Synchronous Full-Field Strain and Temperature Measurement.

High temperature is a critical concern for most testing in the automotive, aerospace, and energy industries. Thermal expansion is an ever-present challenge, often making it difficult to distinguish strains caused from mechanical load from those originating solely due to material temperature change. Moreover, material deformation and its surface temperature change are strongly coupled because a significant part of the stress-energy used to induce the deformation is converted to heat. This has the effect of raising the material temperature and affecting the material deformation. Digital Image Correlation is the most efficient optical non-contact measurement method to measure strains. Since 2021, a productive Partnership between Telops and Trilion Quality Systems has led to the integration of Telops high-speed infrared cameras into ARAMIS Thermography solution for measurement of thermal and mechanical strains. This application note shows some results from this collaboration.

Introduction

The inelastic deformation behavior of practically all materials is known to be affected by both strain and temperature, although the extent of these effects can vary substantially within and between different groups of materials. Moreover, these effects are strongly coupled because a significant part of the energy used for the deformation is converted to heat, raising the temperature of the material, which in turn affects the material and the plastic deformation that is taking place.

The tensile test is probably the most commonly used experiment for determining the basic engineering properties of materials. The test typically provides the average bulk properties of the material and the data obtained from the tests are typically presented as a stress-strain curve. These curves are sensitive to the experimental methods used to acquire the underlying stress and strain measurements. Additionally, the material temperature change occurring during the test may also affect the obtained results. Therefore, at least for scientific purposes, the seemingly simple tensile test and the interpretation of the obtained results can turn out to be much more complex than generally assumed.

In recent years a new optical non-contact measurement method, called Digital Image Correlation (DIC), has been introduced and is increasingly being used to measure strains. The surface of the specimen is usually painted with a white and black speckle pattern and one or two high speed cameras are used to record images of the deforming surface. The images are processed by DIC software that calculates the full-field deformation on the surface of the specimen throughout the test.

By synchronizing a DIC setup with a high-speed infrared camera, synchronous full-field strain and temperature measurement can be conducted. Indeed, accurate measurement of the temperature increases during a material characterization test can provide valuable information for studying the thermal influence of material deformation on the extracted properties.

In this application note we discuss the integration of Telops high speed infrared cameras into the ARAMIS Thermography solution. The integration was conducted in collaboration with Trilion and the resulting system represents a full turn-key thermography and deformation testing solution for materials analysis with applicability to a wide-range of measurement challenges.

Experimental Information

The Telops M3K Infrared Camera

A Telops FAST M3K camera (fig.1) was used to collect all data presented in this application note. This camera features a sterling-cooled indium antimonide (InSb) focal plane array detector of 320×256 pixels which is sensitive over the 1.5 – 5.5 µm spectral range (3– 5.5 µm optional) and is optimized for high-speed data acquisition. The M3K is the fastest thermal infrared camera available on the commercial market and is capable of acquiring full-frame images at up to 3100 Hz and sub-window images at up to 100,000 Hz. Figure 2 details the M3K acquisition speeds for different windowing formats.

Figure 1. Telops Fast M3K infrared camera.

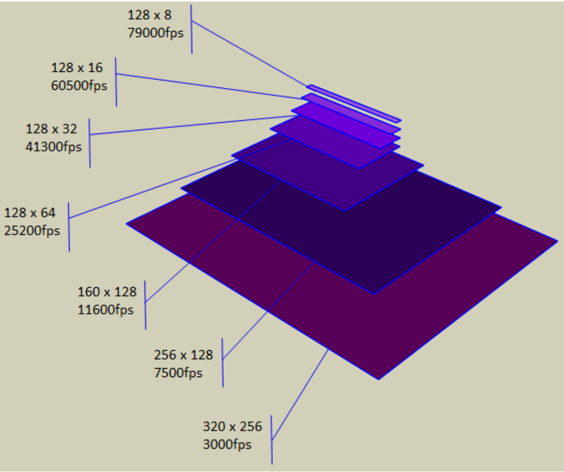

Figure 2. Telops M3K acquisition speeds for different windowing formats.

The cooled InSb detector used in the M3k is configured with large 30 um pixels, ensuring adequate area for light collection and allowing for the visualization of very small temperature differences even when operated with the low exposure time required for high-speed operation. The camera also includes 16 GB of high-speed internal memory for data recording (32 GB on demand). Moreover, the camera benefits from a unique proprietary real-time processing enabling permanent pixel-wise calibration and automated exposure control (AEC). These unique features translate into ease of use and operational flexibility while maintaining high accuracy performance over the entire range of camera operating parameters.

The ARAMIS 3D Thermography solution.

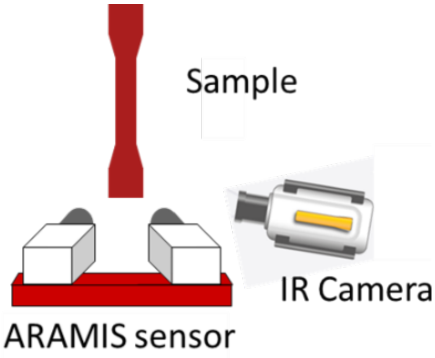

Figure 3. The ARAMIS Thermography setup.

The ARAMIS Thermography solution combines the ARAMIS Optical Strain Gauge system (Fig. 3 left) with a high-speed infrared camera (Fig. 3 right), placed to give a similar field of view as seen by one of the two ARAMIS high-speed visible cameras. An add-on Python script embedded in ARAMIS Professional software allows the combination of DIC with IR thermography. The IR camera is synchronized with the ARAMIS sensor and the collected temperature data is brought into the ARAMIS software and mapped across the sample surface within a common 3D coordinate system. The ARAMIS Optical Strain Gauge system (Fig. 3 left) is a non-contact and material-independent measuring system based on digital image correlation. The sensor is based on a stereo camera system which delivers precise 3D coordinates based on triangulation and using stochastic patterns or reference point markers.

Tensile test setup

In order to demonstrate the capabilities of this Telops-Trilion partnership, we conducted a tensile test on a steel sample at a load rate of 8 mm/s. Both the ARAMIS 2.3 Mega pixel system (fig. 4 right side) and the Telops M3K FAST IR camera (fig. 4 left side) were used for the experiments. The two systems were synchronized using a common trigger input signal which allowed for temporal alignment of the visible and Infrared images.

Figure 5 depicts an example of measurements obtained with the two systems including the temperature map (left) and strain map (right). The necking and sample fracture can clearly be identified from both images.

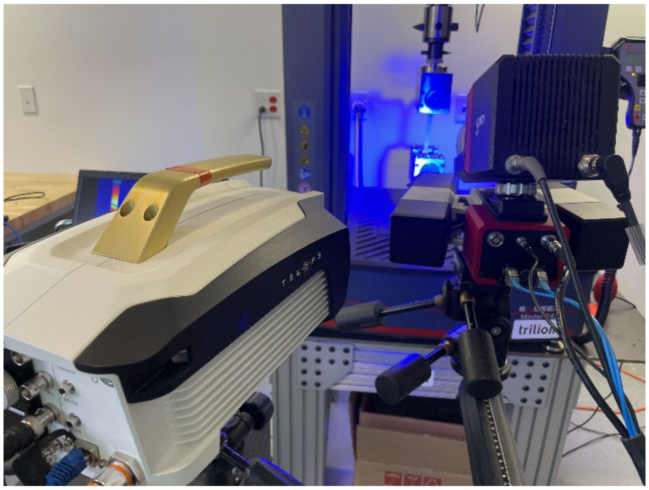

Figure 4. Tensile test conducted with Telops M3k and the ARAMIS Thermography setup.

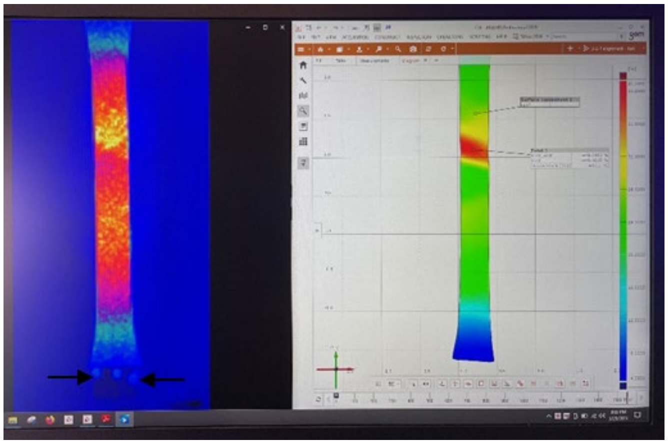

Figure 5. Temperature (left) and strain (right) fields measured with Telops M3k and ARAMIS 2.3 Mega pixel system.

Thermal changes during the test and necking can significantly affect the material properties. In this work we show that synchronous strain and temperature measurement using ARAMIS 3D-DIC with Telops infrared camera allow correcting these effects and provides highly accurate materials properties.

Results and discussion

The temperature and strain data synchronously measured by the Telops IR camera and ARAMIS system were both loaded into the ARAMIS Professional 2019 software. In order to match visible and thermal images the two systems were set to use the same frame rate. Both systems were synchronized for temporal alignment of the recorded images and the same field of view was set to facilitate the spatial alignment. The dots shown with black arrow in the thermal image in Figure 5 were used to perfectly overlay the thermal images on top of the ARAMIS images. Figure 6 shows thermal images mapped onto the specimen at two different times during the tensile test. The alignment is very straightforward in the software with negligeable deviation and allows the user to link the surface temperature increase to the sample deformation. A high-temperature domain can be identified in the lower image with peak temperatures around 40 °C indicating the location where the material will soon rupture.

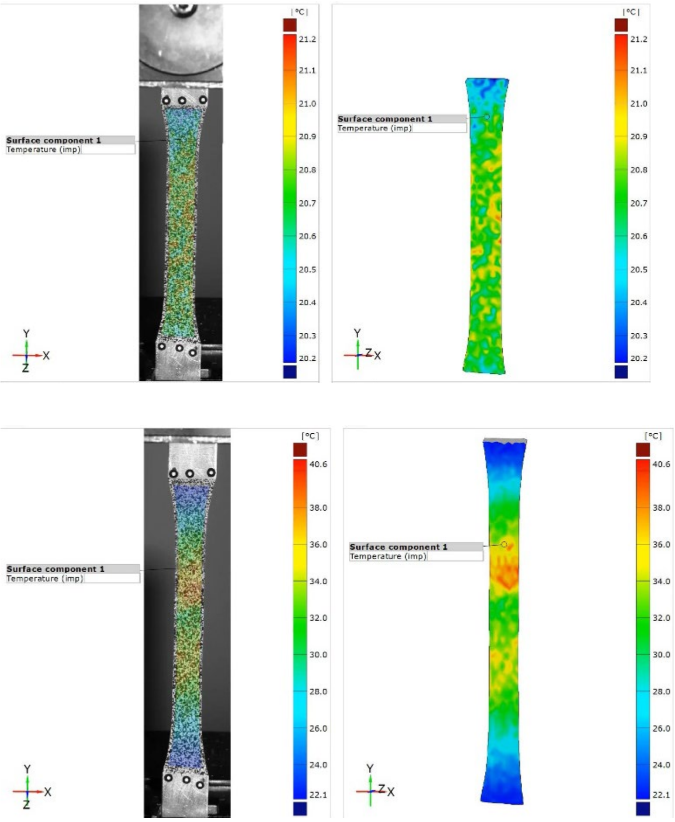

Figure 6. Selected images of the measured temperature data mapped onto the sample.

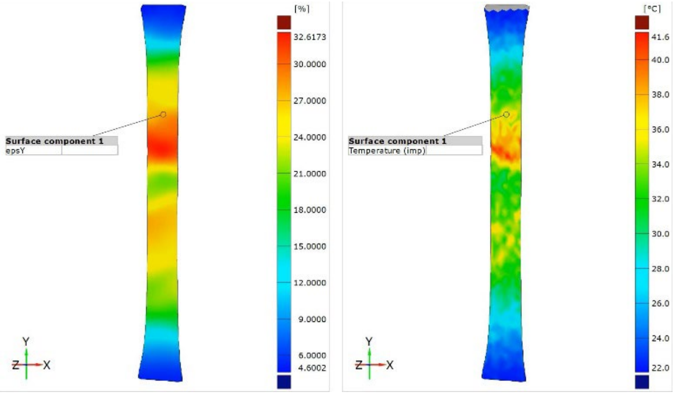

Figure 7. Selected images of the measured epsilon Y (left) and temperature (right).

The correlation between the surface temperature and strain are shown in Figure 7. Inspection of these images reveals that the strain increase in certain regions are accompanied by increases in the surface temperature, with a peak in the strain and temperature around the necking and rupture zone.

The temperature data obtained during the test allows for the correction of the total strain measurements for thermal expansion and extraction of the true mechanical strains. This correction is performed automatically in the software by incorporating the coefficient of thermal expansion (α) of the inspected specimen material. The material used in this test is steel with a value $\alpha = 13 \times 10^{-6}$ °C^{-1}. The correction results are illustrated in Figure 8 showing, in the same plot *epsilon Y*, *epsilon Y_corr* (the corrected strain) and temperature.

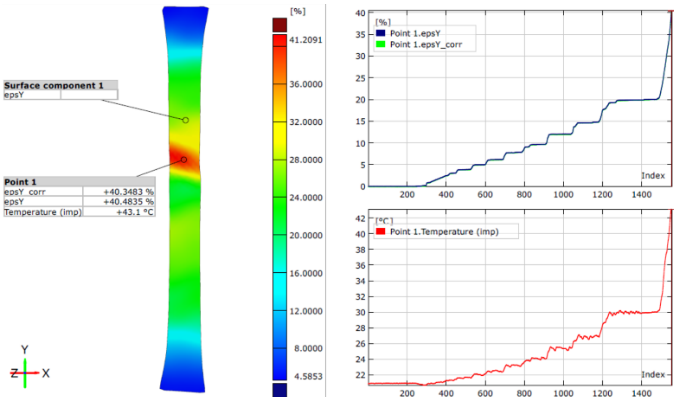

Figure 8. measured surface strain epsilon Y, corrected surface strain from the thermal expansion epsilon Y_corr, and measured temperature.

The values displayed on **Point 1** show a very small difference between *epsilon Y* (+40.3483 %) and *epsilon Y_corr* (+40.4835 %) due to the fact that the temperature increase is not very high in this case.

In general, when a material is stressed, a significant part of the energy used for the deformation is converted to heat which in turn affects the material properties. The synchronous full-field strain and temperature measurements demonstrated in this application note are of high interest in experimental mechanics, automotive and aerospace engine testing applications. The thermal expansion correction can be useful in operations such as welding inspection applications where temperature variations play an important role in the material and structural response.

Conclusions

The work presented in this application note demonstrated synchronous full-field strain and temperature measurement. This capability was developed during a Telops-Trilion collaboration that led to the integration of Telops high-speed infrared cameras into the ARAMIS Thermography solution. The resulting system is of high interest in experimental mechanics, automotive and aerospace engine testing and in applications such as welding where temperature variations play an important role in the material and structural response.

Acknowledgements

We acknowledge the fruitful collaboration with Trilion, and thank Justin Bucienski and Joseph Horn for their intensive work in collecting experimental data.

Telops Inc.

100-2600 St-Jean Baptiste Ave
Québec, QC, Canada, G2E 6J5

+1-418-864-7808
sales@telops.com
telops.com