Insights into how the machining process and related surface defects affect the magnetic performance of the soft magnetic materials

Prof. Zhirong Liao, University of Nottingham, UK

Abstract

We are entering an era of "re-electrification," seeking high-power density electrical machines with minimal resource use. Significant performance gains in electrical machines have been achieved through new soft magnetic materials development. To achieve high machine efficiencies, it is desirable for these soft magnetic materials to be able to achieve a high saturation magnetisation whilst incurring minimal core losses. However, despite precise manufacturing processes, including the shaping/cutting of magnetic materials, the induced manufacturing damage still deteriorates their magnetic properties hence these materials could not achieve their designed performance. Currently the mechanisms by which machining influences this deterioration are less understood.

University of Nottingham Rolls-Royce UTC team has long track record on the machining and surface integrity research. To reveal the how machining affects the surface integrity and magnetic properties of soft magnetic materials, we studied the magnetic deterioration after four machining methods: Abrasive Waterjet, Wire Electric Discharge Machining, Pulsed Laser, and Continuous Wave Laser. We employed a state-of-the-art magnetic domain imaging method to study the mechanisms causing magnetic deterioration. For the first time, we made the initial quantitative evaluations on how the magnetic domains are affected in the superficial layer that is the result of machining.

Further, to understand the underlying mechanism of how the micromagnetic behaviour is affected by mechanical interference, we examined the impact of sub-micron deformations at opposing strain rates on the micromagnetic behaviour of soft magnetic materials. Using a diamond probe to indent within a single grain of polycrystalline material at different velocities, we induced quasi-static and dynamic mechanical loading. Our analysis, employing magnetic force microscopy, transmission Kikuchi diffraction, and scanning transmission electron microscopy with a pixelated detector, reveals that magnetic texture disturbances rely on the time-dependent dislocation dynamics of the Fe-BCC material. These findings highlight the importance of considering even ultra-small loads in the manufacturing of next-generation electric machines, as they can significantly affect magnetic texture and performance.

Biography

Prof. Zhirong Liao finished his PhD study at Harbin Institute of Technology, China and joined the Rolls-Royce UTC in Manufacturing and On-Wing Technology, University of Nottingham as a Research Fellow since 2016. He was awarded a Nottingham Research Fellowship and started his independent academic career at the University of Nottingham in 2019, and was promoted to Associate Professor in 2022 and to professor in 2025. He is also a member of the Propulsion Futures Beacon of Excellence at the University of Nottingham. His research area mainly focuses on conventional and nonconventional manufacturing technologies with conscious of materials science. He is an Associate Member of the International Academy for Production Engineering (CIRP), Chairman of CIRP UK, Member of Institution of Mechanical Engineers (IMechE), Member of the International Society for Nanomanufacturing (ISNM). Prof. Zhirong Liao is also the Associate Editor of the International Journal of Machine Tools and Manufacture, Senior Editor of Journal of Materials Processing Technology. Prof. Zhirong Liao has closely work with industry, e.g., Rolls-Royce, SECO Tools, Sandvik, Stryker, Smith-Nephew, etc., to develop advanced manufacturing technologies to solve the industrial needs from different sectors such as aerospace and biomedical.