Automated ultrasonic immersion testing of fusion reactor components: implementation and evaluation with high accuracy.

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Abstract. Future fusion power plants will be in competition with other energy technologies. The blanket will play a decisive role in this context, since its thermal efficiency and power density influence directly to the overall performance of the power plant. The blanket must perform three functions: conversion of neutron energy from the fusion reaction into thermal energy, breeding of the fuel tritium by the capture of neutrons in lithium and shielding the superconducting magnets from neutron and gamma radiation. The first wall (FW) of blanket is directly facing the fusion plasma and is exposed to a surface heat flux of about 0.5 MW / m². As a structural material for blanket components, the reduced activation ferritic-martensitic (RAFM) steel EUROFER (major components 89 wt. % Fe, 9 wt. % Cr and 1.1 wt. % W) was developed. A blanket module consists of diffusion-welded cooling plates (CPs), which are interconnected by various welding methods. The welds were examined using non-destructive ultrasonic immersion testing method, which were performed on an automated modern ultrasonic immersion system KC-200 manufactured by GE Inspection Technologies. To characterize the material and structure irregularities more precisely and examine the quality of the diffusion bending interfaces, the ultrasonic immersion testing results are evaluated and illustrated using 3-D visualization software.

1. Introduction

Energy consumption is anticipated to triple in the next 50 years and if the share among the sources remains as of now the risk of a major climate change due to the release of CO_2 from burning of fossil fuels, with catastrophic consequences on the environment, is high. The development of sources with better compatibility with the environment and acceptable to society, such as fusion, as well as of more efficient energy technologies, should be pursued with a great determination [1]. The blanket is an in-vessel component which plays the roles of heat-exchange and fuel breeding. For purposes of maintenance on the interior of the vacuum vessel, the blanket wall is modular. To investigate the reaction of Blanket concept on magnetic and thermo-mechanical transients, neutron and gamma radiation, as well as its integral behavior under Fusion relevant conditions, the test will be performed in the international thermonuclear experimental reactor (ITER) on Test Blanket

Modules (TBM). Several Test Blanket Modules will be tested in row. In part of the European Breeding Blanket Program at KIT, the conceptual designs of the European TBM have been developed. Test Blanket Module (TBM) will be located to occupy a half of a horizontal port of ITER. The resulting dimensions for the TBM will be of $1270\ \mathrm{mm} \times 740\ \mathrm{mm} \times \sim 700\ \mathrm{mm}$ (width × height × depth). The TBM is constituted basically by the following subcomponents: first wall (FW), caps, stiffening grid (SG), breeding units (BU), back plate/manifolds (BPM) and attachment system. The FW is U shaped and has cooling channels in radial and toroidal direction [2]. The thermal load of the wall material makes very special requirements on the materials. Additionally by activation in the materials generated the radioactive nuclides. Compatibility with coolant and other materials, such breeding materials and neutron multipliers, must be maintained also. In the last decades reduced activation ferritic-martensitic steels (7-10% Cr), among others EUROFER [4] (major components 89% iron, 9% chromium and 1.1% tungsten) have been developed for application as structural material for blanket components.

2. Examination procedure

In this study a different components of the European test blanket module (TBM) have been investigated, such as mock-ups (MU) and diffusion bonded plates and components for the first wall (Fig. 1). For quality assurance of the diffusion bonding and material homogeneity first wall MU-plates were non-destructively tested using the ultrasonic immersion technique. For testing the immersion system KC- 200 by GE Inspection Technologies was used. The immersion system KC-200 consists of a water tank, X, Y and Z axes scanning unit, multi-channel ultrasonic device USIP-40 connected to the PC and controlled by special software for high-performance data recording with different scanning formats. The test results can be illustrated by means of A-, B-or C-scan. The ultrasonic examinations were performed by straight beam and using the probe TS 6PB 4-20 P50 (frequency - 20MHz, transducer - 6mm in diameter, focus - 50mm) from Karl Deutsch. The plates were scanned focusing on different levels (from the surface to the HIP-area) and at the sound velocity C_l = 5920 mm/s for EUROFER and C_l = 5775 mm/s for Chromelso 92 (so-called P92).

3. Result and discussion

During the ultrasonic immersion testing of the so-called 1/8 FW mock up plate (Fig.1), the following is identified : at the welding -zone between two webs (18.5 mm depth) a chamfer up to a width of 1.2 mm are exists , which probably caused by the mechanical processing. Flaws in material are detected at a depth of about 13.5 mm and at a depth between 8.8 and 9.2 mm. Pores or non-metallic inclusions of different sizes in the range of 50 µm to 300 µm are found at a depth of 3-4 mm as shown in Figs. 2 and 3. All ultrasonic immersion testing data are used as input for 3D visualization software programmed by I-Deal Technologies, which allows more clearly characterization and measurement of the material imperfections. The results are presented on the Fig. 4. After the non-destructive testing, a section has been cut from the plate in order to measure the cooling channels. Fig. 5 shows the chamfer at the end of each bonding interface.

Furthermore, the uniaxial diffusion-welded and argon protected plate (U-DW-Ar-FW mock up) has been examined (Fig.1). The plate was cut across into two parts and each part was scanned separately. During the ultrasonic scanning, the following features are detected: a flaw at the diffusion bonding plane (≈ 16.5 mm from the component surface) in the cooling channel.

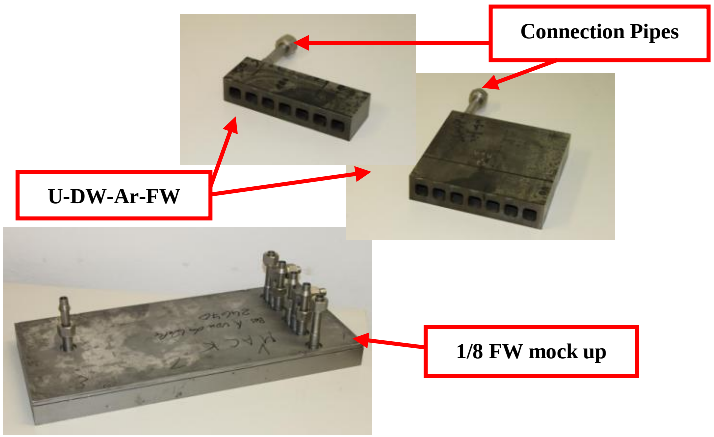

Fig. 1 Examined components of Test Blanket Module (TBM)

The size of the defect is about 4.7 x 2.0 mm. During the leak tightness test a leak was found which located visible in the end wall of plate at the welding zone to the connecting pipe (Fig. 1 and 6). This pipe has been required to perform the leak test and was joined to diffusion bonding plate by TIG welding.

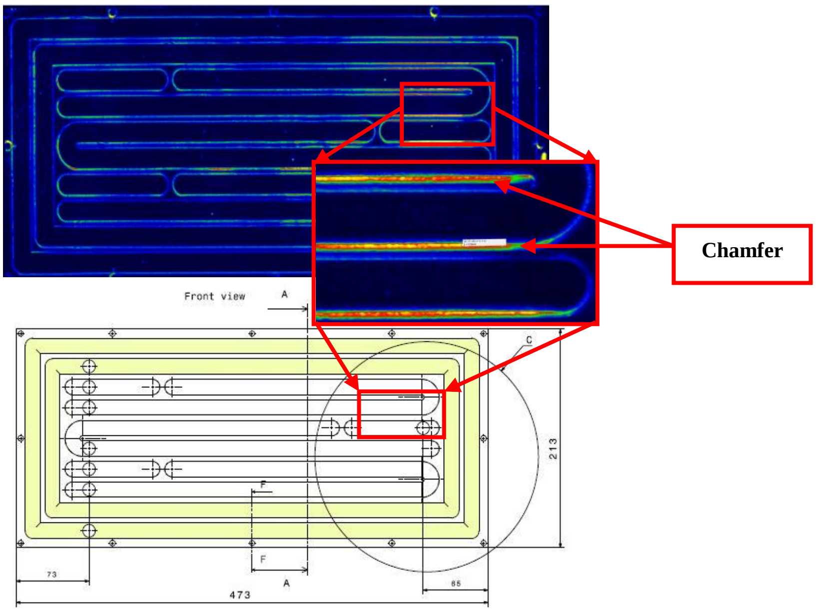

Fig. 2 C-Scan image with overview of chamfer in 1/8 FW HIP Mock Up plate

Thereafter this leak was marked for further investigation. During the ultrasonic immersion examination the size of the leakage has been determined clearly. The length is about 41 mm. At a 14.0 mm deep position few pores or non-metallic inclusions with sizes of 50-150 µm exist (Fig. 6). In the case of this tested plate (U-DW-Ar-FW mock up), no cavities exist at the diffusion bonding zone, which means that the diffusion bonding process of the plates well optimized. Using 3D visualization software, all detected flaws can be clearly visualized and measured (Fig. 7).

Additionally, the uniaxial diffusion-welded cooling plate of a stiffening grid (U-DW-Ar-welded cooling plate) was tested for controlling the bonding seams and to characterize the material quality. According to the ultrasonic immersion testing, webs and the bonding zone contain no imperfections and cavities. Many defects (non-metallic inclusions or pores) with sizes between 50 and 500 µm exist in material, beginning from a depth of 4 mm and repeatedly appropriate every 2-3 mm (Fig. 8).

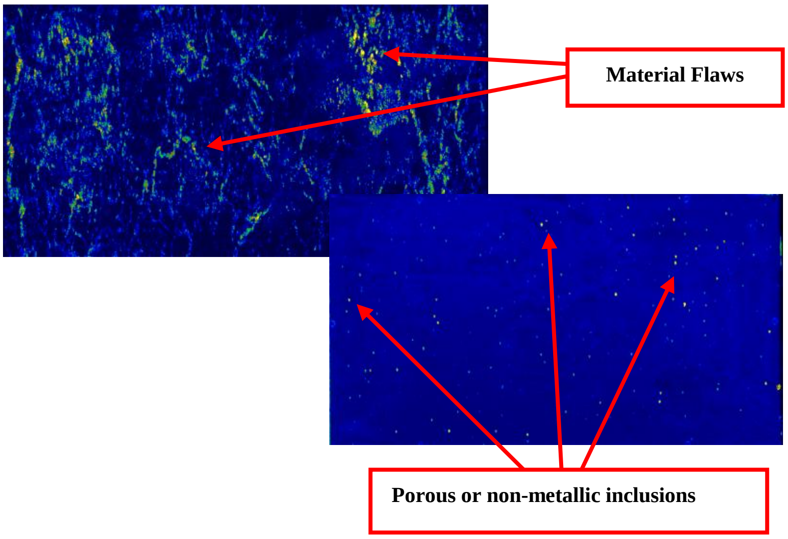

Fig. 3 C-Scan image with overview of material defects in 1/8 FW HIP Mock Up plate

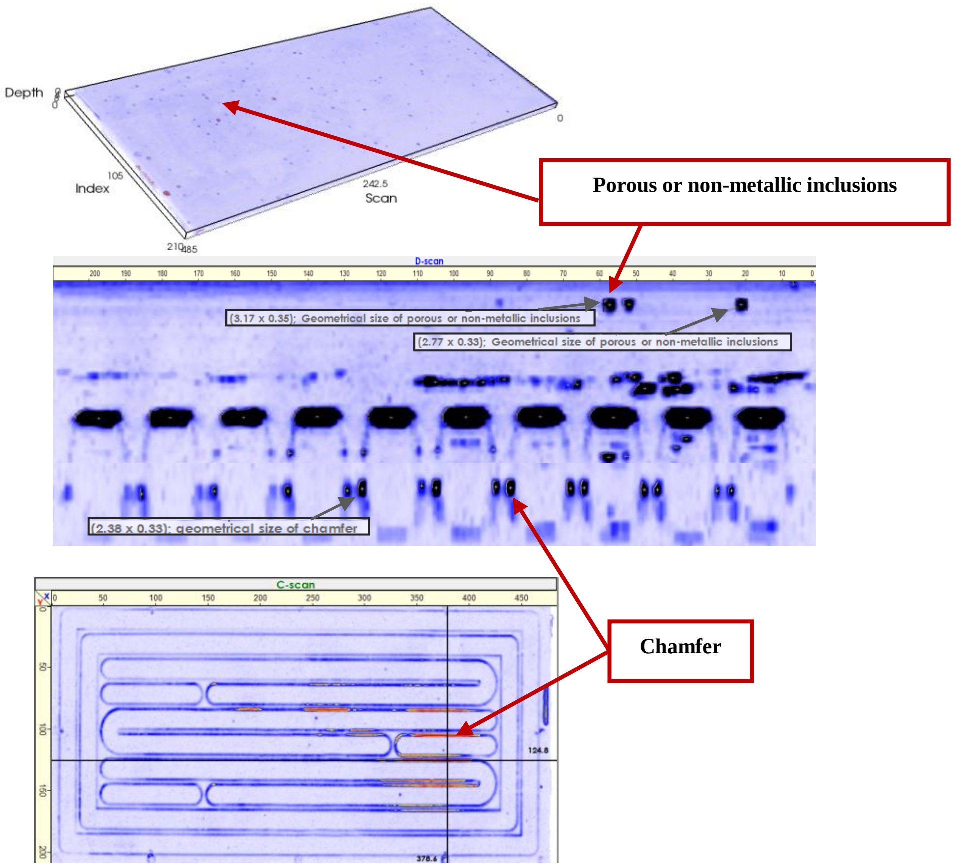

Fig. 4 Screen-shot of 3D visualization of 1/8 FW HIP Mock Up plate

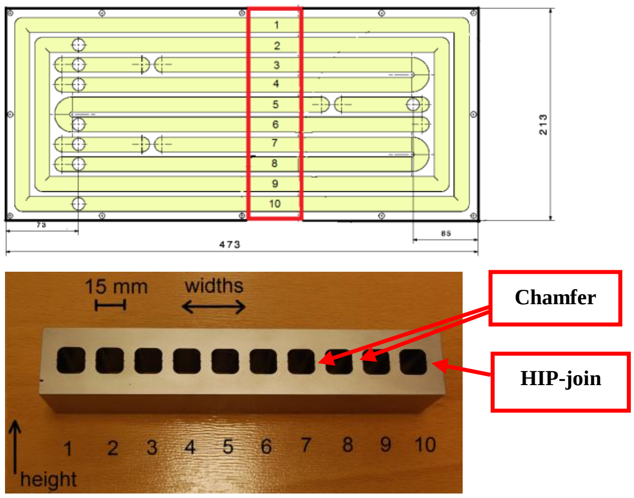

Fig. 5 Cut-out of 1/8 FW HIP Mock Up plate

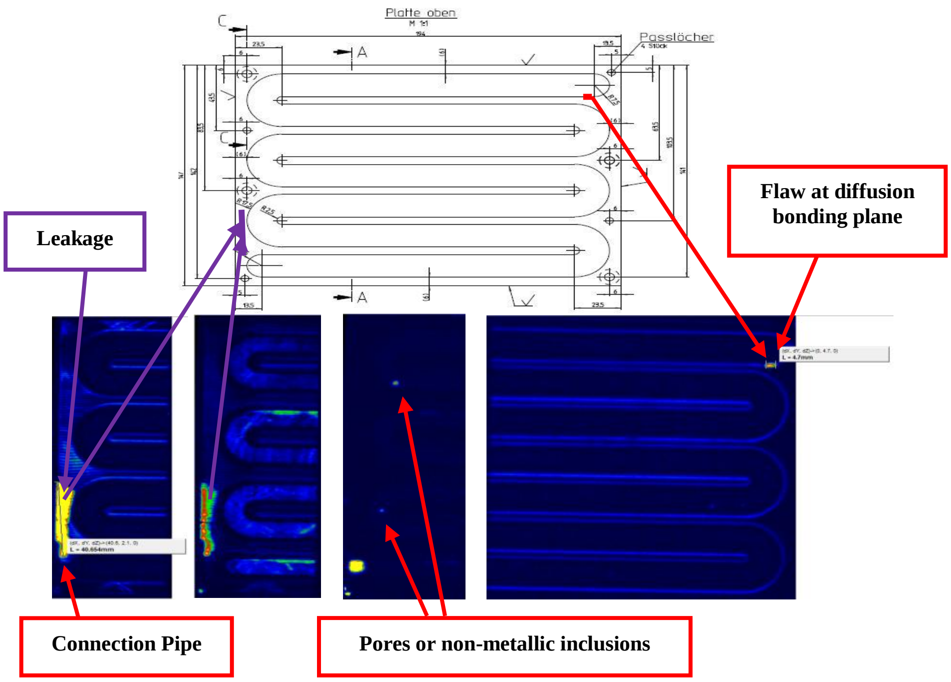

Fig. 6 C-Scan image and overview of detected flaws in U-DW-Ar-FW mock up plate

In the last non-destructive ultrasonic testing, it was observed that the material used for the MU-components contained a lot of defects e.g. pores or non-metallic inclusions. This is not expected for the used material. Therefore the other four work pieces (100 x 100(80) x 50(30) mm from Chromelso 92 (so-called P92) fabricated by MAN (Diesel & Turbo)) were non-destructive investigated in as-received condition to exclude material inhomogeneity or imperfections. During the ultrasonic testing, inclusions or impurities of different sizes from 50 µm to 1.0 mm are determined at all four test pieces and located in a depth range from 5 to 10 mm. In addition, the inclusions were evaluated and measured using 3D visualization software (Fig.9). Hence, it has been decided to investigate the defect sources. For these investigations, samples are cut from the work piece at the depth, at which the defects are found. These samples are ground and polished and then investigated by light microscope. During the metallographic examination some inclusions are identified and measured.

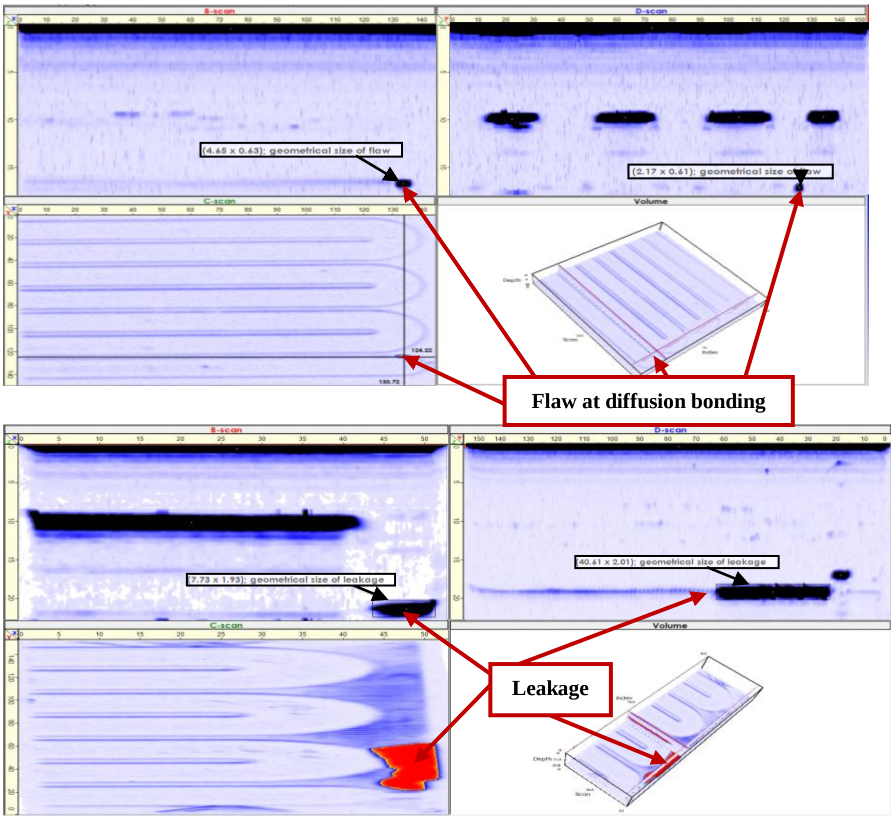

Fig. 7 Screen-shot of 3D visualization of U-DW-Ar-FW mock up plate

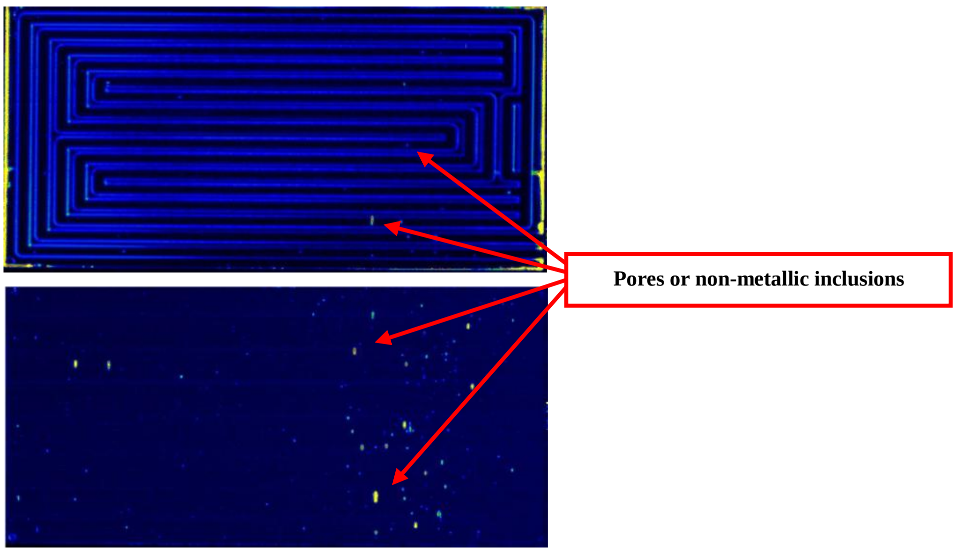

Fig. 8 C-Scan image of U-DW-Ar-welded cooling plate of a stiffening grid

On Fig. 9 the measurements of the selected inclusions has been presented, which was performed by different procedure. Comparing both methods for determination of the size of impurities, it can be seen that the measurement results by 3D software is quite accurate. The deviation is about ± 10 %. The determined inclusions were examined by SEM (scanning electron microscope) and their element distribution is analyzed by EDX (energy dispersive X-ray spectroscopy). The results can be seen in Fig. 10. The EDX results show that the detected inclusions consist of various oxides of Al, Si, Ca, Mg and Mn base. Probably these impurities were caused by the used manufacturing process.

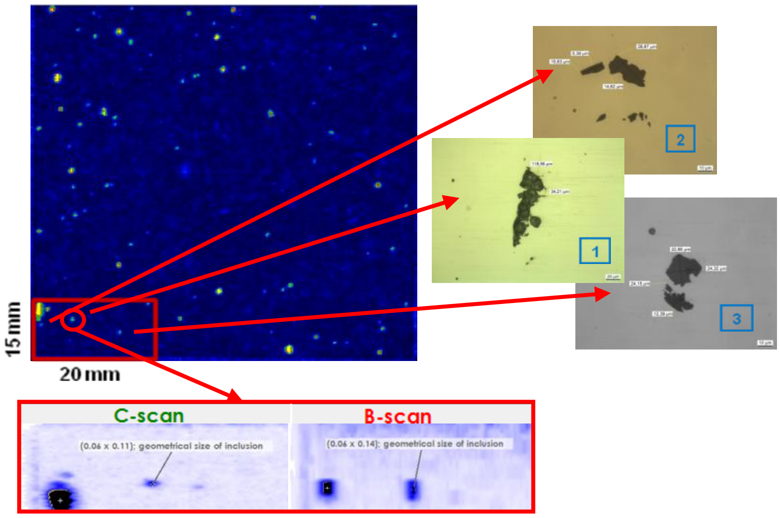

Fig. 9 Measurements and metallographic examination of inclusions

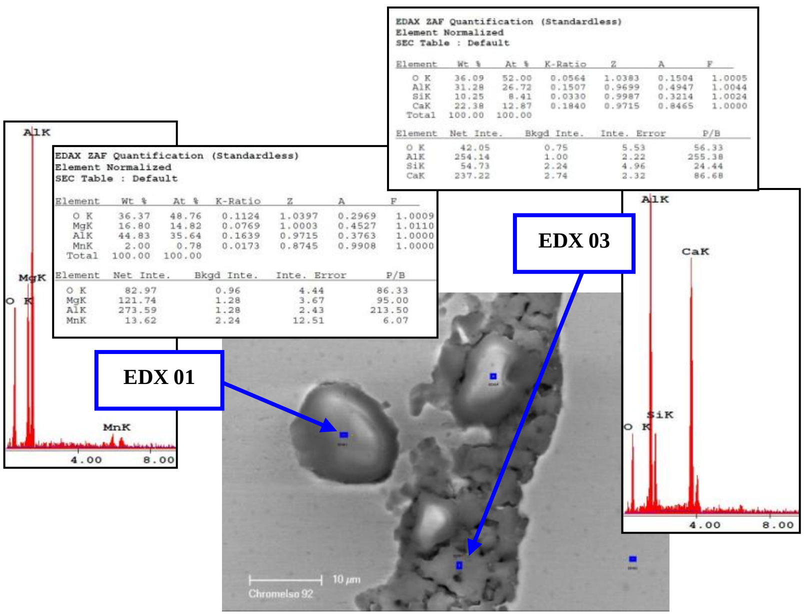

Fig. 10 EDX analysis of the inclusion No. 1 (lower part)

4. Conclusion

In this work, irregularities and flaws in various fusion reactor components are examined and characterized using ultrasonic immersion testing. The shape and size of various material and structure imperfections were evaluated and measured by means of 3D software visualization with higher accuracy. For selected predetermined inclusions, SEM (scanning electron microscope) and EDX (energy dispersive X-ray spectroscopy) analyses are performed to verify the non-destructive testing results and to investigate the inclusions in more details. The EDX results present that detected inclusions consist of different oxides of Al, Si, Ca, Mg and Mn.

5. Reference

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