Study on Stress Luminescence Phenomena

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1. Outline

Solid materials that emit luminescence upon fracture (e.g., sugar ice) have been known for a long time. In 1999, a material that emits strong luminescence (observable with the naked eye) under stress in elastic deformation region was reported for the first time. [1] In the following, the latter will be referred to as “stress luminescent material”. A stress luminescent material stores energy by absorbing short wavelength light, and releases the stored energy as luminescence when stress was loaded. We have conducted basic research on the luminescence properties of a stress luminescent material.

2. Results

We used strontium aluminate ($SrAl2O4:Eu^{2+}$) in the experiments. This is the first-reported and most representative stress luminescent material. Powder of strontium aluminate was mixed with liquid epoxy resin and poured into a 6 mm square mold, then the resin was cured. In this process, it was difficult to distribute the powder evenly; the powder was distributed mostly along one of six planes of the epoxy cube.

Next, we developed a device to irradiate with blue laser light (wavelength of 405 nm), apply a load, and measure intensity of luminescence due to stress. Figure 1 shows the photograph of this device.

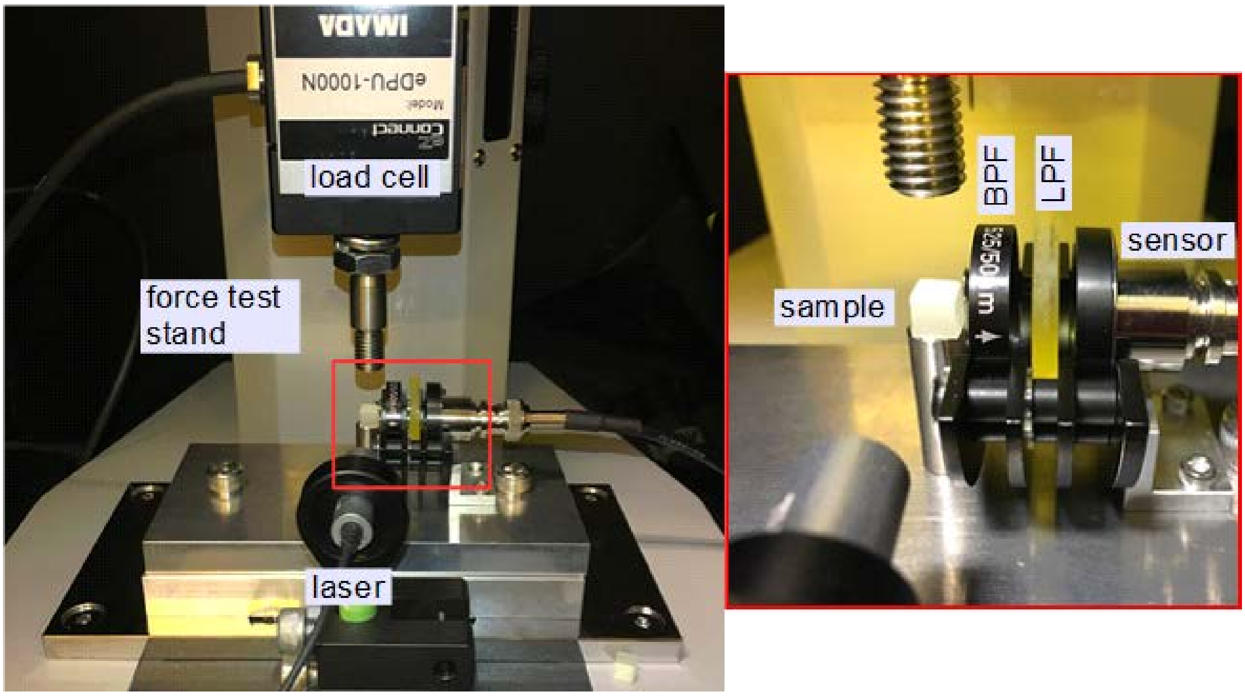

Figure 1: Device for measurement of stress luminescence. BPF: Band Pass Filter, LPF: Low Pass Filter.

A load is applied from the top of the sample, a laser beam is irradiated from the side, and luminescence is detected in the orthogonal direction. The load cell is eDPU-1000N. Two filters are placed between the sample and the optical sensor (photodiode) to cut off the laser light and detect only the luminescence. The intensity of luminescence is measured as voltage. In the measurement, the following cycle was repeated three times: The contact section is lowered at 70 mm/min to contact the sample, then holds the specified load for 0.3 s, and returns to the initial position at 300 mm/min. A dark box was also fabricated, which covers the entire apparatus including the force test stand.

First, basic measurements were carried out, and it was found that the intensity of luminescence under load was stronger when the powder-rich plane was placed on the top or bottom. This is consistent with the numerical analysis of the stress distribution by simulation. It was also found that 10 seconds of laser irradiation before the application of load was sufficient, and that the intensity of luminescence did not increase even after longer irradiation.

Next, we investigated the relationship between the retained stress and the luminescence intensity. In this experiment, the above cycle of sapplication of load was started 10 seconds after the laser beam irradiation. Figure 2 shows a graph of the time versus luminescence intensity; the peak around 2 seconds indicates the luminescence caused by the first application of load.

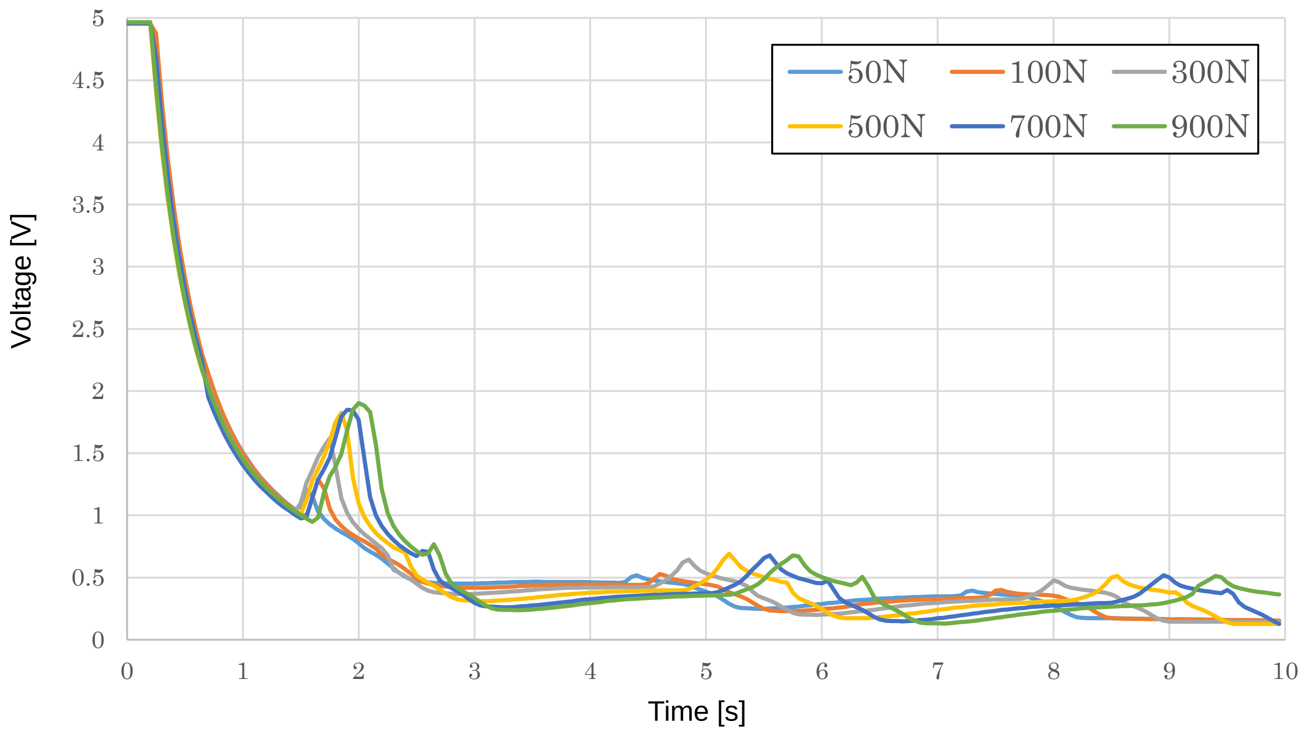

Figure 2: Time variation of intensity of stress-luminescence

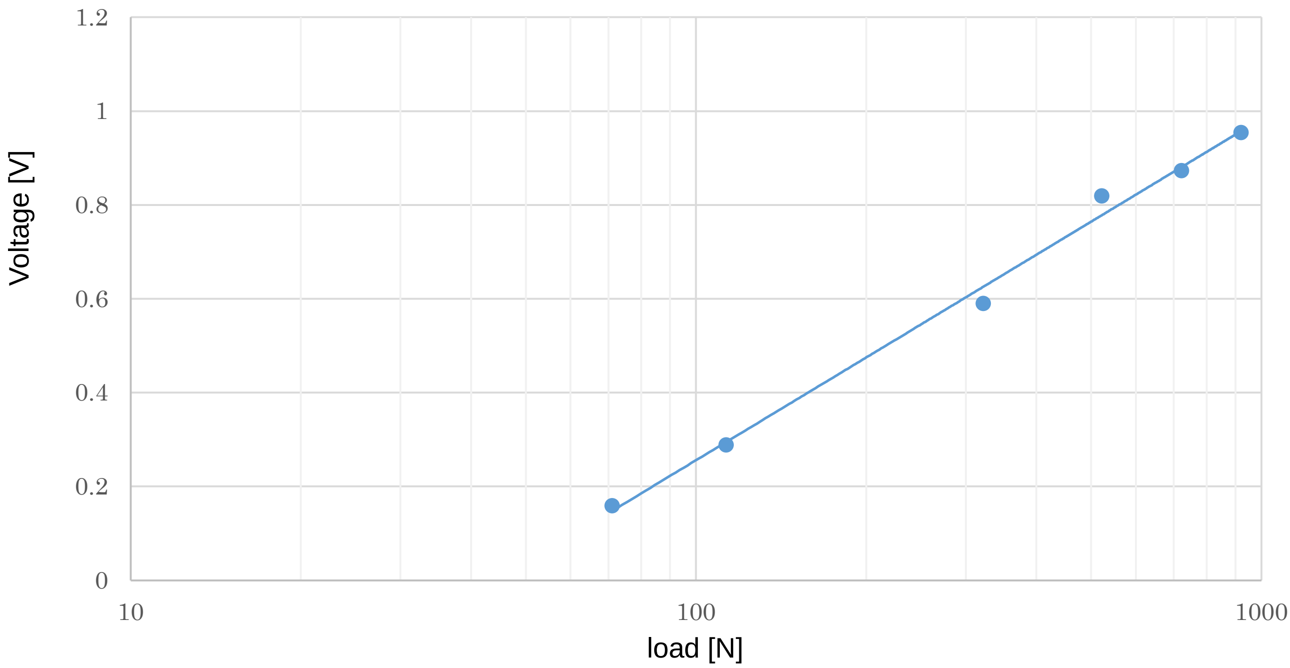

Figure 3: Relationship between luminescence intensity (difference between voltage values of the first peak and valley just before the first peak) and load

The relationship between the retained load and the luminescence intensity (first cycle) obtained from this experiment is shown in Figure 3. As shown in Figure 3, the luminescence intensity increased linearly with the logarithm of the load. Here, logarithm was taken just to fit the data; there is no theoretical background.

3. Progress with the Introduction of Force Test Stand

In this study, the EMX-1000N force test stand (IMADA Co., Ltd.) was used to apply the load. In the past, the load was applied by a self-made device using a lever (Fig. 4). However, it was difficult to obtain a sufficient load for luminescence. Thus we attached a weight to the furthest point from the fulcrum of the lever and let it fall, so that instantaneous impact force was applied, then the sample emitted luminescence. Although we could observe the luminescence with this device, there were several drawbacks, such as the inability to apply the load for a long time (control of the load in time axis was impossible), variation occurred in each trial, the load applied to the lever rod was so large that the lever wad deformed, and this device was not suitable for automation. By introducing the force test stand, it is possible to apply stress quantitatively,

Figure 4: load application device before introducing force test stand. The horizontal bar is the leverage.

and control the stress in time accurately.

4. Future development

In this experiment, it is necessary to control the illumination (light irradiation to the stress luminescent material) and measure the luminescence intensity, in addition to the application of load. Our current task is to automate all of these processes so that they can be controlled from a personal computer.

Moreover, the spectrum width of luminescence becomes narrower at low temperatures, then the wavelength of luminescence can be measured more precisely. For this reason, we would like to build a device that can apply a load at low temperatures.

5. Acknowledgements

We would like to appreciate IMADA Co., Ltd. for providing us with equipment such as Force Test Stand, Force Gauge, and Load Cell.

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References

[1] C.-N. Xu, T. Watanabe, M. Akiyama, and X.-G. Zheng, “Direct view of stress distribution in solid by mechanoluminescence,” *Appl. Phys. Lett.*, vol. 74, no. 17, p. 2414, Apr. 1999, doi: 10.1063/1.123865.