Aalto University
School of Engineering

MEC-E6007 – Mechanical Testing of Materials

LABORATORY EXERCISE 3 – STANDARDIZED TESTING

Report

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OBJECTIVE:

Test mechanical properties of Titanium and compare the results we get in the tensile and strain measurement tests

BASIC INFORMATION

- Sample material: Titanium Grade 5
- Measurement of transverse via attached strain gauges (KYOWA KFGS-5-120-C1-11 L1M2R) and axial strain via Extensometer
- Testing machine: MTS Insight Electromechanical 30 kN Standard Length

INTRODUCTION IN STRAIN MEASUREMENT AND TENSILE TESTS

In this laboratory exercise, the uniaxial tensile test and strain measurement test were used to determine mechanical properties of a titanium grade 5 specimen. These methods are widely used for evaluating the mechanical properties of materials.

Uniaxial Tensile Test:

The uniaxial tensile test is a common method used to determine the mechanical properties of materials under tensile stress. It involves applying a uniaxial load to a specimen to measure its response to the applied force. The test provides information about the material's behavior under load, including its elongation, strains, and stress-strain curves.

Strain Measurement:

Strain is a measurement of the deformation of a material under load. Strain can be measured using strain gauges or extensometers, which are attached to the specimen and measure the change in electrical resistance as the specimen deforms. Extensometers directly measure the change in length of the specimen [1].

Extensometers are technical devices, used to measure changes in the length of the specimen, which are applied directly to the testing object by clamping.

Strain gauges are sensors, mostly glued on the specimen’s surface to measure strain variation inside the specimen du to changing resistance with changing applied forces.

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Both devices measure changes during the test and send automatically the measured information to the used software to generate live force-strain diagrams.

In this test, several parameters are measured to understand the material's behavior under load such the applied elongation, strains and stress-strain-curves. Some of the most important mechanical properties are for example:

Elastic modulus: Material's stiffness or resistance to deformation under load [1].

Yield strength: The stress at which a material begins to exhibit plastic deformation.

Ultimate tensile strength: The maximum stress a material can withstand before failure.

Ductility: The ability of a material to deform plastically before fracturing.

Toughness: The ability of a material to absorb energy before fracture [1].

The tested specimen consists of Titanium Grade 5, also known as Ti-6Al-4V, which is a commonly used titanium alloy. It is composed of 90% titanium, 6% aluminum, and 4% vanadium. Titanium Grade 5 exhibits excellent strength-to-weight ratio, corrosion resistance, and biocompatibility, making it suitable for various applications, including aerospace and biomedical industries [1].

Some of the most important properties [2]:

- Tensile Strength, ultimate: 950 MPa
- Tensile Strength, yield: 880 MPa
- Modulus of Elasticity: 113.8 GPa = 113800 MPa
- Elongation at Break: 14%

PRECAUTIONS:

To guarantee good testing results, some of these crucial considerations and potential sources of errors need to be considered:

- Preparation of the specimen concerning SFS-EN ISO 6892-1:2019 Method of tensile testing at room temperature [3]:
    - Grind the surface (in our case P500)
    - Clean the surface by wiping in one direction till there is no more dirt visible
    - Apply adhesive to the bonding site and place the strain gauge in the center of the specimen
    - Press and hold for one minute until the adhesive is completely dried
- Testing conditions concerning standards and manufacturer information for the used test equipment should be observed (temperature ~21 degree room temperature , speed control, …)

THEORY

In the elastic range, strain given by Hook's law and can be calculated the following way:

$$\varepsilon = \frac{\delta}{E}$$

By knowing the applied forces and the resulting stresses, we can derive Young's module. To achieve this, strain rate epsilon dot is applied, which is given in the standard [3]:

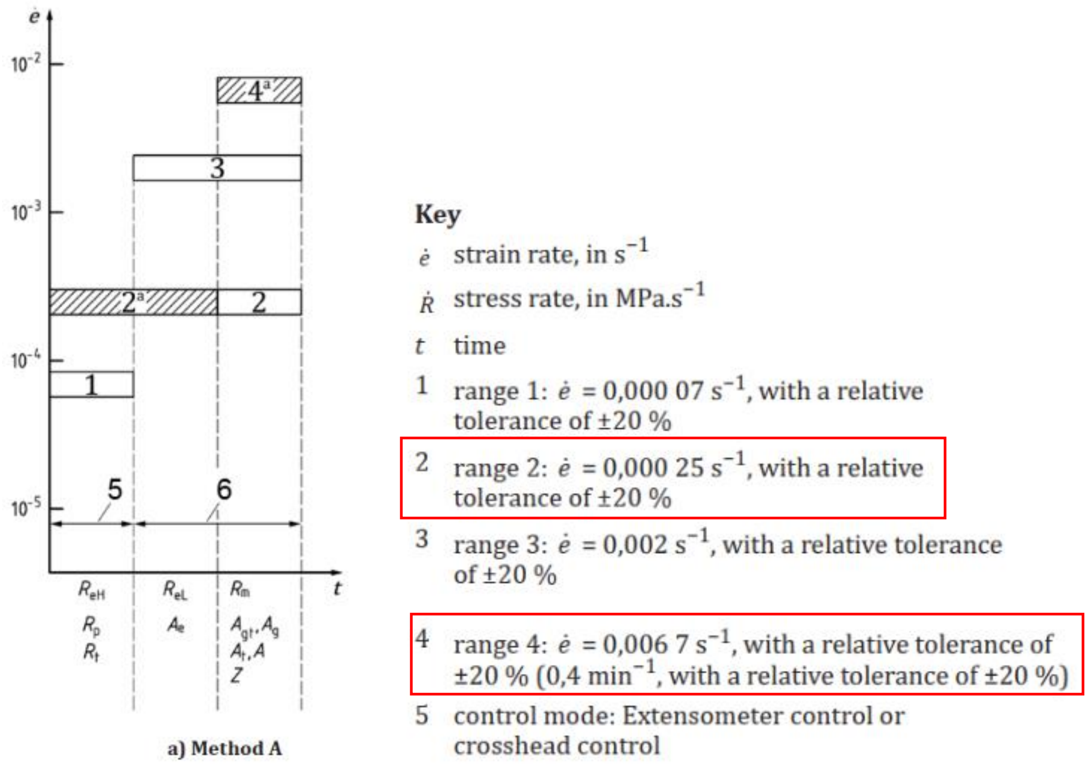

Figure 1: strain rate determination concerning SFS EN-ISO 6892-1:2019

For the first run, the rate in range 2 was chosen, range 4 for the second run. Considering a length of interest of 100 mm, leads to the applied testing speed

$$v = \dot{e} * l$$

$$v_1 = 0.000\,25 \frac{1}{s} * 100\,mm = 0.025 \frac{mm}{s} = \mathbf{1.5} \frac{\boldsymbol{mm}}{\boldsymbol{min}}$$

$$v_2 = 0.00\,67 \frac{1}{s} * 100\,mm = 0.67 \frac{mm}{s} = \mathbf{40.2} \frac{\boldsymbol{mm}}{\boldsymbol{min}}$$

As you will see, the testing speed was increased in the first range to 2 mm/min to get faster results and for the second run, testing speed was increased up to 6 mm/min.

By knowing the applied forces F, stresses sigma can derived:

$$\delta = \frac{F}{A}$$

Young's modulus can be then calculated as

$$E = \frac{\delta}{\varepsilon}$$

EXPERIMENTAL SETUP

In this experiment, strain was measured using the strain gauges and the extensometer. For this purpose, strain gauges were used to measure the transverse strain while extensometer measured the lateral or strain along the specimen's axis.

The experimental setup consists of a tensile tester having electromechanical puller for applying axial or tensile load on the specimen in the range of 30kN. The specimen under the application of this force develops strain and as the stress level reaches the point where the specimen can no longer be strained, it breaks. This point is called the ultimate tensile strength of the material. At some point plastic deformation is starting, which is called the yield point for that specific material. The software automatically plots a graph against applied force and strain which clearly indicate the point where yielding starts and where the material breaks.

The specimen's original dimensions:

- Original length l_0 = 200 mm
- Original width b_0 = 20 mm
- Original thickness t_0 = 0.58 mm
- Original cross section A_0 = 11.60 mm^2

In comparison to a common tensile test for metals, the specimen wasn't shaped like the usual hourglass due to the fact that the sample was taken from the sheet metal itself. While applying the forces on via the crosshead, the surrounding material gets compressed, resulting in higher material stresses, which cause interferences in the test results. To avoid this effect, the testing object's length was divided into several parts:

- 2x 50 mm clamped zone
- 1x 100 mm testing zone
    - 2x 10 mm transition zone
    - 1x 80 mm zone of interest

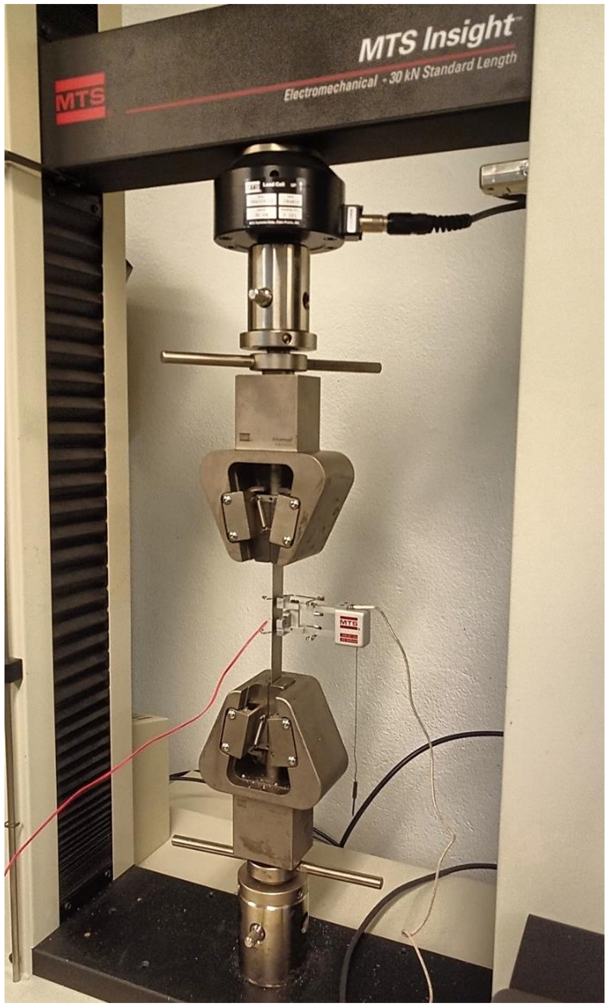

Figure 2: specimen clamped on the tester with extensometer clipped in axial direction

In this lab session, the extensometer was measuring the lateral strain with a speed of 2mm/min up to 3% strain. The chosen speed is higher than the calculated speed concerning the standard due to time management. After, the speed was supposed to be increased without unloading but due to wrong programming of the software, the force was completely removed. Because of this, a permanent deformation on the specimen was introduced.

The second time around, the extensometer was set for 1.5% strain measurement with a speed of 2 mm/min and an increasement up to 6 mm/min until the material breaks.

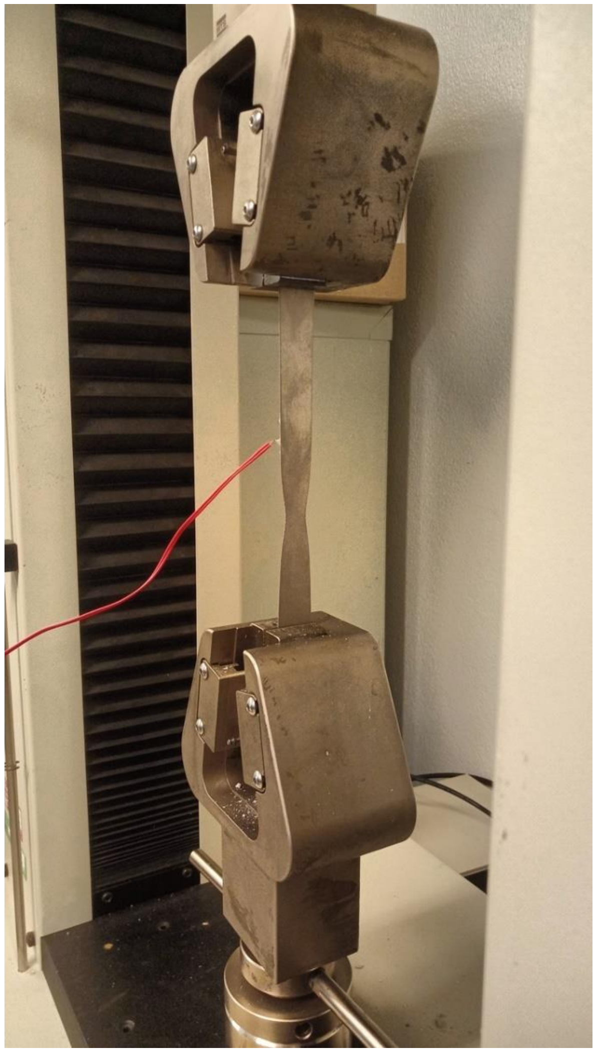

Figure 3: tested specimen during the second run after extensometer was removed

To get better and comparable results, two measurements were driven at the same time: tensile testing machine and the extension measurement through the catmanEasy V5.5.3 software. The resulting plots can be seen in the following section.

RESULTS AND INTERPRETATION

After running the second try, the testing object was pulled until the specimen broke as shown in Figure 4. As you can see, the crack didn't occur in the middle of the testing zone, where the strain gauge is located. When looking at Figure 5 we can see that in this region, the glue for the strain gauge is applied. This leads to the assumption that the applied glue affects the material properties by increasing tensile strength in this specific area.

When comparing the initial length interest and the resulting length after the tensile test, we can observe that we got an extension of 35 mm (115 mm/80 mm = 143.75%). As the extensometer is only able to measure accurate strains in the range up to 3-5%, we can only work with the measured results from the tensile machine itself.

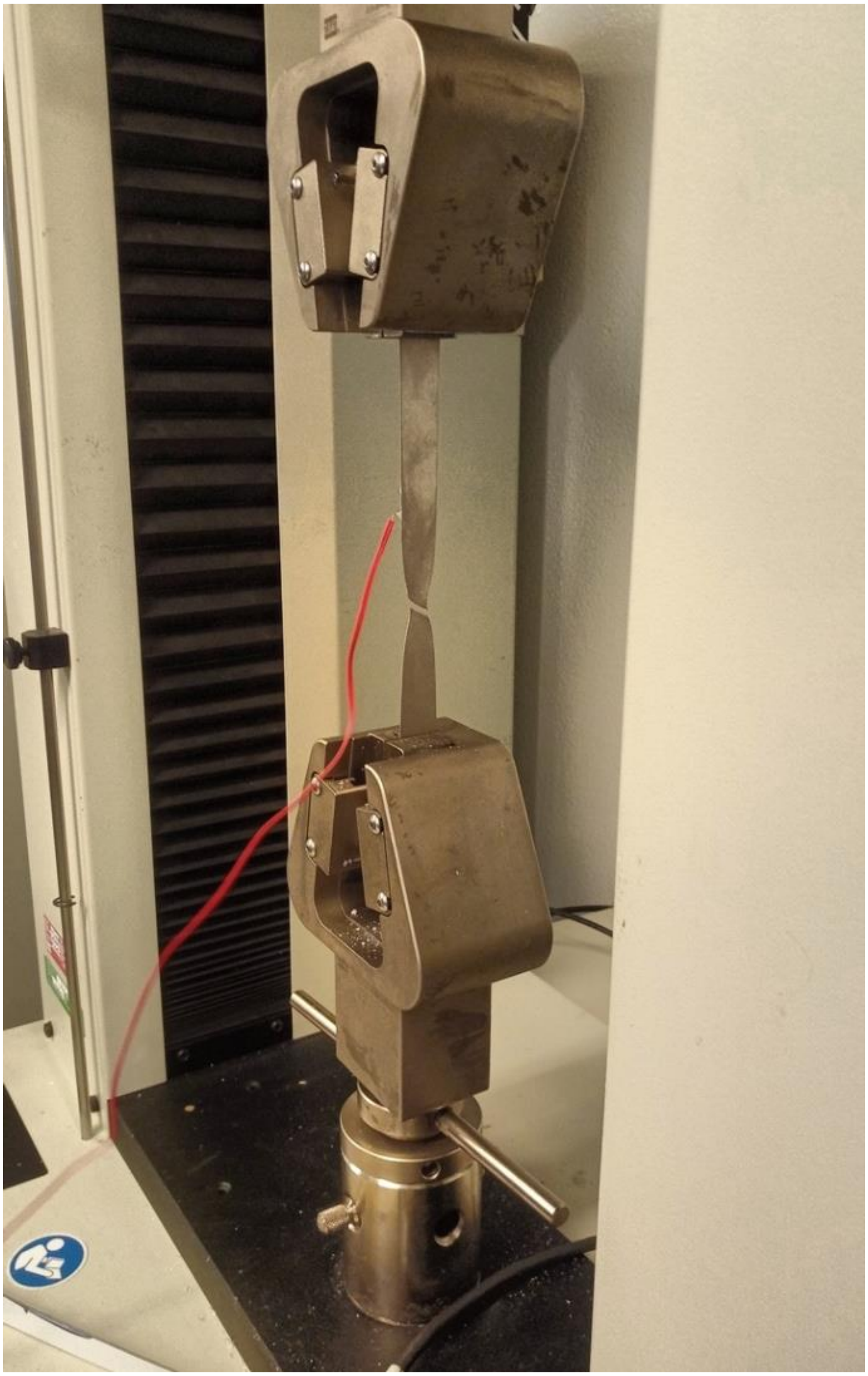

Figure 4: broken specimen after the ultimate tensile strength was reached

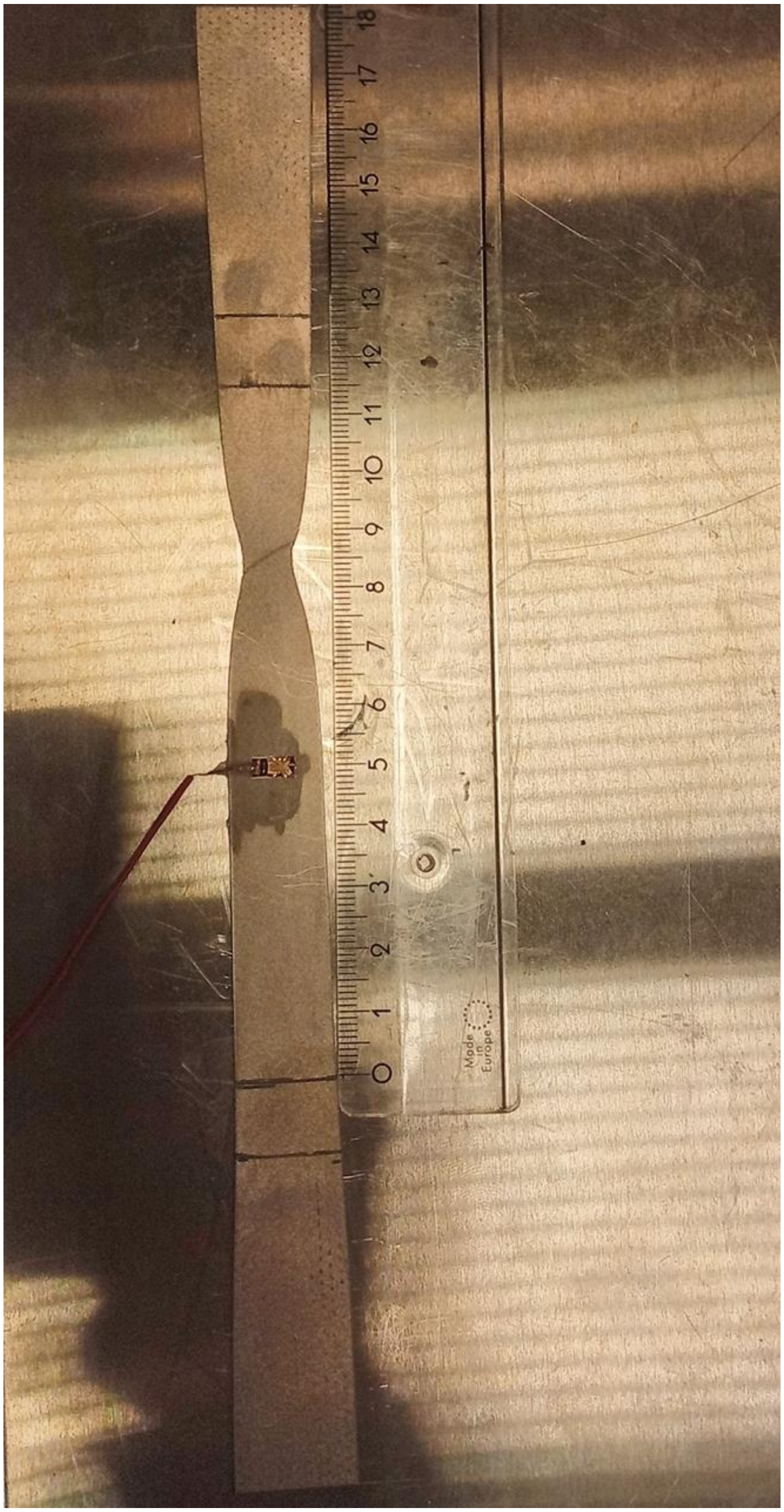

Figure 5: plastic deformation of the specimen after material breaking

As mentioned before, two tests were driven at the same time to get comparable results. The measured forces and strains of both tests can be seen in the following figures. Figure 6 and Figure 7 are showing the resulting plots of strains (x-axis) and applied forces (y-axis). As you can see, the curve is linearly increasing up to ~0.5% strain before a slower slope starts. This indicates the beginning of plastic deformation. The tensile test was continued until 3% strain were reached. After, the force was removed which you can also see in the plot.

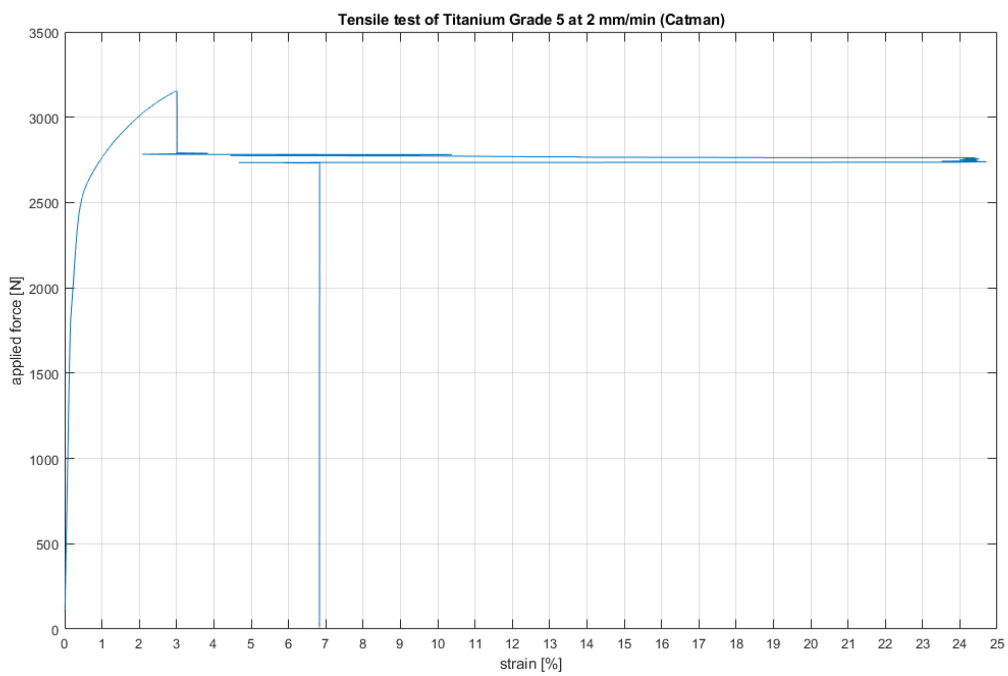

Figure 6: first run with Catman software

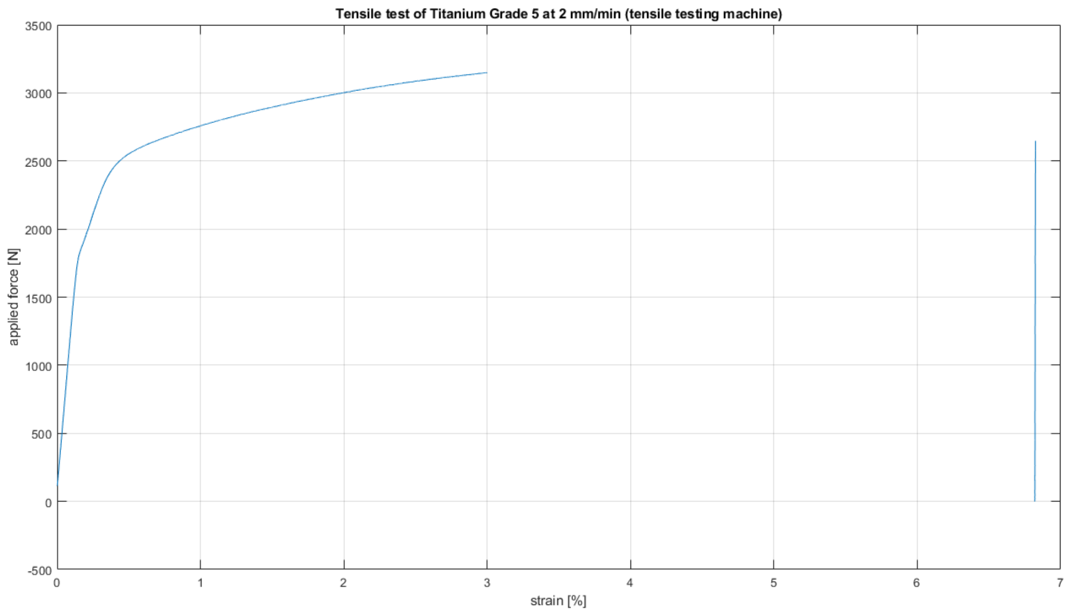

Figure 7: first run with tensile testing machine

In Figure 8 and Figure 9 the second try with increasing testing speed up to 6 mm/min after reaching 1.5% strain are plotted. As you can see, through introducing a permanent deformation, we got a hardening effect which is increasing tensile strength of the specimen. At around 21% strain we can see that the measurement stops so ultimate tensile strength is reached.

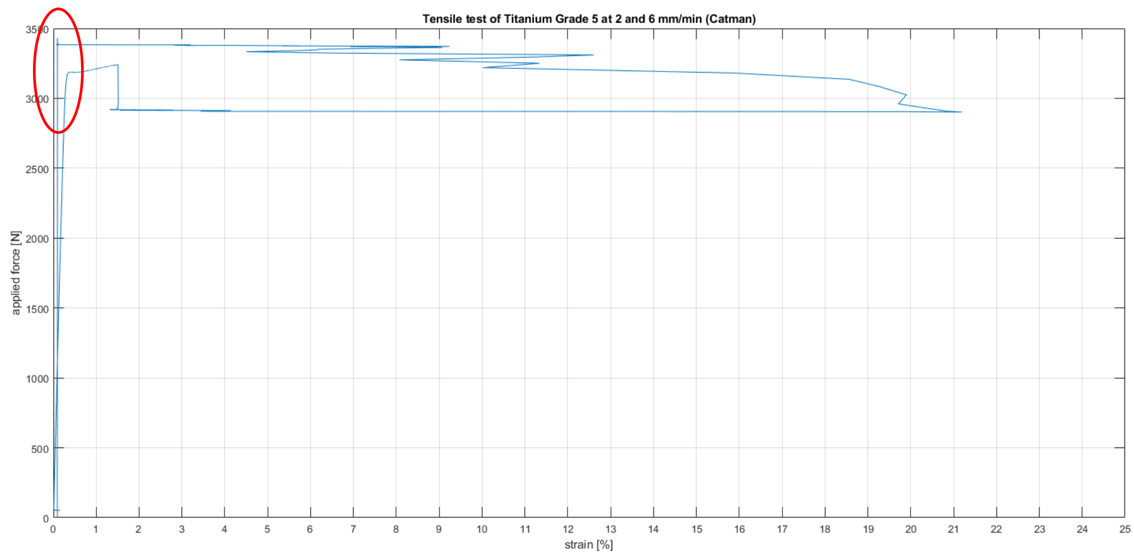

Figure 8: second run with Catman software

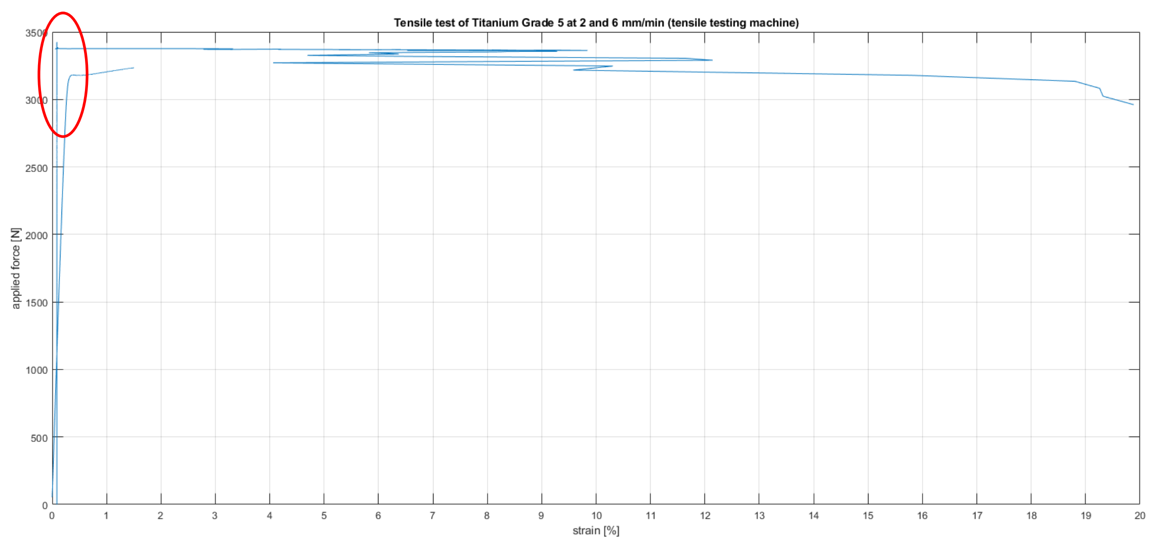

Figure 9: second run with tensile testing machine

CONCLUSION AND COMPARISON WITH MECHANICAL PROPERTIES

As already mentioned in the introduction, the mechanical properties of Titanium Grade 5 are the following:

- Tensile Strength, ultimate: 950 MPa
- Tensile Strength, yield: 880 MPa
- Modulus of Elasticity: 113.8 GPa = 113800 MPa
- Elongation at Break: 14%

In Figure 10 and Figure 11 the resulting stresses of the second run are plotted as a function of strain.

As Young's modulus is given by

$$E = \frac{\delta}{\varepsilon}$$

We can see that our specimen isn't reaching the expected values. When looking at the applied stresses, we can also see that our tested results do not match with the given data from source 2. Also the elongation of the specimen is much longer than it should be considering the given data of 14% (in comparison 43.75%). This could be due to the hardening effect caused by the introduced permanent deformation in the first run.

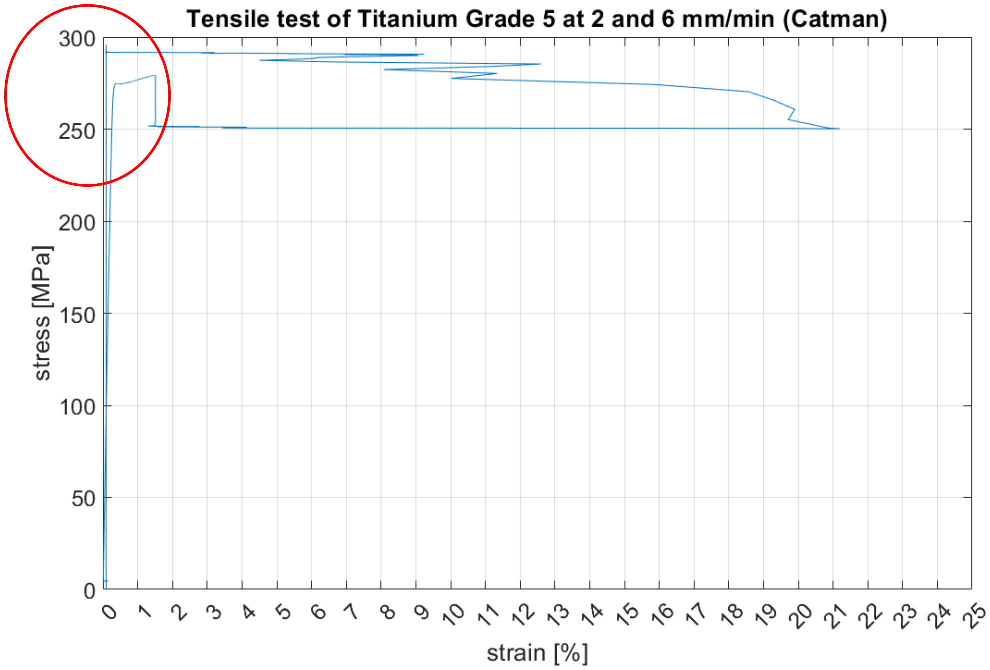

Figure 10: resulting stresses as a function of strain, second run Catman software

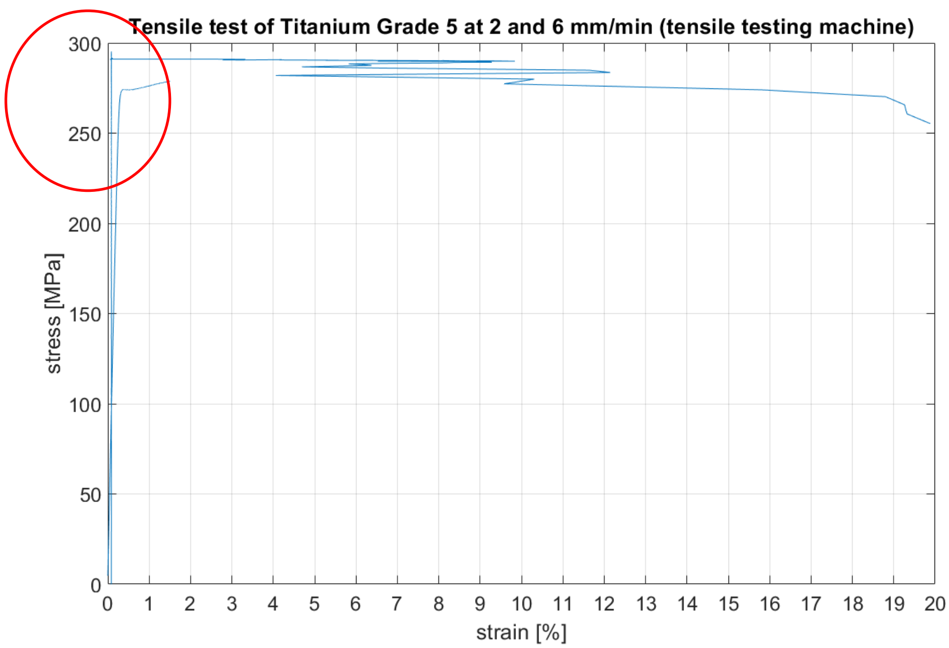

Figure 11: resulting stresses as a function of strain, second run tensile testing machine

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REFERENCES

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2. ASM Aerospace Specification Metals Inc: Titanium Ti-6Al-4V (Grade 5), Annealed [https://asm.matweb.com/search/SpecificMaterial.asp?bassnum=mtp641]
3. SFS-EN ISO 6892-1:2019 Method of tensile testing