Coupling thermal and kinematic full field measurement for the mechanical characterization of metals at high temperature

Rébecca Bonnaire, Benjamin Verdeil, Rémi Gilblas, Yannick Le Maoult, Thierry Sentenac

Coupling thermal and kinematic full field measurement for the mechanical characterization of metals at high temperature

R. Bonnaire, B. Verdeil, R. Gilblas, Y. Le Maoult, T. Sentenac

Institut Clément Ader (ICA), Université de Toulouse, CNRS, INSA, UPS, Mines Albi, ISAE-SUPAERO, Toulouse, France

Abstract — Mechanical tests were developed to characterize metallic materials at high temperature. Specimens used in these tests can have 3D complex geometry. During the tests, measuring both thermal and kinematic fields is important. Thermal measurement is well control for plane shape samples with a relatively homogenous surface state, but not when the part is convex or concave. Kinematic measurement is well controlled at room temperature but not at high temperature. The aim of this study is to develop a device to measure both temperature and shape during mechanical testing with a 3D complex geometry sample at high temperature.
Key Words — DIC, infrared thermography, complex geometries, high temperature.

Context

Materials used in automotive and/or aeronautic industries undergo complex mechanical stresses in service. To test these materials in service, simplify mechanical tests can be realized: tensile tests, flexion tests, … These tests can be realized at high temperature to test materials at temperature needed to manufacture the pieces. The strongly coupled thermo-mechanical character implies an instrumentation of these mechanical tests in both thermal and kinematic fields. Some studies realized this coupling but not in theses testing conditions [1-2].

Thermal measurement is well controlled for plane shape samples with a relatively homogenous surface state. When the part is convex or concave, the risk of artefact cannot be ignored [3-4]. The kinematic measurement is well controlled at room temperature, but has high measurement errors when the temperature is higher than 50°C. Technical problems (realization of the speckles, visible measurement area, …) and thermal effects (mirage effect, decreasing image contrast, …) may appears during the measurement [5-7].

Aims

The principal aim of this study is to measure both temperature and shape during mechanical testing with a 3D complex geometry sample at high temperature. For this, the study is divided in three parts: highlighting artefact in thermal measurement for 3D complex geometry, highlighting measurement errors in high temperature shape measurement and using kinematic measurement to correct artefacts created by 3D complex geometry thermal measurement. The third part is still in progress and will not be presented here. Thermal measurement will be realized by infrared thermography. Digital Image Correlation (DIC) will measure shape.

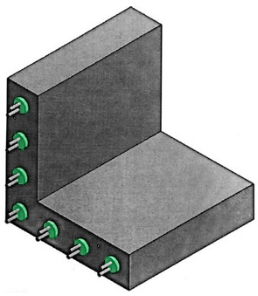

Figure 1: Stainless steel T-square

Temperature full field measurement

The studied specimen is a stainless steel T-square, represented in figure 1, heating by seven cartridge heaters.

Temperature field was measured in different conditions in this specimen. Three spectral ranges (0.9 μm to 1.7 μm, 3 μm to 5 μm and 8 μm to 12 μm), four temperatures (100°C, 200°C, 300°C and 400°C), two surface finishes (polished or black painting surface) and five viewing angles were testing.

These different experiments reveal a lot of artefacts. For example, measurement in front of the internal surfaces of the T-square shows reflections in the three spectral ranges (figure 2).

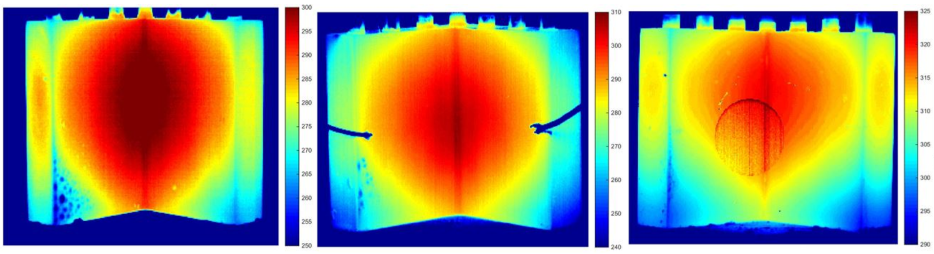

Figure 2: Infrared thermography in front of the internal surfaces of the T-square black painted at 300°C for the three spectral ranges: 0.9 µm to 1.7 µm (left picture), 3 µm to 5 µm (central picture) and 8 µm to 12 µm (right picture)

Kinematic full field measurement

The same studied specimen was used. Shape was measured for four temperatures (100°C, 200°C, 300°C) during 5min with 1Hz frequency using stereo-DIC. Convective flow was estimated in all the measurements by putting a plate on the back of the specimen. T-square surfaces were painted with black and white paints to obtain speckle pattern. Four mean planes were defining for the four surfaces of the T-square by using least squares method. Mean planes were compared to the real geometry of the T-square.

Difference between the four mean planes and the real four surfaces of the T-square are negligible at 100°C. Difference at 200°C is 1.5µm between the internal measured mean planes and the real internal surfaces and 3µm between the internal measured mean planes and the real internal surfaces of the T-square. Difference increases with the temperature.

Discussion and Conclusion

Different experiments were used to highlight the effect of 3D complex geometry for temperature measurement by infrared thermography and the effect of high temperature for shape measurement by stereo-DIC. Shape can be used to correct some artefacts on temperature measurement by infrared thermography. Some algorithms are now developed to correct shape measurement by stereo-DIC. This study, in long term, will allow to use infrared thermography coupling with stereo-DIC during complex mechanical tests in high temperature.

References

[1] N. Cholewa, P.T. Summers, S. Feih, A.P. Mouritz, B.Y. Lattimer, and S.W. Case. A Technique for Coupled Thermomechanical Response Measurement Using Infrared Thermography and Digital Image Correlation (TDIC). *Experimental Mechanics,* 56(2):145-164, 2016.

[2] L. Li, J.-M. Muracciole, L. Waltz, L. Sabatier, F. Barou, and B. Wattrisse. Local experimental investigations of the thermomechanical behavior of a coarse-grained aluminum multicrystal using combined DIC and IRT methods. *Optical Lasers Engineering*, 81:1-10, 2016.

[3] G. Cardone, A. Ianiro, G. dello Ioio, and A. Passaro. Temperature maps measurements on 3D surfaces with infrared thermography. *Experimental Fluids*, 52(2):375-385, 2012.

[4] J. Peeters, B. Ribbens, J.J.J. Dirckx, et G. Steenackers. Determining directional emissivity: Numerical estimation and experimental validation by using infrared thermography. *Infrared Physics Technology*, 77:344-350, 2016.

[5] A. Delmas, Y. Le Maoult, J.M. Buchlin, T. Sentenac, J.J. Orteu. Shape distortions induced by convective effect on hot object in visible, near infrared and infrared bands. *Experimental Fluids*, 54:1452-1458, 2013.

[6] J.S. Lyons, J. Liu, M.A. Sutton. High-temperature deformation measurements using digital-image correlation. *Experimental mechanics*, 36(1):64-70, 1996.

[7] Y.Q. Su, X.F. Yao, S. Wang, Y.J. Ma. Improvement on measurement accuracy of high-temperature DIC by grayscale-average technique. *Optics and Lasers in Engineering*, 75:10-16, 2015.