Applied Acoustics 129 (2018) 335–345

Contents lists available at ScienceDirect

Applied Acoustics

journal homepage: www.elsevier.com/locate/apacoust

Feasibility study of monitoring the steel quenching process using acoustic emission technology

Bor Mojškerc, Tomaž Kek, Janez Grum *

University of Ljubljana, Faculty of Mechanical Engineering, Aškerčeva 6, 1000 Ljubljana, Slovenia

ARTICLE INFO

Article history:
Received 19 May 2017
Received in revised form 10 August 2017
Accepted 16 August 2017
Available online 20 August 2017

Keywords:
Non-destructive testing
Underwater acoustics
Acoustic emission
Signal analysis
Quenching

ABSTRACT

This paper presents a non-destructive method of monitoring and evaluating the steel immersion quenching process using AE (acoustic emission) technology. The immersion quenching process is used in the heat treatment industry in order to harden metals and to achieve the required mechanical properties. During quenching, several stages of heat transfer occur, each stage with its own thermo-fluid dynamic phenomena and an AE signature. In order to ensure high quality of quenched workpieces and repeatability of the production process, a method of quality control is required. Several cylindrical steel specimens are quenched in water or in aqueous polymer solutions with 10% or 20% concentration. AE signature of the quenching process is recorded using a piezoelectric hydrophone. AE signal characteristics are considered in correlation with video recordings. After quenching, mechanical properties of specimens such as hardness and tensile strength are determined. A correlation between AE signal characteristics and mechanical properties is established. Results show a non-linear correlation between AE signal peak amplitude, signal RMS (root mean square) value and mechanical properties, and a nearly linear correlation between AE signal duration or number of signal packets and mechanical properties. The total elastic energy correlation is omitted due to high sample standard deviations. Based on the results, it is concluded that AE is a reasonable way of monitoring the steel quenching process and mechanical properties of quenched workpieces.

© 2017 Elsevier Ltd. All rights reserved.

1. Introduction

The immersion quenching process is used in the steel heat treatment industry in order to increase mechanical properties of workpieces, such as hardness, yield strength and tensile strength. A workpiece is heated to a temperature of 800–900 °C for a part size or purpose dependent time period and then rapidly cooled. During heating, an austenitic phase transformation takes place, resulting in the required microstructure for quench-hardening. If the workpiece then reaches a sufficiently high cooling rate, a diffusionless martensitic phase transformation occurs, giving the workpiece high hardness and strength but also brittleness.

The immersion quenching process can be influenced by a variety of factors, one of the most important being the quenchant. Quenchants such as water, aqueous brine solutions, aqueous polymer solutions and oils are most commonly used in the heat treatment industry. Other quenching conditions include shape, size, surface roughness and thermo-physical properties of the workpiece, bath concentration, temperature and agitation.

During immersion quenching, stages of heat transfer such as the initial contact, vapour blanket stage, transition stage, nucleate boiling stage and convection stage are present, each stage with its own wetting kinematics, thermo-fluid dynamic phenomena [1,2] and an acoustic signature. These phenomena influence the uniformity, distortion, cracking and residual stresses of the workpieces. In order to ensure better process repeatability and workpiece quality, stages of heat transfer should be monitored, evaluated and correlated with mechanical properties, preferably in a non-destructive way.

Several authors investigated heat transfer acoustic phenomena. Bessho and Nishihara [3] investigated bubble AE (acoustic emission) and dynamics in correlation with boiling heat transfer. Kudo et al. [4] applied the pattern recognition technique to the detection of boiling at the surface of a stainless steel heater. Aberle et al. [5] experimentally determined the acoustic transfer function of a reactor core and demonstrated the detectability of localized boiling in sodium-cooled breeder reactors. Narazaki et al. [6] measured the sound pressure level during quenching of a silver specimen and established a correlation with specimen temperature and stages

* Corresponding author.
E-mail addresses: bor.mojskerc@fs.uni-lj.si (B. Mojškerc), tomaz.kek@fs.uni-lj.si (T. Kek), janez.grum@fs.uni-lj.si (J. Grum).

http://dx.doi.org/10.1016/j.apacoust.2017.08.013
0003-682X/© 2017 Elsevier Ltd. All rights reserved.

of heat transfer. Ravnik and Grum [7,8] measured the sound pressure changes during the quenching of steel specimens, discriminated heat transfer stages based on the sound pressure level and analysed AE phenomena during quenching. Prezelj and Čudina [9] recorded sound pressure signals generated by quenching a steel specimen in water or aqueous polymer solutions. Okumiya et al. [10,11] discriminated stages of heat transfer in quenching, based on the FFT (fast Fourier transform) algorithm. Kichigin et al. [12] used an acoustic method to monitor boiling conditions in quenching and to determine the duration of the heat treatment. Kobasko et al. [13,14] used a noise control system to confirm the absence of the vapour blanket heat transfer stage when quenching specimens in cold water or aqueous brine solutions with a specific concentration. Moskalenko et al. [15] developed an acoustical noise analysis system for the control of cooling capacity of quenchants. Nikhare et al. [16] investigated quenching of tool steel and demonstrated the correlation between the acoustic signal and specimen size or its temperature. Erich et al. [17] studied the correlation between acoustic signals and mechanical properties during quenching of cold drawn steel. Stoebener and Goch [18] measured the wetting state of cylindrical workpieces during immersion cooling based on the pulse-echo ultrasonic method. Other authors [19–21] used the pulse-echo ultrasonic technique to evaluate specimen microstructure and mechanical properties after quenching, based on ultrasonic velocity and sound attenuation coefficient in the quenched material.

Previous work of researchers focused mainly on describing the basic acoustic signature of the quenching process using convectional sound recording techniques. In this paper, use of AE technique as a method of monitoring the steel immersion quenching process is discussed and an experimental correlation between the AE signature and mechanical properties after quenching is established. The proposed method could be used as quality control in the quenching heat treatment industry.

2. Materials and methods

2.1. Specimens characterization and heat treatment

An alloyed carbon steel for quenching and tempering, 25CrMo4 (1.7218), was used for the experiments. This type of steel is commonly used in components for aerospace, automotive and machine industry, such as engine mounts, axles, turbine components, hydraulic or machine tools, welded tubing, chains, forgings, etc. It contains 0.25 wt% of carbon and alloying elements such as Mn, Cr and Mo with wt% of 0.71, 1.03 and 0.21, respectively. The material was supplied in the QT (quenched and tempered) condition in the shape of round bars with dimensions of $\phi 25 \times 680$ mm. Mechanical properties of the material are presented in Table 1.

Specimens for quenching were machined with turning on an automated lathe. The steel bar diameter was machined to $\phi 24$ mm in order to achieve a uniform surface roughness of $R_a = 3.6\ \mu m$ across all specimens. The machined bars were then cut to size to produce the final specimen dimensions of $\phi 24 \times 100$ mm. Altogether, 15 specimens were made. Two $\phi 4$ mm holes were drilled on the upper sides of each specimen in order to ease furnace handling and to properly position the specimen during quenching.

The experimental design and specimen designation are presented in Table 2. The specimens were quenched in water or in aqueous polymer solutions with concentration of 10% or 20% and a bath temperature of 20 °C. A water-miscible PAG (polyalkylene glycol) polymer quenchant, Aquatensid BW, was used. Each quenching condition was replicated five times in order to ensure a sufficient number of specimens for testing of mechanical properties. AE was only measured in the first four replication sets and not in the video recording set.

Each specimen was heated inside a furnace with an inert atmosphere of argon gas in order to prevent surface oxidation and to maintain the surface roughness level, both of which can significantly influence the course of the quenching process. The austenitizing temperature was set to 880 °C according to heat treatment recommendations for this type of steel. The austenitizing time was set to 30 min in order to achieve a full austenitic microstructure prior to quenching. This way, a sufficient martensitic phase transformation can occur during quenching, giving the specimen the desired strength and hardness. After 30 min, each specimen was carefully removed from the furnace with a custom made wire handle and quickly transferred to the quenching bath. The wire handle was heated beforehand in effort to reduce conductive heat transfer between the specimen and the handle.

2.2. Experimental AE system setup and signal analysis

A glass container with external dimensions of $330 \times 330 \times 240$ mm and a thickness of 5 mm was used to contain the quenchant. In effort to reduce echoes, acoustic foam was positioned inside the container in a cylindrical shape around the quenched specimen. The experimental system setup for monitoring the steel quenching process using AE is presented in Fig. 1. During quenching, rapid release of energy from localized sources generates transient elastic waves, which can be detected using a hydrophone. For this experiment, type 8103 Brüel & Kjær hydrophone was used. Type 8103 is a small size acoustic sensor with dimensions of $\phi 9.5 \times 50$ mm. It contains a high sensitivity piezoelectric transducer for acoustic measurements in the frequency range from 0.1 Hz to 180 kHz, with a receiving sensitivity of -211 dB re 1 $V \mu Pa^{-1}$. The hydrophone was connected to an AEP4 preamplifier via a double shielded low noise integral cable. The preamplifier was set to a gain of 40 dB and connected to the Vallen Systeme AMSY-5 AE measurement system. The AE Suite software was used for online monitoring of AE measurements.

Most industrial AE tests are performed in the frequency range from 20 to 1200 kHz [22]. Frequencies below 30 kHz were expected during the steel quenching process [7,8]. The sampling rate of the transient elastic waves recording was set to 625 kHz with a sampling period of 1.6 μs. Transient waveform data was recorded in continuous AE mode and divided into AE signal packets, each packet with a length of 104857.6 μs. A custom made high-pass filter with a cutoff frequency of 1.6 kHz was used. The peak amplitude threshold for detection of AE signals was set to 26.5 dB.

In addition to AE measurements, the steel quenching process was recorded using a Sony DSC-WX220 digital camera with a frame rate of 60 frames per second and a resolution of

Table 1
Mechanical properties of 25CrMo4 steel (1.7218) in QT condition.

Hardness [HV]	Tensile strength [MPa]	Yield strength [MPa]	Elongation after fracture [%]	Reduction of area [%]	Modulus of elasticity [GPa]	Density [kgm^{-3}]
276	903	828	21.6	65.2	210	7860

Download English Version:

https://daneshyari.com/en/article/5010767

Download Persian Version:

https://daneshyari.com/article/5010767

Daneshyari.com