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SCUOLA DI ARCHITETTURA URBANISTICA
INGEGNERIA DELLE COSTRUZIONI

EXECUTIVE SUMMARY OF THE THESIS

Dynamic tests' plastic strains estimation through thermal imaging measurement

TESI MAGISTRALE IN AERONAUTICAL ENGINEERING – INGEGNERIA AERONAUTICA

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1. Introduction

The main objective of this work is to produce a methodology for the estimation of the plastic strains produced during dynamic events by exploiting the link with the temperature.
Measurements through thermal imaging, while not devoid of issues, have great advantages.
As a non-contact type of measurements is not subjected to the dynamic of the test and its less prone to be in condition to break.
In respect to the popular DIC analysis, this method tries to bypass its main issue. As the DIC calculate strains tracking a stochastic pattern on the surface of the body, the measurement can be thwarted during dynamic tests as the body can deform in ways that partially or totally obstruct the surface pattern from the camera.

2. Plastic strain and temperature link

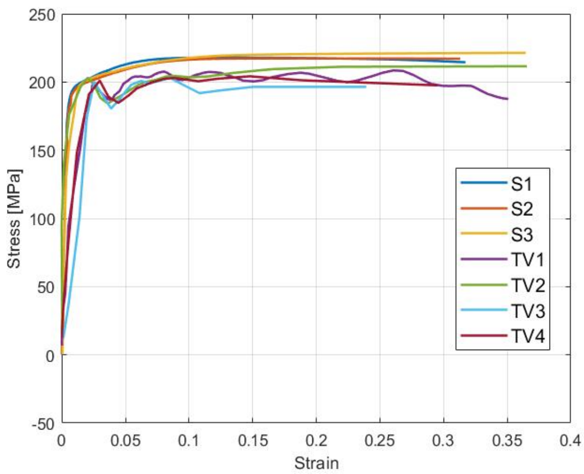
The link between temperature change and plastic strains is found in the energy balance equation.

$$\rho C_p \dot{T} - K\nabla^2 T = \beta \sigma_{ij} \dot{\varepsilon}_{ij}^{p}$$

To simplify the method some terms of the equation are ignored.
As can be found in literature convection and radiation can be not considered if the test is fast enough, generally the strain rate must be over 0.1 s^{-1}, easily achievable during dynamic tests.
The thermoelastic effect is also ignored as its contribution is much lower in respect to the others.
The term of conduction can also be ignored at high strain rates assuming adiabatic deformation, but, as the computation of this term is relatively easy, its effect is taken into account.

3. Mechanical characterization

As the strain will be calculated integrating the energy equation, the plastic region of the material must be characterized so the hardening rule must be found.
In this work the hardening rule is found testing the specimens at various speeds with the traction test machine and drop tower machine.
The strains are found using the DIC analysis. This method was chosen as it provides the entire strain field that can be also used to validate the results of the thermal imaging method.
The tests show that the material tested is independent form the strain rate.
The hardening rule chosen is the simplified Johnson-Cook model.



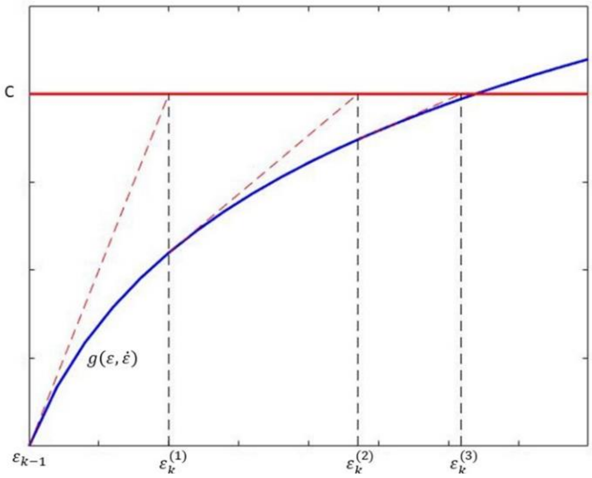
2 Material curves

4. Iterative time integration

The time integration is performed through the Crank-Nicolson method.

$$Y_k = Y_{k-i} + \frac{h}{2}\dot{Y}_k + \frac{h}{2}\dot{Y}_{k-i}$$

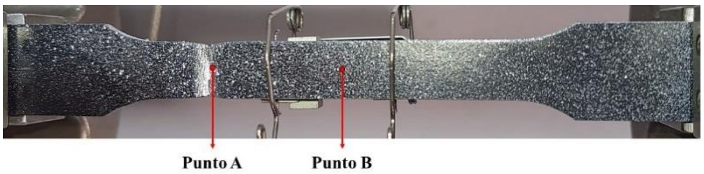
As the equation to be integrated is generally nonlinear, an iterative process must be implemented. In this case a Newton-Raphson method was implemented.



1 Newton-Raphson iteration method

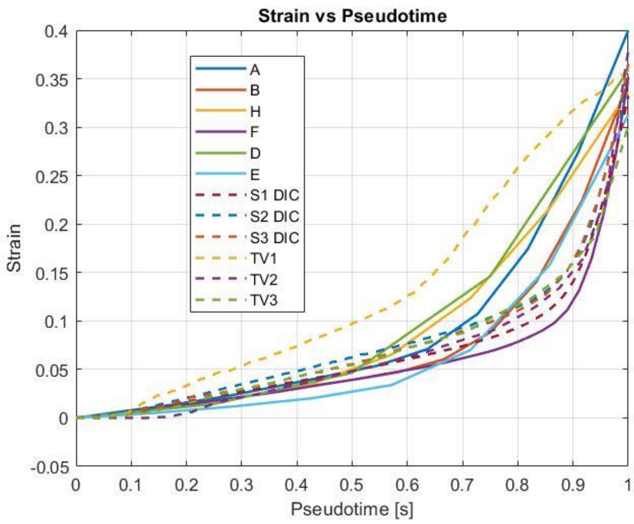
5. Integration results

The integration results are extracted in two different points, one near the break point, the other in the midsection of the specimen away from the point of rupture.

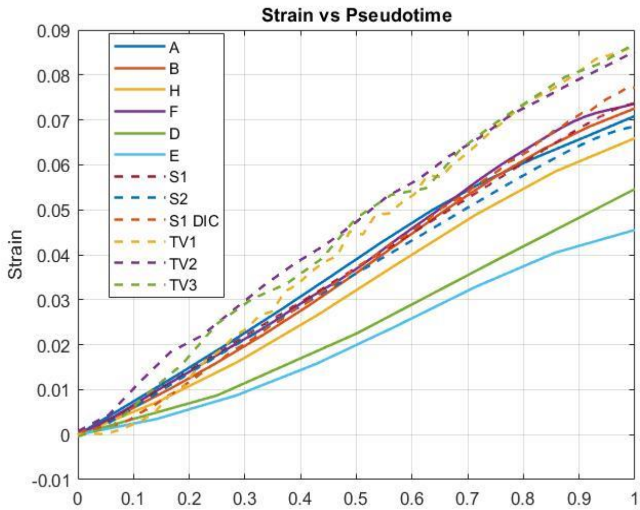


3 Results points location

These results are then compared with the results of the DIC analysis and of the strain gauge.



4 Result comparison point A

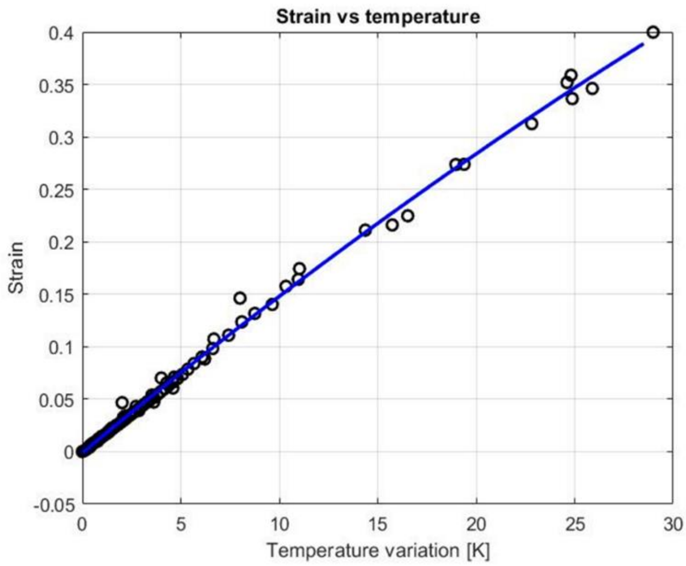


6 Results comparison point B

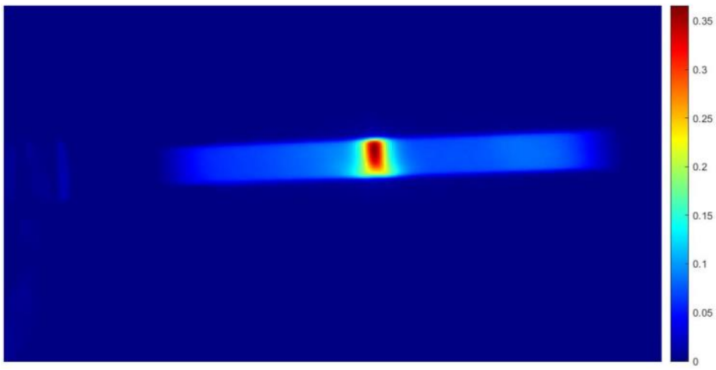
As can be seen the integration results are in accordance with the results from the DIC analysis and the strain gauge. The exception are the results from the midsection point for the specimen D and E. This inaccuracy is probably caused by a too small sampling rate along with a smaller variation in temperature making the integration more susceptible to inaccuracies in the temperature measure.

6. The link between strain and temperature

While the integration of the energy equation can give good results it certainly loses a lot of functionality if a more complex geometry or deformed shape are taken into account. The integration requires the entire time history of the point that must be tracked during the entire event. As the tracking of a general dynamic test is quite difficult a different approach is needed.
The integration results are confronted with the respective change of temperature and a characterization curve is found applying a second order regression to the data.
This curve can then be used to generate the entire strain field directly from the temperature field without having to track the points or worrying about the integration requirements.
The validity of the curve has been tested applying it to the thermal image of the specimen obtaining similar results to the one previously found.



5 Characterisation curve



7 Curve application example

7. Application to a dynamic test

To test the application on dynamic tests presenting a more complex deformation, the method was applied to a compression tests for circular tubes.
Since these tests predate the beginning of this work, the material making up the cylinders is different from the one characterized in this study.
Even though the materials are different they are both aluminium alloys so a similar behavior can be assumed.
Taking advantage of the almost linearity of the characterisation curve a scaling coefficient can be applied to it that take into consideration the ratio of the plastic works of the two material.
Parting the linear term of the plastic work, proportional to the base value of the yieldind stress, from the non linear term and assuming the

same hardening rule it's possible to find the scaling coefficient L(ε) as

$$\frac{1}{L(\varepsilon)} = 1 + \frac{\Delta\sigma_y \varepsilon}{\sigma_{y1}\varepsilon + H(\varepsilon)}$$

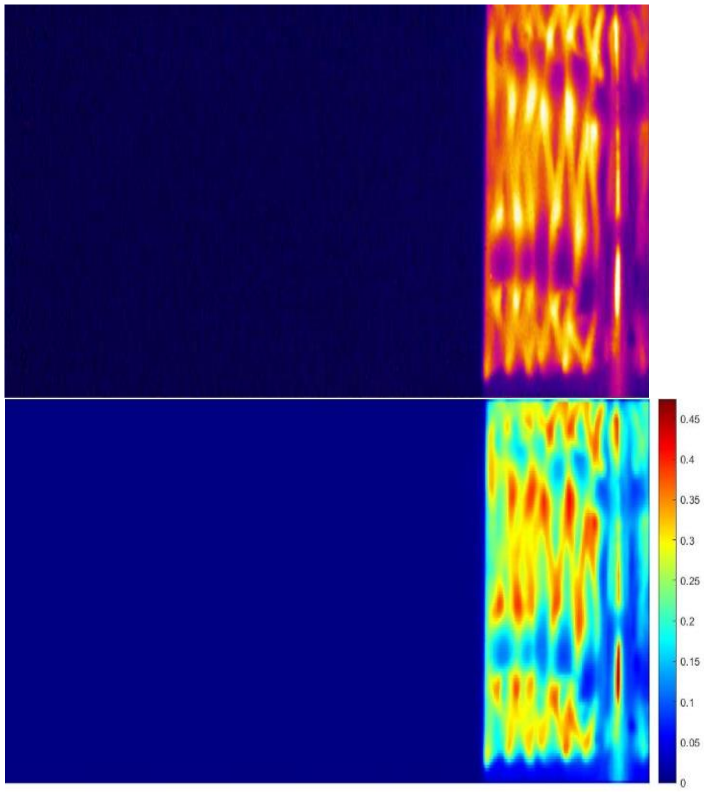
$\Delta\sigma_y$: difference between the yielding stresses
σ_{y1}: yielding stress of the characterised material
$H(\varepsilon)$: Non linear component of the plastic work

In the case of the simplified Johnson-Cook model can be easily expressed as

$$H_{(\varepsilon)} = \frac{B}{N+1}\varepsilon^{N+1}$$

The strains are calculated from the temperature data using the characterization curve and then are scaled by the coefficient L(ε) calculated using the strains just found.

8 Compressed cylinder



9 Thermal image and calculated strain

8. Conclusions

The objective of the study was to derive an empirical relationship to link plastic deformation and the generated temperature change to use for measuring strains during dynamic tests.
Integration of the energy equation, through the temperature data from the thermal imaging camera, yielded results mostly in agreement with the reference results obtained from DIC and strain gauge analysis.
This made it possible to derive a material characterization curve, the application of which gave very satisfactory results that could generate the strain field directly from the thermal camera measurement.
The application on the cylinders, while only qualitatively, show the capabilities of this method for measurements during dynamic tests.
The application on the cylinders, with the results derived from the scaled curve, show the capabilities of this method for measurements during dynamic tests.
As the application on the dynamic tests has been performed through a scaled curve, the objective is now to apply it in a test with the same material studied in this work.

9. Bibliografy

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