

NUMERICAL XFEM FRACTURE ANALYSIS OF FRP REPAIRED PIPELINES

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1. Introduction

Tubular structures such as pressurized pipes are under the different of failure mechanisms in his lifetime. Existence of cracks is cause of load capacity reduction, fluid leakage and structural collapse. Use of proportional repair techniques is necessary to operate pipelines systems toward end of their design services lives. High strength fiber reinforced polymer composite (FRP) repair systems are easy implementation, and increasingly used for retrofitting and strengthening of steel tubular joints, inshore and onshore systems and offshore pipelines[1–3]. In this paper, XFEM was used for analysis of cracked pipe with composite wrappings. The Stress intensity factor, as a main fracture criterion is investigated in two conditions of cracked pipe and the cracked pipe repaired with FRP.

2. Extended Finite Element Method

The extended finite element method (XFEM) is a powerful numerical approach for analysis of weak or strong discontinuities. In this method, there is no need for crack faces to match the finite element edges and therefore no remeshing techniques is required in crack growth problems[4,5]. Assume there is a discontinuity or singularity in an arbitrary domain discretized into some n-node finite elements. In the extended finite element method, the displacement for a point x inside the element is divided into two parts[6].

$$u^h(x) = u^{FE} + u^{enr} \quad (1)$$

Where u^{FE} is the classical finite element displacement field,

$$u^{FE} = \sum_{j=1}^n N_j(x) u_j \quad (2)$$

Where n is the number of nodes of each finite element with classical degrees of freedom u_j and N_j are the shape functions. u^{enr} can be expressed in terms of crack-split u^H and crack-tip u^{tip} components as,

$$u^{enr} = \left[\sum_{h=1}^{mh} N_h(x) H(x) a_h \right] + \left[\sum_{k=1}^{mt} N_k(x) \left(\sum_{l=1}^{mf} F_l(x) b_k^l \right) \right] \quad (3)$$

where mh is the number of nodes associated with the crack face, a_h is the vector of additional degrees of

freedom for modelling crack faces by the Heaviside function $H(x)$, mt is the number of nodes associated with the crack tip, b_k^l is the vector of additional degrees of freedom for modelling crack tips $F_l(x)$ are the crack-tip enrichment functions, defined in terms of the local crack tip polar coordinate system (r, θ) ,

$$F_a(r, \theta) = \left\{ \sqrt{r} \sin \frac{\theta}{2}, \sqrt{r} \cos \frac{\theta}{2}, \sqrt{r} \sin \frac{\theta}{2} \sin \theta, \sqrt{r} \sin \theta \cos \frac{\theta}{2} \right\} \quad (4)$$

3. Material Properties

3.1. Steel Pipe

The extended finite element simulations are performed in plane strain condition. The young's modulus of API 5L-X60 steel pipes is 210 GPa. The internal diameter and nominal thickness of pipe are given as 219mm and 10.3-mm and the internal pressure is 22 MPa [7]

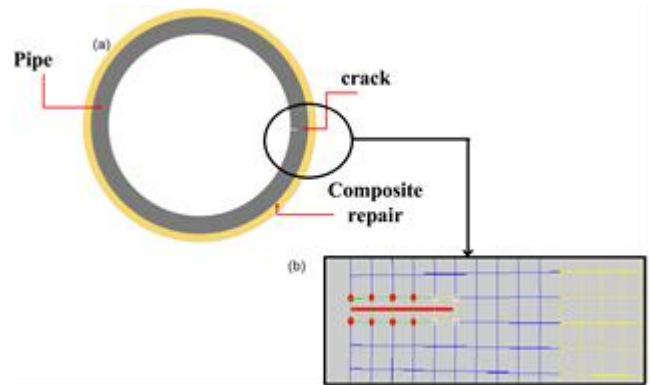


Figure1. (a) Repaired composite pipe and (b) Enriched nodes with the crack tip enrichments and the Heaviside function

3.2. FRP Properties

Three types of composite repair materials are selected to investigate the reduction of stress intensity factor in each cases. They include 1-Glass/epoxy with [3,8]: $E_1 = 38.6$, $E_2 = 8.27$, $E_3 = 8.27$ GPa, $\nu_{12} = 0.26$, $\nu_{23} = 0.33$, $\nu_{13} = 0.26$, $G_{12} = 4.14$ GPa, 2- composite sleeves with: $E = 49$ GPa [8], and 3- AS4/3501-6 with $E_1 = 126$, $E_2 = 11$, $G_{12} = 6.6$ GPa, $\nu_{12} = 0.28$ and $\nu_{23} = 0.4$ [7 - 10]. The composite wrap has 4mm thickness (see Figure 1-a).

4. Results and Discussion

The stress intensity factor is computed for an edge cracked 2D pipe model. Tables 1 and 2 compare the results for mode I stress intensity factors in different repair strategies. 8020 elements and 11228 nodes are used to create the XFEM model. SIF are calculated by the integration method, with the domain size of about 0.3-0.5 of crack length. The tip and split elements are shown in Figure 1-b.

Table 1. Mode I Stress intensity factor for un-repaired pipe.

Length of crack (mm)	K_I (MPa.mm ^{0.5})
a = 3	1145.59
a = 5	2228.0117
a = 7	4273.4553

Table 2. Mode I stress intensity factors for repaired cracked pipe.

Composite material	Length of crack	K_I MPa.mm ^{0.5}	K_I Reduction (%)
Glass/epoxy	a = 3	1062.18	7.2
	a = 5	2013.99	9.3
	a = 7	3691.81	13
AS4	a = 3	1016.65	11
	a = 5	1913.82	14
	a = 7	3402.24	20
Composite sleeve	a = 3	985.98	15
	a = 5	1747.62	24
	a = 7	2961.21	32

5. Conclusion

The obtained results shows, that the composite wrap reduces SIF in crack tip in comparison with the unrepaired pipe. In addition, decline in the rate of stress intensity factor depends on the composite material properties and the length of the crack. When the crack length is 7 mm, the rate of the SIF reduction in cracked pipe repaired with Glass/epoxy FRP, AS4 and composite sleeve are 13%, 20% and 32%. Accordingly the use of composite sleeve is more effective in stress intensity factor reduction.

6. References

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