7-2 Simulated Melting and Solidification of Metal

—Extension of Mechanistic Liquid-Gas Two-Phase Flow Analysis Method—

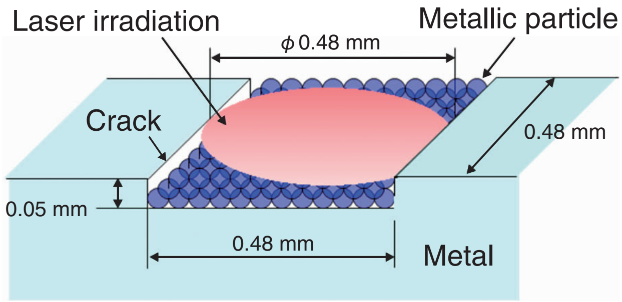

Fig.7-7 An example of crack repair using laser welding
Laser is irradiated roundly toward metallic particles from the upper part of the crack (0.48×0.48×0.05 mm), as can be seen in red. A diameter of one metallic particle is 0.04 mm. Irradiation causes the metallic particles to melt. After the laser irradiation is stopped, the temperature of the liquid metal decreases gradually. The crack is sealed when the liquid metal completely becomes hard.

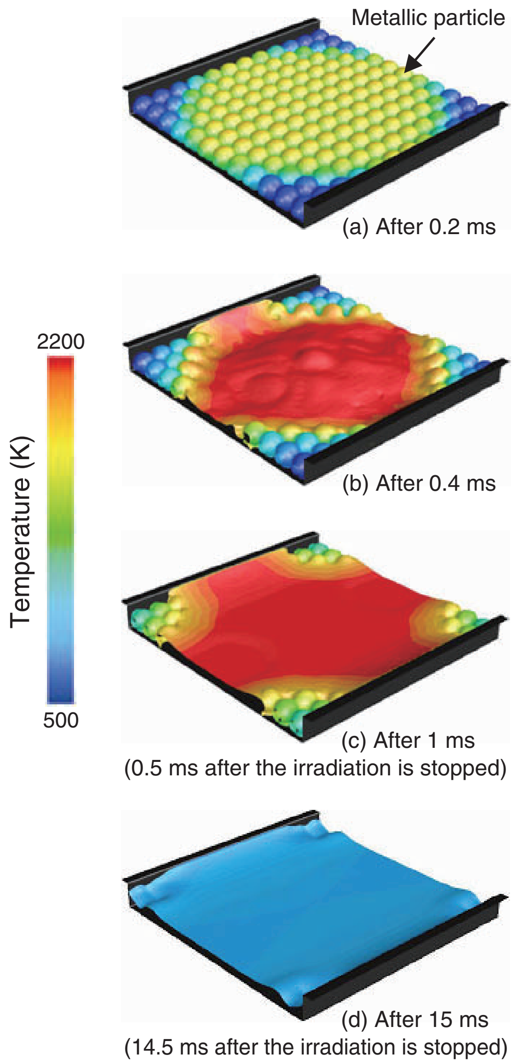

Fig.7-8 Time variations of the predicted temperature distribution in the crack
Upon laser irradiation, (a) the temperature of the metallic particles rises in the circular domain in which the laser is irradiated; (b) the metallic particles melt after the temperature reaches their melting temperature, and the laser irradiation is stopped 0.5 ms after the irradiation started; (c) the metallic particles outside the circular domain melt from the residual heat and become liquid, and the temperature falls gradually; finally, (d) solidification of the liquid metal takes place.

As a part of the development of a repair technique based on laser welding for nuclear power plants, we are developing a three-dimensional numerical analysis method to simulate the melting and solidification of metals by fiber-laser irradiation.

The outline of the laser welding process is shown in Fig.7-7. As an example, when a crack is detected on the outer surface of a pressure vessel in a nuclear power plant, minute metallic particles are first sprayed on it, and then the particles are melted by using a laser so that they seal the crack. Finally, the outer surface of that can be repaired.

In order to enable the laser welding simulation, a mechanistic liquid-gas two-phase flow analysis method which has already developed is extended for simulating the phase change between the liquid and solid phases, on the basis of the melting and solidification temperatures of the metal. In the present analysis, the laser output 160 W is irradiated roundly up to 0.5 ms to the minute metallic particles as shown in Fig.7-7.

Fig.7-8 shows the predicted temperature distributions in a crack. (a) The temperature of the metallic particles increases in the circular domain irradiated by the laser; (b) the metallic particles melt when the temperature reaches their melting temperature, and the irradiation is stopped 0.5 ms from the start; (c) the metallic particles outside the circular domain melt because of the residual heat, and the temperature decreases gradually with time; finally, (d) solidification of the melted metallic particles occurs.

The present numerical analysis is indispensable and can be used as a substitute for similar experiments. This research has received high evaluation from the related societies, such as winning a best paper award at the International Symposium on Visualization in Joining & Welding Science through Advanced Measurements and Simulation (Osaka, 2010).

Reference

Takase, K. et al., Numerical Visualization on Melting and Solidification of Micron-Sized Metallic Particles by Laser Irradiation, Yosetsu Gakkai Ronbunshu (Quarterly Journal of the Japan Welding Society), vol.29, no.3, 2011, p.43s-47s.