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Analyses of cracks in thick stiffened plates repaired with single-sided composite patch

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ABSTRACT

This study investigated the effect of composite patches applied to thick stiffened plates with single-sided repairs. A simplified analytical model was derived to predict the reduction in the mode I strain energy release rates resulting from the single-sided composite patches. Finite element analyses were also conducted to compute the mode I strain energy release rates with and without composite patches, and their results were compared to the analytical model prediction. Furthermore, changes in the location of the neural axis with single-side patches were examined with their effects on the effectiveness of the patch repair with variations in both material and geometric parameters of the patch and plate. The neutral axis location in the patched plate played an important role to influence the effectiveness of the composite patch.

1. Introduction

The advancement of composite materials has led to an increase in their use for a wide variety of applications. Both the marine and aerospace industries have gravitated towards the use of composite materials because of their favorable properties. One application that has gained favorable attention in recent years is the use of composites for patches in the repair of cracks in aluminum structures.

During the service life of a vessel or aircraft, various repetitive loadings occur leading to fatigue cracking. Fatigue cracks can continue to grow and adversely affect the structural integrity of the ship or aircraft [1,2]. For example, some naval ships experienced severe fatigue cracking early in their service life. The ships were designed with a steel hull and a continuous aluminum superstructure welded to the deck. The shape of the superstructure created numerous stress concentration areas. Some other ships had experienced stress corrosion cracking in areas of relatively low stress levels. Composite patching has been applied to the cracks to retard the crack growth.

The aircraft industry has been using composite materials for several decades with great success. The high strength-to-weight ratio of composites has naturally lent themselves to this field. This wide acceptance of composites has included their use as a method of repairing cracked aluminum surfaces [2]. Traditional methods of repair normally consisted of riveting an additional reinforcement onto the damaged area. This would create new defects and stress concentrations which could lead to additional cracking. On the other hand composite patches did not cause any further damage to the affected area and could be removed and reapplied several times if necessary. They were also found to be an easier method for quick repairs and could be formed around complex areas of an aircraft structure [2,3].

Composite patching of cracks in aluminum structures has been studied to a great extent. There have also been many studies involving the effect that stiffening members have on crack growth. Double-sided or symmetric patching is the strongest configuration when applying a composite patch. This has been shown as an effective means of lowering the Stress Intensity Factor (SIF) and in turn increasing the fatigue life [4–6]. Symmetric patching has been shown to provide a more even distribution of stress across the thickness of the plate. For the same configuration, a study showed that a double-sided patch has twice the fatigue life of a single-sided patch [7].

Aircraft and ship structures are often inaccessible on one side and therefore do not lend themselves to symmetric patching. Or in some cases, an aircraft would prefer to have a patch on the internal side of its skin to reduce drag. For these reasons, asymmetric patching is the most common application and has led to several studies to focus on this configuration. [3,8,9] Asymmetric patching causes a shift in the neutral access away from the center of the plate towards the patched side. The shift in the neutral axis introduces a bending moment that increases the stress on the

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unpatched surface [3]. This causes an increase in the SIF which in turn lowers the effectiveness of the patch [3].

The majority of studies on composite patching have modeled thin aluminum plates to represent the skin of an aircraft where patches have been predominantly used. The increasing use of composite patching for naval applications has led some studies to consider the significance of patching thicker plates [6,9]. They have conducted experimental and finite element comparisons of a thick aluminum plate with various composite patch repairs.

There are many geometric, material and loading parameters affecting the effectiveness of the composite patch repair. Some of the previous studies examined those effects. For example, patch dimensions including patch thickness was studied. [5,8] The layer orientation of fibrous composite was studied. [4,10] The effect of mismatch in coefficients in thermal expansion was studied [9,10], and the effect of welding stiffeners on residual stresses were also considered. [11–13] A study conducted both experimental and finite element research on composite patched plates with riveted stiffeners. [14] The study showed that a composite patch applied to an unstiffened plate increased the fatigue life of the plate by 10 fold, however when applied to a stiffened plate the fatigue life only increased by 5 fold.

Developing an analytical model for a patched plate allows for easy selection of patch parameters to reduce crack growth. Analytical models have been developed for patched plates along with cracked [15]. A simple analytical expression for use in designing single-sided composite patch for an unstiffened thick plate was developed previously. [9] There has yet to be one developed for a stiffened plate with a single-sided composite patch. A key attribute to an analytical model is its ease of use.

Overall, there has been significant effort in the study of composites patching for thin flat aluminum plates. However, there has been much less focus on thicker plates or plates with stiffening members. This study investigates the effect of composite patches applied to thick stiffened plates with single-sided repairs. A simplified analytical model is developed to aid the patch design for single side repair of thick stiffened plates. The model determines how much reduction in SERR will be obtained with selection of patch parameters like material properties and the thickness of the patches. Finite element analyses are also undertaken to compute the mode I strain energy release rates with and without composite patches in order to validate the developed analytical model. Additionally, the numerical studies exam the effectiveness of single-side patches with different patch parameters. Especially, the change in the neural axis location is investigated to determine its influence on the patch effectiveness.

2. Finite element models

The finite model used in this study is intended to represent a portion of a ship's structure. To accomplish this, several features included in the model are varied as they would in ships structures.

2.1. Model description

The finite element model for this study is constructed with the geometry as shown in Fig. 1. The base of the model is a flat plate 0.61 m long, 0.61 m wide and 6.35 mm thick. A horizontal crack is modeled through the thickness of the plate. Both the cracks size and position vary along the *x*-axis. The material properties for the plate are selected to resemble aluminum which is often susceptible to cracking.

A T-beam stiffener is used throughout this study. This is to represent one of the more common support members found in ships structures. The stiffeners in the model run the length of the plate and are depicted as gray rectangles in Fig. 1. The stiffeners have two configurations. They are either on the same side or opposing side as the patch. The initial dimensions of the stiffeners used for the current analysis can be seen in Fig. 2. Both tensile and bending loads are applied to the model, respectively to represent the forces experienced by a ship. Both of these loads are represented by applying a pressure to the ends and top of the plate, respectively. For both loading conditions, the plate is simply supported on two opposite edges of the plate, which is parallel to the crack orientation.

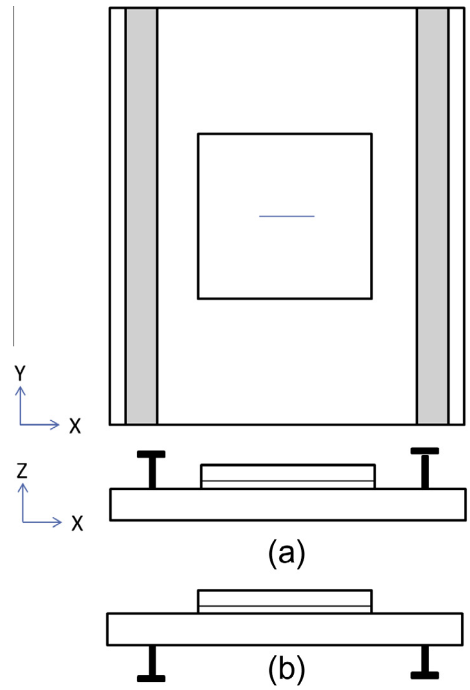

Fig. 1. Model of stiffened plate with single-sided patch. (a) Patch on the stiffener side, (b) patch on the opposite side from the stiffeners.

The stiffened plate with or without a patch is molded using a twenty-node solid brick element. Due to the varying parameters in this model, it is not possible to take advantage of any symmetry. Instead, in order to decrease the computational time, the mesh size is varied. In vicinity of the crack tip very refined mesh is used, and the further from the crack the coarser the mesh becomes.

The two opposite crack faces of a through-the-thickness crack in a plate may contact each other as the plate is bent by external loading. As a result, the contact boundary condition is included in the analysis. Contact problems result in nonlinear analysis and significantly increase the run time of the model. For this reason, they are only used when necessary. The preliminary numerical

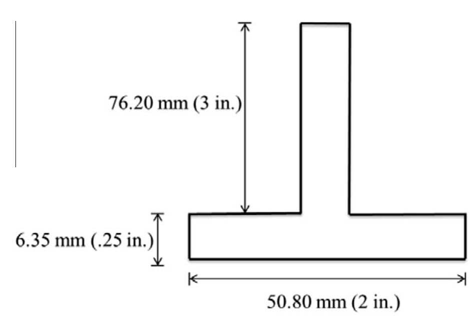

Fig. 2. Stiffening member dimensions.