ROLE OF WIRE ASPECT RATIO AND CRACK ASPECT RATIO ON FRACTURE BEHAVIOR OF WIRE SPECIMEN

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Abstract
Accurate stress intensity factor (SIF) solutions for cylindrical specimens with different wire aspect ratios and crack aspect ratios are required to determine the fracture toughness of rods and wires. The mode I geometric factor solutions of various crack configurations in a cylindrical fracture specimen in tension have been determined using liner elastic fracture mechanics. Finite element analysis (FEA) is applied to compute this as a function of wire aspect ratio ($\frac{H}{D}$), crack aspect ratio ($\frac{a}{b}$), and relative crack depth ($\frac{a}{D}$). It is found that the geometric factor is independent of wire aspect ratio for shallow cracks but has a major influence for deeper cracks. Also, the geometric factor is higher for concave cracks which facilitates the crack propagation. The mechanistic causes of the same are explained. Fracture toughness measurements on polymethylmethacrylate (PMMA) were carried out for the experimental validation of the solutions. The application of these solutions to fracture toughness measurements at the micro- and nanoscale, particularly in ceramic fibers and high strength metallic wires, is discussed.

1. Introduction
Wires are used in almost all kinds of applications ranging from macroscale elevator cable ropes, underwater sea cables to nanoscale semiconductor structures and multi quantum well nanowire heterostructures. Determining the fracture properties across different length scales becomes crucial for designing and manufacturing these wires with appropriate commercial certification. Evaluation of geometric factor of different crack aspect ratios also becomes important as elliptical cracks are found at many places – (1) Semi elliptical cracks are the most common type of crack in offshore structures and generally initiate at the tubular intersections, (2) the pit shape due to corrosion pitting in wide range of steels and aluminium alloys may approximate that of a flat semi ellipsoid, (3) the surface and the corner cracks in pressure vessel pipe are always in three-dimensional stress status. Due to the uncertainty of the surface crack front shape, crack growth analysis has become the focus of attention of this study.

FEA was performed to calculate the geometric factor for various crack and wire configurations as described below. The simulations of the transverse cracked cylindrical specimen subjected to tensile loading were carried out in commercially available FEA software ABAQUS CAE 6.14-4. Numerical analysis (using XFEM) was performed on cylindrical wires to obtain K_I as a function of wire aspect ratios, crack aspect ratios and relative crack depths. Mesh convergence studies were performed, and a suitably fine mesh with approximately 2,00,000 elements was chosen that yields precise K_I solutions. Simulations were run for wire aspect ratios: $\frac{H}{D}$ = 2,4,6,10,16,20,30,50 at $\frac{a}{D}$ varying between 0.10 and 0.70 and crack aspect ratios $\frac{a}{b}$ varying between 0.2 and 1 for concave and convex cracks. See Fig.1 for reference. The obtained K_I solutions [where $K_I = \sigma\sqrt{\pi a}\, f(\frac{a}{D}, \frac{H}{D}, \frac{a}{b})$ and f is geomteric factor] were normalized to get the geometric factor.

2. Results
Geometric factor for various crack and wire configurations are as described below and summarized in Fig 1:

a. Effect of varying wire aspect ratio ($\frac{H}{D}$) on the possibility of crack growth was systematically studied and it was found that stable crack growth can be achieved in specimens with low $\frac{H}{D}$ ratios. Also, for shallow cracks, the geometry factor did not vary much on changing $\frac{H}{D}$ ratios.
b. Bending of wire in tensile loading is more in longer wires, converting it to a superposition of tensile and bending configurations. This intensifies the K_I at the crack tip in longer wires. A higher geometric factor indicates a more severe stress singularity in the crack opening mode (mode I), leading to a crack growing more easily.
c. The extent of bending was also affected by the shape of crack front curvature. The effect was maximum for a perfect concave crack and showed a decreasing nature as the curvature was gradually varied from concave to straight to perfect convex. This also led to higher stress intensification at crack tip of perfect concave crack as compared to other shapes.
d. K_I at the crack center (Point A – Fig.1(a)) is more than the crack periphery (Point B) in perfect concave crack. As the curvature is varied from concave to convex, they equalize and finally K_I at crack periphery gradually becomes greater than at center. Thus, cracks try to convert to a straight fronted crack.

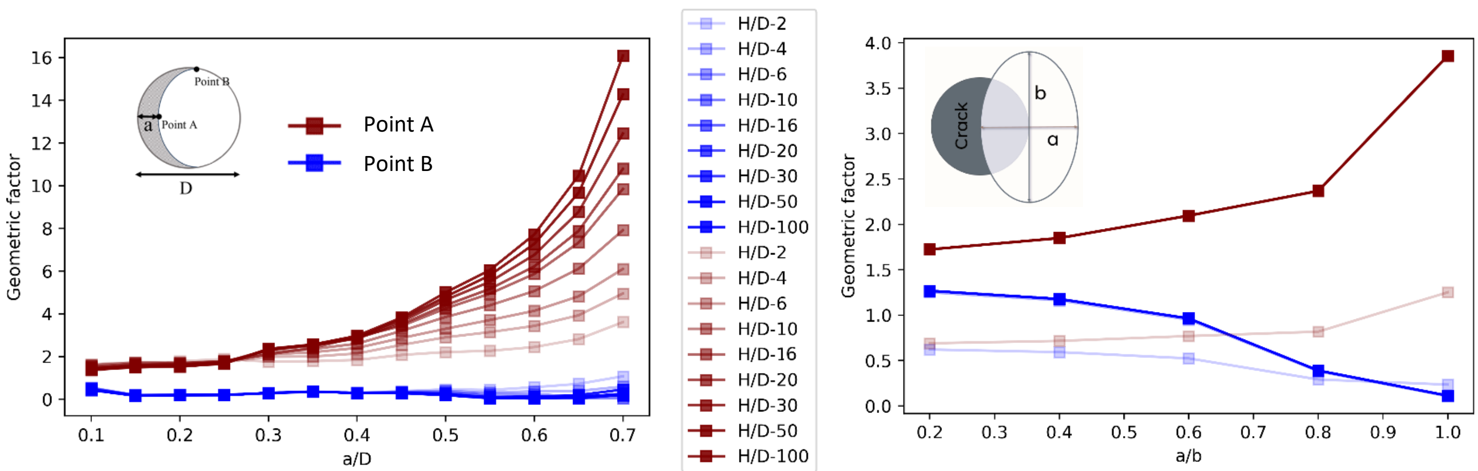

Fig.1(a) Variation of geometric factor with H/D for concave crack [Reproduced with permission from (Sahasrabuddhe et al. 2022)], (b) Variation of geometric factor with crack aspect ratio for concave crack

Experimental confirmation of the obtained geometry factor solutions was performed on PMMA with a known notch toughness. Different crack fronts were introduced into the PMMA rods using laser cutting. These notched rods were then subjected to tensile loading conditions using Jinan Engineering Corporation (TE) UTM system with a 5kN load capacity.

3. Conclusions

The present study proposes revised geometry factor solutions for various crack configurations of transverse cracked cylindrical fracture specimen in tension over a range of wire aspect ratios: $2 \leq \frac{H}{D} \leq 100$, crack aspect ratios: $0.2 \leq \frac{a}{b} \leq 1.0$ and relative crack depths: $0.1 \leq \frac{a}{D} \leq 0.7$. The influence of wire aspect ratios is more for deeper cracks and saturates for ratios around 100 implying for longer wires geometric factor values of $\frac{H}{D} = 100$ can be used. The bending is more for concave cracks which intensifies K_I at crack tip.

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