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Development of non-destructive and depth-selective quantification method of sub-percent carbon contents in steel by negative muon lifetime measurement

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When a negatively charged muon stops in a material, the muon makes muon atomic orbitals around an atomic nucleus in the material. The muon orbiting its 1s orbital is absorbed into the nucleus with a mean lifetime depending on the atomic number of the nucleus (Z). This no-electron-emission process competes with the natural decay of the muon into an electron with a lifetime of 2.2 μs. The nuclear absorption rate becomes faster as Z increases. The apparent lifetime of the muons gets shorter with Z; e. g. 2.0 μs in carbon and 0.20 μs in iron. It is possible to identify the element that captured a muon by measuring the lifetime. A compound's elemental composition can be non-destructively determined by measuring the electron lifetime spectrum. We have conducted a feasibility study on the non-destructive identification of carbon contents in steel (iron-containing carbon).

The muon experiment was conducted at the D1 area of the Muon Science Establishment in the Japan Proton Accelerator Research Complex (J-PARC MUSE). The decay electrons were measured by the large-solid angle plastic scintillation counter system Kalliope for μSR. Standard steel samples with known carbon content were used for obtaining a calibration curve. A stacked steel sample consisting of three steel plates with carbon contents of 0.51%, 0.20% and 1.03 % of 0.5 mm in thickness was irradiated by three different muon beam momenta to stop muons in the middle of each layer.

The lifetime spectrum was fitted by four components; iron, carbon, air (N, O and Ar) and a long-lifetime background. The carbon contents in the stacked sample determined by the lifetime spectra agreed well with the known carbon contents in each steel layer. In summary, we successfully demonstrated the non-destructive and depth-selective determination of sub-percent carbon contents in steel by muon lifetime measurement.

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