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The Influence of the Crack Opening in the UT Inspection Qualification

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ABSTRACT

The character of cracks is an important parameter in manufacturing of test pieces for UT qualification. In these studies we (Trueflaw and Fortum Nuclear Services) have manufactured 22 cracks by different production methods. Opening of cracks have been manipulated for different values. Sizing of the true dimensions of cracks has been made by destructive tests. These values are the basis for the evaluation of the accuracy of different NTE techniques. This presentation will focus on NDT aspect. The purpose of these studies is to find dependency in test results and opening of cracks. We also try to find out differences in accuracy between various techniques.

The test pieces have been inspected by nine inspectors from Finnish NDT vendors (Polartest, Inspecta, VTT). Inspectors used different techniques and procedures for flaw size evaluation. Three inspectors made sizing (size defining) by traditional manual method. They used different techniques and probes. Two inspectors used manual phase array technique and four inspectors made sizing (size defining) by mechanizesd phase array technique. All inspections were blind tests. In the evaluation of the results it has been concentrated in the used techniques and procedures. Influences of human elements has not been studied.

INTRODUCTION

One important detail in qualification process is to select right defects to the test specimens. Qualification defect types must be realistic compared to postulated defect types. Influence of crack opening has been one explanation for unsuccessful NDT- results. Also it is unfair to inspectors if there are defects that are unrealistic to detect. When qualification body selects the defects to be used in qualification project, it must have know-how about behavior of ultrasonic with different crack types. In this project we hope to find out some answers to these questions.

EXPERIMENTAL

This study includes NDT results from four companies and nine inspectors. All inspection companies used their own NDT equipment. Used inspection methods included manual inspection, phased array inspection and mechanized inspection. Manual inspections were conducted using Finish ISI procedure ISI511 and conventional flaw detectors units (Krautkrämer USN series, Epoch IV). Used probes were WSY60-2, WSY70-2, ADEPT60, MWK55-2 and MWB45-5. Phased array inspections were conducting using OMW-610.424 procedure with Omniscan units. In mechanized inspection were used the same probes as in manual inspection. The analysis was made from pre-collected data with possibility to use B- and C-screens for the evaluation of crack height. All the cracks were also evaluated by scanning acoustic microscope (SAM). These measurements were performed with smaller samples cut near the crack face. Scanning measured reflection and shadowing of cracks. Frequencies used were 5 MHz and 10 MHz (Figure 1).

Six test specimens were produced for this study. Three different flaw types were used: solidification cracks, welded fatigue surfaces and thermal fatigue cracks. The samples and flaw types are documented in detail by Kemppainen et al. [2].

RESULTS

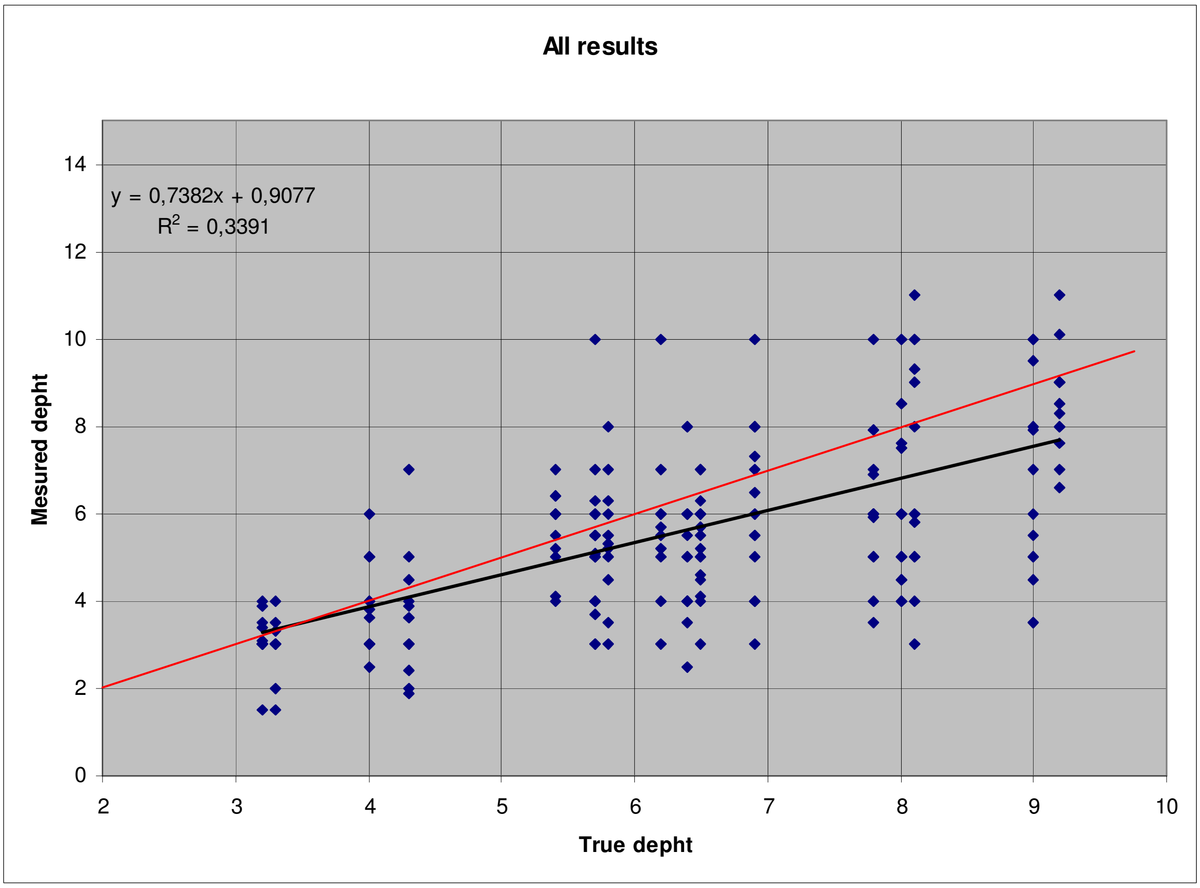


Figure 1 - All results

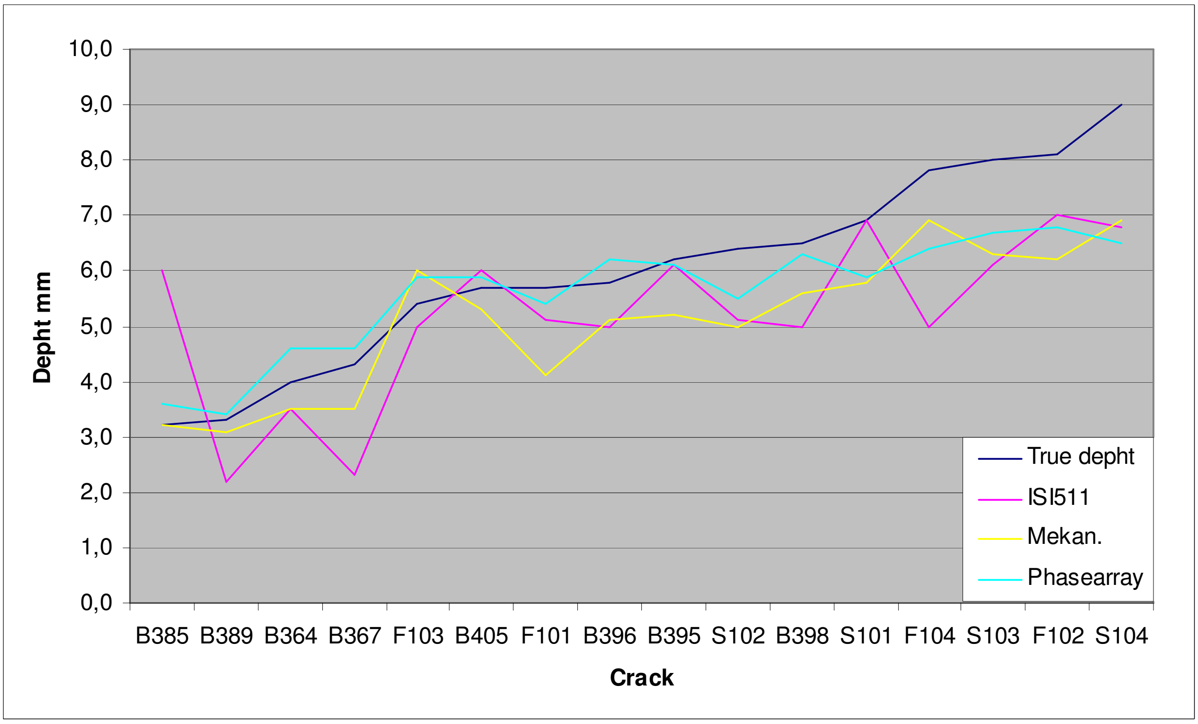


Figure 2 - Average depths of cracks measured by different techniques

Crack	Crack	Opening	Depth (mm)				Deviation (mm)			
Type	Number	Tip (µm)	True	ISI	Mechan	Phase	Total	ISI	Mechan	Phase
Thermal	B405	4,8	5,7	6,0	5,3	5,9	1,7	3,6	0,3	0,9
	B395	0,8	6,2	6,1	5,2	6,1	1,8	3,6	0,9	0,6
	B396	0,1	5,8	5,0	5,1	6,2	1,4	2,3	0,4	0,6
	B398	5,5	6,5	5,0	5,6	6,3	1,1	2,8	0,3	0,5
	B364	1,5	4,0	3,5	3,5	4,6	1,1	1,3	0,6	1,1
	B367	2,2	4,3	2,3	3,5	4,6	1,4	0,6	0,9	1,4
	B385	0,4	3,2	6,0	3,2	3,6	0,7	0,9	0,2	0,5
	B389	0,4	3,3	2,2	3,1	3,4	0,7	0,8	0,1	0,5
Fatique	F101	3,9	5,7	5,1	4,1	5,4	1,0	0,9	1,1	1,0
	F102	0,5	8,1	7,0	6,2	6,8	2,6	3,2	3,2	1,8
	F103	0,3	5,4	5,0	6,0	5,9	0,9	1,1	0,8	0,5
	F104	0,7	7,8	5,0	6,9	6,4	1,6	0,8	2,8	0,5
Solidif.	S101	9,1	6,9	6,9	5,8	5,9	1,9	2,5	1,7	1,7
	S102	12,5	6,4	5,1	5,0	5,5	1,6	2,4	0,8	1,6
	S103	14,9	8,0	6,1	6,3	6,7	2,0	2,7	1,5	2,1
	S104	5,7	9,0	6,8	6,9	6,5	2,4	2,4	2,8	2,3

Table 1 - Measured average crack depths and deviation from true value

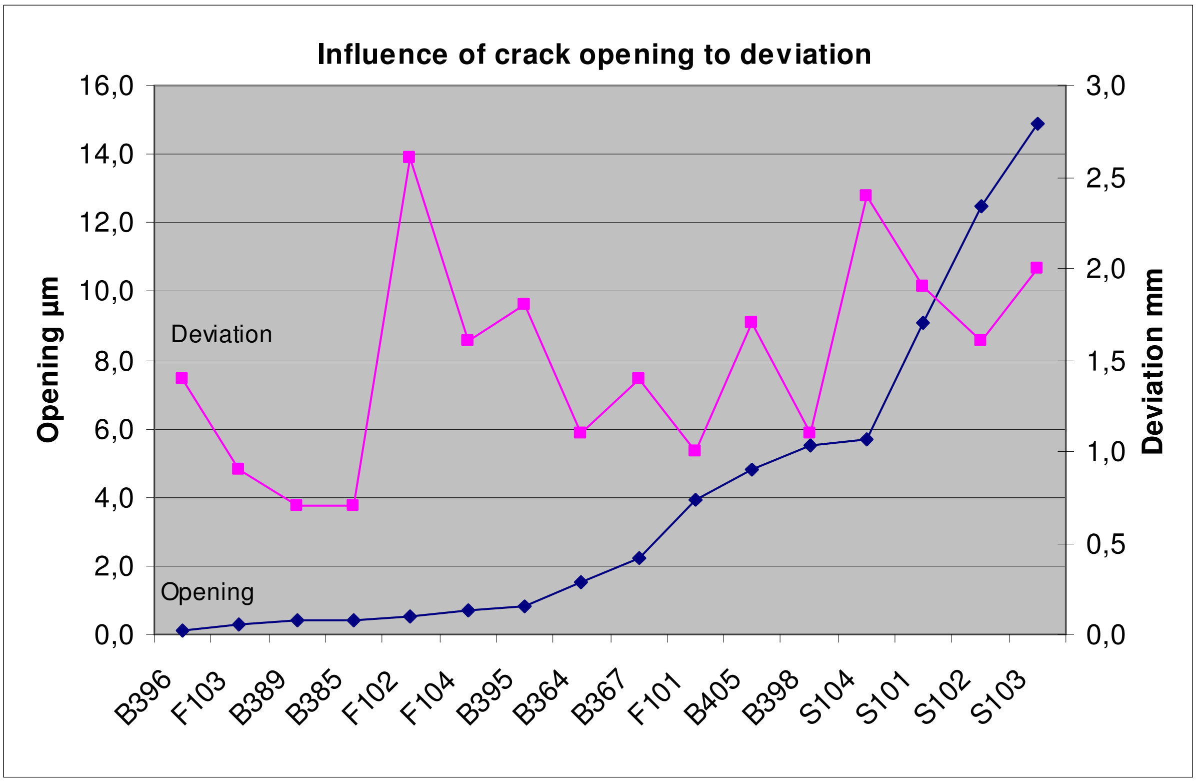


Figure 3 - Opening of crack tip and deviation (mean value)

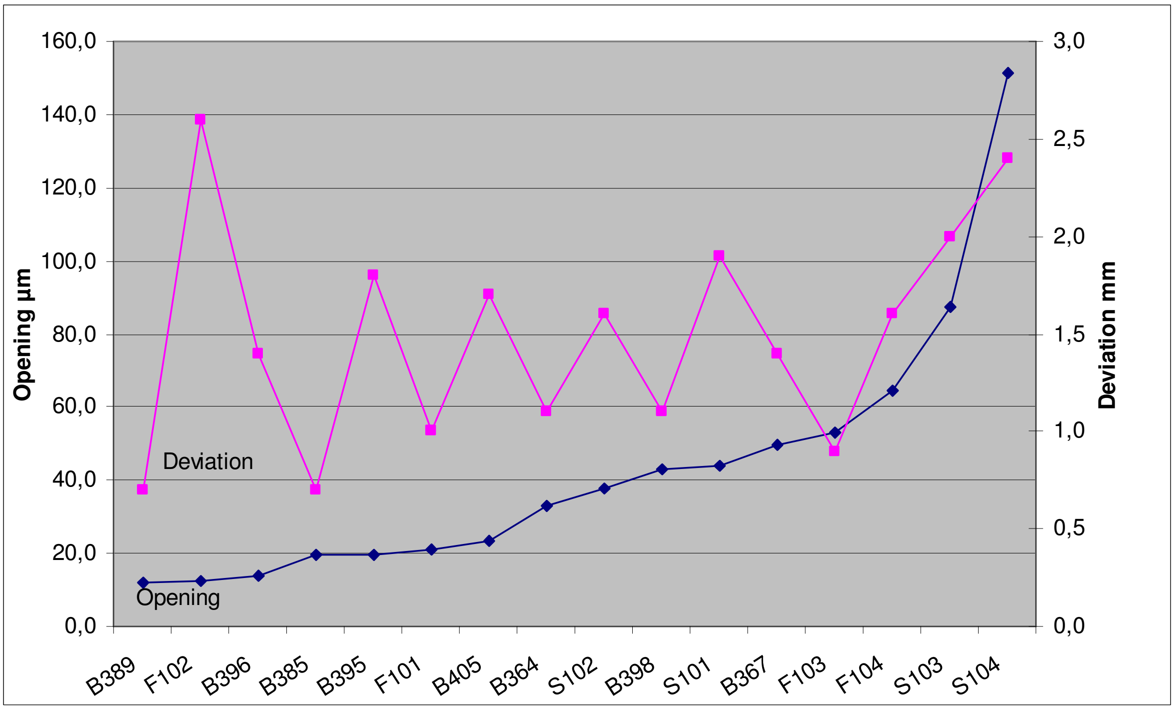


Figure 4 - Opening of crack tip area and deviation (mean value)

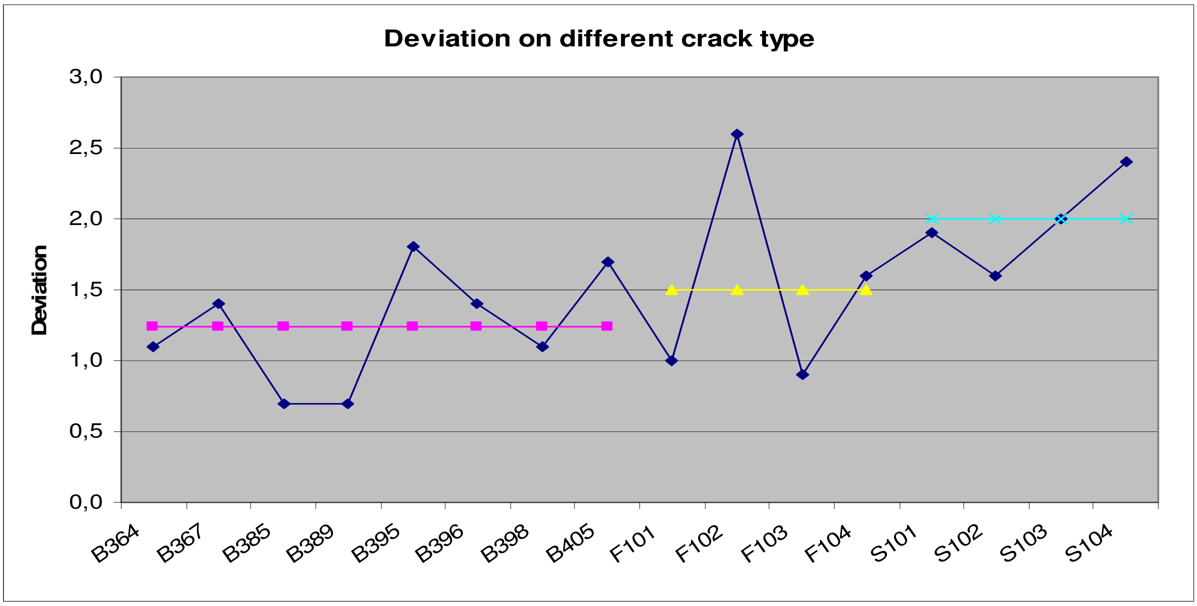


Figure 5 - Average deviation on different crack types.
(thermal magna, fatigue yellow and solidificion blue)

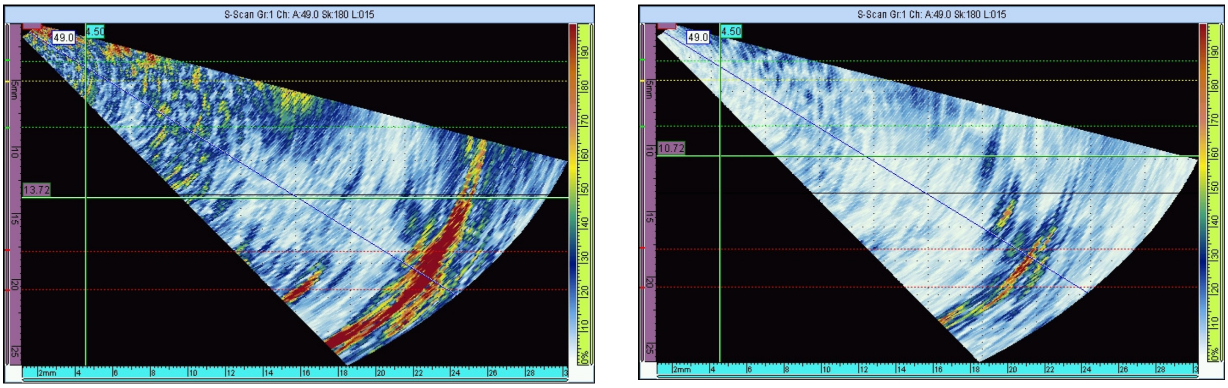
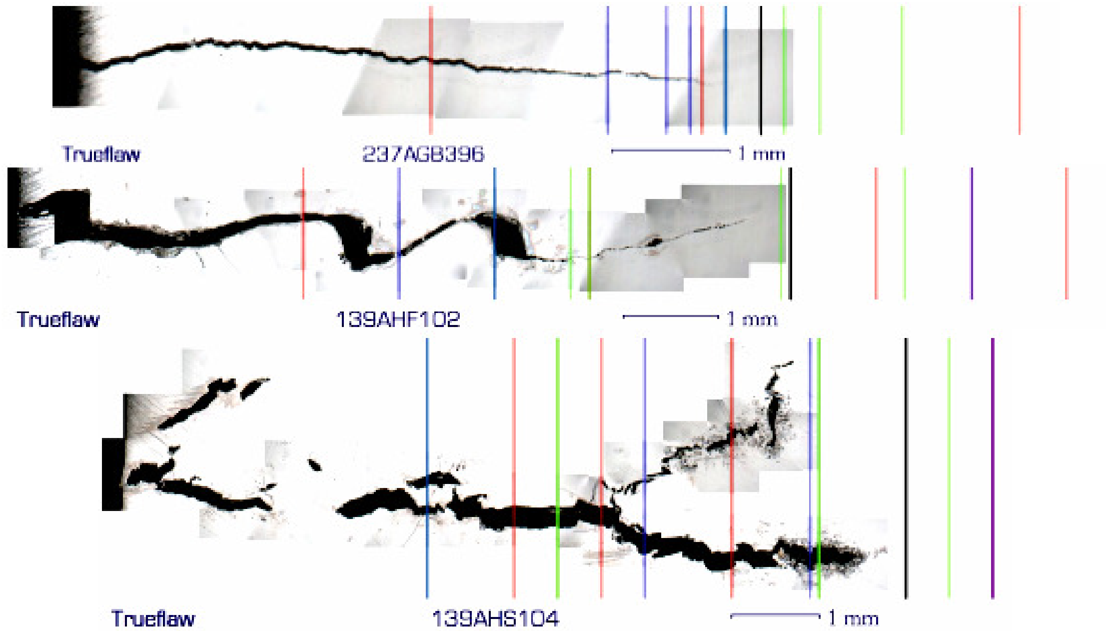


Figure 6 - Correllation between opening and UT amblitude in crack tip. Left crack B396 and right F102.



Picture 7 - NDT size measurements from different cracks (B396 thermal, F102 fatigue and S104 soludification)

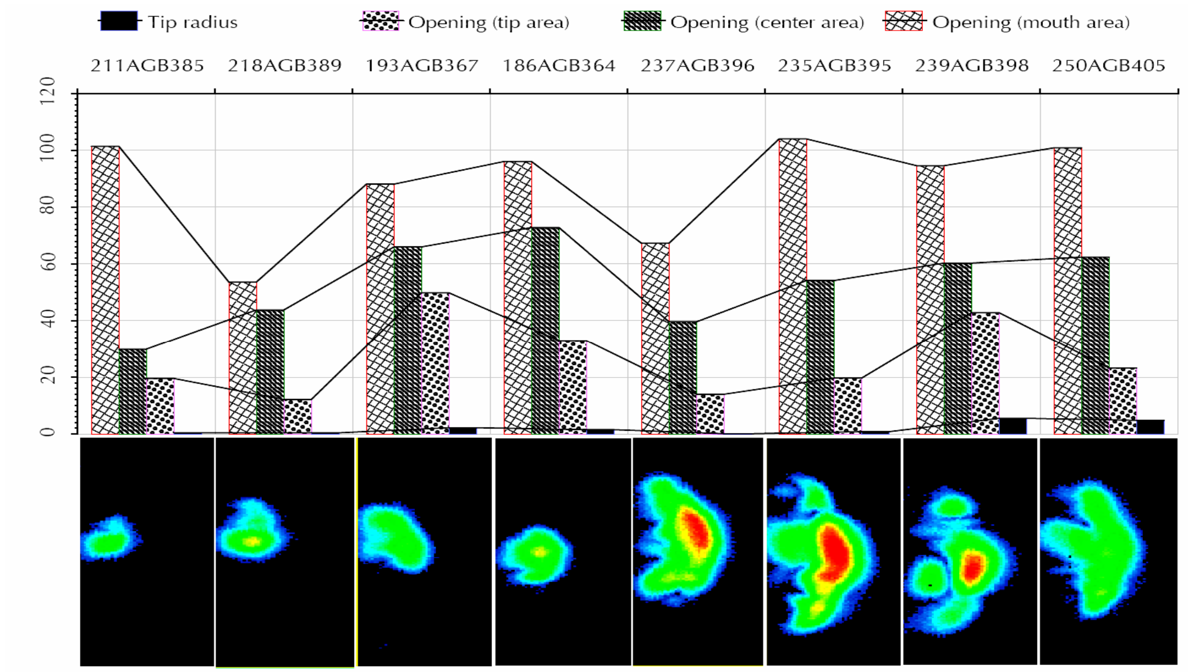


Figure 8 - Reflection of thermal fatigue cracks in acoustic microscope. Correlations between the crack opening and the ultrasonic response.

DISCUSSION

Crack tip opening affects the amplitude of the crack tip signal (Figure 6). Smaller opening gives smaller signal amplitude. In figure 8 no correlation can be seen with the SAM signal amplitude and crack face opening measured from metallographic examination.

Flaw sizing results shown in Figures 2 and 3 are in line with general expectations. Small defects were sized quite well and deep defects were undersized. The same behavior is seen in many studies. In Table 1, it can be seen, that increasing crack size is associated with increasing sizing error (undersizing). In order to understand the reason for this, it is necessary to discus the sources of sizing error present in this study.

All sizing techniques used utilize crack tip signal to determine crack size. The error in sizing may thus come from two distinct sources. Firstly, when the inspector has correctly identified the crack tip, there is some error associated with the procedure of correctly locating the source of the signal within the sample. For present discussion, this error is termed "measurement error". It is typically reasonably small, in the order of ±1 mm and comes from sources like error in calibration, resolution of the device used etc. The error may be assumed to be centered around the true location of the signal and to be normally distributed. This error is not affected by crack characteristics.

The other possible source of error is the error in correctly identifying the crack tip signal. For present discussion, this type of error is termed "interpretation error". When the inspector fails to correctly identify the crack tip signal, he is, in fact locating the singal from some other source. This source may be signal from other parts of the crack, besides the tip or from microstructural noise (and not from crack at all). This error can not be assumed to be centered around the true depth of the crack and nor can it be assumed to be normally distributed.

The crack characteristics have influence on the interpretation error. Firstly, the strength of the crack tip signal affects the likelihood of misinterpretation. The stronger the tip signal is, the easier it is to correctly distinguish from microstructural noise etc. The crack opening, and crack tip opening in particular affect the strength of the crack signal. Secondly, the artificial flaws may have features other than the deepest tip that give strong signal and thus may easily be misinterpreted as the crack tip. For example, strong twists or branches with secondary tips may act this way. It should be noted, that other factors affect the interpretation error, as well. For example, if the inspected component contains welds or other strong sources of microstructural noise, the likelihood of interpretation error increases.

Consequently, to correctly asses the effect of crack characteristics on the sizing reliability, one needs to asses whether the error includes interpretation error and if so, what is it, that the inspector has, in fact, located in stead of the crack tip. To this end, all the NDT results from these flaws (as reported in 2) were plotted on the cross section images from the cracks. With this visualization, it was possible to determine, not only which results included interpretation error but also, whether the inspectors in these cases had studied random noise or some other feature of the crack. When reading these images, it should be noted that the thermal fatigue cracks were introduced to base material so the microstructural noise was very low. In contrast. All solidification cracks and welded fatigue surfaces were introduced near or within weld material and thus had much higher level of noise.

The analysis of these images is revealing. For thermal fatigue cracks, both the mechanized and phased array inspections (green and blue lines) have correctly identified the crack tip. The error is small and centered around the true crack depth. However, the most of the manual inspectors (red lines) have not correctly identified the crack tip even in this simple geometry and in absence of weld. The error signals in manual inspection cannot be linked to any feature of the crack and thus it is assumed, that the inspectors have located signals from microstructural noise. In crack 218AGB389, the two erroneous manual inspection results are near a place, where the crack opening suddenly decreases, but there's not enough data to determine whether this is an isolated case.

In case of welded fatigue surfaces, there are errors too big to be attributed to measurement error in all inspection types (manual, mechanized and phased array). This may be attributed to the weld present, which increases noise level and thus the likelihood of interpretation error. In this case, however, the erroneous interpretations are connected with strong twists in the flaw. Thus, it may be concluded, that when the inspectors have failed to correctly identify the crack tip they have, in most cases, located signal coming from a twist in the crack. This lead, on average, to undersizing of the flaws. Curiously, it also decreases the average error in cases, where the inspetor has failed to correctly identify the crack tip. This can be attributed to the fact, that welded fatigue surfaces (with the exception of 139AHF103) have a characteristic twist quite near (within 2 mm of) the true crack depth which many inspectors have, incorrectly, interpreted as the crack tip. Consequently, although the event of failing to correctly determine the crack tip is much more common in welded fatigue flaws than in thermal fatigue cracks, the average error in sizing is nearly the same (in case of mechanized and phased array inspections) or smaller (in manual inspection) that in case of thermal fatigue flaws.

In case of solidification cracks, yet another behaviour can be observed. The flaws are characteristically heavily branched and have numerous similar crack tips, which are metallographically similar. Consequently, the main source of interpretation error is not that the inspector has located signals from random noise or signals from twists or other crack features. In stead, the inspector has picked the wrong (that is, other than the deepest) tip to analyze. The tip that the inspector has picked is, however, likely to be near the true deepest tip, and thus the average error in this case also reasonably small and the inspectors are much more likely to undersize than oversize the crack.

For further studies, it would be interesting to investigate all crack types in more realistic components and with welds, where microstructural noise would be significant. This might reveal more about the influence of crack characteristics to in service inspection accuracy.

CONCLUSIONS

The following conclusions can be drawn from this study:

- Crack opening affects the amplitude of the crack tip signal. Smaller opening gives smaller signal amplitude.
- With decreasing signal amplitude, the likelihood of misinterpretation in identifying crack tip signal increases.
- With increasing noise amplitude (for flaws near weld), the likelihood of misinterpretation in identifying crack tip signal increases.
- For thermal fatigue flaws included in this study (in base material), mechanized and phased array inspections correctly identified the crack tip signal and sizing accuracy is thus good.

- In manual inspection (for all flaw types) the likelihood of misinterpretation in identifying crack tip signal is high

REFERENCES

1) Kemppainen, M., *Realistic artificial flaws for NDE qualification – novel manufacturing method based on thermal fatigue*. Dissertation for the degree of Doctor of Science in Technology. Espoo, Finland, 2006. (Available online from: http://lib.tkk.fi/Diss/2006/isbn9512282631/)
2) Mika Kemppainen, Iikka Virkkunen, Trueflaw Ltd. Raimo Paussu, Fortum NuclearServices Oy. Tapani Packalén, Juha Sillanpää, Inspecta Certification Oy. *Importance of crack opening in U-inspection qualification*