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Corresponding Author:	Nils Friedrich Technische Universitat Hamburg Hamburg, Hamburg GERMANY
Corresponding Author's Institution:	Technische Universitat Hamburg
Corresponding Author E-Mail:	nils.friedrich@tuhh.de
Order of Authors:	Nils Friedrich
	Sören Ehlers
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TITLE:

Crack Monitoring in Resonance Fatigue Testing of Welded Specimens Using Digital Image Correlation

AUTHORS AND AFFILIATIONS:
Nils Friedrich[1], Sören Ehlers[1]

[1]Institute for Ship Structural Design and Analysis, Hamburg University of Technology (TUHH), Hamburg, Germany

Corresponding Author:
Nils Friedrich (nils.friedrich@tuhh.de)

Email Addresses of Co-authors:
Sören Ehlers (ehlers@tuhh.de)

KEYWORDS:
resonance testing machine, digital image correlation, technical crack, crack propagation measurement, fatigue test, welded specimen, beach marks

SUMMARY:
Digital image correlation is used in fatigue tests on a resonance testing machine to detect macroscopic cracks and monitor crack propagation in welded specimens. Cracks on the specimen surface become visible as increased strains.

ABSTRACT:
A procedure using digital image correlation (DIC) to detect cracks on welded specimens during fatigue tests on resonance testing machines is presented. It is intended as a practical and reproducible procedure to identify macroscopic cracks at an early stage and monitor crack propagation during fatigue tests. It consists of strain field measurements at the weld using DIC. Images are taken at fixed load cycle intervals. Cracks become visible in the computed strain field as elevated strains. This way, the whole width of a small-scale specimen can be monitored to detect where and when a crack initiates. Subsequently, it is possible to monitor the development of the crack length. Because the resulting images are saved, the results are verifiable and comparable. The procedure is limited to cracks initiating at the surface and is intended for fatigue tests under laboratory conditions. By visualizing the crack, the presented procedure allows direct observation of macrocracks from their formation until rupture of the specimen.

INTRODUCTION:
Welds are particularly prone to fatigue damages. Their fatigue properties are commonly determined on small-scale specimens that can be efficiently tested. During the tests, a cyclic load is applied. Eventually a crack will initiate and grow to macroscopic size. The crack will then grow and propagate through the specimen. The test is usually run until the specimen fails in full. The result of the test is the number of load cycles until failure for the applied load. This final failure is

usually obvious. On the other hand, crack initiation is more complex to determine. However, it might be of interest in investigations on parameters that are not uniform over the specimen thickness or that affect the crack initiation specifically (e.g., residual stresses or post-weld treatments).

Different methods exist for the detection of cracks during fatigue tests. The simplest are visual inspection, dye penetration testing, or the application of strain gauges. More sophisticated methods include thermography, ultrasound, or eddy current testing. Crack propagation can be determined using apposite strain gauges, acoustic emission, or the potential drop method.

The proposed procedure uses digital image correlation (DIC) to visualize surface strains on the specimen. It allows detection of the formation of macroscopic cracks during fatigue tests. Furthermore, crack propagation can be monitored over the duration of the test. For DIC, an irregular pattern is applied to the specimen surface and monitored by cameras. From the distortion of the pattern under loading, surface strains are computed. Cracks will appear as elevated strains exceed a defined threshold value (> 1%) and therefore become visible.

With the advance of computational technologies, DIC is becoming more and more popular for industrial and research applications. Several commercial measurement software systems as well as open-source software are available[1]. The proposed procedure offers another use of a technology already available in an increasing number of research facilities in mechanical and civil engineering.

Compared to visual inspections or dye penetration testing, the proposed procedure is not based on subjective perception, which depends on an operator's experience and the local geometry at the weld toe. Even with high magnification it may be challenging to detect cracks at an early stage (i.e., crack initiation), especially if the exact location is not known in advance. Furthermore, using DIC the results are saved and therefore reproducible and comparable, whereas visual inspection is possible only momentarily.

Using a full-field measurement the procedure allows monitoring the whole width of the specimen or length of the weld. Using strain gauges, it would be necessary to apply several gauges over the specimen width, because their measurement is localized. The changes in the strain gauge signal would depend on the distance and the position relative to the crack. The result would depend on whether the crack would initiate in between two gauges or by chance in front of one.

Another benefit of DIC is that it is visual, and it gives a descriptive image of the crack. Using strain gauges for crack detection or acoustic emission for crack growth, the crack length itself is not monitored but it is determined by changes in the measured strain or acoustic signals respectively. For example, in Shrama et al.[2] DIC allowed for the understanding and interpretation of acoustic emission signals. Other influencing factors or interfering signals may affect the measured signal, leading to uncertainties and requiring careful interpretation of the results.

Various applications of DIC to monitor cracks in fatigue tests have been reported. In many cases

DIC is used to assess the strain field at the crack tip[3-5] and determine stress intensity factors[6-8] or detect fatigue damages on a microscopic scale[9,10]. In these cases, microscopic images are used to investigate areas of interest in the range of a few millimeters. The tested specimens consist of machined base material with dimensions in the millimeter range. Larger measuring areas were recorded by Tavares et al.[11] to determine stress intensity factors, by Shrama et al.[2] to study acoustic emission signals, and by Hasheminejad et al.[12] to investigate cracks in asphalt concrete. Poncelet et al.[13] applied DIC to detect crack initiation based on the relative strain increment over a certain number of load cycles. The tests were performed on specimens with a machined surface. Welded[14,15] or brazed specimens[16] were studied using DIC to record the development of strains during fatigue tests. The specimens were observed from the side, showing the development of the crack in the depth direction, on the edge of the specimen.

All the aforementioned experiments were conducted on servo-hydraulic testing machines with load frequencies of a few hertz (< 15 Hz). Usually the tests were interrupted to record the images for DIC. Vanlanduit et al.[17] took images during the running test and applied algorithms to compensate for the different testing and image recording frequencies. Lorenzino et al.[18] performed tests on a resonance testing machine and captured DIC images with microscopic cameras. Kovárík et al.[19,20] performed tests on a resonance testing machine with a frequency of 100 Hz without interruptions, using a procedure very similar to the one presented here. The tests were conducted on flat, coated specimens under bending loads. A single camera and a triggered flash were used to capture images of an area of ~20 x 15 mm. Different crack assessments based on the strain field and on the displacement field were applied.

The procedure presented in this paper is applied to welded specimens presenting a notch, and thus a stress concentration. A 3D DIC-system with two cameras is employed, which allows to account for out of plane displacements of the specimen. The cameras are triggered while lighting is constant. Crack detection is based on the strain field measured on an area of 55 x 40 mm.

The procedure offers a robust and comparable way to detect cracks in fatigue tests. Furthermore, it provides a record of crack propagation. It is applicable on resonance testing machines with high loading frequencies. The tests do not have to be interrupted for measurements, and no operator needs to be present during the test. The procedure can therefore be efficiently applied to large numbers of tests to retrieve information on crack initiation and propagation.

PROTOCOL:

1. Specimen preparation

CAUTION: The use of welding or machining equipment is potentially dangerous. The work should be executed by qualified personnel and according to the instructions provided by manufacturers.

1.1. Prepare specimens with the desired weld geometry (e.g., butt weld, longitudinal stiffener, fillet weld). If the whole specimen width should be measured, specimen size might be limited by the area pictured by the employed camera system. In the tests presented here, specimens containing a multilayer K-butt weld between two plates of different thicknesses were used (**Figure 1**). The specimens were made of structural steel S355 using metal active gas welding. Further information on the specimen preparation can be found in Friedrich and Ehlers[21].

1.2. If necessary, mitigate competing crack locations by grinding. These might be the weld toe on the opposite side of the plate or the other end of a stiffener. Here, the surface should be ground until smooth and free of sharp notches to avoid cracks.

1.3. Clean the specimen surface in the area around the weld using a cleaning cloth and a cleaner to degrease. Carefully remove all loose material from the weld surface and weld toe using a brass wire brush. The surface should be oil and grease-free.

1.4. Apply the speckle pattern for DIC using alternating applications of black and white spray paint. Do not point the spray directly at the surface, but let the spray mist settle on the specimen. No continuous layer is needed. The speckle size should be as fine a possible, in the magnitude of 0.1 mm (see **Figure 2**).

NOTE: Matte paint is preferable in order to reduce reflections.

2. Test setup

CAUTION: The use of mechanical or servo-hydraulic testing equipment is potentially dangerous. Operate with caution and follow the instructions provided by the manufacturer.

2.1. Position the DIC cameras to capture the area of interest on the specimen placed in the testing machine. The exact setup will depend on the employed equipment. In the tests presented here, the cameras were mounted on a scaffold reaching over the specimen arranged horizontally in the testing machine (**Figure 3**).

2.2. Meticulously adjust the focus of the camera objectives to ensure that the measured area is in focus. On the employed cameras this is done by screwing the objectives in or out to change the distance between the lenses and the sensor of the camera.

2.3. Adjust the position of the lights to maximize illumination (here, four 16 Watt LED lights were used; this allowed a uniform illumination of the measuring area, but other configurations are also possible). The use of polarization filters properly installed on the lights and objectives is recommended to reduce reflections on the metallic surface.

2.4. Choose an adequate exposure time. It will depend on the testing frequency and should be a small enough fraction (~1/35) of the duration of one load cycle. In the test presented here, the exposure time was 0.8 ms for a testing frequency of 34 Hz.

2.5. Calibrate the DIC system. The procedure will depend on the employed system and should be described in the specific user manual.

2.6. Take some pictures with the selected exposure time. Compute strains using apposite DIC software. Verify that the image quality is good enough to calculate any strains, that the scatter in the results is not excessive (in the unloaded state strains it should be close to zero), and that the results cover the entire region of interest. If the images are too dark, adjust the lighting. It might be necessary to open the aperture on the objectives, although this will reduce the depth of focus. A brighter speckle pattern might help as well.

2.7. Connect the force signal output from the testing machine to trigger the cameras. A commercial DIC system including hardware and software that allows setting off the trigger at specific intervals of load cycles was used. For this purpose, the load cycles are counted by the rising force signal crossing a certain value. When the specified number of load cycles is reached, the cameras are triggered, and counting starts over again. An exemplary triggerlist is supplied as a supplementary file.

2.8. Perform a test run to determine the delay between the trigger signal and the camera exposure. Set the trigger before the peak of the load signal to compensate for the delay. If using the triggerlist (see step 2.7) adjust the parameter value to the required load signal in voltage. In the tests shown, the cameras were triggered at 91% and 96% of the maximum force, respectively. These values are only given as an example and are not always suitable.

NOTE: It is not necessary for the images to be taken exactly at the load peak. Cracks should become visible nonetheless.

2.9. Set the trigger to an interval of load cycles so that the total number of images over the expected test duration is in the magnitude of 100−200 (e.g., every 10,000 cycles for a test with 10^6 load cycles). In the triggerlist (see step 2.7) adjust the value of loops to the desired number of load cycles.

3. Fatigue test

CAUTION: The use of mechanical or servo-hydraulic testing equipment is potentially dangerous. Operate with caution and follow the instructions provided by the manufacturer.

3.1. Install the specimen in the testing machine.

3.2. If required, take DIC images before loading. This is not necessary for crack detection, but it allows using DIC to measure the surface strain under loading.

3.3. Apply the first load cycle statically. Stop at maximum load and take some images for DIC. One image should be sufficient, but because the quality of the DIC results may not always be optimal, it might be helpful to have a few more images to choose from for analysis. For these images, a longer exposure time can be used as appropriate.

NOTE: This static load cycle can be omitted, but the images acquired statically are probably of better quality than those acquired during the dynamic test, thus improving DIC results.

3.4. Set the load range and start the cyclic test. Optionally, obtain beach marks by including intervals in which the upper load is maintained but the load range is reduced. For the examples shown here, one half of the load range was applied in 15,000 cycles for every 40,000 regular cycles. Beach marks are not necessary for the presented procedure but offer the possibility to validate the detected crack lengths.

3.5. Specify the static and dynamic load and run the test until the specimen fails. In the presented tests a static load of 0 kN and dynamic amplitude of 22.5 kN were applied. Respectively 50 kN static and 50 kN dynamic load were used on the stress-relieved specimen.

4. Postprocessing

4.1. Evaluate the DIC and calculate the strain in the specimen's axial (loading) direction using apposite software. Commercial software (see **Table of Materials**) that includes the automated computation of strains was employed. Information on the computation of strains can be found in Grédiac and Hild[22] and an overview of current commercial and open source DIC software is given in Belloni et al.[1]. Use the image from the first, static load cycle acquired in step 3.3 as a reference image. Here, a facet size of 19 x 19 pixels (~0.32 x 0.32 mm) and a facet distance of 15 x 15 pixels was applied for the DIC assessment.

4.2. Make a plot of the calculated strain and set the legend of the plot to relatively high values (0.5% to 1.0%) to suppress possible noise. Depending on the applied software, these plots will be available in the results section after displacements and strains have been computed (4.1).

4.3. Run through the image sequence acquired over the duration of the test. A forming crack will become visible in terms of elevated strains. A macroscopic crack may occur when strains exceed 1%.

4.4. To compare different test results, it might be of interest to determine when the crack reaches a specified length. Crack lengths of ~2 mm were considered technical or macroscopic cracks.

REPRESENTATIVE RESULTS:

To detect cracks and monitor crack propagation the strain in the loading direction of the specimen was plotted. Cracks became visible in terms of elevated strains (> 1%).

The results obtained from two fatigue tests are presented. The tests were performed at different loads and load ratios. The results are not intended for direct comparison between the two tests but represent typical outcomes of these tests and demonstrate the capabilities of the presented procedure.

The development of a crack in a specimen in as-welded conditions is shown in **Figure 4**. The specimen contained residual stresses caused by the shrinkage of the weld during cooling. They were measured by X-ray diffraction and hole-drilling and calculated by welding simulations[21]. Because of tensile residual stresses in the middle of the specimen, the crack initiates at the center line. First, the strain began to increase at the location of the forming crack. A technical crack was assumed when strains exceeded 1% over a length of 2 mm (N = 755,000). The crack then propagated symmetrically to both sides. The detected crack length was compared to beach marks generated during the test and showed good agreement. The video of the DIC results shows how crack propagation slowed down during the formation of the beach marks.

The development of a crack on a stress-relieved specimen is shown in **Figure 5.** Crack initiation was not influenced by residual stresses. Several cracks formed at different locations along the weld. A crack of 2 mm was detected after 574,000 cycles. The single cracks then grew and eventually unified. The detected crack length was compared to the beach marks again.

The generation of beach marks offers a good possibility to validate the crack lengths detected using the DIC technique. Furthermore, it offers the possibility to correlate the depth of the crack with the length measured on the specimen surface. At an early stage of the crack, close to the surface, it might be challenging to obtain beach marks that are clearly visible. Here, the results showed the advantage of the DIC approach.

As presented in **Figure 4** and **Figure 5** the outcome of the procedure is a series of images (or a video) showing the development of cracks at the weld. From these images, it is possible to determine the origin and the number of cracks. Furthermore, they can be used to determine when a crack has reached a specific length. Cracks 2 mm in length were considered macroscopic or technical. This crack length could reliably be retrieved from the images and in this study was used to compare the outcome of a series of tests. Furthermore, from an engineering point of view, this crack length would be detectable in service using available inspection techniques. By measuring the crack length from the resulting images and correlating it to the number of load cycles, it is also possible to plot a crack growth curve or determine crack growth rates. These may be of interest in fracture mechanical calculations of crack propagation.

FIGURE AND TABLE LEGENDS:

Figure 1: Multilayer K-butt weld specimens used for the fatigue tests. Dimensions in millimeters.

Figure 2: Speckle pattern for digital image correlation at the weld.

Figure 3: Test setup with DIC cameras and lights supported by a scaffold structure installed above the specimen.

Figure 4: Percent strain in the loading direction (vertical) showing the development of a crack and comparison with beach marks on a specimen in as-welded conditions. N = number of load cycles.

Figure 5: Percent strain in the loading direction (vertical) showing the development of cracks and comparison with beach marks on a stress-relieved specimen. N = number of load cycles.

Figure 6: Percent strain in the loading direction at maximum load on the first, static load cycle (N = 1) and at the beginning of the fatigue test at different numbers of load cycles.

DISCUSSION:

The presented procedure consists of using DIC to detect and monitor fatigue cracks on welded specimens tested on a resonance testing machine without interrupting the test. The main challenge in the application is the high load frequency of the resonance testing machine. It requires relatively short exposure times and thus high illumination for the acquisition of the images for the DIC tests. Therefore, lighting has to be maximized. On the other hand, reflections on the metallic surface may require the use of polarization filters, which will reduce the amount of light entering the cameras. To make better use of the light available, the aperture of the objectives may be enlarged. This will reduce the depth of focus. It is therefore necessary to set the focus exactly at the distance of the specimen surface and the out of plane movement of the specimen should not exceed the focused range. The setup of the cameras and lighting requires particular care.

Nevertheless, the strains calculated by DIC might not be very accurate (**Figure 6**). The computed strains might show high noise. On some of the facets used for DIC, the speckle pattern might not be recognized and strains will not be calculated. But the proposed procedure has proven robust with respect to the quality of the DIC results. Even if the results are not good enough to determine the strains at the weld precisely, it should still be possible to detect cracks.

The butt weld presented here has a relatively smooth weld toe compared to other weld geometries. Cracks are likely to initiate at imperfections along the weld toe with a sharp notch and thus high stress concentration. Unfortunately, it may not be possible to evaluate strains by DIC at these exact locations because the facets used for the computation may not be recognized. For example, **Figure 5** shows a crack initiating at the left side of the specimen, missing facets at +25 mm horizontal / -5 mm vertical. But as shown in the example, even if some facets are not evaluated it is still possible to determine when the crack initiates and starts to grow. For welds with a steeper angle and sharper notches (e.g., longitudinal stiffener, fillet weld) it may help to tilt the cameras ~15° to increase the angle to the weld surface. The proposed procedure was applied on longitudinal stiffeners as well. Despite the relatively sharp notch at the weld toe it was possible to reliably detect crack initiation.

Macroscopic cracks are assumed when strains of 1% or more are reached. In a study by Kovářík et.al.[20], DIC was applied to detect cracks on thermal spray-coated, unnotched specimens. It was stated that the threshold value for crack detection could be set in the range of 0.5% and 1% without significantly affecting the results. These values are confirmed by the comparison with the beach marks (**Figure 4** and **Figure 5**). A lower value will lead to an earlier crack detection but might be more prone to uncertainties and produce less comparable results. A higher value will lead to a later recognition of crack initiation, but the results will probably be more comparable and reproducible.

Applying the first load cycle statically (step 3.3) may result time consuming when many tests are performed. If no plastic strains occur at the weld toe (notch) it might also be omitted and the unloaded condition (step 3.2) used as a reference for strain calculations. Otherwise, one of the images acquired at the beginning of the dynamic test can be used if the image quality is adequate (see **Figure 6**).

If only a few specimens are tested, the setup time should not be underestimated. It may require some time and iterative loops to install and set up the cameras accurately and perform the calibration to get proper images for the DIC assessment.

Specimen preparation, on the other hand, is quick and inexpensive. Specimens need only be cleaned and sprayed with color to apply the speckle patter. This comes at little cost and makes the proposed DIC-based procedure practical, particularly if a large number of specimens will be tested.

A further benefit, especially for large sets of specimens or tests running overnight, is that the cameras are triggered automatically, and the tests do not need to be interrupted.

A restriction of the DIC procedure is that as an optical method it is limited to surface cracks. Furthermore, it requires that the area to be monitored be visible by the cameras while the specimen is mounted in the testing machine.

The presented procedure was used mainly to detect the start of technical cracks. But as demonstrated, it also allows for the assessment of crack growth (e.g., to determine crack propagation rates). The result will be the length visible on the surface. Crack front curvature cannot be detected, however.

The procedure proved its applicability on welded specimens presenting a relatively complicated surface topology. It should also be applicable to non-welded specimens, as the absence of geometrical notches should facilitate the DIC measurements. A similar procedure has been applied in Kovárík et al.[20] on unnotched specimens.

Furthermore, the procedure could also be applied for fatigue tests on servo-hydraulic testing machines. Here, the testing frequency would be lower than on a resonance testing machine. The exposure time of the cameras could thus be longer, which should facilitate the camera setup.

In conclusion, the presented procedure offers a straightforward way to study the development of cracks in fatigue tests. It allows detection of technical cracks and monitoring of crack propagation (e.g., to determine crack propagation rates in fatigue tests). The illustrative nature of the results facilitates their interpretation and assessment. The technique is applicable to resonance testing machines with high loading frequencies without interrupting the tests. The measurements are fully automated, so no continuous supervision is needed. It is applicable on welded specimens presenting a relatively complicated geometry in the region of interest. On small-scale specimens, it allows coverage of the whole width of the specimen. Furthermore, the procedure is characterized by a simple setup and basic post processing, making it a practical alternative to existing methods.

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DISCLOSURES:

The authors have nothing to disclose.

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Figure

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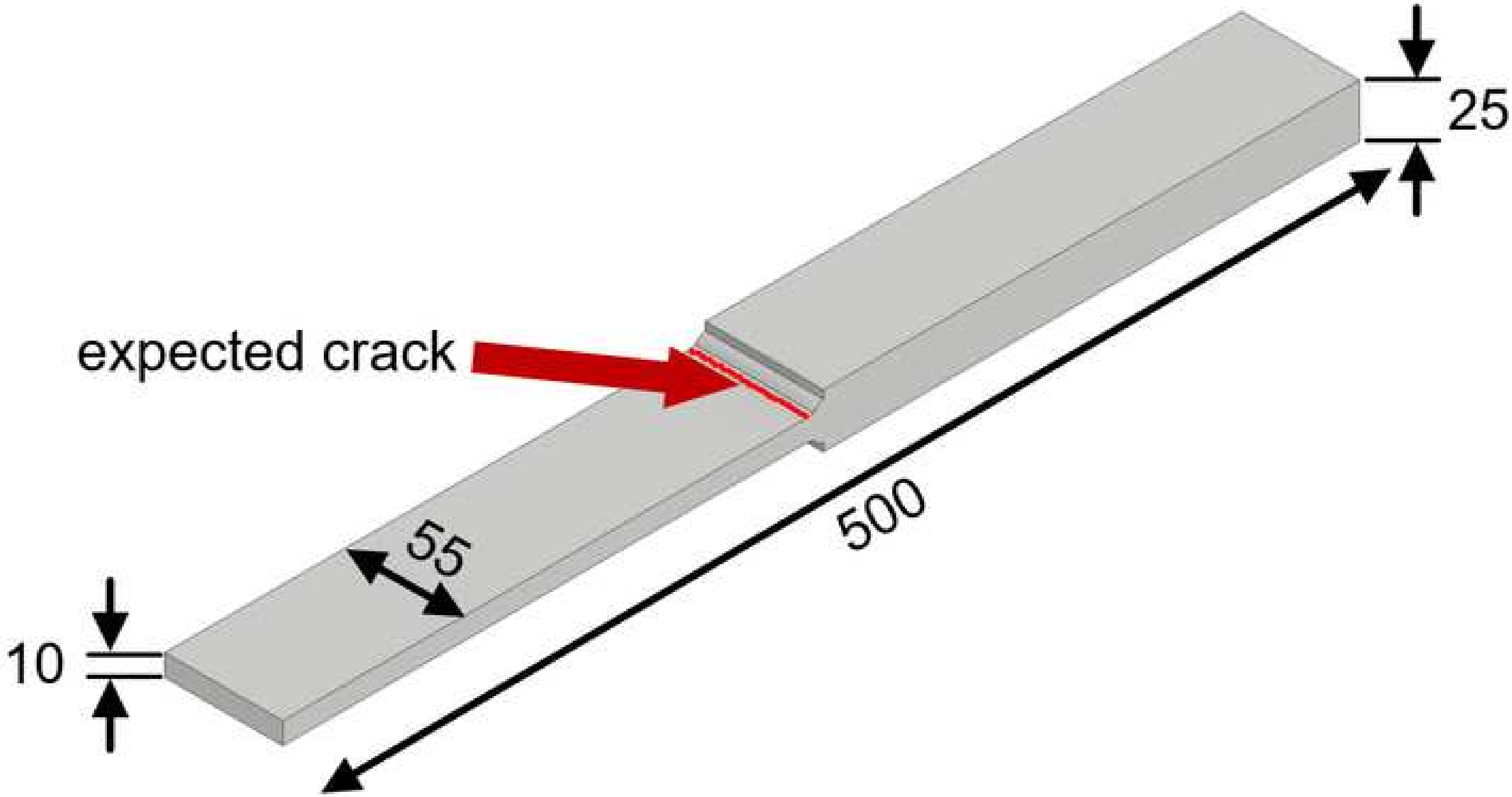

Figure

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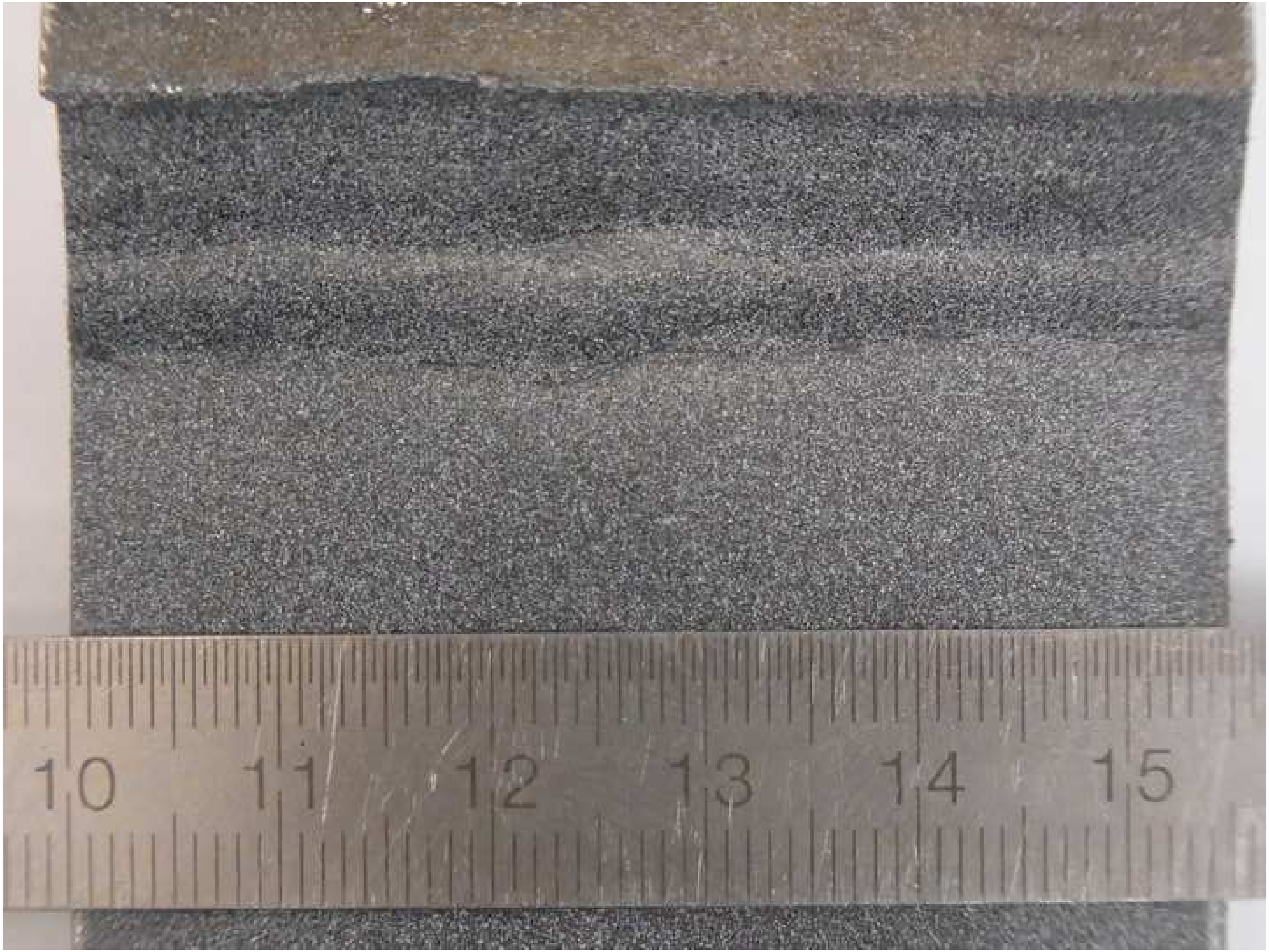

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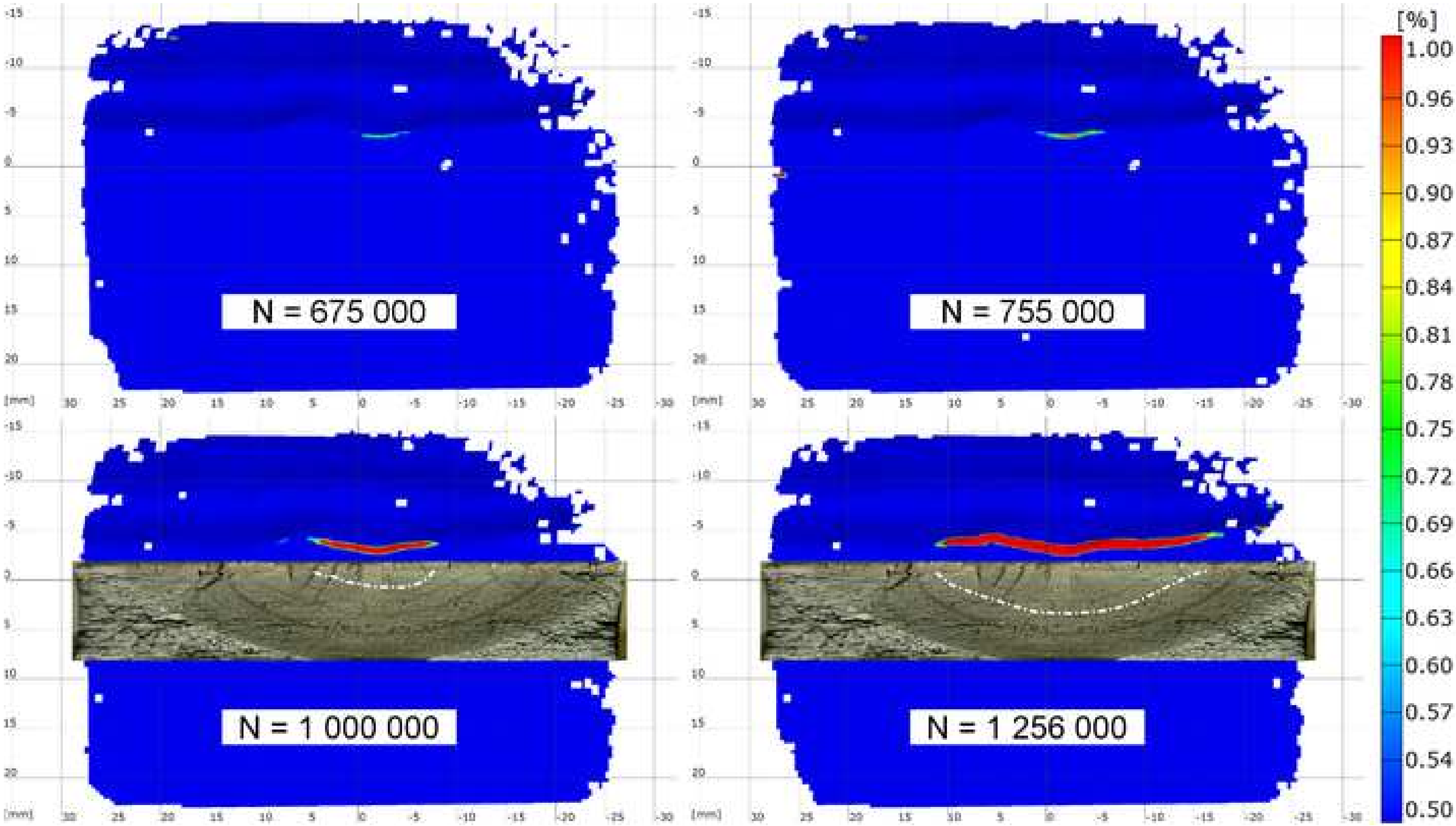

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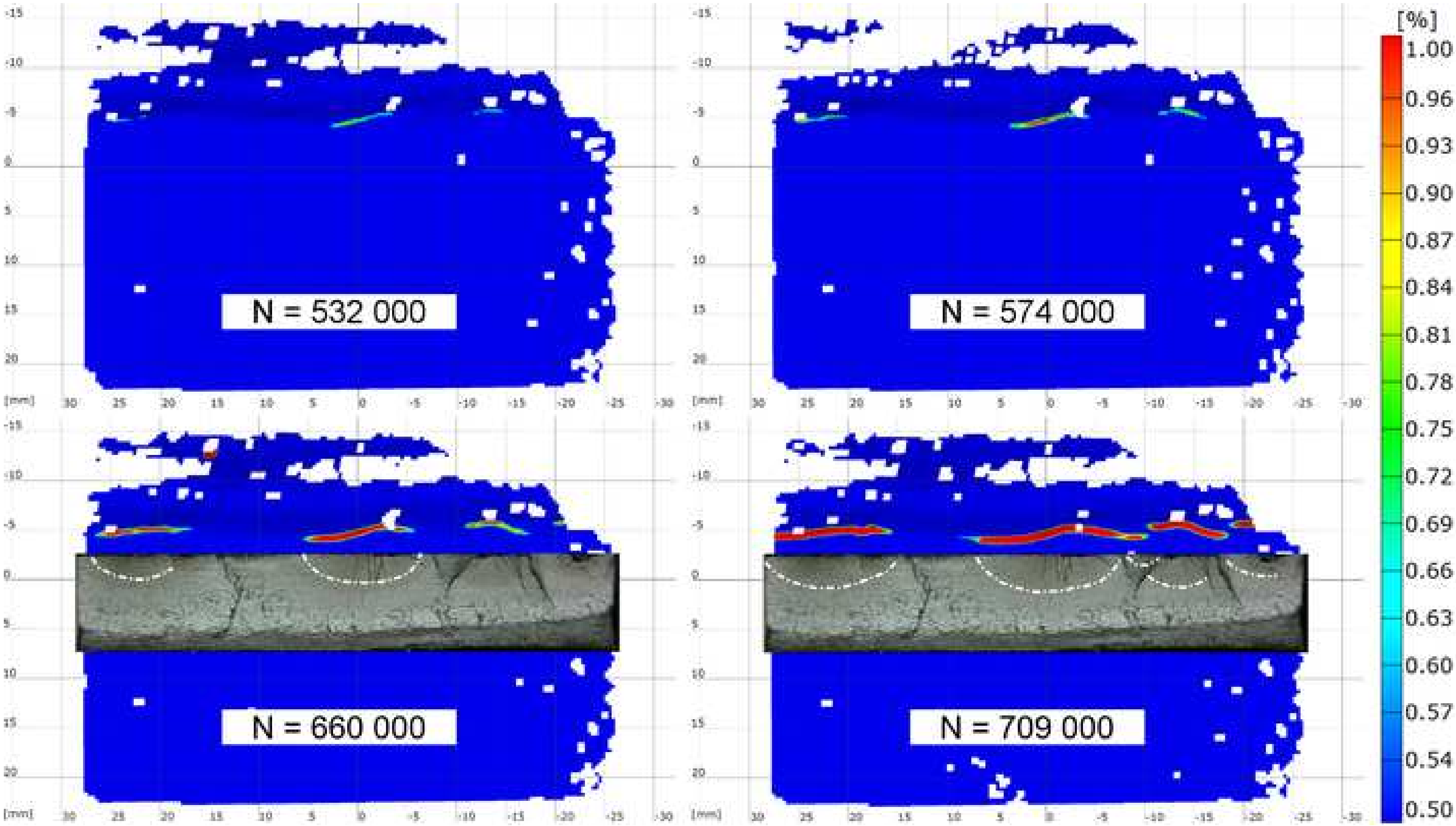

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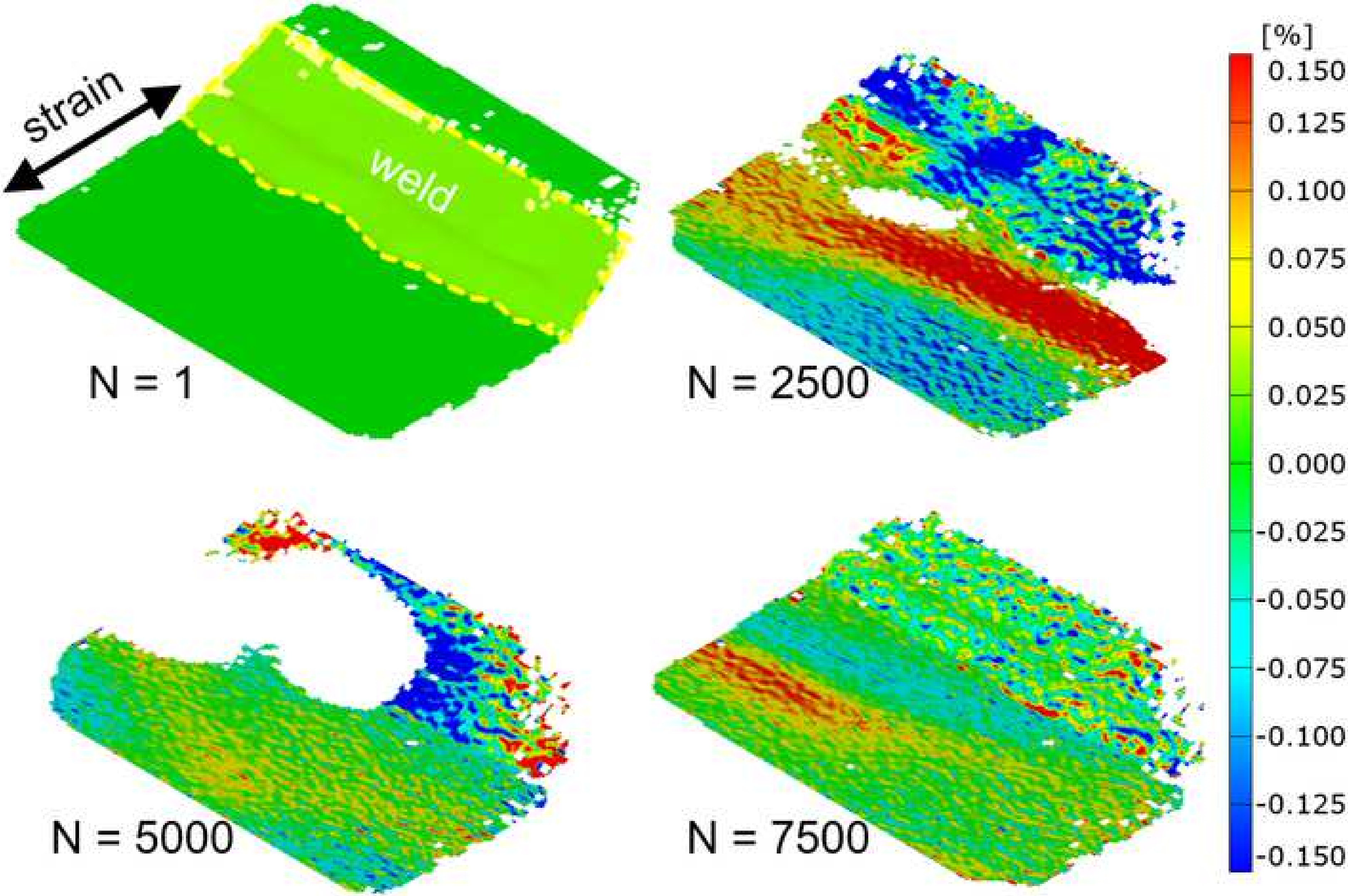
strain
weld
N = 1
N = 2500
N = 5000
N = 7500
[%]
0.150
0.125
0.100
0.075
0.050
0.025
0.000
-0.025
-0.050
-0.075
-0.100
-0.125
-0.150

Name of Material/ Equipment	Company	Catalog Number	Comments/Description
ARAMIS 5M	gom		DIC system including two 5 megapixel cameras and control unit
ARAMIS	gom	v6.3.1-2	DIC software
Calibration object	gom	CP 20	MV 30 x 24 mm²
Camera objectives, 50 mm			Titanar 2.8 / 50
Hydraulic Wedge Grip	MTS	647.25A02	
Hydraulic Grip Supply	MTS	685.10	10,000 Psi
LED lights	Diana LEDscale	KSP0495-0001A	4 x 16 W LED lights
Polarization filters	Schneider-Kreuznach		52,0 AUF (2 x for cameras)
Polarization filters	Schneider-Kreuznach		67,0 AUF (4 x for lights)
Resonance testing machine	Schenck		200 kN resonance testing machine
Resonance testing machine control unit	Rumul	v 2.5.3	Resonance testing machine control unit and software
Spray paint			Black and white spray paint, matt

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Title of Article:	Crack monitoring in resonance fatigue testing of welded specimens using digital image correlation
Author(s):	Nils Friedrich, Sören Ehlers

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CORRESPONDING AUTHOR

Name:	Nils Friedrich
Department:	Ship Structural Design and Analysis
Institution:	Hamburg University of Technology
Title:	

Signature: Nils Friedrich Date: 05.06.19

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Editorial comments:

General:

1. Please take this opportunity to thoroughly proofread the manuscript to ensure that there are no spelling or grammar issues.

Protocol:

1. For each protocol step, please ensure you answer the "how" question, i.e., how is the step performed? Alternatively, add references to published material specifying how to perform the protocol action. If revisions cause a step to have more than 2-3 actions and 4 sentences per step, please split into separate steps or substeps.

More details on "how" to perform the protocol steps were added.

Specific Protocol steps:

1. 2.6: 'test if strains can be computed' is unclear; please elaborate.

A more detailed description was added.

2. 4.1-4.2: Please include more information or a citation outlining how to do these image processing steps.

Information referring to the software used by the authors and citations containing more general information on DIC evaluation was added.

Figures:

1. Figures 2 and 3: The scale bar is in '%'; percentage of what? Please clarify in the legend.

The strain is plotted in [%]. This was added to the legend.

References:

1. Please include references in the main text (i.e., not as an endnote).

The reference list has been reformatted as regular text. References in the text should be as in the template.

Table of Materials:

1. Please ensure the Table of Materials has information on all materials and equipment used, especially those mentioned in the Protocol.

Information was added to the table of materials. For some equipment not all information was available.

Video:

1. Please ensure that the video corresponds with the manuscript text, in particular the protocol, as much as possible; e.g.:

Manuscript text and video are now in agreement.

a. 1.1: The exact specimen used is outlined in the video, but not here.

The exact specimen type and a sketch of it were added to the manuscript.

b. 2.3: You show 4 lights in the video-is this recommended?

The 4 lights and a comment on their use have been added to the protocol.

c. 3.4/Results: You describe beach marks in the protocol and show how they correspond to your other results in the video, but discussion is limited here.

The beach marks were added to the figures in the manuscript. In 3.4 the motivation to do beach marks was added and in Results the comparison with the DIC results is now discussed.

Reviewers' comments:
Reviewer #1:
Manuscript Summary:
The article describes the method of crack detection using strain field at the specimen surface obtained by digital image correlation method. The strain field is referenced to the uncracked specimen loaded close to tensile stress maximum. The crack is detected by thresholding the strain component corresponding to specimen loading direction. The images are obtained by commercial 3D-DIC system using force based trigger and short exposure time. The simplicity of the test setup together with only basic postprocessing make the whole method readily applicable at many material testing labs. It should be noted, however that much better image quality may be obtained by using a phase triggered flash system. The fractographic marking used makes the presentation very illustrative. The method is applied to observe cracks in welded specimens, i.e. on specimens with relatively complicated geometry at the region of interest (ROI).

The article is clearly structured and can be easily followed and contains relevant references. However before the publication, the author should address some comments below. Therefore MINOR REVISION of the article is recommended by the reviewer.

Major Concerns:
A. The title suggests focus on welded specimens i.e. specimens with relatively complicated surface morphology and nonhomogeneneous material properties in the ROI. Therefore the reader expects some specifics of crack initiation and propagation in that particular type of the specimes, i.e. the origin of crack initiation, the direction of crack propagation, the effect of propagation dynamics etc.. catured i.e. by an example of crack growth curve
I agree with your comment. The focus was intentionally set on welded specimens to point out that the procedure works on relatively complicated geometries and to distinguish from other studies performed on other types of specimens or microscopic dimensions.
As shown in the exemplary results, the characteristics of crack growth specific to welds can be monitored graphically (origin of crack initiation, crack propagation, etc.). Thus, the presented results should be only representative, to demonstrate what the result of the procedure would look like and what information it delivers (origin of crack initiation, direction and speed of crack propagation, etc.).
A crack growth curve was intentionally not shown because it is not part of the method. It could be generate from the results. But the paper is intended to explain or demonstrate the procedure/method, rather than to present results specific to a certain specimen.
Furthermore, the illustrative, especially in form of a video, representation of crack growth might be more informative than a crack growth curve.

B. The trigerring mechanism should be described in more detail. The values should be specified in % of Fmax rather than in volts.
Description of the triggering mechanism was added and values were specified in %. An exemplary “triggerlist” to be used in ARAMIS was added as supplementary file.

C. L48 - the outcome of the method should be presented more clearly. I.e. why is it particularly important to know the lifetime to 2mm long surface crack in the weld. Can these cracks be detected in service ? Is the crack growth rate (not presented in paper) of interest ?
A description of the outcome was added to the representative results section. It motivates the detection of the 2 mm cracks and mentions that the results can be used to determine crack growth curves and rates.

D. "Technical crack initiation" - try to avoid this term, the crack first initiates, then it grows to macroscopic or 'technical' size. The proposed method simply detects dimensionally short cracks. (see abstract, L43,L55, L195)
As suggested, "technical crack initiation" was paraphrased in the text. In the video the expression is still used, because from an engineering point view it is clear what is meant and it is easy to understand. Expressing the same concept in another way, would need much more explaining, which would make the narration/video more difficult to follow.

E. The DIC is performed with single reference image. The surface of the material will change during the test as a result of localized cyclic plasticity, possibly leading to missing facets. It may be beneficial to reference the strain to an image taken recently e.g and at minimum load. Eventually an incremental DIC may be used with the images already captured.
Definitely an interesting suggestion. We did not experience the described effect neither on the presented K-butt weld specimen nor on tested longitudinal stiffeners (not in the paper). Missing facets were more likely attributed to moderate image quality or a particularly sharp notch. Probably such plastic strains would be so localized and with limited magnitude, that they would not exceed the noise/scatter of the computed strains.
Taking reference images at minimum load might not work. On one test with compressive loading ($R = -\infty$) the images were taken at minimum load and the crack became visible anyway.
Approaches considering the strain increment rather than absolute strain have been applied by other authors (Poncelet et al., 2010). But they did not apply incremental DIC.
It might help in some cases. But it would make post processing more complicated and results less intuitive. While the presented approach is very simple but yet effective.

F. Paper is missing Conclusions
Conclusions were added.

Minor Concerns:
L59: the 'elveated strain' should be specified here
Specification was added.

L171: is the statical preload necessary ? What are the benefits of this image to the image taken at one of the first full amplitude loading cycles ?
The static load cycle at the beginning is not absolutely necessary. But the images taken statically are probably better than those from the dynamic test (longer exposure time possible). This will give a better reference image for DIC and thus help to improve DIC results. A short comment on this was added to the text.

Furthermore the static load cycle allows to measure plastic strains after unloading. This is not relevant to crack detection but might be of interest.

L188: Paper images do not show contour plots, but more descriptive false color map.
The word “contour” was removed. “false color map” might be misunderstood. In the end they are just color plots, in which most values exceed the legend scale.

L202: the authors should explain why there is tensile residual stress in center 'width'? of the specimen, eventually how it was measured.
Explanation of residual stresses and a reference containing measurements and simulations was added.

Reviewer #2:
Manuscript Summary:
This paper presents the procedure of using Digital Image Correlation (DIC) to detect cracks on welded specimens that were subjected to fatigue tests on resonance testing machines. It is well relevant to the JoVE focus and would be useful to the relevant engineering practitioners and researchers. However, this paper seems more descriptive rather than informative and it does not allow its readers to replicate the tests for the same results reported.

Major Concerns:
The details of the specimens and the setup of instruments and testing machine were missing, which does not allow its readers to replicate the tests for the same results reported in the paper.
Of course in general a protocol of an experiment should allow the reproduction of the experiment and the same results. Therefore, more detailed information on how to perform each step of the protocol was added.
It has to be noted though, that considering the usual scatter in fatigue tests, it is practically impossible to reproduce exactly the same results. Therefore the paper/video is also intended to present the procedure in a way to allow readers to adapt it to their specimen type, testing machine, DIC system, etc.

Minor Concerns:
Less critical comments and discussion have been given to the conventional methods and the advance of technology.

1. The lines 36 to 38: Is there any evidence to support your statement? Has it been done in your reported tests?
The sentence about servo-hydraulic testing machines was removed from the abstract.
The cracks observed in the video and paper are described as macro-cracks here, to make a clear distinction to microscopical crack, which cannot be observed with the presented procedure/setup.

2. The lines 50 to 99: Less critical comments on the existing methods and advances of technology to justify the use of DIC method.

The remarks on alternative methods are not intended so much as critical comments. They should rather point out the weak points of existing methods to emphasize the advantages of DIC in comparison.
A short comment on the advancing technologies and the diffusion of DIC was added to the text.

3. The lines 111 to 127: the details of the specimens were missing. No evidence was presented for what had been done on the specimens for specimen preparation.
The type of specimen, a short description of specimen preparation and a sketch showing the dimensions were added. A reference with further information was also added.
Point 1.2 was actually not applied to the specimens presented here. It is intended as a general advice. In the test series conducted with the presented specimens under tensile cyclic loading most specimens showed cracks starting from the top side (observed by DIC). For compressive or partly compressive loading part of the specimens failed from the bottom side, so that crack initiation could not be detect by DIC.

4. The lines 129 to 196: the applications and setup of the instruments and testing machines for the tests were missing.
Information on the setup and for specific to the presented tests was added. Details on the used instruments were added to the Table of Materials.

5. The lines 221 to 223: Is there any evidence to support your statement? Has it been done in your reported tests?
Lines 222-223: the statement was removed. It was moved to the end of Discussion and a short explanation was added. The authors have not tested non-welded specimens but results from similar approaches can be found in literature. The authors have also tested longitudinal stiffeners (not presented here). Crack propagation outside the weld was clearly visible in DIC.
The authors did not test on servo-hydraulic machines. But considering the lower testing frequency, which would allow longer camera exposure times, the application should be even easier and results probably better.
Lines 221-222: the presented tests were performed on a resonance testing machine without test interruption.

6. The lines 224 to 274: Some more Figures may be included to support / evidence the discussion.
Figures were complemented and more figures were added.

7. The authors had better give the conclusion according to the guideline for authors
Conclusions were added.

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