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Real-time Monitoring of Dynamic Stress Concentration by Mechanoluminescent Sensing Film

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Abstract. In this paper, we demonstrate that a dynamic stress concentration around Lüders band can be directly displayed using mechanoluminescence (ML) sensing film of $SrAl_2O_4$:Eu (SAO) coated on the surface of metal. Uniaxial tensile test of an aluminum alloy (2.5% Mg) plate coated with the SAO sensing film was performed and the ML images were recorded using a high-speed camera. Captured ML images confirmed the formation and propagation of Lüders band clearly in real time.

Introduction

Real-time monitoring of dynamic stress concentration is one of the most efficient methods for deterioration diagnosis and remaining life prediction of materials. Several optical non-contact methods are utilized for stress detection in full field, such as Electronic Speckle Pattern Interferometry (EPSI), Digital Correlation Method, etc., which need large amounts of data processing to obtain a distribution of stress concentration. Currently there is no realization for directly visualizing a dynamic stress concentration in real time.

Mechanoluminescence (ML) is a light emission induced by mechanical deformation during applied stress. As it enables us to see the stress distribution directly by the naked eyes, this technique has become very attractive. An exciting evolution has been achieved in ML technique [1,2], which can directly view a stress distribution even for a small strain in the region of elastic deformation of metal [3,4]. However, for more complex phenomena occurring in the region of plastic deformation of metal, ML technique has not yet been used.

Lüders band is a spectacular phenomenon of dynamic stress concentration linked with stress fluctuations, a macroscopic spatiotemporal localization of plastic deformation and an intense acoustic emission. It can be observed in most of bcc metals and aluminum alloy metals. In this paper, we demonstrated that ML technique could be successfully utilized to monitor the formation and propagation of Lüders band in real time. An aluminum alloy plate coated with ML sensing film of $SrAl_2O_4$:Eu (SAO) was used for this study.

Experimental

The sample SAO was prepared by mixing a high purity (> 99.9%) ultra fine powder (< 0.2 μm) of $SrCO_3$, α-Al_2O_3 and $Eu(NO_3)_3 \cdot 2H_2O$ with a small amount of Ho_2O_3, calcining at 1300 °C for 4 h in a reducing atmosphere (H_2 + Ar). An efficient ML paste was prepared by mixing the SAO powder with a commercial optical epoxy ink. A coating method using screen-printing technique was developed. The resulting smart ML coating can transfer mechanical energy into the photo energy of light emission, which is capable of sensing the dynamic stress of substrate materials. The coated ML sensing film adhered to the metal substrate tightly enough to deform identically with the underlying metal without any peeling. The luminescence of the SAO sensing film was extremely high and enabled the monitoring of stress distribution of a metal under various stress conditions in real time using a high-speed camera.

As shown in Fig. 1, we set up a ML image system consisting of three parts: (1) a material test machine to apply a mechanical load (MTS 810, MTS Corp.), (2) a high-speed camera to capture ML images and (3) a computer to set up system software and record real-time ML images (Focuscope SV200-i, Photron Corp.).

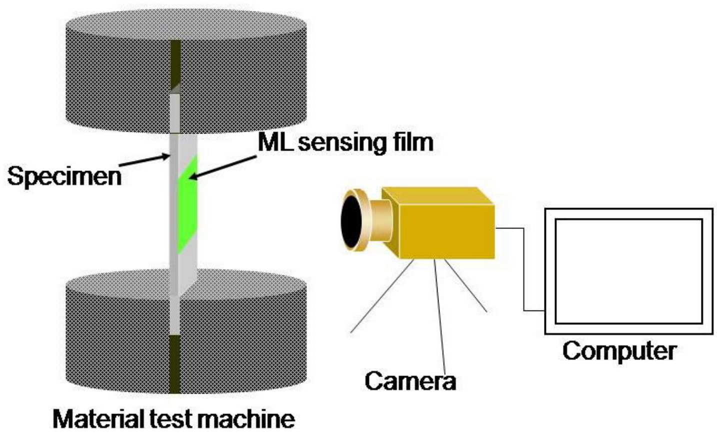

Fig. 1 ML image system.

An aluminum alloy plate (JIS A5052, 2.5% Mg) with dimensions of 225 mm by 25 mm by 3 mm was prepared as a uniaxial tension specimen. A region of target that is in the center of specimen surface about 35mm by 25mm was coated with ML sensing film. Figure 2 shows a typical coated specimen used in this uniaxial tension test. The coated specimen was set on the material test machine. The material test machine conducted the uniaxial tension test with a constant load speed of 0.5 kN/sec. Load and displacement were recorded by the material test machine automatically. Strain in gauge length was calculated assuming that it was proportional to the displacement. Simultaneously, the ML images were recorded at a frame rate of 125 fps using the high-speed camera. Experiments were carried out in a dark room at room temperature (25 ± 5 °C).

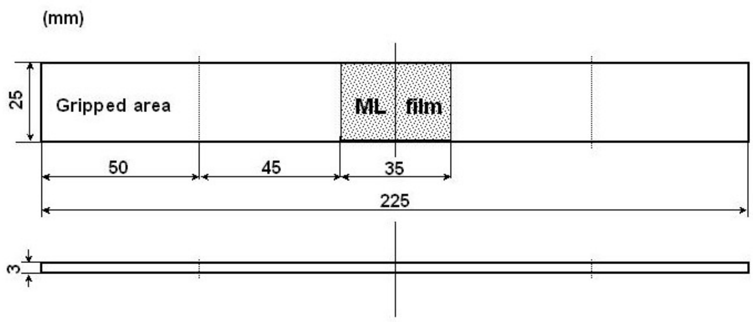

Fig. 2 Schematic drawing of specimen.

Results and Discussion

Figure 3 shows the stress-strain curve obtained from the uniaxial tension test. A dynamic strain aging occurred in the region of plastic deformation, which was manifested by distinct serrations of the stress-strain curve. Lüders band was pointed out to appear and propagate with these serrations [5].

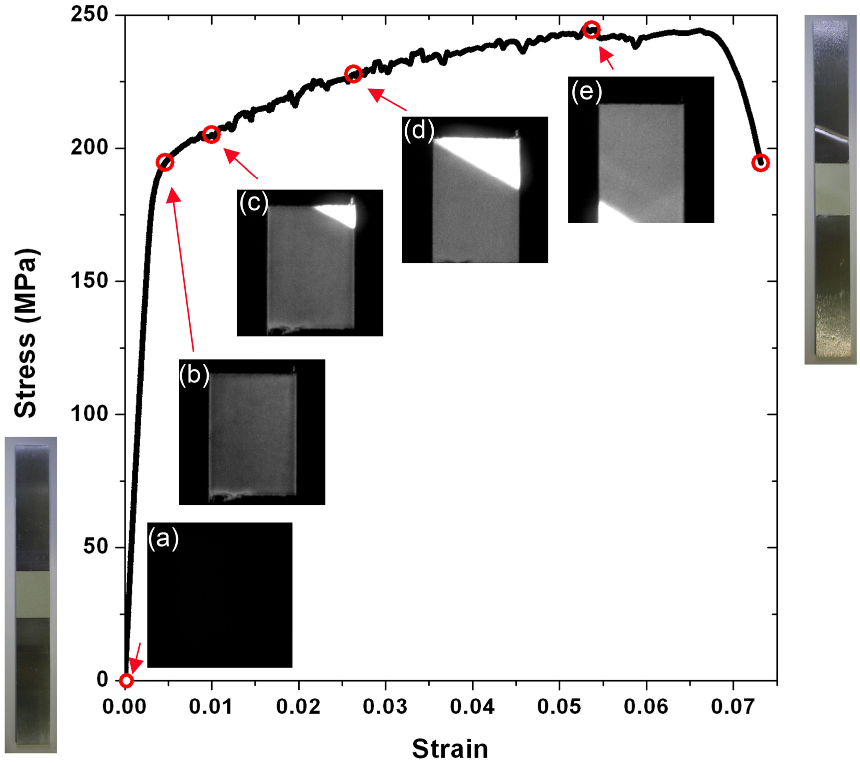

Fig. 3 Stress-strain curve and real-time ML images.

The real-time ML images during this process of elastic-plastic deformation are exhibited in Fig. 3, where images (a) to (c) correspond to each point as indicated on the stress-strain curve. In the image (a) there was no ML excited by stress because the initial load was zero. With the increasing stress there was a consequent increase of ML intensity. As shown in the image (b), ML sensing film brightened up uniformly in full area, which indicates that the whole specimen was still in elastic deformation and the distribution of stress was uniform. Afterwards, the stress in the specimen departed from linear relation to strain and the distinct serrations appeared to imply an occurrence of Lüders band. Figure 3(c) shows the ML image which was recorded at the primary stage of the serrations. An extremely strong ML can be observed at the upper right corner clearly. It indicates that an intense stress concentration was initiated from the upper shoulder of specimen, which was related to Lüders band. Then the extremely strong ML propagated at an angle along the specimen between the two shoulders as shown as Fig. 3(d) and (e).

Notice that, as shown in Fig. 4, the tangent angle θ of the leading edge of strong ML to the tensile direction y is 56°. It corresponded well with the result about Lüders band in other experimental study [6], in which the uniaxial tension test was stopped before fracture and then found that the angle of 57° between Lüders band and the tensile direction was occurring in an aluminum alloy (5.5% Mg). Such a good agreement with the characteristics of Lüders band indicates that the formation and propagation of Lüders band can be visualized in real time using ML sensing film. Significantly, we could see a dynamic stress concentration directly from light emission with the naked eyes, which is more convenient than other methods. Compared to other optical non-contact methods such as Photoelastic Coating and Digital Correlation Method, the advantages of ML technique are (1) the visual observation can be achieved in real-time easily without complex data processing and (2) it is suitable for the analyses of various stresses and capable of monitoring the intricate phenomena in plastic region.

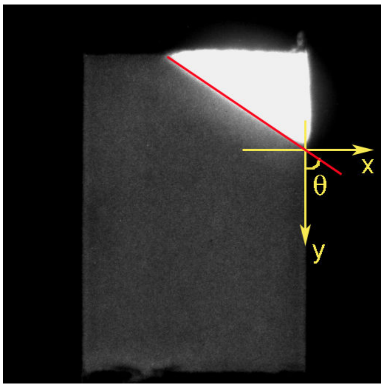

Fig. 4 Angle showing the leading edge of strong ML to the tensile direction. It is 56° and corresponds with the direction of Lüders band in uniaxial tension test.

Conclusion

In this paper we demonstrated that the formation and propagation of Lüders band could be directly displayed by ML sensing film coated on the surface of metal. Utilizing this novel technique, a real-time system for monitoring stress abnormality can be developed, and then the system can be tied up by a network to establish a comprehensive safety monitoring system for the detection of danger signs in structural objects.

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