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Peel resistance of adhesive joints with elastomer–carbon black composite as surface sensing membranes

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ABSTRACT

The peel resistance of four adhesives ("J-B Weld" by J-B Weld (adhesive A), 3 M Scotch-Weld DP 125 Gy (adhesive B), Loctite PL Premium (3x) Construction Adhesive (adhesive C), and Henkel Hysol EA9394 (adhesive D)) is investigated for their bonding performance of a styrene-ethylene/butylene-styrene–carbon black (SEBS–CB) composite membrane used in structural health monitoring (SHM) applications. Tests are performed on membrane samples bonded on four common structural materials, namely aluminium, steel, concrete, and fiberglass, to obtain the peel resistance of adhesives. Results show that adhesive B has the highest strength for aluminium, steel, and fiberglass substrates, and that adhesive C has the highest strength for the concrete substrate. The performance is also evaluated versus adhesive cost, a critical variable in SHM applications. Here, adhesive C performed best for all substrates. Lastly, membrane residuals resulting from the peel tests are compared. Tests show that Adhesive B resulted in the highest residual percentage for aluminium, while adhesive C performed better for all other substrates. However, membrane residuals for adhesive C do not show a positive correlation with the peel resistance.

1. Introduction

Structural Health Monitoring (SHM) is the automation of the condition assessment process of structural systems. Many SHM applications are engineered for mesosystems, such as transportation infrastructures [1,2], energy production structures [3–5], and aerospace systems [6]. To enable SHM of geometrically large systems, various types of sensing membranes or skins have been researched and developed [7–10]. The main characteristic of such technology is the deployment of a local sensing solution over a global system, analogous to biological skins. However, the electrical (e.g., signal) and mechanical (e.g., durability) performance of these systems is highly dependent on the adhesive bonding the membrane onto the monitored substrate.

The authors have recently proposed a sensing skin for SHM of wind turbine blades [11,12]. The sensor is a soft elastomeric capacitor. Its dielectric is fabricated from a styrene–ethylene/butylene–styrene (SEBS) filled with titania, and sandwiched between two layers of electrodes consisting of an SEBS–carbon black (CB) mix (SEBS–CB). Once installed, one of the electrode layers (SEBS–CB) is directly deployed onto the monitored surface.

In this paper, the performance of four different adhesives for bonding elastomeric sensor electrodes onto various structural substrates is investigated. Performance of adhesives is a modern area of research due to the growth in the fabrication of composite structures. In particular, researchers have studied the resistance-to-peel strength of adhesives for vehicles and aircraft applications [13–15]. Others have investigated the problem of peel stress [16,17], and fracture mechanisms of epoxies [18–20]. The adhesives under study in this paper are J-B Weld (adhesive A), 3M Scotch-Weld DP 125 Gy (adhesive B), Loctite PL Premium (3x) Construction Adhesive (adhesive C), and Henkel Hysol EA9394 (adhesive D). The selection was based on experience in prior work, availability, and differences in claimed strength, applications, and curing time. Selected structural substrates are 6061 aluminium, A36 steel, concrete, and fiberglass. They were selected due to their common utilization in structural engineering. The comparison between adhesives is conducted by determining the peel resistance, and evaluating cost versus performance, and analyzing SEBS–CB residuals after peel.

The paper is organized as follows. Section 2 discusses materials and methods for the sensing membrane fabrication, sensing membrane adhesion, and the peel resistance measurements and

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analysis. Section 3 presents and analyses experimental results, including an analysis of the peel resistance and its correlation with post-peel membrane residuals on different substrates. Section 4 concludes the paper.

2. Material and methods

2.1. Sensing membrane fabrication

Sensing materials were fabricated following a previously established fabrication methodology [1,11,21,22]. Briefly, the SEBS-titania composite dielectric was fabricated using a solution casting method. SEBS pellets were dissolved in toluene, and titania particles (Sachtleben R 320 D) were added and dispersed using sonication. The resulting solution was cast on a 10 cm × 10 cm glass plate and kept at room temperature for 5 days to allow toluene to evaporate. The electrodes were fabricated by mixing CB particles (Printex XE 2-B) into an SEBS solution to produce a conductive paint, which was sprayed onto both surfaces of the dielectric to constitute the sensor. Fig. 1(a) shows a picture of the resulting sensor. Fig. 1(b) shows a picture of a typical sample cut from the fabricated sensor.

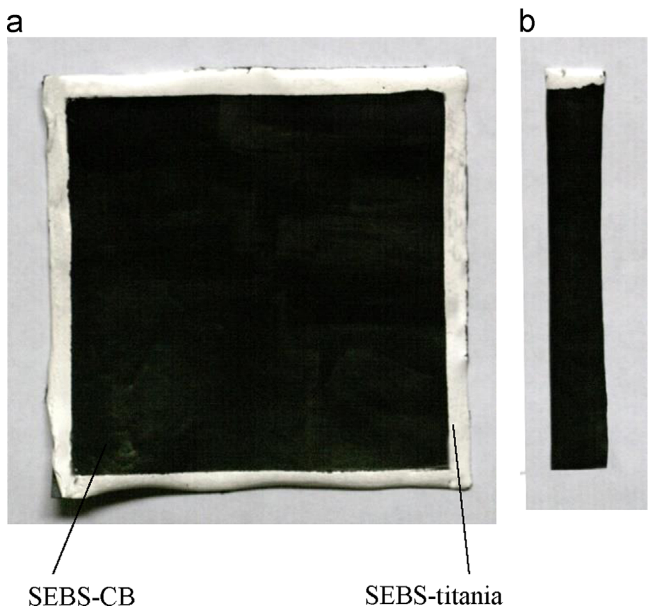

Fig. 1. (a) A 10 cm × 10 cm sensing membrane; and (b) a typical 1.3 cm × 9.5 cm sample cut from the fabricated membrane.

2.2. Sensing membrane adhesion

The bonding performance of adhesives was examined for four different substrates: 6061 aluminium plates, A36 steel plates, concrete slabs, and fiberglass sheets, cut into cylindrical shapes of 15 cm diameter and 2.5 cm height (aluminium and concrete), square shapes of 15 cm × 15 cm and 2.5 cm height (steel), and square sheets of 15 cm × 15 cm (fiberglass). Aluminium and steel plates were purchased from Speedy Metals. Concrete slabs were cut from concrete cylinders fabricated using Portland cement and limestone in our lab. Fiberglass sheets were fabricated by structural fiberglass-reinforced polyester (FRP), purchased from McMaster-Carr. The substrates' surfaces are shown in Fig. 2(a). Six peel-testing strip samples (each 1.3 cm × 9.5 cm) were cut from each membrane (Fig. 1(b)) and adhered onto each substrate. Substrate surfaces were ground using abrasive papers and cleaned with ethanol. A thin layer of adhesive was then smoothly applied on the surface and hand-spread as thin and uniformly as possible. The membrane samples were then deployed by hand onto the adhesives and any air bubbles were gently squeezed out. The mixing and curing procedures of adhesives were based on the commercial instructions given for each adhesive. Fig. 2(b) is a schematic of the prepared specimen for a single strip. Approximately 30 mm over one end of the strip was not adhered to allow mechanical attachment of the grip for the peel test. Four different adhesives were selected for testing their bonding performance: adhesive A, adhesive B, adhesive C, and adhesive D. Table 1 lists the main characteristics of each adhesive.

2.3. Peel test procedures

Peel tests were done to acquire the peel resistance of adhesives by peeling a flexible adherend from a rigid adherend at a 90-degree angle. A single-degree-of-freedom Instron 5569 platform was used to conduct the peel test. Peel tests were initiated at 90 degrees and the angle between the flexible membrane and the substrate was allowed to vary naturally as the flexible adherend peeled from the rigid adherend. All strip specimens were prepared with the same adhered length and unadhered length (shown in Fig. 2) to ensure the identical peel-angle and comparable data. Tests were conducted at constant rates of extension (peeling rates) at 25 mm/min and 250 mm/min. Fig. 3 shows a picture (Fig. 3(a)) and a schematic (Fig. 3(b)) of the test setup. A copper tape was used between the grips and the membrane to increase friction.

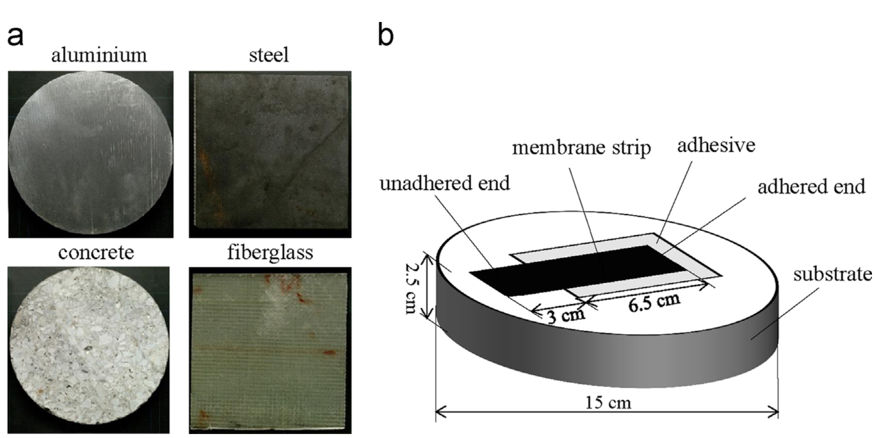

Fig. 2. (a) Substrate surfaces; and (b) a schematic of one strip adhered on the substrate.