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► **To cite this version:**

B. Berthel, A. Galtier, Bertrand Wattrisse, Andre Chrysochoos. Thermographic analysis of fatigue dissipation properties of DP60 steel. Photomechanics'01, 2006, Clermont-Ferrand, France. hal-00572478

**HAL Id: hal-00572478**

**<https://hal.science/hal-00572478v1>**

Submitted on 22 Sep 2021

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# Thermographic analysis of fatigue dissipation properties of DP60 steel

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**ABSTRACT:** This paper presents dissipation fields accompanying a high cycle fatigue test. Heat sources induced by the fatigue mechanisms were derived from thermal data provided by an IRFPA camera. Our experiments underlined the precocious, heterogeneous development of the dissipation sources. They also pointed out a linear evolution of the dissipation intensity as a function of the loading frequency.

## 1. CONTEXT

The temperature evolution during a fatigue test has been studied for a long time. Several research teams proposed empirical methods based on the warming of the specimens to get a rapid estimate of the fatigue limit. These methods sometimes led to disputable results. The temperature variation indeed depends on the intensity and the distribution of heat sources, on the heat diffusion within the material and then on thermal boundary conditions.

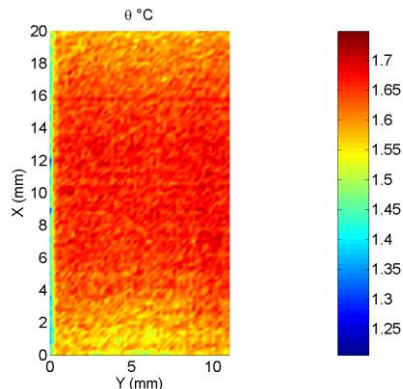


Figure 1 : thermal image

Because of heat diffusion, the pattern of temperature is very smooth and regular as shown in Figure 1, even if the heat sources inducing these temperature variations may be heterogeneously distributed. This is the reason why we chose to analyze the fatigue mechanisms in terms of heat sources distribution. Therefore, we developed an image processing method that enables us to take account of the heat diffusion and to estimate the distribution of sources throughout a fatigue test.

## 2. FATIGUE TESTS

The fatigue tests were carried out on an ARCELOR steel, the DP600 grade ( $R_e=400\text{MPa}$ ;  $R_m=610\text{MPa}$ ). We realized blocks of 20 000 cycles, each block being characterized by the following parameters: the stress amplitude  $\Delta\sigma$  varying approximately from 80MPa to 500MPa. The periodic loading was characterized by a load frequency  $f_L$  ranged from 3Hz to 30Hz. Finally, we used a unique load ratio  $R=-1$ .

## 3. METHOD AND RESULTS

Heat sources accompanying the fatigue mechanisms have at least two possible origins. On the one hand, the thermoelasticity gives coupling sources related to the thermal expansion (Lord Kelvin, 1880). On the other, the irreversibility that accompanies the microstructure evolution is translated by a dissipated heat that warms the sample. In the case of the fatigue of steel, this heat source intensity is a hundred times smaller than thermoelastic source variations. Therefore, we developed an appropriate image processing method to estimate separately fields of mean dissipation per cycle  $d_1$  and fields of thermoelastic source amplitude  $\Delta S_{\text{the}}$ . To estimate the heat sources, a local least-squares fitting of thermal data has been chosen. The local approximation function has the following form:

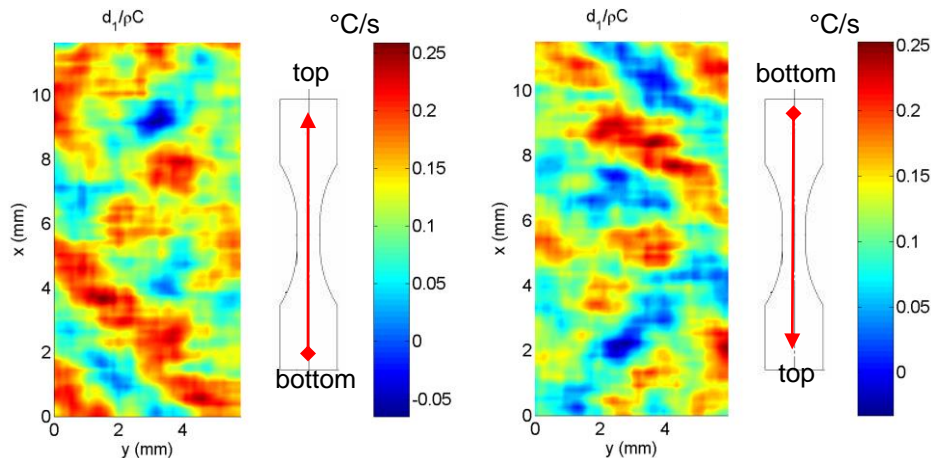
$$\theta^{\text{app}}(\mathbf{x}, t) = \underbrace{\rho_1(\mathbf{x})t + \rho_2(\mathbf{x})}_{\text{drift}} + \underbrace{\rho_3(\mathbf{x})\cos(2\pi f_L t) + \rho_4(\mathbf{x})\sin(2\pi f_L t)}_{\text{periodic response}} \quad (1)$$

The trigonometric time functions describe the periodic part of the thermoelastic effects (with a possible phase shift) while the linear part takes into account transient effects due to heat losses, dissipative heating and possible drifts of the equilibrium temperature. The functions  $\rho_i(\mathbf{x})$ ,  $i=1,\dots,4$ , are :

- second order polynomials of  $x$  and  $y$  (2D analysis)
- second order polynomials of  $x$  (1D analysis)
- constants (local analysis)

Until the crack onset, we observed quasi-uniform patterns of thermoelastic source amplitudes as expected for a simple tension-compression test. Besides, the experiments showed that  $\Delta s_{\text{the}}$  increased linearly with stress and the load frequency as predicted by a linear thermoelastic law.

Conversely, Figure 3 shows a heterogeneous distribution of dissipative sources  $d_1$ . During a fatigue block, this pattern remains spatially constant whatever the set of loading parameters as long as fatigue effects are low and do not herald a crack inception. So, the experimental method enables us to detect this crack localisation several hundreds of cycles before its onset.



**Figure 3 : distribution of dissipation: a material effect**

Moreover, if we turn over the specimen such as we look at the same face but we reverse the position of the heads (top/bottom), the dissipative field follows this rotation. Thus we showed that the distribution of dissipative sources is actually related to microstructural defects. Finally we showed that  $d_1$  linearly increases with the loading frequency, at constant loading amplitude, in every point of the sample gauge part.

#### 4. CONCLUSION

We developed an original IR method for analysing the irreversibility accompanying the fatigue localization. In terms of structure design, the method may be used to detect fatigue zones. In terms of material analysis, the dissipation distribution can be combined with other measurement fields to built up complete energy balance. Our ultimate objective is to determine a stored energy pattern useful to identify a material fatigue criterion.

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