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Experimental Investigations on the Hole Drilling Method for the Residual Stress Measurement on Different Materials According to the new ASTM E837-20

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The life expectancy of a mechanical component is mainly determined by the interaction between defects in the part and the stresses to which it is subjected. These stresses are the result of stresses applied in service, compounded with stresses that develop in the object during all the machining and manufacturing processes. Applied stresses are generally taken into account in design engineering, but residual stresses are often overlooked, being closely correlated with the material, the manufacturing processes and its heat treatment. The hole drilling method is the most effective approach to evaluate residual stress in a wide range of materials: it is not only able to be applied on metals but also on polymeric, composite, and ceramic materials. This method has the advantage that the measurements can be made over a small area; a special strain gage rosette is bonded to the surface of the specimen and a hole is drilled through the centre of the rosette. The strains measured at the surface correspond to the stresses relaxed during the drilling process; using the measured strains and appropriate models (e.g. the new release of the ASTM E837-20 [1]) it is possible to calculate the stresses that exist in the material. MTS3000-Restan, developed by SINT Technology [2], is the automatic system for the measurement of these stresses, by means of the hole drilling strain gauge method, according to the new standard. This poster presents some different cases of residual stresses: a classic reference test on aluminium, a test on a glass specimen, a polymeric component and a sample in additive manufacturing. For example, the application of the hole drilling method to polymers and glass is very complex due to the higher coefficients of expansion and the viscoelastic behaviour of polymeric materials [3], and to the brittleness of the glass. When applying the hole drilling technique to these materials, it is essential to minimize the thermal and mechanical effects due to both temperature variations and hole drilling procedures, also avoiding the rise in temperature near the strain gauges because of the electrical resistance heating. The hole drilling method can be also applied to innovative materials, like additive manufacturing components: a case study of residual stresses into these materials will be presented in this poster as well.

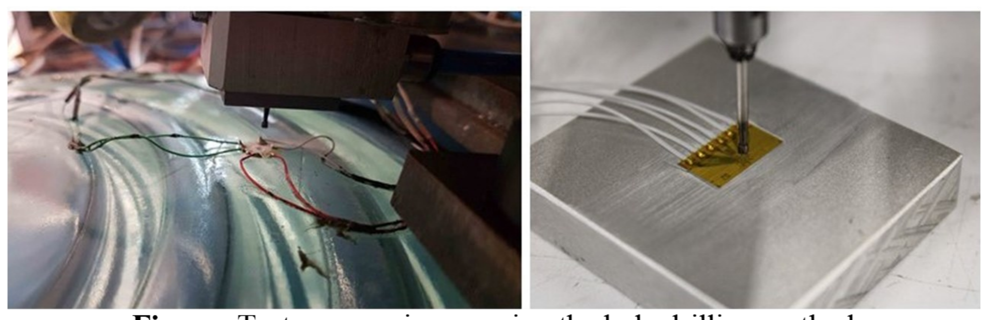


Figure: Tests on specimens using the hole drilling method

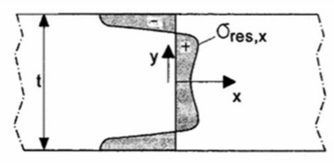
References
[1] ASTM, ASTM E837-20 Standard Test Method for Determining Residual Stresses by the Hole-Drilling Strain-Gage Method, 2020.
[2] A. Benincasa, E. Valentini, E. Boccini, S. Gulisano, An Automatic System for Residual Stress Measurements by Hole Drilling, 4th International Conference on Structural Integrity, 2021.
[3] E. Valentini, A. Benincasa, L. Bertelli, Improvements in the Hole-Drilling Test Method for Determining Residual Stresses in Polymeric Materials, Materials Performance and Characterization, doi:10.1520/MPC20170123, www.astm.org, 2017.

Origin of residual stresses

Residual stresses can be originated by several causes (and their combination):

Thermal Effects | Surface Machining and Treatments | Chemichal and Phase Change

Residual stresses are **self-balanced** within the component: it means that, in absence of any external load, the composition of all the forces and all the moments acting of the workpiece are equal to zero.



$$\int_{-t/2}^{t/2} \sigma_x \cdot dy = 0$$ FORCE EQUILIBRIUM

$$\int_{-t/2}^{t/2} y \cdot \sigma_x \cdot dy = 0$$ MOMENT EQUILIBRIUM

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ASTM E837-20: Introduction

The hole-drilling strain-gage method is the only method for calculating residual stress that is **STANDARDIZED** at world level (**ASTM E837**).

The first version of this standard dates back to 1989, the latest version is available from November 2020.

Designation: E837 – 20

Standard Test Method for
Determining Residual Stresses by the Hole-Drilling Strain-Gage Method[1]

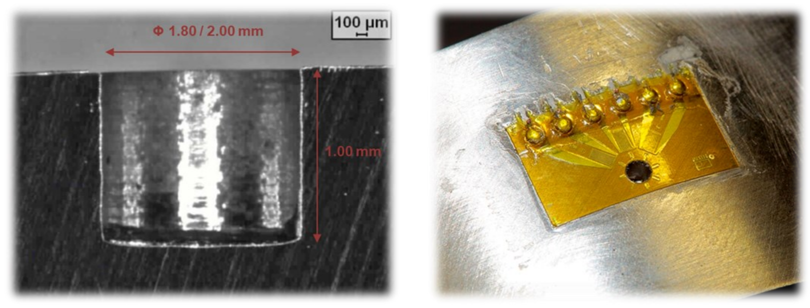
Standard ASTM E837-20 specifies:

- **Limit of applicability** of the method
- The total drilling / analysis **depth** and the applicable **calculation algorithms**
- The number of **drilling increments** required
- The **numerical coefficients** for determining the value of residual stresses
- The **data processing** method and the measurement-related **uncertainty**

Hole drilling strain gage method

The hole drilling method consists in drilling a small hole **(approx. 1.8 mm x 1.0 mm)** into the center of a special 3-element strain rosette.

The hole changes the initial strain allowing **redistribution** of the internal stresses originally existing in the material.

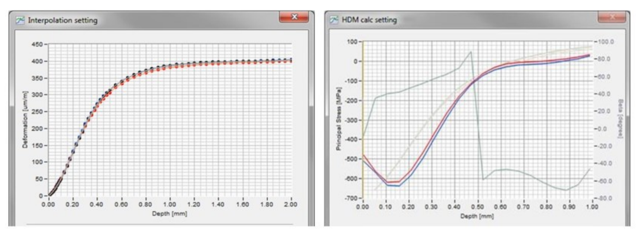


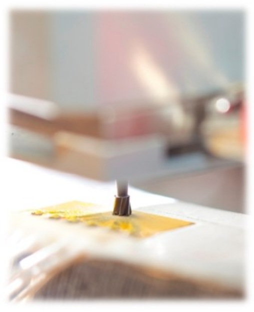
Restan – MTS3000

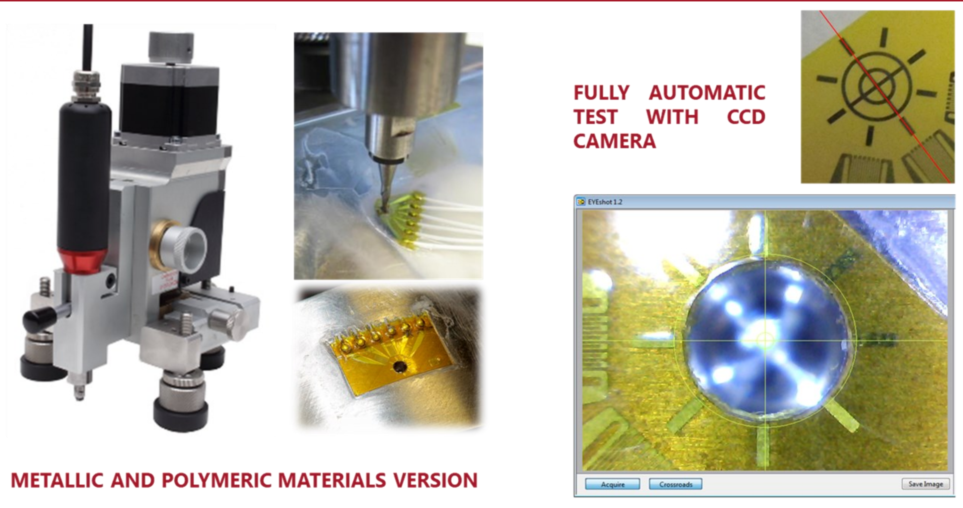
An automatic system for measurement of **residual stresses** by the hole-drilling strain gauge method, in accordance with **ASTM E837-20 standard**.

The system consists of **mechanical** and optical device, **electronic** control unit, **software** to run the test and software to process the results.

The **EVAL 7** software provides a great variety of calculation methods depending of the stress distribution on the workpiece under testing.



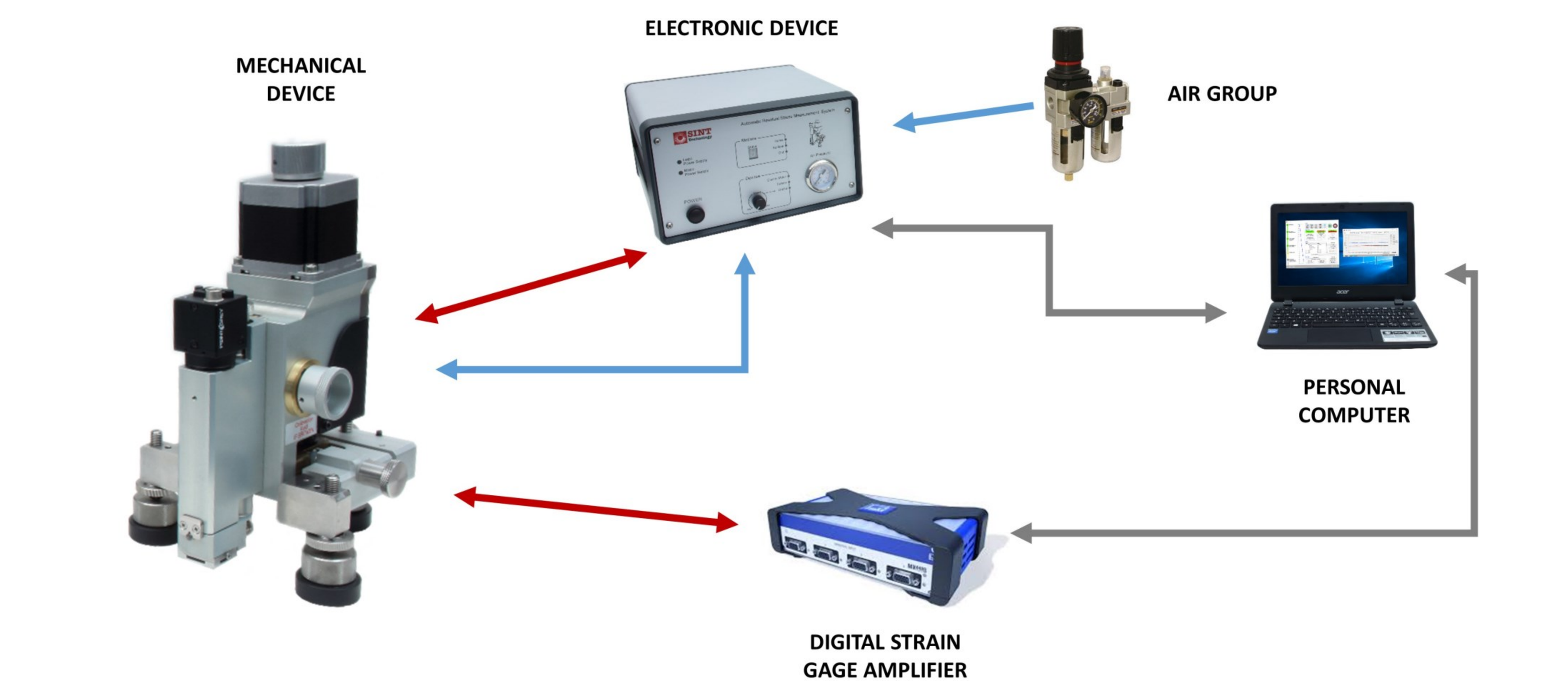


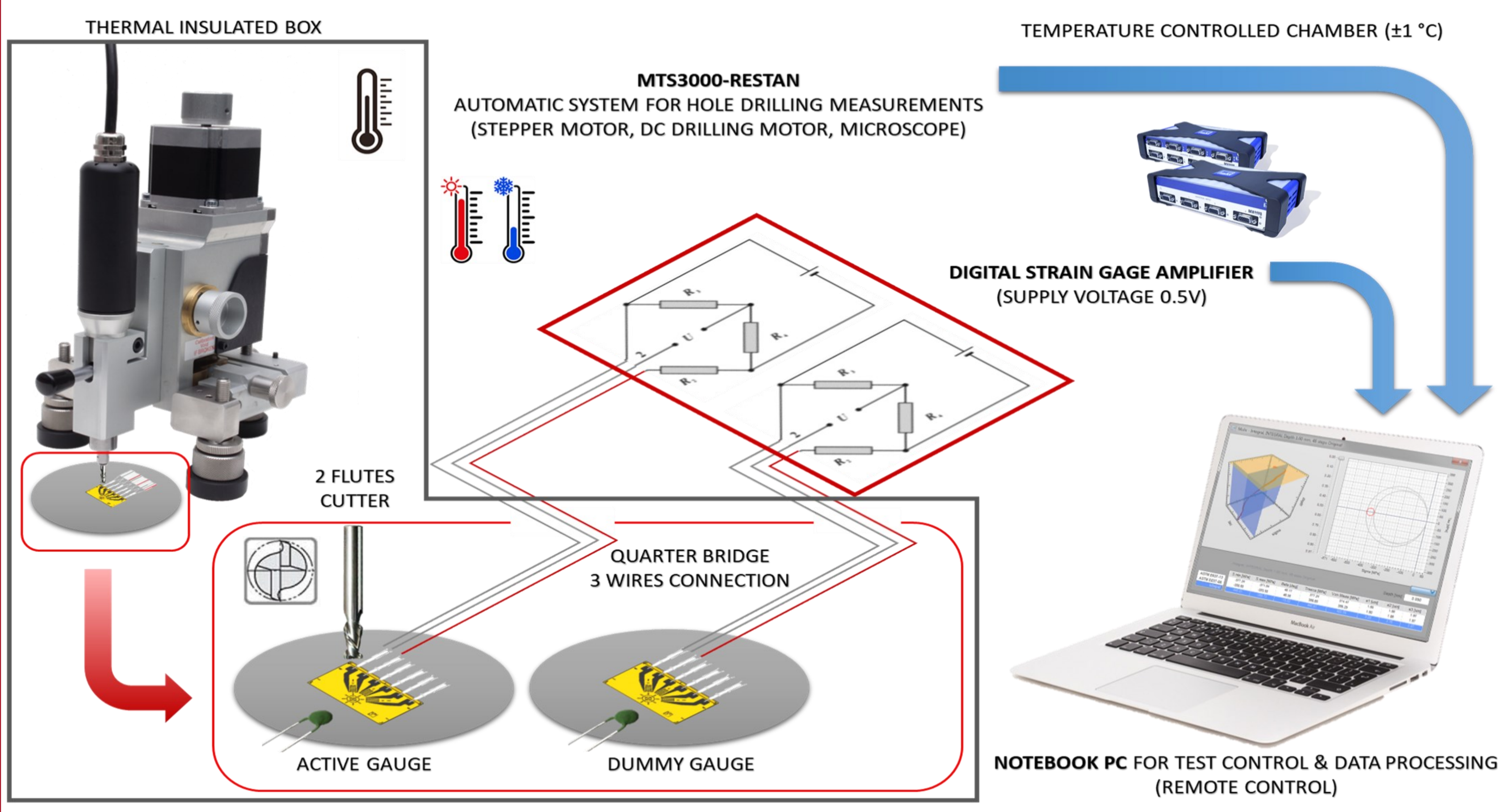


METALLIC AND POLYMERIC MATERIALS VERSION

https://www.mts3000.com/ https://www.sintechnology.com/products/mts3000-restan/

MTS3000-Restan: system connections



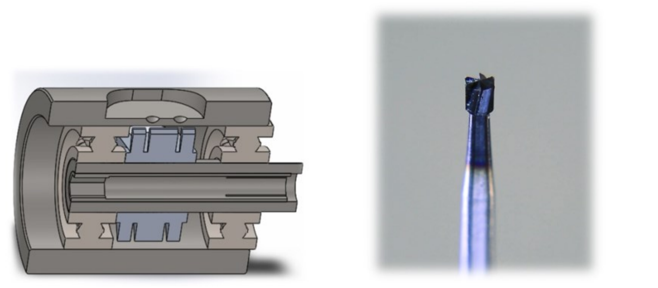


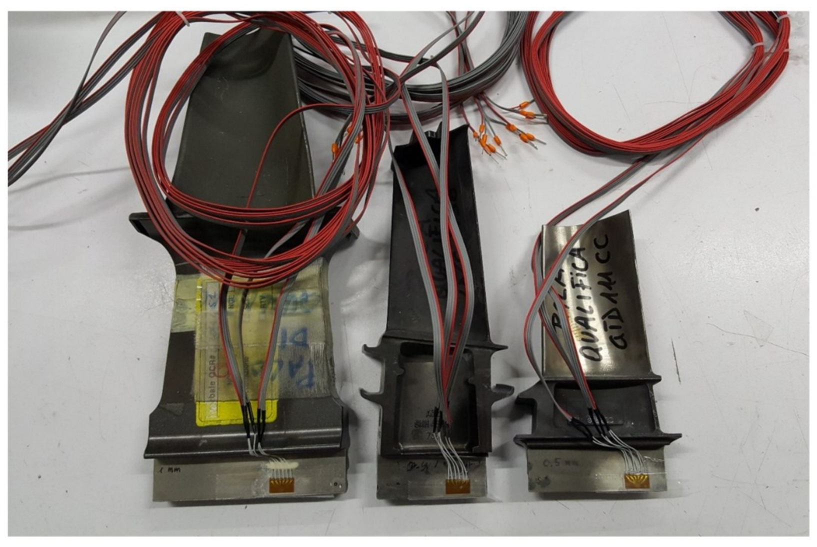
Oil & Gas Industry (Inconel turbine blades)

High-speed drilling has the merit of not changing the state of stresses in the material. It allows relief holes to be drilled without inducing new stresses.

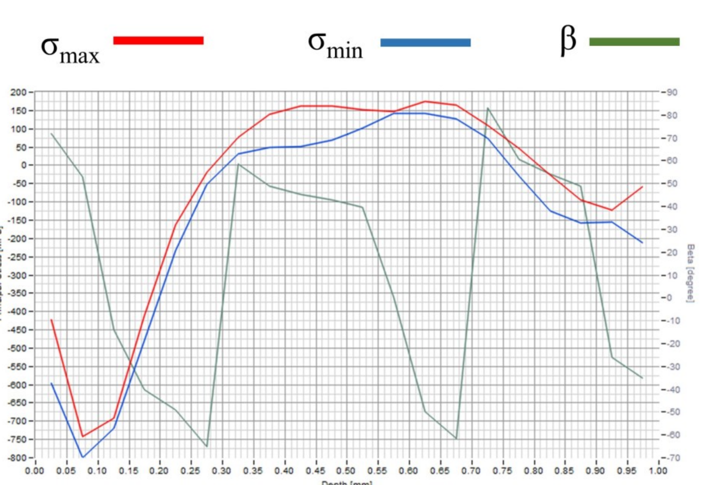
The high-speed drilling system includes:

- a high speed air turbine **400.000 RPM** (at 4 bars of pressure)
- a tungsten carbide **inverted cone** milling cutter

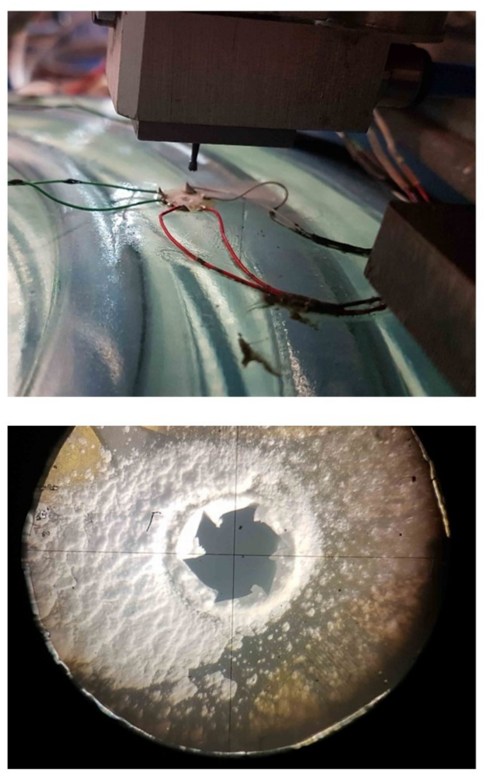




Not-uniform residual stress:



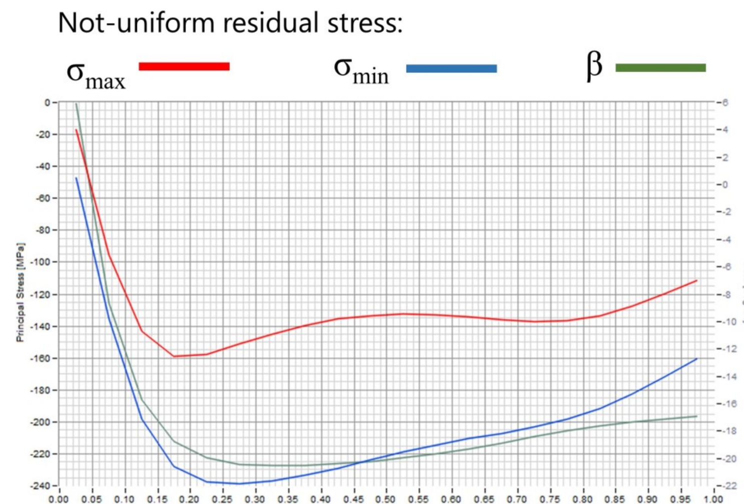
Glass component (Tempered glass)



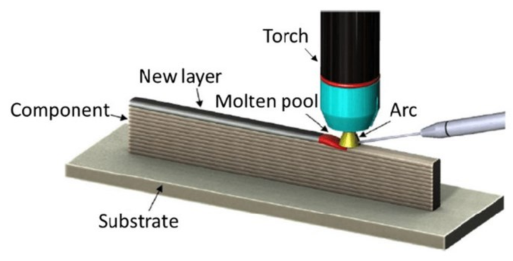
The MTS-3000 Restan can be used to determine residual stresses in uncharted fields:

- Application of **residual stress** measurements on glass components
- Characterization of the **tempered glass**
- Correction of **thermal effects** with low rotational speed and acquisition delay time

Not-uniform residual stress:



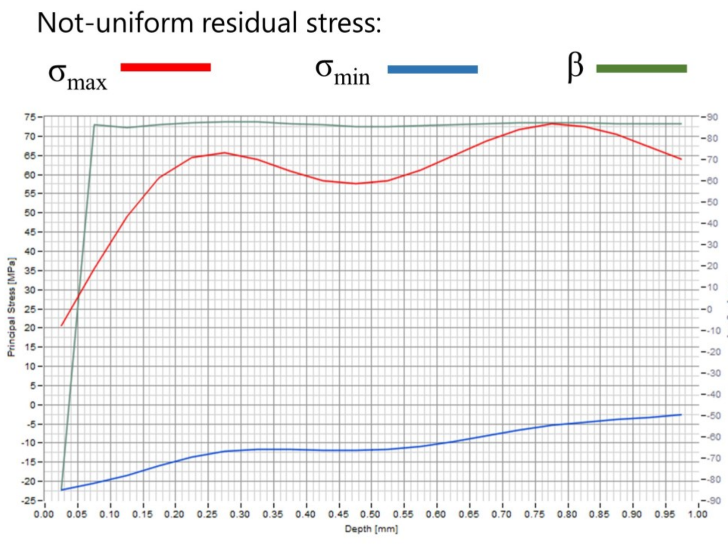
Innovative Materials: Additive Manufacturing (Wire Arc Additive Manufacturing)



This system can be used to determine residual stresses in innovative materials:

- Application of **residual stress** measurements on innovative materials, such as additive manufacturing components made by WAAM method
- Characterization of the **3D printing** in order to know the best settings for the parameters process

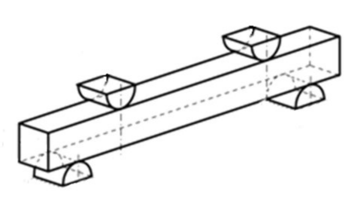
Not-uniform residual stress:



Polymeric component (4 points bending test rig)

A special **version** of MTS-3000 with a modification of the standard drilling technology:

- **very low speed** in order to avoid local heating in the tested material
- **dummy gage** for the correction of the thermal strain generated by any variation on the environmental temperature
- control the **acquisition delay** time at the end of each step and correct the thermal effects



Uniform residual stress: