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ACCEPTANCE CRITERIA FOR NON-DESTRUCTIVE TESTING OF PE ELECTROFUSION JOINTS

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SHORT SUMMARY
On request of the Dutch DSO's and in cooperation with all important Dutch stakeholders (producers, suppliers, contractors and the regulator), Kiwa Technology investigated the relevancy of defects found with Phased Array Ultrasonic Testing (PAUT) and if it was possible to determine acceptance criteria. The project showed that using the PAUT non-destructive testing (NDT) method, mainly voids are found, and that there is a relationship between presence of voids and destructive test results. Based on the results, preliminary acceptance criteria are proposed.

KEYWORDS
Electrofusion joint, non-destructive testing, PAUT

ABSTRACT
On request of the Dutch DSO's and in cooperation with all important Dutch stakeholders (producers, suppliers, contractors and the regulator), Kiwa Technology investigated the relevancy of defects found with Phased Array Ultrasonic Testing (PAUT). The objective was twofold:

- Can relevant defects, that occur in practice, be found with PAUT?
- Is it possible to setup acceptance criteria?

The project showed that with PAUT mainly voids are found in electrofusion joints made in practice. It was not possible to detect so called cold welds (brittle failure) directly. Still, there is a relationship between the presence of deviations and brittle failure in a peel decohesion test (ISO 13954 [1]). Based on these results, the stakeholders agreed on preliminary acceptance criteria.

INTRODUCTION
In a GERG investigation [2], the PAUT (Phased Array Ultrasonic Testing) technique had shown promising results for electrofusion joints. This appealed to the Dutch distribution system operators (DSO's) for gas, since the current practice of sampling 5% to 10% of all joints and test them destructively is very costly and time consuming. Therefore the Dutch DSO's decided to bring the technique from laboratory into practice. They first

needed to get confidence that the technique is capable in finding relevant errors that occur in practice, since former results were mainly based on joints with artificial errors. Furthermore, in the GERG project the 'quality' assessment using PAUT was based on an expert opinion rather than on objective criteria. In order to apply the PAUT technique into practice, clear and objective acceptance criteria are needed.

The objective of testing

A common mistake is to think that the objective of the inspection of joints is to determine the (mechanical) quality of the individual joint. But this is really not the case. Instead, the objective is to check the quality of workmanship: is the joint made in accordance with the prescribed procedure.

> **Cooperation with all stakeholders is essential**
> When developing an inspection method, it is very important to involve all stakeholders. Not only has the inspection method to work properly, but it should also be trusted and supported. This is especially important when establishing acceptance criteria.
>
> Therefore the Dutch DSO's involved manufacturers, material suppliers, contractors and the Dutch regulator in the project.

The precondition for inspection is a qualified procedure. A qualified procedure is a procedure whereof has been established that, when followed correctly, the joint will be of good quality. The only guarantee for the quality of a joint is the application of the qualified procedure by a qualified welder, using qualified material and equipment. This does not mean that any deviation from the procedure automatically results into a bad joint, but the quality of the joint is at least uncertain.

The objective of visual and other types of non-destructive inspection is to check if the qualified procedure has been applied correctly by checking for any anomalies that are not to be expected. An anomaly is an indication that at some point in the procedure something went different than it should, and therefore the quality of the joint is uncertain.

Non-destructive testing is supplementary to the visual inspection

After the electrofusion joint is made, a visual inspection is performed. The joint is checked on any anomalies, like exposed wires, melt out and misalignment. If any deviation is found, the joint is rejected. Once again: not because the quality is not good, but because the quality is uncertain.

Non-destructive testing, in this case using the PAUT technique, is supplementary to this visual check. With PAUT any anomalies in the fusion plane can be visualized. PAUT is especially sensitive to the presence of voids and pollutions, but it is not possible to distinguish between the two.

Destructive testing as a reference

The current practice in the Netherlands is that 5% to 10% of the newly made electrofusion joints in PE gas pipes is taken out for inspection by destructive testing. Of course, destructive and non-destructive testing are very different, but in this case, both the random destructive testing and the non-destructive testing have the same objective: checking for good workmanship.

Of course, one could say that with destructive testing the mechanical quality of each specific tested joint is known. However, this is on itself not very useful, since the tested joint is no longer part of the gas piping system. Why is the destructive testing still relevant? That is because of the assumption that the tested joints are representative for all other joints made by this particular welder in this particular project. This is only true if a fixed (qualified) procedure has been applied. And therefore the objective of the destructive test becomes the same as for the non-destructive inspection: checking if the prescribed procedure is being followed.

Although the objective is the same, the tests are not the same. Therefore it will not be a surprise that there are differences between outcomes of destructive and non-destructive testing as well. It is important to keep the differences in mind:

Table 1: Important properties compared

Destructive testing (Peel decohesion)	Non-destructive testing (PAUT)
Tests the strength	Checks for deviations
Only small part of the joint is investigated.	Almost the whole circumference of the joint is inspected
Type of errors: brittle failure (also skew pipe-end / pipe under penetration* and voids if visible)	Voids, pollutions, skew pipe-end / pipe under penetration*
Destructive: joint no longer part of the pipe system and a new joint has to be made instead (in some cases even two joints)	Non-destructive: joint stays in the pipe system.

*) The pipe-ends have to be straight and fully inserted into the coupler. Otherwise the skew pipe-end or the under penetration will cause melted material flowing from the fusion zone into the pipe.

The above summarized: following the qualified procedure is the warrant for the quality of the joints, while the aim of inspection is to check whether the welder applied the qualified procedure correctly or not.

EXPERIMENTAL

Acceptance criteria based on empirical data

Keeping in mind that the objective of testing is to check if the procedure is applied correctly, any deviation that is not expected when applying the procedure, could lead to rejection. However, in practice acceptance criteria are often less strict formulated, allowing a certain amount and size of anomalies. The difficulty is to establish what is acceptable and what is not. For this project empirical data was used to make a first proposal for acceptance criteria. Electrofusion joints were taken from practice and first non-destructively examined with PAUT and afterwards tested destructively.

The size, amount, surface-area (both absolute and relative) and location of the anomalies found with PAUT were compared to the results of destructive testing (peel decohesion test in accordance with ISO 13954 [1] and crush test in accordance with ISO 13955 [3]. Also, a part of the joints with anomalies were cut at the location of the anomaly in order to determine what the anomaly was.

The investigated samples

In total 202 electrofusion joints were investigated. The joints were taken out for the regular quality check at locations throughout the Netherlands, created by almost 100 different welders. Only joints that satisfied the visual inspection criteria were investigated. Therefore none of the joints had misalignment of the pipes, visible melted material or visible heating wires outside the EF coupler. The major part concerned George Fisher couplers. The other part concerned primarily Frialen couplers, but some other brands as well. The size was mainly 110 mm and larger, but some smaller ones were investigated as well, see figure below.

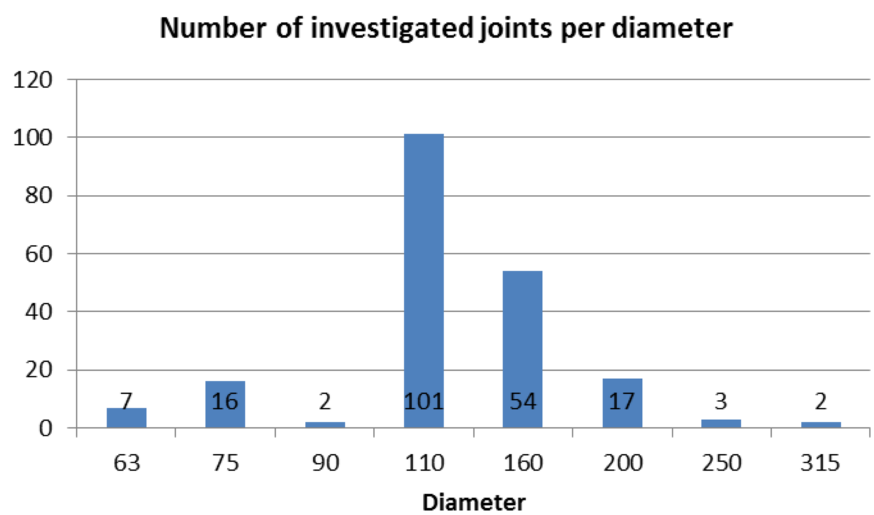

Figure 1: Distribution of the number of investigated joints per diameter

Sizing and locating anomalies

Using a so-called scanner, a PAUT record of the circumference of each joint was made. The record was afterwards analysed and both the position and size of the anomalies were recorded:

- Radial position in reference to the wires
  The position of the anomaly in reference to the heating wires was recorded as follows:

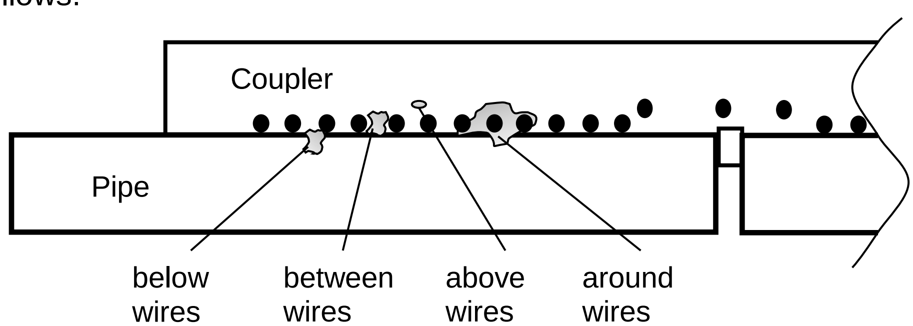

Figure 2: Possible positions of anomalies in reference to the heating wires

- Axial length
  The axial length of the anomaly is the maximum length measured in axial direction, as shown below:

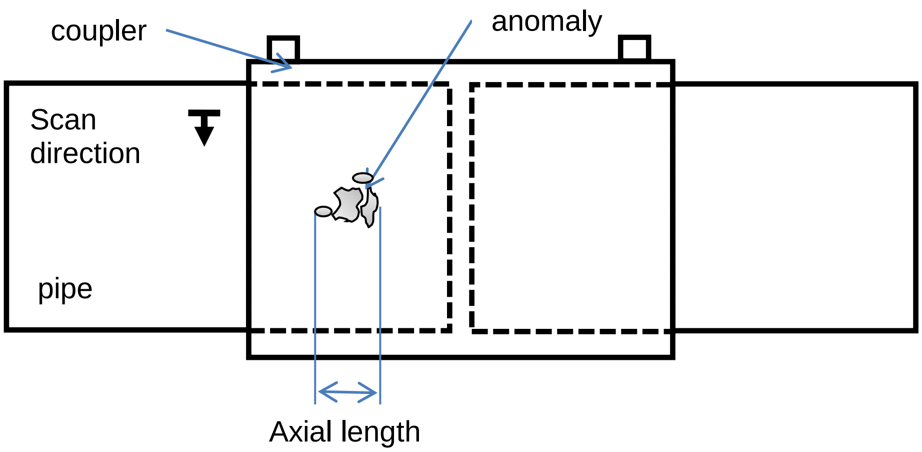

Figure 3: Axial length of the anomaly

- Relative axial length
  The relative axial length was calculated by dividing the measured axial length by the whole axial length of the fusion zone.
- Circumferential length
  The circumferential length of the anomaly is the maximum circumferential length measured, as shown below:

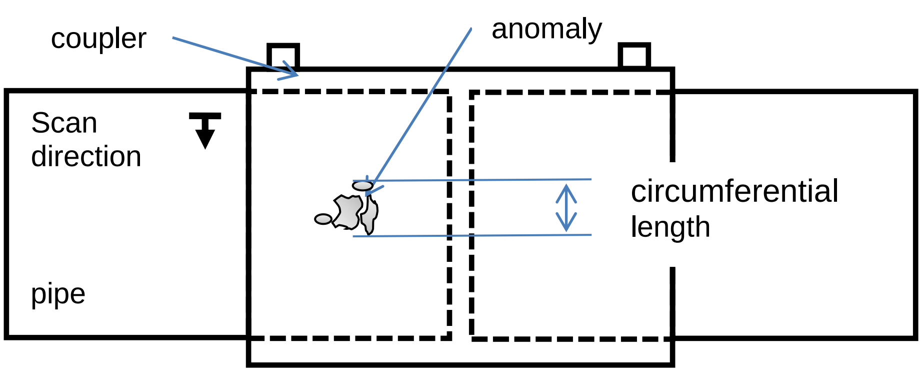

Figure 4: Measurement of the circumferential length

- Calculated anomaly surface-area
  Per side the “surface-area” of each anomaly was calculated by multiplying the maximal axial length with the maximal circumferential length. Keep in mind that this is always larger than the real surface-area of the anomaly.
- Total calculated anomaly surface-area per side (and radial position)
  Per side the sum of the calculated surface-areas of all anomalies was calculated.
- Relative total anomaly surface-area per side
  Per side the percentage of the total calculated anomaly surface-area with respect to the total welded surface area was calculated.

- Amount of anomalies
  Per side the amount of anomalies was counted. Anomalies that at some point are linked together, were counted as one.

The minimal size of an anomaly detected with PAUT is about 1 to 2 mm. So very small anomalies already show up. The difficulty was that most of the investigated couplers do not have a smooth surface. This causes noise in the PAUT image. As a consequence, when small anomalies are concerned, it is not always clear whether it is noise or an anomaly.

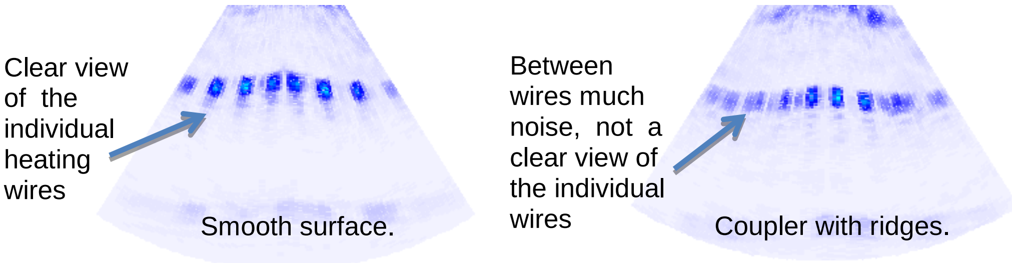

Figure 5: PAUT image of a coupler with a smooth surface and a coupler with ridges. The ridges of the coupler causes noise in the PAUT image.

Mainly voids

About 33 different joints were cut open in order to see wat the anomaly was. In total 50 anomalies were checked. For 80% of the cases a void was found.

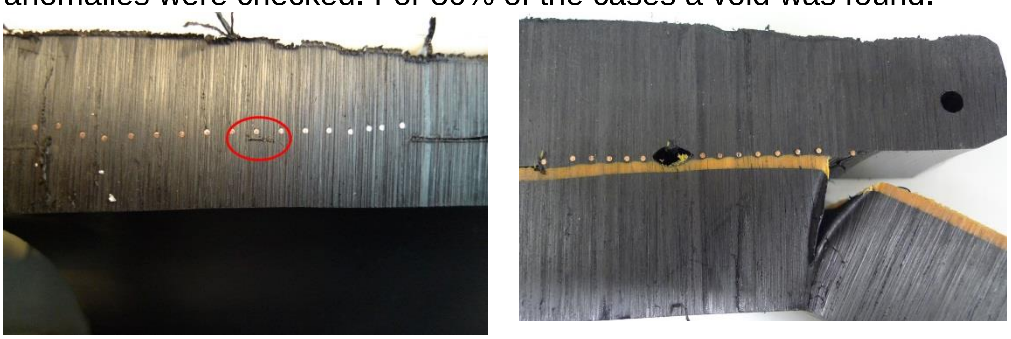

Figure 6: Examples of different types of voids found with PAUT analysis

For 6% of the cases displacement of the wire was found, always up in radial direction (visible as an anomaly above the wires). In 14 % of the cases, nothing was found. This concerned small sized anomalies, where in some cases the PAUT inspector explicitly remarked his doubts if it concerned an anomaly or noise.

Another error that can occur is a skew pipe-end (pipe-end is not straight) or pipe under penetration (pipe is not fully inserted into the coupler). In both cases this will result in a flow of melted material from the fusion zone into the interior of the pipe and a dislocation of the wires, which would be clearly visible with PAUT. However, this was not the case with any of the investigated joints.

DISCUSSION

Different possibilities for acceptance criteria.

The stakeholders discussed different possibilities for acceptance criteria. For each type of acceptance criteria was analysed what the results would be, when applied to the investigated samples:

- The ratio between accepted and rejected samples
- Part of the rejected samples that showed brittle failure (peel decohesion test).
- Part of the accepted samples that showed brittle failure (peel decohesion test).

Below some examples of different proposed acceptance criteria with the pros and cons and what the results would be if applied on the investigated samples:

Table 2: Examples of different possibilities of acceptance criteria.

Suggested criteria	Arguments	If applied to the investigated samples
No anomalies	Pros: • Any anomaly is an indication that something went different. Cons: • The joints are made in all kinds of situations. Little anomalies are probably to be expected without being an indication of a wrong procedure.	42% would be rejected whereof 12% showed brittle failure 58% would be accepted whereof 2,6% showed brittle failure.
Maximal one anomaly with an axial length ≤ 2mm	Pros: • New Dutch criteria demand that at cut of the peel test sample no more than one void of maximal 2 mm is visible. Cons: • Applying this to PAUT would be much stricter, since PAUT checks the whole circumference.	38% would be rejected whereof 13,3% showed brittle failure 62% would be accepted whereof 2,4% showed brittle failure
Summed surface area <=50 mm^2	Pros: • The joint is only rejected when the size of anomalies gets serious, allowing the presence of some small anomalies. Cons: • The limit of 50 mm^2 is arbitrary. • Should small anomalies and big anomalies not be distinguished? • Should this not be relative to the total fused surface-area?	35% would be rejected whereof 14,5% showed brittle failure 65% would be accepted whereof 2,3% showed brittle failure
Relative surface-area <=0,25%	Pros: • The joint is only rejected when the surface of anomalies is serious with respect to the total surface-area. Cons: • The limit of 0,25% is an arbitrary value (it also seems rather small, but this is due to the large fused surface-area) • Should small anomalies and big anomalies not be distinguished?	35% would be rejected whereof 14,5% showed brittle failure 65% would be accepted whereof 2,3% showed brittle failure

Statistical analyses

As can been derived from the table above, there is no direct relationship between the PAUT analysis and the peel decohesion test. There are some examples where no anomaly was visible with PAUT, and still the peel decohesion test showed too much brittle failure. Also, the presence of anomalies doesn't always mean that there will be brittle failure in the peel decohesion test. Still, when anomalies are present, the chance on brittle failure is clearly higher than when no anomalies have been detected.

Using a statistical analyses the relation between the PAUT results and destructive test results was investigated. The statistical analysis was limited to the samples with a diameter of 110 mm or more. The reason is that for smaller diameters (up to 90 mm) a different destructive test is used (crushing decohesion, in accordance with ISO 13955 [3]). These results cannot be compared with the peel decohesion test (ISO 13954 [1], used for diameters above 90 mm). Since most samples had a diameter of 110 mm or more, it was decided to only use the results of these diameters in the statistical analyses.

Contrary to the expectations, the correlation between size and surface-area, no matter if it was absolute or relative, was quite weak. Instead, the correlation between the amount of anomalies and the destructive test results appeared to be stronger.

The cause and relevancy of voids

Since most anomalies concerned voids, the question was raised what could cause voids and can they affect the quality of the joints. The cause of voids was not part of this research programme. However, the following possible causes were mentioned:

- Production process
  According to coupler manufacturers it cannot be excluded completely that in some cases a void arises in the coupler during production. But it is not very likely that such a void would move during the welding to the fusion zone. This would mean that such a void would rather be visible as an anomaly above the wires.
- Moisture
  From experience Kiwa knows that moisture can cause voids. Moisture can be present due to a humid environment. But it can also be the remains of a cleaning agent.
- Shrinkage cavities
  According to the coupler manufacturers, shrinkage cavities sometimes arise when welding larger diameters (315 mm and above). However, this would be an unlikely explanation for the mainly smaller diameters couplers in the investigated sample set.
- Voids due to premature movement
  According to the coupler manufacturers, voids could also arise when the joint is moved prematurely during the cooling phase.
- Ideal conditions: no voids
  Beside the samples from practice, about ten examination samples were investigated. These type of joints are made by welders during their assessment

for getting a license. The conditions are always ideal. None of these samples showed any anomalies. This supports the idea that voids are an indication that something went wrong during the process.

Based on this information, it can be assumed that in a normal situation voids should not occur. Still it can be questioned if the presence of voids is relevant for the quality. The answer is yes, because, as is clear from the results, joints with anomalies have a higher chance of brittle failure.

The value of PAUT, even if it can't replace all destructive testing

The stakeholders decided that at this point they could not agree on acceptance criteria for the PAUT inspection that would make destructive sampling completely redundant. They had the following arguments:

- Can voids in any case be avoided?
  Since most of the time the anomalies concerned voids, the question was raised if all voids could be avoided in any case by good workmanship. If not, than it would not be justified to reject a joint based on the presence of an anomaly, even more so since the presence of an anomaly is not synonym to bad bonding.
- The part of joints with deviations is too large
  Rejecting 20-30% of all joints seemed not right, especially since the amount of brittle failure is much lower. On the other hand, it is expected that the amount of joints with voids will drop when there is more attention for this type of deviation.

Even when PAUT does not replace destructive testing completely, the stakeholders agreed that application of PAUT inspection can be valuable non the less. In their opinion the chance on brittle failure for joints with no visible deviations, is acceptable. Therefore PAUT can be used to accept the major part of the joints. If about 70% of all investigated joints can be accepted based on PAUT inspection, already much is gained: joints are not taken out and results are immediate. This will be a valuable saving of both time and cost. Furthermore, direct feedback to the welder should have a positive effect as well.

Preliminary acceptance criteria

Based on the discussion above, the stakeholders agreed to define transition criteria. In this way PAUT inspection can be applied in combination with destructive testing. The stakeholders agreed on the following preliminary criteria, where only anomalies below and between wires are concerned:

Table 3: Preliminary acceptance criteria

Criteria (per side)	Verdict	If applied to investigated samples
Amount of anomalies ≤ 2 and anomaly surface area < 500 mm^2	Accepted	74% whereof 2% showed brittle failure
Amount of anomalies > 2 and anomaly surface area < 500 mm^2	Take out for destructive test. Outcome of destructive test is leading.	11% whereof 19% showed brittle failure
Anomaly surface area > 500 mm^2	Reject	15% whereof 20% showed brittle failure

Mind that the joint has to comply both to the visual and PAUT inspection criteria, since the PAUT inspection is supplementary to the visual inspection.

A pilot with PAUT inspections based on the preliminary criteria

Now that preliminary criteria have been established, the next step is to check them in practice. In order to do so, a pilot project has been started where on-site PAUT inspections are carried out. The objective of the project is to check the validity of the preliminary criteria and if PAUT inspections live up to the expectations in terms of time and cost saving and positive effects of the direct feedback to the welder. For this project the majority of the inspected joints is still taken out for a destructive test. This is necessary to check if the former found chances on brittle failure keep on being valid.

CONCLUSIONS

The project results show that in practice PAUT will mainly find voids. The presence of these voids and other anomalies is relevant, since they show that at some point there has been a deviation from the required procedure. The fact that joints with anomalies have a higher chance on brittle failure is even more convincing. Even though not all joints that show brittle failure, show anomalies that are detectable with PAUT, stakeholders in the Dutch gas distribution are convinced that PAUT can have a valuable role in inspecting electrofusion joints. The stakeholders where able to agree upon preliminary acceptance criteria, that are currently evaluated in a pilot project with PAUT.

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Other stakeholders were in this project represented by the following companies: De Jongh Pipe Systems (supplier), SodM (regulator), George Fisher (manufacturer), Akatherm (representing manufacturer Frialen in the Netherlands), Wavin (manufacturer), Van Gelder and Van der Lubbe projecten (both representing Bouwend Nederland, the organization that represents all Dutch contractors).

The following companies supported the project with advise: Advanced Ultrasonics and Liandon.

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[3] *ISO 13955: Plastics pipes and fittings -- Crushing decohesion test for polyethylene (PE) electrofusion assemblies,* 1997.

