SUMMARY

Sudden failure of different structural members of stress levels much below the material yield stress can very often be attributed to the presence of cracks or flaws in them. This clearly shows that the standard methods of evaluation of strength properties of structural members alone is quite insufficient to predict the strength behaviour under service conditions. Fracture mechanics enables one to assess the real life strength and behaviour of structures in the presence of any defects as cracks, flaws etc. In the past few decades, study of the cracks and flaws were done, with an assumption for simplicity, that there is negligibly small plastic deformation surrounding the cracks or flaws. As the analysis is done elastically, such analysis is very often referred to as Linear Elastic Fracture Mechanics or in short LEFM. Different experimental and analytical techniques have been developed to study a structural member having cracks but still the accurate evaluation of the stress field in the close vicinity of the crack-tip is a difficult task. The basic fracture mechanics parameter, K, known as Stress Intensity Factor, a measure of stress singularity at the crack tip is derived from the theory of elasticity. In general, K is a function of crack geometry and the applied stress and can be determined by the available experimental and analytical methods. The Linear Fracture Mechanics parameter, K represents the crack-tip stress field fairly well only when the crack-tip plastic deformation is very small. When there is a large plastically yielded region

surrounding cracks or flaws, K, no longer depicts the true picture of the stress field in the close vicinity of the crack or flaws.

Several attempts have been made to extend the scope of linear fracture mechanics to cope up with the fracture mechanics problems involving moderate plastic yielding by the incorporation of different plasticity correction factors. It has been observed that under plane strain condition the crack-tip plastic region is comparatively very small unlike that under the plane stress condition, where the area of the plastically deformed region is considerably large.

So, for a plane stress problem the linear elastic fracture mechanics parameter, K does not depict the true picture of the stress field surrounding the crack or flaw. To account for the elasto-plastic behaviour of structural members, the concept of resistance to crack growth was introduced following the energy balance theory. The parameter, R denotes the resistance to crack growth, which increases as the crack grows from a notch or a fatigue crack. The increase in resistance is due to the increase in crack length and an increase in plastic zone size. To account for the elasto-plastic condition in plane stress, the elasto-plastic field of the crack is represented by that of a longer equivalent crack in a purely elastic field. This assumed new crack length is called the effective crack length.

The fracture energy release rate, G is very often expressed in terms of stress intensity factor, K. With the necessary correction for the crack length and finite width, the effective value of K is obtained, which accounts for the elasto-plastic condition. The plot of the effective value of K against the difference of effective crack length and initial crack length gives the R-curve. Also by experimental methods, the same effective value of K and the corresponding effective crack growth can be obtained to plot the R-curve. The critical conditions for fracture under plane stress conditions can be evaluated from the R-curve.

The design of aerospace structures extensively involves thin sheet materials and the presence of small cracks or flaws in them during their service life is inevitable. With the help of the principles of fracture mechanics, estimation of life and critical strength properties, can help the designers to design a fail safe or damage tolerant structure. In this context, the present investigation has been carried out on very thin panels of aluminium alloy (2024-T3, ALCLAD) with small widths and having flaws in the form of some initial fatigue cracks of different sizes at the centre.

In the present investigation only Mode-I cracks (opening Mode) have been considered. By finite element analysis, the stresses, displacements, stress intensity factors etc. have been computed for particular crack configuration and loading. For the analysis, plane eight noded quadratic quadrilateral isoparametric finite elements have been considered. The elements surrounding the crack-tip have been collapsed to meet at the crack tip. The mid-side nodes close to the crack-tip have been shifted to one quarter position, away of the crack tip, to achieve the required inverse square root singularity. For evaluation of the element stiffness matrix the Gauss point method of numerical integration has been employed.

The energy method has been applied to compute the strain energy release rate, G from the nodal displacements for any initial crack and then allowing a small amount of crack growth. Different initial crack to width ratios, starting from 0.1 to 0.6 have been tried and also the computations have been carried out for different stress levels.

Both the elastic finite element analysis and the elasto-plastic finite element analysis have been attempted at. For the same crack geometry, both elastic and elasto-plastic analyses have been carried out and the plastic zone shâpes and sizes compared. In the elasto-plastic analysis, the full load was assumed to be acting at the beginning and the solution is achieved by an iteration process. Metamorphosis of the plastic-zone shapes, during the iteration process has been studied for a 0.6 crack. Also, the SIF along different radial lines, with varying angles, starting from the crack-tip, have been plotted and the crack-tip SIF has been studied.

Equivalent plastic zone radii have been calculated for a 0.25 crack, at different stress levels considering both Tresca and Von-Mises yield criteria from both the elastic and elasto-plastic FEM data. The results have been compared with the plastic zone correction, r_p obtained by Irwin's method and the present photo-stress coating method. It has been observed that FEM results are agreeing well with those of photo-stress coating results. However, the values are on the higher side of Irwin's plastic zone correction values. Also, it has been observed that the maximum tilt angle θ_{max} obtained at different stress levels decreases gradually from lower to higher stress values. A comparison of the normalized maximum spread of the plastic zone has been done with those of other workers and it appears that r_{pmax} obtained through the present FEM are slightly on the higher side.

R-curves have been plotted from the strain energy release rate, G and the critical conditions for fracture have been evaluated in terms of K_c, σ_c and a_c. The results are in general agreement with the present experimental results and also with those available in the literature.

In the present investigation, photo-stress coating method has been applied to study the plastic zone shapes and sizes at different stress levels. The plastic zone was visualized in the Photo-stress coating. Considering Tresca yield criterion and setting a priori the fringe order corresponding to the yield stress on a Babinet-Soleil compensator the line of total extinction as viewed through the reflection polariscope set for isochromatics, represented the elasto-plastic boundary. The plastic zone shapes were studied from a series of coloured photographs and the equivalent plastic zone radii calculated for different initial crack configurations. The results compared with those of other workers and with those of the present numerical analysis. From the plots of the normalised r_{peq} and Irwin's plastic zone correction factor, r_p it appears that upto a certain lower stress level there is a good agreement between the curves. At higher stresses, r_{peq} obtained through the present FEM and photo-stress coating technique give more conservative estimate of the plastic zone correction factor. Moreover, using the r_{peq} obtained from photo-stress coating as the plastic zone correction factor in conjunction with the DCPD test data one can draw a purely experimental R-curve.

It has been observed during the photo-stress coating analysis that the maximum tilt angle, θ_{max} of the plastic zone gradually decreases with the increase of stress level which confirms the observation made by FEM.

During the present investigation, the Direct Current Potential Drop method has been applied to generate experimental R-curves for different crack configurations and specimen geometries. A number of calibration tests have been done to establish the relationship between the crack growth and the change in potential across the crack. Calibration curfes agree very well with those found in the literature and also with those of the theoretical calibration proposed by some researchers.

R-curves have been drawn with proper plastic zone correction. It has been observed that R-curves depend considerably on the sheet thickness and to some extent on a_0/W ratio, but almost independent of the width. Of course upto a certain stress level, R-curve is independent of those parameters.

The critical conditions for fracture instability have been studied from the tangency condition of R-curves. Critical values of stress, crack length and stress intensity factors have been evaluated and compared with the results of the present theoretical analysis and as well as with those of the other workers wherever possible.

The net section yield criterion has been studied from the critical conditions obtained by the R-curve method. It has been observed that the limit of net section plasticity can safely be assumed as $\sigma_n/\sigma_s = 0.95$.

The yield loci have been plotted with the critical values obtained from R-curves and compared with the general yield line of the material, which show a general agreement.

The entire work reveals that the R-curve method can be a well suited method to study the critical conditions of failure of a structural member under plane stress condition. The shape and size of the crack-tip plastic zone can be evaluated more accurately by an elasto-plastic FEM or photo-stress coating technique. Introduction of the equivalent plastic zone correction factor, r_{peq} as a substitute for the Irwin's plastic zone correction, r_p permits a conservative estimation of the critical conditions for thin sheet fracture. Moreover, R-curves can be drawn purely experimentally using photo-stress coating r_{peq} in-conjunction with the DCPD test data.

In this dissertation, Chapter I gives an extensive review of the relevant literature, as available to the present investigator, concerned with the general or specific interest to the present investigation. The objective of the investigation has also been narrated in brief at the end of the chapter.

Chapter II describes the elastic finite element analysis which has been carried out to study the crack-tip SIF, plastic zone shape and size. The strain energy method has been applied to generate R-curves and study the critical conditions for thin sheet fracture. The results have been presented in graphical and tabular forms at the end of the chapter and discussed.

Chapter III describes the elasto-plastic finite element analysis to study the plastic zone shape and size. Metamorphosis of the plastic zone shape during elasto-plastic iteration process has also been studied. The results have been presented at the end of the chapter in graphical and tabular forms and discussed.

Chapter IV describes the photo-stress coating technique to study the plastic zone shape and size at the crack-tip. Equivalent plastic zone radius, r_{peq} has been calculated to use as a plastic zone correction factor. The results have been presented in the form of graphs and tables. Also some coloured photographs have been presented to show the crack-tip plastic zone along with other fringes.

Chapter V describes the Direct Current Potential Drop Method to generate the crack growth resistance curve. Effect of different geometrical parameters on the R-curve has been studied. The critical conditions for thin sheet fracture for particular specimen geometry and crack configuration have been studied. The limit of the net-section plasticity has been evaluated. Yield locus has been plotted from the critical values for fracture obtained from R-curves and compared with the general yield line of the material. The results have been presented in the form of graphs and tables and discussed.

Chapter VI presents the overall discussion of the entire investigation and conclusions made therefrom.

Chapter VII presents some suggestions for further research in the field of thin sheet fracture mechanics.

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