VOL. 11, NO. 3, FEBRUARY 2016 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

MESO-SCALE NUMERICAL STUDY OF COMPOSITE PATCH REPAIRED HOLE DRILLED STEEL PLATE

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ABSTRACT

A large number of steel structures, such as bridges, offshore platforms, large mining equipment and buildings, need retrofitting [1]. The use of composite materials patching is a very attractive alternative to the traditional reinforcement or repair methods (i.e. bolted doubler plates, welding), overcoming many of their limitations and disadvantages [2]. In this paper numerical models of hole drilled steel plate without repair and composite patch repaired hole drilled steel plate were developed, analyzed and compared using ANSYS software. The hole acts as damage, such as severe localized corrosion, in the steel plate, resulting in the development of high stress concentrations. Stress and strain results of the damaged steel plate indicated that three-ply composite patch reduced the maximum equivalent (von-Mises) stress and maximum equivalent elastic strain of the damaged plate by approximately 17.7% and 19.5%, respectively. Analyzing strains, stresses and failure criteria of the composite laminate requires to model the single layers a composite design is built up by. This method is called meso-scale approach. It requires material properties and thicknesses for each layer of the design. Plywise stress and strain results of the composite patch repair revealed that maximum stress and strain took place in the center of the first ply.

Keywords: composite patch repair, steel plate, failure criteria.

INTRODUCTION

Engineers are faced with a rising level of aging infrastructure which has, in turn, led them to implement new materials and techniques to efficiently combat this problem. The use of FRPs as external reinforcement of concrete structures has shown itself to be a successful alternate method of repair, and has been around for about 20 years. However, research related to FRP applications to steel structures has started fairly recently and there are still few applications in practice [3].

In this paper numerical models of damaged steel plate without repair and composite patch repaired damaged steel plate were developed, analyzed and compared using ANSYS software. In ANSYS, there are two methods available to model a composite laminate, namely macro-scale approach and meso-scale approach (laminate level). In this research meso-scale approach is chosen and ANSYS composite PrepPost (ACP) module, which is an add-on module to ANSYS, is utilized. In this approach, individual ply properties alongside with laminate stacking sequence are defined in ACP-Pre and composite specific results of a design, such as stress, strain and failure criteria of each ply, are evaluated and visualized in ACP-Post [4].

NUMERICAL MODEL OF HOLE DRILLED STEEL PLATE

A plate of 30cm x 30cm with thickness of 1cm and a centered hole with diameter of 2cm were modelled. A fixed support for one side of the plate and a static tension load of 250 KN for other side of steel plate were assigned, as shown in Figure-1.

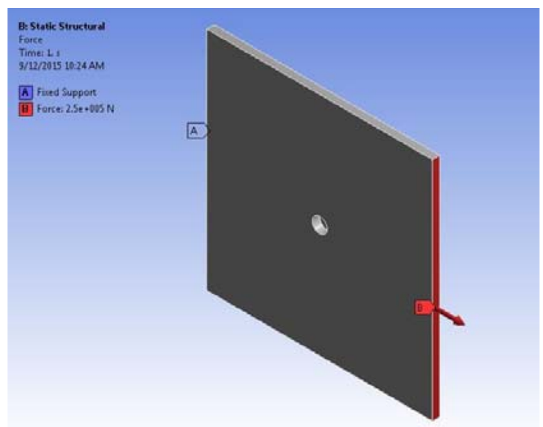

Figure-1. Steel plate with a centered hole.

Stress and strain analysis of the steel plate (before repair), as shown in Figure-2 and 3, indicated the maximum equivalent (von-Misses) stress of 269.89MPa and maximum equivalent strain of 1.38E-03.

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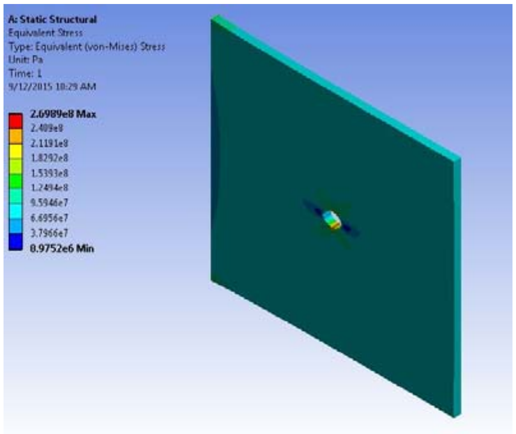

Figure-2. Equivalent (von-Mises) stress of steel plate.

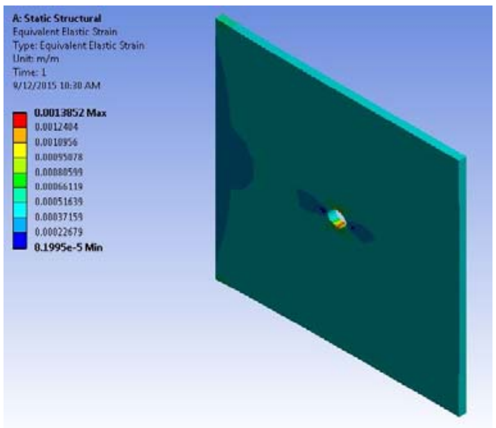

Figure-3. Equivalent elastic strain of steel plate.

MESO-SCALE NUMERICAL MODEL OF COMPOSITE PATCH REPIARED STEEL PLATE

A composite patch of 15cm x 15cm was consider to repair the damaged steel plate, as shown in Figure-4. The material of *epoxy carbon UD 230GPA wet* from engineering database of the software was used in this model. Carbon fiber-reinforced polymer is commonly used for the strengthening of steel structures because its modulus is close to or higher than that of steel [5]. Between the composite patch and the surface of steel tubular member, bonded contact was assigned. Therefore, it is assumed that separation or sliding on the interface between the composite and steel substrate does not take place under the assigned load.

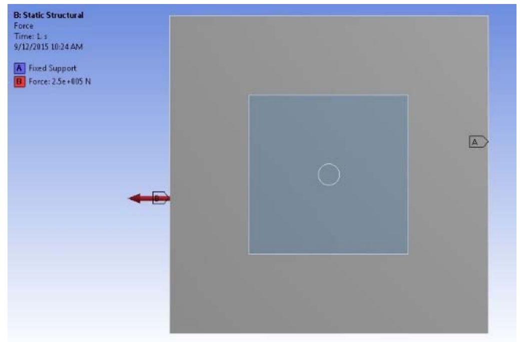

Figure-4. Composite repaired steel plate.

Three-ply composite patch with a thickness of 1mm/ply was modelled in ACP-Pre. Fiber orientation of first ply was assigned parallel to the load, while fiber orientations of second and third plies were rotated 45º and 90º respectively, as shown in Figure-5(a) to 5(c).

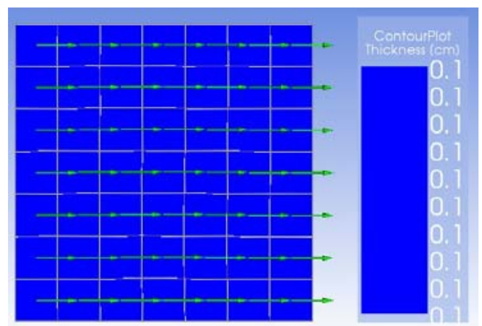

Figure-5(a). Thickness and fiber orientation of the first ply.

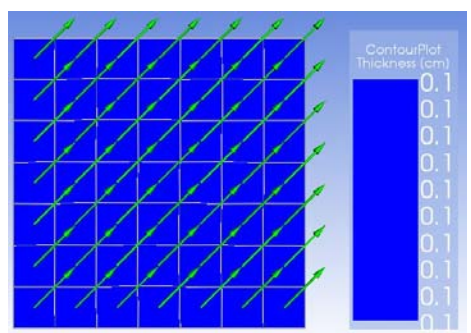

Figure-5(b). Thickness and fiber orientation of the second ply.

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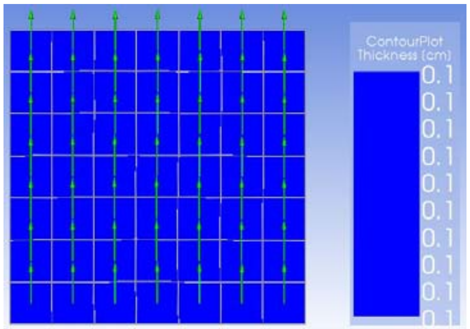

Figure-5(c). Thickness and fiber orientation of the third ply.

Stress and strain analysis of the repaired steel plate, as shown in Figure-6 and 7, indicated the maximum equivalent (von-Mises) stress of 222.65MPa, which is less than yield strength of structural steel, and maximum equivalent elastic strain of 1.11 E-03. Therefore, composite patch repair reduced maximum equivalent (von-Mises) stress and maximum equivalent elastic strain of the steel plate by approximately 17.7% and 19.5%, respectively.

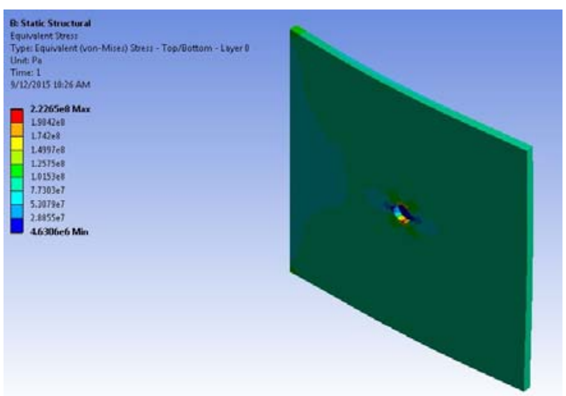

Figure-6. Equivalent (von-Mises) stress of repaired steel plate.

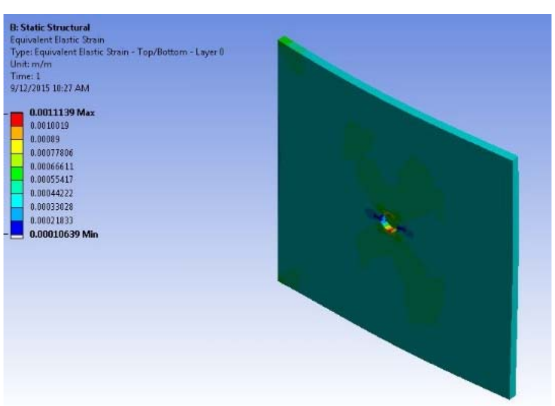

Figure-7. Equivalent elastic strain of repaired steel plate.

Composite patch was evaluated based on stress, strain and failure criteria within the layer in ACP-Post. In-plane (along fiber orientation) stress results of composite patch were evaluated layer by layer as shown in Figure-8(a) to 8(c). Maximum stress of composite patch was observed in the center of first ply.

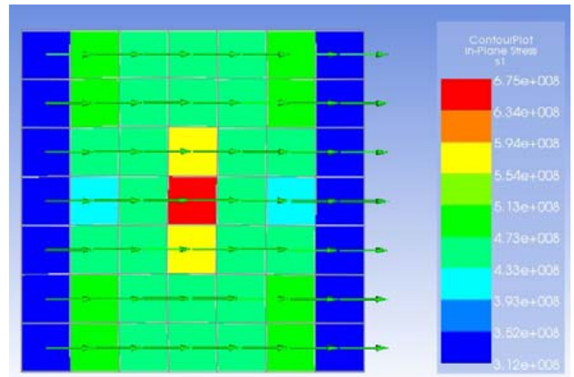

Figure-8(a). In-plane stress of the first ply.

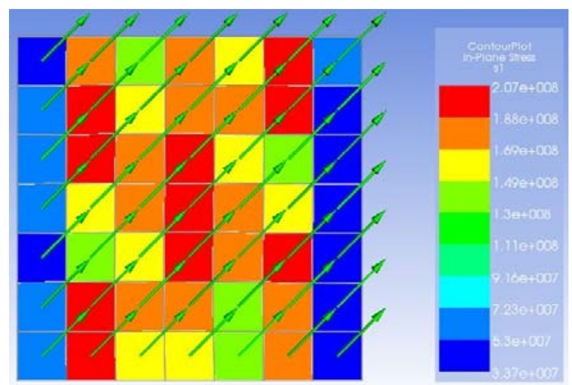

Figure-8(b). In-plane stress of the second ply.

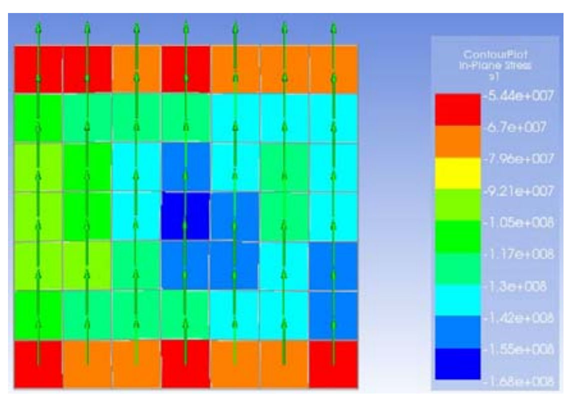

Figure-8(c). In-plane stress of the third ply.

Strain results of composite patch were evaluated layer by layer as shown in Figures 9-(a) to 9(c). Maximum strain of composite patch was noticed in the center of first ply.

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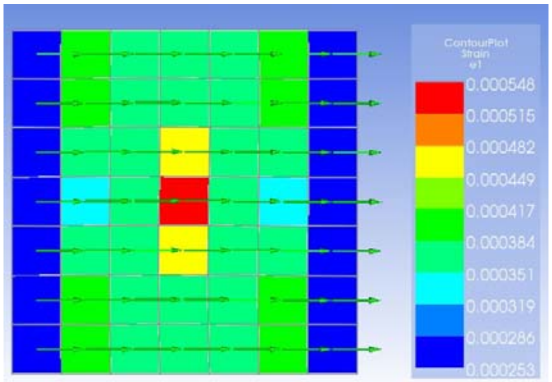

Figure-9(a). Strain of the first ply.

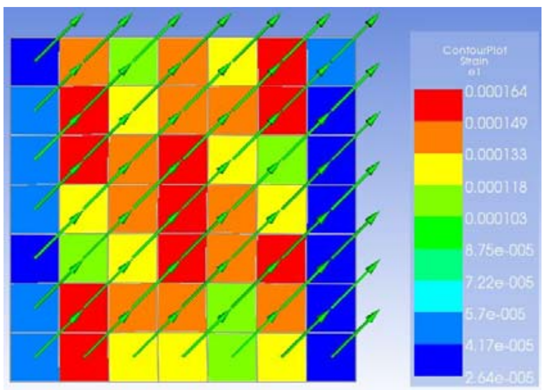

Figure-9(b). Strain of the second ply.

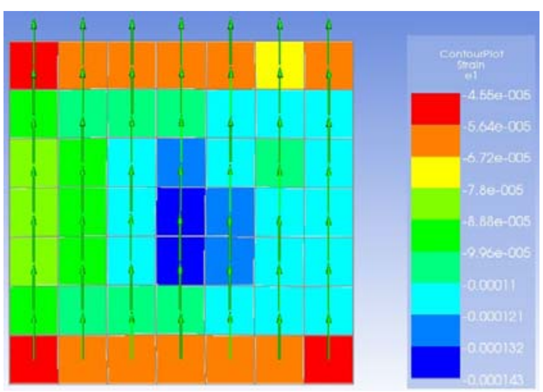

Figure-9(c). Strain of the third ply.

Due to their orthotropic material behavior and multiple possible failure modes, failure analyses of composites are significantly more complex than for isotropic materials. Multiple failure criteria are available to predict different failure modes. Failure criteria compare loading conditions (stress and/or strain values) with defined strength values for the composite material. The following failure criteria are currently available in ACP: Maximum strain and maximum stress, Tsai-Wu, Tsai-Hill, Hashin, Puck, LaRC, Cuntze, Core Failure and Face Sheet Wrinkling [4].

Failure criteria results of composite patch were evaluated layer by layer as shown in Figure-10(a) to 10(c). In addition to the layerwise postprocessing, failure criteria were evaluated as all in one overview plot as shown in Figure-11. In one view, critical failure criteria and critical layers are illustrated. Under assigned load, no critical region or critical failure criteria in composite patch was observed.

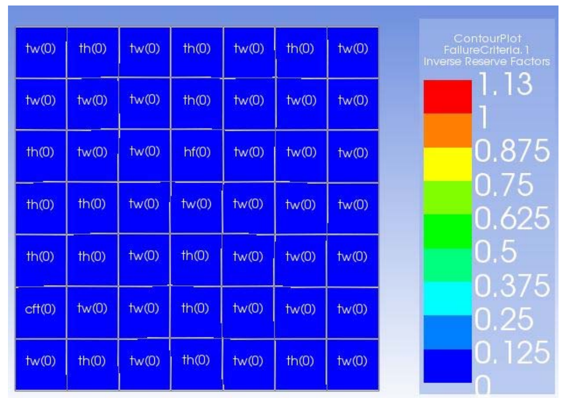

Figure-10(a). Failure criteria of the first ply.

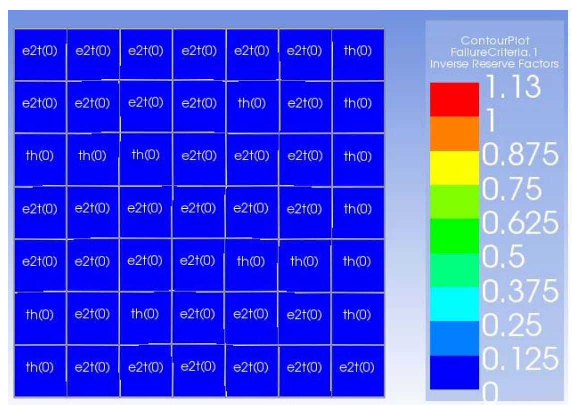

Figure-10(b). Failure criteria of the second ply.

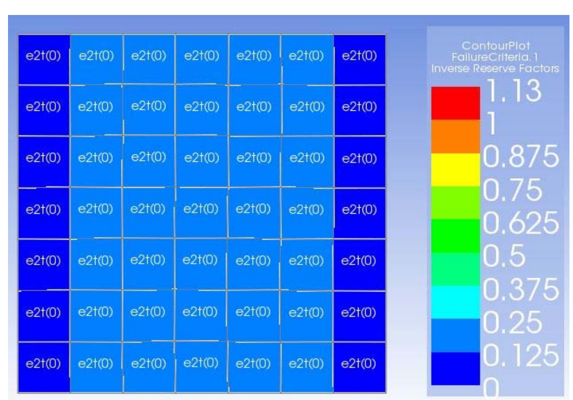

Figure-10(c). Failure criteria of the third ply.

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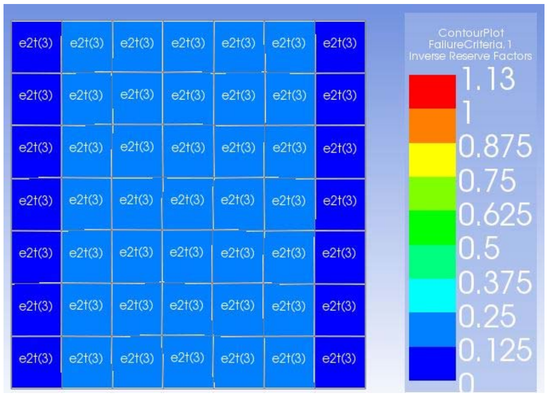

Figure-11. Failure criteria of composite patch.

CONCLUSIONS

In this research, attempt was made to enhance the existing knowledge on the meso-scale finite element modelling of composite patch repair of damaged steel structures. The three-ply composite patch (with different fiber orientation in each ply) reduced the maximum equivalent (von-Mises) stress and maximum equivalent elastic strain of the hole drilled steel plate by approximately 17.7% and 19.5%, respectively. Composite patch was evaluated based on stress, strain and failure criteria within the layer. Plywise stress and strain results indicated that maximum stress and strain has taken place in the center of the first ply. Plywise failure criteria analysis demonstrated that under assigned load there is no critical region or critical failure criteria in plies of composite patch.

ACKNOWLEDGEMENTS

The first author would like to thank for the graduate assistantship of the Universiti Teknologi PETRONAS (UTP) and acknowledge University Research Internal Fund (No. 153AA-B74) of UTP. This research was also supported by the Technology Innovation Program (Grant No.: 10053121) funded By the Ministry of Trade, Industry and Energy (MI, Korea).

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