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Study of Microscopic Analysis and Nonlinear Behavior of Damaged Steel Pipe Using Composite Materials

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***Abstract* -This paper presents studies of microscopic analysis and nonlinear behavior of composite system for the rehabilitation of steel pipes by analytical models, based on the fracture mechanics and finite element techniques were developed to evaluate the deflection, failure pressure (blister pressure) and stress strain curves for damaged area [1,2].**

The modeled pipes were carbon steel pipe with internal diameter of 83 mm, thickness 12.5mm and length of 900 mm. The damage was simulated as a hole at the middle of the tube. The composite repair was fiber glass reinforced polyester quiasi-istropic laminate. It was concluded that the models appear to describe the blister propagation well [1]. The experimental stress-strain relationship was nonlinear up to failure, which probably due to the matrix cracking and delamination [2].

Microscopic examination was carried out to investigate the matrix micro-crack and effect of crack density on effective modulus of laminates.

Keywords—Composite, steel pipe, delamination, matrix cracking, clamp, quasi-isotropic laminate, blister pressure, rehabilitation, failure mode, stress and strain, microscopic of laminates.

I. Introduction

The use of composite materials in oil and gas industry has been increased widely in the last decays due to superior properties of these materials such as corrosion resistant, high specific strength and modulus, easy to deploy with low maintenance and an extended lifetime in service. The most important uses are in the pipelines, flow lines, pressure vessels. Recently, this use has been extended to rehabilitation of steel pipes that can cope with internal pressure and external corrosion as well as mechanical damage. This rehabilitation is useful, because do not require plant shutdown and is capable of being applied without hot work.

The steel piping systems are usually exposed to severe environmental conditions leading to internal or external corrosion damages such as holes, cracks and slots. These damages may cause the products leakage out of the tubes and loose production especially for pipes which are used in the offshore and petrochemical applications. Depending on the severity of the damage, the pipes either can be replaced or rehabilitated. The replacement option is considerably expensive [3].

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 economic of the option. The replacement and dawn rating are expensive options [1,3].

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 [5]. 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 [4].

In this paper, depended on previous studies of a novel technique for repairing metallic pipes using composite material and bolted clamp including experimental procedure to evaluate the failure modes, stress-strain curves [1,2].

II. Test Procedure

Figure1 shows a photograph of an assembly pipe. The test was started by filling the pipe by fresh water and switching on the pump, and then increase the pressure by small increment until failure occurs. At each pressure increment, pressure and strain readings were recorded from the pressure gauge and the strain meter respectively.

III. Optical Microscopic Tests

Optical microscopic tests were carried out to examine the microstructure of failure layer of pipes as shown in Fig.2. A number of different sizes samples were carefully cut from failed pipe using small hand hocksaw to minimize damage during sample preparation as shown in Fig.3. Each sample was mounted in a polyester resin in the form of a small mould as shown in Fig.4. All samples were labeled for identification. The molded samples were ground to flatten the surface and remove rough edges using a grinding machine with silicon carbide paper. When the surface of the sample became flat, it was polished using an oil based cloth until all scratches disappear. After that, the samples were examined by optical microscopy to observe any micro-cracks or delamination in the samples.

IV. Microscopic Analysis

Figure 5 shows an optical micrograph of a polished sample of composite laminate (as manufacturing). The small circles represent the fibers aligned at warped angles $\left[0/90^o/\pm 45^o\right]_S$ while matrix or resin is around the fibers.

Figure 6 shows an optical micrograph of a polished sample. The tested pipe can be seen. The black lines are matrix cracks. It can be seen that the cracks appeared and traveled through the ply thickness to reach the nearest interfaces and propagated transversely in the resin matrix between fibers.

Other examples of transverse matrix cracks are illustrated in Fig 7 (a), (b) and (c). Fig 7 (a) shows micro-cracks propagated from the void in two opposite directions. Fig 7 (b) illustrates a micro-crack induced by a micro-void in the interface region between plies and Fig 7 (c) illustrates a micro-crack in the interface region between plies. One possible explanation for these cracks is that the voids, which were entrapped during the manufacturing process [1,2] caused a stress concentration in the repairing laminate at region defected hole.

Figure 8 (a), (b) and (c) shows interlaminar micro-cracks propagated parallel to the lamina plane near the interface between plies and interlaminar cracks running in the interface region between the ply. This type of crack is probably formed in response to the interlaminar shear strains which may develop due to the high isotropic interaction between the plies. The occurrence of interlaminar cracking may cause continuous crack paths which increase the probability of weepage occurring by increasing the length of cracks crossed by other cracks [6,7] Figure 9. shows optical micrographs of polished samples. Fig 9 (a) shows a delamination failure which occurred between two plies. This delamination may occur as a result of interlaminar cracks. The delamination may lead to plies separation as illustrated in Fig 9 (b) and (c). Similar results have been presented by [8]. They concluded that in filament wound composite tubes delamination failure most likely occurs, under different biaxial loadings, as a result of high interlaminar stress due to the effect of an isotropy of plies

V. Non-linear Behaviour

A. Resin Cracking

The degradation of the transverse and shear moduli due to matrix cracking was estimated by recalling equations (1 and 2) [9] as:

$$E_2 = E_2^o \exp(-z_2\rho) \quad (1)$$

$$G_{12} = G_{12}^o \exp(-z_3\rho) \quad (2)$$

Where

E_2 and E_2^o are effective and initial young's moduli of ply respectively.

G_2 and G_{12}^o are effective and initial shear moduli of ply respectively.

z_2 and z_3 are dimensionless constants.

ρ is a crack density function, which can be estimated [9] by:

$$\rho = k\left[\frac{\sigma_{fm} - \sigma_t}{\sigma_{fm}}\right]^{1/2} \quad (3)$$

Where:

σ_t is the tangential stress, which was estimated [2].

σ_{fm} is the failure strength of the matrix which was estimated [2].

$$k = \sqrt{\frac{(E_1 + E_2)G_{12}}{E_1 E_2}} \quad (4)$$

We were applied the equations (3) and (4) at defected area 20mm,15mm,10mm [1,2] as shown in table I.

B. Effect of Crack density on Effective

Modulus of laminates.

Figure 10 shows typical plot of normalized transverse modulus (E_2/E_2^o) versus dimensionless crack density (ρ) for defected holes of 20mm, 15mm, and of 10mm. It can be seen that curves decrease with increase in crack density. This decrease is related to the degradation of modulus due to matrix cracks. Also it can be noted that the degradation of modulus in defected holes are approximately equal. This is due to the small holes defect. The values of the crack density parameters, z_2 in equation (1) were found to be about 0.67 [9]. The crack density depends on the tangential stress σ_t of composite laminate. The value of matrix failure strength was estimated from stress- strain analysis for each test.

VI. Conclusions

The study showed that, matrix cracks and delamination were observed in the failed pipes. The cracks may occur due to failure strains or due to manufacturing defects such as voids.

- There is relationship opposite between transverse young's modules and crack density for defected holes.

VII. Figures and Tables

Fig.1. Shows photograph of assembly test rig.

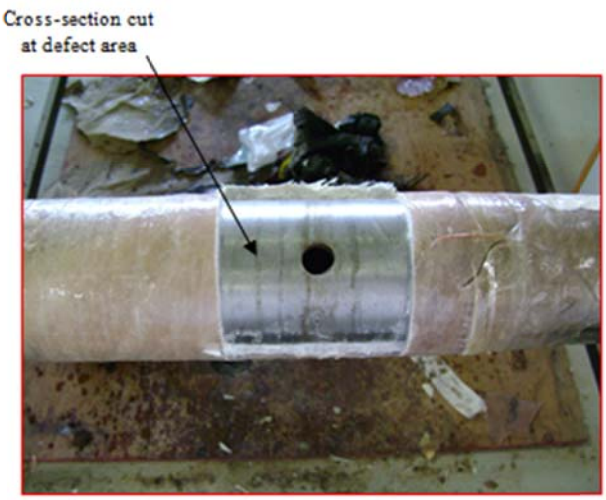

Fig. 2. Shows a photograph of the sampling area of the pipe.

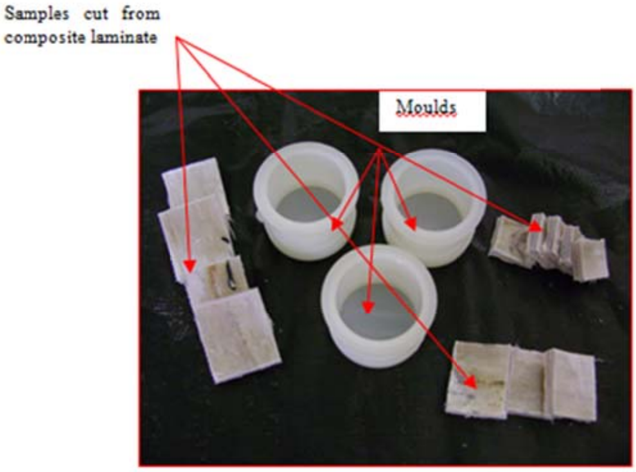

Fig. 3. Samples for microscopic examination.

Fig.4. Shows a photograph of samples immersed in a polyester resin.

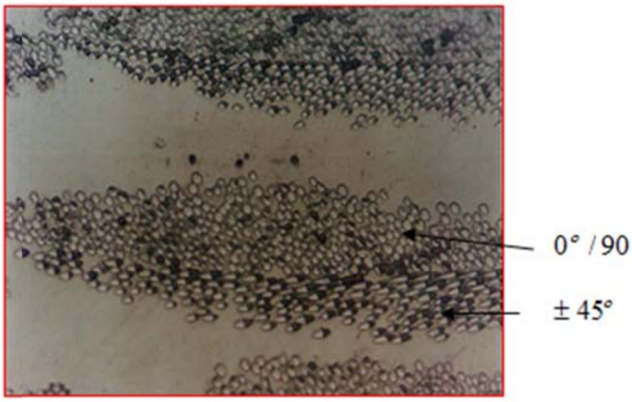

Fig.5. Shows photo-micrograph of a cross-section of repairing composite laminate.

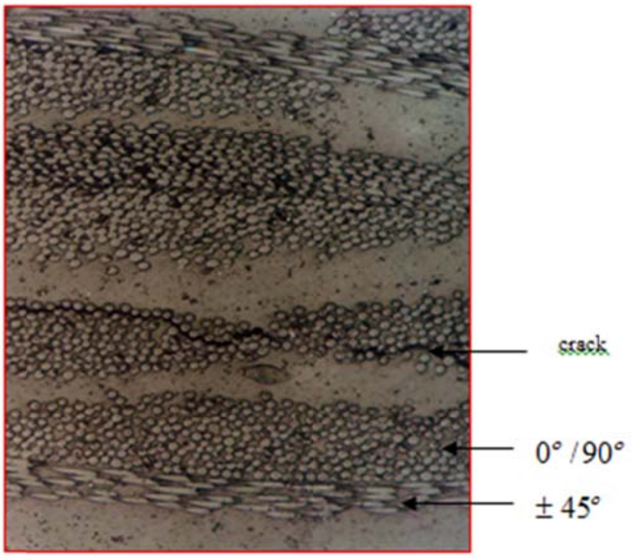

Fig.6.Shown photo-micrograph of polished sample from repaired laminate. Black lines are transverse cracks and white dots are fibers.

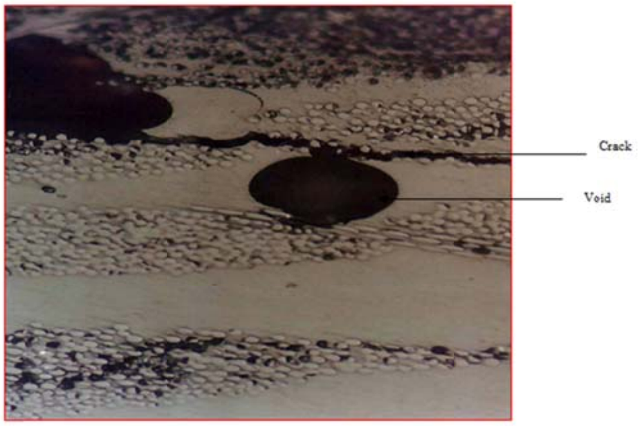

Figure 7. Shows optical micrographs of polished sample (a) transverse cracks propagated in opposite directions after being initiated in a void pocket in the lamina in a section at region defected hole.

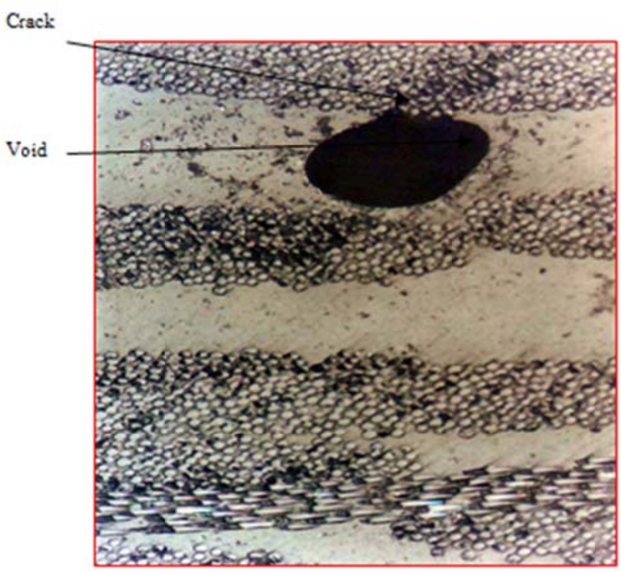

Fig..7. Shows optical micrographs of polished sample (b) transverse micro-crack initiated in a void pocket and small cracks propagated through the thickness.

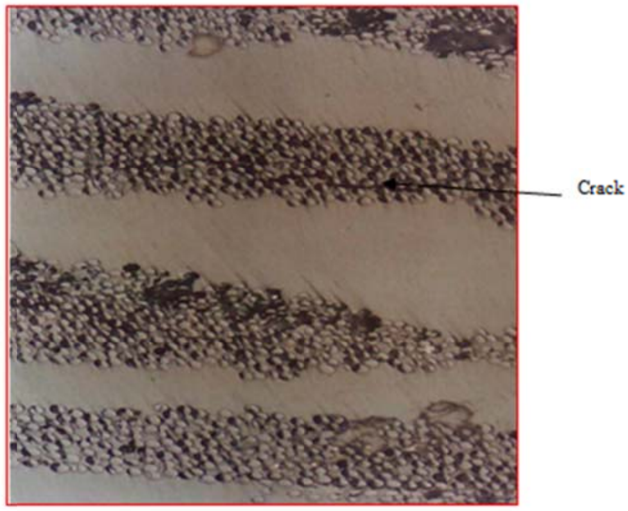

Fig.7.Shows optical micrographs of polished sample (c) Two transverse micro-cracks propagated in a lamina..

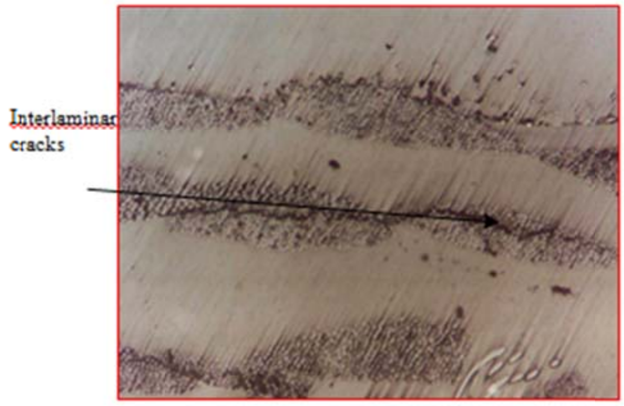

Fig. 8. Shows optical micrographs of polished sample. (a) Interlaminar cracks propagated parallel to the lamina plane in the interface between plies.

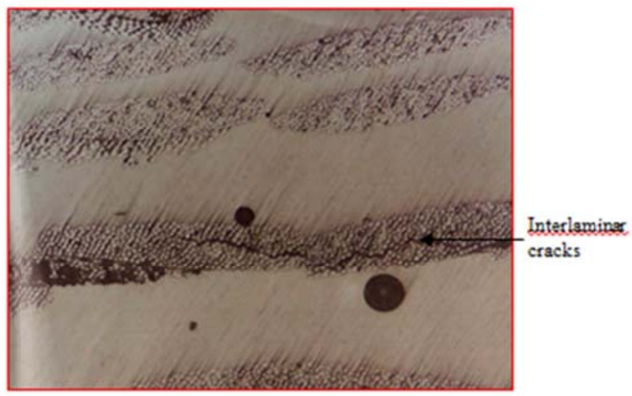

Fig. 8. Shows optical micrographs of polished sample. (b) Interlaminar cracks propagated parallel to the lamina plane in the interface between plies.

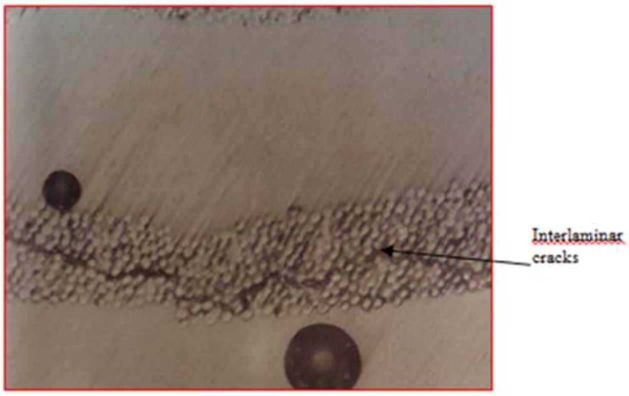

Fig. 8. Shows optical micrographs of polished sample. (c) Interlaminar cracks propagated parallel to the lamina plane in the interface between plies.

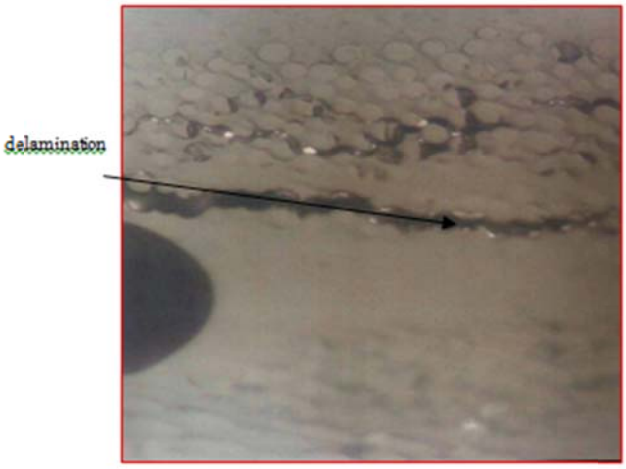

Fig. 9.Shows optical micrographs of polished sample :(a) delamination in the interface region.

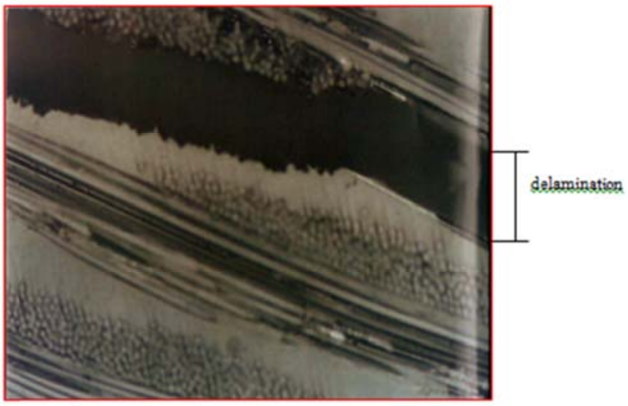

Fig.9.Shows optical micrographs of polished sample: (b) delamination leads to the separation of plies.

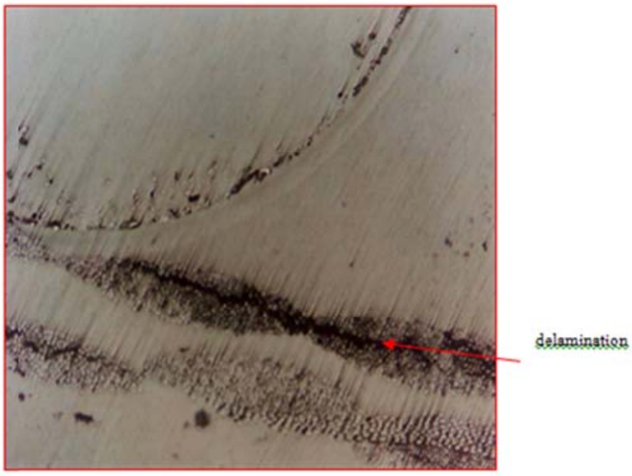

Fig.9. Shows optical micrographs of polished sample: (c) delamination leads to the separation of plies

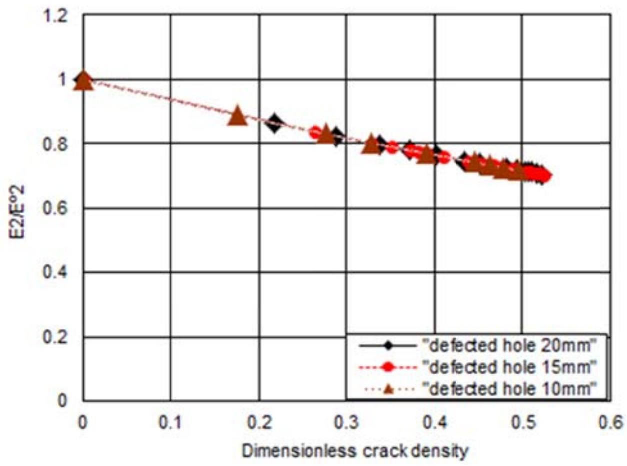

Fig.10. Shows normalized transverse young's modules versus dimensionless crack density for defected holes.

Table I. Calculation non-linearity of defected holes

20mm		**15mm**		**10mm**	
E_2 / E_2^o	*Density crack* ρ	E_2 / E_2^o	*Density crack* ρ	E_2 / E_2^o	*Density crack* ρ
0.705	0.521	0.704	0.523	0.718	0.495
0.707	0.517	0.706	0.520	0.725	0.479
0.711	0.51	0.707	0.518	0.733	0.463
0.712	0.506	0.708	0.515	0.742	0.446
0.714	0.502	0.709	0.514	0.77	0.391
0.718	0.494	0.71	0.512	0.803	0.327
0.724	0.482	0.712	0.508	0.831	0.277
0.739	0.452	0.712	0.506	0.889	0.175
0.747	0.435	0.714	0.503	0.718	0.0
0.764	0.402	0.719	0.493		
0.78	0.371	0.721	0.489		
0.797	0.338	0.727	0.476		
		0.732	0.466		
		0.735	0.460		
		0.739	0.451		
		0.742	0.445		
		0.745	0.439		
		0.76	0.410		
		0.77	0.391		
		0.775	0.381		
		0.78	0.371		
		0.791	0.350		
		0.803	0.327		
		0.838	0.263		
		1	0.0		

VIII. References

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