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A new test method to characterize heat transfer coefficient distribution in industrial gas quenching systems

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Gas quenching is drawing more attention of the heat treat industry recently. The heat transfer coefficient (HTC) could be up to 2000 $W/m^2{}^\circ C$ when using high pressure and high velocity nitrogen, helium, or the mixture [1]. The HTC of water quench is between 3000 – 4000 $W/m^2{}^\circ C$ [1]. Under lower HTC condition, the workpiece might have less distortion and residual stress after gas quenching [2]. Compared to water, polymer and oil quenching, gas quenching is environmental friendly, and the surface of the part is clean after quenching [1].

Experimental measurement on HTC distribution in the furnace becomes necessary to validate the modelling simulation. Sugianto [6] used nine thermocouples to measure the thermal history of a helical gear and predicted the outside HTCs. Cosentino et al. [5] compared the cooling curves of experiment and simulation of CMSX-10 superalloy during gas quenching. Liščić quench probe [7] and CHTE quench probe [8] are the standard probes embedded with thermocouples to measure the cooling rate and HTC. The cooling curves can be directly measured by thermocouples or quench probes, but related software package or database is needed to provide the corresponding HTC.

AISI 4340 cylindrical specimens were used. The specimen has a diameter of 12.5mm and a height of 100mm as shown in Figure 1 (a).

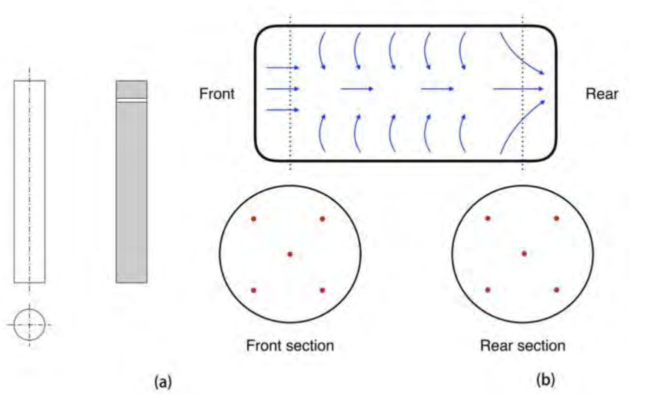

Figure 1 (a) AISI 4340 specimen sketch, (b) The horizontal gas flow pattern and the locations of specimens in a 0.2 MPa nitrogen gas quench furnace. Dots represent the specimens.

Figure 1 (b) presents the horizontal gas flow pattern of a 0.2 MPa nitrogen gas quench furnace. Five specimens are located at the front section and five specimens at the rear section. Dummy thermal load was used in the experiment to evaluate the HTC distribution in practical production. It took 2h to heat the specimen and the dummy thermal load up to 850 °C in the vacuum furnace. The holding time is 30min before gas quenching.

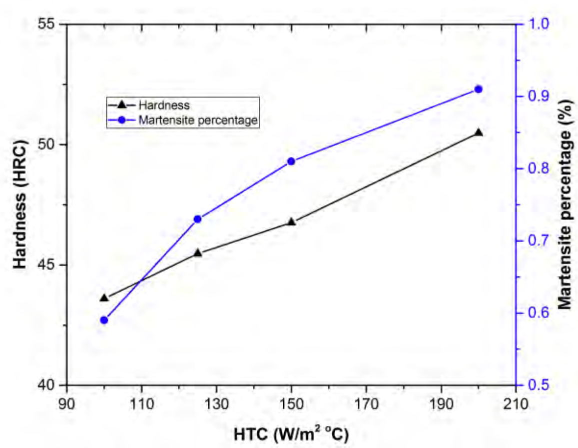

Figure 2 The simulated relation between outside HTC and core hardness of AISI 4340 specimens after gas quenching.

Figure 2 presents the the simulated relation between outside HTC and core hardness of AISI 4340 specimens after gas quenching. The blue line represents the martensite percentage and the black line represents the corresponding hardness. With the increasing of the HTC, the core martensite percentage and hardness increases. This relation can be used to evaluate the HTC distribution in 0.2 MPa nitrogen gas quench furnace.

After the specimens were gas quenched in the 0.2MPa nitrogen furnace, the core hardness of AISI 4340 specimens measured from 44 HRC to 49.5 HRC. The hardness distribution at the front and rear side were shown in Figure 3 (a) and (b). The average hardness of the front side was higher than the rear side. The gas pressure and velocity can be assumed as constant, but the temperature of gas is higher at the rear side compared the the front size. The gas was heated by the workpiece and the fixture, which leads to lower HTC at the rear side. The lowest hardness appears at the lower left corner of the rear side. The workpiece at this location may not get the required microstructure and mechanical properties even when workpieces at other locations achieve the requirement.

Using the simulated relation in Figure 2, the HTC can be pinpointed by only measuring the core hardness of AISI 4340 specimens. For example, the hardness at the core of the specimen is 46.8 HRC after gas quenching. The corresponding HTC is 150 $W/m^2{}^\circ C$, which is the outside HTC at this position in the furnace. The HTC distribution at the front and rear side were presented in Figure 3 (c) and (d). HTC distribution in gas quenching furnace was successfully measured.

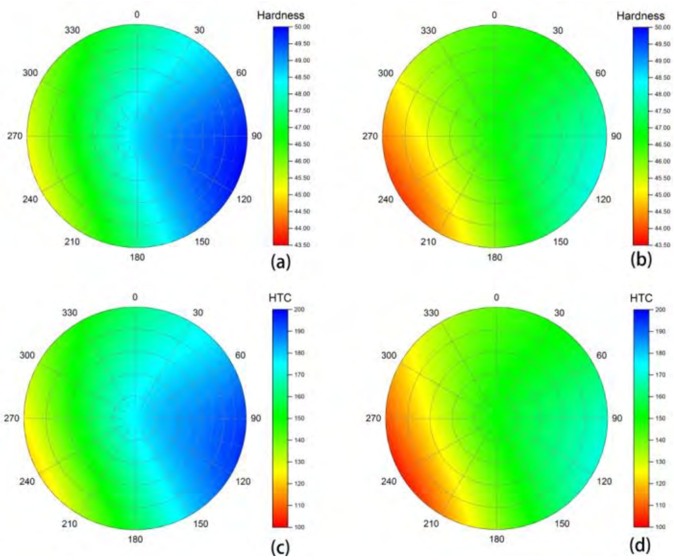

Figure 3 (a) Hardness distribution at the front side, (b) Hardness distribution at the rear side, (c) HTC distribution at the front side, (d) HTC distribution at the rear side.

It should be noted that even for the same steel grade, chemical composition variation and initial microstructure would strongly affect the microstructure and mechanical properties under the same quenching condition.

References:

[1] J. Dossett, G.E. Totten, ASM Handbook, Volume 4A, Steel Heat Treating Fundamentals and Processes, ASM International, 2013.

[2] V. Heuer, K. Löser, D.R. Faron, D. Bolton, Low distortion heat treatment of transmission components, in: 2010.

[3] N. Lior, The cooling process in gas quenching, Journal of Materials Processing Technology. 155-156 (2004) 1881–1888. doi:10.1016/j.jmatprotec.2004.04.279.

[4] I. Elkatatny, Numerical analysis and experimental validation of high pressure gas quenching, International Journal of Thermal Sciences. 42 (2003) 417–423. doi:10.1016/S1290-0729(02)00042-X.

[5] F. Cosentino, N. Warnken, J.-C. Gebelin, R.C. Reed, Numerical and experimental study of post-heat treatment gas quenching and its impact on microstructure and creep in CMSX-10 superalloy, Journal of Materials Processing Technology. 213 (2013) 2350–2360. doi:10.1016/j.jmatprotec.2013.06.025.

[6] A. Sugianto, M. Narazaki, M. Kogawara, A. Shirayori, S.-Y. Kim, S. Kubota, Numerical simulation and experimental verification of carburizing-quenching process of SCr420H steel helical gear, Journal of Materials Processing Technology. 209 (2009) 3597–3609. doi:10.1016/j.jmatprotec.2008.08.017.

[7] B. Liščić, Critical Heat-Flux Densities, Quenching Intensity and Heat Extraction Dynamics During Quenching in Vaporizable Liquids, (2003) 161.

[8] M. Maniruzzaman, J.C. Chaves, C. McGee, S. Ma, R.D. Sisson, CHTE quench probe system - A new quenchant characterization system, in: 2002: pp. 619–625.

[9] Y. Lu, Critical Heat Transfer Coefficient Test Method for Gas Quenching Steel Hardenability, (2015).

[10] B. Liscic, H.M. Tensi, L.C.F. Canale, G.E. Totten, Quenching Theory and Technology, Second Edition, CRC Press, 2011.

[11] T.L. Bergman, F.P. Incropera, A.S. Lavine, Fundamentals of heat and mass transfer, John Wiley & Sons, 2011.

[12] B.L. Ferguson, Z. Li, A.M. Freborg, Modeling heat treatment of steel parts, Computational Materials Science. 34 (2005) 274–281. doi:10.1016/j.commatsci.2005.02.005.

[13] A. Freborg, B. Ferguson, Z. Li, Predicting Distortion and Residual Stress in a Vacuum Carburized and Gas Quenched Steel Coupon, Proceedings From the 6th International Quenching and Control of Distortion Conference. (2012) 22–33.