CHAPTER V

CONCLUSIONS AND REMARKS

An extensive parametric study has been conducted to thoroughly investigate the influence of the thickness and material properties on the behavior of the stress intensity factor along the crack front of the compact tension (CT) specimen. A numerical technique based upon the weakly singular, symmetric Galerkin boundary element method (SGBEM) has been adopted to perform three-dimensional stress analysis of the corresponding boundary value problem. The stress intensity factor has been accurately computed using an explicit formula in terms of the nodal data along the crack front. In the modeling of the relative crack-face displacement in the local region surrounding the crack front, special crack-tip elements with a square-root function embedded in the shape function have been utilized. Use of these crack-tip elements renders the stress intensity factor being captured accurately using relatively coarse meshes.

Geometry of the CT specimen and the loading condition considered in the present study has been chosen to be consistent with ASTM E399-90 except that (i) a notch in front of the crack plane has been removed to simplify the meshing procedure and (ii) the specimen thickness has been varied to investigate its influence on the stress intensity factor across the thickness. A level of mesh refinement has been investigated to ensure that converged numerical results have been obtained for various thicknesses and material properties. To reduce the meshing effort, a simple strategy based on the coordinate stretching and insertion of an interior layer has been exploited to generate meshes for larger thicknesses. In addition, benchmark solutions for some special cases have been compared to verify both the numerical technique used and the meshing scheme.

Extensive numerical experiments have indicated that the specimen thickness shows very significant influence on the value of the mode-I stress intensity factor across the thickness both in terms of the distribution characteristic and the magnitude. In particular, the stress intensity factors predicted by a three-dimensional model exhibit substantial discrepancy from the plane strain solution for almost the entire crack front when the thickness of the specimen is relatively small compared to other specimen dimensions. However, when the thickness of the specimen is sufficiently large, a plane strain dominated zone has been observed in the central region of the crack front and the size of this zone increases with the specimen thickness. It is important to remark that the behavior of the singular stress field near the vertex (a point where the crack front meets the outer boundary) has been found very complex and the stress intensity factor in this local region generally exhibits the rapid drop when moving towards the vertex. Such complex behavior cannot be captured by using two-dimensional mathematical models. Based on numerous results from a parametric study of material properties for both isotropic and transversely isotropic cases, it has been found that the distribution of the stress intensity factor along the crack front exhibit very weak dependence on the material properties but show significant impact on its magnitude. In addition, material properties have been found to strongly influence the value of the average stress intensity factor across the thickness and the rate of convergence to the plane strain solution. This implies that specimens made of different materials may require different thickness in order to gain the same level of plane strain condition across the crack front.

Results obtained from the present investigation should provide better insight into the behavior of the stress intensity factor along the crack front for brittle materials where the small-scale yielding pertains. This knowledge can be used directly as a useful guideline in the design of test specimens to determine the fracture toughness, an essential material property in fracture mechanics. In general, fracture toughness obtained from experiments can be thickness-dependent if the specimen thickness is not chosen properly. To obtain the fracture toughness that represents the true material property, the specimen thickness must be chosen sufficiently large to ensure that the behavior along the majority of the crack front is dominated by a plane strain condition. A comprehensive, three-dimensional stress analysis (similar to that employed in the current study) may be performed in advance for various thicknesses to gain an insight into the distribution of the stress intensity factor along the crack front and help to choose proper specimen dimensions.

As a final remark, fracture toughness depends not only on the specimen thickness but also on the temperature, loading rate and the extent of inelastic deformation near the process zone. It has been known that the variation in temperature and loading rate and the plastic zone size ahead of the crack front can have the strong impact on the fracture toughness. Modeling of such influences is not included in this study but still requires further rigorous investigation.