AN ACCELERATED EXPOSURE TEST FOR THE EVALUATION OF CRACK BRIDGING ABILITY OF ROOF COATINGS UNDER HOT CLIMATIC CONDITIONS

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The flat roof, made of poured or foamed concrete, is the most common type of roofing in Israel, as it is in other hot climates. It is usually waterproofed with an upper layer of bituminous or polymeric coating materials which, unless promptly protected, are exposed to the damaging radiation of the sun.

A major limitation of these coatings is their inability to bridge over forming cracks in the structure or substrate layer. These cracks are mostly "working cracks", which alter their dimensions continuously or periodically. They result from the shrinkage of the drying concrete, structural movements or external changes of temperature and humidity. Some of these phenomena are strongly enhanced by the hot climate of the area. In some cases the cracks open during daytime and close during the night. In other cases the process is reversed.

The crack bridging problem becomes more severe over the years as the coating membrane deteriorates due to its external exposure, especially to solar ultraviolet radiation.

The ability of roof membranes to bridge over existing or forming cracks, particularly "working cracks" has caused great concern among producers and researchers working in the area. It resulted in some standards and publications dealing with possible test methods for the evaluation of the crack bridging property.

Two standards published by the American Society for Testing and Materials in the last decade contain test methods for evaluating the flexibility and cycling crack bridging ability at low temperatures[1,2], and the extension of a membrane over a forming and widening crack[1].

Various researchers have developed test methods and equipment to face the problem. Thus, for example, the BRE laboratories have introduced a system which forms a fine crack, not exceeding 0.025mm, in concrete slabs[3,4]. This method enables one to examine the ability of the membrane to remain intact in spite of the cracking of the substrate.

Reid[5] and Laaly and Sereda[6] suggest methods in which two touching concrete plates are coated by a membrane and moved apart at a desired rate. This determines the ability of the membrane to bridge over the extending crack. A similar method was applied by Nihei and Iwai[7] on membranes which were exposed first to 400 hours of ultraviolet radiation. Martin[8] suggested a system for forming a "working crack" which extends to 3.5mm at 0C and contracts to 0.5mm at 80C. It is composed of a wooden plate and a blackened aluminum profile which alters dimensions as a function of temperature. A special system testing the behavior of materials under cycling extension-contraction movements while exposed to external weathering, was described by Karpati[9]. The equipment utilizes the different thermal expansion coefficients between steel and aluminum to produce a system which "works" as a function of the external temperature. It is designed for testing sealants rather than roof coating membranes.

It was, therefore, the purpose of this work to form a system, resembling, as much as possible, a crack in a roof, which is suitable for testing the bridging ability of membranes under real external conditions. This was done as part of extensive exposure tests of roofing materials in an external exposure site. To accelerate the examination, the system was designed so that the extension and contraction of the crack could be caused and enhanced by external temperature changes and radiation from the sun.

DESCRIPTION OF THE SYSTEM

The crack containing system is made of a reinforced concrete slab to which two black aluminum profiles were connected along its length (*Figure 1a*). The crack is directed to be at the center width by weakening the cross-section region with a metal strip introduced at the bottom of the slab during the casting process. The crack usually can be formed after the application of the membrane by applying mechanical forces with two appropriate screws. If required, the slab can be cracked prior to the application of the membrane, thus testing the performance of the coating membrane over an existing crack.

As the linear thermal expansion coefficient of the aluminum is 2.5 times as large as that of reinforced concrete, it is expected that the crack opening will be greatly enhanced*. In order to enhance the crack-extending process even further, the aluminum profiles are painted black and enclosed in "solar-boxes" (*Figure 1b*) made of wood and transparent acrylic sheets. The aluminum profiles thus act as solar receptors and heat to temperatures much higher than that of the concrete slab or the coated membrane, causing, altogether, an "exaggerated" widening of the crack, during daytime.

The slab, measuring 50cm × 100cm × 3cm, contains a reinforcing frame which stabilizes it and connects it to the aluminum profile on one hand, but enables it to crack, on the other. Figures 2 and 3 show the concrete slab and the reinforcing frame, respectively.

**The linear thermal expansion coefficient of the concrete and aluminum are $1 \cdot 10^{-5}\,°C^{-1}$ and $2.5 \cdot 10^{-5}\,°C^{-1}$ respectively.*

The frame is made of two flat steel bars 70cm long, to which four steel rods are welded. To stabilize these rods, they are connected crosswise by two thinner steel rods on both sides of the center of the frame.

In order to permit the slab to crack, and its two parts to move freely, the long rods are cut alternately at a distance 7.5cm from their centre, as indicated by the arrows in Figure 3. The cut parts are enclosed in short, 15cm plastic pipes having an appropriate internal diameter. This permits free movement of the steel rods. The small gap between the plastic pipe and the rod is filled with a heavy lubricant to decrease possible friction and prevent water accumulation.

The two flat steel bars of the frame are connected by two U-shaped aluminum profiles, one on each side of the slab. The aluminum profiles are connected to the steel bars with screws. A soft rubber spacer separates the two different metals.

The slab itself can be cast from regular or foamed concrete of any desirable composition. It has an elevated edge, 3cm high, to form a closed rectangular pan. This shape enables the system to hold water above the "working-crack." The system, exposed to solar radiation and other external climatic conditions, rests on two free-moving metal pipes, thus permitting the two parts of the slab to move freely.

MEASUREMENTS AND RESULTS

The expected dimensional changes of the crack width, as a function of the temperature variation, can be calculated from the thermal expansion equation

$$\Delta L = \alpha_1 L_1 \Delta T_1 - \alpha_2 L_2 \Delta T_2$$

where α is the linear thermal expansion coefficient, L the initial length, and ΔT the temperature difference, subscripts 1 and 2 stand for the aluminum and concrete, respectively. Assuming that on a hot summer day the aluminum frame heats up due to the solar radiation from 20C, at which the crack is completely closed, to 80C, whereas a white concrete slab heats up only to 30°C. Under these conditions the aluminum profile expands 1.5mm and the concrete slab only 0.1mm. The expansion of the aluminum frame causes the "opening" of the crack. The expansion of the slab causes its "closing". This results in a theoretical crack expansion of 1.4mm. In this system the crack "opens" during the day, while heating, and "closes" at night, while cooling.

Figure 4 shows measurements of a typical crack width and the temperature of the aluminum profile, as a function of the time of the day. It is clearly seen that there is a direct relationship between the two. At night, when the aluminum temperature drops to approximately 20C, the crack "closes" completely, while at midday, when the aluminum frame heats up to about 80°C, the crack widens to about 1mm.

To test the system, various temperature measurements were made with RTD devices glued on top of the measured surface. The width of the crack was measured by a mechanical-electronic device.

The system can be further developed and altered to fit cases in which the crack expands as the system cools and contracts as it warms.

It is suggested that this system, or further modifications of it, should be used as a recommended test method for the evaluation of the bridging ability of roof membranes over a "working-crack," while exposed to the damaging solar radiation and other external climatic conditions.

REFERENCES

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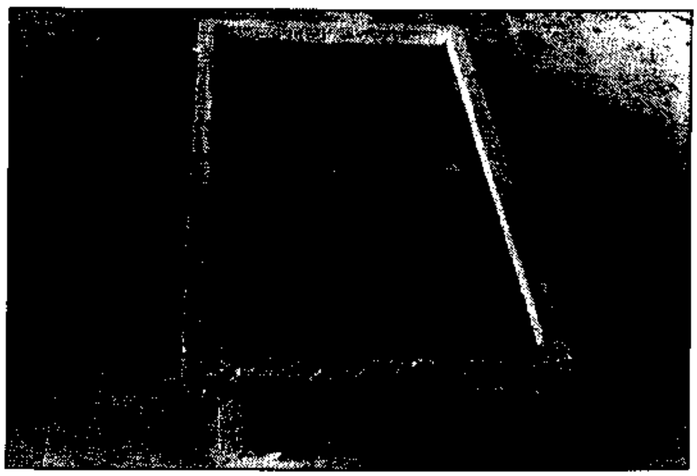

Figure 1a The cracked concrete slab without the "solar-boxes"

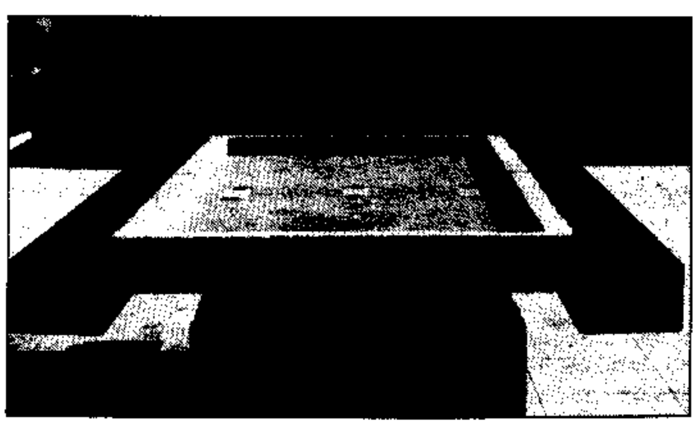

Figure 1b The cracked concrete slab with the "solar-boxes"

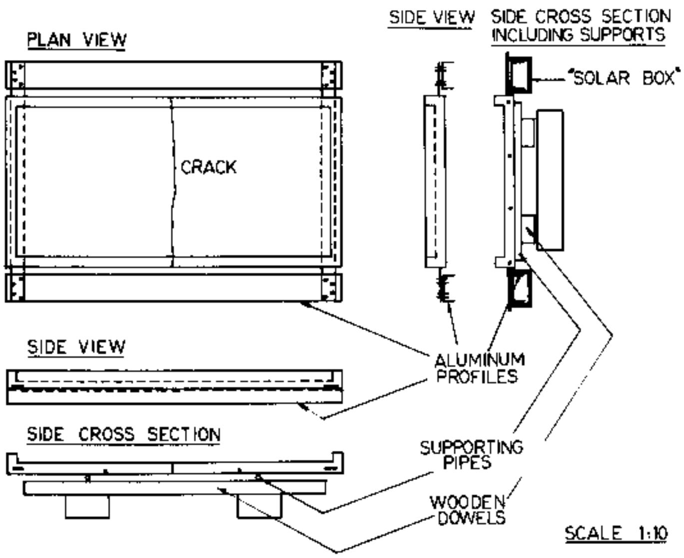

Figure 2 *The concrete slab*

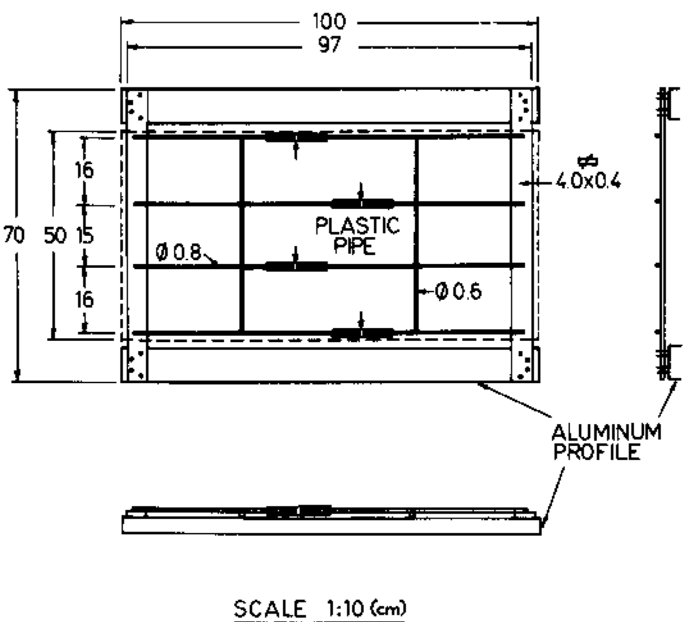

Figure 3 *The reinforcing frame and aluminum profiles*

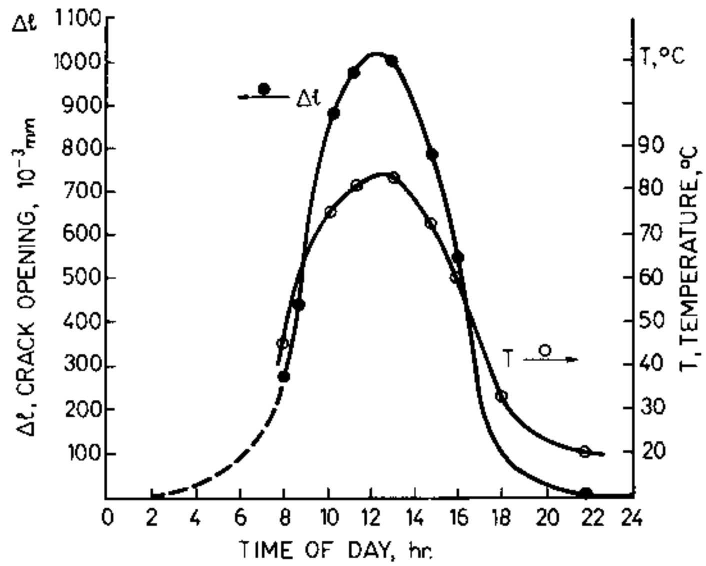

Figure 4 *Variation of the temperature (o) of the "solar-receptor" and the width of the crack (•) as a function of the time of the day. At mid-day the crack is at its maximum opening, while at night it "closes" to its minimum width.*