Synergistic effect of external magnetic field on initiation of crack propagation in pre-cracked current-carrying Al foil

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Applications such as microelectronic systems, integrated circuits, electromagnetic devices experience electrical surges of very high current density, of the order of 10^9A/m^2, during their service. The structural integrity of such components is a concern as flaws can propagate due to such high current densities. These components also experience the magnetic fields of the other surrounding conductors, which may enhance the severity of the electromagnetic forces. In this study, we have investigated the effect of the external magnetic field on the fracture behavior of pre-notched current-carrying Al foil. Experiments were carried out using a custom-built setup wherein current pulses were passed through the foil in presence of a uniform external magnetic field. The effect of increasing magnetic field on the critical current density required to initiate crack propagation was determined through these experiments. Numerical analysis was also performed to understand the coupling of the self-induced magnetic field and the external magnetic field. Furthermore, the effect of an external magnetic field on the stress distribution in the foil was analysed, based on which the equation of Mode I stress intensity factor for the electromagnetic loading in the presence of an external magnetic field was defined. The results were found to be consistent with the experimental behavior. Finally, the evaluated transient stress intensity factors were compared with the plane stress fracture toughness of a 11µm thick Al foil. A good match was observed between the two, indicating that fracture initiated when ($K_{I\ transient} \approx K_{IC}$). The role of temperature and buckling was also determined while explaining the phenomena using linear elastic fracture mechanics (LEFM).

Keywords: Current density; electromagnetic forces; external magnetic field; stress intensity factor; linear elastic fracture mechanics