DEFECT SIMULATIONS FOR INTERDENDRITIC STRESS COROSSION CRACKS IN ALLOY 182 WELDS

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Abstract: In-service Inspections in Swedish nuclear power plants requires qualified non-destructive techniques. If a qualification will include practical demonstration, then realistic test specimens are mandatory in this work. Extensive resources have been put on manufacturing specimen with attention to geometry and defect simulations. During year 2002/2003 SQC, the Swedish Qualification Cent has managed a development project, DAS 182/PostDAS, with special focus on defect simulation of simulate Inter Dendritic Stress Corossion Cracks (IDSCC).
Previous defect simulation techniques, manufactured fatigue and solidification cracks, used in the qualification of Eddy Current (ET) and Ultrasonic (UT) techniques, has been identified to be unsuitable to simulate IDSCC.
An IDSCC crack is characterised by very small crack width and unbroken ligaments in one plane (i.e. both in surface and in depth). Due to these properties a number of NDT procedures for in-service inspections of Alloy 182 welds have been reported to fail in both detection with ET and height sizing with UT of defects. In the project a number of new IDSCC simulation techniques were tested.
ET and UT signal responses from these simulations were compared with signal responses from real IDSCC defects. The collection and evaluation of data was carried out using previously qualified procedures for inspection of Alloy 182 welds. The objective was to identify simulations that could produce signal patterns typical for IDSCC defects. The project was successful and one of the defect simulation techniques, Mechanical Tightened Defect (MTD), was able to produce signal patterns very similar to the ones created by real IDSCC defects.

Introduction: In the year of 2000, four defects where found in Alloy 182 safe end welds in the Swedish nuclear plant Ringhals. Boat samples, containing the defects, where cut out from welds. The destructive testing and laboratory results identified the defects as Inter Dendritic Stress Corrosion Cracks, IDSCC. It became evident that in some cases these types of cracks were very difficult to detect with Eddy Current since only two of them were detected and reported during the initial inspection.
It also became apparent that the height sizing was very difficult on these cracks. On two of the cracks, depths were underestimated and outside of heights sizing tolerances. A number of influential factors were identified as the reasons behind the poor performance of the NDT techniques on these defects.
IDSCC cracks: One of the most influential parameters on the signal response from this defect type is the in many cases relatively small crack width throughout its entire depth. Another important property of this defect type is the *unbroken ligaments* both in depth and in the crack opening to the surface. These ligaments are created as a result of the crack propagation in the dendritic structure of the nickel-based welding material. The propagation of the cracks tends to follow a line around the dendrites rather than through them. This behaviour generates cracks with a winding character both in length and depth with the dendrites creating interruptions in the crack, i.e. unbroken ligaments. In the crack opening to the surface these ligaments causes electrical coupling between the crack flanks making it difficult for the ET-technique to properly detect, characterise and length size the crack.

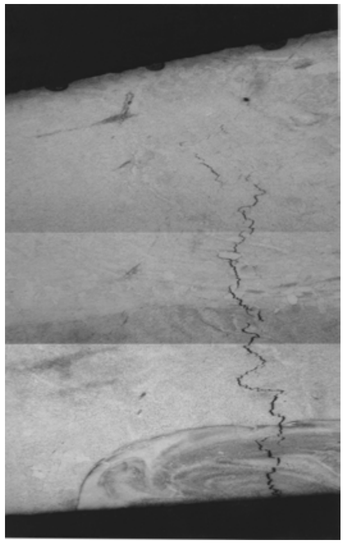

Fig 1. IDSCC crack. Winding, with several unbroken ligaments in one plane

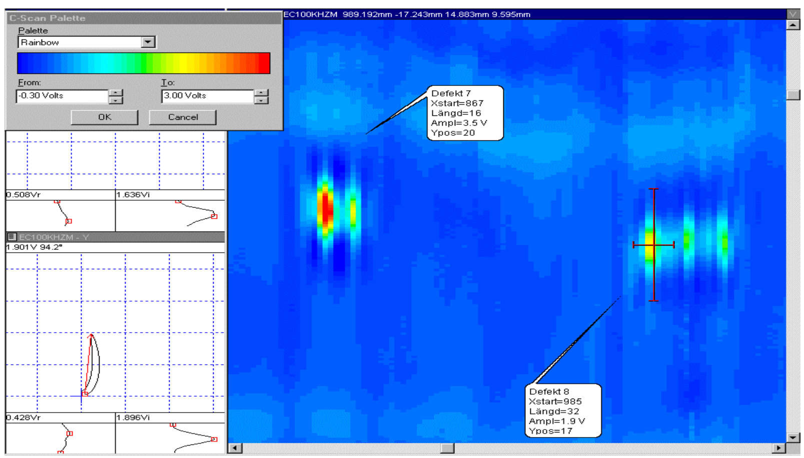

Fig 2. IDSCC ET – response with typical unbroken ligaments in the surface.

The relatively small crack opening to the surface (1-60µm) is also a factor, which has influence on the ET response from IDSCC-cracks. The amplitude is clearly affected by this and tends to be much lower compared to amplitude generated by other types of cracks.

Its influence on the Ultrasonic Sizing Technique is of similar nature., The unbroken ligaments in the depth direction are creating acoustic coupling between the flanks of the crack. These areas of acoustic coupling are acting as crack tips from the ultrasonic point of view, as they generate signals, very similar to crack tip diffraction from the real crack tip. This can of course, be a source of serious mistakes when IDSCC cracks are to be sized for height.

The small width also makes the crack more transparent for the ultrasound, and thus less distinct. These effects are most evident when Time Of Flight Diffraction Technique, TOFD, is applied. Another feature of this crack type is the relationship between crack length and crack depth. They can be relatively short but still have a great extension in depth., which is not the case for most other crack types.

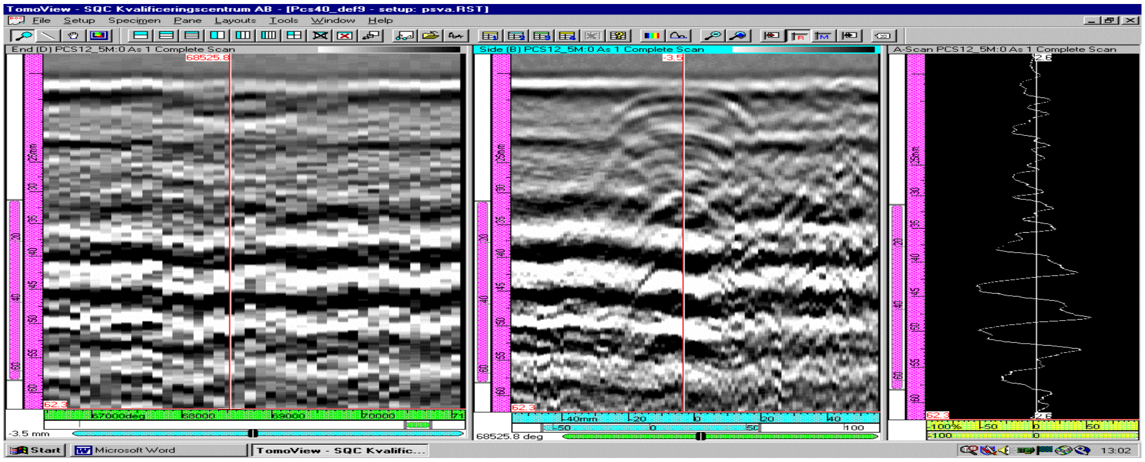

Fig. 3. Signal pattern from a TOFD-scanning on a IDSCC crack. There are several signals appearing in the depth direction that can be interpreted as crack tip signals.

DAS 182: When it became evident that the IDSCC cracks had these specific characteristics, the previously qualified inspection systems had to be under consideration. Were the defect simulations that had been used in qualifications so far for inspection of alloy 182 welds designed to handle these IDSCC characteristics? The failed inspections indicated that they were not. In order to get a clear view of this, a project (DAS 182 –Defect simulation in alloy 182 welds), was launched. The Swedish utilities and SQC decided to run a project with the objective to compare inspection signals from ET and UT signals from real IDSCC defects with existing defect simulations and also to, if necessary, develop new simulation techniques. A number of defect simulations were introduced into a test block with an alloy 182 weld and buttering. Some of the simulations were of the old type, which had been used in previous qualifications but the test block also contained different new simulation techniques. The signal responses from the simulations in the test block were then compared with signals from actual inspection data from alloy 182 welds containing IDSCC defects.

Results from DAS 182: From the results of the project work two conclusions could be drawn:

The old type of simulations used in previous qualifications were not suited to simulate IDSCC cracks. They produced ET-responses with amplitudes, which clearly exceeded signals from real cracks and did not reproduce the unbroken ligaments in the surface.

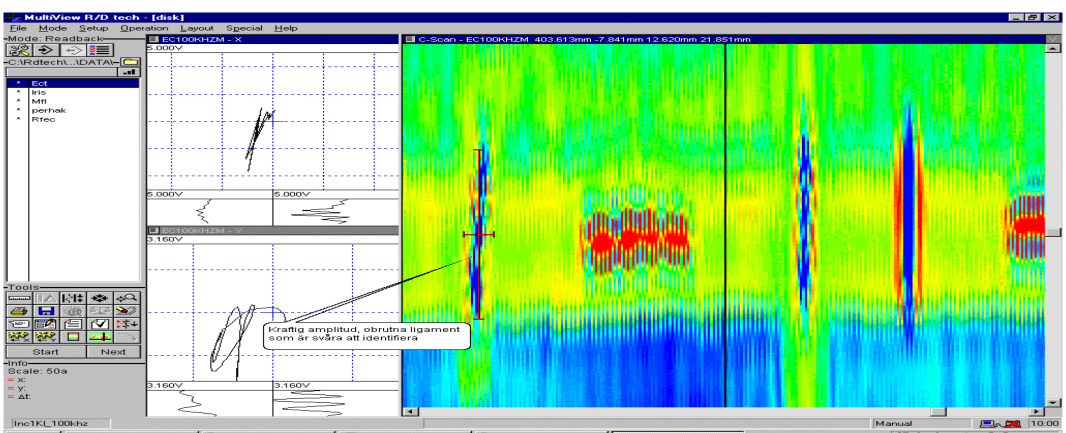

Fig 4. ET responses from “old type” of defect simulations in Alloy 182 welds

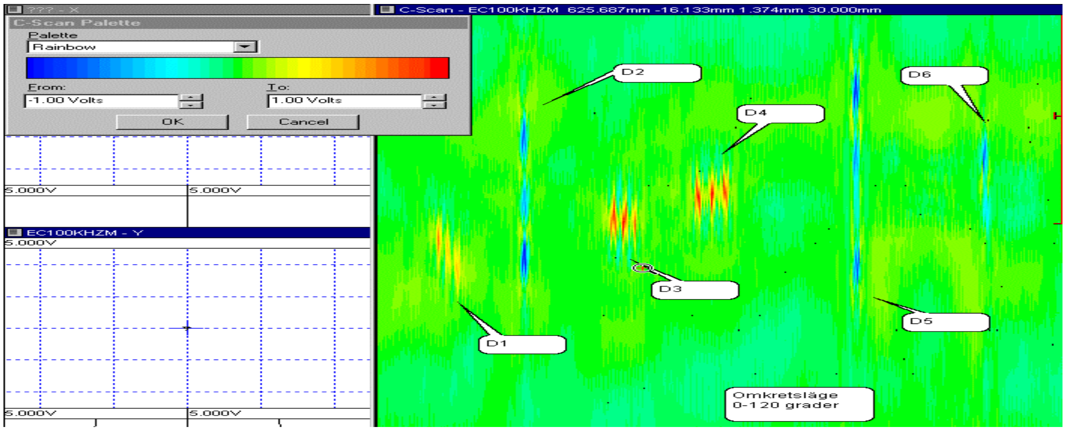

Fig 5. ET responses from the “new type” of IDSCC simulations in Alloy 182 welds

For UT height sizing the results were similar as for ET. The old types of defect simulations could not produce the typical IDSCC signal patterns with multiple responses in the depth direction of the crack. They also had an appearance of being too wide. This can be recognised through a clear break in the lateral wave and a distinct “shaft” around the crack in the depth direction. These signal patterns are caused by the relatively great crack width, which gives no transparency for the ultrasound through the crack itself. Instead the ultrasound reflects of the crack surface to a larger extent compared to the behaviour on the IDSCC cracks.

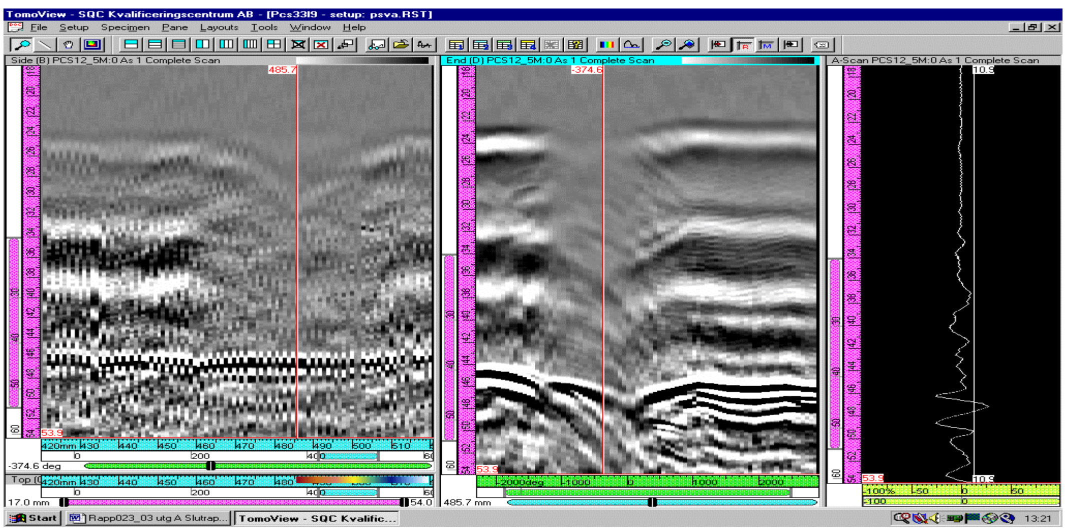

Fig 6. UT/TOFD response from an “old type” defect simulation in an Alloy 182 weld.

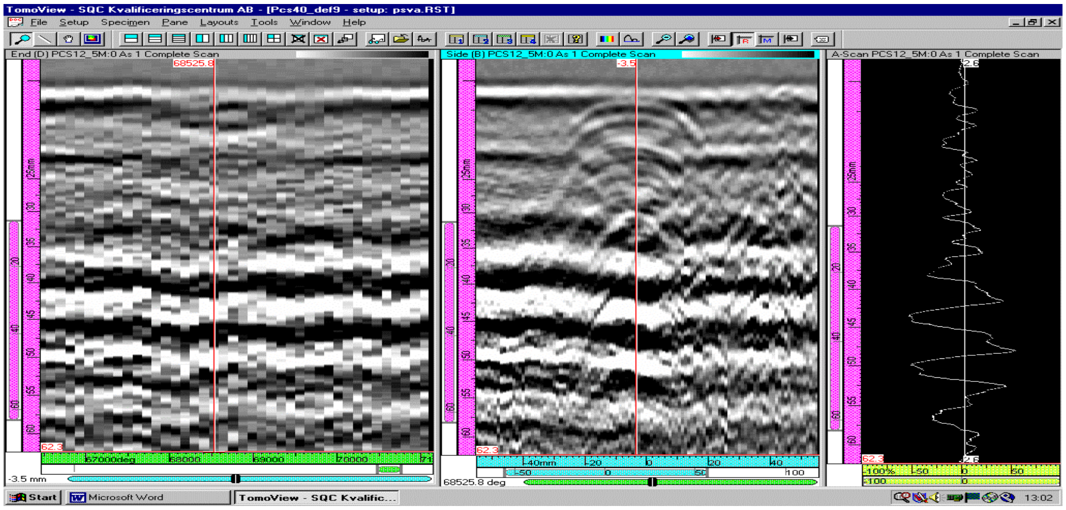

Fig 5. UT/TOFD response from a "new type" of IDSCC simulation in an Alloy 182 weld.

It was also concluded that the new simulation technique, Mechanically Tightened Defects (MTD), gave a very realistic response of IDSCC-cracks. The simulations showed all the right properties for both ET detection and UT height sizing and simulated the important characteristics of IDSCC cracks.

PostDAS: In view of the results from the DAS 182 project it was obvious that previously qualified procedures for inspection of Alloy 182 welds could be seriously questioned in terms of their ability for inspection of possible IDSCC cracks. It was also obvious that the quality of the procedures in this respect had to be verified on IDSCC defects.

The Swedish utilities together with SQC decided that these demonstrations were to be performed in a project, called PostDAS, which would cover verification of all procedures that had been qualified on the old defect simulations. The procedures were grouped into different categories of similar objects to reduce the number of test blocks and defect simulations that had to be manufactured for the demonstrations. The categories were based on each of the procedures regarding geometry, wall thickness, defects sizes etc.

The test blocks were designed to meet the requirements from the DAS 182 project. A total of 15 test blocks were manufactured containing 130 defect simulations. In the first stage demonstrations were carried out as blind tests with previously qualified personnel for each of the procedure. The result of the demonstrations had to be within the specified criteria and tolerances for the qualification.

If the first demonstration proved to be successful the qualification was considered to be valid.

If the result was outside the requirements an analysis of the results took place. The analysis was carried out by the performing inspection laboratory, with the aim of identifying the source of the failed results. If the source was judged to be due to minor limitations in the procedure the procedure could then be revised and a second demonstration could take place. However, the revision of the procedure had to be limited to an extent where the personnel qualifications for that procedure would still be considered valid. A second demonstration was then performed.

It was also desired that if the procedure failed during this new demonstration and the reason was of technical reason, the certificate had to be revoked.

Results of PostDAS: A total of 12 procedures performed according to requirements. However, most of them passed only after adjustments. Two of the demonstrated procedures did not pass the demonstration within the stipulated tolerances.

The dominating part of adjustments for the ET-procedures was made on reporting levels. Almost all of the ET-procedures rely on a reporting criteria based on phase angle and an amplitude level. Because of the lower amplitude levels, generated by IDSCC cracks and naturally, the reporting levels must be lowered accordingly. In many cases down to the noise level, which means that the phase angle is crucial for the reporting. The low amplitude levels also affected length sizing. It simply becomes more difficult to separate defect signals from noise.

As for the UT height sizing the demonstrations revealed that it was obvious that procedures that rely on a single UT technique in many cases failed to meet the requirements. Especially procedures that rely on TOFD only, proved to be very inconsistent in their performance. The most difficult part for TOFD is the number of signals produced by the unbroken ligaments. It's simply too difficult to single out the true crack tip signal from the signals produced by these features.

One procedure relying on just Puls-Echo technique for height sizing performed within the tolerances after some modifications. However that procedure was limited to height sizing in a limited volume in the depth direction close to the scanning surface. In this case there was naturally fewer signals to choose from in the depth direction of the crack since the defects in this volume had a limited depth.

Conclusion: The introduction of a new simulation technique for IDSCC defects in Alloy 182 welds has proven successful and has made it possible to improve inspection techniques and procedures for this type of inspection.