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NEW MODIFIED FORMULA OF RICHARD MODEL FOR CRACK GROWTH DIRECTION

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ABSTRACT

This research proposed a modification of Richard formula regarding crack growth direction via considering a particular case study concerning small bore copper pipes (12200) under mixed mode (I/II) conditions as a consequence to multiaxial cyclic loads effect on the proposed pipe where the geometry selected in such away the real service conditions have been simulated with different crack inclination (from 00 to 900) to demonstrate the modified formula clearly , so the results have been justified and good agreement has been received to illustrate the durability of the new formula to be applicable for different crack inclination.

INTRODUCTION

Stress intensity factors ($K_I and\ K_{II}$) used in engineering solid mechanics to estimate stress state at crack tip due to applied stresses where the value of these SIF depends on the geometry and initial crack configuration of the specimen [1]. There are different component like piping system in actual service conditions that are subjected to multiaxial cyclic loads which lead to crack propagation in specified path to final fracture, hence, case study were proposed to investigate a crack growth trajectory for crack that proposed with various inclination (from 0^0 to 90^0) with respect to pipe axial axis, and as mentioned previously that the geometry adopted as per actual conditions to be workable with previous laws. Special stress intensity factors (SIFs) have been utilized in this work that based on the proposed formula in Ph.D. thesis by J.J.F. Bonnen [2], adding to this that one of the most famous formula for Erdogan-Sih[3] concerning crack trajectory that had been established for brittle plate were adopted in this work for ductile pipe . Reference [3] proposed that the crack grow in plate toward the direction that perpendicular on the maximum tension which was considered under plane loading and transverse shear. Reference [4] assumed that the crack grow in a direction when strain energy density factor reaches a minimum value. Reference [5] studied a mixed mode crack propagation and new empirical law had been proposed to be approximated for Erdogan-Sih formula to predict crack growth direction. Reference [6] investigated crack propagation path for plate specimen with two holes under mixed mode conditions for the two dimensional structural elements. Reference [7] investigated the crack growth direction in AISI 304L stainless steel under axial – torsional loads.

The aim of this work is to modify Richard formula to be suitable for different crack inclination by estimation the direction of crack path for different angles to be compared later with previous well known formula of Erdogan-Sih [3] and clarified the compliance between real service and previous theories. Based on Figure (1), the crack grew in clockwise direction and θ_c estimated with respect to initial crack line according to each selected angle ($\propto$).

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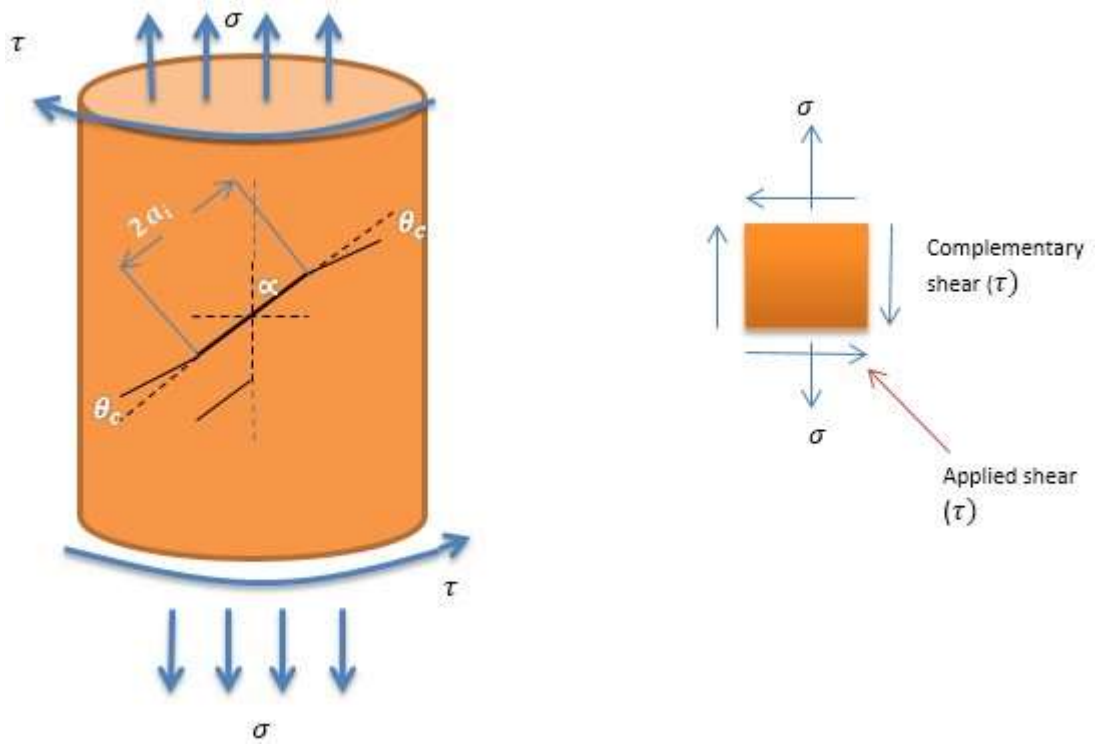

Fig.1 Illustration of crack growth trajectory due to multiaxial cyclic loads

PROPOSED CASE STUDY

Real service condition has been suggested in Figure (1) and Figure (2), so the oscillation considered to be equal to around 1800 r.p.m. for proposed specimen, adding to this that gauge length was equal to (180 mm), wall thickness equaled to 0.7 mm and outside diameter equaled to 12.6 mm. The shear stress (τ) considered to be equal to 55.92 Mpa , and bending stress σ equaled to 219.77 Mpa under fully reversed conditions where stress ratio(R) equal to (-1), adding to this that initial surface crack length ($2a_i$) was equal to 6.94mm, so the crack grew after test commencement in the left hand side (LHS) and right hand side (RHS) in clockwise or counterclockwise direction with respect to crack tip and according to the value of K_{II} as will be illustrated in upcoming items.

Table1. Mechanical and chemical properties (copper pipe)

Mechanical properties				
Yield point stress (Mpa) , $\sigma_{y.p.}$	Ultimate stress (Mpa) , $\sigma_{ult.}$		modulus of rigidity (Gpa) , G	modulus of elasticity (Gpa) , E
240	269.5		43.583	115.93
Chemical properties				
Zn%	Pb%	P%	Fe%	Al%
0.0062	0.0205	0.0376	0.0127	0.0221
S%	Ni%	Bi%	Sb%	Cu%
0.0116	0.0052	0.0147	0.114	≈99

ANALYTICAL PART

The experiments have been analyzed to confirm the validity of the new modified formula, further, crack direction has been studied by using maximum tangential stress theory that proposed by Erdogan-Sih [3], regarding crack growth direction. Specified SIFs for (mode I) and (mode II) have been utilized by John Joseph Francis Bonnen [2] to be considered and substituted in Erdogan-Sih formula:
SIFs for modes (I/II) were adopted to find out θ_C, as following:

$$K_I = \sigma\sqrt{\pi a_i}\left[sin^2 \propto + \frac{\pi\rho^2}{32}(3 - 2cos2 \propto - cos4 \propto)\right]$$
$$+\tau\sqrt{\pi a_i}\left[sin2 \propto + \frac{\pi\rho^2}{32}(9sin2 \propto + 2sin4 \propto)\right] \quad (1)$$

$$K_{II} = \sigma\sqrt{\pi a_i}\left[\frac{1}{2}sin2 \propto + \frac{\pi\rho^2}{32}sin4 \propto\right]$$
$$+\tau\sqrt{\pi a_i}\left[cos2 \propto - \frac{\pi\rho^2}{16}(1 - 2cos2 \propto - cos4 \propto)\right] \quad (2)$$

Maximum tangential stress formula for Erdogan-Sih is:

$$\theta_C = \pm arccos\left(\frac{3K_{II}^2 + K_I\sqrt{K_I^2 + 8K_{II}^2}}{K_I^2 + 9K_{II}^2}\right) \quad (3)$$

Empirical formula for Richard is:

$$\theta_c = \pm\left[155.5^0\frac{|K_{II}|}{|K_I| + |K_{II}|}\right] - 83.4^0\left[\frac{|K_{II}|}{|K_I| + |K_{II}|}\right]^2 \quad (4)$$

New modified formula:

$$\theta_c = \pm\left[\left[155.5^0\frac{|K_{II}|}{|K_I| + |K_{II}|}\right] - 83.4^0\left[\frac{|K_{II}|}{|K_I| + |K_{II}|}\right]^2\right] \quad (5)$$

It is worth mentioning that above mentioned formulas depend on Mode I and Mode II and insensitive to Mode III. Noting that the sign of θ_C is positive (counterclockwise) if K_{II} negative and vice versa whereas $K_I > 0$ [5], moreover, $K_{min} = 0$ in case of R≤0 and as recommended by reference [8].

RESULTS AND DISCUSSION

Based on the suggested case study the following table have been arranged to be discussed accordingly.

$\propto$ (deg.)	K_I(Mpa$\sqrt{m}$)	K_{II}(Mpa$\sqrt{m}$)	θ_C(Erdogan-Sih formula) (deg.)	θ_C(Richard formula) (deg.)	θ_C(modified formula) (deg.)
0	0	8.549	-70.528	-238.9	-72.1
10	6.589	13.351	-61.455	-141.507	-66.727
20	15.136	15.426	-53.417	-99.733	-57.239
30	23.902	14.484	-44.204	-70.547	-46.799
45	34.058	8.764	-25.914	-35.317	-28.331
60	38.354	1.324	-3.945	-5.282	-5.096
62.9	38.522	-0.003	0.01	0.014	0.014
75	37.471	-4.649	13.74	16.149	16.149
90	33.596	-8.549	25.688	28.11	28.11

The results between Erdogan-Sih formula and Richard formula were far apart , whereas the results between Erdogan-Sih formula and modified formula were convergent up to appoint. Generally Richard formula non workable from 0^0 up to 60^0 , but the results can be convergent by increasing $\propto$, on the other hand, modified formula was workable from 0^0 up to 90^0.

It is worth emphasizing also that new modified formula was applicable on any suggested case study for different crack inclination with good agreement.

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CONCLUSIONS

It is evident that new modified formula was more sensible and applicable comparing with Richard formula for different crack inclination (0^0 to 90^0) with respect to Erdogan-Sih. A little consideration will show that same results have been received from 62.9^0 to 90^0 regarding Richard formula and new modified formula.

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