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Some basic aspects of electromagnetic radiation emission during plastic deformation and crack propagation in Cu–Zn alloys

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Abstract

This paper presents some basic aspects of electromagnetic radiation (EMR) emission during plastic deformation and crack propagation in Cu–Zn alloys. Six parameters, viz. stress intensity factor, elastic strain energy release rate, EMR amplitude (maximum and rms), EMR frequency, and electromagnetic energy release rate, at different percent of zinc content have been analyzed. Results show that EMR parameters increase with increase in zinc up to 30% and then they decrease with higher zinc percentage. Investigations showed that the electromagnetic energy release rate has a direct correlation with the elastic strain energy release rate, which can prove to be a novel technique for the evaluation of fracture toughness. It was further observed that the electromagnetic energy release rate bears a parabolic relation with the ratio of stress at crack tip instability, σ, to the stacking fault energy, U_f, where cross-slip energy is also known to be only a function of (σ/U_f).

Keywords: Copper–zinc alloys; Radiation; Dislocation; Plastic deformation; Fracture toughness

1. Introduction

Understanding plastic deformation and crack initiation at atomic level has been a crucial aspect of material research. Role of dislocation–dislocation, dislocation–solute, and dislocation–electron interactions in plastic deformation requires still deeper investigations. In this context, emission of electromagnetic radiation (EMR) during plastic deformation and crack propagation in metals and alloys, and generation of transient magnetic field during crack initiation in ferromagnetic materials reported in a series of papers by one of the authors, Misra [1–7] and Misra and co-workers [8–19] appear significant. These effects have been confirmed and explored by some more researchers [20–24]. A recent paper by Srilakshmi and Misra [14] contains the relevant informations. The fact that the rms value of EMR amplitude bears a parabolic relation with the Debye frequency of metals, was proved, both theoretically and experimentally by Misra and Ghosh [8]. Further, EMR peak voltage varies linearly with the bond energy of metals while frequency varies parabolically with the bond energy; EMR amplitude and frequency decrease with increase in lattice parameter [12]. Recently, Srilakshmi and Misra [15] have reported an additional phenomenon of secondary electromagnetic radiation during plastic deformation and crack propagation of metal-coated and uncoated metals.

Misra reported emission of EMR during pronounced transient changes in the dislocation structure, which occur, for example near the yield point, start of strain-hardening, crack initiation, and propagation, and fracture [4]. Molotskii considered these stages of pronounced transient changes in the dislocation structure. Since long-range electric fields exist near dislocations in metals, Molotskii argued, the appearance of accelerated dislocations could result in the emission of EMR [25]. In a recent work [26], Misra and his co-workers have presented a generalized model for this EMR emission, which indicates the role of dislocation–solute/dislocation–dislocation interactions during the onset of plastic deformation leading to the generation of EMR.

An important aspect of the EMR emission is the effect of solute addition in a metal. Till date no systematic investigations on the EMR emission in metal alloys have been made which could correlate EMR emission with phase transformations, stacking fault energy, like parameters.

With this aim in view, some basic aspects of EMR emission have been investigated in copper–zinc alloys, which has wide

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range applications, and results are presented in this paper. One of the important reasons of selecting Cu–Zn alloy is the remarkable changes in its physical and mechanical properties at the transition from α-phase to $\alpha + \beta'$ phase.

2. Materials and specimens

Preliminary experiments were conducted on hard rolled commercial 68–32 brass sheets of dimensions 100 mm × 14 mm cut with their longitudinal axis along the rolling direction. This eliminated the anisotropic effect on the EMR emission. The thickness of the specimens were $h = 0.20$, 0.38, 0.96, and 1.88 mm. The chemical composition of 68–32 brass sheet was: Cu, 67.8%; Fe, 0.15%; Pb, trace; Mn, trace; rest Zn.

Cu–Zn alloys with 10, 20, 30, and 40% zinc content were procured from the National Metallurgical Laboratory, Jamshedpur, India. The Cu–Zn alloy ingots were cold-rolled to reduce the thickness of sheets to 1 mm by 90% reduction. Specimen dimensions were 100 mm × 14 mm × 1 mm, with longitudinal axis along rolling direction of sheets. The Cu–Zn alloys had the following chemical compositions:

90–10 Cu–Zn alloy: Cu, 90%; Pb, 0.05%; Fe, 0.02%; Mn, trace; rest Zn.
80–20 Cu–Zn alloy: Cu, 79.5%; Pb, 0.04%; Fe, 0.03%; Mn, trace; rest Zn.
70–30 Cu–Zn alloy: Cu, 70%; Pb, 0.05%; Fe, 0.03%; Mn, trace; rest Zn.
60–40 Cu–Zn alloy: Cu, 59.7%; Pb, 0.05%; Fe, 0.03%; Mn, trace; rest Zn.

An initial straight single edge notch of length $a = 7$ mm, corresponding to the initial notch length, a, to specimen width, w, ratio $(a/w) = 0.50$ as per standard of fracture tests, was provided in the central region of each specimen. All experiments were performed at the room temperature. Since Mode I loading (opening or tensile mode, where the crack surfaces move directly apart) is encountered in the overwhelming majority of actual engineering situations involving cracked components, all investigations were carried out under this mode.

3. Instrumentation

A manually operated portable horizontal Hounsfield tensometer of 1 tonne capacity was used for loading the specimens. One 150 MHz (200 MS/s) analog-digital HAMEG Oscilloscope HM1507-3 and one 199 Fluke Scopmeter (200 MHz, 2.5 GS/s) incorporating SCC 190 Accessory Kit (RS 232 adaptor and Fluke software) were used to record the signals. The software in-built with the HM1507-3 oscilloscope had fast Fourier transform (FFT) facility to convert the time-domain EMR signals into frequency domain. An IBM Pentium IV was used for data storage and processing. Since the EMR frequency has a very wide spectrum, it was decided to examine the low kHz frequency signals in this phase of experiments. Hence, a frequency filter of 500 Hz to 10 kHz range was designed and employed during the experiments. Two copper chips of dimensions 12 mm × 12 mm × 0.34 mm, were fixed on insulation sheet and then fixed on the two sides of the specimen with proper adhesive. Both chips were joined electrically and this acted as an antenna. The oscilloscope was operated at "single-shot mode" to pick up the transient EMR signals. The details of experimental procedure can be obtained from earlier papers [14–16].

4. Results and discussion

Now, in actual conditions the development of initial cracks existing in a body may depend on the following basic parameters: (i) material, (ii) the shape and dimensions of the body, (iii) the mode of applying an external load, (iv) time duration of the load, (v) number of cycles of load in fatigue loading, (vi) temperature, (vii) the degree of environmental reactivity, and (viii) the strain rate and deformation history.

Since EMR emission is likely to be associated with the plastic deformation, crack propagation, and fracture, it was important to ascertain when the first EMR emission occurs in Cu–Zn alloy specimens and how further EMR emissions appear during the loading, and which signal should be used for further analysis.

In order to achieve this, opening mode experiments were conducted on commercial (68–32) brass sheet specimens of dimensions 90 mm × 14 mm × 1.0 mm with initial single edge straight notch as mentioned above. A strain gauge was fixed, within the remainder zone, on one side of the specimen. The longitudinal tensile strains were recorded at different intervals by using a Model RSI-S strain indicator and a digital time indicator. A copper chip of dimensions 5 mm × 3 mm × 0.20 mm, pasted on an insulating paper, was fixed on the other side of the specimen. This copper chip, acted as the EMR signal pick-up/antenna. Since the oscilloscope had to be operated at 'single-shot mode'

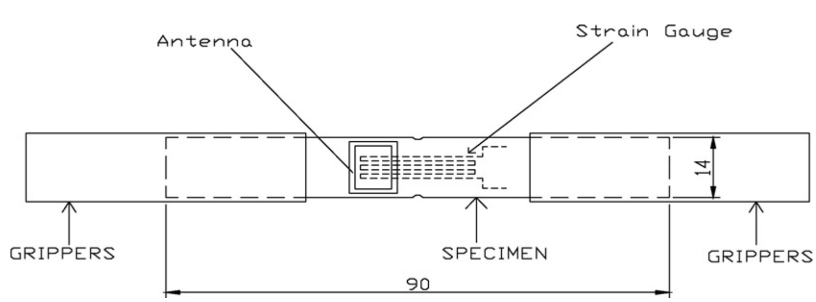

Fig. 1. Configuration of specimen with strain gauge and antenna.