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Laboratory evaluation of a silicone foam sealant bonded to various header materials used in bridge expansion joints

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ABSTRACT

A silicone foam sealant was developed to provide an easy-to-use and economical joint sealant for small-movement bridge expansion joints. In studies reported previously, various laboratory tests were conducted to evaluate the performance of the sealant using concrete as the bonding substrate. In the present study, laboratory tests on the sealant were conducted using other substrates found in practice, including steel, asphalt, and polymer concrete. Some of the tests conducted included a tension test, repair test, oven-aged bonding test, salt water immersion test, and a cure (modulus over time) test that evaluated the mechanical properties of the sealant as it developed its final state of cure. Through the laboratory tests, it has been observed that the silicone foam has the ability to bond to various substrate materials and can easily accommodate deformation typical of small-movement expansion joints in bridges.

1. Introduction

Expansion joints are a vital component in the design of a bridge. These joints accommodate movement of the road deck caused by temperature changes, vehicle loads, humidity, shrinkage, creep, seismic loading, and other factors. It is these factors that keep bridge components in a constant state of expansion and contraction. Bridge expansion joints are designed to allow the bridge to continue this constant movement while maintaining its structural integrity [1]. If not sealed properly, however, the expansion joints permit leakage of water and corrosive deicing materials that can damage the components beneath the road deck, thus reducing the life of the bridge. In the worst-case scenario, this deterioration of the bridge deck and internal elements could result in structural failure of the bridge. Sealants for bridge expansion joints, thus, become a necessary element in the construction of new bridges and the maintenance of existing ones.

A few commercial joint sealants specialized for bridges are available for use, including the Dow Corning 902 joint sealant [2] and the WABO two-part silicone sealant distributed by the Watson Bowman Acme Corporation [3]. Joint sealants of every type are vulnerable to damage or failure. There are many factors that can cause a joint seal to tear or pull off of a joint header. Accumulation of debris, damaged joint headers, water leakage, and an inability to deform with the expansion and contraction of the joint are just a couple scenarios where a joint sealant could fail [4,5].

Previously, a study was conducted on the development of a silicone foam sealant with the ability to expand in volume as it cures [5–7]. The expansion of the foam means that only certain, carefully calculated, amounts of sealant need to be poured into the expansion joint. As the sealant expands it gradually fills the joint volume and presses into the interstices of the header for optimal bonding. In this previous investigation the sealant was subjected to various laboratory tests that evaluated its tensile strength, compressive strength, reaction to various temperatures, stress and creep behavior, and bonding capabilities to concrete.

Concrete is a common bridge joint header material; however, other materials, such as steel, are used as well. Polymer concrete, made by combining aggregate with a polymerizing monomer, is a high-strength material that is also used as a joint header material on certain bridges [8]. While the previous studies of silicone foam sealant [5–7] evaluated it's performance on concrete substrates, they did not investigate the performance of the sealant when bonded to other substrates available in practice. This paper presents results from various laboratory tests on the silicone foam sealant having been bonded to asphalt, steel, and polymer concrete. The tests chosen were tension, retrofit/repair, oven-aged bonding, salt water immersion, and modulus vs. time.

2. Silicone foam development

The silicone foam sealant discussed in this paper is made from five ingredients [5]: WABO two-part silicone sealant [3], water, crosslinker [9,10], and a platinum catalyst [10]. Two parts of the WABO sealant, one white and one gray, create a solid sil-

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icone sealant when mixed and cured. The addition of water (1.53% of total sealant mass), hydrosilane crosslinker (2.3% of total sealant mass) and a platinum catalyst (0.38% of total sealant mass) to the two-part solid sealant creates the silicone foam. The foaming is the result of the reaction of water with hydrosilane, which produces silanol groups (–SiOH) and hydrogen gas. The silanol groups condense and thus aid the polymerization, while the hydrogen gas creates bubbles within the sealant, resulting in a foam material. Depending on conditions, the volume increase due to the foaming ranges between 50% and 70%. Two different types of hydrosilane were used in the laboratory tests, both of which displayed equal hydrogen content. The tension and salt water immersion test used a hydrosilane called Baysilone U 430 Crosslinker produced by GE Bayer Silicones [11]. This crosslinker is now known as Silopren U Crosslinker 430 produced by Momentive Performance Materials [9]. The remaining tests used a crosslinker from Gelest, Inc. [10]. The laboratory tests conducted are described below.

3. Laboratory experimental methodology

To evaluate the performance of the silicone foam sealant several laboratory tests were conducted, including tensile properties, repair, oven-aged bonding, salt water immersion, and modulus over time. Some of these tests were performed using asphalt, steel, and polymer concrete as the bonding substrates and some using just the steel and asphalt substrates. These substrates were used to make test specimens depicted in a schematic in Fig. 1. Each test specimen consisted of two blocks of the substrate material separated by a 1.27-cm (0.5-in.) gap to be sealed. Each block had a length of 7.62 cm (3 in.), width of 5.08 cm (2 in.), and a depth of 1.27 cm (0.5 in.), except for the steel specimens which had a depth of 0.95 cm (0.375 in.). For comparison purposes, the tests were conducted using specimens with the silicone foam and the WABO two-part silicone sealant, which will be now, onward, called the "solid" sealant. Prior to the making of the test specimens, the substrates were cleaned with a lint-free cloth and secured to hold a gap of 1.27 cm (0.5 in.) between the pieces. The sealants were hand mixed and immediately poured into the gap between the substrates. For the foam sealant, the gap was partially filled to account for the expansion of the sealant as it cures. For the solid sealant the entire depth of 1.27 cm (0.5 in.) of the gap was sealed, as the material does not expand. The specimens, depending on which test was performed, were pulled at a specific crosshead velocity to a specific strain or until the sealant failed, depending on the test. Failure means either a complete tearing within the sealant (cohesive failure), a separation from the bonding substrate (adhesive failure), or a mixture of both. The various laboratory tests conducted using the test specimens are briefly described below [12]:

3.1. Tension test

Two types of tension tests were performed: pull-to-fail and load/unload. For both tests, 8 specimens–4 using the foam and 4 using the solid–were made using each of the following substrates: asphalt, steel, and polymer concrete. For the pull-to-fail test each specimen was cured for 21 days at room temperature (23 °C), after which they were placed in a machine that pulled the two substrate blocks apart at a crosshead velocity of 10 mm/min until failure. For the load/unload test the specimens were also cured for 21 days at room temperature (23 °C). This time, however, the specimens were pulled at a crosshead velocity of 10 mm/min up to 300% strain and then unloaded until they reached zero stress before the next cycle of loading/unloading. This loading and unloading process was repeated for another 4 cycles for a total of 5 cycles.

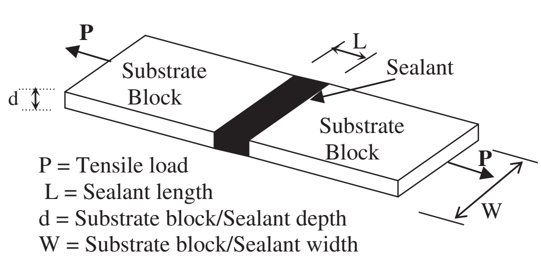

Fig. 1. Tension test specimen.

3.2. Retrofit/repair test

It is possible that the sealant could be damaged after it has been applied to a bridge expansion joint in the field. Thus, it is important to determine if a damaged sealant can be repaired simply by adding a fresh mixture of sealant to the damaged section. To evaluate this situation, a "repair" test was devised and performed. Test specimens were made where each of the samples had a cured sealant, foam or solid, on the surface of the bonding area. The specimens were then sealed with new (freshly made) sealant. The test units were made with the following characteristics: 4 samples of new foam sealed to old (previously cured/used) foam, 4 samples of new solid to old foam, 4 samples of new foam to old solid, 4 samples of new solid to old solid. A pull-to-fail tension test was performed on each sample at a crosshead velocity of 10 mm/min.

3.3. Oven-aged bond test

An oven-aged bond test was performed on the sealants to evaluate the effects of extreme changes in temperature on the bonding capabilities of the sealant as it cures. Tests were done on specimens with steel, asphalt and polymer concrete substrates. For each bonding substrate, eight test specimens, four for the foam sealant and four for the solid sealant, were prepared. These specimens were cured for 7 days at room temperature (23 °C), and then they were placed in an oven for 7 days at 70 °C. After the oven aging, the specimens were placed in an insulated box and held at −29 °C for 4 h using dry ice. After this cooling period, the test units were tested by loading them at a crosshead velocity of 6 mm/min until they reached 300% strain. The specimens were removed from the machine and left out on a table for 4 h to regain their original length. The specimens were then put in the dry ice at −29 °C for 4 h again, tested, and allowed to recover. The process of freezing, testing, and recovery was repeated for 5 cycles. This test procedure follows substantially the ASTM D 5893-96 standard [13].

3.4. Salt water immersion test

A salt water immersion test was performed on test specimens to evaluate the effects of prolonged exposure to salt water on the material and bonding of the foam and solid sealants to different substrates. For this test also two types of substrates, asphalt and steel, were used. For each substrate 8 specimens were made, 4 with foam and 4 with solid. The specimens were allowed to cure for 7 days at room temperature (23 °C), and then placed in a bucket of saturated salt water for 14 days. During this time period, the salt water was kept at a temperature of 45 °C. After the 2 weeks of submersion, the specimens were removed from the water, allowed to dry for 4 h, and tested. A pull-to-fail tension test was performed on the samples using a crosshead velocity of 10 mm/min.

3.5. Modulus over time test

The amount of time that the sealant has cured may have an effect on the strength of the sealant. To test this effect, laboratory specimens were made by bonding the foam and solid sealants to asphalt and steel substrates. For each substrate, 8 specimens were made: 4 with the foam and 4 with the solid. The specimens were extended to 100% strain at 10 mm/min and then unloaded completely. The first was done on the sealants right after they were allowed to cure for 3 h. Subsequently, this loading and unloading was repeated on the same specimens at several other time intervals, including 6, 18, and 24 h followed by once every day for the next 42 days.

4. Results and discussion

Results obtained from the laboratory tests and brief discussions on them are presented below. This should be noted that the stress–strain response for elastomers does not have any linear region. The other aspect of elastomers is that there is invariably a bit of slack at low strains as the sample straightens out. For these reasons, it is traditional in the elastomer business to report the secant modulus at 100% strain, as has been done in this paper. This allows more precise comparison of the relative properties of the materials.

The impact of the variables on properties was tested using the Student *t*-test for significant differences between the means of the observations. The assumptions behind this test are that the observations are independent and normally distributed. The *t* statistic is basically the ratio of the difference in the means to a weighted average standard deviation of the means. A high *t* is indicative of a significant difference in the means. The degree of significance is found by calculating the *p* statistic. *P* is the probability of finding a *t* as large or larger than that observed by chance