§6. Application of Electromagnetic Energy to Materials and Environmental Processing

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We have performed 5 years' project "Science of high temperature non-equilibrium reaction field excited by microwave". Along with this projects, we had carried out close contact with NIFS.

In this collaboration work, following two studies were conducted. 1. Microwave heating by ferro-magnetic resonance. 2. Microwave penetration distance estimation into a FeOOH/C powder mixture. They are fundamental studies for magnetic materials' processing and environmental processing, respectively.

The experimental method of the first study: Magnetic materials (Fe sheet and Fe_3O_4 powder compact) were placed in a microwave (5.8GHz) magnetic field maximum position in a TE103 cavity. Static magnetic filed was applied perpendicular to the microwave magnetic field, and gave rise the ferro-magnetic resonance heating. The control system of the external magnet was installed by the financial support of this program. FeOOH is a one of the major components of pickling of steel products. Powder mixture of FeOOH and graphite (C) was microwave heated for reduction of FeOOH. In this heating process, estimation of microwave penetration distance is important. For this purpose, permittivity of the powder mixture was measured with variation of the powder composition and the degree of powder compression.

First, the specimen was heated (to the starting temperature) by microwave magnetic field, then external static magnetic field was imposed with variation of the magnetic field intensity. The specimen temperature increased and had a maximum at the same magnetic field intensity (resonance field) on ascending and descending of the field intensity. The degree of temperature increase (temperature difference) was larger as the lower starting temperature and the degree decreased as the starting temperature is coming closer to the Curie point. And it was shown that the resonance field increased as the increase of the starting temperature.

This is interpreted considering the following equation which indicates the relationship between the external magnetic field (H^{ext}) and the resonance microwave frequency (5.8GHz, fixed):

$$\omega = \gamma \sqrt{H_r^{ext}\left(H_r^{ext} + \frac{I_s}{\mu_0}\right)}$$

where, γ and μ_0 are the gyro-magnetic constant and the magnetic permeability of vacuum. I_s is the saturation magnetic field, which decreases toward the Curie point. Therefore, as an increase of temperature toward Curie point, H^{ext} has to become larger along with the decrease in I_s.

It was not possible to heat the FeOOH powder alone, therefore graphite addition was atempted. However it was demonstrated that microwave penetration distance decreased as an increase of either graphite content or the lerger degreen of the powder compaction by compression. In order to examine the relationship quatitativly, permittivity measurement of the powder mixture was conducted. The estimated penetration distance is plotted with respect to the C (graphite) volume fraction in Fig. 1.

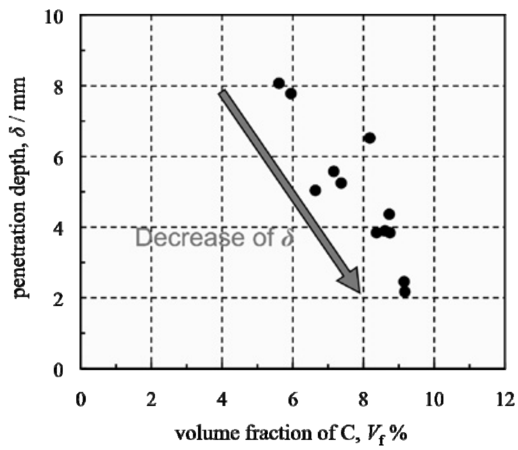

Fig. 1: Relationship between the C fraction and the estimated microwave penetration distance.

It was shown that the distance decreased as an increase of the C fraction. Above 10%, percolation occurs and the specimen became conductive.

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