# Three-Dimensional Fracture Mechanics: Bridge the Gap from Laboratory to Engineering Structures

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The fracture mechanics theories have been developed actively for several decades, and have been successful for many specific engineering applications and serves as the fundamental for damage tolerant design of structures. In 1957, William and Irwin obtained the stress intensity factor *K* dominated solution of the singular stress and strain fields near crack tip in linear elastic plate, provided the theoretical basis for linear elastic fracture mechanics. In 1968, the famous *J*-integral dominated HRR solution for plane stress and plane strain cracked plates of power law hardening materials has long served as the fundamental of elastic-plastic fracture mechanics and similar solution has been developed for power law creeping cracked plates in 1980s. In 1986, Li and Wang solved the higher terms to the HRR solution and proposed that the J-dominated plane strain HRR solution is not enough for finite sized plates. Discussions about the higher order solutions widely attracted the attention of the fracture community in the world during 1990s and developed into constraint theories to consider the in-plane constraint effects. However, all the HRR solution based higher order solutions and constraint theories are mainly limited to two-dimensional cracked plates at the two limits of out-of-plane constraint $T_z = \frac{\sigma_{zz}}{\sigma_{xx} + \sigma_{yy}}$ =0 for plane stress and 0.5 for ideal plane strain states. In 1993, we developed the two parameter $J$-$T_z$ dominated singularity solution for cracks in power law hardening materials under general out-of-plane constraints ranging from 0 to 0.5, filling the gap between the plane stress and plane strain states [1]. We have also developed the $J$-$T_z$ solution to three parameter $J$-$T_z$-$Q_T$ solutions to consider both the in-plane and out-of-plane constraints, and recently to $C^*$-$T_z$-$Q^*$ solution for power law creeping solids [2-4].

Based on this three-dimensional (3D) theory, we have made great efforts in the past 20 years to bridge the gap for fracture and fatigue from laboratory standard specimens to complex engineering structures [5-12]. In this talking, we will address the advances in the following critical issues and introduce our most recent works along the line.

1) From 2D fracture mechanics to 3D fracture mechanics;
2) From tensile to mixed mode loadings;
3) From static/toughness to fatigue/durability;
4) From ambient to high temperature environments;
5) From empirical design to predictive design;
6) From continuum methodology to multiscale simulations.

## Reference

1. Guo, W. Elastoplastic Three-dimensional Crack Border Field-I~III. *Engng. Fract. Mech*. I: 1993, 46: 93-104; II: 1993, 46: 105-113; III: 1995, 51: 51-71. *Science and Technology Report of NPU* 1990, SHJ9022.
2. Xiang, M. J., Yu, Z. B., Guo, W. L. (2011). Characterization of three-dimensional crack border fields in creeping solids. *International Journal of Solids and Structures, 48(19),* 2695-2705.

3. Xiang, M. J., Guo, W. L. (2013). Formulation of the stress fields in power law solids ahead of three-dimensional tensile cracks. *International Journal of Solids and Structure, 50(20),* 3067-3088.
4. Guo, W., Chen, Z., She, C. (2018). Universal characterization of three-dimensional creeping crack-front stress fields. *International Journal of Solids and Structures, 152,* 104-117.
5. Guo, W. (1999). Three-dimensional analysis of plastic constraint for through-thickness cracked bodies. *Engineering Fracture Mechanics, 62*, 383-407.
6. Guo, W., Wang, C., Rose, F. (1999). The Influence of cross-sectional thickness on fatigue cracks growth. *Fatigue & Fracture of Engineering Materials & Structures*, *22*, 437-444.
7. Guo, W. (2002). Theoretical investigation of elastoplastic notch fields under triaxial stress constraint. *International Journal of Fracture, 115*, 233-249.
8. Shen, H., Guo, W., Lu, G. (2002). Corrosive fatigue of structures with dimple holes under spectrum environments. *Fatigue & Fracture of Engineering Materials & Structures*, *23*, 1-11.
9. Guo, W., Zhang, B., Feng, Q., Li, C. (2005). Lifecycle safety guarantee of structures. *Chinese Journal of Mechanical Engineering, 18(2),* 279-285.
10. Yu, P., Guo, W. (2013). An equivalent thickness conception for evaluation of corner and surface fatigue crack closure. *Engineering Fracture Mechanics, 99,* 202-213.
11. Yu, P. S., Guo, W. L. (2012). An equivalent thickness conception for prediction of surface fatigue crack growth life and shape evolution. *Engineering Fracture Mechanics, 93,* 65-74.
12. Zhang, S. Q., Guo, W. L., Li, H., Deng, Y. (2011). Experimental investigation of three-dimensional mixed-mode fracture of a titanium alloy at room and elevated temperatures. *Science China Technological Sciences, 54(10),* 2760-2767.

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