Non-Destructive Evaluation of micro-cavity defects in steels using digital positron annihilation lifetime spectroscopy – μNDE-PALS

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The steel alloys used in power generation, petrochemical and manufacturing can often degrade over long term use, especially when subjected to the extreme conditions of temperature and stress found in many industrial processes. The creation of micro-cavities or micro-defects within the metal is a serious problem that can occur in the initial material degradation processes such as creep. However, these defects are too small to be directly quantifiable in-situ by current methods such as ultrasonic, electrical or electromagnetic non-destructive testing. The proposed positron annihilation technique has a strong potential to address this measurement challenge, being able to detect microscopic voids in metals at very low concentrations, and provide a measurement of the size distribution and density of micro-cavities. It is anticipated that positron annihilation will be able to provide an early warning of steel alloy degradation: the objective of this proposal is to implement the experimental techniques to demonstrate this in the lab, and then design and develop the instrumentation required for in-situ measurements.

Positrons can be obtained from a small and relatively safe radioisotope source (eg sodium-22) that can be applied to the surface of a sample in the form of a small patch The positrons will diffuse through the metal sample where they have a high probability of being trapped in any cavities as small as vacancies. When a positron is trapped, it will after some time combine with a free electron and decay, to produce two gamma rays of a unique energy. The lifetime of the trapped positron increases with defect size, and the number of entrapments increases with number of defects. By detecting the initial decay that gives rise to the positron emission, and correlating it with the distinctive gamma ray pair emitted, one can obtain the positron lifetime and with enough events a meaningful statistical measurement of defect size and defect density.

Positron annihilation lifetime spectroscopy (PALS) is well known as a sensitive lab based technique for scientific studies of vacancies and defects in materials. Despite its use in academic research, it has not crossed into industrial applications. This research project will develop the experimental method and the data analysis required to make possible the leap from specialised lab based measurement to a viable, portable measurement technique for use on industrial samples in situ. This is possible because of recent technical developments in the electronics used to perform the necessary timing measurements, improving the resolution and stability of the measurement. The project will set the foundation for the development of a new digital positron lifetime spectroscopy package for use in science and industry, giving the UK a global lead in developing a new NDE technique that will provide both industrial benefits and generate new scientific knowledge.

The main challenge in this research is that it is necessary to be able to make measurement in-situ, which prevents the adoption of the conventional positron annihilation lifetime spectrometer experimental geometry. The conventional approach requires two small samples to be cut out from the component under study and placed either side of the radioactive source, and with detectors either side of this arrangement. This is clearly not feasible for in-situ measurements on industrial systems. The project is largely targeted at meeting this challenge. Initially, the project will involve the implementation of a new digital positron lifetime spectrometer in the lab at Warwick. This will be characterised and then, by studying deliberately progressively damaged steel samples supplied by industry, the needed data analysis methodology will be determined. The next step will be the main challenge: to develop the novel “single sided” geometry required for in-situ measurements of steels in industrial settings.