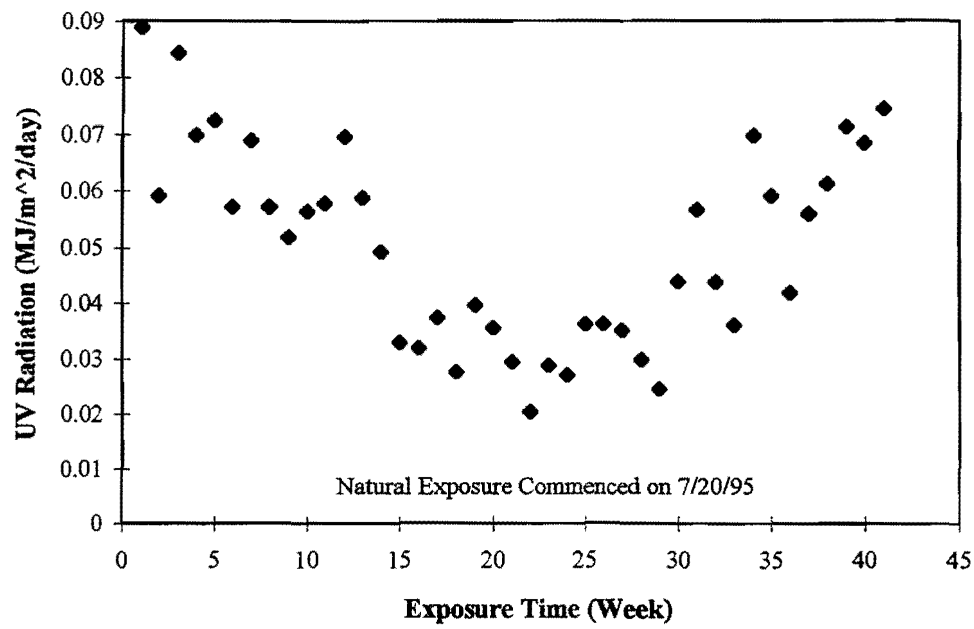



**Figure 24.** Average Daily Solar Radiation per Week at the Exposure Site.

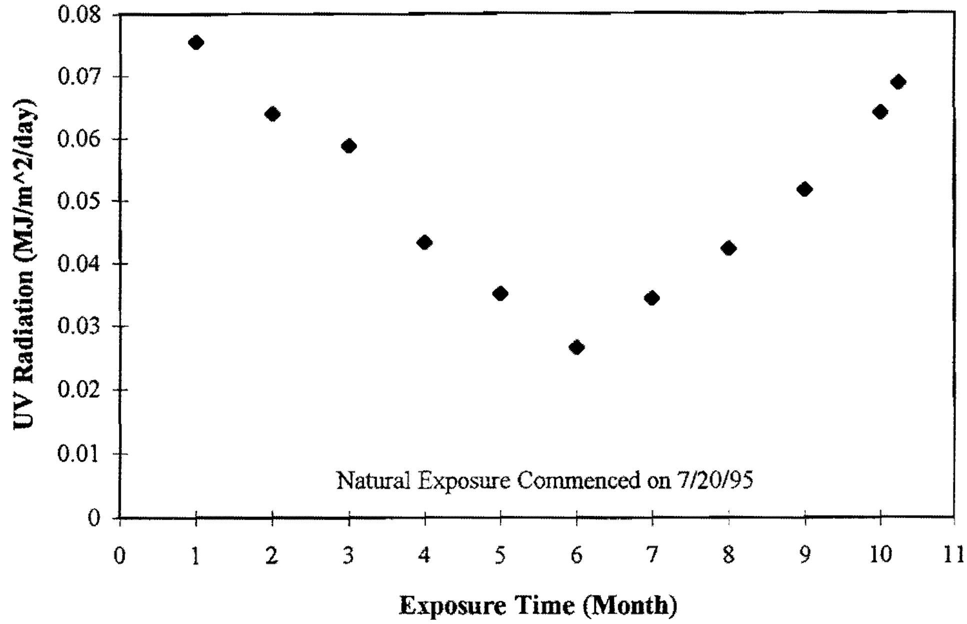



**Figure 25.** Average Daily Solar Radiation per Month at the Exposure Site.

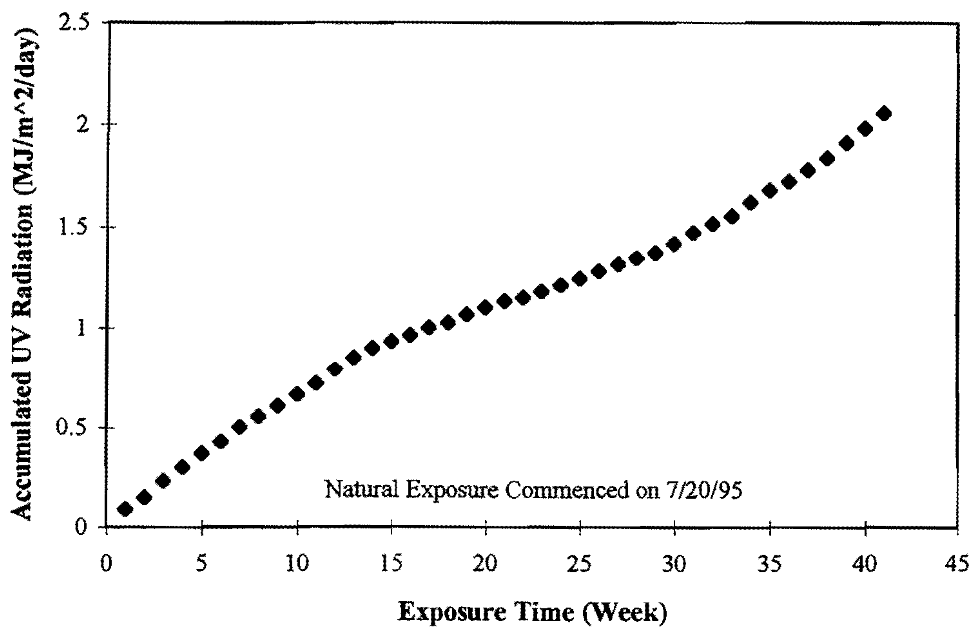



**Figure 26.** Accumulated Solar Radiation at the Exposure Site.

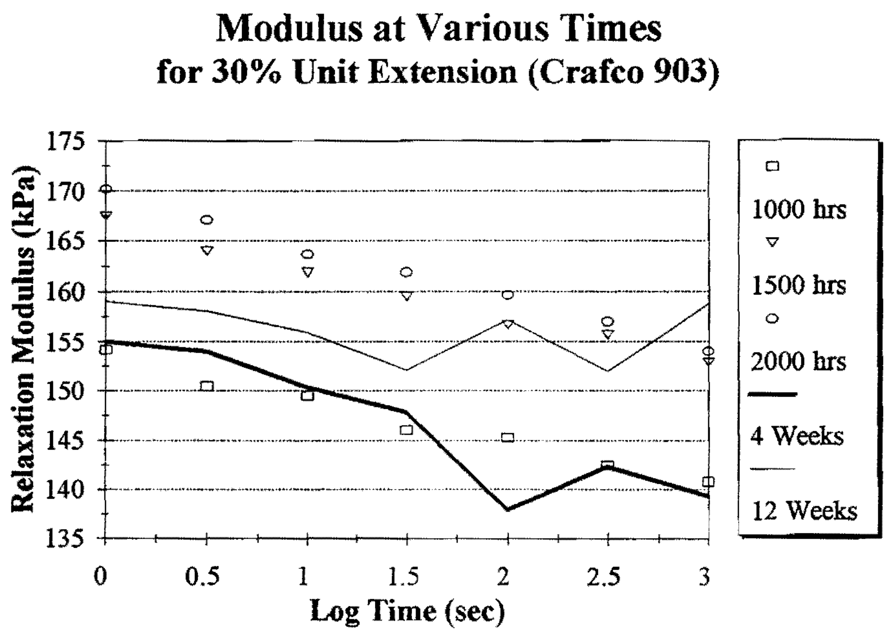



**Figure 27.** Relaxation Moduli of Crafco 903 SL After Natural and Artificial Weathering.

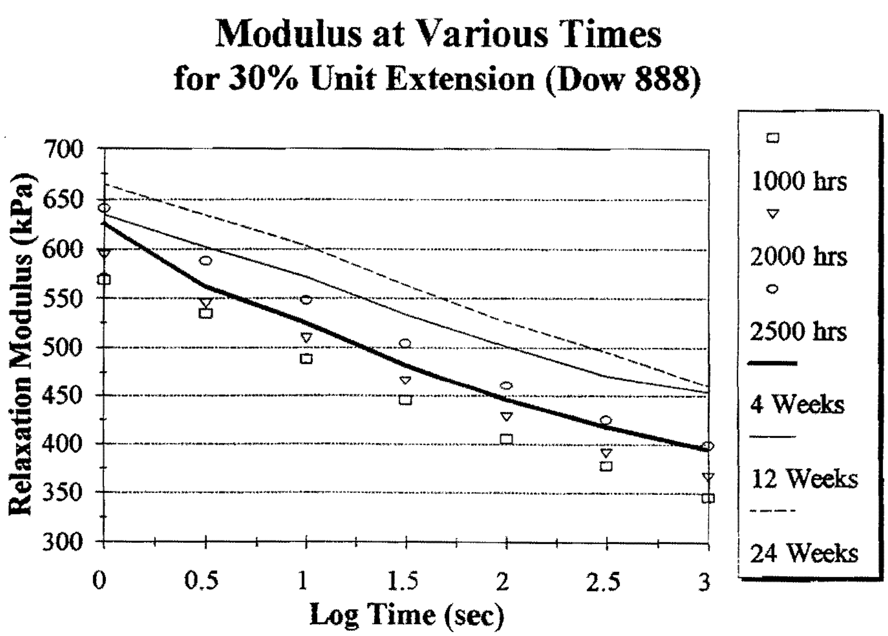



**Figure 28.** Relaxation Moduli of Dow Corning 888 After Natural and Artificial Weathering.

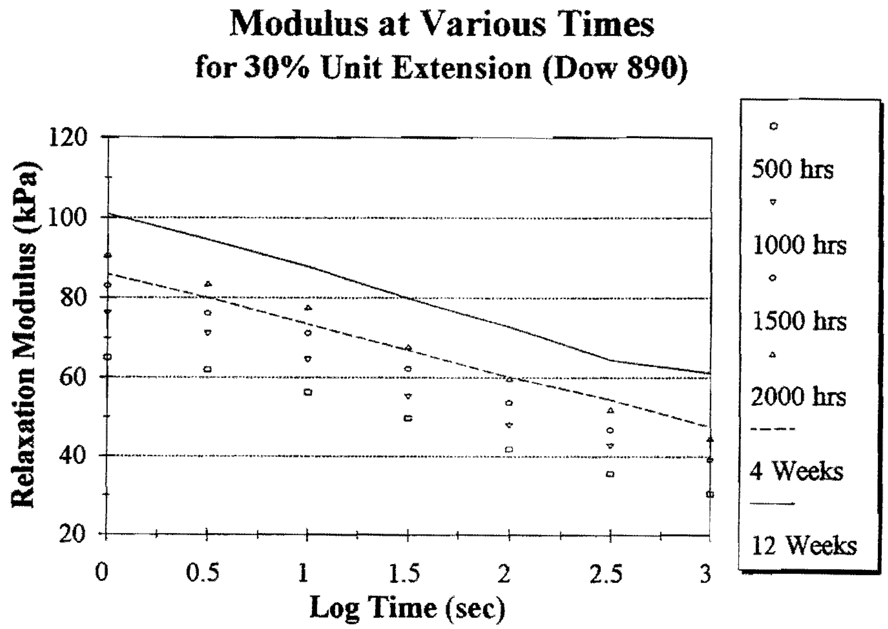



**Figure 29.** Relaxation Moduli of Dow Corning 890 SL After Natural and Artificial Weathering.

radiation is similar to that of the solar UV radiation, sunlight provides abundant visible and infrared rays which are scarce in the Weather-Ometer chamber. These rays apparently have significant effects on sealant material aging. To accurately simulate natural weathering, mechanisms of sealant material degradation should be studied. The major factors responsible for the degradation of a specific material must be counted in artificial weathering.

Apparently, artificial weathering represents the natural aging effects at different levels for different materials. In order to account for the effect of aging in the service life prediction process discussed in the next chapter, this effect will need to be incorporated to improve the prediction method.

# CHAPTER 6 PROCEDURE FOR ESTIMATION OF SERVICE LIFE OF A JOINT SEALANT

## INTRODUCTION

The procedure presented in this chapter is intended to assist in estimating the service life of a joint sealant material in concrete pavement. The proposed procedure is based on the laboratory findings and field performance data available for various joint sealants. This service life estimate can be used in performing cost-to-benefit analysis. There are situations where the sealant is needed only for a short duration, and then there are instances where maximum possible life is sought. Cost-to-benefit analysis is desirable in order to optimize the selection and use of joint sealant. The proposed procedure can be updated and modified by local agencies to suit their needs. A flow chart is presented in Figure 30 to illustrate the steps for using this procedure. The parameters for the service life of the, $N_b$ , $N_{lab}$ , and $N_{design}$ are all expressed in terms of the number of cycles of load. To estimate the expected service life of a joint sealant material for the purpose of design $N_{design}$, the following operations need to be executed in order:

- Step 1: obtain base life $N_b$ from the performance model under the standard conditions,
- Step 2: obtain the modified base life $N_{lab}$ , to account for the material and construction technique to be used, and
- Step 3: calibrate the modified life to local prevailing field conditions to determine $N_{design}$ .

To fulfill steps 1 and 2, a limited number of laboratory materials tests, including bond tests and relaxation tests, are necessary. Procedures for these tests of different types of sealant materials are provided in Appendices A and B. The sealant life determination procedure does not require fatigue tests since these tests are the most time consuming. Based on results of project 1371 and this project, effects of different service and construction conditions on the fatigue life of the sealant have been summarized in terms of adjustment factors. These factors can be easily determined by looking up the tables and graphs provided in this chapter.

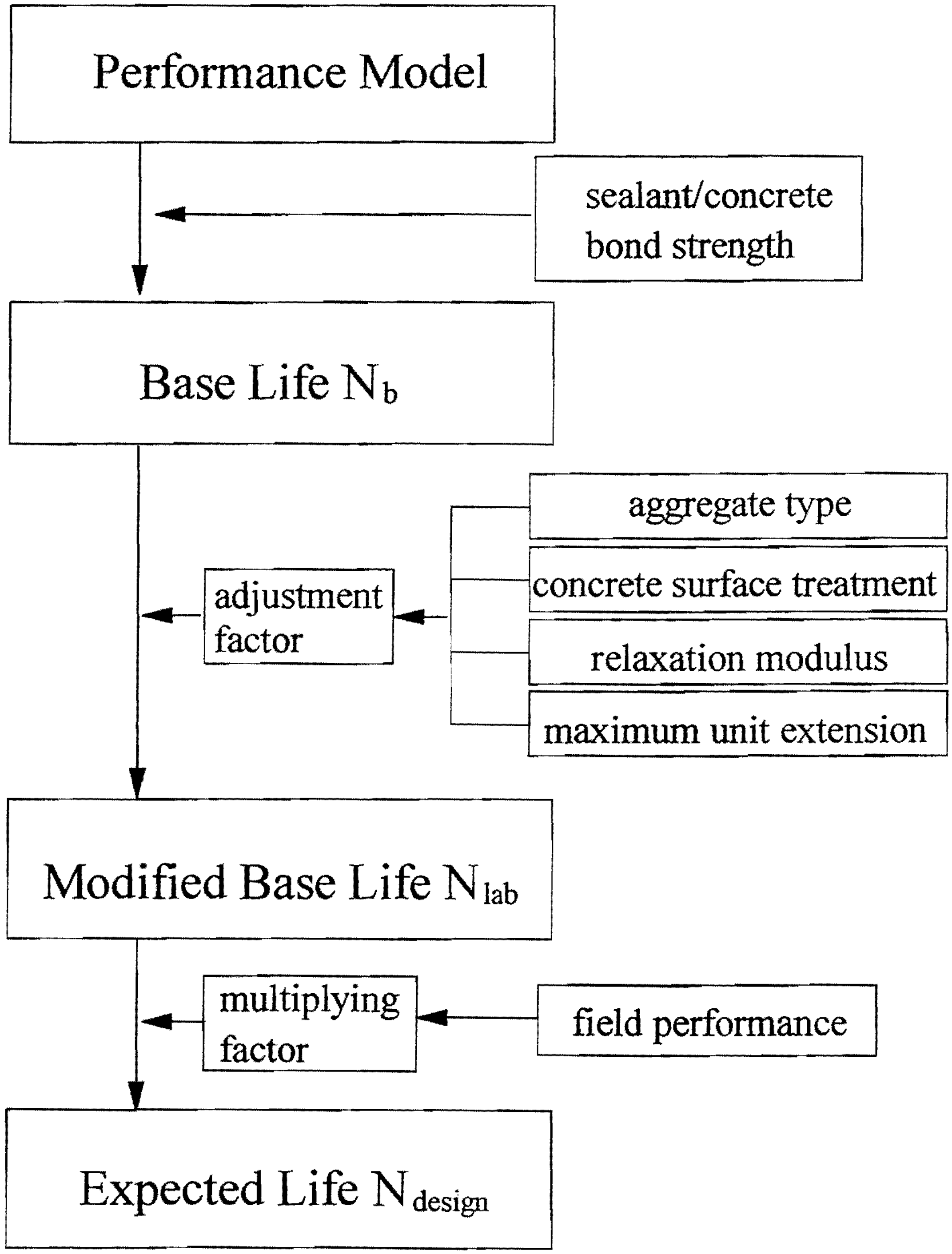



**Figure 30.** Flow Chart of the Service Life Estimation Procedure for Concrete Pavement Joint Sealants.

## ESTIMATION PROCEDURE

### Step 1: Determination of the Base Life from the Performance Model

As the first step, the user needs to determine the base life of the sealant, $N_b$, from the performance model. The performance model was proposed in the final report of project 1371 [1] based on a series of laboratory tests, including relaxation tests, bond tests, and fatigue tests. Procedures for these tests are covered in Appendix B. The model predicts the life of the sealant under the standard conditions:

$$N_b = f_1 \frac{S_b}{E} \varepsilon_s^{f_2} \varepsilon_L^{f_3} \quad \textbf{(13)}$$

where

| | | |
|---|---|---|
| $N_b$ | = | Number of cycles to failure observed in the laboratory under standard conditions, |
| E | = | Long term relaxation modulus at 25 °C and 20% unit extension, |
| $\sigma_b$ | = | Bond strength, |
| $\varepsilon_s$ | = | Seasonal opening, |
| $\varepsilon_L$ | = | Maximum joint opening due to load, and |
| $f_1$, $f_2$, $f_3$ | | are all constants. |

The standard conditions mean that (1) the ambient temperature is 25° C, (2) the maximum extension level is 20%, (3) limestone is used as the coarse aggregate in concrete mix, and (4) concrete surface is sand-blasted and then cleaned before the sealant is applied. The constants, $f_1$, $f_2$, and $f_3$, are experimentally determined. Their values for Percol joint sealant, Dow Corning 888, and Crafco 903 SL have been obtained [1] and are listed in Table 13. With this performance model, the life of a sealant material can be predicted without doing very time-consuming fatigue tests.

Based on these test data, the base life, $N_b$, versus the bond strength, $\sigma_b$, curves at the standard conditions for the three types of sealant materials are shown in Figure 31. The user of this procedure can estimate the base life of a sealant material of one of the three types. (Refer to Appendix A for other types of sealant materials.)

**Table 13.** Coefficients in Performance Model.

| Sealant | Material Type | $f_1$ | $f_2$ | $f_3$ |
|---|---|---|---|---|
| Percol joint sealant | 2 | 4641 | -0.985 | -0.739 |
| Dow Corning 888 | 1 | 10664 | -0.377 | -1.053 |
| Crafco 903 SL | 3 | 1715 | -1.201 | -1.520 |

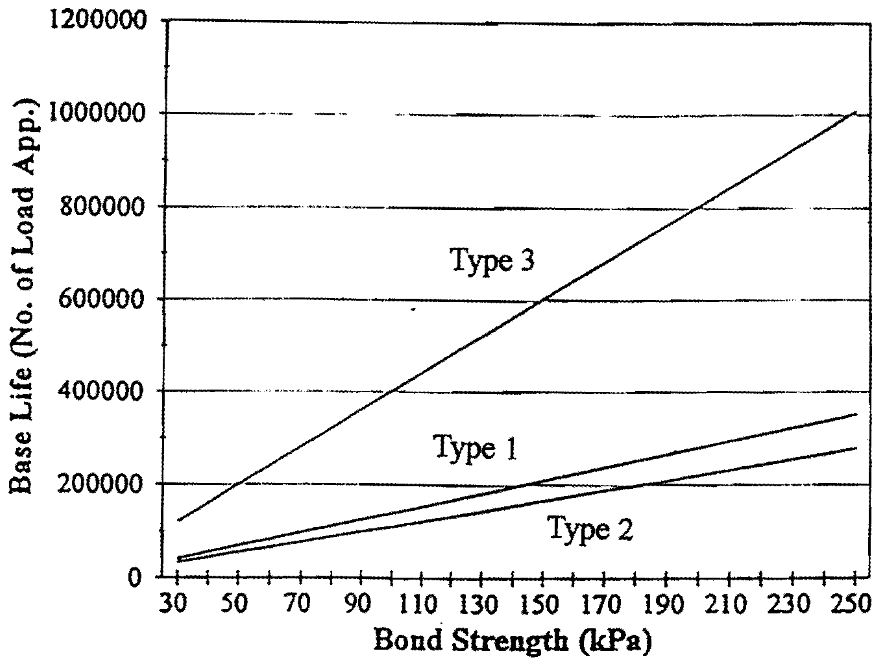



**Figure 31.** Base Life for Different Types of Sealants.

**Step 2: Determination of the Modified Base Life**

The base life is obtained under specific laboratory conditions which are referred to as the standard conditions. When the conditions are different, adjustment should be made to modify the base life for the standard conditions to the modified base life to take into account various factors pertaining to the intended field site. Main factors that affect the service life of joint sealants include aggregate type, surface preparation, relaxation modulus of the sealant, and strains due to seasonal changes and load. The adjustment is made through the following equation:

$$N_{lab} = a_m \cdot N_b \tag{14}$$

where

$$a_m = a_1 \cdot a_2 \cdot a_3 \cdot a_4 \tag{15}$$

is proposed with

$N_{lab}$ = modified base life in number of cycles to failure,

$N_b$ = base life under standard conditions, and

$a_m$ = overall adjustment factor.

$a_1$ is the adjustment factor for aggregate type; $a_2$ is the adjustment factor for the preparation technique used to prepare the joint concrete surface to bond the sealant; $a_3$ is the adjustment factor for long-term relaxation modulus, and $a_4$ is the adjustment factor for the expected maximum unit extension level. All these adjustment factors can be found in Tables 14-17, respectively. The shaded cells represent the coefficient values for the standard conditions. The relaxation modulus needs to be acquired from the relaxation test. For the procedure for this test, please refer to Appendix D. The relaxation test should be conducted at the temperature at which the sealant is to be in service to include the temperature effect on the service life.

**Step 3: Determination of the Expected Service Life**

The actual service life of sealant is different from the one obtained in step 2 (modified base life, $N_{lab}$) due to complicated geological and climatic conditions in the field as well as traffic density and the pavement joint system. Hence, the life obtained in the laboratory ($N_{lab}$) should be converted to the expected service life at the field. To realistically achieve this, a number of important variables are needed. First and foremost, past performance data of various sealant classes should be known or estimated. A framework of calibration of life in the laboratory to field condition is presented below.

**Table 14.** Adjustment Factor for Aggregate Type.

| Aggregate Type† | Adjustment Factor, $a_1$ | | |
|---|---|---|---|
| | Type 1 | Type 2 | Type 3 |
| Limestone | 1.00 | 1.00 | 1.00 |
| Rivergravel | 1.15 | 1.16 | 1.19 |

† Type of the coarse aggregate used in concrete.

**Table 15.** Adjustment Factor for Preparation Technique.

| Surface Preparation‡ | Adjustment Factor, $a_2$ | | |
|---|---|---|---|
| | Type 1 | Type 2 | Type 3 |
| Sand Blast | 1.00 | 1.00 | 1.00 |
| Water Blast + Sand Blast | 1.00 | 0.973 | 0.917 |
| Sand Blast + Primer | 1.00 | 1.00 | 1.26 |

‡ The method used to finish the concrete joint surface.

**Table 16.** Adjustment Factor for Relaxation Modulus.

| Relaxation Modulus† (see Figures 3-5) | Adjustment Factor, $a_3$ | | |
|---|---|---|---|
| | Class 1 | Class 2 | Class 3 |
| Above the Standard Curve‡ | 0.90 | 0.90 | 0.90 |
| Equal/Crosses | 1.00 | 1.00 | 1.00 |
| Below the Standard Curve | 1.10 | 1.10 | 1.10 |

† Relaxation modulus test in accordance with the test specification proposed.

‡ The standard curves for Types 1, 2, and 3 are shown in Figures 32-34, respectively.

**Table 17.** Adjustment Factor for Unit Extension Level.

| Unit Extension Level‡ | Adjustment Factor, $a_4$ | | |
|---|---|---|---|
| | Class 1 | Class 2 | Class 3 |
| 10% | 1.91 | 1.33 | 1.75 |
| 20% | 1.00 | 1.00 | 1.00 |
| 30% | 0.75 | 0.90 | 0.63 |
| 40% | 0.51 | 0.75 | 0.47 |

‡ The expected unit extension of the sealant in service. The unit extension is $[(W-W_0)/W_0]\times 100\%$, where $W_0$ is the original joint width, and W is the expected maximum width of the joint.

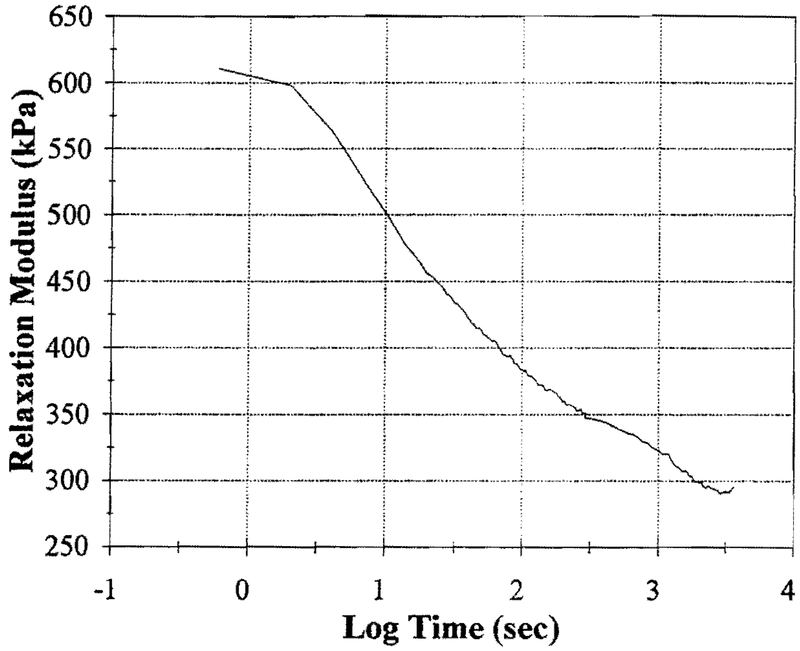



**Figure 32.** Relaxation Modulus of Type 1 Joint Sealants.

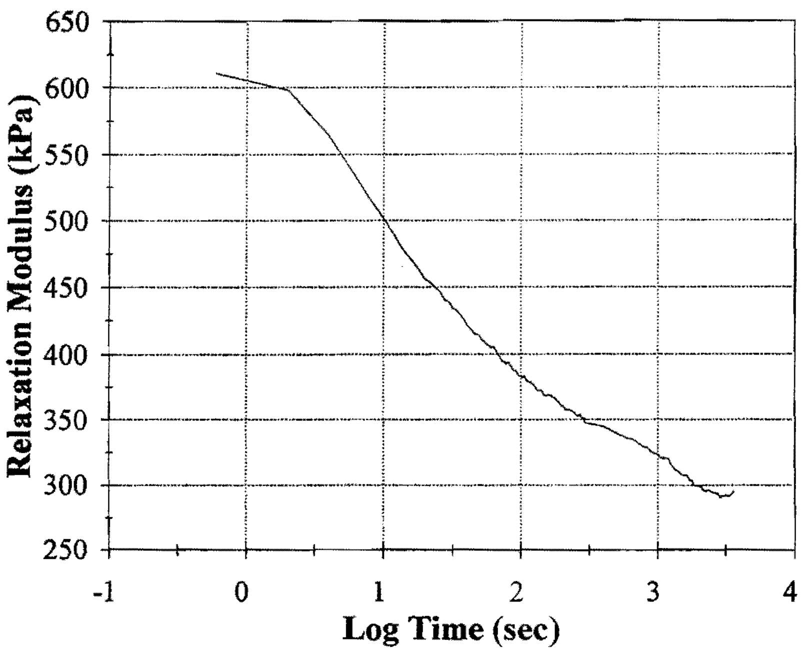



**Figure 33.** Relaxation Modulus of Type 2 Joint Sealants.

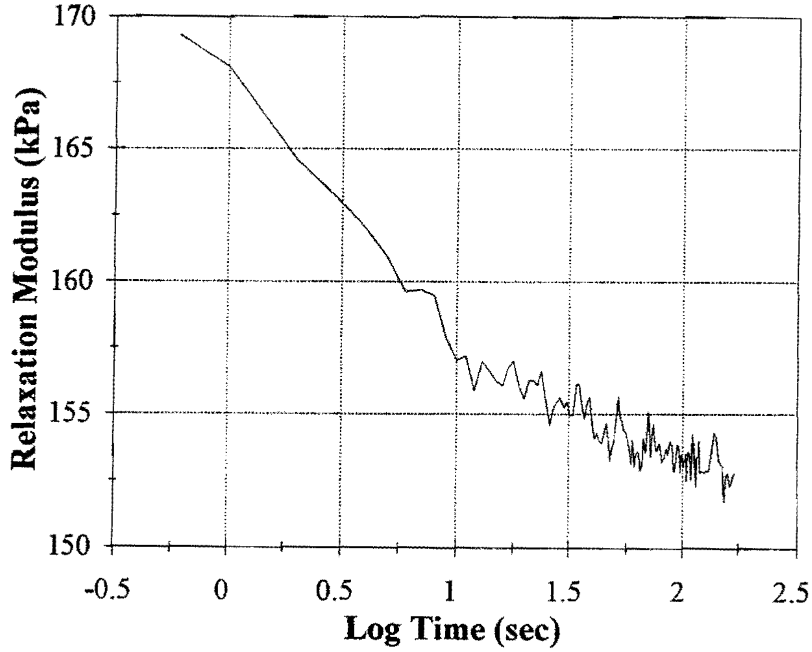



**Figure 34.** Relaxation Modulus of Type 3 Joint Sealants.

*Field Calibration of Modified Base Life*

**Collection of Field Data:** To estimate the service life of a joint sealant, it is important to know different variables such as geographical location of site, traffic density, etc. Previous field data of joint failure versus traffic are also needed. This data should be for the same type of sealant material as the one that is being evaluated. A Weibull distribution curve can then be constructed to fit these observed data points in order to characterize the performance of the sealant at a particular field site. This will result in determination of the two Weibull distribution parameters called shape factor (γ) and size factor (λ). The relationship between load cycles and damage level, as measured in terms of full depth debonding failure, is given as:

$$N_f = \frac{1}{\lambda}[-\ln(d_b)]^{\frac{1}{\gamma}} \tag{16}$$

where

| | | |
|---|---|---|
| $N_f$ | = | number of load cycles, |
| γ, λ | = | shape and scale factors, and |

$d_b$ = percentage of the sealant in the joint length where full depth debonding has occurred.

The relationship between $N_f$ and $d_b$ can be determined for each pavement and sealant type as a unique property of the individual pavement section. Before more performance data are available, $\gamma = 0.522$ and $\ln\lambda=19.39$ for silicone based sealants and $\gamma = 0.83$ and $\ln\lambda=17.87$ for asphalt-based sealants are suggested for dry, non-freeze areas in Texas. These values are obtained based on field data from the Phoenix, Arizona, test site in the SHRP H-106 study. The climatic conditions of the site are similar to those of many areas in Texas. Acquirement of these data are discussed in a following section "Illustration of Estimation Procedure." For a chosen maximum value of $d_b$, referred to as $d_{b\,max}$, corresponding life $N_{fc}$ can be determined easily as:

$$N_{f_c} = \frac{1}{\lambda}\left[-\ln(d_{b_{max}})\right]^{\frac{1}{\gamma}} \quad (17)$$

where,

$N_{fc}$ = number of cycles to failure corresponding to $d_{b\,max}$.

**Multiplying Factor:** The multiplying factor is simply the ratio of the number of load repetitions to the failure of the test specimen in the laboratory to the life observed in the field for the same unit extension level. This level is represented as $\varepsilon_f$ which is a characteristic of the pavement section.

$$MF_c = \frac{N_{lab}(\varepsilon_f)}{N_{f_c}(\varepsilon_f)} \quad (18)$$

where,

$MF_c$ = multiplying factor,

$N_{lab}(\varepsilon_f)$ = number of load cycles to failure in lab at $\varepsilon_f$ level,

$N_{fc}(\varepsilon_f)$ = number of load cycles to failure in field at $\varepsilon_f$ level, and

$d_{b\,max}$ = maximum level of damage allowed.

*Expected Life of a Joint Sealant*

For a given design unit extension level, $\varepsilon_d$, the life can be determined using the following equation:

$$N_{f_{design}} = \frac{N_{f_{lab}}(\varepsilon_d)^*}{MF_c} \quad \textbf{(19)}$$

where,

$N_{lab}(\varepsilon_d)^*$ = expected life at the extension level of $\varepsilon_d$ in laboratory based on local conditions, and

$N_{design}(\varepsilon_d)$ = expected design life at the field conditions.

This number of cycles can be easily converted to life in years by estimating the average daily traffic density.

## EFFECTS OF SEALANT GEOMETRY

Concrete pavement joint sealants have displayed a high incidence of adhesive failure. Although many efforts have been made to improve the adhesion, adhesion failure is still the primary cause of sealant failure. Laboratory bond-strength and fatigue tests conducted in project 1371 simulated this failure mode. In other words, the sealant life determination procedure given in the previous section predicts the service life of the sealant that finally fails because of debonding from the concrete wall of the joint. In the bond-strength tests, (the aspect ratio, the ratio of the depth to the width of the sealant material) which was 4, much larger than the aspect ratio used in pavement. Therefore, the service life determination procedure gives a conservative estimate because a higher aspect ratio causes higher adhesive stresses.

The finite element analysis conducted at the University of Cincinnati [19] shows that because of the effects of variations in sealant geometry upon the magnitude and distribution of adhesive stresses, rectangular sealants with low aspect ratios are preferable to those with high aspect ratios. The same work also analyzed trapezoidal sealants and concluded that trapezoidal geometry was apparently neither advantageous nor disadvantageous. Since the small deformation theory was used to analyze finite deformation in this work, the computation results may involve large errors; however, it indicated a trend. The viscoelastic behavior model of the sealant material constructed in Chapter 4 is based on the finite deformation theory and can provide considerably more accurate solutions of stress distribution in the joint sealant in service. Because of the limited time and funding, numerical analysis was not conducted in project 1371 or this project.

Instead of numerical analysis, the effects of the sealant geometry were investigated in the field test section (Chapter 2), where four aspect ratios were applied, i e., 1, 3/4, 1/2, and 1/4 (Figure 2). The round backer rod formed concave surfaces at the bottom of the installed sealants. The concave surface helped reduce stress concentration near the bonded region. The top surface of the sealant was leveled flat for installation convenience. These sealants of different geometries should be surveyed in the future relative to their performance. Although it would be difficult to make trapezoidal joints, geometry was not advantageous, as indicated by the finite element analysis [19]. Accordingly, the field test section did not employ this geometry for joints.

## ILLUSTRATION OF ESTIMATION PROCEDURE

This section illustrates the procedure for estimation of the expected life of the joint sealant in the concrete pavements. Field data from the Phoenix, Arizona test site in the SHRP H-106 study [20] were selected because the climatic conditions of this site (dry, non-freeze Region III) are similar to those in many areas of Texas. Many different types of sealant materials were installed in the test site. Surveys of the performance were conducted 3, 5, 9, 14, 18, 31, and 43 months after sealant installation was made. The average daily traffic (ADT) at this site was estimated as 18,000.

**Step 1**. For illustration purposes, it is assumed that the bond strength obtained in the laboratory for Type 2 sealant is 100 kPa. From Figure 31, we first determine the base life $N_b$ = 120,000 cycles under the standard conditions.

**Step 2.** Consider that the concrete pavement is made up of river gravel, and the surface is sandblasted prior to the sealant application. Upon performing a relaxation test, it was found that the relaxation curve of the material was below the standard curve shown in Figure 32. With the assistance of Tables 14-17, the overall adjustment factor is found to be

$a_m = (1.16)\times(1.0)\times(0.9)\times(1.33) = 1.388$ for $\varepsilon_f = 10\%$, and

$a_m = (1.16)\times(1.0)\times(0.9)\times(1.0) = 1.044$ for $\varepsilon_d = 20\%$.

Thus,

$N_{lab}(\varepsilon_f) = 1.388 \times 120{,}000 = 166{,}700$ for $\varepsilon_f = 10\%$, and

and

$N_{lab}(\varepsilon_d) = 1.044 \times 120{,}000 = 125{,}300$ for $\varepsilon_d = 20\%$.

**Step 3.** Choosing the maximum allowable damage level ($d_{b\,max}$) of 10%, we obtain $N_{fc}$, = 21,000,000 cycles for the silicone sealant. Note that the $\varepsilon_f = 10\%$ but design unit extension $\varepsilon_d$ is 20%.

Plots of full-depth failure versus traffic was obtained for silicone sealants and asphalt sealants and the Weibull distribution curves are drawn for them, shown in Figures 35 and 36, respectively. Constants $\gamma$ and $\lambda$ for silicone-based sealants are $\gamma = 0.522$ and $\ln \lambda = 19.39$, respectively, and for asphalt-based sealants, $\gamma = 0.83$ and $\ln \lambda = 17.87$, respectively. (Note that we only demonstrate the calculation example for the silicone sealant.)

The multiplying factor according to Equation 18, is then found to be:

$$MF_c = \frac{N_{lab}(\varepsilon_f)}{N_{fc}(\varepsilon_f)} = \frac{166{,}700}{21{,}000{,}000} = 0.079$$

Therefore, for a design unit extension level of 20%, the expected life is given as:

$$N_{design}(\varepsilon_d) = \frac{125{,}300}{0.0079} = 15{,}800{,}000$$

Finally, this expected life can be easily converted into life in years if the average daily traffic density is known. With assuming the average daily traffic density = 18,000 in this particular site, the life of the above sealant is then 2.43 years, or 2 years and 5 months.

Values of parameters $\gamma$ and $\lambda$ vary with types of sealants, climatic conditions, and traffic levels. It is proposed that more field data should be accumulated in different areas in Texas for accurate prediction of service life of sealants.

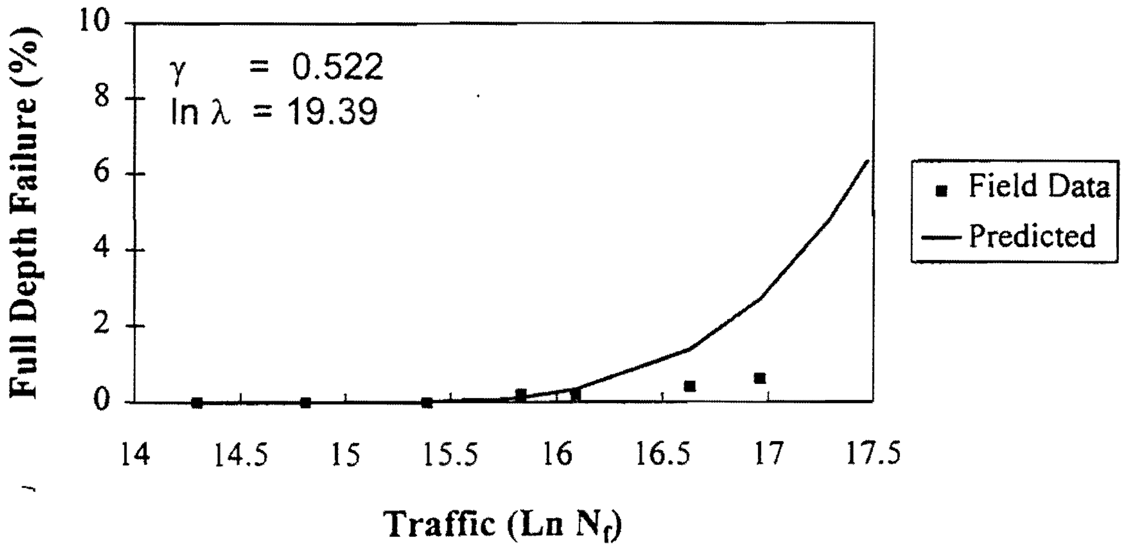



**Figure 35.** Adhesion Loss versus Number of Load Repetition for Silicone-Based Sealants at Phoenix, Arizona Test Site.

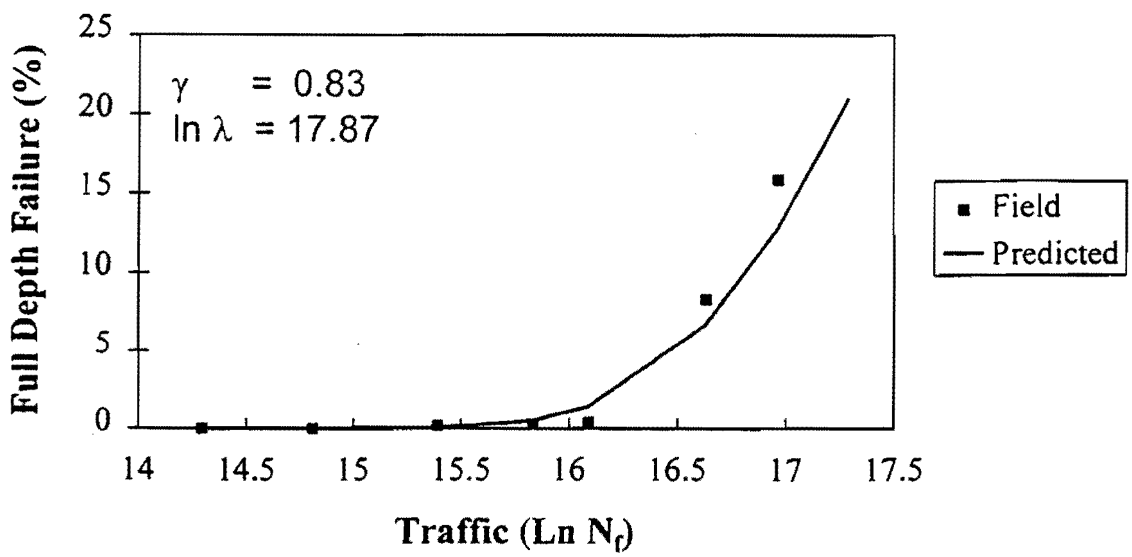



**Figure 36.** Adhesion Loss versus Number of Load Repetition for Asphalt-Based Sealants at Phoenix, Arizona Test Site.

# CHAPTER 7 CONCLUSIONS AND FUTURE RESEARCH

This report summarizes the findings obtained under project 0-187 task 15, which was a continuation of project 1371 "Evaluation of Joint Sealants." Laboratory tests, including relaxation tests, bond-strength tests, and fatigue tests of sealant materials used in concrete pavement joints, were completed. A field test section was set up, and initial surveys of sealant performance in concrete pavement joints were conducted. Based on test results, sealant material behavior and performance models were proposed. By combining these models with the effects of field conditions, a procedure for estimating the service life of a joint sealant was developed. Proposed also were specification and test protocols for the concrete pavement joint sealants, based upon the use of the service life estimation procedure. These procedures can be applied in concrete pavement design and maintenance to improve joint sealant material and reduce maintenance cost.

Bond-strength tests and fatigue tests were conducted under project 1371. These tests have been reported in the final report of project 1371 "Evaluation of Joint Sealants of Concrete Pavements." However, more relaxation tests were conducted under project 0-187-15, including tests at different temperatures, tests of specimens after naturally and artificially weathering, respectively, and tests of performed sealants. A material behavior model for relaxation modulus was constructed and verified which reflects the effects of temperature, deformation, and age on the modulus by converting these factors to a factor of time. Stresses in the sealant are determined by the relaxation modulus under any given movement of the pavement. In addition, degradation of the sealant material by material aging can be measured by the increase in the relaxation modulus. Therefore, relaxation moduli of a fresh specimen and a weathered specimen are suggested to be included in a modified sealant specification.

The effects of aging were also demonstrated in the behavior of preformed compression joint seals. Compressive reaction of the seal maintains it in place. With time and aging, the relaxation lessens the compressive reaction. A preformed compression joint seal needs sufficient stiffness for adequate performance. The effect of aging was apparent in the tested seals as it counteracted the effect of the sealant stiffness on performance. Consequently, the amount of increase in stiffness (and the concomitant reduction in compressive force) was large enough to warrant its inclusion in the design process, thus mandating the use of a calibration procedure in the life prediction analysis process.

Relaxation tests were used to correlate natural and artificial weathering for individual sealant materials. Correlations for three materials were obtained. The researchers found the correlation to be material-dependent, because different mechanisms prevailed in degradation of different sealant materials.

In this project, a procedure for estimation of the service life of the joint sealant was proposed, which expressed the fatigue life in terms of a number of variables including bond strength, relaxation modulus, and deformation due to seasonal changes and traffic loads. Some material tests are necessary in the testing protocols, but the most time-consuming fatigue tests were avoided. After proper calibration, this procedure can be used to predict the life of a sealant under specific field conditions.

A field test site was established near Liberty, Texas, and surveyed. The site should be monitored regularly to record the performance data. This continuous monitoring will help researchers better understand the field behavior of the various joint sealants placed at the test site. This may then be used to better correlate the laboratory data to the field performance and eventually verify and improve the service-life estimation procedure.

A joint sealant survey form was also circulated through the offices of TxDOT districts to procure information pertaining to the use and performance of sealants they employed in the past. It was found that most districts tended to use silicone-based sealants based on past experience.

A specification and a test protocol for joint sealants in concrete pavements were developed. These were based on the present specification used by TxDOT and modified to include bond-strength and relaxation tests. It is hoped that by introducing these tests, the selection of joint sealants can be made more discriminatory and based on the engineering properties. These guidelines are necessary for use of the service life estimation procedure.

For future research, additional surveys of the Liberty, Texas, field sites need to be conducted for a trial demonstration of the TTI method for predicting the service life of a joint sealant, which was developed in this project. A database of sealant types, locations, and traffic levels needs to be developed to provide a basis for future performance model calibration. Although several tests of preformed compression joint seals were conducted in this project, a performance model needs to be developed to predict their service life. Relationships between natural and artificial weathering need to be improved based on further understanding of the mechanism of sealant degradation.

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# APPENDIX A

# PROPOSED SPECIFICATION FOR JOINT SEALANTS IN CONCRETE PAVEMENTS

# PROPOSED SPECIFICATION FOR JOINT SEALANTS IN CONCRETE PAVEMENTS

## 1. Scope

**1.1** This specification covers joint sealants for concrete pavements.

**1.2** The values stated in SI units are to be regarded as the standard.

## 2. Referred Documents

**2.1** TxDOT Test Method Tex-525-C.

**2.2** ASTM C 33, C 150, C 192, D 3583, D 2170, D 2171, D 3407, D 2528, D 4798, G 26.

**2.3** TxDOT Departmental Materials Specification - D-9-6310.

## 3. Significance and Use

**3.1** This specification is intended to provide information in assisting the selection of joint sealant material for concrete pavements.

## 4. Types of Sealants

**4.1** Joint sealants shall conform to one of the sealant types described in this section. The actual sealant type(s) to be used shall be designated on the plans or governing specifications. The contractor shall furnish to the state and comply with the manufacturer's recommendations for placing the sealant(s).

**4.2** The sealant material shall be classified into the following categories:

**4.2.1** Type 1 - Non-Sag Silicone or Polysulfide Sealant

**4.2.2** Type 2 - Two-Part Self-Leveling Silicone or Polyurethane

**4.2.3** Type 3 - One-Part Self-Leveling Silicone

**4.2.4** Type 4 - Hot Poured Asphaltic Rubber

**4.2.5** Type 5 - Preformed Joint Sealant

**4.2.6** Type 6 - Future new product

## 5. Sampling and Testing

**5.1** Sampling and testing shall be in accordance with the Texas Department of Transportation, Materials and Tests Division, Manual of Testing Procedures, and the ASTM procedures stated herein.

## 6. Packaging, Labeling, and Storage

**6.1** The joint sealant material shall be delivered in suitable factory-sealed containers or packaging where applicable. The type of material, brand name, name of manufacturer, lot or batch number, date of packaging, expiration date, quantity contained, and mixing instructions shall be clearly marked on the label of the container.

## 7. Measurement and Payment

**7.1** Procurement by the State - Measurement and payment for a material is governed by this specification and shall be in accordance with the conditions prescribed in the purchase order awarded by the state.

**7.2** Contracts - Measurement and payment for all materials governed by this specification and utilized in the performance of work specified in the contract shall be considered subsidiary to the governing bid item in the contract.

## 8. Performance Requirement

**8.1** The following requirements shall be used to qualify joint sealants for use in concrete pavement joints. These shall also be used to ensure that the sealant material chosen has the appropriate material characteristics.

**8.2** *Type I - Non-Sag Silicone Sealant or Polysulfide Sealant* - The physical, mechanical, and performance properties of the Type I sealants shall conform to the following requirements:

| Property | Requirement | Test Method |
|---|---|---|
| Flow, mm | 5 maximum | ASTM D 3407 |
| Extrusion Rate, g/minute | 90 to 250 | ASTM C 1183 |
| Tack Free Time, 25 + 1 °C, minutes | 35 to 75 | ASTM D 2377 |
| Tensile Strength | | Tex-525-C |
| Initial, 7 days cure, 25 + 1 °C, kPa | 69 to 345 | |

| | | |
|---|---|---|
| After Water Immersion | 69 to 345 | |
| After Heat Aging, kPa | 69 to 345 | |
| After Cycling, -29 °C, 50%, 3 cycles, kPa | 69 to 345 | |
| 24 Hour Extension Test | Pass † | Tex-525-C |
| Bond Strength, kPa | 100 min. | Test #1 |
| Loss in Relaxation Modulus, After 1 hour | 20% min. | Test #2 |
| Increase in Modulus after 500 hrs of exposure | 50% max. | Test #2, Sec. 3 |

† After 24 hours, there shall be no evidence of cracking, separation, or other opening that is over 3 mm deep at any point in the sealer or between the sealer and the test blocks.

**8.3** *Type 2 - Two-Part Self-Leveling Silicone or Polyurethane Sealant* - The physical, mechanical, and performance properties of the Type 2 sealants shall conform to the following requirements:

| Property | Requirement | Test Method |
|---|---|---|
| Flow, mm | 5 maximum | ASTM D 3407 |
| Extrusion Rate, g/minute | 90 to 250 | ASTM C 1183 |
| Tack Free Time, 25 + 1 °C, minutes | 30 to 70 | ASTM D 2377 |
| Tensile Strength | | Tex-525-C |
| Initial, 7 days cure, 25 + 1 °C, kPa | 28 to 207 | |
| After Water Immersion | 28 to 207 | |
| After Heat Aging, kPa | 28 to 207 | |
| After Cycling, -29 °C, 50%, 3 cycles, kPa | 28 to 207 | |
| 24 Hour Extension Test | Pass† | Tex-525-C |
| Bond Strength, kPa, min. | 50 | Test #1 |
| Loss in Relaxation Modulus, After 1 hour, min. | 20% | Test #2 |
| Increase in Modulus after 500 hrs of exposure | 50% max. | Test #2, Sec. 3 |

†After 24 hours, there shall be no evidence of cracking, separation, or other opening that is over 3 mm deep at any point in the sealer or between the sealer and the test blocks.

**8.4** *Type 3 - One-Part Self- leveling Silicone Sealant* - The physical, mechanical, and performance properties of the Type 3 sealants shall conform to the following requirements:

| Property | Requirement | Test Method |
|---|---|---|
| Tack Free Time, 25 + 1 °C, minutes | 120 max. | ASTM D 2377 |
| Tensile Strength | | Tex-525-C |
| Initial, 7 days cure, 25 + 1 °C, kPa | 28 to 207 | |
| After Water immersion | 28 to 207 | |

| | | |
|---|---|---|
| After Heat Aging, kPa | 28 to 207 | |
| After Cycling, -29 °C, 50%, 3 cycles, kPa | 28 to 207 | |
| 24 Hour Extension Test | Pass † | Tex-525-C |
| Bond Strength, kPa, min. | 50 | Test #1 |
| Loss in Relaxation Modulus, After 1 hour | 20% min. | Test #2 |
| Increase in Modulus after 500 hrs of exposure | 50% max. | Test #2, Sec. 3 |

†After 24 hours, there shall be no evidence of cracking, separation, or other opening that is over 3 mm deep at any point in the sealer or between the sealer and the test blocks.

**8.5** *Type 4 - Hot Poured Asphaltic Rubber* - The physical, mechanical, and performance properties of the Type 4 sealants shall conform to the requirements mentioned as follows:

| Property | Requirement | Test Method |
|---|---|---|
| Penetration, 25 °C, 150 g, 5 s, 0.1 mm, max. | 90 | ASTM D 3407 |
| Flow (5 h, 60 C, 75° incline), max. | 3 mm | ASTM D 3407 |
| Resilience at 25 °C, original material, min. | 60% | ASTM D 3407 |
| Absolute Viscosity, 60 °C, P | 400 | ASTM D 2171 |
| Bond (3 cycles at -29 °C). | Pass† | Tex-525-C |
| Bond Strength, kPa, minimum | 50 | Test #1 |

† There shall be no crack in the joint sealant material or break in the bond between the sealer and the mortar blocks over 6 mm deep for any of the specimens after completion of the test.

**8.6** *Type 5 - Preformed Joint Sealant* - The physical, mechanical, and performance properties of the Type 5 sealants shall conform to the requirements mentioned in Texas Department of Transportation, Department Materials Specification: D-9-6310.

**8.7** *Type 6 - Unclassified Sealant* - Classified product not conforming to present specification shall be submitted to material test division for evaluation.

# APPENDIX B

# PROPOSED TEST PROTOCOL FOR JOINT SEALANTS FOR CONCRETE PAVEMENTS

# PROPOSED TEST PROTOCOL FOR JOINT SEALANTS FOR CONCRETE PAVEMENTS

## INTRODUCTION

These methods cover the various test procedures for evaluating concrete pavement joint sealant materials. The results obtained from these tests may be used for specification purposes.

## LIST OF THE TEST PROCEDURES PRESENTED

Test 1. Test Method for Determining Tensile Bond Strength Between Sealant Material and Concrete

Test 2. Stress Relaxation Test for Types 1, 2, and 3 Sealant Materials in Concrete Pavements

Test 3. Test Method for Measurement of Tensile Strength of Types 1, 2, and 3 Sealant Material

Test 4. Test Method for Measurement of Viscosity of Type 4 Asphalt-based Sealant Material

Test 5. Test Method for Measurement of Penetration, Flow, and Resilience Type 4 Sealant Material

Test 6. Test Method for Type 5 Preformed Joint Seals for Concrete Pavement Joints

## TEST 1. TEST METHOD FOR DETERMINING TENSILE BOND STRENGTH BETWEEN SEALANT MATERIAL AND CONCRETE

### 1. Scope

**1.1** This test furnishes a method of measuring, in the laboratory, the tensile bond strength between concrete blocks and sealant material for sealant Types 1, 2, 3, and 4.

**1.2** The values stated in SI units are to be regarded as standard.

### 2. Referenced Documents

2.1 *ASTM Standards:*

C 33 Specification for Concrete Aggregates, Vol. 04.02.

C 150 Specification for Portland Cement, Vol. 04.02.

C 192 Method of Making and Curing Concrete Test Specimens in the Laboratory, Vol. 04.02.

D 3583 Testing Joint Sealant, Hot-Applied, Elastomeric-Type, for Portland Cement Concrete Pavements, or Joint Sealant, Hot-Applied, Elastomeric, Jet-Fuel-Resistant-Type, for Portland Cement Concrete Pavements, Vol. 04.03.

### 3. Significance and Use

3.1 This test method provides one measure of tensile bond strength for sealant materials and may be used to measure bond strength for specification requirements.

### 4. Apparatus

**4.1** *Mold* - The mold assembly shall be similar in design to that shown in Figure 37. The mold shall be made of two concrete blocks and two spacers made of wood or metal. The concrete blocks shall conform to ASTM C 33, except as specified herein. The aggregate gradation shall be as shown in Table 18. The coarse aggregate shall consist of crushed limestone having a water absorption of not more than 1.5%. Portland cement shall conform to Type II of specification ASTM C 150. The concrete shall have a water-to-cement ratio of 0.49, a cement factor of 335 ± 30 Kg/m$^3$ (6.0 ± 0.5 bags of cement/yd$^3$), and a slump of 63 ± 12.7 mm. The concrete shall be prepared in accordance with the procedure specified in ASTM C 192.

**4.2** *Dimensions* - The concrete blocks shall measure 76 x 51 x 12.5 mm and will be prepared with a limestone coarse aggregate. The spacers can be made out of metal, wood, or any suitable rigid plastic. The spacers shall measure 12.5 x 12.5 x 51 mm.

**4.3** *Rubber bands, metal plates, and silicone lubricant* - These materials are needed to prepare and secure the mold assembly.

**4.4** *Extension Testing Machine* - A machine capable of griping the concrete blocks and separating them at a uniform speed of 12.7 mm per minute through a minimum displacement of 250 mm without undue vibration. This machine shall have one stationary grip. Where available, a data acquisition software program shall be used to record the displacement.

**5. Procedure**

**5.1** *Test Specimen* - Assemble sufficient molds to prepare three specimens. Sandblast the intended contact surfaces (76 x 51 mm) of the concrete blocks until all surfaces are clean of any foreign material. Lightly coat the spacers with the silicone lubricant. Form the mold assembly by placing the spacer between the two concrete blocks and securing them with rubber bands, clamps, or other suitable means. Place and secure a treated metal plate at one end of the mold to form a cavity; open on one face only. Make sure that the inside surface of the metal plate is also lubricated with silicone to assist in latter removal without damage to the test specimen. This should result in an assembly with a cavity size of 51 x 51 x 12.5 mm. Pour the sealant material in the upright mold to fill it completely, and immediately level off the top surface with a spatula.

**5.2** *Curing* - Place the three molds with sealant specimen for curing under standard conditions of 25 °C and 50% relative humidity for the curing period specified by the manufacturer.

**5.3** *Testing* - Remove the spacers and measure the actual dimensions of the test specimen to the nearest 0.1 mm; record using Table 19 (Figure 38). Place the specimen in the extension testing machine specified in 4.4, and extend the test specimen at a rate of 12.7 ± 2.5 mm/min. Continue the extension until the specimen fails either in adhesion or cohesion.

**6. Record**

**6.1** Record the maximum load for all three specimens in Table 19.

**6.2** Record the failure mode (cohesion or adhesion).

**6.3** Inspect the failure surfaces, and record the existence of any excessively large air bubbles or honey combing.

**7. Calculation**

**7.1** Calculate the bond strength by dividing the maximum load by area of contact for each specimen as follows:

$$\sigma_b = 1000 \times \frac{P_{max}}{L \bullet W}$$

where

$\sigma_b$ = bond strength, kPa,

$P_{max}$ = maximum tensile load to failure, N (1 lb = 4.448 N), and

L, W = measured length and width of the test specimen, mm.

**7.2** Average the three bond strengths.

**8. Report**

**8.1** Report the average bond strength of the joint sealant tested.

**8.2** Report the failure mode.

**8.3** Report any large air pockets observed on the failure surfaces.

**Table 18.** Aggregate Grading.

| Type | Sieve Size | % Passing |
|---|---|---|
| Coarse Aggregate | 19 mm | 97 to 100 |
| | 12.7 mm | 63 to 69 |
| | 9.5 mm | 30 to 36 |
| | 4.75 mm | 0 to 3 |
| Fine Aggregate | 4.75 mm | 100 |
| | 2.36 mm | 82 to 88 |
| | 1.18 mm | 60 to 70 |
| | 600 m | 40 to 50 |
| | 300 m | 16 to 26 |
| | 150 m | 5 to 9 |

**Table 19.** Data Collection Sheet.

| Specimen | Length L (mm) | Depth D (mm) | Width W (mm) | Contact Area L×D ($mm^2$) | Maximum Load $P_{max}$ (lb) | Bond Strength 4447.7 P/(L×W) (kPa) |
|---|---|---|---|---|---|---|
| 1 | | | 12.5 | | | |
| 2 | | | 12.5 | | | |
| 3 | | | 12.5 | | | |
| Average Bond Strength of the Sealant Material | | | | | | |

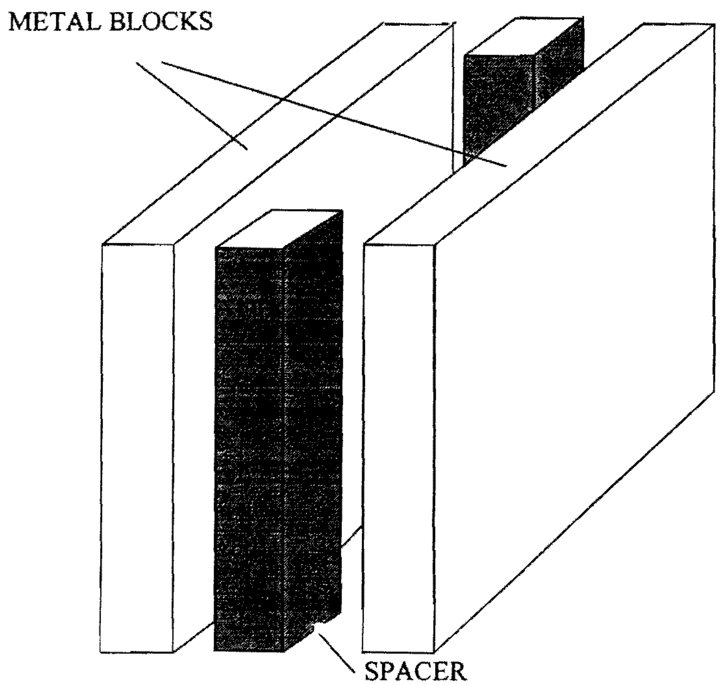


**Figure 37.** Mold Assembly for Bond Test Specimen.

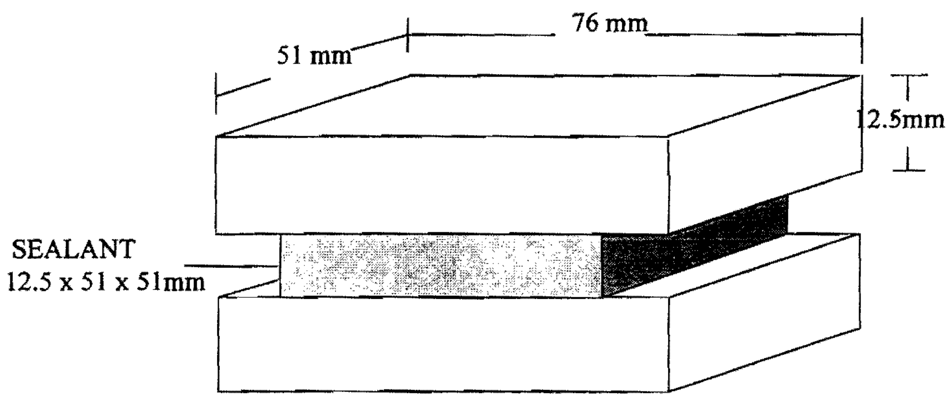


**Figure 38.** A Typical Specimen for Bond Strength Test.

## TEST 2. STRESS RELAXATION TEST FOR TYPES 1, 2, AND 3 SEALANT MATERIALS FOR CONCRETE PAVEMENTS

### 1. Scope

**1.1** This test method provides a means of measuring the amount of stress relaxation or the time dependence of stress for a Type 1, 2, and 3 joint sealant material.

**1.2** The values stated in SI units are to be regarded as the standard.

### 2. Summary of the Method

**2.1** In this method, the specimen is subjected to an extension that is held constant with time. The load required to maintain the displacement is measured at time. The load readings are converted to relaxation stress in the specimen, which is plotted against the logarithm of time in seconds.

**2.2** The relaxation test is also performed on artificially aged specimens for specification purposes.

### 3. Apparatus

**3.1** *Mold* - The mold assembly shall be similar in design to that shown in Figure 39. The mold shall consist of two steel plates and a channel-shaped spacer.

**3.2** *Dimensions* - The steel plates shall measure 100 x 50 x 6.5 mm. The channel-shaped spacer shall be made of steel or plastic with the depth of channel equal to 12.7 mm and a length of 100 mm, as shown in Figure 40.

**3.3** *Rubber Bands, Clamps, Lubricant* - Rubber bands, clamps or any other means of securing the mold shall be used. Silicone lubricant must be applied to all the surfaces that will come in contact with sealant.

**3.4** *Epoxy, Plywood Strips* - Plywood strips 3 mm thick, 12.7 mm wide, and 25 mm long shall be used to make rigid ends for the specimen.

**3.5** *Extension Testing Machine* - An extension machine capable of griping the test specimen and performing a stress relaxation test shall be used. The specimen shall be stretched at a rate

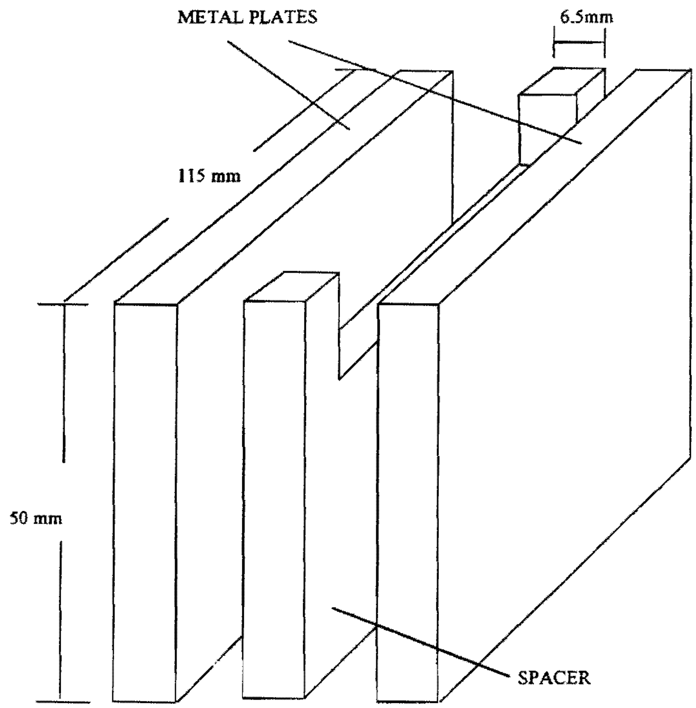


**Figure 39.** Mold Assembly for Relaxation Test Specimen.

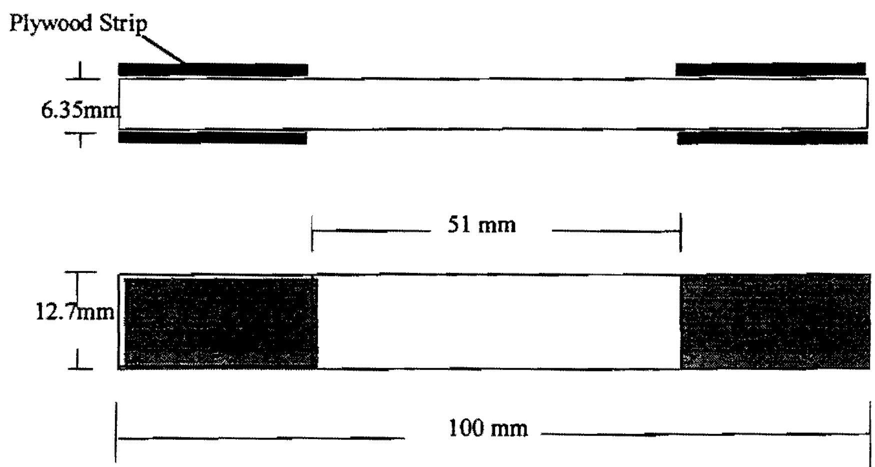


**Figure 40.** Relaxation Test Specimen with End Plates.

of 51 mm per minute to the desired extension and held constant for one hour. The machine shall also be capable of displaying the load required to maintain the extension at any time *t*.

## 4. Specimens

**4.1** *Specimen Preparation* - Assemble molds to prepare four specimens. Two specimens will be tested immediately upon curing, and two specimen will be artificially aged as described in section 4.6 before testing. Apply a thin layer of silicone lubricant on all the surfaces of the mold that may come in contact with the sealant material. Form a mold assembly by placing the spacer between the two steel plates and securing it with rubber bands or clamps (Figure 39). Carefully pour the sealant in the upright mold, and level the top with a spatula. This should result in a specimen with a cross-section of 12.7 x 6.5 mm and the length of 100 mm.

**4.2** *Curing* - Place all four molds with the sealant for curing under standard conditions of 25 °C and 50% relative humidity for the curing period specified by the manufacturer.

**4.3** *Artificial Aging* - After the specimen has been cured for a specified time period, remove the molds from two specimens. Artificially age two of the four specimens, while still in the molds, according to Section 5 "Artificial Aging."

## 5. Artificial Aging

**5.1.** *Referenced Documents*

**5.1.1** ASTM Standards

D 4798-88 Standard Test Method for Accelerated Weathering Test Conditions and Procedures for Bituminous Materials (Xenon-Arc Method), Vol. 04.04.

G 26 Practice for operating Light-Exposure Apparatus (Xenon-Arc Type) with and without Water for Exposure of Nonmetallic Materials, Vol. 14.02.

**5.2** *Exposure Apparatus* - The apparatus employed shall use xenon-arc lamps as the source of radiation. The term "cycle" is defined as the total time for all exposure conditions that are repeated. The apparatus should be equipped with a suitable frame in the test chamber to uniformly expose all specimens.

**5.3** *Test Specimens* - The test specimen shall be made in accordance with section 4.1. The test specimen shall be held in the mold while subject to radiation in order to expose the top surface only to aging. Two specimens of each material shall be aged.

**5.4** *Exposure Procedure* - Proceed in accordance with the Method 2 of standard practice G 26 of ASTM standards with following modifications:

**5.4.1** The recommended minimum spectral irradiance level is 0.35 $W/m^2/nm$ band at 340 nm. The precise irradiation level employed shall be stated in the report.

**5.4.2** Operate the apparatus continuously according to cycle specified in Table 20 below:

**Table 20.** Operating Cycle of the Exposure.

| Test Conditions | Time |
|---|---|
| Light only (60 °C ± 3 °C black panel temperature) | 60 minutes |
| Light with spray | 40 minutes |
| Dark | 20 minutes |
| A complete cycle | 120 minutes |
| Total cycle time (twelve complete cycles) | 24 hours |

**5.4.3** The duration of exposure under this test method shall be 21 repetitions of a 24-hour cycle of operation, in accordance with Table 3, resulting in approximately 500 hours of exposure.

**6. Relaxation Test Specimen**

**6.1** Clean the specimen free of lubricant and other mold-release coating that may deter adhesion of plywood strips to the specimen. *Iso*-octane or other suitable solvent may be used to clean the specimen.

**6.2** The test specimen shall have a gauge length of 51 mm. This can be achieved by applying a thin layer of epoxy glue and adhering four 25 mm long plywood strips, two on each side of the specimen, as shown in Figure 41. Let the glue completely cure before testing.

**6.3** Measure and record the dimensions of the specimens to the nearest 0.1 mm.

**7. Relaxation Test Procedure**

**7.1** Grip the specimen, as shown in Figure 41, and balance (zero) the load and strain. The specimen is to be held such that there is no 'pinching.' Set the reading on the strain indicator for the specified unit extension level. Unit extension is the relative elongation with respect to the original length, that is, $(L - L_0)/L_0$, where L is the length of the specimen under extension, and $L_0$ is the original gauge length of the specimen. Specimens shall be subjected to a unit extension level of 10% of original gauge length. The two readings shall be averaged and

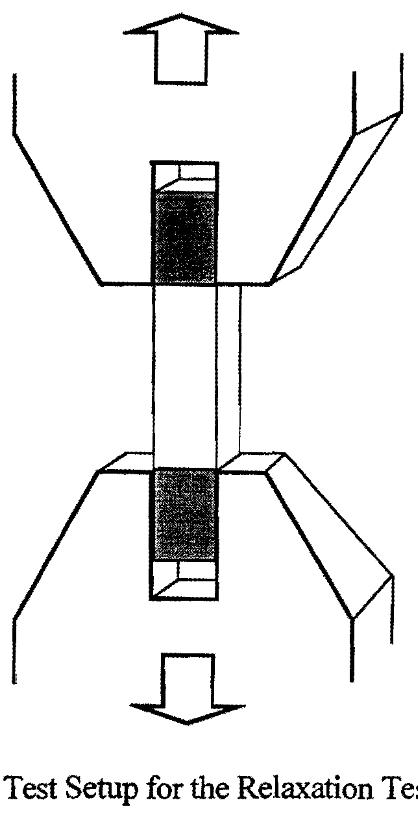

**Figure 41.** Test Setup for the Relaxation Test.

reported. This shall also be done on the two aged specimens of the material tested. Extend the specimen at a rate of 51 mm/min. to the required unit extension level, and hold the test specimen in that position. Immediately record the "initial load" (at time $t$=0), and continue to record the load-at-time intervals as shown in the data acquisition sheet (Tables 21-22). Alternatively, if possible, data acquisition software may be used to record the load with time.

**7.2** Each relaxation test shall be conducted for a duration of one hour on each separate specimen.

## 8. Report

**8.1** Report the results of relaxation tests on the semi-log graph provided, which has standard relaxation curves.

**Table 21.** Relaxation Test Data Acquisition Table for Unaged Specimens.

| Time | Load, P(t), lb | | Relaxation Modulus $E_r$ = 150.5×P(t), kPa | | |
|---|---|---|---|---|---|
| t, minutes | Sample 1 | Sample 2 | Sample 1 | Sample 2 | Average |
| 0 | | | | | |
| 1 | | | | | |
| 5 | | | | | |
| 10 | | | | | |
| 15 | | | | | |
| 20 | | | | | |
| 30 | | | | | |
| 40 | | | | | |
| 50 | | | | | |
| 60 | | | | | |

**Table 22.** Test Data Acquisition Table for the Aged Specimens.

| Time | Load, P(t), lb | | Relaxation Modulus $E_r = 150.5 \times P(t)$, kPa | | |
|---|---|---|---|---|---|
| t, minutes | Sample 1 | Sample 2 | Sample 1 | Sample 2 | Average |
| 0 | | | | | |
| 1 | | | | | |
| 5 | | | | | |
| 10 | | | | | |
| 20 | | | | | |
| 30 | | | | | |
| 40 | | | | | |
| 50 | | | | | |
| 60 | | | | | |

## TEST 3. TEST METHOD FOR MEASUREMENT OF TENSILE STRENGTH OF TYPES 1, 2, AND 3 SEALANT MATERIAL

### 1. Scope

**1.1** This test provides a method of measuring tensile strength for type 1, 2, and 3 joint sealants material.

**1.2** The values stated in SI units are to be regarded as standard.

### 2. Referenced Documents

**2.1** This test shall be performed in accordance to Texas Department of Transportation, Materials and Tests Division Test Method Tex-525-C.

## TEST 4. TEST METHOD FOR MEASUREMENT OF VISCOSITY OF TYPE 4 –ASPHALT-BASED SEALANT MATERIAL

### 1. Scope

**1.1** This test provides a method of measuring viscosity for Type 4, asphalt-based joint sealants.

**1.2** The values stated in SI units are to be regarded as standard.

### 2. Referenced Documents

**2.1** *ASTM Standards:*

ASTM D 2170 (AASHTO T 201) Test Method for Kinematic Viscosity of Asphalt, Vol. 04.03.

ASTM D 2171 (AASHTO T 202) Test Method for Viscosity of Asphalt by Vacuum Capillary Viscometer, Vol. 04.03.

## TEST 5. TEST METHOD FOR MEASUREMENT OF PENETRATION, FLOW, AND RESILIENCE OF TYPE 4 – ASPHALT-BASED SEALANT MATERIAL

### 1. Scope

**1.1** This test provides a method of measuring penetration, flow, and resilience for Type 4, asphalt-based joint sealants.

**1.2** The values stated in SI units are to be regarded as standard.

### 2. Referenced Documents

**2.1** *ASTM Standards:*

ASTM D 3407 Standard Methods of Testing Joint Sealants, Hot-Poured, for Concrete and Asphalt pavements, Vol. 04.03.

## TEST 6. TEST METHOD FOR TYPE 5 – PREFORMED JOINT SEALS FOR CONCRETE PAVEMENT JOINTS

### 1. Scope

**1.1** This test provides a method of testing preformed joint seals for concrete pavements.

**1.2** The values stated in SI units are to be regarded as standard.

### 2. Referenced Documents

**2.1** This test shall be done in accordance to Texas Department of Transportation, Materials and Tests Division's Test Method Tex-525-C.

**2.2** *ASTM Standards:*

D 2628 Standard Specification for Preformed Polychloroprene Elastomeric Joint Seals for Concrete Pavements, Vol. 04.02, 04.03.

# APPENDIX C

# JOINT SEALANT SURVEY FORM

## JOINT SEALANT SURVEY

The following survey form is being circulated among TxDOT districts to gather information pertaining to the use and performance of concrete pavement joint sealants in Texas. The information obtained through your co-operation will greatly help in developing guidelines for selection, installation and maintenance of joint sealants in concrete pavements.

1. Please check the sealants that your district has used in the recent past ( < 8 years). If the brand name of the sealants that were used does not appear on the list, please write the brand names of the sealant in items (j - m).

| Primary Study Types | | Other Types |
|---|---|---|
| a. Dow Corning 888 | _______ | j. _______ |
| b. Dow Corning 890 | _______ | k. _______ |
| c. Crafco SL | _______ | l. _______ |
| d. Percol | _______ | m. _______ |
| e. Fox Industries | _______ | |
| f. Crafco 231 (asphaltic) | _______ | |
| g. Durafill (asphaltic) | _______ | |
| h. Solarite (asphaltic) | _______ | |
| I. D.S. Brown Neoprene Preformed | _______ | |

2. Please circle the number that describes the performance of the sealant as you observe it. Generally, a joint sealant which fails within 6 months of installation is considered ***poor,*** while a joint sealant which did not need a rehabilitation or showed any failure in 5 years is considered ***excellent***.

| Sealant Name | Poor | Good | Excellent |
|---|---|---|---|
| a. Dow Corning 888 | 1 | 3 | 5 |
| b. Dow Corning 890 | 1 | 3 | 5 |
| c. Crafco SL | 1 | 3 | 5 |
| d. Percol | 1 | 3 | 5 |
| e. Fox Industries, FX-570 | 1 | 3 | 5 |
| f. Crafco 231 | 1 | 3 | 5 |
| g. Solarite | 1 | 3 | 5 |
| h. Durafill | 1 | 3 | 5 |
| I. D.S. Brown Neoprene preformed | 1 | 3 | 5 |
| j. ____________ | 1 | 3 | 5 |
| k. ____________ | 1 | 3 | 5 |
| l. ____________ | 1 | 3 | 5 |
| m. ____________ | 1 | 3 | 5 |

**Figure 42.** Joint Sealant Survey Form Distributed to TxDOT Districts (Part I).

3. Please enter any specific comments you may have about the mode of failure (i.e, debonding, cracking, extrusion etc.) exhibited by the sealants that you observed or are aware of.

| Sealant Name | Poor | Good | Excellent |
|---|---|---|---|
| a. Dow Corning 888 | 1 | 3 | 5 |
| b. Dow Corning 890 | 1 | 3 | 5 |
| c. Crafco SL | 1 | 3 | 5 |
| d. Percol | 1 | 3 | 5 |
| e. Fox Industries, FX-570 | 1 | 3 | 5 |
| f. Crafco 231 | 1 | 3 | 5 |
| g. Solarite | 1 | 3 | 5 |
| h. Durafill | 1 | 3 | 5 |
| I. D.S. Brown Neoprene preformed | 1 | 3 | 5 |
| j. ____________ | 1 | 3 | 5 |
| k.____________ | 1 | 3 | 5 |
| l. ____________ | 1 | 3 | 5 |
| m.____________ | 1 | 3 | 5 |

4. Please indicate (by the corresponding letter) for any of the sealant types that you responded to in Item 2 or 3 if any of the following information is available.

| | Sealant Name (letter designator) |
|---|---|
| Approximate date of sealant installation | ____________ |
| Joint well geometry details | ____________ |
| Sealant/joint maintenance history | ____________ |
| Associated traffic data | ____________ |

5. Are you aware of or planning any construction or rehabilitation projects that will involve the placement of concrete pavement joint sealants by August 1996? If so, where and approximately when is construction work expected to begin?

6. Please provide the name and address of the person who should be contacted if further information is needed. Thank you for your time.

____________________________

____________________________

____________________________

____________________________

7. Please return the completed forms to:

**Dr. Dan Zollinger**
Suite 503E TTI/CE Bldg,
Texas Transportation Institute,
Texas A&M University System,
College Station, TX 77843-3135
(409) 845-9918

**Figure 43.** Joint Sealant Survey Form Distributed to TxDOT Districts (Part II).

# APPENDIX D

# RELAXATION TEST RESULTS FOR SEALANT MATERIAL CRAFCO 903 SL

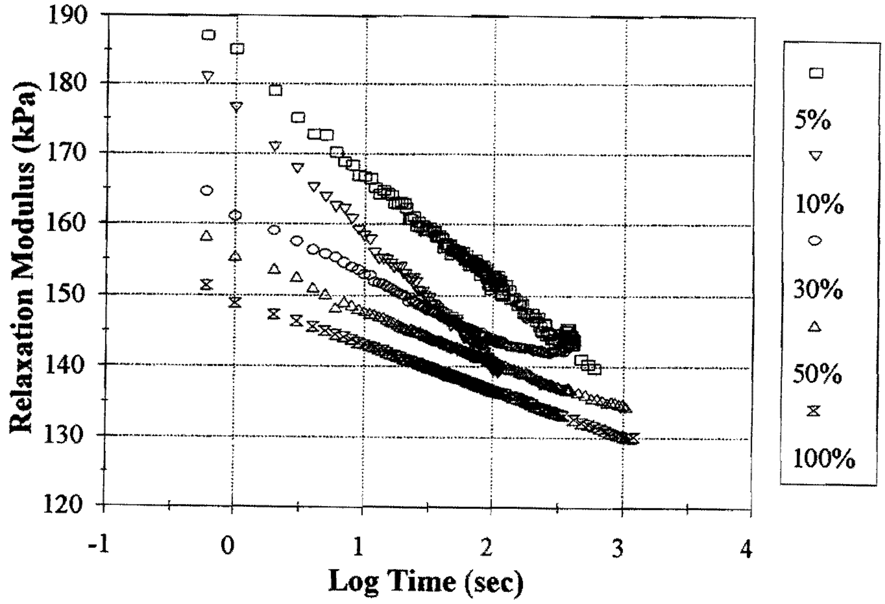


**Figure 44.** Relaxation Modulus of a Fresh Crafco 903 SL Specimen at -25 °C.

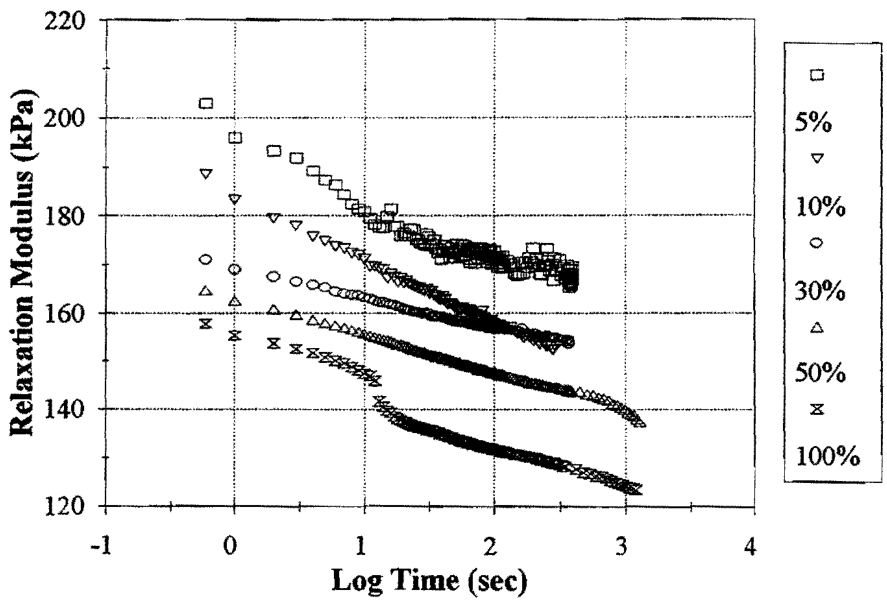


**Figure 45.** Relaxation Modulus of a 500 Hours Artificially Weathered Crafco 903 SL Specimen at –25°C.

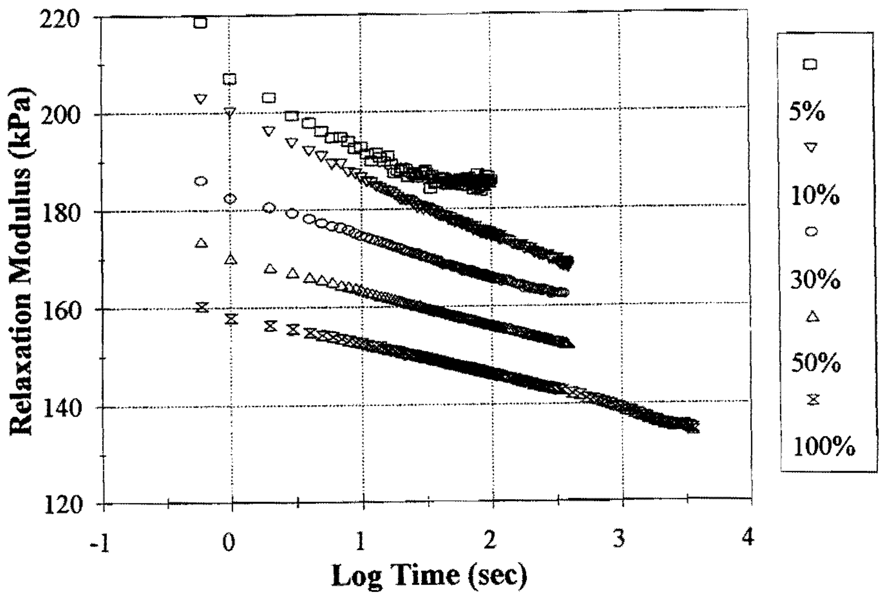


**Figure 46.** Relaxation Modulus of a 1000 Hours Artificially Weathered Crafco 903 SL Specimen at -25 °C.

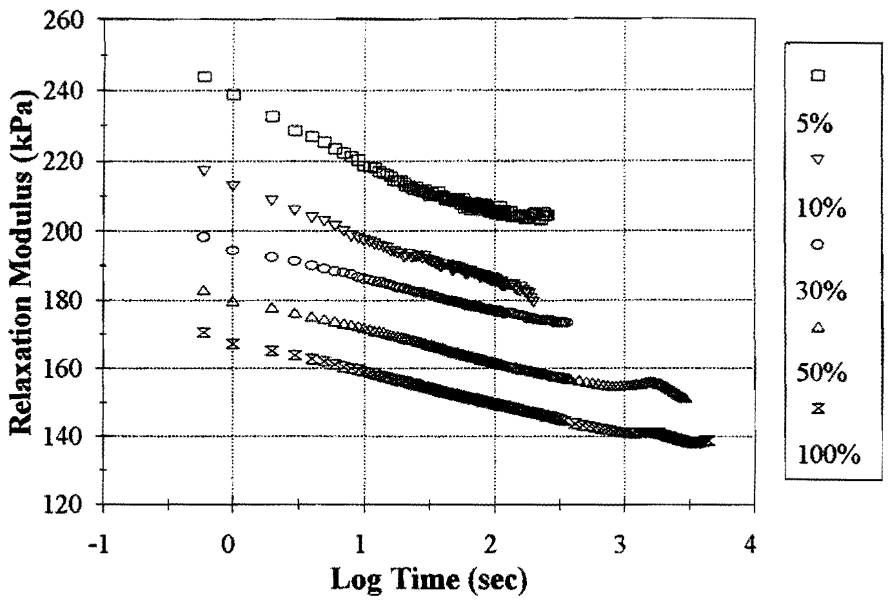


**Figure 47.** Relaxation Modulus of a 2000 Hours Artificially Weathered Crafco 903 SL Specimen at -25 °C.

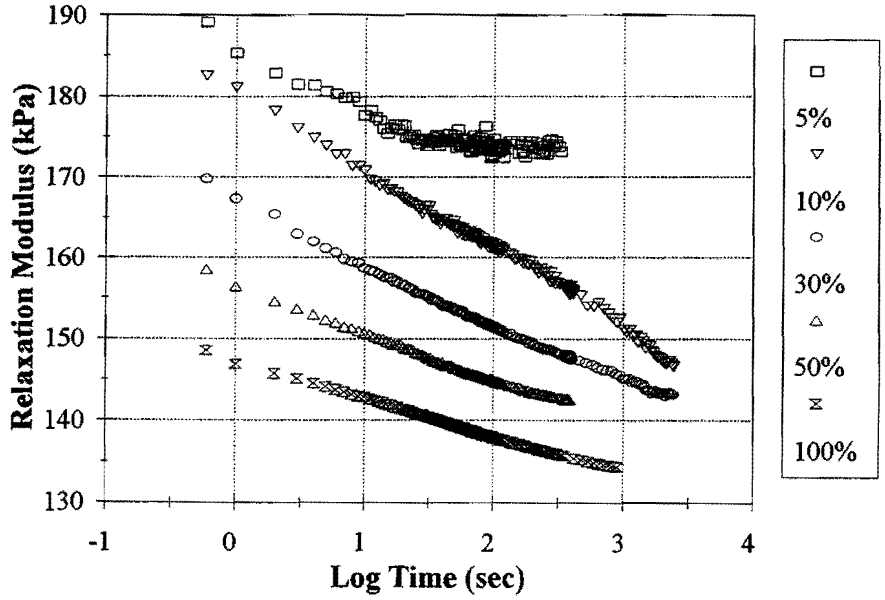


**Figure 48.** Relaxation Modulus of a Fresh Crafco 903 SL Specimen at 0 °C.

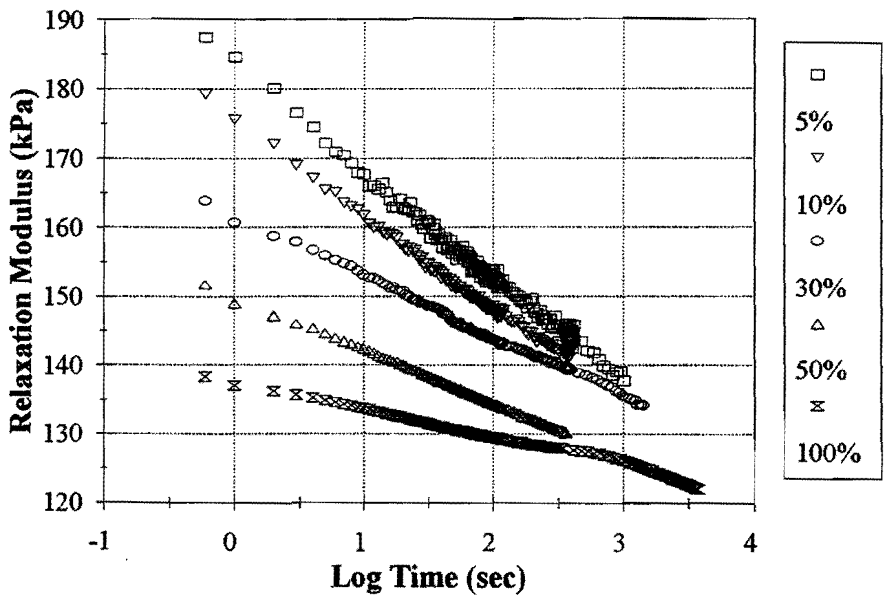


**Figure 49.** Relaxation Modulus of a 500 Hours Artificially Weathered Crafco 903 SL Specimen at 0 °C.

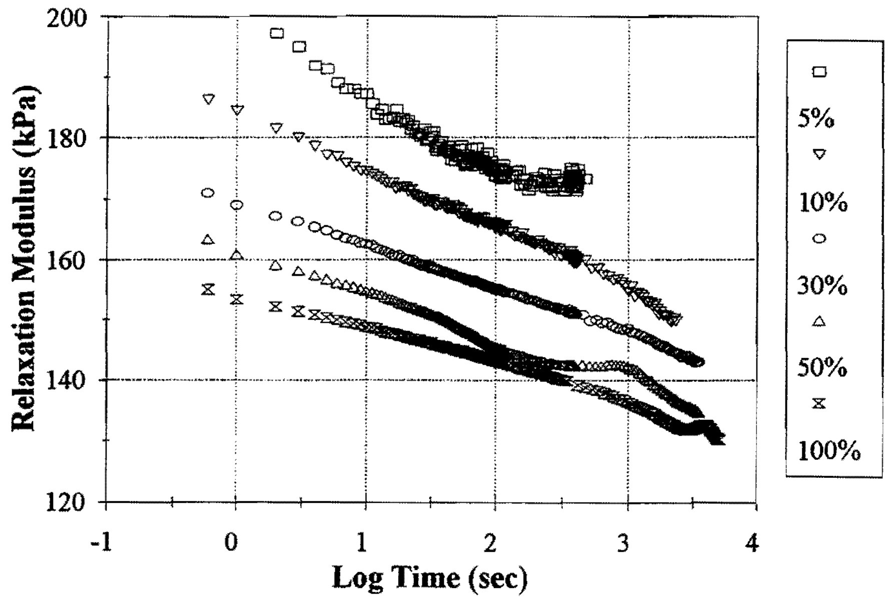


**Figure 50.** Relaxation Modulus of a 1000 Hours Artificially Weathered Crafco 903 SL Specimen at 0 °C.

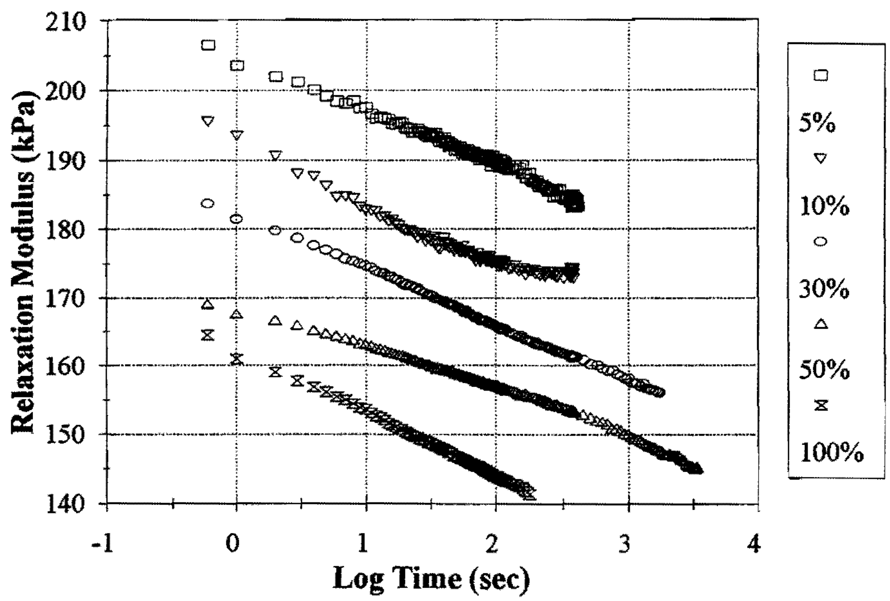


**Figure 51.** Relaxation Modulus of a 2000 Hours Artificially Weathered Crafco 903 SL Specimen at 0 °C.

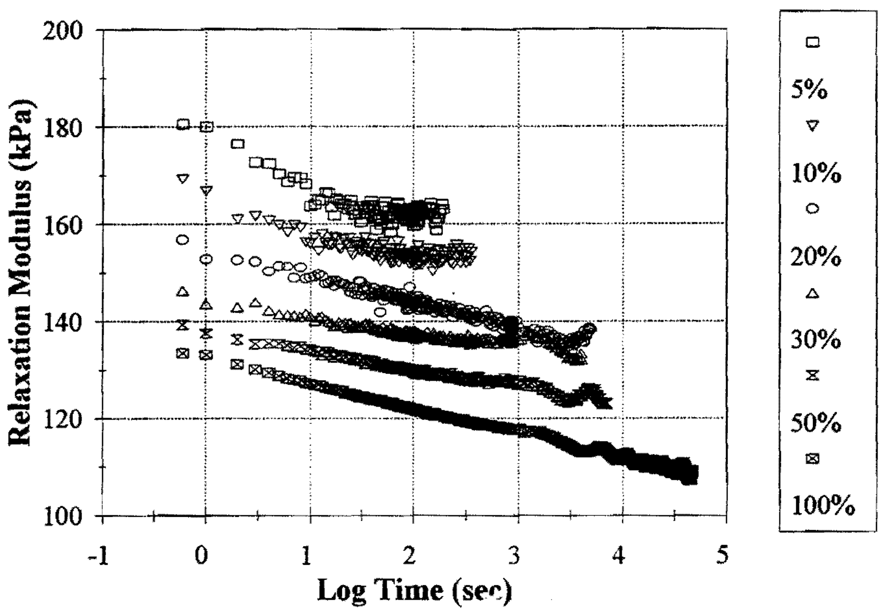


**Figure 52.** Relaxation Modulus of a Fresh Crafco 903 SL Specimen at 25 °C.

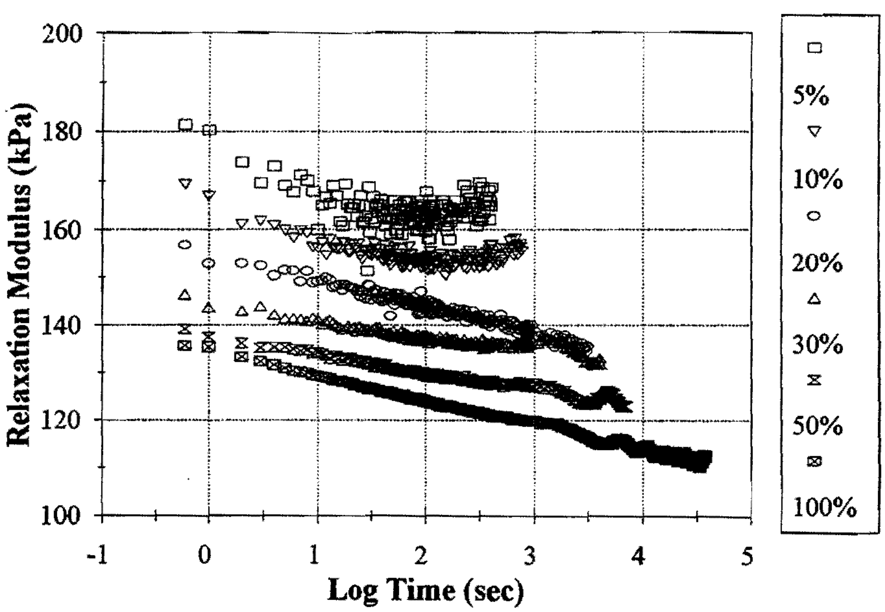


**Figure 53.** Relaxation Modulus of a 500 Hours Artificially Weathered Crafco 903 SL Specimen at 25 °C.

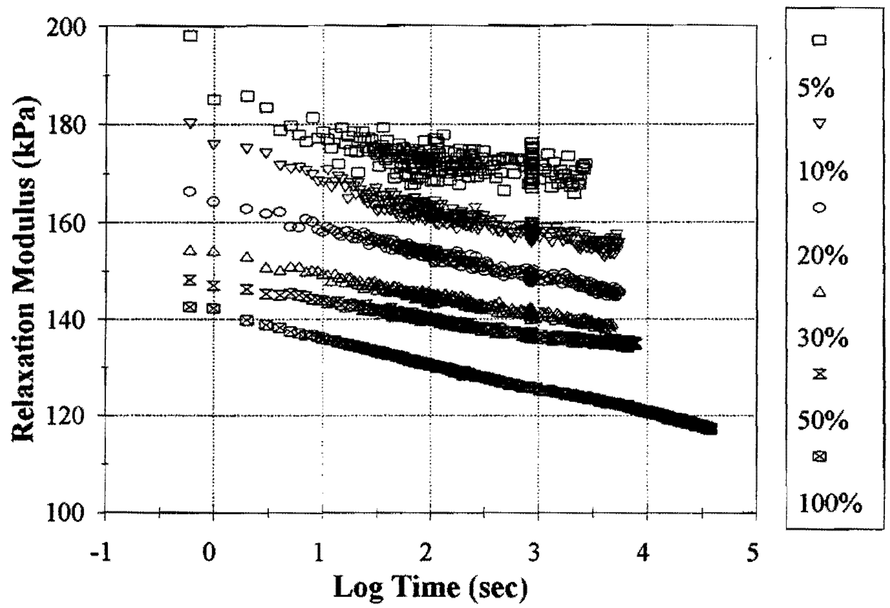


**Figure 54.** Relaxation Modulus of a 1000 Hours Artificially Weathered Crafco 903 SL Specimen at 25 °C.

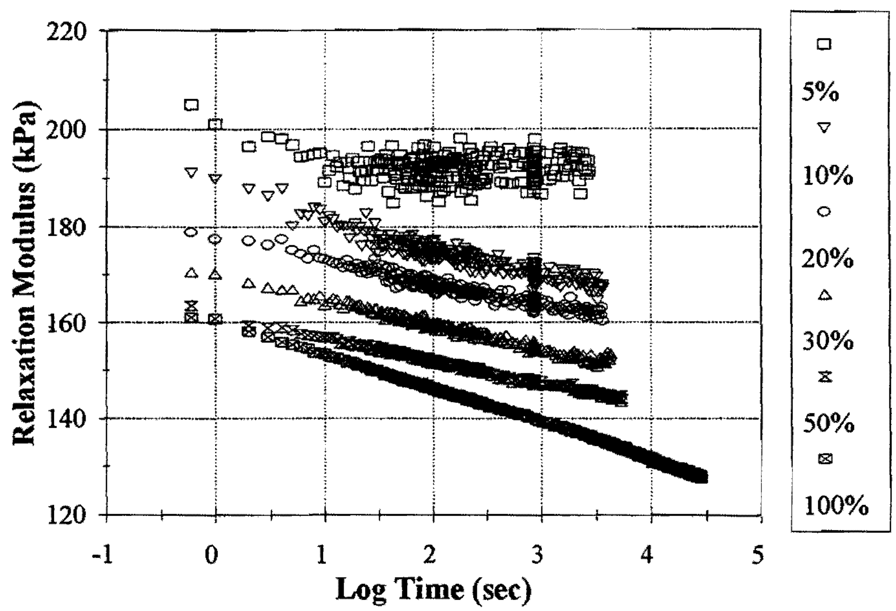


**Figure 55.** Relaxation Modulus of a 2000 Hours Artificially Weathered Crafco 903 SL Specimen at 25 °C.

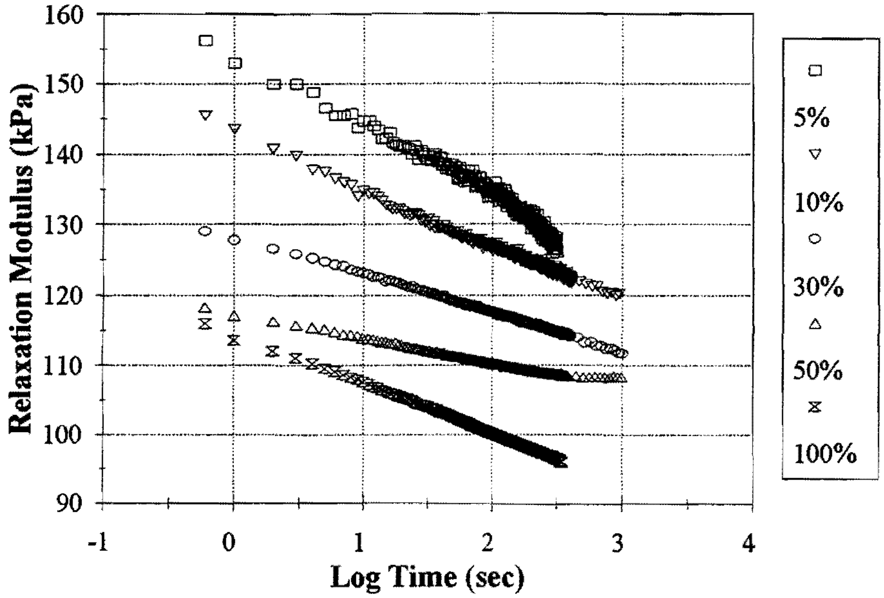


**Figure 56.** Relaxation Modulus of a Fresh Crafco 903 SL Specimen at 40 °C.

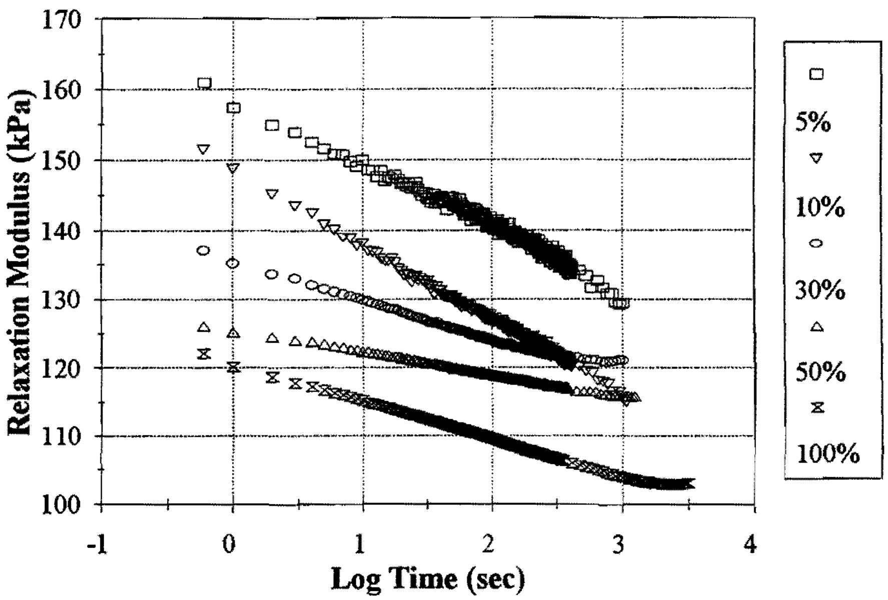


**Figure 57.** Relaxation Modulus of a 500 Hours Artificially Weathered Crafco 903 SL Specimen at 40 °C.

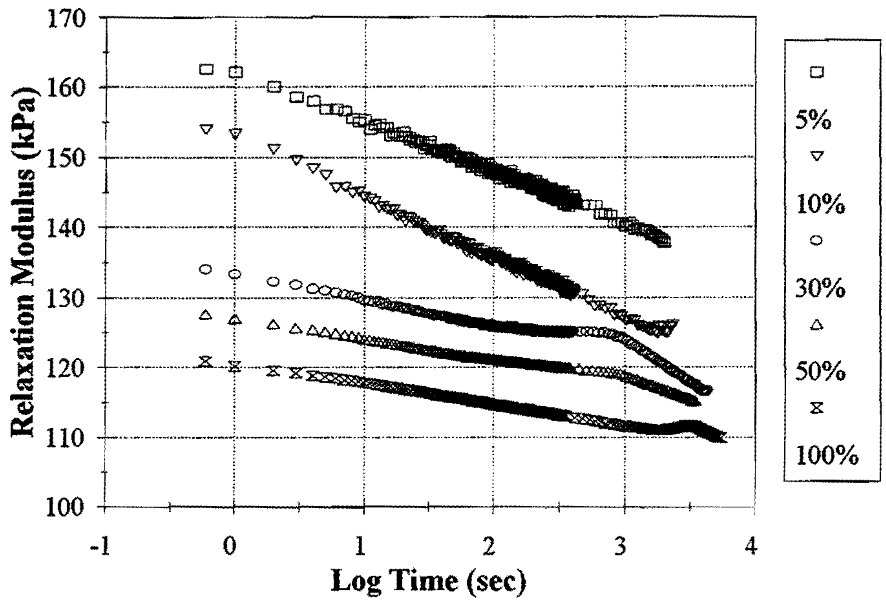


**Figure 58.** Relaxation Modulus of a 1000 Hours Artificially Weathered Crafco 903 SL Specimen at 40 °C.

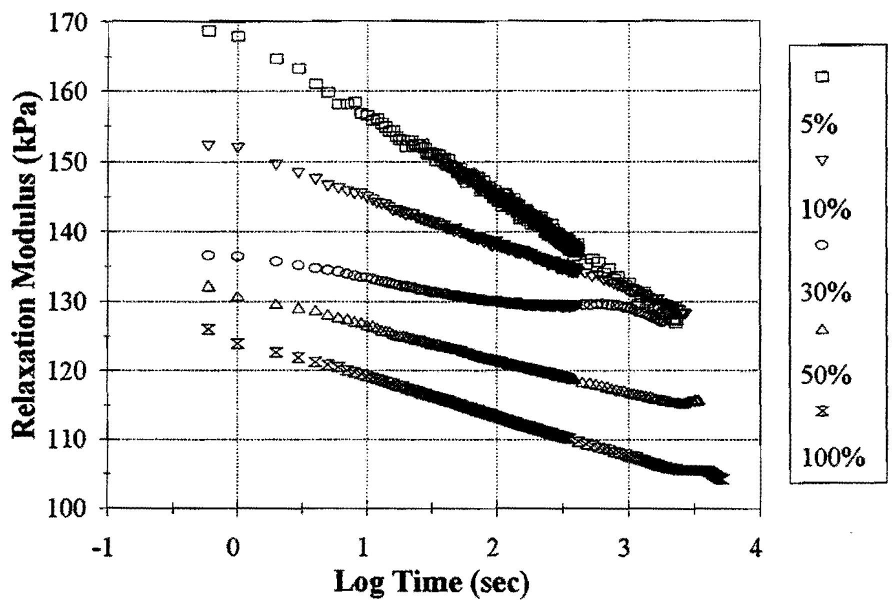


**Figure 59.** Relaxation Modulus of a 2000 Hours Artificially Weathered Crafco 903 SL Specimen at 40 °C.

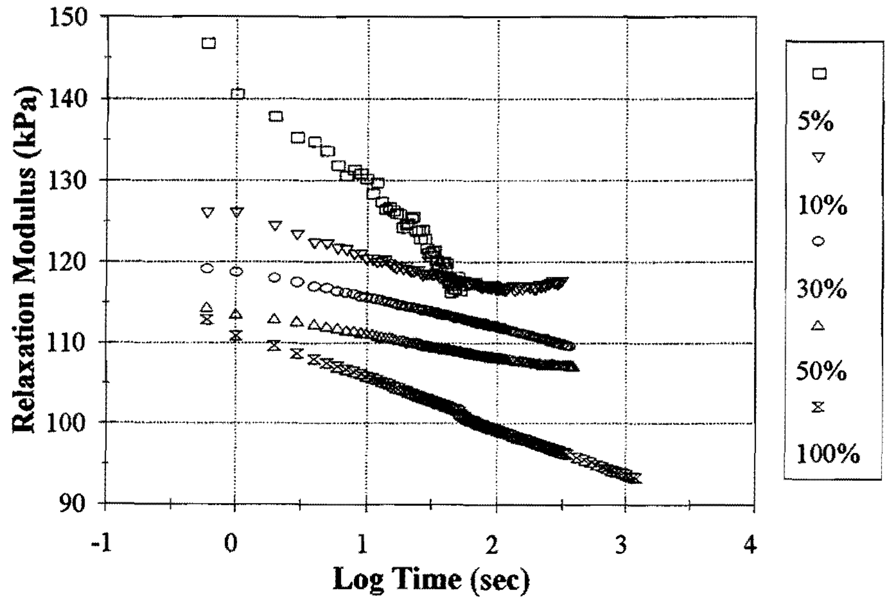


**Figure 60.** Relaxation Modulus of a Fresh Crafco 903 SL Specimen at 60 °C.

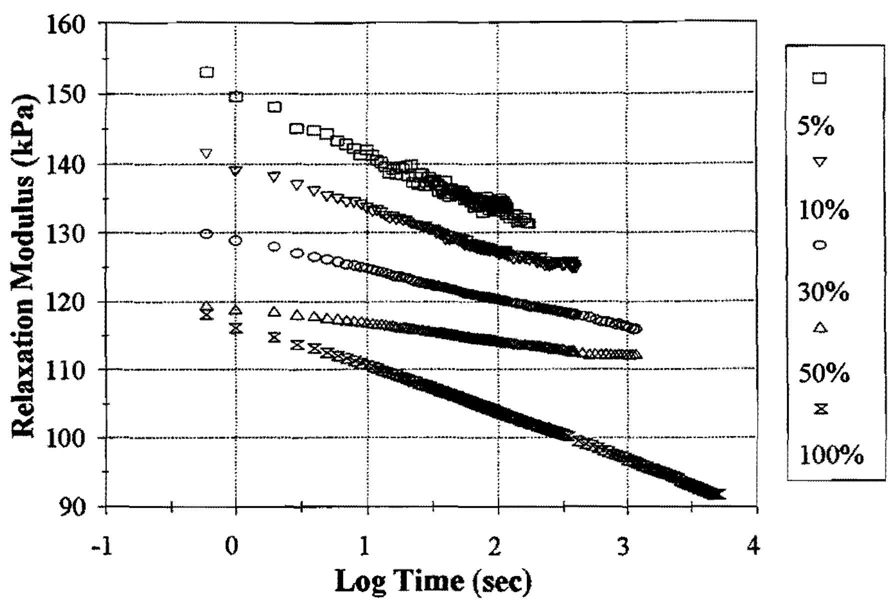


**Figure 61.** Relaxation Modulus of a 500 Hours Artificially Weathered Crafco 903 SL Specimen at 60 °C.

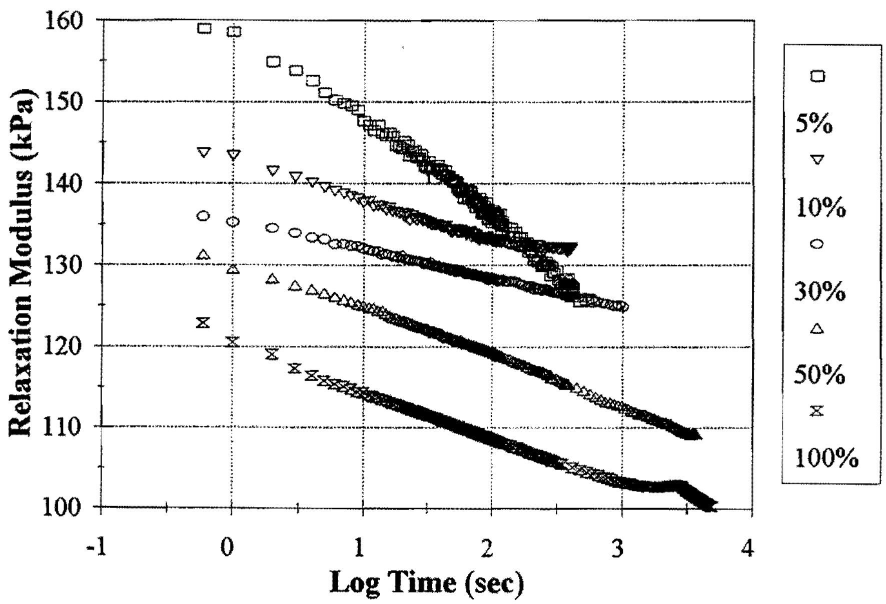


**Figure 62.** Relaxation Modulus of a 1000 Hours Artificially Weathered Crafco 903 SL Specimen at 60 °C.

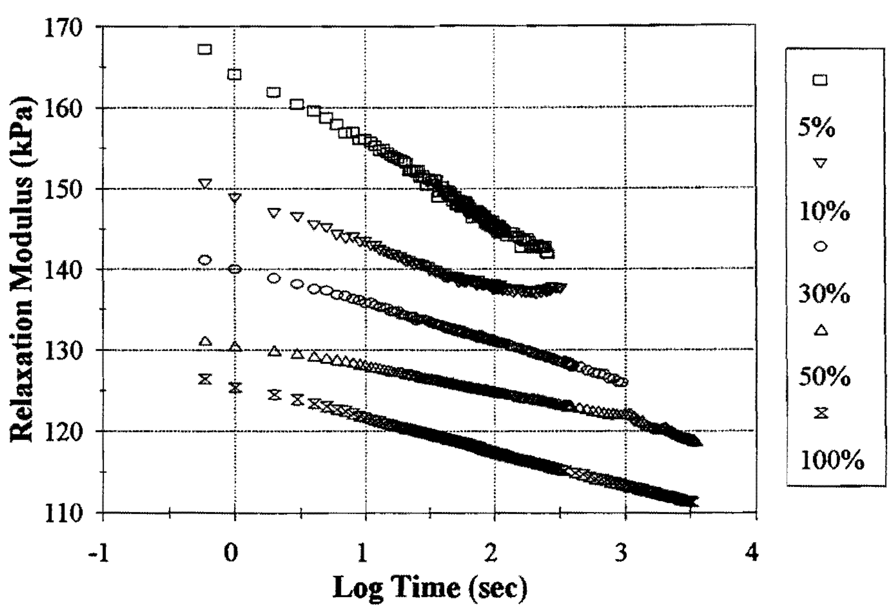


**Figure 63.** Relaxation Modulus of a 2000 Hours Artificially Weathered Crafco 903 SL Specimen at 60 °C.

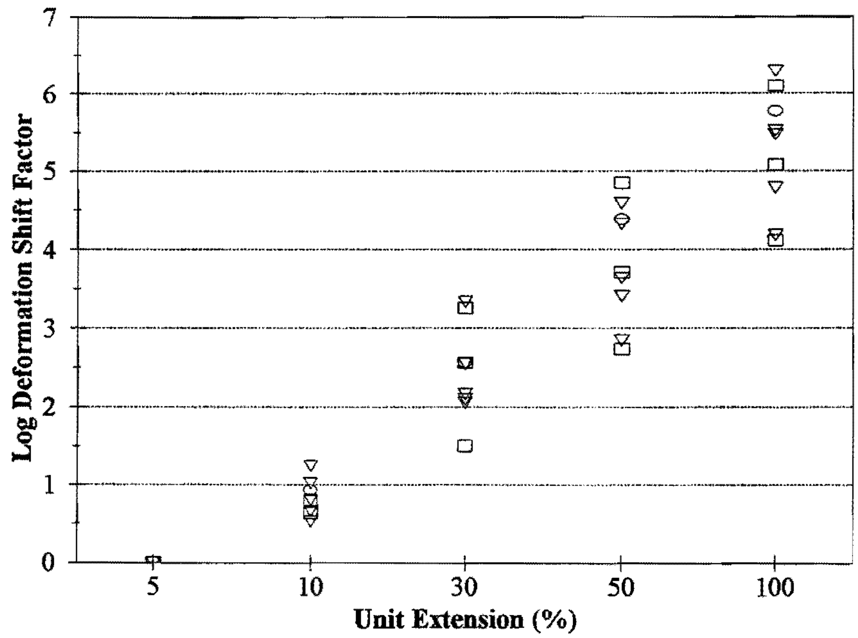


Figure 64. Time-Deformation Shift Factor Relationship for Crafco 903 SL.

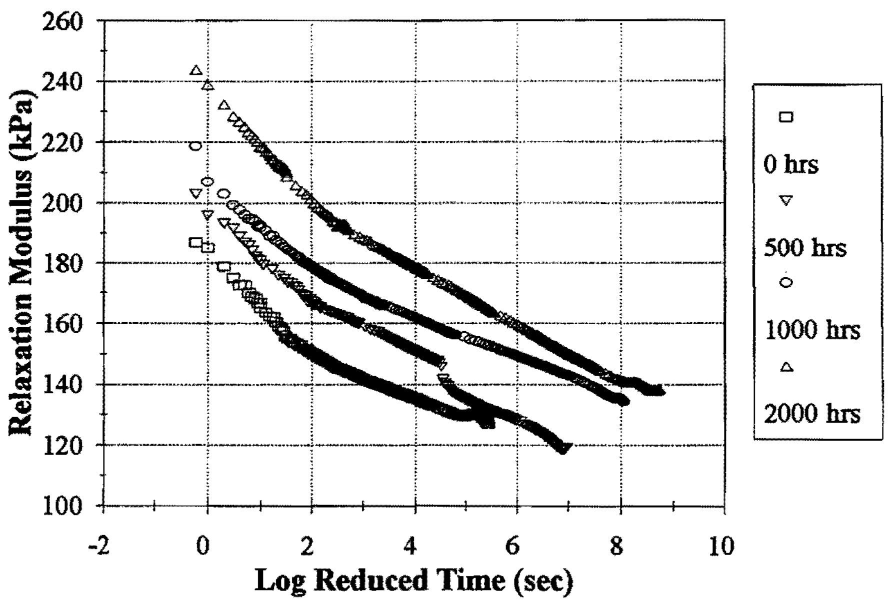


Figure 65. Relaxation Modulus Curves Normalized for Extension at -25 °C.

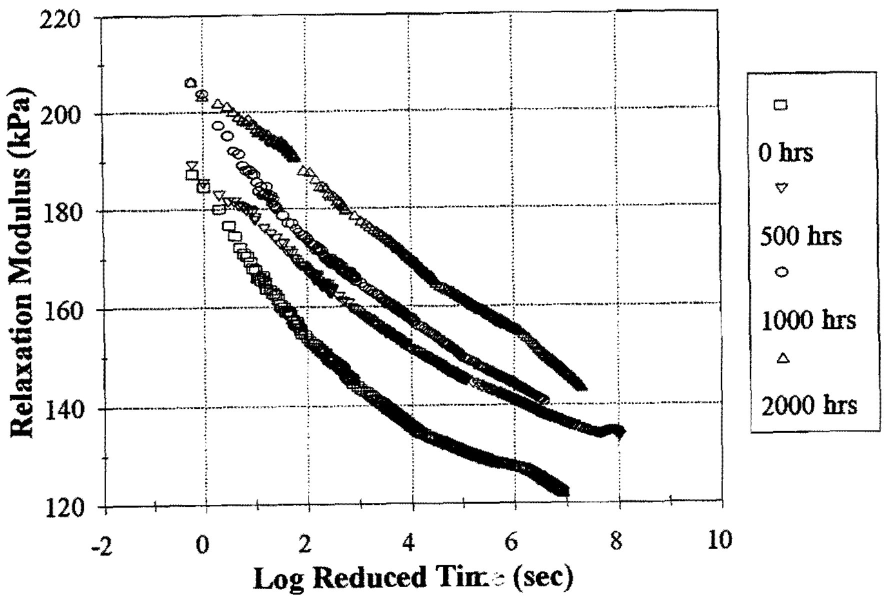


**Figure 66.** Relaxation Modulus Curves Normalized for Extension at 0 °C.

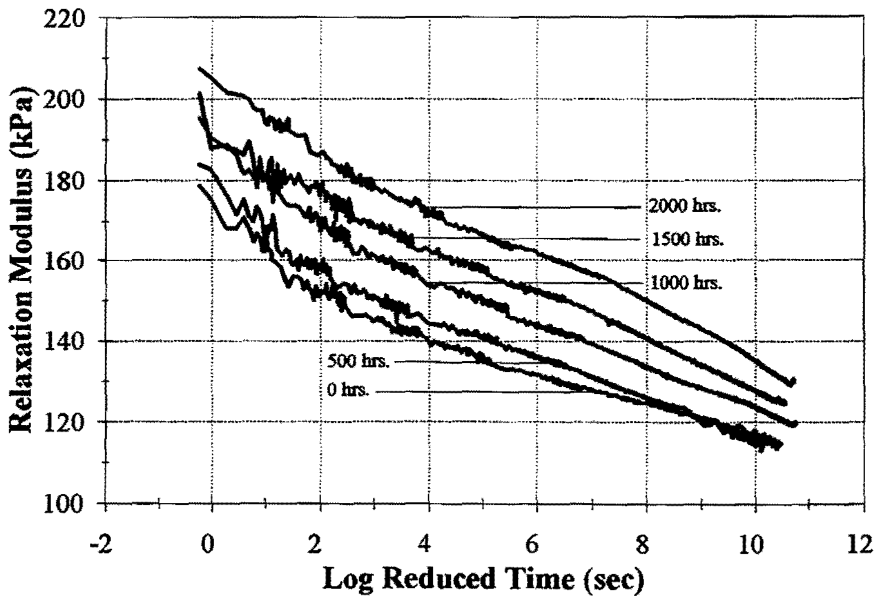


**Figure 67.** Relaxation Modulus Curves Normalized for Extension at 25 °C.

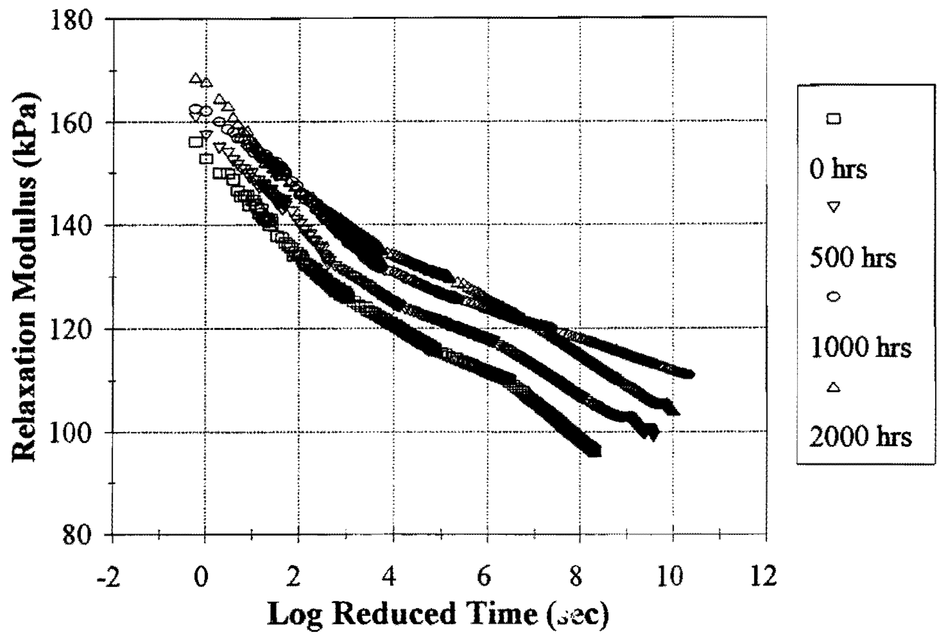


**Figure 68.** Relaxation Modulus Curves Normalized for Extension at 40 °C.

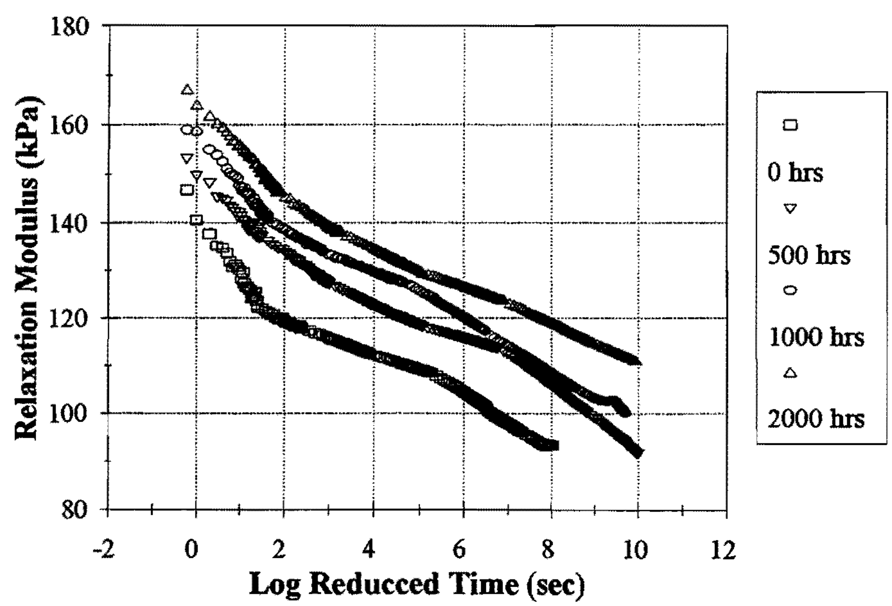


**Figure 69.** Relaxation Modulus Curves Normalized for Extension at 60 °C.

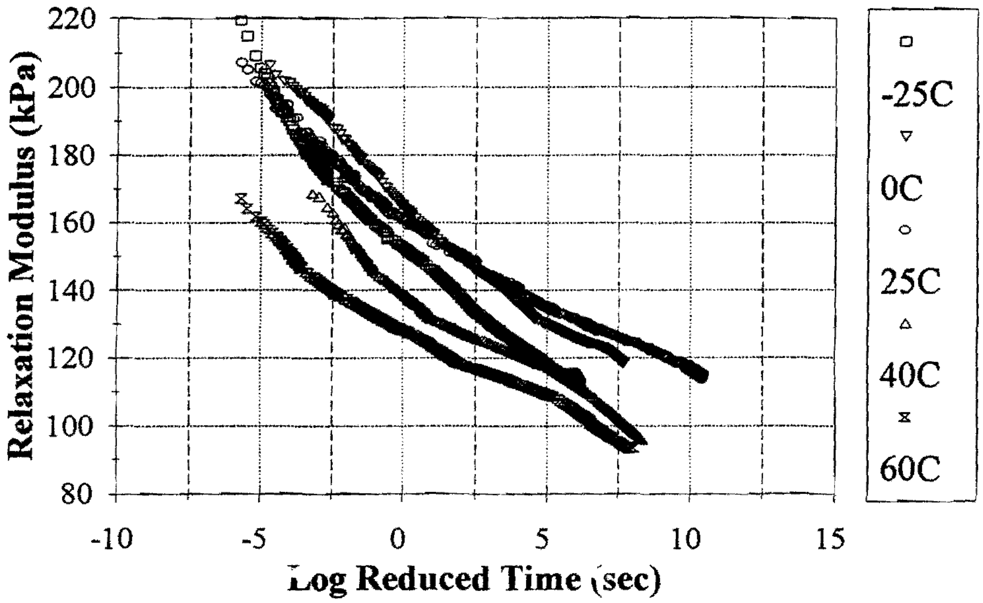


**Figure 70.** Relaxation Modulus Curves Normalized for Age and Extension for Crafco 903 SL.

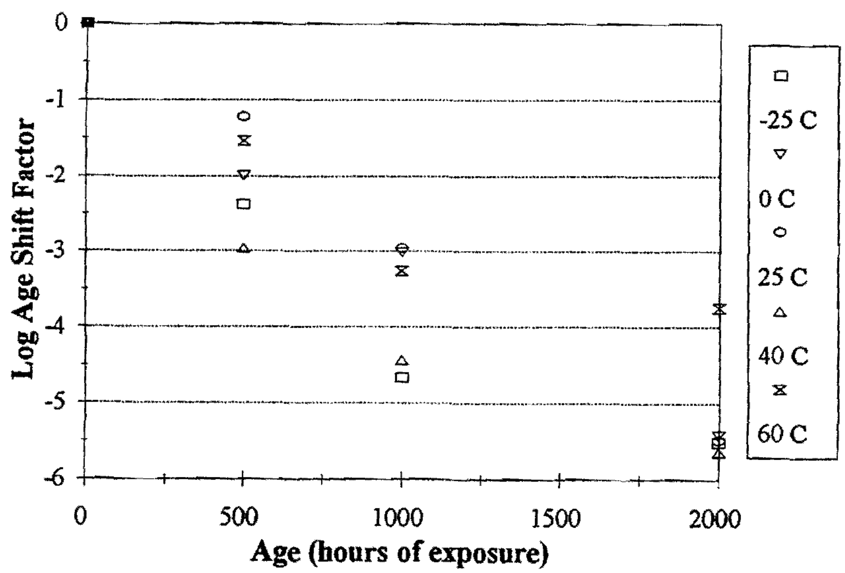


**Figure 71.** Time-Age Shift Factor Relationship of Crafco 903 SL.

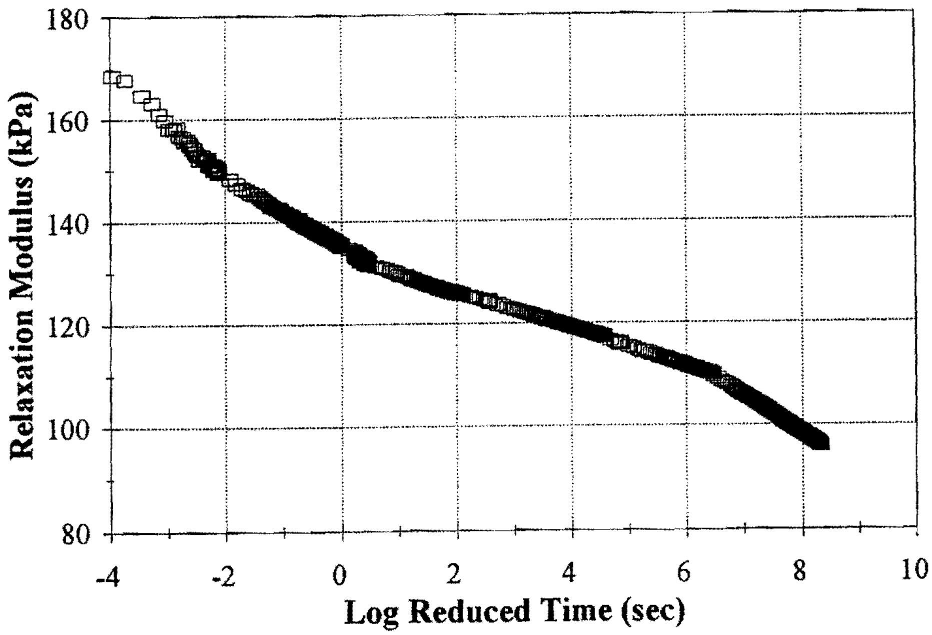


**Figure 72.** Master Relaxation Modulus Curves Normalized for Extension, Age, and Temperature for Crafco 903 SL (with Reference Conditions: $E_0$=5%, $A_0$=0 hrs., $T_0$ = 25 °C).

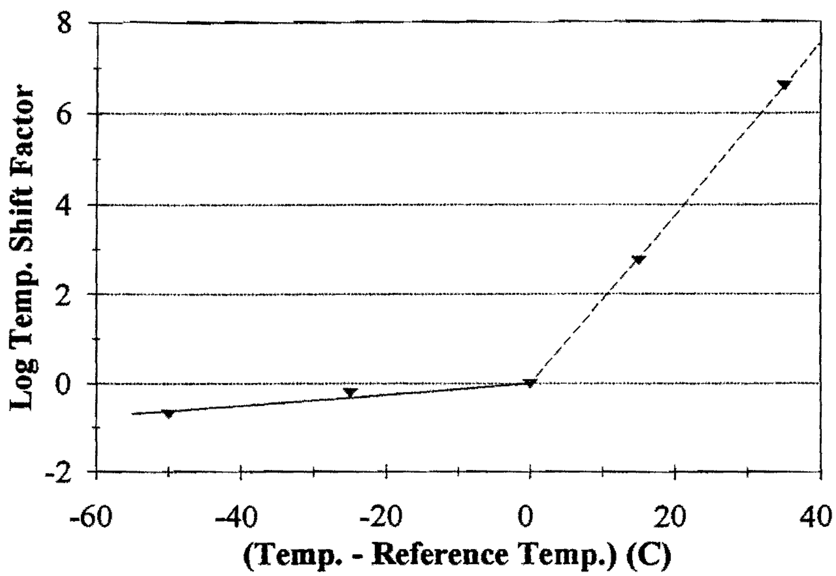


**Figure 73.** Time-Temperature Shift Factor Relationship of Crafco 903 SL. (Reference temperature = 25 °C.)