

Structural Repair using Smart Materials

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Damages such as a crack/notch and delamination in aerospace, mechanical and offshore structures due to fatigue, corrosion or accident are inevitable during services. Such damages will grow at an alarming rate due to the stress/strain concentration around the damage locations and cause possible failures of structures [1-4]. Thus, the structural repair has become an important and practical research topic since the last several decades and attracted much attention in academy and industry. A key objective in a repair design is to lessen the stress/strain concentration at the damaged part of a structure, e.g. the tips of the notch/crack and delamination, to reinforce the damaged structure. Structural repair with bonded materials has been the most traditionally used technology to increase the service life of damaged structures [5]. The traditional method was to weld or mount additional high stiffness patches onto the damaged area to improve the mechanical function of a damaged structure. In 2002, a patch repair of cracks in the longeron of an F16 aircraft was reported by Hart and Boogers [6]. The main cause for cracking was the occurrence of assembly stresses due to an improperly repaired access panel 2408. Since a conventional mechanical repair could not be done, a cost effective bonded patch repair was evaluated and applied to the cracked longeron. Titanium 6A14 V sheet was used for repair of the 2 mm thick 2024-T62 aluminium longeron flange. A symmetric bonded repair was done with a room temperature curing acrylate based adhesive. The feasibility of the proposed repair geometry was determined by periodic inspections to check on de-bonding and fatigue crack propagation. However, it was noted that the repair process was designed for an air craft with a limited service life (400 flight hours). A major problem is that additional stress concentration may possibly be induced at the bonding area [7]. Moreover, the repair method using normal additional patch cannot adjust itself to newly induced damage due to unexpected external loadings.

In view of the limitations of the structural repair with traditional methods, smart materials have been employed in applications of structural repair due to their adjustable mechanical property. As a type of common used smart materials, piezoelectric materials refer to substances that have the electro-mechanical coupling effect: i.e. an electric charge will be produced when an external load is applied on a piezoelectric material, and conversely a mechanical deformation will be generated by applying an electric field to the piezoelectric material. Owing to its active electro-mechanical property, the employment of piezoelectric materials in structural repair with different damages has been investigated with remarkable and attractive research findings. Wang et al. [8] first presented a study on repair of a cracked beam under a static transverse loading. A voltage, which was obtained from a numerical model of a simply supported beam, was applied to a piezoelectric patch bonded on the beam to ensure the reduction of the stress around the crack. A study on smart-patch repair of cracked aircraft panels was addressed by Sekine [9]. The patching efficiency in cracked aircraft panels repaired with piezoelectric patches was examined, and the enhancement of patching efficiency due to the activation of piezoelectric actuators was presented. In addition, a close-loop feedback control repair method using piezoelectric patch for repair of a notched beam subjected to a dynamic loading was proposed by Wang et al. [10]. The piezoelectric patch was used for both vibration sensor and repair actuator in the close-loop feedback control process. In repair of delaminated

structures under dynamic loadings, Wu and Wang [11] developed a design for repair of a vibrating delaminated beam structure bonded by piezoelectric patches. Expect the numerical simulations, an experimental study on the active reduction of the crack propagation using piezoelectric patch was proposed by Platz et al. [12]. A piezoelectric patch was applied directly to the crack area to lower the cyclic stress intensity factor at the crack tip so that the crack propagation can be reduced. Another experimental study was conducted by Wu and Wang [13]. The reduction of the slope discontinuity at the notch position, which directly represented the intensity of the stress concentration at the notch tip, was achieved in finding the feedback factor that was to be multiplied to the feedback voltage from the piezoelectric sensor for an actuation voltage. Although the structural repair using piezoelectric materials have been well studied and proved to be feasible with numerical simulations and experimental studies, the limitation of its practical application is still evident. For example, the force generated by the normal piezoelectric patch, which is the widely used piezoelectric structure, is relatively small for the repair of large damaged structures, such as the frame of large aircraft, the chassis of heavy duty vehicles and civil structures. Furthermore, the crisp mechanical properties of most of the piezoelectric materials, especially the piezoelectric ceramics, is another key factor restricting its wide application on engineering structures, when the piezoelectric patch is mounted directly on the surface of the substrate structure with the large deflection or deformation.

Thus, future works on the structural repair using smart materials would concentrate on the methods to increase the generated repair force and improve the adaptability of the smart materials for different structures and working conditions. To increase the generated force from the smart structure, the design and electro-mechanical property of the piezoelectric stack should be further studied. On the other hand, the study of the piezoelectric fiber composite material will be an important research topic to improve the adaptability of the application of smart materials on different engineering structures as sensors and actuators. Moreover, using Shape Memory Alloys (SMAs) instead of piezoelectric ceramics as the actuator for the structural repair is another solution as SMAs could generate larger force and hold much larger deformation than the piezoelectric ceramics. The main problem using SMAs as the structural repair actuator is that the reaction process of SMAs under an active control is usually slow compared with the fast electro-mechanical reaction process of the piezoelectric materials. To reduce the response time of the SMAs will be another interesting and practical research topic within this field.

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