10.21611/qirt.2022.3041
16th Quantitative InfraRed Thermography Conference

Advances in Hardness Depth Profiling by Photothermal Radiometry of Steel Mechanical Components in Vehicles

by R. Li Voti* G. Leahu*, M. Deni**, G. Guerrini**, P. Moro*** and R. Biason***,

* Department SBAI, Sapienza University of Rome, Via A.Scarpa 16, 00161 Rome, Italy.
** MDM Metrosoft Laboratorio Metrologico, Via IV Novembre 22 - 40061 Minerbio, Italy
*** Bifrangi, Via A.Manzoni 14 - 36065 Mussolente, Vicenza, Italy

Abstract

A novel device based on photothermal radiometry is here developed and validated for the NDE & Testing of steels. The use of such an instrument from one side strongly reduces the measurement time of the standard hardness and other mechanical tests, from the other side allows to perform quick nondestructive and noninvasive automatized measurements. A detailed description of the methodology for the reconstruction of the hardness depth profile will be given in the presentation. The results on wheel hubs show the relevant impact in the field of quality control of mechanical components for automotive industry.

1. Introduction

Quality control of the performance of mechanical components subjected to hardness processing is a topic of fundamental importance in the field of automotive. The lack of hardening, may cause failures with serious repercussions. The industry and the companies responsible for the hardening processes as well as for the quality control of the mechanical components are continuously seeking for improvements in the standard destructive tests performed by Vicker or Brinell durometers.

In this paper a new methodology based on photothermal radiometry (PTR) is introduced for NDT of steel mechanical components for vehicles [1-3]. Such a methodology is useful for a fast nondestructive and noninvasive inspection of the hardness depth profiles, of the effective hardening depth, of possible lack of hardening. We describe here a PTR compact system (RHADEPS), fully automatized with robotic arms to measure the hardness depth profile of S53CG steel samples subjected to induction hardening.

For the calibration of the system we have applied photothermal deflection technique to measure the thermal diffusivity of the S53CG steel, so to determine the hardness/thermal diffusivity anti-correlation curve [1]. A thermal diffusivity changes from 13 x 10^{-6} m^2/s (unhardened) to 9 x 10^{-6} m^2/s (at 300 HV) has been found. Experimental results show accurate hardness profile reconstructions in comparison with the hardness measurements by standard Vicker test.

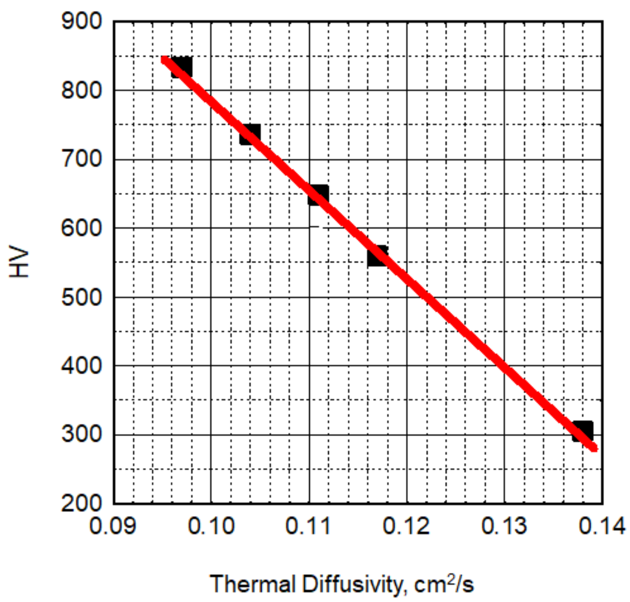

***Fig. 1**: Correlation between thermal diffusivity and hardness in S53CG steel subjected to induction hardening*

2. New approach for NDE & Testing

In this paper we introduce a new light and compact PTR device for a high accuracy measurements of the hardness depth profile of wheel hubs based on photothemal depth profiling [3-6].

The hardware of this system has been improved, made more compact, and integrated with mechanized and robotic arms for industrial needs (see figure 2)

In particular the system uses a powerful IR laser working at 9W, modulated at a frequency ranging from 0.1Hz to 1kHz so to generate the thermal waves with a penetration depth from microns to millimetres. These waves penetrate the surface hardened steel layer and are backscattered by the inner interface with the untreated steel. The effects of thermal wave reflection are revealed by a Peltier cooled infrared sensor working in the range MIR 3-5 μm [6].

The software of the system has been developed so to retrieve the diffusivity/hardness depth profile by applying a machine learning approach based on Singular Value Decomposition tool to solve the severely ill posed inverse problem of the photothermal depth profiling, The SVD is usually truncated *ad hoc* so to limit the effect of the noise with some minimal loss of spatial resolution. This innovative software has been implemented in Labview, so to be run in real time with the data acquisition.

3. Experimental Results

Preliminary results on S53CG induction hardened steel wheel hubs show accurate hardness profile reconstructions in comparison with the hardness measurements by standard Vicker test. In Figure 2 for example the hardness depth profile determined nondestructively, ex-ante, by using the PTR (red and violet lines) is compared with the one measured destructively, ex-post, by Vicker test (back squares). The excellent agreement between PTR and Vicker measurements has been confirmed on the whole set of samples, where the accuracy in the estimate of the effective hardened depth of about 3 mm is usually of about 0.25 mm.

In synthesis we have here established the fundamental role of photothermal radiometry as non-destructive technique applicable to the determination of the hardness depth profiles of wheel hubs. Such a system is very flexible and fully automatized, allowing to measure the hardness depth profiling of mechanical components with arbitrary shapes.

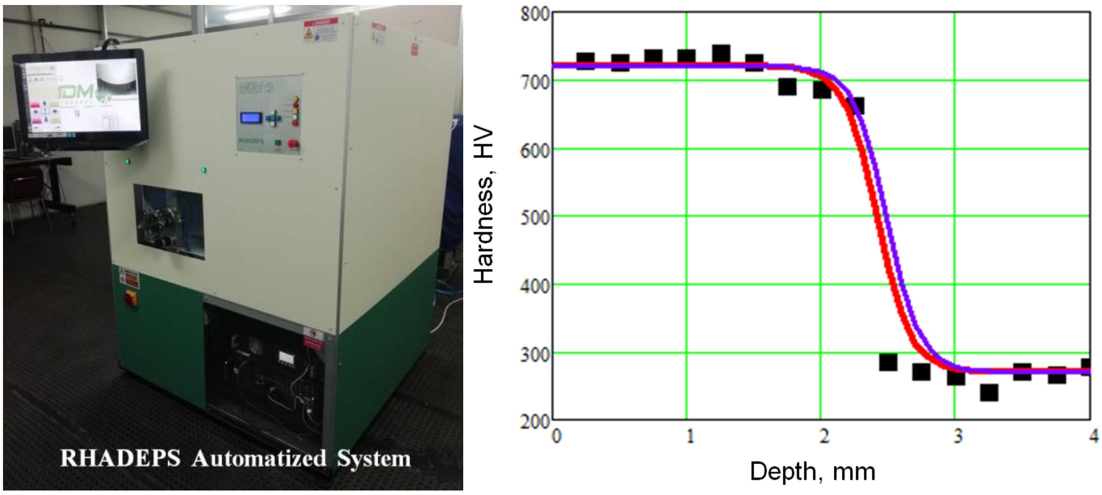

***Fig. 2**: (a) RHADEPS Automatized System for the PTR measurement of the hardness depth profiles in industrial environment; (b) comparison between the new PTR nondestructive test (red and violet lines stand for minimum and maximum hardness profile) and standard Vicker test (black symbols)*

REFERENCES

[1] H. G. Walther, D. Fournier, J. C. Krapez, M. Luukkala, B. Schmitz, C. Sibilia, H. Stamm, and J. Thoen, Analytical Sciences, **17**, s165 (2001).
[2] C. Wang, A. Mandelis, H. Qu, and Z. Chen, J. Appl. Phys. **103**, 043510 (2008).
[3] Glorieux, R. Li Voti, J.Thoen, M.Bertolotti and C.Sibilia, J. Appl. Phys. **85** (10), 7059 (1999).
[4] Glorieux, R.Li Voti, J.Thoen, M.Bertolotti and C.Sibilia, Inverse Problems **15** (5), 1149 (1999).
[5] R. Li Voti, et al. Thermal wave physics, Journal of Optoelectronics and Advanced Materials **3**, 779-816 (2001).
[6] R. Li Voti, G. Leahu and C. Sibilia, A New Device for High-Accuracy Measurements of the Hardness Depth Profile in Steels, in Proc. of 4th Int.Conference in Software Engineering for Defence Applications SEDA 2015 in Advances in Intelligent Systems and Computing, **422,** 239 (2016).