Statistical assessment of the quality of CFC tile bonding on divertor components for W7-X

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The manufacturing and quality assurance of highly heat loaded divertor components for long pulse fusion experiments is an ambitious task. The nearly 20 m² water-cooled divertor plates of WENDELSTEIN 7-X (W7-X) consist of 890 CuCrZr components covered with 18,000 CFC flat-tiles as plasma-facing material.
The debonding of CFC tile and cooling-structure is the most critical issue relating to reliable long pulse and long term operation. Only the HHF testing can investigate the thermo-mechanical behaviour of an individual CFC/Cu joint under realistic loading conditions. From this point of view, the assessment of the industrial manufactured components requires high heat flux (HHF) tests complementary to the in-process NDE.
As the most important result of the HHF tests of the latest 10 pre-series element, no inadequate bonded tile was discovered. Same results were found with the transient thermography method (ARGUS) performed by PLANSEE before and after testing. The percentage of CFC tiles without any indications of bonding defects after HHF loading performed at 10 MW/m² and 100 cycles amounted to 99.4 %. Only one edge of a CFC tile was indicated as questionable. This level of reliability could be reached in intensive interactions of pre-series testing, metallography for failure assessment and improvements of component fabrication.
Additionally individual elements were tested up to 5,000 and 10,000 cycles, respectively. Thermal screening was successfully performed up to 32 MW/m².
All these results demonstrated the sufficient reliability of the industrial manufacturing and examination process. This high quality level must be maintained for the series production of the 890 target elements.
The results of IR examination of the pre-series elements tests have been statistically assessed. Following the industrially established “six-sigma” method, the paper presents a detailed statistical analysis of the surface temperature increase of the CFC tiles during 100 cycles at 10 MW/m² testing. The analysis results in a Gaussian distribution with a standard deviation $\sigma = 9.1 \pm 0.6$ K. The failure criterion of 75 K temperature increase would correspond to a distance of 8 σ from the centre of the distribution.
Assuming that the series elements behave in a similar fashion to the pre-series elements this statistical assessment could also be performed for the series elements. Once the variance of the Gaussian distribution for the series elements is established, the number of tested elements can be determined on the basis of a chi-square test as function of an acceptable broadening of the Gaussian distribution. The advantages and disadvantages of this statistical approach to testing are compared with other possible testing approaches.