Max-Planck-Institut
für Plasmaphysik

Report on

HHF testing of W-monoblock mock-ups made by VITZRO Nextech
PO No. : VNT-201013

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2020/12/16
rev. 2021/01/08

Executive Summary

This report presents results of high heat flux tests performed on three actively water-cooled W monoblock mock-ups made by VITZRO Nextech. The mock-ups named “sample 1, 2” and “Spare” were tested in the HHF test facility GLADIS at IPP Garching in November 2020. The following tests are summarized in this report according to the agreed test procedure:

1. Screening tests 6 - 20 MW/m² of all samples, each loading step 5 pulses with 30 s duration, water-cooling parameter: v=12 m/s axial velocity, 20°C inlet and a static system pressure of 1MPa,
2. Low cycle fatigue tests of sample 1 &2, each 100 x 10 MW/m², 10 s duration
3. Cycling tests of sample 1 &2, each 500 cycles 20 MW/m², 10 s duration, water-cooling parameter: v=12 m/s axial velocity, 20°C inlet, 1MPa static system pressure.
4. All samples survived in good conditions, no detectable bonding defects, cracks or notable surface modification occurred during the HHF tests. We did not detect any degradation of the mock-ups.

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Abbreviations

HHF	High Heat Flux
IR	Infra red
W	Tungsten
ε	Emissivity
T-KLEIB	One-color pyrometer, type KLEIBER KMGA 740, limit 3500 °C
T-QKTR	Two-color pyrometer, with digital quotient calculation, type Maurer QKTRD 1075, limit 1700 °C

1 Introduction, aim of HHF tests

The HHF tests were performed to support the qualification of actively water-cooled W monoblock mock-ups.

Fig. 1: Samples after arriving at IPP.

All HHF tests were performed in the H neutral beam test facility [1] at IPP Garching. Compared to the loading in an electron beam test facility, scanning of a high energy electron beam, the test in a neutral beam facility offers a homogenous loading of the sample.

2 Loading and cooling conditions of the HHF tests

HHF tests of all three components with cooling water at room temperature were performed. This allowed the use of the vacuum lock system at GLADIS to reduce the operating effort and costs. All mock-ups were installed and tested individually in GLADIS. The mock-ups were installed in the horizontal direction, normal to the beam axis. The actively water cooled mock-ups reached the thermal equilibrium after ~7 s loading, meaning a constant temperature and stress profile across the component. Therefore, all cyclic tests were performed with 10 s loading followed by 50 or 80 s cooling, respectively. The applied hydrogen neutral beam (Gaussian profile with 150 mm FWHM) ensures a simultaneous and homogeneous heating of all monoblocks of the mockups as shown in figure 2.
This profile was measured during the test campaign to check the applied heat loading on the mock-ups according to the methode which is described in [1].

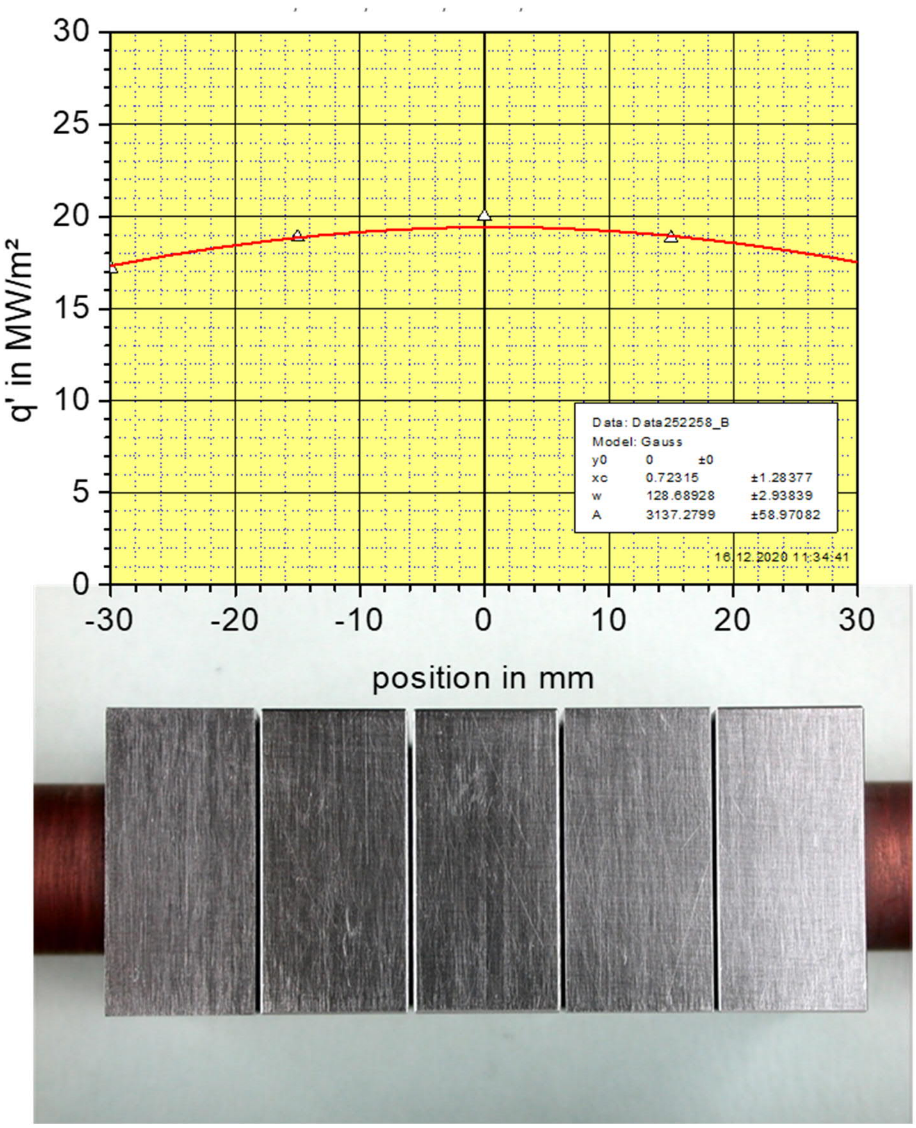


Fig. 2: Applied heat flux profile across the sample shown for the 20 MW/m² loading case.

The variation of the beam and diagnostics parameter is within ±5% during the performed tests. The surface temperature of the exposed mock-ups was measured with one- and two-colour pyrometers as well as monitored by an infrared camera Infratec VARIOCAM HD. The two-colour pyrometer (Ø8 mm focus, $\lambda = 1.4–1.75\ \mu m$, temperature range 500 °C–1700 °C) was used as reference for the emissivity (ε) determination of the one-colour pyrometer (Ø22 mm focus, $\lambda = 2.0–2.2\ \mu m$, temperature range 350 °C–3500 °C) and the IR camera.

All tests were performed at the following cooling conditions:

- Inlet water temp. 20 °C, axial velocity v=12 m/s, 1MPa static pressure,
- Calculated local critical heat flux (CHF), > 60MW/m²

3 Summary and results of HHF tests

3.1 Screening tests

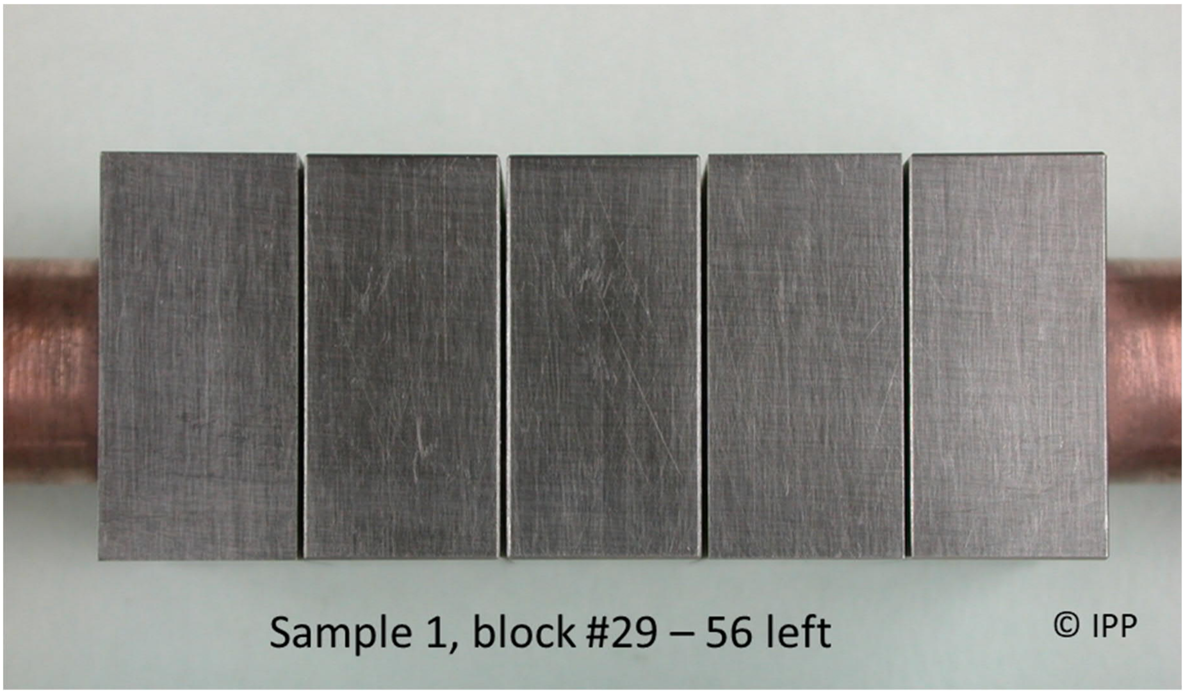


Fig. 3: High heat flux loaded surface of sample 1 before HHF tests

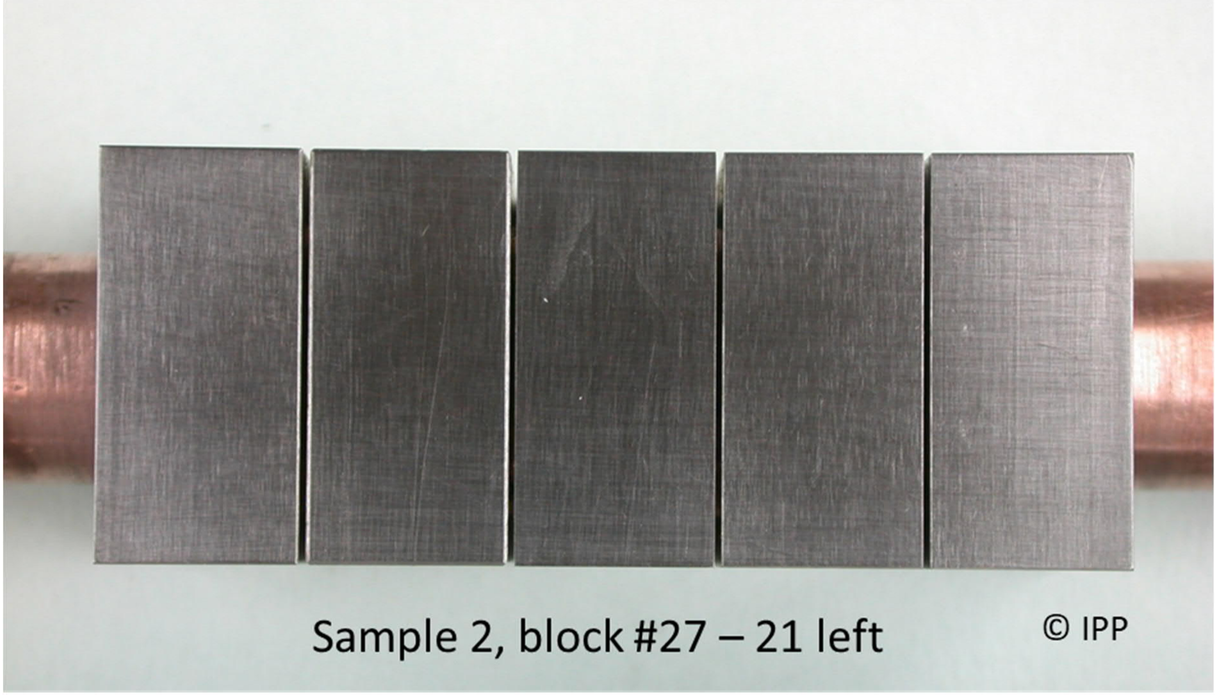


Fig. 4: High heat flux loaded surface of sample 2 before HHF tests

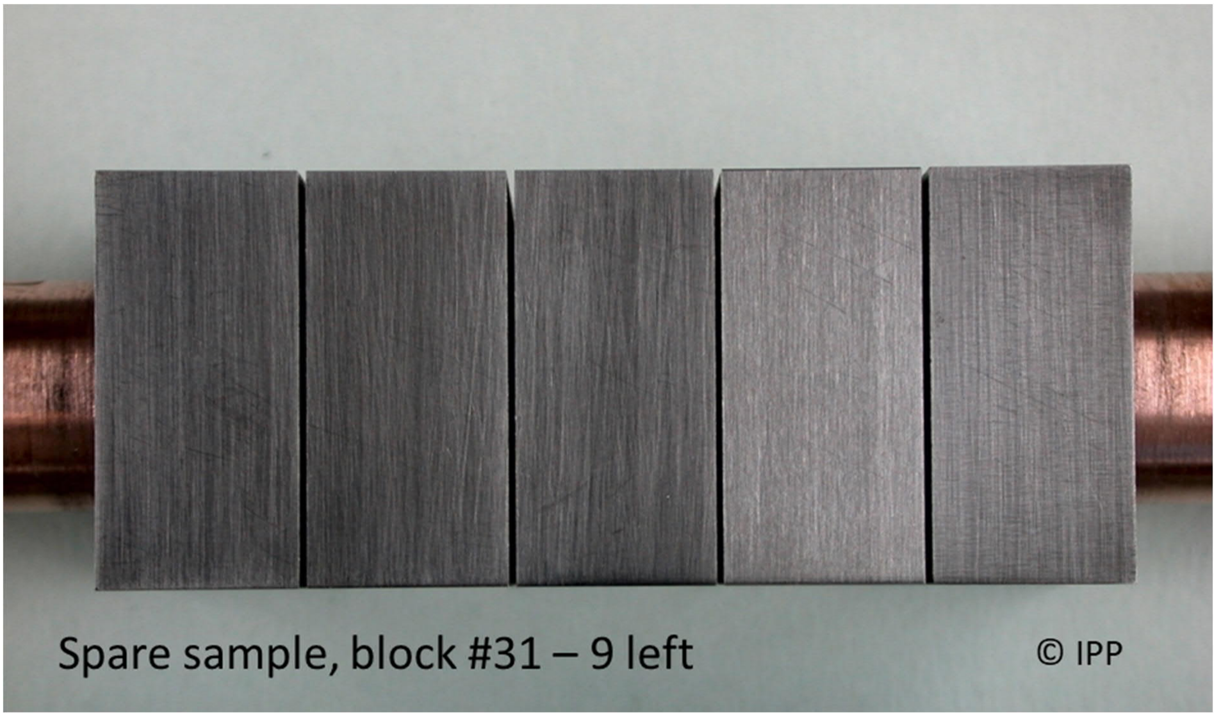


Fig. 5: High heat flux loaded surface of Spare sample before HHF tests

The results of the pyrometrically measured surface temperature of the screening tests are shown in Fig. 3. The applied pulse length was extended to 30 s each. Each data point presents the average of 5 pulses typically. The focus of the pyrometers was directed to the centre of block 3.

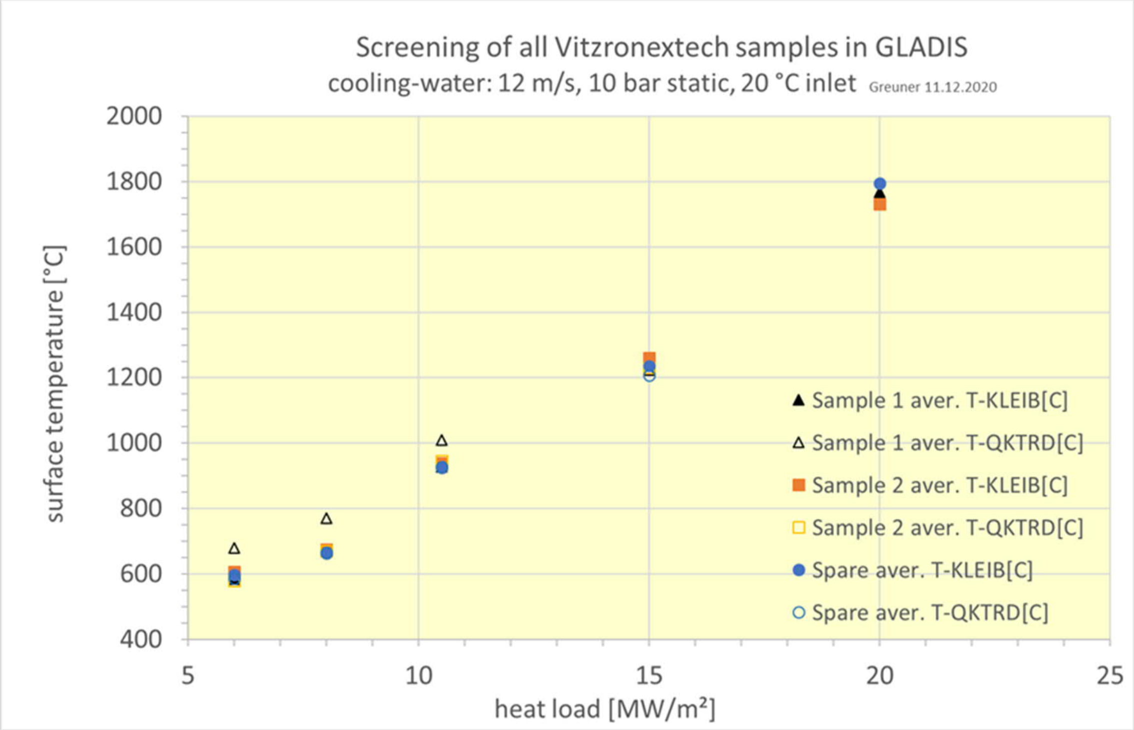


Fig. 6: Summary of the screening test of all samples. The one-colour pyrometer data (T-KLEIB) are recorded with ε= 0.3.

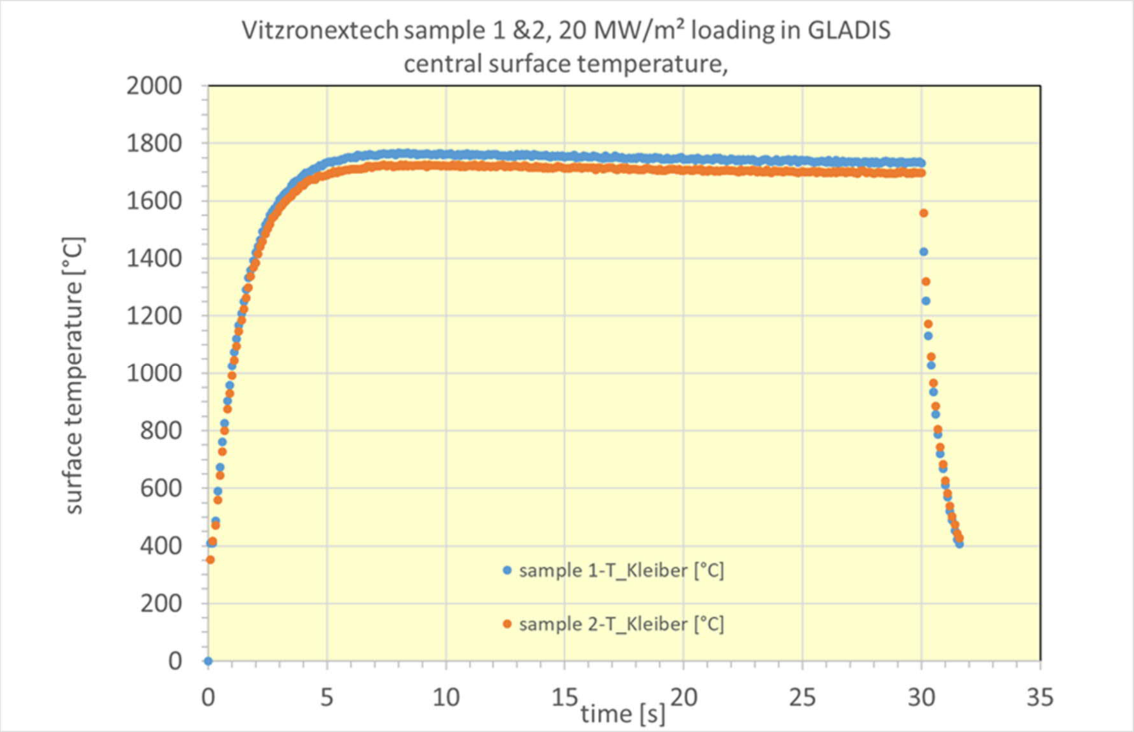


Fig. 7: Pyrometrically measured surface temperatures of sample 1 and 2 during the last 20 MW/m² screening pulse. The one-colour pyrometer data (T-KLEIB) are recorded with ε= 0.3.

3.2 10 MW/m² low cycle fatigue tests

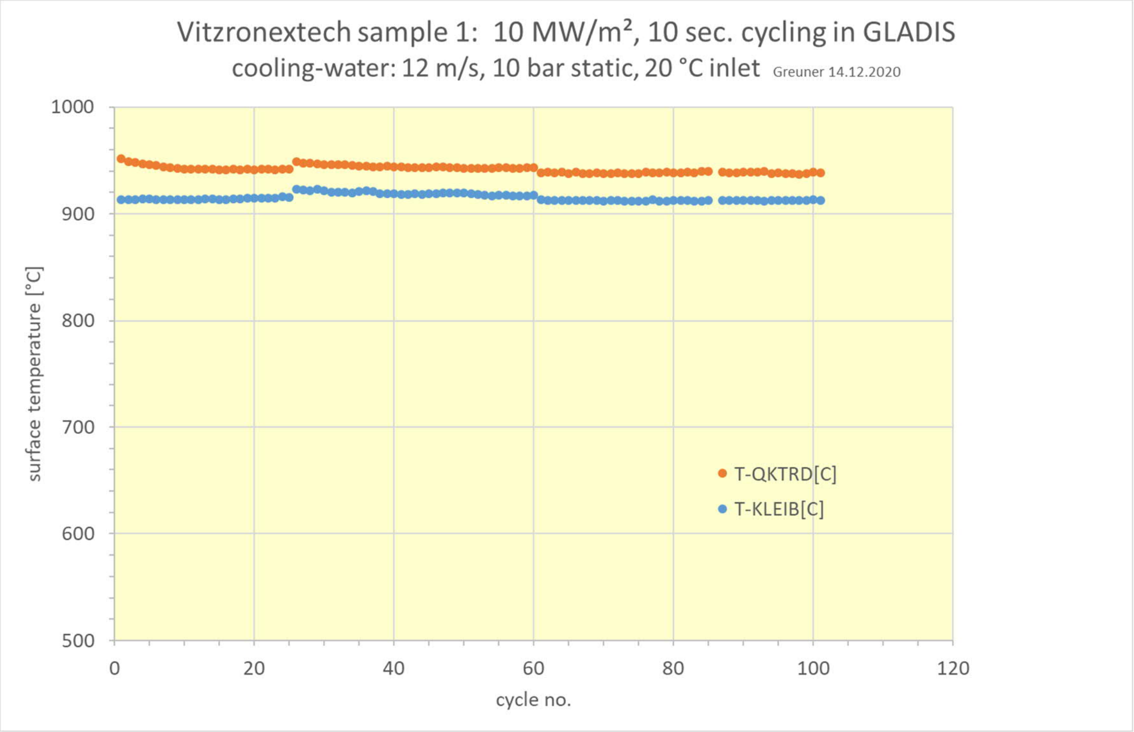


Fig.8: Pyrometrically measured surface temperatures of sample 1 during cycling at 10 MW/m². The one-colour pyrometer data (T-KLEIB) are recorded with ε= 0.3.

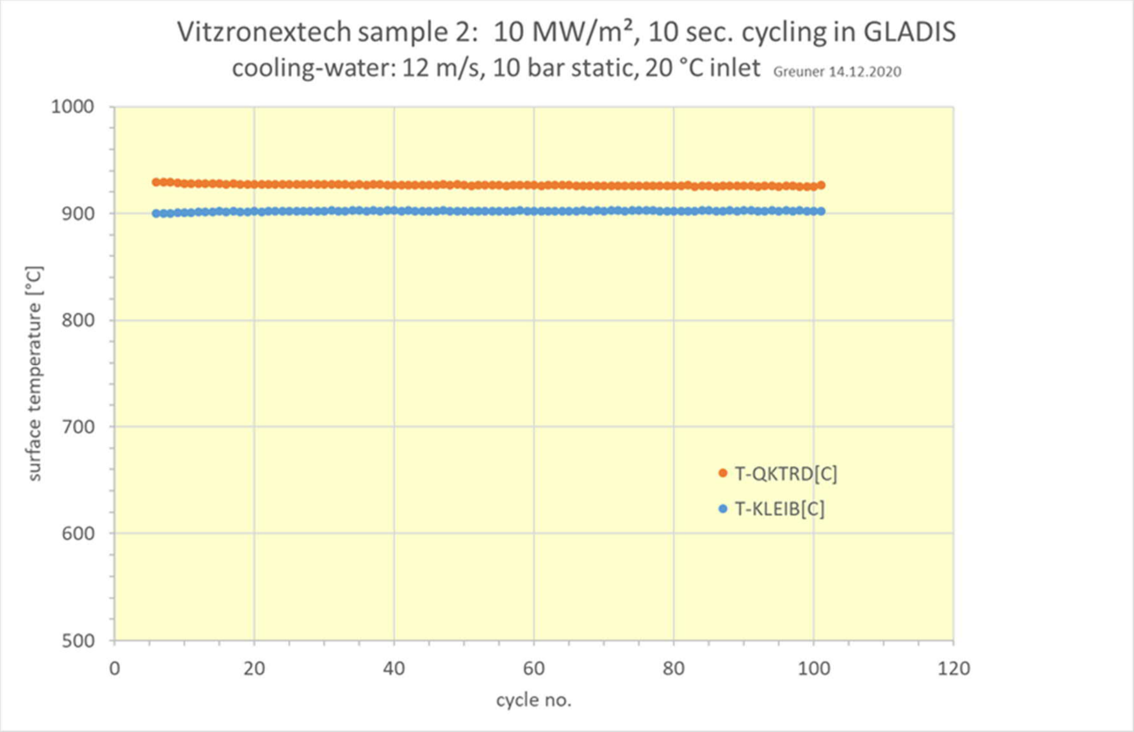


Fig. 9: Pyrometrically measured surface temperatures of sample 2 during cycling at 10 MW/m². The one-colour pyrometer data (T-KLEIB) are recorded with ε= 0.3.

3.3 20 MW/m² x 500 cycles tests

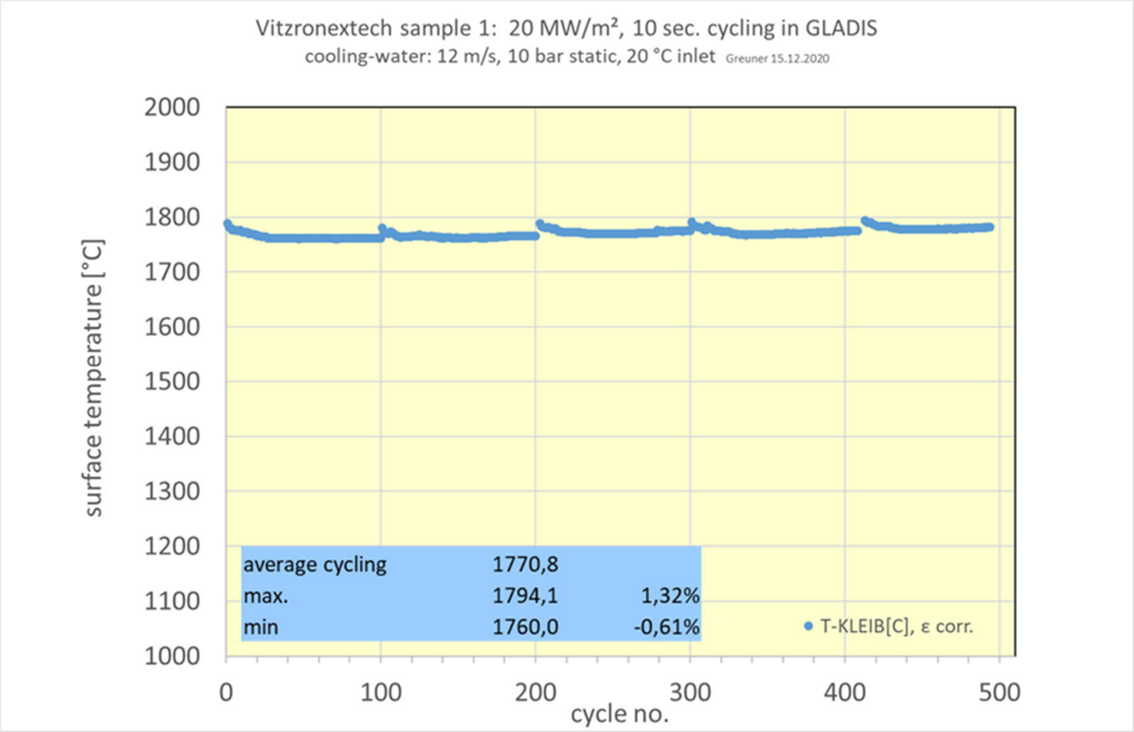


Fig. 10: Pyrometrically measured surface temperatures of sample 1 during cycling at 20 MW/m². The one-colour pyrometer data (T-KLEIB) are recorded with ε= 0.3 – 0.34.

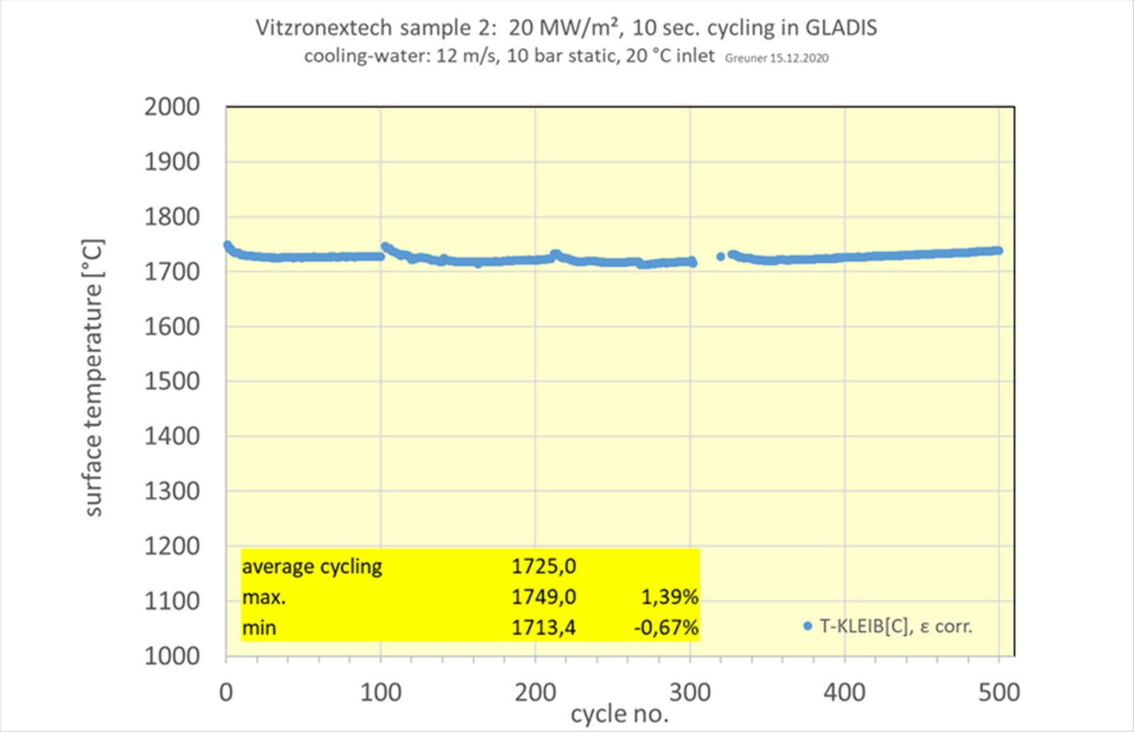


Fig. 11: Pyrometrically measured surface temperatures of sample 2 during cycling at 20 MW/m². The one-colour pyrometer data (T-KLEIB) are recorded with ε= 0.3 – 0.355.

3.4 Surface images during 20 MW/m² cycling test

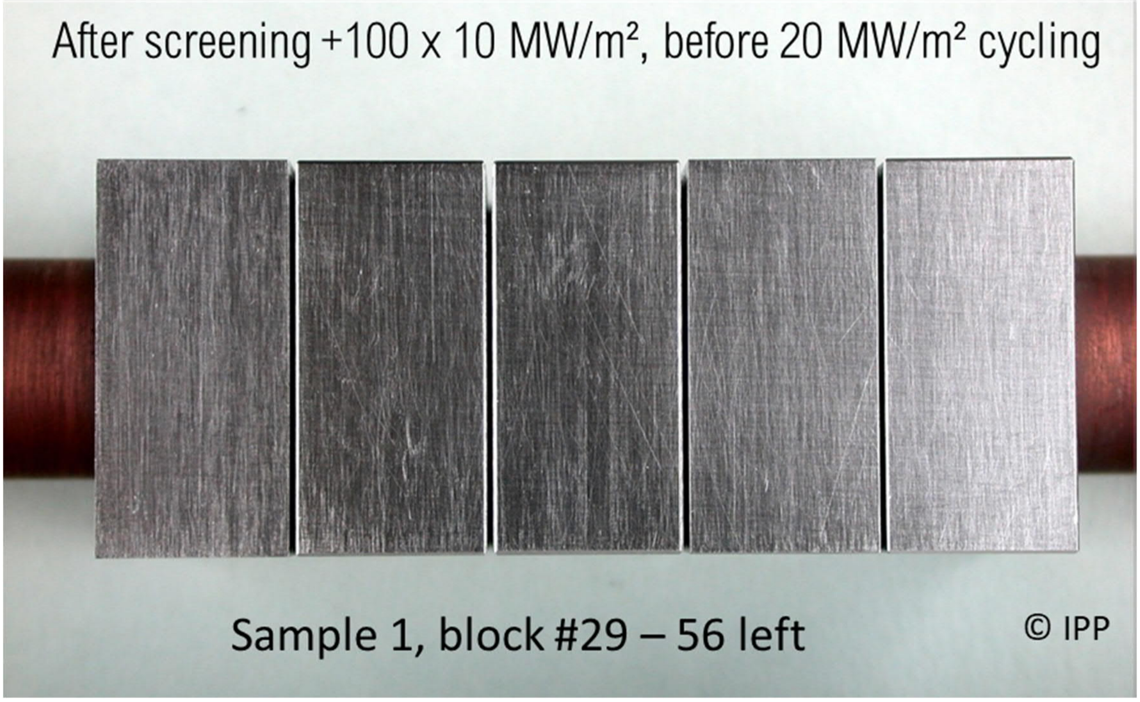


Fig. 12: High heat flux loaded surface of sample 1 before cyclic 20 MW/m² loading.

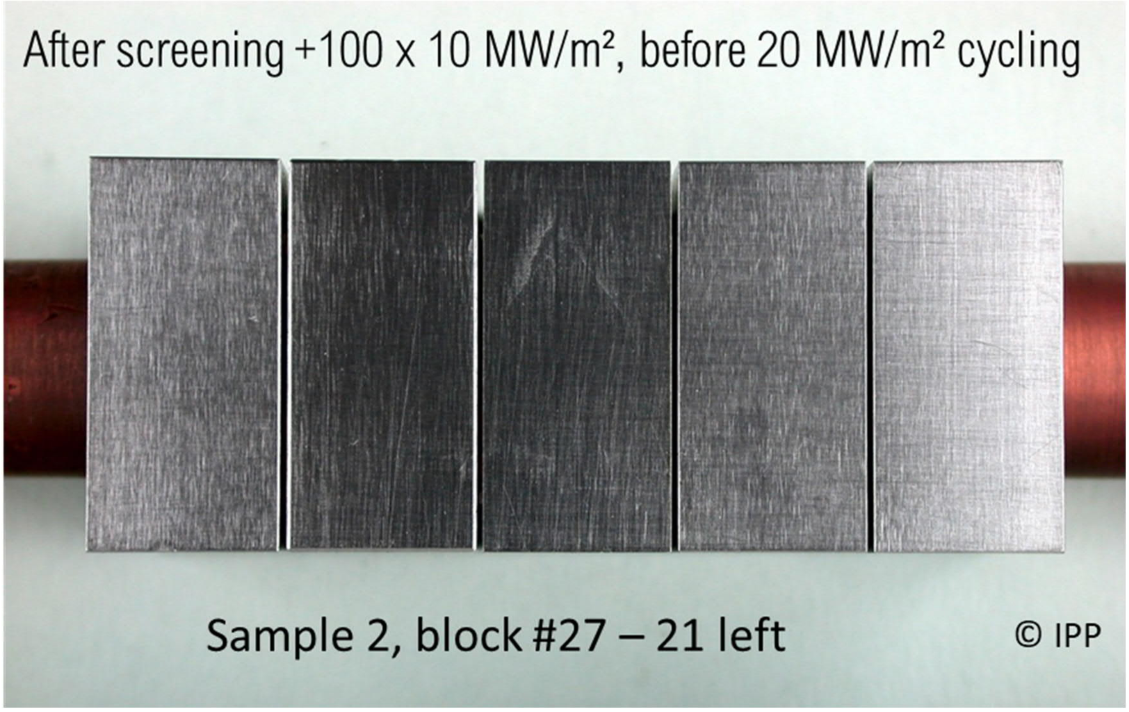


Fig. 13: High heat flux loaded surface of sample 2 before cyclic 20 MW/m² loading.

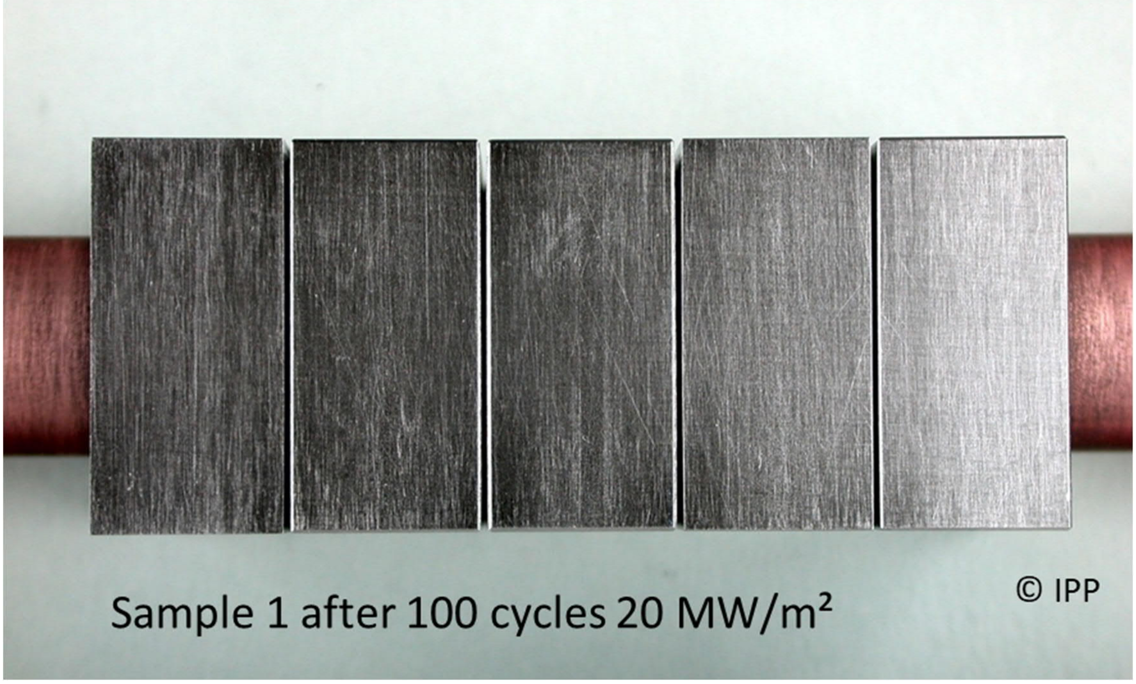


Fig. 14: High heat flux loaded surface of sample 1 after 100 cycles at 20 MW/m².

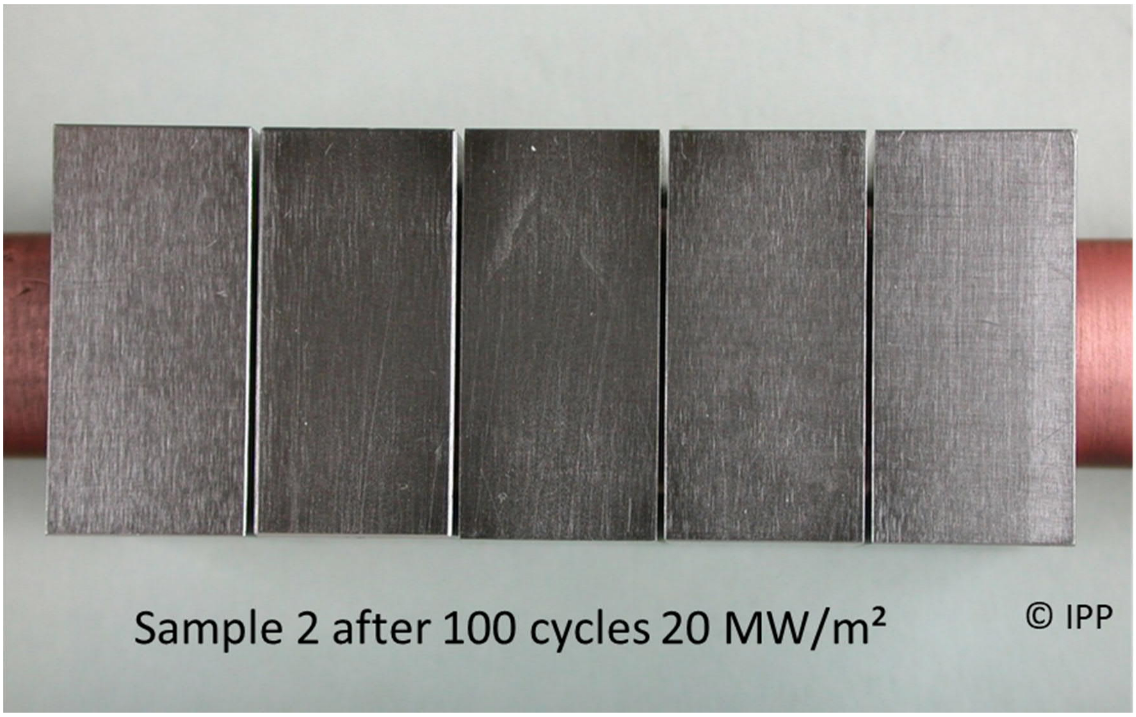


Fig. 15: High heat flux loaded surface of sample 2 after 100 cycles at 20 MW/m².

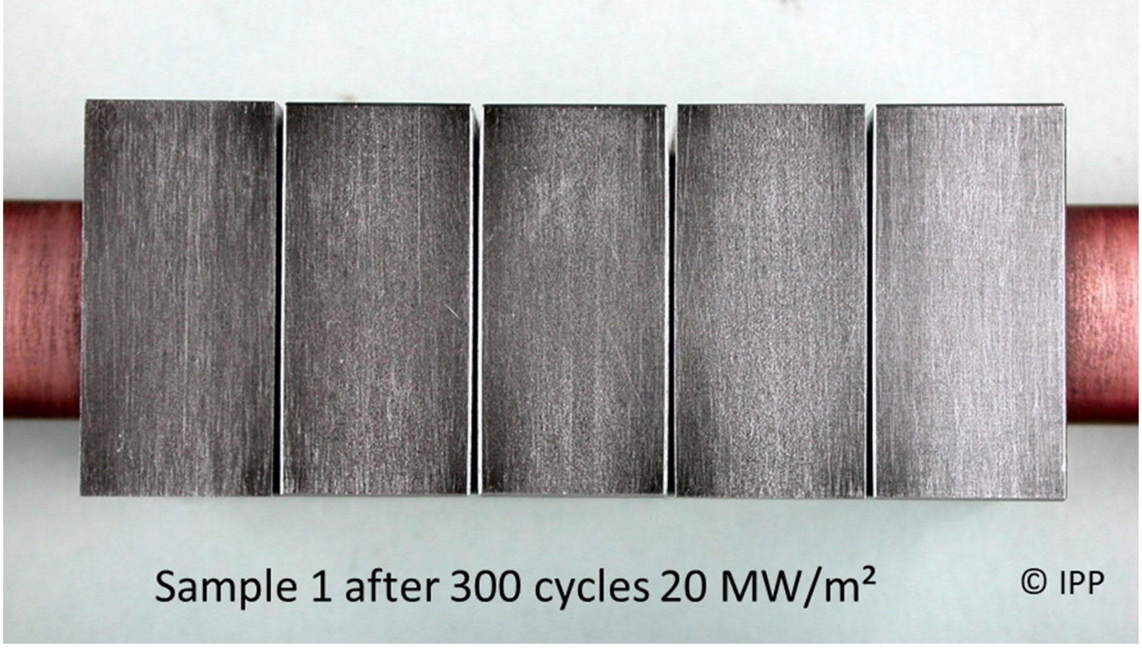


Fig. 16: High heat flux loaded surface of sample 1 after 300 cycles at 20 MW/m².

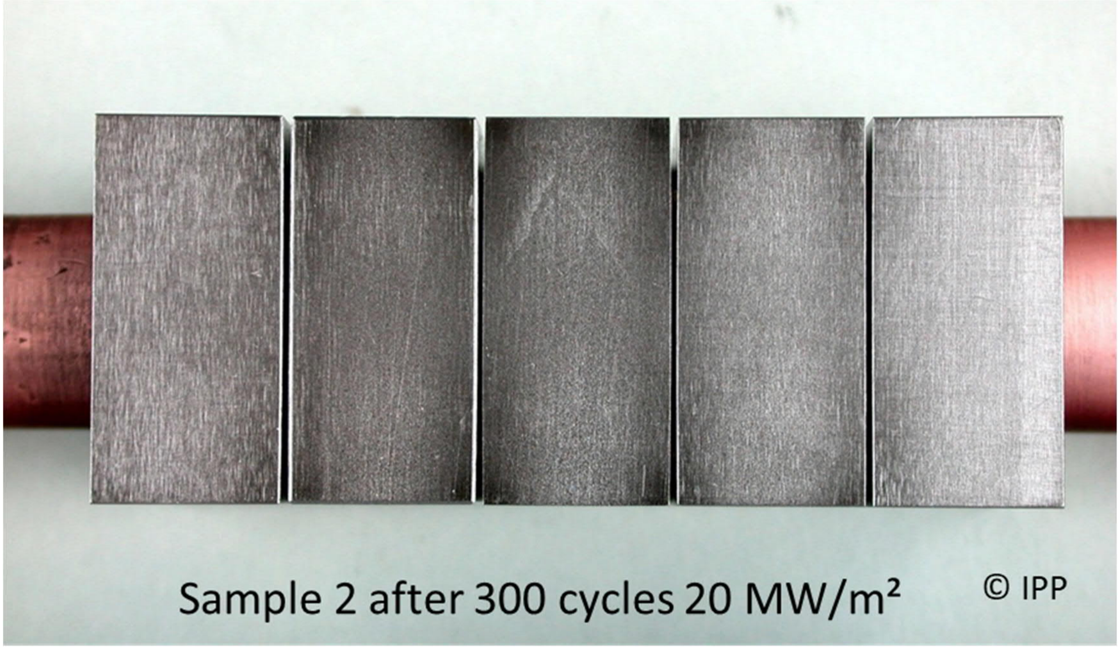


Fig. 17: High heat flux loaded surface of sample 2 after 300 cycles at 20 MW/m².

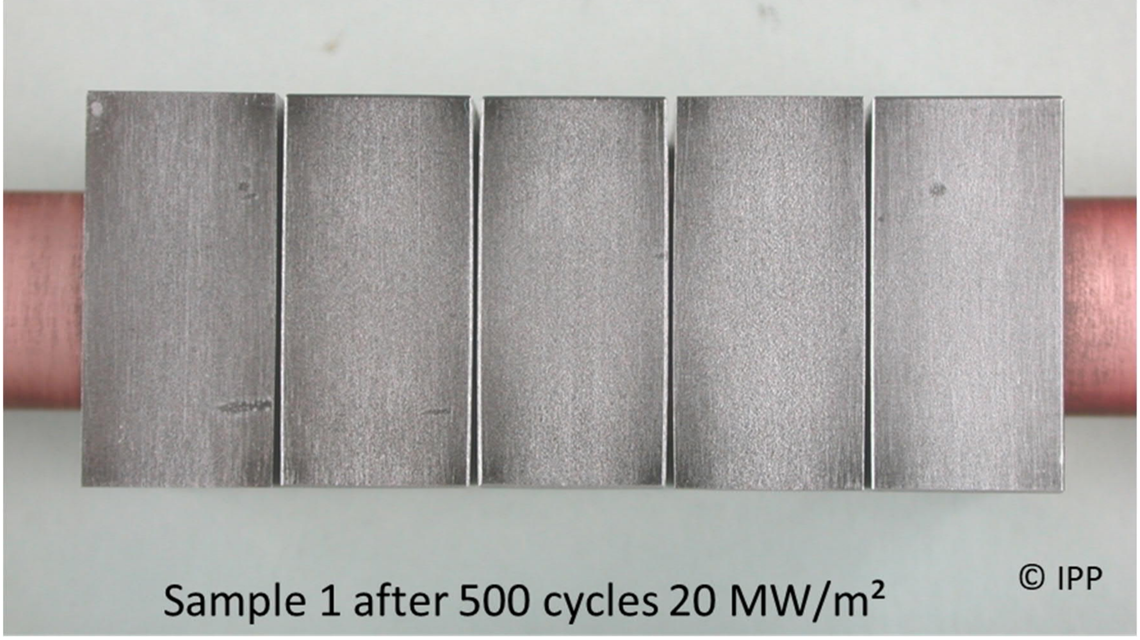


Fig. 18: High heat flux loaded surface of sample 1 after 500 cycles at 20 MW/m².

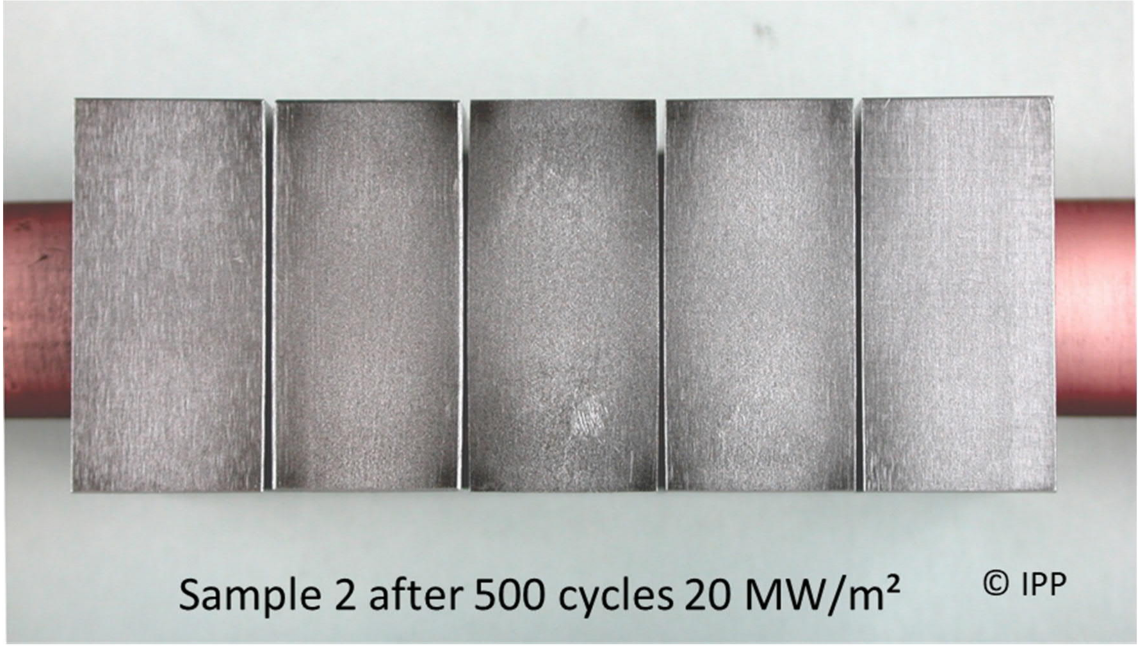


Fig. 19: High heat flux loaded surface of sample 2 after 500 cycles at 20 MW/m².

3.5 IR images of cycling at 20 MW/m²

All IR images were taken in the steady state phase at the end of each pulse.

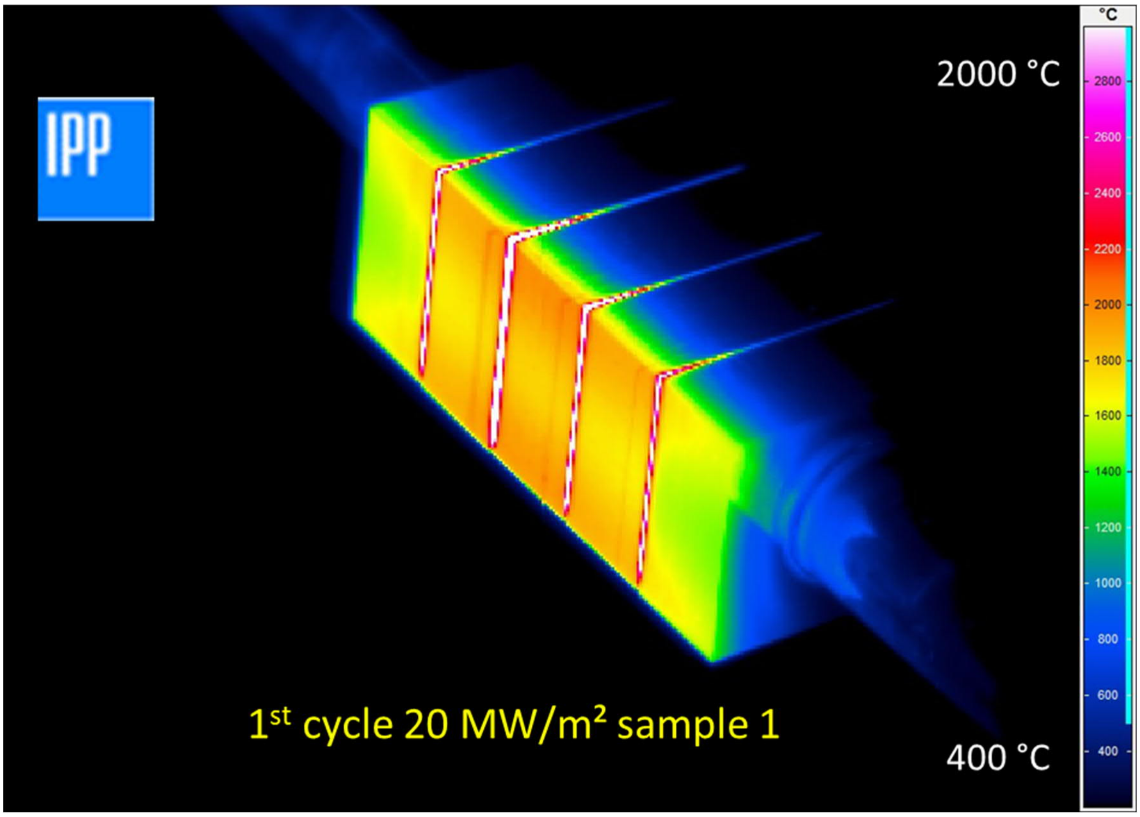
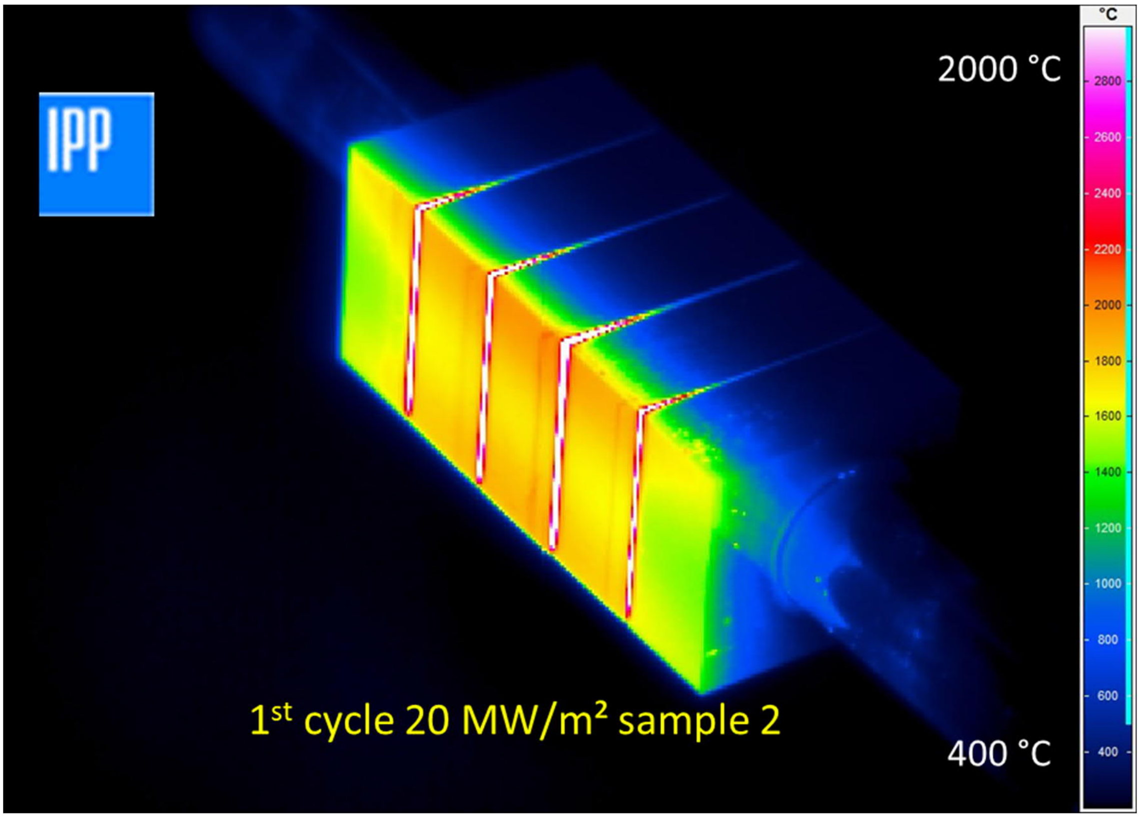


Fig. 20 (top), Fig. 10 (down): IR images during 20 MW/m² cycling.



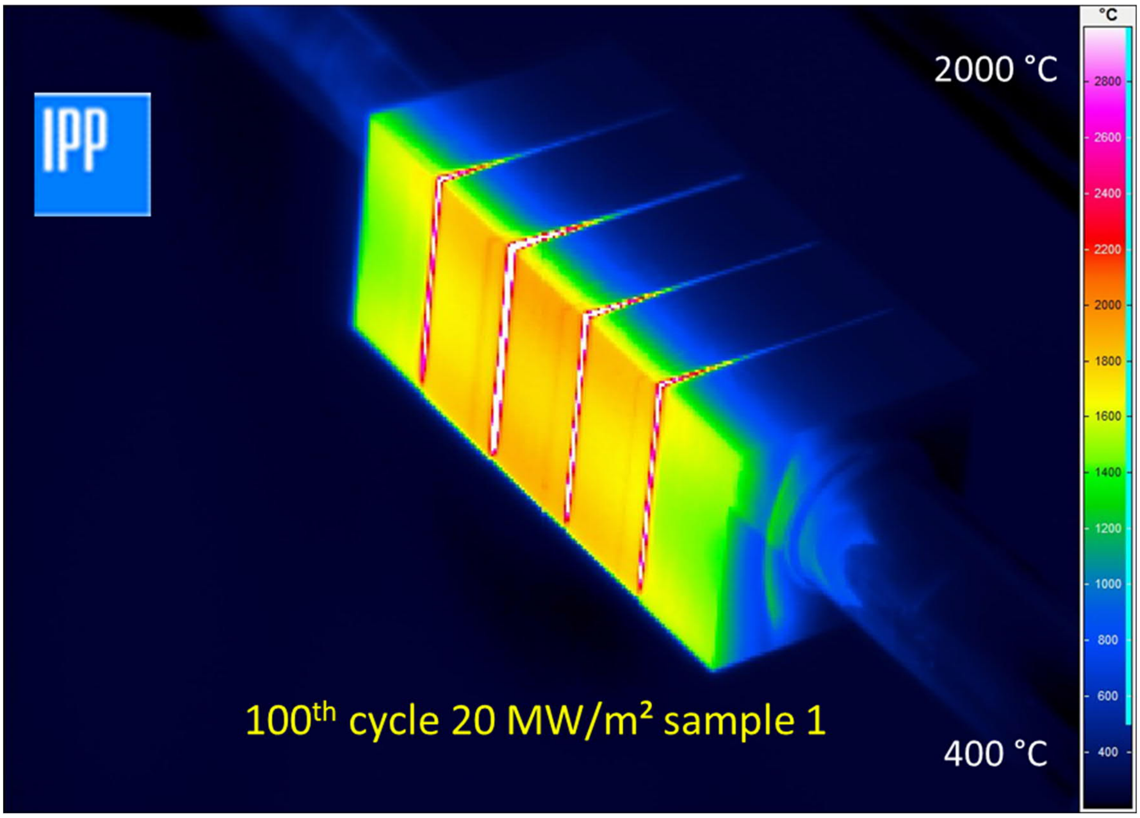


Fig. 21: IR image during 20 MW/m² cycling.

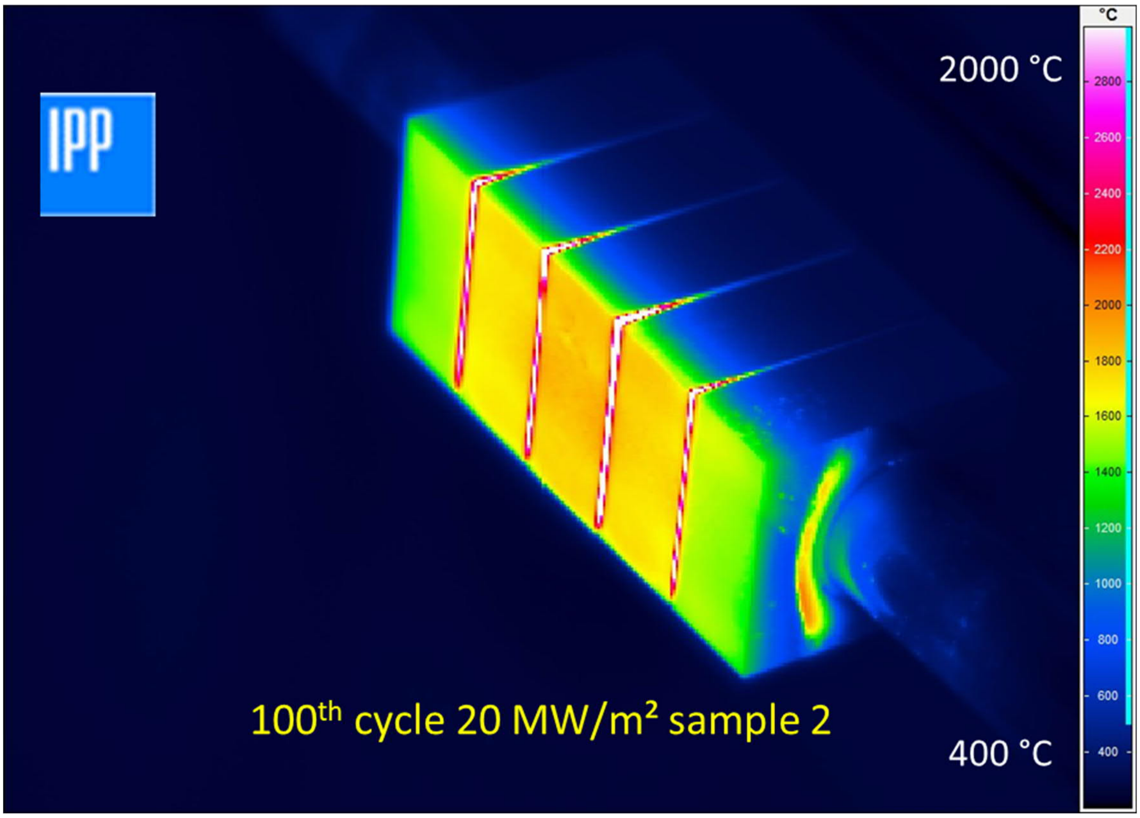


Fig. 22: IR image during 20 MW/m² cycling.

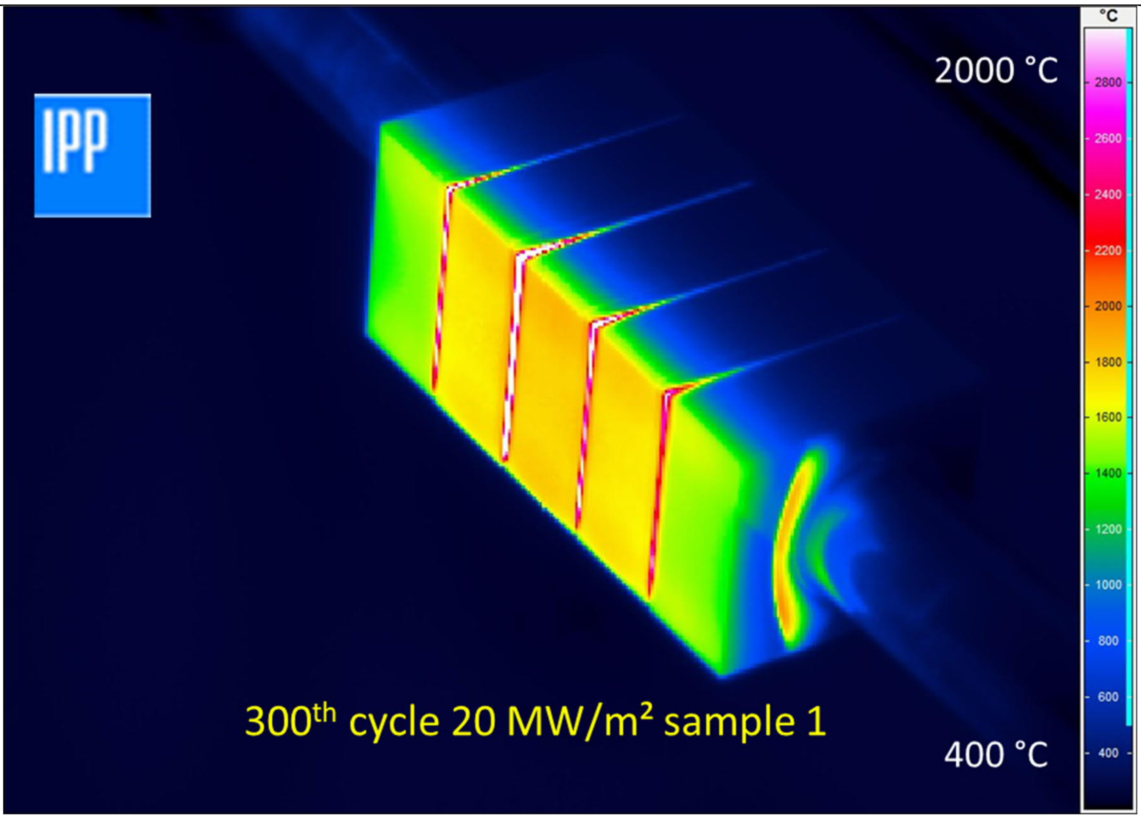


Fig. 23: IR image during 20 MW/m² cycling.

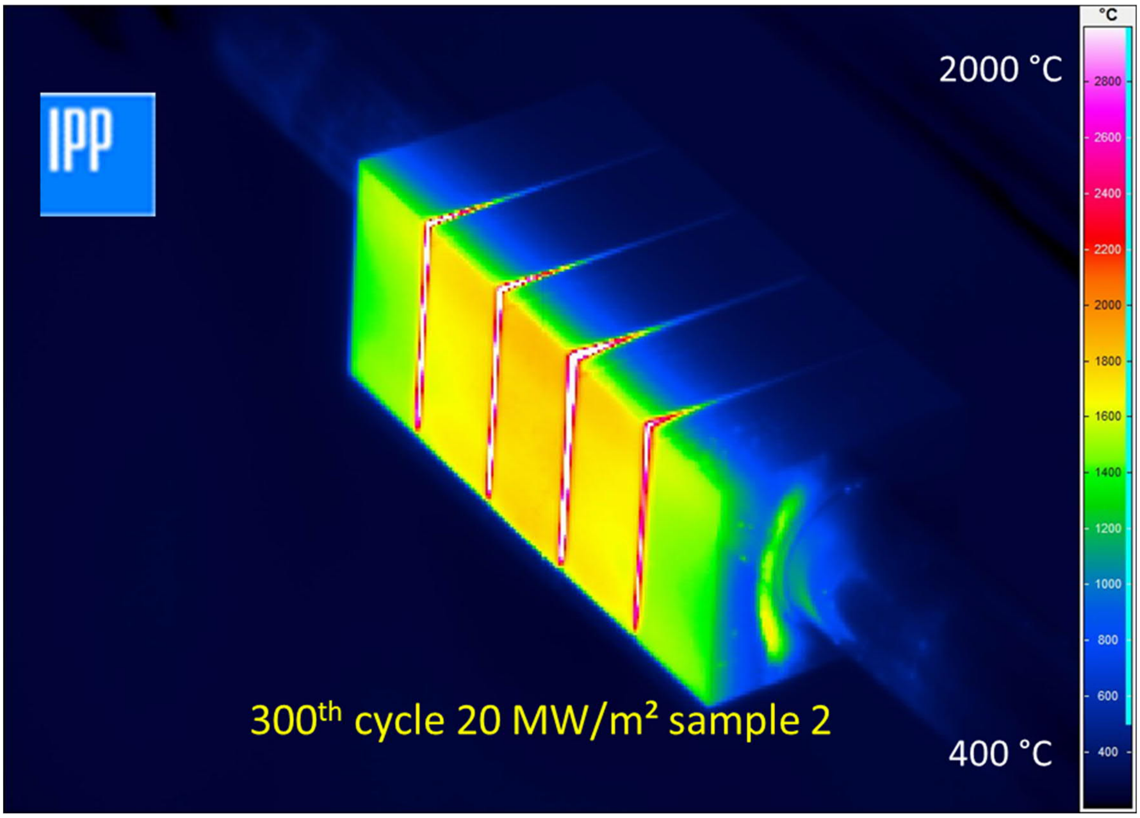


Fig. 24: IR image during 20 MW/m² cycling.

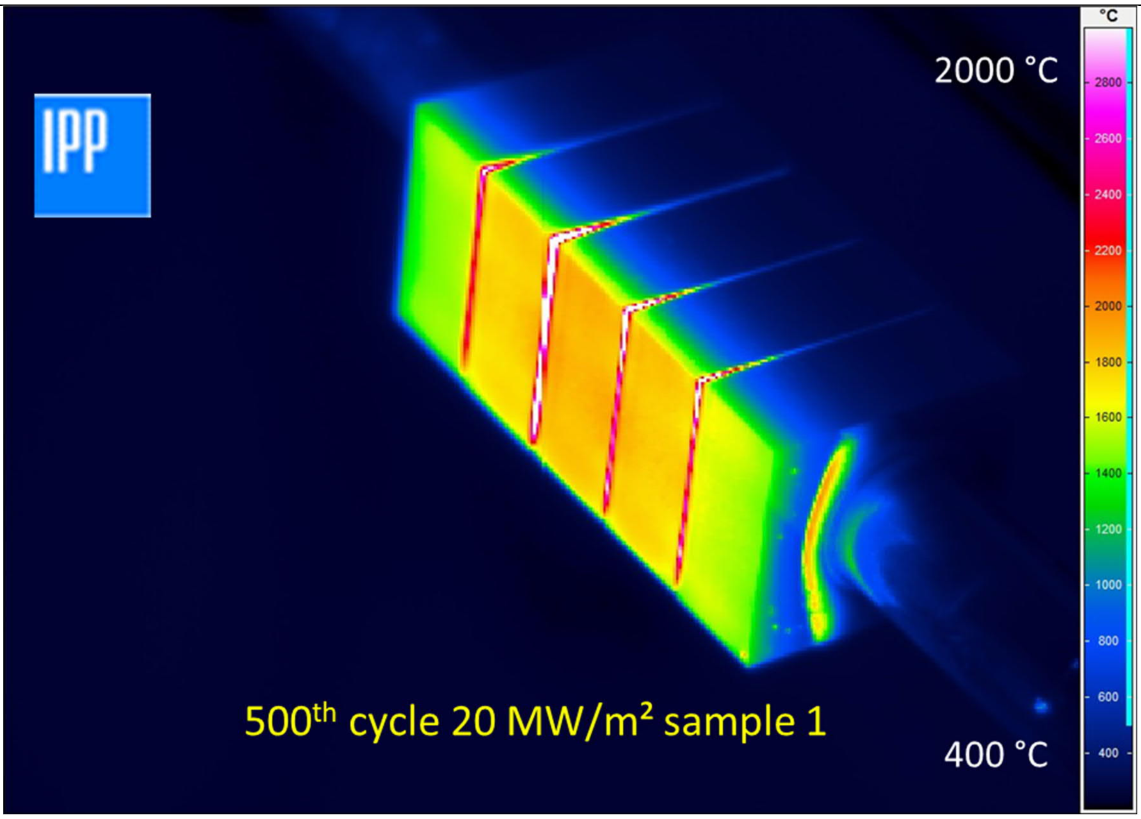


Fig. 25: IR image during 20 MW/m² cycling.

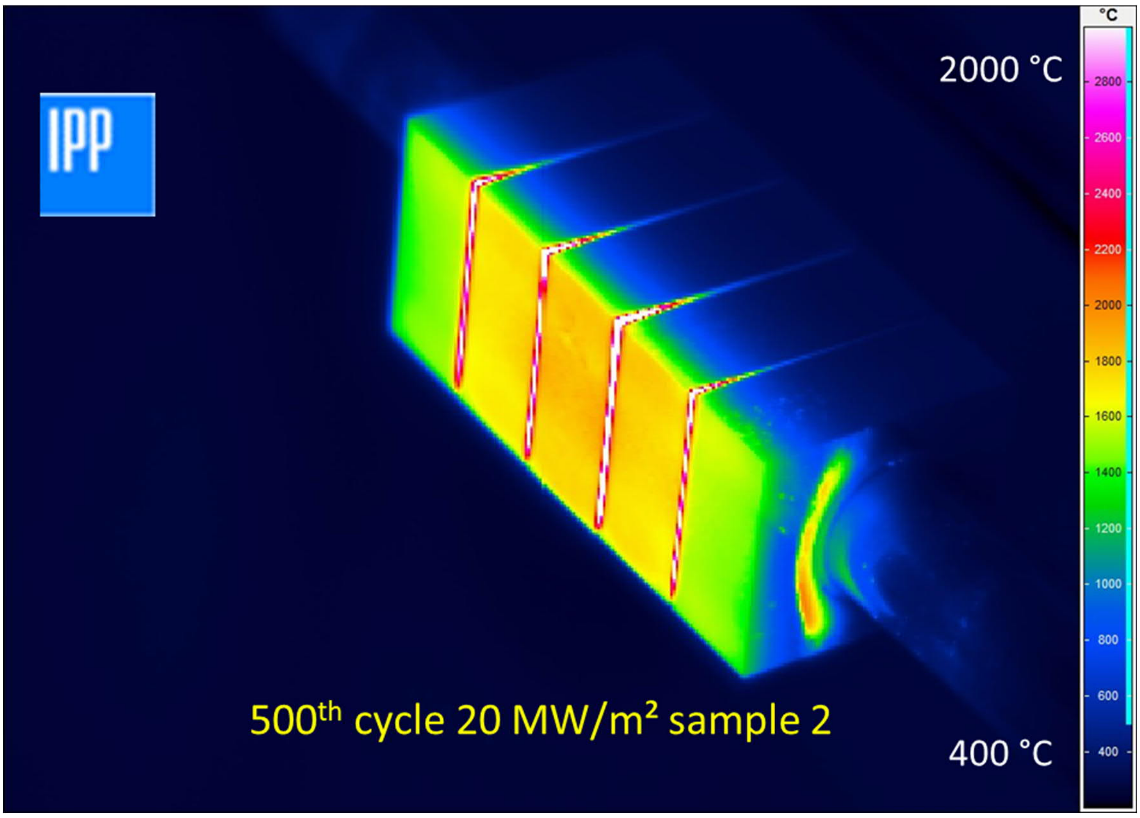


Fig. 26: IR image during 20 MW/m² cycling.

4 Summary

The successful design and manufacturing of W monoblock mock-ups by VITZRO Nextech were confirmed by HHF tests with cyclic heat loading of 500 x 20 MW/m². The tests were performed in the neutral beam test facility GLADIS at IPP Garching.

- No unexpected defect occurred during cyclic testing of the samples.
- We could not detect any surface cracks of the W monoblocks or notable surface modification occurred during the HHF tests.
- We did not detect any degradation of the mock-ups.

Summary table of main results:
Please consider the mentioned 5% accuracy of the data.

Loading case, sample	surface temperature, center block 3 mean value, cycling	surface temperature, center block 3 max. value, cycling	surface temperature, center block 3 min. value, cycling
Cycling 100 x 10 MW/m², S1	915.2 °C	923.2 °C	911.7 °C
Cycling 100 x 10 MW/m², S2	901.9 °C	903.0 °C	897.1 °C
Cycling 500 x 20 MW/m², S1	1770.8 °C	1794.1 °C	1760.0 °C
Cycling 500 x 20 MW/m², S2	1725.0 °C	1749.0 °C	1713.4 °C

5 References

[1] H. Greuner et al. / Journal of Nuclear Materials 367–370 (2007) 1444–1448