

Chapter 2

Fracture Mechanics of Concrete – State-of-the-Art Review

2.1 Introduction

The genesis of the development of fracture mechanics goes back to the beginning of 20th century when Inglis (1913) published a pioneer work on stress analysis for an elliptical hole in an infinite linear elastic plate loaded at its outer boundaries, in which a crack-like discontinuity was modeled and stress singularity was observed at the crack tip by making the minor axis very much less than the major axis. The actual development in this field could not occur until a new approach was postulated by Griffith (1921). Since then, it took around another four decades when for the first time the concept of fracture mechanics was applied to cementitious materials. Thereafter, the study of crack propagation in cement-based materials and structures attracted interest of a large number of researchers around the world until today. In this chapter, a state-of-the-art review on various aspects of fracture process of concrete-like materials now-a-days called as *quasibrittle* materials is presented.

2.2 Linear Elastic Fracture Mechanics

From analysis of a sharp crack in a sheet of brittle material (glass) subjected to a constant remotely applied stress, Griffith (1921) presented the first explanation of the mechanism of brittle fracture using a new energy-based failure criterion. According to this criterion, a certain amount of the accumulated potential energy in the system must decrease to overcome the surface energy of the material in order for the crack to propagate. It was shown that the stresses near the crack tip tend to approach infinity.

The Griffith's theory for ideally brittle materials was extended to account for the limited plasticity near the crack tip in majority of the engineering materials (Irwin 1955, Orowan 1955). It was postulated that the resistance to crack extension is taken as sum of the elastic surface energy and the plastic work. For ductile materials, the plastic dissipation energy is much greater than the elastic energy; therefore, resistance to crack growth is mainly governed due to plastic work.

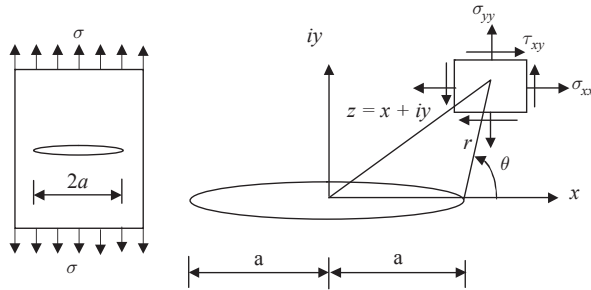


Fig. 2.2 Stress field in the vicinity of crack tip for mode I fracture using Westergaard complex coordinates

2.2.1 Significance of Stress Intensity Factor

The term stress intensity factor is different from the term stress concentration factor, which is used to characterize the ratio between actual and average or nominal stress at a geometric discontinuity. On the other hand, the stress intensity factor defines the amplitude of the crack-tip singularity, that is, the stress field in the vicinity of the crack tip increases proportionally to stress intensity factor. When a structural component is stressed in tension or bending, the developed stress field in the vicinity of a crack tip under elastic conditions shows a singularity following an inverse square root relationship with distance from the crack tip. In other words, stress intensity factor describes the strength of this singularity. Since the stress and displacement field in the vicinity of the crack tip is controlled by the stress intensity factor, it may be further assumed that critical stress or displacement condition at the crack tip can be explained using a critical value of stress intensity factor for any modes of failure. Hence the concepts of linear elastic fracture mechanics may be reasonably characterized using a single parameter, that is, stress intensity factor. Furthermore, local yielding occurs in engineering materials that relieves the singularity and hence the size of the plastic zone can be directly related to the stress intensity factor.

2.2.2 Concept of R Curve

In early 1960s, the R -curve approach (Irwin 1960, Krafft et al. 1961) based on energy balance was proposed. In the R -curve concept, an energy release rate G as a measure of the energy available for an increment of crack extension was postulated. According to definition, crack extension occurs when strain energy release rate G is equal to R , where R is called the material resistance to crack extension. The R curve is represented by a plot between the crack extension resistance expressed in terms of either strain energy release rate G or stress intensity factor K and the corresponding crack extension Δa as shown in Fig. 2.3. It is generally called as G_R curve and K_R curve depending upon the unit of the crack resistance parameters strain energy

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