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Revision	Date	Description
A	02-SEP-2021	First release [DRAFT]
B	11-OCT-2021	Updated with feedback TNO

Introduction

Villari has developed a sensor unit (the RedFox v2, see Figure 1) that can detect and monitor fatigue damage in steel structures. The sensor strips continuously measure the magnetic field at specific locations in a structure that already contain a fatigue crack or where fatigue damage is expected in the future. The sensor data can be read out remotely to observe any changes in the magnetic field in time. Changes in the magnetic field might indicate fatigue crack initiation and/or propagation. We expect that the RedFox v2 can detect cracks in a very early stage due to the Villari-effect: build-up of magnetization due to changes in mechanical stress, such as plastic deformation which occurs right before cracking / near the crack tip.

The RedFox v2 transmits raw magnetic field data wirelessly to our servers, after which it is analyzed at the office and reported to the client. No on-chip data processing is being performed as of today. Asset owners can use the information from the sensors to make decisions regarding future maintenance operations and replacement to ensure safe usage of the structures. The sensors are an interesting alternative to more conventional inspection techniques and potentially cheaper, more reliable, and less disruptive.

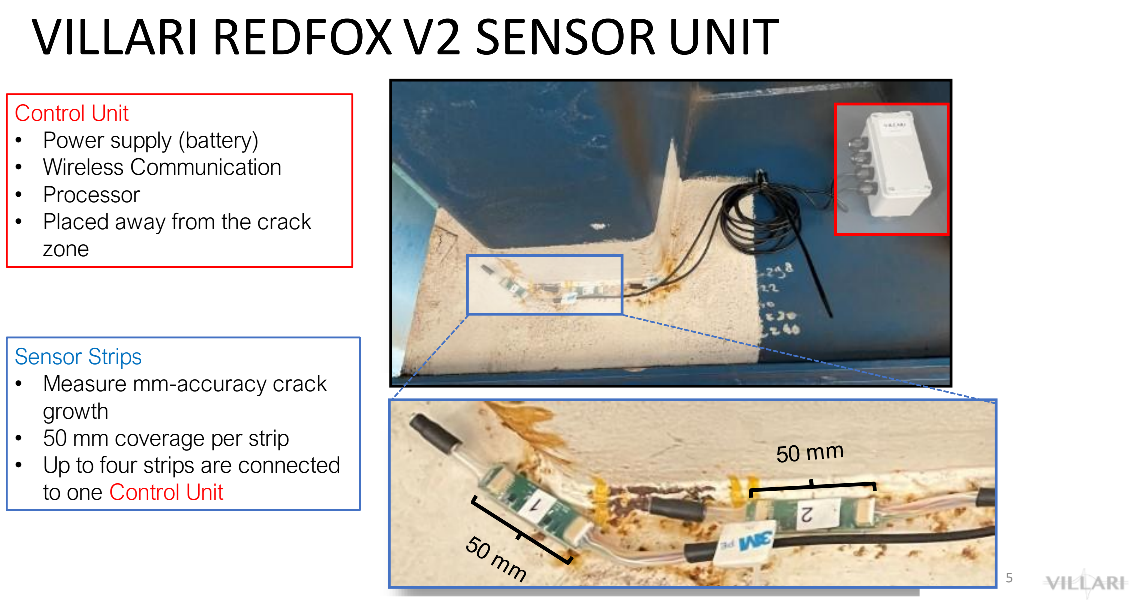

Figure 1: Villari RedFox v2 sensor unit installed on a highway bridge.

Villari has installed sensors on various structures over the past year, providing insightful information about the functionality and reliability of the sensors. A more extensive testing program is deemed necessary to provide more information about reliability, accuracy and limitations of the sensors. The current documents presents a test plan to derive the capabilities of the sensors which can be used on future projects, such as for the City of Amsterdam. The lessons learned from these initial applications are used in the current testing program to explore potential optimizations in the future use of the sensors.

Objectives

The objective of the testing program is to:

- Demonstrate the capabilities of using the RedFox V2 Sensor Unit **to detect** fatigue crack initiation and propagation.
- Demonstrate the (potential) capabilities of using the RedFox V2 Sensor Unit **to size** fatigue cracks (both crack length as crack depth)
- **Define** the usage of the RedFox V2 Sensor Unit in terms of fatigue crack initiation and propagation detection. This implies defining detection limits for out sensor strips in relation to crack size and distance between the sensor strip and the crack.
- Observe potential limitations and influencing factors that require **additional future research**.

We aim to carry out all tests at the laboratories of the Technical University of Delft. This can be both Delft Aerospace Structures and Materials Laboratory (DASML) or the Stevinlab used by the Civil Engineering faculty. This is subject to change depending on theavailability of the test rigs.

Stakeholders

This document intends to inform Villari staff on the testing procedure. It also aim to inform our partners City of Amsterdam and TNO and ask for their feedback. Rijkswaterstaat will also be notified of this test plan due to their previous experience with our technology, and the document can also be shared in the future with other engineering / fatigue damage industry experts.

Planning

A planning is included seperately. We aim to finish the testing in early 2022. This might change depending on the availability of material and test equipment.

Test Set-Up

The following tests are being prepared, each with their own objective(s):

1. Uniaxial static tensile tests on dogbone specimens (2 sets of 5; 10 in total)
    a. Validate the Villari effect with RedFox V2 Sensor Units.
    b. Potentially optimize the usage of RedFox V2 Sensor Units by enhancing the magnetic field in the specimens
2. 4-point bending fatigue tests on Single-Edge Notched Bending (SENB), base and bead-on-plate welded specimens (4 sets of 5; 20 in total)
    a. Verify sizing capabilities (both depth and length)
    b. Verify effect of relative distance crack tip and sensor
    c. Verify fatigue initiation detection capabilities
    d. Verify effect of welding (i.e. geometry, residual stress) on sensor capabilities
    e. Potentially optimize the usage of RedFox V2 Sensor Units by enhancing the magnetic field in the specimens
3. Uniaxial fatigue tests on welded cruciform joints with various degradation mechanisms (root and toe cracking). (3 sets of 5; 15 in total)
    a. Verify sizing capabilities (both depth and length)
    b. Verify fatigue initiation detection capabilities

A description of each test is discussed in the following chapters. The reason of having three different tests is to build up the complexity step by step to increase the understanding of the capabilities of the RedFox V2 Sensor Units. The final part, cruciform joints, are most representative for the real world applications at different bridges in the City of Amsterdam

Quasi-Static tensile tests

Two subsets of static tensile tests on dogbone specimens are carried out (each with 5 repetitions):

A. As-received material
B. Material that has been magnetically enhanced

The main objective of these static tensile tests is to relate the difference in strain (known from force, but validated with strain gauge) to the difference in the magnetic field during the tests, including hysteresis effects. This test thereby demonstrates the capabilities of the sensor to detect the Villari effect, which was not formally validated by us thus far. An initiating and propagating fatigue crack in a structure leads to a difference in strain in the vicinity of the crack. Proving the Villari effect on this small scale is a therefore a good first step before actual fatigue tests are carried out. It is expected that at low change in strain (or force) not much changes in the magnetic properties of the steel, but that this changes nonlinearly when increasing the stress closer to the yield stress or even above.

Geometry

The geometry of the dogbone specimens is based on NEN-EN-ISO 6892-1 which contains guidelines for tensile tests on metallic components at room temperature. The dogbones are rectangular with plate thickness 8mm using S355J2+N material (3.1 certificate is required). See Figure 2 for a top view of the specimens.

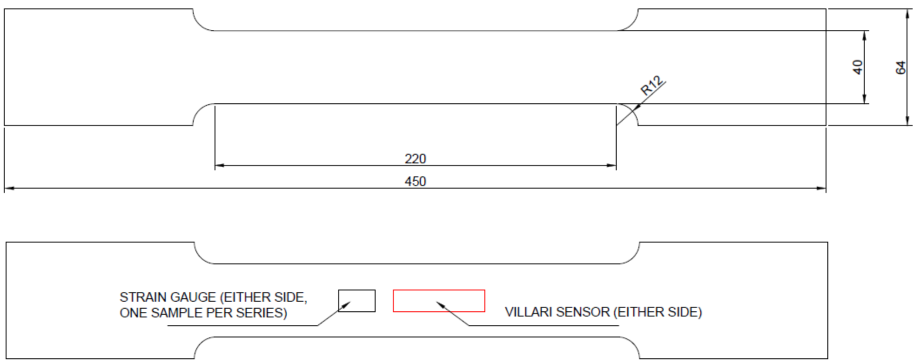

Figure 2 Geometry of the dogbone specimens, RFV2 sensor strip in red.

Additional aluminum dogbone specimens are produced with similar dimensions of the steel dogbones. When the same tests are performed using an aluminum specimen, which hold no magnetization, only the Earth magnetic field will be measured. This can then be subtracted from the tests with the steel dogbones in order to only measure the effect due to the steel specimen itself and not the background field. Since we're looking at differences compared to the initial measurement we do not expect the static background field to have a lot of effect, but when looking at a percentual change it could provide a slight benefit to our analysis and the understanding of the Villari-effect.

It should be noted that in real world applications filtering out the background effects is impossible, so in the analysis we will both investigate the data with and without background field.

Load

The test should be carried out as displacement (strain rate) controlled. The tests will be completed as displacement controlled, the force levels mentioned below are indicative. The first tensile test will be equipped with a strain gauge to tailor the displacement levels of the test rig. The specimen geometry and load application are taken from NEN-EN-ISO 6892-1.

A machine speed of 0.002 s^{-1} can be used to control the displacement of the test rig. Three tensile tests should be carried out initially to verify the full stress-strain curve of the applicable material before completing the additional tests.

The load sequence aims to load and unload to the levels given in Table 1. The values in this table are based on the nominal yield stress of the plate (355 MPa) which needs to be adjusted following the first tensile tests to verify the actual yield stress of the material. The load should be reset after each load increment to:

- zero after each increment before moving to the next level for the first three tests within each subset (first 3 out of 5 samples).
- half the load level at it's current load phase for the remainder two tests within each subset (final 2 out of 5 samples)

After a test the sample can no longer be used since it has been stressed above the yield stress and therefore has experienced plastic deformation.

The reason for unloading the specimens is to analyze the hysteresis effect within each sample during the test. A structure subjected to fatigue loading always contain some stress due to dead wind or other love load (i.e. temperature, wind). Varying the rest stress value might help to more reliably understand the hysteresis effect and how this affects the sensors detection capabilities. The two different load series are visualized in Figure 3.

Table 1 Load table for the tensile tests.

σy [%]	**F [kN]** *(indicative)*
0	0
20	22,72
40	45,44
60	68,16
80	90,88
100	113,6
105	119,28
110	124,96
115	130,64
120	136,32

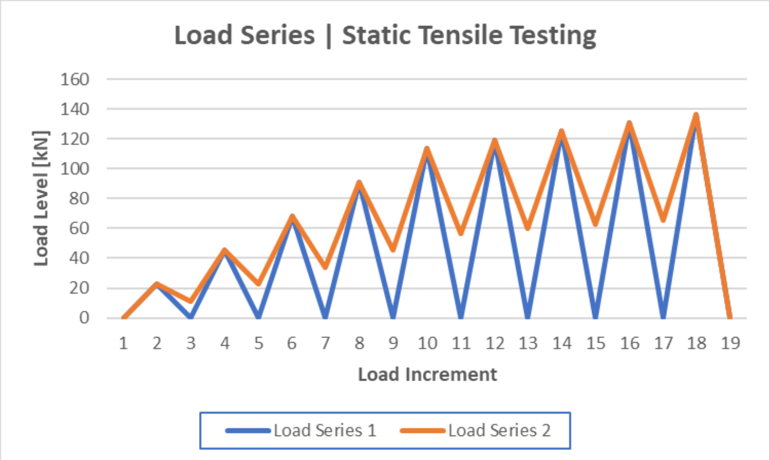

Figure 3 Load series of the quasi- static tensile testing.

Equipment

Two sensor strips are applied in the center of the specimen oriented longitudinally either side of the specimen using two-sided 3M VHB tape, see Figure 2. This tape is similar to the tape we use in the field. The only difference is that this is uncoated steel whereas steel in real world is always coated in order to prevent corrosion. Although we expect that a sub-mm thick layer of coating does not influence the magnetic readings too much. A reading of the sensor should be completed at each load increment (so each peak and valley) as visualized in Figure 3 resulting in 19 measurements per sample. The sensors are applied longitudinally such that we minimize edge effects that could jeopardize the sensor reading during the tests. These edge effects are in continuum structures not present and should therefore be excluded/minimized in the tests.

One specimen per series should be equipped with an uniaxial strain gauge either side of the specimen for strain validation (2 in total). The strain gauges measure the strain in the narrow area for validation. The parallel length of the specimens should be sufficient to obtain a uniform stress field such that strain gauges are not necessary for all specimens. This is demonstrated by equipping one sample within each series with strain gauges. The strain gauges will measure the strains in the narrow part of the specimen which can be used as a measure for all specimens.

Evaluation

The evaluation of the tests is to compare the difference in strain relative to the difference in magnetic field for each test at each load increment. A statistical evaluation of the sensor's accuracy (i.e. mean and standard deviation) for each series is being presented after the evaluation.

The strain readings are used to confirm the hand calculation of converting the applied force to strains in the narrow area of the dogbones. This will give us a curve the shows how the magnetic field changes (nonlinearly an hysteretically) with increasing stress.

Conclusion:

This test series concludes on the following aspects:

- The accuracy of the RedFox V2 Sensor Units in terms of measuring strain differences in metallic structures.
- The effect of changing the initial magnetic field prior to changing the stresses/strains by a mechanic load. By adding more magnetization to the specimen, we might be able to increase the measured effect and thereby make the sensor more efficient.

Fatigue SENB tests

Four series of fatigue tests are carried out on SENB specimens (single edge notched bending), each with 5 repetitions:

A. Base material with an initial notch (as is + enhanced)
B. Bead-on-plate welded material with an initial notch (as is + enhanced, *based on previous results*)
C. Bead-on-plate welded material without an initial notch (as is + enhanced, *based on previous results*)

Having two different types of specimens (base/welded specimens and with/without an initial notch) allows us to increase the complexity in phases; isolating the effect of welding and being able to detect fatigue crack initiation in as-welded specimens. The objectives of each tests are shown in the table below.

Table 2 Test objectives per series.

Series	**Sizing**	**Crack initiation**	**Distance between sensor strip and crack**	**Effect of welding**	**Affecting initial magnetic field**
A	X		X		X
B	X		X	X	X
C & D	X	X	X	X	X

Geometry

The geometry of the SENB specimens in chosen in such a way that:

- A substantial fatigue crack can be grown in the specimens prior to failing, resulting in a specimen thickness of 50mm.
- The sensor can be applied along the depth of the specimen, thereby minimizing edge effects. The depth of the specimens should not be chosen to large since this will result in a varying crack depth along the depth of the specimen due to plane strain/plane stress differences that effect the crack growth rate. The balance is to choose a depth of 60mm.
- The length of the specimen is chosen in such a way that:
    - A 250 kN load applicator can be used
    - Each test takes about 100.000 – 300.000 cycles until failure, each test takes maximum 8 hours until failure at a frequency of 10 Hz.
    - Large scale plastic yielding is kept to a minimum

  These aspects have resulted in a specimen length of 310 mm, with a support spacing (L2) of 280 mm and a spacing between the load applicators (L1) of 140 mm.

No specific code was used to define this geometry, but experience from previously completed test series in the past as well as hand calculations. The specifications for the initial notch are:

- For the base material specimens:
  - 1mm deep
  - Width is dependent on the manufacturing process (ideally EDM or wire-EDM)
  - Over the full width of the specimen (60 mm)
  - Notch should be applied at the center of the specimen (one side)
- For the bead-on-plate welded specimens:
  - 0.5mm deep
  - Width is dependent on the manufacturing process (ideally EDM or wire-EDM)
  - Full width of the specimen
  - The notch should be applied directly parallel next to one of the weld toes

With regards to the notch depth being different in the bead-on-plate welded specimens than in the base material specimens: The depth of the base material notch is chosen slightly differently to reduce the length of the fatigue testing for the base material. For the bead-on-plate welded specimen we have chosen a smaller notch to make it more comparable to the as-welded condition and to include more effects of the welded condition (i.e. microstructure of HAZ, stress raising effect weld profile, residual stresses, etc.).

A single, base plate of 2000 x 310 mm S355J2+N is procured by the steel fabricator, including a 3.1 certificate. A section of 700 x 310 is used to prepare the base material specimens (not using 50mm on either side of the 600 mm wide plate section), resulting in 10 base material specimens.

A single weld bead is then applied on the 1300 x 310 mm steel base plate. The welding procedure for the bead-on-plate welded specimens should be MIG/MAG/FCAW resulting in a bead that is 10-15mm wide with a weld cap of 2-4 mm. The base material should be preheated to 50 degrees Celsius prior to welding. The bead-on-plate welded specimens are being cut from the welded 1300 x 310 mm steel plate. The first 50mm at both edges are not used in the testing to exclude the effect of weld start/stop locations.

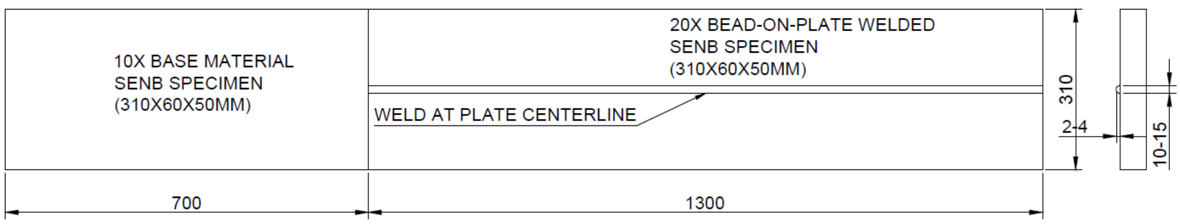

Figure 4 Fabrication of the SENB specimens.

In total, we need :

- 10 base material specimens with an initial notch of 1mm deep (series A, Figure 5)

- 5 bead-on-plate specimens with an initial notch of 0.5mm deep at one weld toe (series B, Figure 6). This means the notched moved slightly to the side (5 - 7.5mm when the weld is 10-15 mm wide)
- 15 bead-on-plate specimens without an initial notch (series C & D, Figure 7)

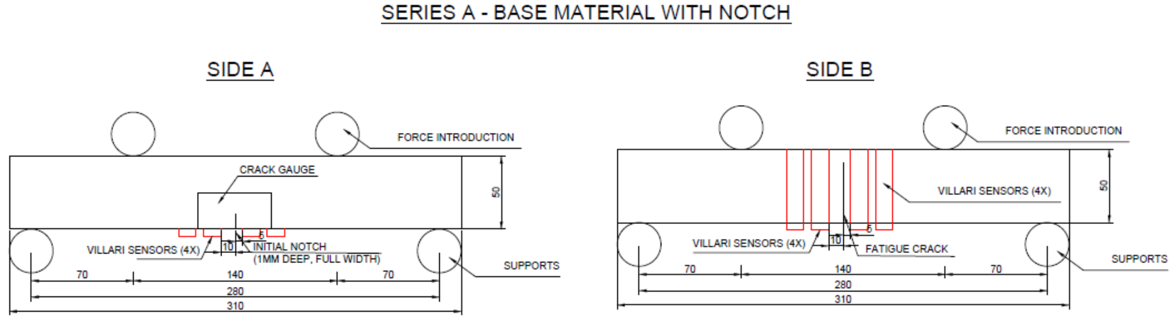

Figure 5 SENB specimens for series A, RFV2 sensor strips in red.

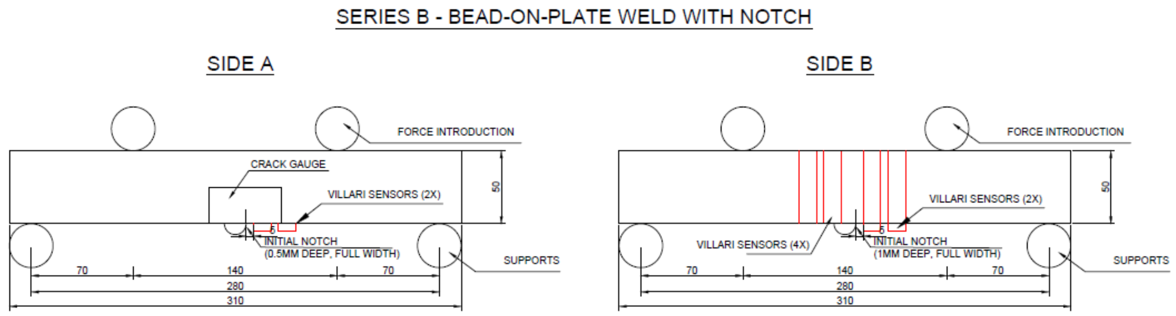

Figure 6 SENB specimens for series B, RFV2 sensor strips in red.

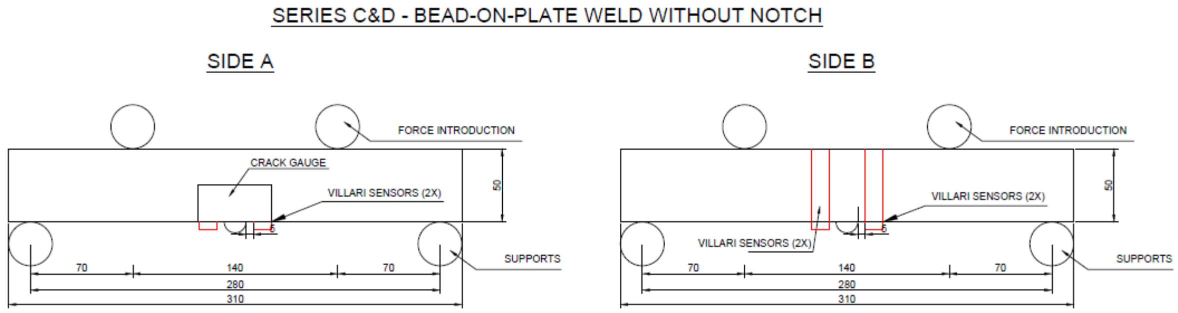

Figure 7 SENB specimens for series C and D, RFV2 sensor strips in red.

Load

All specimens within all four test series are subjected to a constant amplitude fatigue load varying between 175 and 17.5 kN (R=0.1). This results in nominal bending stress range of 220.5 MPa (σmax=245 MPa and σmin=24.5 MPa). Failure is expected between 100.000 and 300.000 cycles, but this is an estimation. The load levels can be adjusted if the time until failure is too short or long, the goal is to reach this amount of cycles in order to guarantee High Cycle Fatigue (no large plastic deformations) but keep the test time as low as possible: ideally above 100,000 but not to far above. The proposed frequency is 10 Hz.

Equipment

All base material samples are equipped with 8 sensor strips (Figure 5Figure 5). These will be attached to the specimens using 3M VHB tape, similar to what we use in the field:

- 2 sensor strips on the top surface at 5 mm and 25 mm at one side of the initial notch
- 2 sensor strips on the top surface at 10 mm and 30 mm at the other side of the initial notch
- 2 sensor strips on the side surface at 5 mm and 25 mm at one side of the initial notch
- 2 sensor strips on the side surface at 10 mm and 30 mm at the other side of the initial notch

All bead-on-plate welded samples with initial notch are equipped with 6 sensor strips (Figure 6):

- 2 sensor strips on the top surface at 5 mm and 25 mm at the side of the initial notch
- 2 sensor strips on the side surface at 5 mm and 25 mm at one side of the initial notch
- 2 sensor strips on the side surface at 10 mm and 30 mm at the side of the initial notch

All bead-on-plate welded samples without initial notch are equipped with 6 sensor strips (Figure 7):

- Two sensor strips at 5 mm from both weld toes on the top surface
- Two sensor strips at 5 mm from both weld toes on either side surfaces (4 in total)

The sensors at the top surface intend to:

- Size fatigue crack propagation through thickness (a-direction) for the specimens containing an initial notch
- Detect fatigue crack initiation
- *Option: We could consider rotating the strip on the top (parallel to the weld) 90 degrees such that such that the build-up of plasticity and magnetization can be seen in one strip (. For this we need to be sure the crack initiates in the middle of the specimen which will follow from the experiments.*

The sensors at the side surfaces intend to:

- Size fatigue crack propagation (c-direction) at the surface for all specimens

The RedFox V2 Sensor Units should measure the magnetic field at the following prescribed instances during the tests:

- Until the crack depth is 5 mm: every 5000 cycles
- From 5 mm to 25 mm crack depth: every 2000 cycles

The sensor readings should be taken at 17.5 (Fmin), 96.25 (Fmean) and 175 kN (Fmax) of force, every 2000/5000 cycles. Taking the readings at different levels provides additional insight in the accuracy of the sensor as a function of the (quasi-) static stress level in a structure. We're investigating if we have to stop the test manually every time for this or if we can configure our setup in such a way that we can take continuous measurements. The latter is preferable because it will greatly speed up test time and allow for overnight tests.

The tests are terminated once the crack depth is 25 mm.

In terms of benchmarking the RedFox v2 sensors we use the following equipment:

- All specimens are equipped with a crack gauge (for example FAC-20) on one side surface of the specimens:
    - Centered and just below the initial notch for the specimens containing a notch.
    - Centered at both weld toes for the specimens not containing a notch. We break the specimens open after testing to see how the crack has propagated through the specimen and to investigate the plane stress / plane strain effect
- One specimen per series (4 in total) are using Digital Image Correlation (DIC) to follow the fatigue crack propagation in through thickness direction continuously at the other side surface of the specimen. DIC is much more accurate than crack gauges but requires a bit more effort to set up.

No additional equipment is used to measure fatigue crack initiation in the bead-on-plate welded specimens. It is expected that the sensor strips pick up differences in strains before a fatigue crack is visible, since this has been observed in previous tests las year. In this case the DIC picked up a difference in strain (plastic deformation) at the notch tip while there was no crack visible (with the naked eye). Since we have validated the strain detection capabilities of the sensor in the static tensile test series we believe that we can detect early fatigue damage development with the RedFox V2 Sensor Units. This will become apparent during the tests and subsequent evaluation.

Evaluation

The bead-on-plate welded specimens are subjected to fluctuating loads such that fatigue crack initiation (samples without an initial notch) is initiated and subsequent propagation (all samples). The main evaluation is to compare the results from the DIC, crack gauge equipment and the RedFox V2 Sensor Units and potential visual observations during the tests. The displacement output from the MTS machine may serve as an indication for crack initiation as the displacement usually starts to increase very gradually when plasticity starts to occur near the crack tip.

Conclusion

The evaluation allows us to complete a statistical evaluation of the sensor capabilities for the following reasons:

- Detect fatigue crack initiation, we expect a difference effect on the magnetic field in the initiation (stress build-up, Villari effect) and propagation (stress relief en geometry change)
- Size fatigue crack propagation (through thickness and along the surface) by comparing the relative change in the magnetic field over time. In the field we

currently use a 5% deviation of the magnetic field as a minimum change in order to indicate crack growth. If we observe similar changes in the laboratory we can safely mark this as crack growth since it exceeds the noise measured in the field.

- Quantify the effect of the relative distance between the crack and the sensor
- Conclude on the effect of welded specimen on the sensor's detection capabilities
- Conclude on the effect of changing the initial magnetic field (depending on tensile test outcome).

Fatigue cruciform joints

Three series of fatigue tests on cruciform joints are completed (each with 5 repetitions):

A. A full penetration cruciform joint at which fatigue crack initiation is expected from the toe of the weld
B. A cruciform joint with filled welds at which fatigue crack initiation is expected from the root of the weld
C. A cruciform joint at which either root or toe failures is expected.

With certain diagrams from the IIW (root fatigue) we can determine where crack initiation occurs based on plate dimensions and the dimensions of the welding. This is checked with separate manual calculations.

This final test series is the most representative of an actual joint in a steel structure. The two preliminary test series should have provided valuable information in terms of:

- Sizing and crack initiation detection capabilities.
- Best practice in terms (de-)magnetization the specimens prior to testing. This is practically doable in the field using a simple permanent magnet swipe or a battery powered DC yoke used in Magnetic Particle Inspection.

All specimens are delivered in the as-welded condition and subjected to fluctuating loads, leading to fatigue crack initiation and propagation, until failure. The sensor strips are positioned on the joint to detect any fatigue damage in the joint. Crack initiation and propagation is verified using conventional NDT techniques that are currently applied in practice for inspecting existing steel structures to benchmark the Redfox sensors, such as PAUT or TOFD. We're still actively figuring out how we can perform this in a cost-efficient way. We're also investigating the options of using Acoustic Emission to pick up crack initiation at an early stage. The lessons learned from the first two series in terms of (de-) magnetization are applied prior to starting the fatigue experiments.

Geometry

Two 12mm steel plates are connected by means of various welding configurations (i.e. full penetration, fillet welds and partial penetration). This is relatively similar to tests performed by TNO The following dimensions are applicable to the plates (Figure 9):

- 2 vertical plates; 164x12x100 mm
- 1 horizontal plate; 100x100x12 mm
- Total specimen height; 340 mm (this might change depending on the relative distance between the load applicators of the test rig).
- The two vertical plates are machined in the following ways per series:
    A. Double sided, full penetration weld. A chamfer of 50 degrees across half the thickness of the 12mm plate

B. Two fillet welds, no machining of the plates is necessary
C. Double sided, partial penetration weld. A chamfer of 50 degrees across the 3mm depth of the plate (leaving a nose of 6mm in the center of the plates)

All three series are being welded together as one piece, before cutting it into 8 samples for each subset (24 samples each, which leaves us with 9 extra samples). All of the base plate dimensions are chosen 100 mm bigger in length to not have disturbances of weld start/stop presences for the fatigue tests. The first 50mm either side of the specimens are not used. The base plate dimensions prior to cutting should be (Figure 8):

- 2 vertical plates; 164x12x900 mm
- 1 horizontal plate; 164x12x900 mm

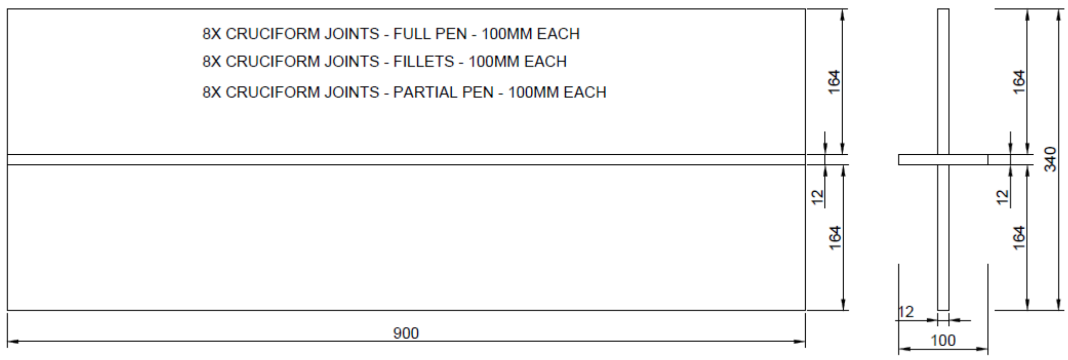

Figure 8 Fabrication of the cruciform joints.

A MIG/MAG/FCAW welding procedure should be completed to fabricate the samples. The base material should be preheated to 50 degrees prior to welding. The welding procedure should result in about 1mm of penetration into the base material, besides the weld throat of 5mm. The fillet welds should be completed with one weld bead. The partial and full penetration welds may be completed with multiple weld beads. Welding distortions should be avoided/minimized throughout the fabrication. The figure below shows the three different types of cruciform joints.

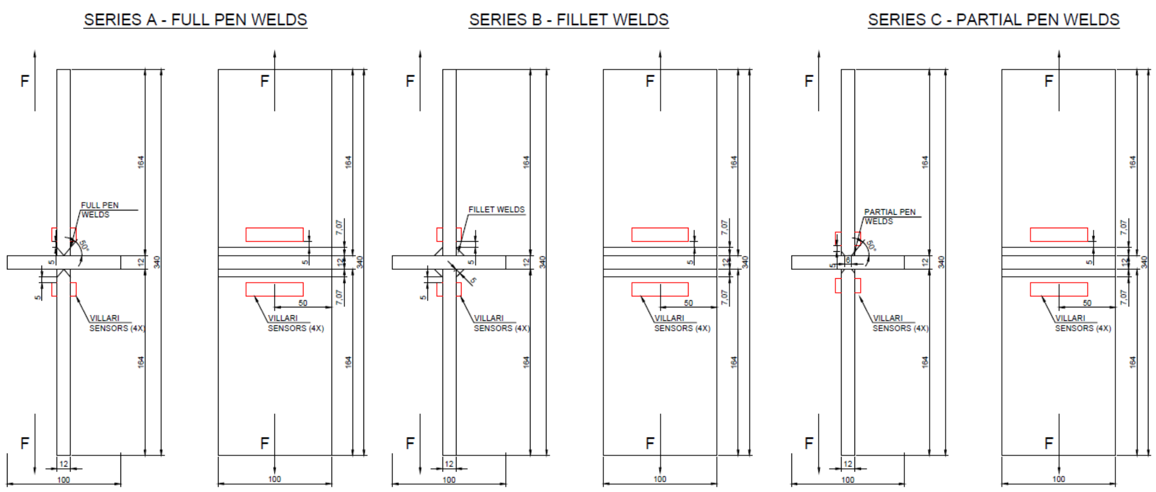

Figure 9 The cruciform joints, , RFV2 sensor strips in red.

Load

The applied load is prescribed in such a way that failure is expected 100.000-300.000 cycles for all specimens. The following load levels are prescribed per series:

1. Fmax = 300 kN, Fmin = 30 kN (R=0.1), resulting in a $\Delta\sigma$=225 MPa in the plate
2. Fmax = 140 kN, Fmin = 14 kN (R=0.1), resulting in a $\Delta\sigma$=105 MPa in the weld
3. Fmax = 264 kN, Fmin = 26.4 kN (R=0.1), resulting in a $\Delta\sigma$=198 MPa in the plate

The test rig should have a capacity of 500 kN to carry out these tests. A test frequency of 10 Hz is proposed.

Beach marking will be applied on 2 samples per series (so six in total). 5000 cycles at a high average load level, but low load range are being included in the testing program such that the crack growth rate reduces and a crack line will become apparent after fracture. This is being programmed in the load set-up as follows:

1. First 100.000 cycles at the load levels defined above.
2. Beach marking with 5000 cycles as follows per series:
    a. Fmax = 300 kN, Fmin = 270 kN
    b. Fmax = 140 kN, Fmin = 126 kN
    c. Fmax = 264 kN, Fmin = 237.6 kN
3. Then again 10.000 cycles with the load defined above
4. Repeat steps 2 and 3 until failure

Equipment

Fatigue crack initiation is expected at the centerline of the plate (halfway the width), at the weld, due to plane strain effects versus plane stress at the plate edges. So, a crack will start halfway the width of a plate, at the weld, and then grow simultaneously sideways and into the depth of the base plate. All sensor strips are therefore positioned at the center of the plates. This also avoids disturbances in the magnetic field at the edges of the plates.

Four sensor strips are positioned on each specimen all at 5mm from the weld toe on the vertical plates, top and bottom surface.

All specimens in each of the three series are being inspected with Phased Array Ultrasonic Testing (PAUT) or Time-of-Flight Diffraction (TOFD) during the test. It will have to be determined how the sensor strips can be placed such that we can perform NDT without having to remove the strips in a later stage. This NDT technique is an advanced and reliable technique that is currently applied on various steel structures for it's good crack detection capabilities. Being able to compare the PAUT results with the RedFox V2 Sensor Unit results will provide useful insight into the differences (i.e. crack detection and sizing capabilities). We're also considering to use Acoustic Emission sensors to pick up crack initiation at an early stage, depending on the outcome of earlier experiments and cooperation with experienced users of this system.

The samples are being monitored during the test as follows:

1. No measurements until 50.000 cycles
2. Every 5000 cycles; a measurement with the sensor and a PAUT scan; both welds

Evaluation

The evaluation is to compare the PAUT results with the RedFox V2 Sensor Units measurements. The beach marking lines allow for an additional comparison between the measurements of both NDT techniques and the actual fatigue crack.

Conclusion

The evaluation allows us to complete a statistical evaluation of the sensor capabilities for the following reasons:

- Detect fatigue crack initiation
- Size fatigue crack propagation (through thickness and along the surface)

A test matrix overview is given in Table 3.

Table 3: Test matrix overview.

Test Matrix overview					
Static tensile tests	Series	Geometry	Magnetisation	# of samples in series	Expected series duration
	A	Flat dogbone	Untreadted (as-is)	5	0.5 day
	B	Flat dogbone	Enhanced	5	0.5 day
Fatigue tests - SENB	Series	Geometry	Magnetisation	# of samples in series	Expected series duration
	A	No weld: 1mm notch	5 Untreated (as-is) + 5 Enhanced	5+5	5+5 days
	B	Bead on plate + 0.5 mm notch	*Based on previous results*	5	5 days
	C & D	Bead on plate without notch	*Based on previous results*	5+5	5+5 days
Fatigue tests - Cruciform Joints	Series	Geometry	Magnetisation	# of samples in series	Expected series duration
	A	Full pen weld	*Based on previous results*	5	5 days
	B	Fillet weld	*Based on previous results*	5	5 days
	C	Partial pen weld	*Based on previous results*	5	5 days

Total: 41 days

A few comments on the total test time:

- We conservatively estimate one specimen per day with 100,000 – 300,000 cycles. With overnight testing and careful test setup calibration this can possibly be increased to 1 specimen during daytime and 1 during nighttime, reducing the test time needed by about 50%.
- Furthermore we planned several series in which in which the magnetization is enhanced or not enhanced. Based on previous test we might conclude, during the program, that enhancement is inefficient or unnecessary which will reduce the amount of repetitions.
- If the above can be established early on we like to propose that we reduce the number of samples in a series to 3 instead of 5 initially. Then we analyze and draw our first conclusions and afterwards we determine if we want to do the remaining 2 samples in each series.