SUMMARY

In the design of aerospace structures involving thin sheet materials, presence of cracks or crack-like defects during the service life of the vehicle is considered inevitable. Consequently a finite life estimation is made for such structures based on fail safe design or damage tolerance criterion. It is in this context that the concepts of fracture mechanics need to be emphasized in the analysis of relatively thin stressed aluminium alloy sheets with real cracks. It is well known that determination of actual stresses in the immediate vicinity of a crack-tip always poses a challenging task to the stress analyst. However, the basic fracture mechanics parameter, the Stress Intensity Factor, 'K' which is a function of the crack geometry, as well as the applied forces, represents the crack-tip stress field and can be determined by the available methods of fracture mechanics.

In this dissertation Mode-I stress intensity factors have been determined by use of numerical techniques like finite element analysis considering thin aluminium alloy (2024 - T3 Alclad) sheets of finite dimensions. For the analysis, plane eight noded quadratic quadrilateral isoparametric elements have been used as conventional elements and these elements were collapsed at the crack tip to form degenerated crack-tip elements, with the formulations for both types of elements remaining the same. Three different crack

configurations, viz. centre crack, single edge crack and double edge crack under uniaxial tensile loading for different crack length to sheet width ratios have been considered. The variety of procedures adopted for inter-pretation of the results of analyses, i.e. determination of stress intensity factor, included direct methods and energy methods based on nodal point displacement solution. The direct methods included the extrapolation of nodal stress intensity factors upto the crack tip using stress and displacement substitution and energy methods included the path independent energy integral or J-integral and the determination of strain energy release rate upon crack growth.

The isoparametric family of elements used at the crack tip in the analysis involved inverse square root singularity. In the present work, the stress intensity factors have been obtained by use of all the above methods for the centre cracked specimen and using direct methods for the other two crack configurations. The results are seen to be in close agreement with those found in literature. The SIF, obtained by use of normal stress along the crack line seems to be most suitable. In this work the effect of singularity and non-singularity formulation for the crack tip elements has been studied. It was observed that the SIF attains a slightly higher value in the singular formulation.

The effect of mesh refinement on SIF has also been studied. Both coarse and fine meshes were considered in the neighbourhood of the crack tip. It is seen that the finer mesh yields slightly lower values for SIF. The effect of crack tip singularity on SIF (obtained from stress considerations) is found to be more pronounced than the effect due to the fineness of grid, surrounding the crack-tip. Further the influence of employing two-point and three-point numerical integration schemes for evaluating the element stiffness matrix on SIF was studied. The variation of SIF value is found to be only marginal, although the three point numerical integration scheme, in general, involves a larger computational time.

It is expected that crack tip stress field in a real life structure would be different from that predicted by the elastic analysis with or without the consideration of crack tip singularity. Therefore an elasto-plastic analysis was made for a centre cracked narrow-thin panel with crack length to sheet width ratio of 0.25 by considering the material elasto-plastic stress-strain behaviour. The solution is achieved by an iterative process which is similar to the linearized total strain method of Zienkiewicz, wherein full load was considered as the initial load. The family of isoparametric elements have also been used for this elasto-plastic analysis. It has been observed that complete convergence of the stresses in all the plastic elements to match the actual stress-strain curve of the material would require a prohibitively large computational time. But despite partial convergence of the results within a reasonably low computation time, it has been found that the elasto-plastic analysis gives a more realistic crack tip stress field, from which an approximate shape and size of the plastic zone could be obtained, considering both the Von-Mises and Tresca criteria for yielding. Variation of these plastic zones at discrete load levels were considered and comparison of these results with those obtained experimentally, by use of photostress coating technique, indicate a reasonable agreement.

It is well known that for a certain combination of crack geometry and stress level, when the SIF reaches a critical value, i.e. plane stress fracture toughness in case of thin sheets, unstable crack growth takes place leading to ultimate fracture. For very thin and less wide panels, the plane stress fracture toughness is not very well defined. A nonmalized geometric stability factor was obtained based on the energy release rate for incremental crack lengths and it has been possible to predict the critical crack length corresponding to fracture instability at a given stress level. An experimental verification has also been made for a particular crack geometry. The static load corresponding to the onset of crack growth instability was found to be in agreement with the prediction by finite element analysis.

In the present investigation the experimental determination of Mode-I SIF was undertaken with a view to verify the validity of the numerical analysis for determining K_1. The experimental methods adopted for the determination of K_1

were strain gauge technique and photostress coating technique. It has been observed that the SIF obtained by these techniques are in reasonable agreement with those obtained from the numerical analyses and also from literature.

In the present investigation, photostress coating technique was also employed for evaluating the shape and size of the plastic zone, developed at the crack tip under uniaxial tensile loading. The plastic zone was visually observed in the coating. This concept of determining the plastic zone size at the crack tip by simple visual observation has been supported by experimental verification at some discrete points on the boundary of the isochromatic fringe, where the principal stresses were separated by oblique incidence measurements. It has been observed that the minor principal stresses were always negative, establishing the fact that the principal stress difference obtained on this isochromatic fringe had the absolute maximum value, or in other words, this gave the absolute maximum shear stress value. At different discrete load levels maximum spread of the plastic zones (r_{pmax}) were found out along with their orientations.

Comparison of these maximum spread of the plastic zones and their tilt angles 'θ_m' at different load levels for a particular crack configuration, with those obtained from the elasto-plastic finite element analysis, shows reasonable agreement. Plastic zone sizes at crack tip, obtained by both theoretical and experimental analyses at different load levels show fairly good agreement when compared with the results obtained from literature.

In this dissertation, Chapter I gives a fairly exchaustive review of the relevant literatures that are both of general interest and of particular value to the problem studied here. The objectives of this investigations is presented at the end of this chapter.

Chapter II describes the elastic finite element analysis carried out to determine the crack tip stress field as well as the Mode-I SIF, K_1 . The results are presented in tabular and graphical forms at the end of this chapter.

Chapter III deals with the prediction of fracture instability in thin narrow panels under uniaxial tension, having a centre crack. The FEM is used for the analysis and the results of the numerical as well as experimental investigations are presented.

In Chapter IV, the elasto-plastic analysis of a centre cracked panel by finite element method are presented. From a somewhat realistic stress distribution so obtained, the shape and size of the plastic zone are evaluated. The results are presented at the end of the chapter, followed by discussions.

Chapter V deals with the experimental determination of SIF by strain gauge technique. The results are presented in the form of tables.

Chapter VI (i) deals with the determination of Mode-I SIF by photo-stress coating technique. The experimental procedure is described and the results are presented in the form of graphs and tables.

Chapter VI (ii) describes the evaluation of the plastic zone size at the crack tip for a centre cracked panel under uniaxial tension. The boundary of the plastic zone is obtained visually by considering Tresca criterion of yielding. Comparison of results are made with the numerically obtained values from previous chapters as well as with results of other investigators wherever possible.

Discussions and conclusions based on the results of this investigation are presented in Chapter VII. In Chapter VIII, some suggestions for further work in this field are noted.