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Comparing Between Simulation of Two Types from Corrosion Cracks with New Designing Module

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***Abstract* —This paper presents theoretical studying for comparing with previous results and data about defected damaged area of two modules with new designing model (ZAMZAM MODEL)[1-3]. Two modules were simulated as circular and rectangular corrosion cracks at the middle of the pipe which was made from carbon steel with internal diameter of 83 mm, thickness 12.5 mm and length of 900 mm . The damaged area of circular was simulated at diameters 5,10,15 mm, and 20 mm for the four pipes respectively[2,3]. While rectangular was simulated at dimensions (5×10),(7×14) and (9×18) mm for the three pipes respectively [3,4]. The new designing model based on the fracture mechanics techniques were developed to evaluate the deflection, failure pressure (blister pressure) and stress strain curves for damaged area. The damage was simulated as a square at the middle of the pipe at dimensions (5×5),(7×7) and (9×9) mm for the three pipes.**

According to results, good correlation between the theoretical models (ZAMZAM MODEL) and fracture mechanics model. In addition, defected area hole is strongest of loading failure from other defected areas as rectangular and square were of strain 520.203 $\mu\varepsilon$ and 1389.43 $\mu\varepsilon$ at diameter 5,10mm respectively. While defected area square is weakest as crack during propagation of pressure failure (loading failure) were 233.0754 $\mu\varepsilon$, 437.79327 $\mu\varepsilon$, and 660.76868 $\mu\varepsilon$ at length 5,7,and 9mm respectively.

Keywords* ——Composite; steel pipe; matrix cracking; clamp; quasi-isotropic laminate; blister pressure; rehabilitation; failure mode; stress and strain.

I. Introduction

Metal tubular systems can be affected by internal or external corrosion or any other mechanical effects resulting in substantial damage to the systems. These lead to shutdown the plant, loss the production and increase the maintenance costs. There are three options can be chosen to solve the problem either replacement, down rating or rehabilitation. The choice depends on the severity of the problem and the economics of the option. The replacement and dawn rating are expensive options [5,6].

The damages derived from corrosion process in industrial installations produce economical losses very important. For gas and petroleum industry, the corrosion is responsible for 33% of the cases [7]. The repair and reinforcement of existing structures has received a significant emphasis over the past few years due to corrosion and infrastructure aging. After some time in service, steel pipeline may be damaged, so they may be in need of repair due to the loss of carrying capacity. Alternatively, existing structures may need to have their resistance or stiffness upgraded to withstand an increased load demand or to eliminate structural design or construction deficiencies [8]. One of attractive cold work is to use composite technology by over-wrapping repair or bonded repair in which several layers of impregnated fiber fabric are warped over the defected area [9]. Most of these works have been focused on modeling analysis either by fracture mechanics or computational analysis, also simulated defect area as hole. For example, Mableson et al [5] presented a experimental and analytical studies for repairing metal pipes using composite materials. They demonstrated that it is possible to employ composite based systems for the external repair of metallic tubular pipes. Their model appeared to describe the blister propagation problem well. Frost and Lee [9] developed a code for guideline for the design and installation of repairs for composite over wrap pipe work repair. Recently, Zamzam at el [6] developed an analytical model based on the fracture mechanics to predict stress strain curves for steel pipes repaired by composite materials.

In this paper, new designing model (ZAMZAM MODEL) is simulated of damaged area as a square crake that will comparing with previous data which were applied of two models (circular and rectangular) to evaluate stress-strain curves for damaged area.

II. MODELING ANALYSIS

It is assumed that the composite repair can be considered as a quasi-isotropic or isotropic i.e. property variations with direction in plane of laminate are ignored **[5,6]**. The composite wrapped materials on the defected area is treated as square plate with built in ends for "b=a" under uniform internal pressure "p" **[10,11]**.

Fig.1 shows a schematic diagram of the defected metal pipe after warped by composite laminate and the *Fig. 2* shows the modeling of the defected area after formation and propagation of pressurized blister.

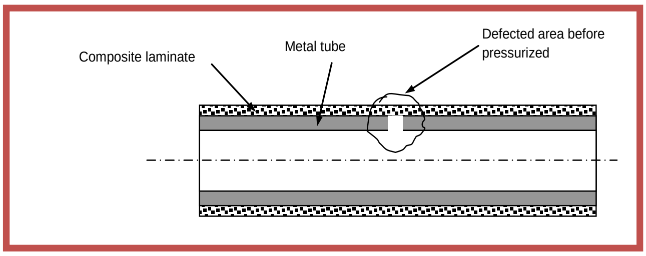

Fig. 1 *shows the schematic diagram of bonded composite repair to a metal pipe*.

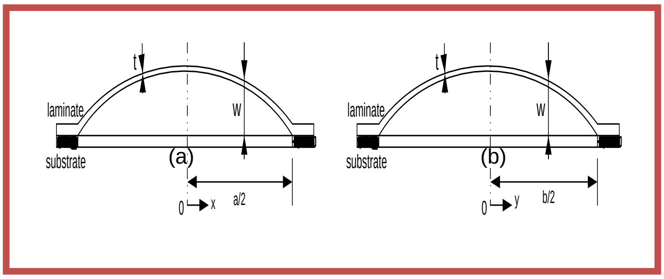

Fig. 2 ： *(a and b) shows modeling of the defect area after formation and propagation of pressurized blister.*

In general equation of deflection in two direction (x-y) for clamp rectangular with uniform internal pressure shown as **[10,11]**:

$$w(x,y) = \frac{2P}{3D(a^4+b^4)}\left(x^2 - \tfrac{1}{4}a^2\right)^2\left(y^2 - \tfrac{1}{4}b^2\right)^2 \qquad (1)$$

Where:

$D = \frac{Et^3}{12(1-\nu^2)}$ is termed the flexural rigidity

A. Starting new model design

For x-direction as:

$$w(x,0) = \frac{P}{48D}\left(x^2 - \frac{1}{4}a^2\right)^2 \qquad (2)$$

For y-direction as:

$$w(0,y) = \frac{P}{48D}\left(y^2 - \frac{1}{4}b^2\right)^2 \qquad (3)$$

1. Analysis stresses

Can be calculated bending stresses in clamped rectangular plates as a function of M_x and M_y [9,10]:

$$\sigma_x = \frac{6M_x}{t^2} \quad \& \quad \sigma_y = \frac{6M_y}{t^2} \qquad (4)$$

$$M_x = -D\left[\frac{\partial^2 w}{\partial x^2} + \nu\frac{\partial^2 w}{\partial y^2}\right] \qquad (5)$$

$$M_y = -D\left[\frac{\partial^2 w}{\partial y^2} + \nu\frac{\partial^2 w}{\partial x^2}\right] \qquad (6)$$

Calculation maximum stresses at the center [10,11]:

$$\left.\frac{\partial^2 w}{\partial x^2}\right)_{x=0} = -\frac{Pa^2}{48D} \qquad (7)$$

$$\left.\frac{\partial^2 w}{\partial y^2}\right)_{y=0} = -\frac{Pb^2}{48D} \qquad (8)$$

Substitute equations (7), (8) in equations (5), (6) lead to:

$$M_x = \frac{Pa^2}{48}(1+\nu) \qquad (9)$$

$$M_y = \frac{Pa^2}{48}(1+\nu) \qquad (10)$$

Substitute equations (9), (10) in equation (4) lead to:

$$\sigma_x = \sigma_y = \frac{Pa^2}{8t^2}(1+\nu) \qquad (11)$$

For they were been a given set of stresses, the normal strains in x and y directions **[10,11]**.

$$\varepsilon_x = \frac{1}{E}(\sigma_x - \nu\sigma_y) \qquad (12)$$

$$\varepsilon_y = \frac{1}{E}(\sigma_y - \nu\sigma_x) \qquad (13)$$

Substitute equation (11) in equations (12), (13) yield as:

$$\varepsilon_x = \varepsilon_y = \frac{Pa^2}{8Et^2}(1-\nu^2) \qquad (14)$$

Calculation maximum stresses at circumferential [10,11].

$$\left.\frac{\partial^2 w}{\partial x^2}\right)_{x=\frac{1}{2}a} = \frac{Pa^2}{24D} \qquad (15)$$

$$\left.\frac{\partial^2 w}{\partial y^2}\right)_{y=\frac{1}{2}b} = \frac{Pb^2}{24D} \qquad (16)$$

Calculation bending moment stresses and maximum stresses [10,11].

Substitute equations(15),(16) in equations (5),(6) yield as:

$$M_x = M_y = -\frac{Pa^2}{24}(1+\nu) \qquad (17)$$

Substitute equation (17) in equation (4) lead to:

$$\sigma_x = \sigma_y = \frac{Pa^2}{4t^2}(1+\nu) \qquad (18)$$

For a given set of stresses, the normal strains in x and y directions:

$$\varepsilon_x = \varepsilon_y = \frac{1}{E}(\sigma_x - \nu\sigma_y) = \frac{Pa^2}{4Et^2}(1-\nu^2) \qquad (19)$$

III. Procedure Analysis.

Table1,2 showed properties material of laminate which calculated by classification laminate theory (CLT) [12]. While table 3 was observed theses properties with it has applied to new designing model .

TABLE I. Material properties of fiber glass, resin and composite laminate [4].

Modulus of elasticity (E) of composite	19.123 GPa
Shear modulus (G) of the composite	7.3 GPa
Poisson's ratio of composite laminate	0.31
Volume fraction	0.42
Overall thickness	3.9mm
Defected rectangular	(5×10),(7×14),(9×18)
Number of plies	8
Warped angles	[0/90/ + 45/ -45]s
Elastic Modulus of resin (Em)	2-6 GPa
Elastic modulus of fiber	72 GPa
Density of the composite laminate	1.9g/cc
Density of the glass fiber	2.54 g/cc
Density of the matrix	1.4 g/cc

TABLE II. Material properties of fiber glass, resin and composite laminate [3,6].

Modulus of elasticity (E) of composite	15.768 GPa
Shear modulus (G) of the composite	5.73 GPa
Poisson's ratio of composite laminate	0.376
Volume fraction	0.41
Overall thickness	4.25mm
Defected Hole	10,15,20
Number of plies	8
Warped angles	[0/90/ + 45/ -45]s
Elastic Modulus of resin (Em)	4 GPa
Elastic modulus of fiber	72 GPa
Density of the composite laminate	1.9g/cc
Density of the glass fiber	2.5 g/cc
Density of the matrix	1.3 g/cc

TABLE III. Material properties of new model design.

Modulus of elasticity (E) of composite	19.123 GPa
Shear modulus (G) of the composite	7.3 GPa
Poisson's ratio of composite laminate	0.31
Volume fraction	0.42
Overall thickness	3.9mm
Defected square	(5×5),(7×7),(9×9)
Number of plies	8
Warped angles	[0/90/ + 45/ -45]s
Elastic Modulus of resin (Em)	2-6 GPa
Elastic modulus of fiber	72 GPa
Density of the composite laminate	1.9g/cc
Density of the glass fiber	2.54 g/cc
Density of the matrix	1.4 g/cc

IV. Theoretical Result.

The theoretical results which were observed of the three pipes with defect lengths of $5, 7, and\ 9\ mm$ by using equations 18, 19 of new designing model to be calculated stress-strain and information table 3 that assembly are shown in *Tables 1,2,* and *3*.

TABLE IV. Stress-strain for square defected with (5×5) mm

Pressure MP_a	$\sigma_x MP_a$	$\sigma_y MP_a$	Theoretical radial strain $\varepsilon_x \mu\varepsilon$
1	0.53830	0.53830	19.42295
2	1.07659	1.07659	38.84590
3	1.61489	1.61489	58.26885
4	2.15319	2.15319	77.69180
5	2.69149	2.69149	97.11475
6	3.22978	3.22978	116.53770
7	3.76808	3.76808	135.96065
8	4.30638	4.30638	155.38360
9	4.84467	4.84467	174.80655
10	5.38297	5.38297	194.22950
11	5.92127	5.92127	213.65245
12	6.45957	6.45957	233.07540

TABLE V. Stress-strain for square defected with (7×7) mm

Pressure MP_a	$\sigma_x MP_a$	$\sigma_y MP_a$	Theoretical radial strain $\varepsilon_x \mu\varepsilon$
1	1.05506	1.05506	38.06898
2	2.11012	2.11012	76.13796
3	3.16519	3.16519	114.20694
4	4.22025	4.22025	152.27592
5	5.27531	5.27531	190.34490
6	6.33037	6.33037	228.41388
7	7.38544	7.38544	266.48286
8	8.44050	8.44050	304.55184
9	9.49556	9.49556	342.62082
10	10.55062	10.55062	380.6898
11	11.60569	11.60569	418.75878
11.5	12.13322	12.13322	437.79327

TABLE VI. STRESS-STRAIN FOR SQUARE DEFECTED WITH (9× 9) MM

Pressure MP_a	$\sigma_x MP_a$	$\sigma_y MP_a$	Theoretical radial strain $\varepsilon_x \mu\varepsilon$
1	1.74408	1.74408	62.93035
1.5	2.61612	2.61612	94.39553
2	3.48817	3.48817	125.8607
2.5	4.36021	4.36021	157.32588
3	5.23225	5.23225	188.79105
3.5	6.10429	6.10429	220.25623
4	6.97633	6.97633	251.7214
4.5	7.84837	7.84837	283.18658
5	8.72041	8.72041	314.65175
5.5	9.59246	9.59246	346.11693
6	10.4645	10.4645	377.5821
6.5	11.33654	11.33654	409.04728
7	12.20858	12.20858	440.51245
7.5	13.08062	13.08062	471.97763
8	13.95266	13.95266	503.4428
8.5	14.82470	14.82470	534.90798
9	15.69675	15.69675	566.37315
9.5	16.56879	16.56879	597.83833
10	17.44083	17.44083	629.3035
10.5	18.31287	18.31287	660.76868

V. DISCUSSION

Fig. 2 shows propagation of experimental pressurized blister (MP_a) versus theoretical radial strain ($\mu\varepsilon$) curves for comparing of previous analytical studies those defected area of hole 5mm and defected area of rectangular $5 \times 10\ mm$ with new designing analytical study (ZAMZAM module) of defected area of square $5 \times 5\ mm$. The theoretical pressure and strain were calculated using the model which was developed in the part one of this work **[2]** and **[1,3]** respectively. It can be noted that all the curves exhibited the same manner. The theoretical curves are linearity behaviour up to failure. Good correlations between the new designing model (ZAMZAM module) and previous analytical studies curves can be observed at stages of loading. In addition, it can observed that defected area square curve was lowest strain of failure comparing with defected area of hole and defected area of rectangular curves at $233.0754\ \mu\varepsilon$ while highest strain was defected area hole at $520.203\mu\varepsilon$.

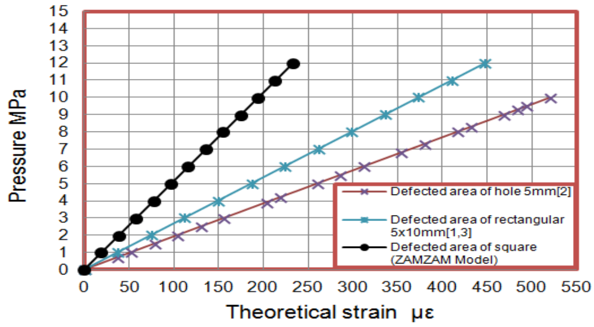

Fig. 3 Comparing between propagation of pressure versus theoretical strain with new designing model of defected areas.

Figure 4,5 and 6 show comparing between the experimental and theoretical radial stress versus radial strain curves of previous studies [1-3] with new designing model (**ZAMZAM Model**). The theoretical stress and strain were calculated using the model which was developed in the part of this work **[1-3]** while new designing model curve is applied using two equations 18,19 in this paper as theoretical study with defect lengths of 5,7, and 9. It can be noted that theoretical curves are linear up to failure, while the experimental curves are linear in the early stages and then exhibited non linear behaviour up to failure [1-3]. In addition, it can be observed that new designing model curve was lowest stress $6.46 MP_a$, $12.13 MP_a$, and $18.31 MP_a$ at $5mm$, $7mm$, and $9mm$ respectively while was highest stress at defected area hole $12.81 MP_a$, and $32.69 MP_a$ at $5mm$ and $10mm$ respectively. Firstly, in Fig. 4 can be noted that new designing model curve corresponding with experimental curve of hole at $5mm$ unite stress $6.46 MP_a$ and strain $233.0754\ \mu\varepsilon$. secondary, in Fig. 5 can be illustrated that new designing model linearity with manner theoretical curves of hole at $10mm$ and rectangular at $7mm$ unite stress $12.13 MP_a$ and strain $437.79327\ \mu\varepsilon$. Finally, in Fig. 6 can be showed that new designing model that linearity with manner theoretical and experimental curves of hole at $10mm$. Also, theoretical curve of rectangular area at $9mm$ unite stress $18.31 MP_a$ and strain $660.76868\ \mu\varepsilon$.

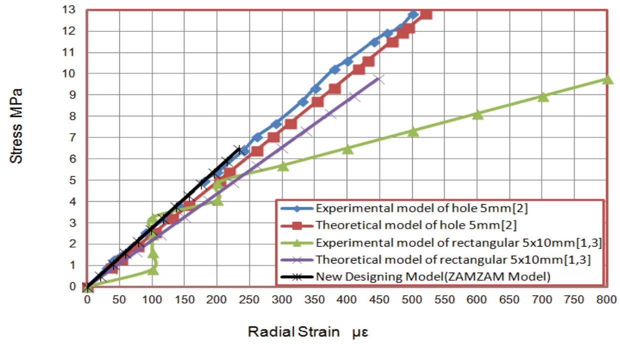

Fig. 4 Comparing between stress and strain with new designing model of defect length 5mm.

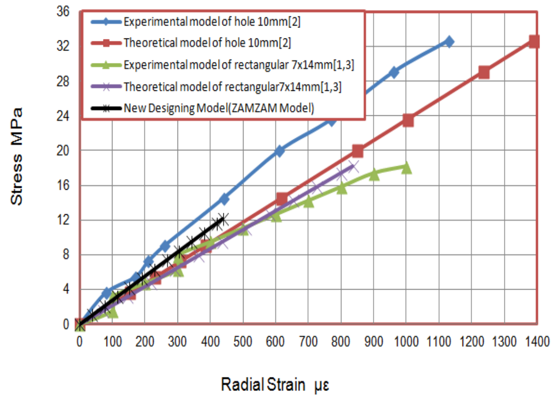

Fig. 5 Comparing between stress and strain with new designing model of defect length 7mm, and 10mm.

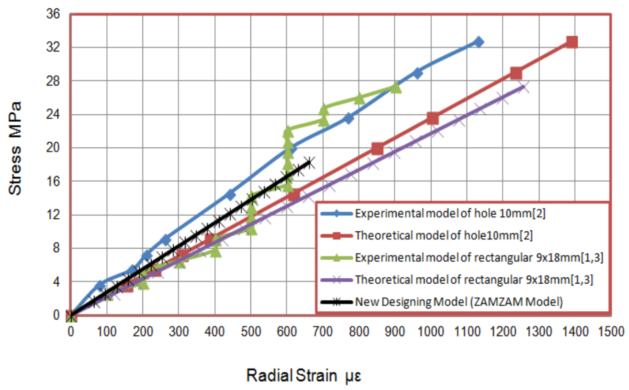

Fig. 6 Comparing between stress and strain with new designing model of defect length 9mm, and 10mm.

VI. CONCLUSIONS

- The project shows that it is possible to employ fibre reinforcement plastic composite materials for external repair of metal piping system.
- Composite materials are capable to fulfilling the design requirement of the bi axial loading
- The proposed model describes the formation and blister propagation well
- The theoretical stress-strain relationships of the failed pipes were liner up to failure , whereas the experimental one is non- linear.
- Good correlation between the theoretical models (ZAMZAM MODEL) and fracture mechanics model results was observed.
- Defected area hole is strongest of loading failure from other defected areas as rectangular and square were of strain 520.203 $\mu\varepsilon$ and 1389.43 $\mu\varepsilon$ at diameter 5,10mm respectively, and rectangular were 447.5559 $\mu\varepsilon$, 836.6919 $\mu\varepsilon$, and 1255.820455 $\mu\varepsilon$ at length 5,7,and 9mm respectively .While defected area square is weakest as crack during propagation of pressure failure (loading failure) were 233.0754 $\mu\varepsilon$, 437.79327 $\mu\varepsilon$, and 660.76868 $\mu\varepsilon$ at length 5,7,and 9mm respectively.

FUTUER WORK

The experimental work is continuing on specimens with defected square for comparing model with experimental results. Also the study will be focused on the improving the failure mode of the tube by using different techniques.

LIST OF SYMBOLS

D bending spiffiness of composite laminate.
E Modulus of elasticity.
G shear modulus of composite laminate.
t thickness of the composite laminate.
w laminate deflection for blister model.
x,y direction of coordination.
a,b the blister radius.
P applied Pressure.
ν Poisson's ratio.
M_x, M_y bending moment per unit length in x,y directions respectively.
σ_x, σ_y stresses in x,y directions respectively.
$\varepsilon_x, \varepsilon_y$ strains in x,y directions respectively.

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