Experimental characterisation of heat flux during industrial quenching processes for accurate estimation of the heat transfer coefficient

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ABSTRACT

High strength steels used in landing gears in aircraft often go through a quench and temper (Q&T) heat treatment cycle that results in the required mechanical properties. Accurate estimation of the heat transfer during the cooling stage (i.e. quench) is of critical importance for reliable prediction of the distortion that could occur after quenching. While standard laboratory test methods are useful to compare the cooling performance of different quenchants; however, such tests hardly represent the actual conditions experienced in industry and often introduce large uncertainties in the predicted severity of the distortion. Specifically, the complex geometry of the component, the positioning of the heating furnace with respect to the quench bath, etc. are illustrative examples of the sources of differences in the heat extraction dynamic on real-life components from laboratory results since small probe diameters tend to produce film boiling caused by a higher heat flux density, which may not be the case for industrialized components. Furthermore, widely accepted quenching intensity factors based on standard testing (e.g., Grossman number) are unable to represent the physical phenomena of the quenching process.

This study presents the results of an experimental characterization of a hybrid quenching process (air transfer + immersion in low viscosity oil) representing the non-uniform conditions in industry. In the examined case study, the component is transferred from the austenitizing furnace to the quench tank. Such a process requirement produces non-homogenous conditions in the form of temperature gradients within the component before immersion that becomes more critical depending on the ruling section.

To characterize the cooling process, special quench probes were designed with multiple near-surface thermocouples capable of identifying the local boundary conditions on multiple surfaces and locations on the quench bath while sizing of the quench probe ensured a one-dimensional heat flux at the sensor’s location. Recorded thermal history was then converted into analytical cooling curves build up through piecewise polynomial interpolation based on characteristic points of mathematical and physical significance. The heterogeneity of the quenching facilities can then be assessed by a systematic review of the cooling characteristics and physics of the multiple cooling regimes. Based on such realistic characterization, it is possible to correlate the geometry and position of the quench probe to the phenomena occurring on large steel components producing a realistic database of industrial facilities.

Keywords: quenching, hybrid quenching, cooling regimes modelling, heat transfer coefficient