Finite Element Analysis of Composite Patch Repaired Cracked Metal Plates and Effect of Patch Thickness on SIF

Shubham Walde, Sunil Lilhare

***Abstract*— The objective of this study was to compare the performance of composite patch repaired cracked metal plate by varying the patch thickness and changing the patch as well as plate material. The finite element method (FEM) is used to compute the stress intensity factor (SIF) at the crack tip. Study shows that the application of the bonded composite patch very effectively reduces the stress intensity factor at the crack tip and hence retards or eliminates the crack propagation. As the chance of fracture is considerably reduced, the life of structure increases by almost twice of the initial.**

***Index Terms*— Adhesively-bonded patch, Crack propagation, Finite Element Analysis (FEA), Stress Intensity Factor (SIF).**

I. INTRODUCTION

Various metal components are used to carry out number of works in every industry. There are circumstances when components develop small or medium cracks on plates when working stresses exceed the design strength of the material. So the component is either discarded or repaired. Discarding component much before its life is not a good choice. Repair using adhesively bonded composite patches reduces the stresses due to local damage and restores the static strength of a component and thereby increases reliability. As a result the life of a component is further increased.

Engineering structures when subjected to high loading may result in stresses in the body exceeding the material strength and thus results in progressive failure. These failures are often initiated by near or near surface crack.

There are very limited industrial applications available for this technology as described by Baker and Rose in their literature on adhesively bonded patch repair. By this sense, this method is still in developing stages. Different patches are selected on the basis of desired properties. Not only the patch but also the adhesive that is used plays a significant role in the combined property of the bond. Hence number of combinations can be made using different patches and several adhesives. Thickness of the patches also plays a significant role in the reduction of fatigue loading and reducing the Stress Intensity Factor. Baker has performed many bonded patching experiments and published numerous journals and books on that topic. He explains the desirable properties of various adhesives available in the market. Baker has also done research on optimum shape of the patch among the various patch shapes. He recommends the use of rectangular patch over other patch shapes. Because of its efficiency in reduction of SIF is highest.

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Both one-sided (un-symmetric) or two-sided (symmetric) patches can be used for some particular application. But it is found that two-sided patching is most efficient and increases the service life of the component. In symmetric patching the there is considerable reduction in SIF with the increase in patch thickness.

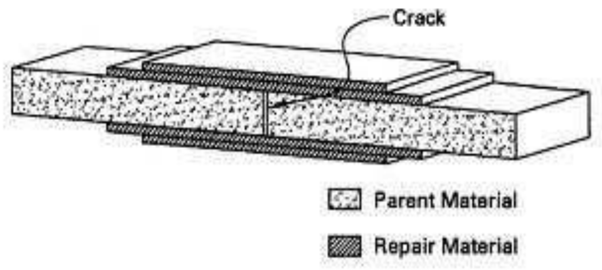


Fig 1.1: Symmetric patch on cracked panel.

The change in patch thickness profoundly affects the SIF for the loaded component or structure. In this work the analysis on Aluminium, Steel and Duralumin plate is done using CFRP, Boron epoxy and Glass epoxy composite patch.

II. LITERATURE

2.1. Analysis of un-patched configuration:
The stress intensity factor is given by,

$$K = \sigma\sqrt{\pi a}\, f\left(\frac{a}{w}\right)$$

The differential term $f\left(\frac{a}{w}\right)$ is a polynomial which depends on number of terms taken in the Taylor's expansion. Its value ranges between 0.92-0.99.
The patch repaired SIF, K_R is given by

$$K_R = Y.\sigma_0/\sqrt{K}$$

Where, Y=1 for centre cracks and

$$\sigma = \sigma_0/(1+s)$$

s = spring constant which depends on material properties of specimen and patch.

III. EXPERIMENT

A metal plate of dimension (L = 10, B = 20, T = 1) (in.) is subjected to tensile load of 100 Mpa at one end and is constraint at the opposite end in x-y directions. A crack of length 2a = 2 inch is present at the centre of the plate as shown below

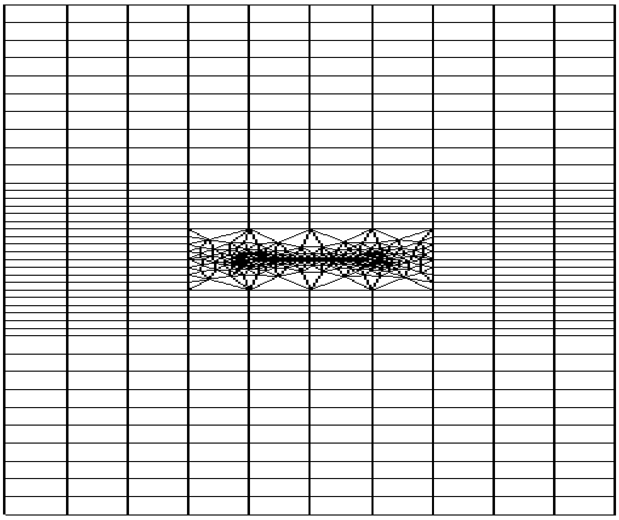


Fig.3.1. Plate mesh with central crack

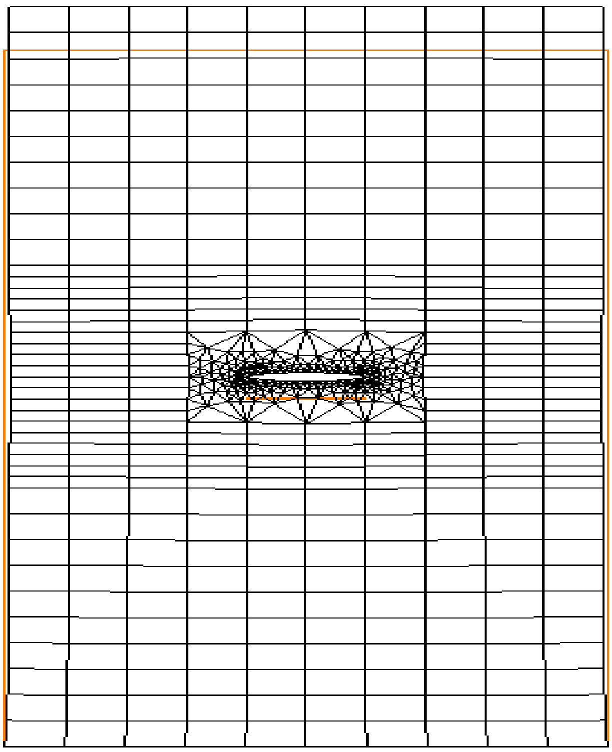


Fig.3.2: Deformed mesh of plate with central crack

The crack shown in fig.2.1 is repaired by adhesively bonding composite patch over the cracked surface. The experiment is performed for frequently used plate and patch material combinations and results are presented.

3.1. Common Data.

Plate materials: Aluminium (Al), Steel and Duralumin(Du).
Patch materials: Carbon fibre reinforced plastic (CFRP), Boron Epoxy (BE) and Glass Epoxy (GE).
Adhesive: Epoxy film adhesive FM-73. (G = 10000 Psi, t = 0.005 in.)

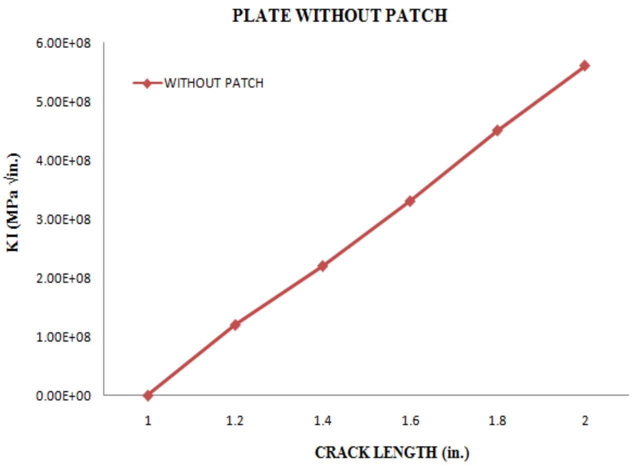
Table: 1. Material properties.

Material	Al	Steel	Du	CFRP	BE	GE
E (Mpa)	10E6	2.9E4	10.5E6	2.17E7	6E7	5.72E6
ν	0.334	0.25	0.33	0.3	0.25	0.3

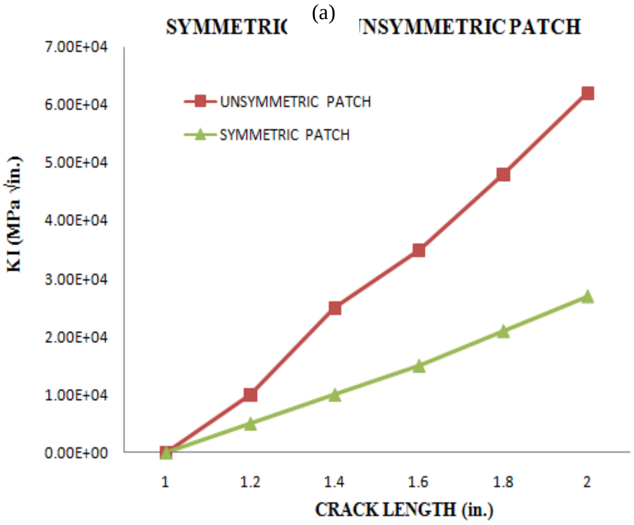
E= Young's modulus. ν= Poisson's ratio.

3.2. Application of patch:

Two types of bonding configurations are mostly used Un-symmetric and Symmetric.
Un-symmetric: When patch is applied on only one side of the plate. Symmetric: When patch is applied on both sides of the plate.
Changes in the value of stress intensity factor KI using the un-patched, un-symmetrically and symmetrically patched configurations are observed and shown in the graphs.



(a)

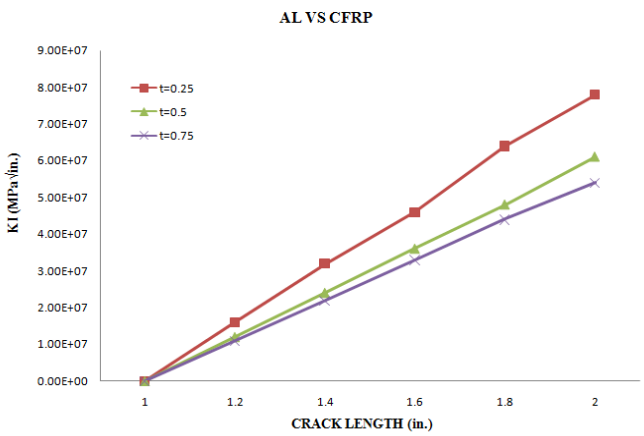


(b)

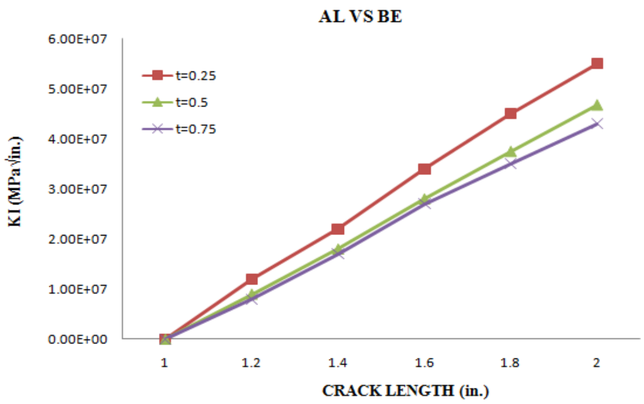
Fig3.2. 1: (a):KI vs Crack length for plate without patch, (b) :Comparison between unsymmetric and symmetric patch configuration

It can be quoted from the above graph that there is considerable reduction in the SIF i.e. KI value when the composite patches bonded to the cracked plate. Moreover the significant reduction in the KI value is found when the symmetric patch configuration is found.

3.3. Effect of patch thickness on KI :



(a)



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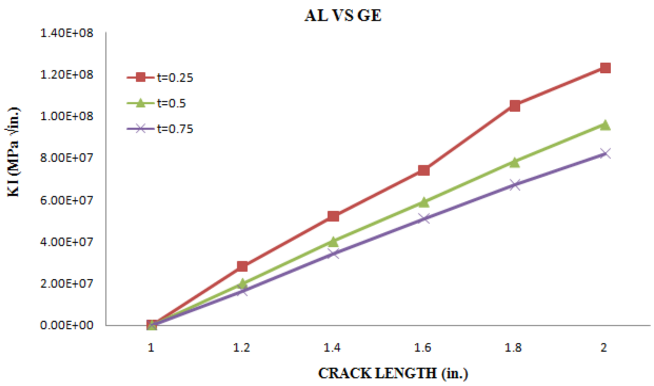

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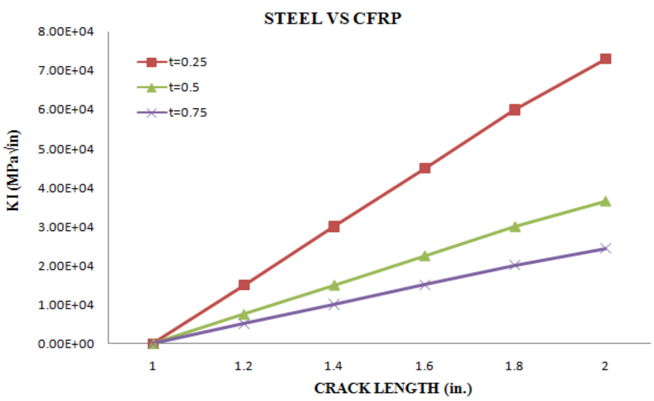

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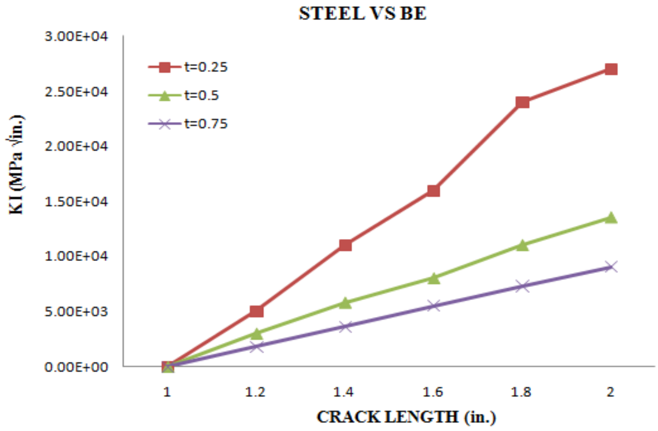

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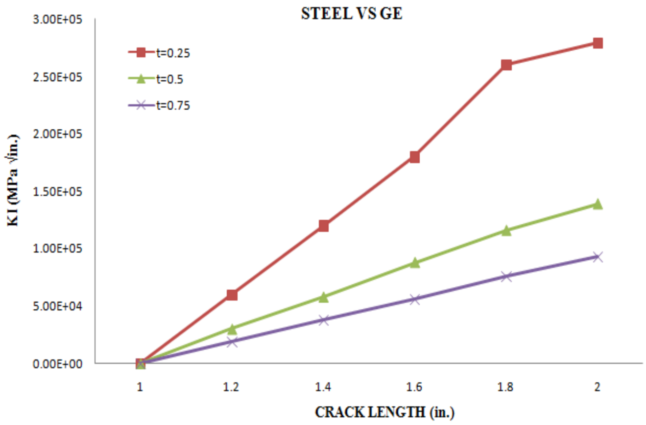

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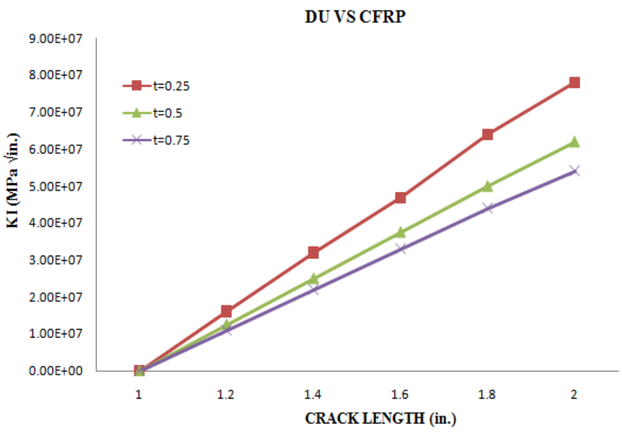

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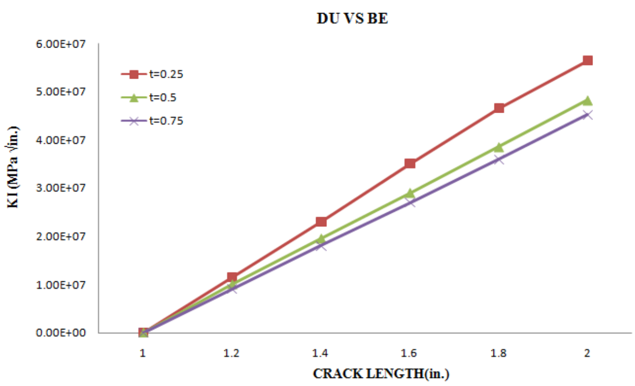

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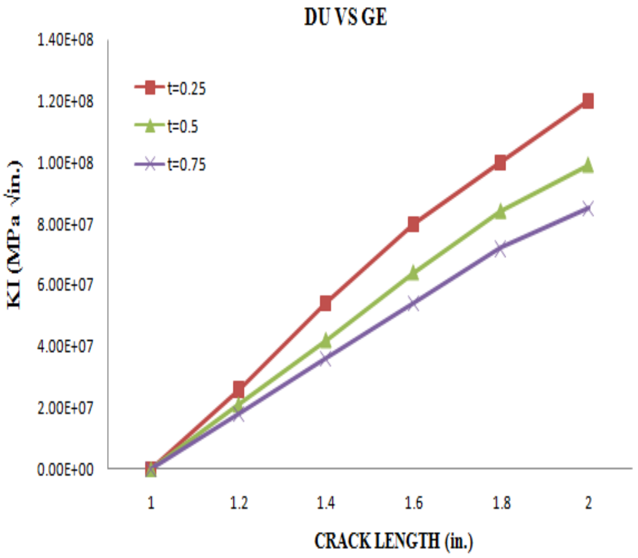

(i)

Fig 2.3 (a)-(i): The effect of variation in thickness of patch on different plate and patch material combinations.

IV. RESULTS AND DISCUSSION:

The graph shown above in section 3.3 indicates that the stress intensity factors for various patch thickness. From it, it is evident that the value of KI decreases with increase in patch thickness. For t = 0.25 the KI is highest in any combination whereas it is minimum for t = 0.75 as per the experiments carried out in FEA software FRANC2DL along with its meshing programme CASCA.

Table 2 : Sample percentage reduction of KI (MPa √in.) for Steel plate with different patch materials.

t (in.)	CFRP	%Red	BE	%Red	GE	%Red
0.25	7.3e4	-	2.7e4	-	2.7e5	-
0.5	3.6e4	50.68	1.3e4	51.85	1.3e5	51.84
0.75	2.4e4	33.4	9e3	30.7	9.3e4	28.46

The tremendous decrease in value of KI is observed when the steel plates are repaired with composite patches which can also be seen in the above given table and same goes for aluminium and duralumin.

V. CONCLUSION

i. The composite patch repair method plays a significant role in reduction of SIF.

ii. The use of symmetric patches over the un-symmetric patches yields more enhanced results.

iii. The increase in the thickness of patch provides further reduction in the KI values at crack tip.

iv. Use of symmetrically bonded composite patches increases the life of damaged component by almost twice of its original life.

v. The method of composite repair is easiest, least instructive, cost effective and efficient as compared to other conventional methods.

vi. This method does not involve any drill holes for fastening of patches to the plates. Thus minimising the risk of further crack propagation through these holes.

vii. CASCA and FRANC2DL are very simple, user friendly, fast and reliable FEA software used for Analysis of composite patch repair technique that provides reliable and satisfactory results.

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