

CRACK LUMINESCENCE AS INNOVATIVE METHOD FOR DETECTION OF FATIGUE DAMAGE

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Abstract:

Conventional methods of crack detection only provide a snapshot of the fatigue evolution at a specific location. The crack luminescence method realizes a clear visibility of the occurring cracks in loaded components during ongoing operation. Several different experiments show that due to the sensitive coating even the early stage of the crack formation can be detected what makes the crack luminescence helpful to determine the incipient crack opening behavior depending on load alternation. The crack luminescence is a passive method and can be used in ongoing operation. There are no skilled professionals needed to detect a crack like in conventional methods. Due to the emitting of light under UV-radiation the crack gets clearly visible what also makes continuous monitoring possible. This can reduce costs and time needed for maintenance und inspection.

Key words: fatigue damage, crack, luminescence, detection

Motivation

In construction parts under vibrational loading fatigue cracks can occur after a certain number of cycles [1]. This initiates an ongoing process of destruction and the residual lifetime of the component comes to an end. Due to security issues components under fatigue loading have to be inspected frequently to counteract in case of cracks or damage. The early detection of a crack helps to lower the costs of maintenance. Thus, the inspection should allow a reliable and efficient detection of fatigue cracks. Conventional methods of crack detection are not suitable for continuous monitoring of construction parts because they are general locally limited. Therefore, the application of these methods requires the information of the crack location in advance which is especially a great challenge for large structures. A new method, the so-called crack luminescence, provides an efficient solution for continuous monitoring of components under fatigue loading.

Principle and application of the crack luminescence method

For the crack luminescence, a special coating will be applied on the surface of critical locations like weld seams for example. This coating includes a fluorescing layer and a dark layer which covers the fluorescing (see Figure 1).

When a crack occurs in the steel's surface the two layers rip open due to its adhesive

properties. If energy-intensive rays (UV) enter the crack, the boundaries of the luminescing layer will emit visible radiation (see Figure 2). This luminescence can be seen from distance what makes remotely monitoring possible by using webcams so that there is no need of stopping any ongoing operations due to inspection issues. This can be helpful especially at locations which are not easy to access. Furthermore, an automated monitoring system is realizable by using image recognition software. Currently, the crack luminescence is limited to research application in laboratories where weather resistance is not necessarily needed but the combination of crack luminescence and corrosion prevention are part of future research.

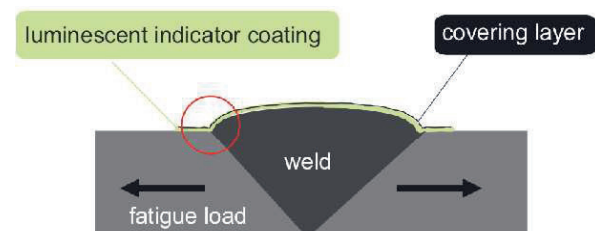


Fig. 1. Application of the crack luminescence coating at a welding seam

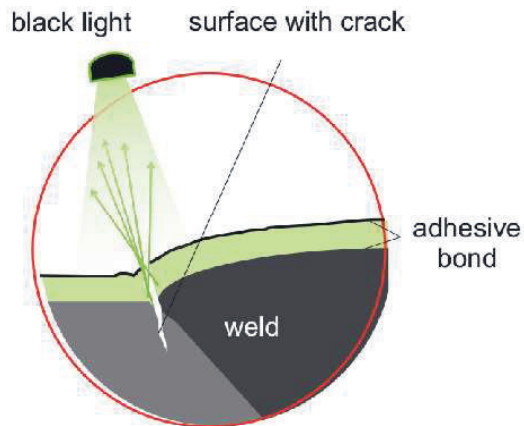


Fig. 2. Case of a crack and the emission of visible radiation

Sensitivity and Durability of crack luminescence

In collaboration with BAM and MR Chemie different fluorescing and cover coatings were developed and tested on special test bodies which allow a measurement of the sensitivity. Figure 3 shows the top view of such a coated testing specimen where the detected crack at a specific crack opening width can be seen. Thereby also the influence of the coatings thickness was determined.

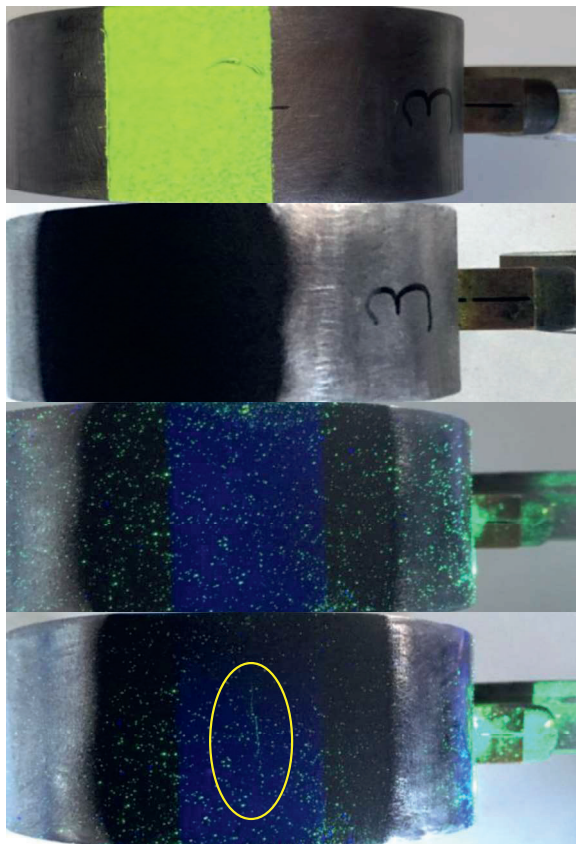


Fig. 3: Application of the coating and detection of a crack on a special test body

To evaluate the adhesive bond and delamination the different coatings were examined in a Mandrel bending test as well.

Two big issues of the luminescence coating are the long-life fatigue strength and the sensitivity while crack formation. On the one hand it should display the crack as fast as possible and on the other hand the coating should not gleam due to a defective cover layer. These quality characteristics were investigated by cyclic tensile tests. Therefore, the coating was applied to thin metal sheets. In one series of tests the specimens were axially loaded 5 million times in order to detect any delamination or ripping process. In the results no delamination in the coating layers was detected which indicates a durability of the coating layers against vibrational loading.

Another series includes vibrational loading of the sheets with a predefined notch (see figure 4) at the edge of the plate. This is meant to form a crack after a great number of load changes with its origin in the notch. This crack leads to the fraction of the sheet. Special attention was paid to the moment when the crack gets visible.

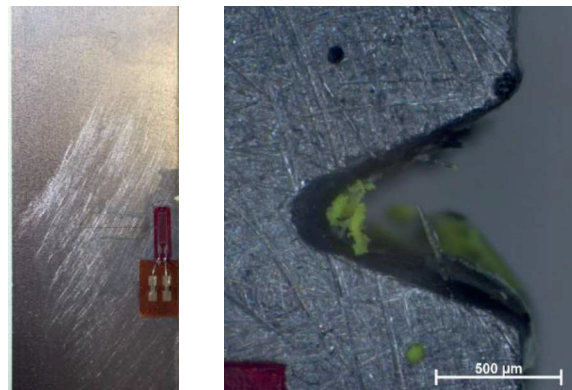


Fig. 4. Metal sheet with notch

Optical changes in the coating during the test were captured in a video. Furthermore, strain gauges were applied on the specimen's surface to measure the strain throughout the whole duration of the test. Figure 6 shows the test setup.

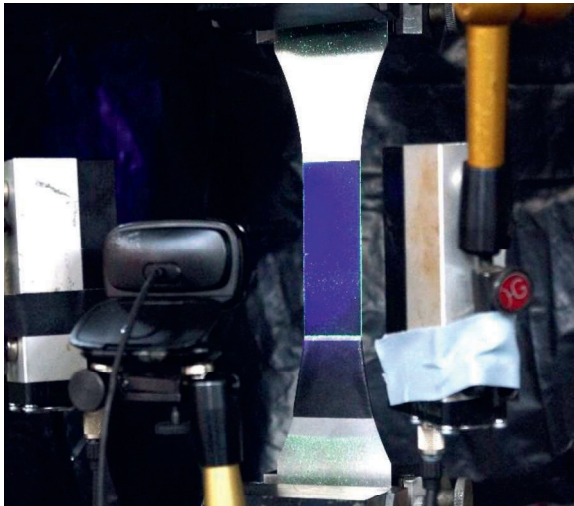


Fig. 5. Tensile test setup

This permanent strain measurement of several specimens is shown in Figure 7. The number of cycles is normalized and the grey area represents the moment when a first weak gleaming gets visible what signals the upcoming crack.

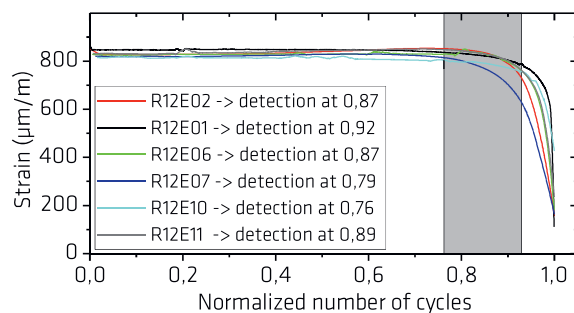


Fig. 6. Evolution of strain (metal sheets with notch)

The evolution of strain was compared with the video material. Figure 8 shows the progression of the crack in the specimen.

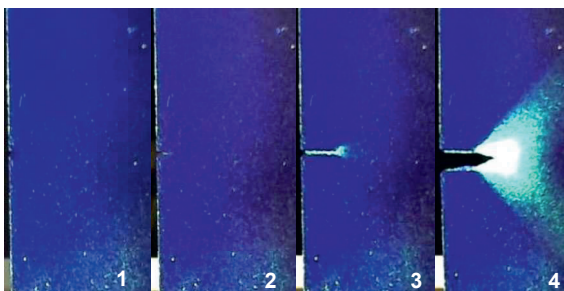


Fig. 7. Crack formation (2), growth (3) and fracture (4) while cyclic tensile test of a metal sheet with notch and luminescence coating

When the maximum strain starts declining, a small gleaming crack in the coating is noticeable as well. Results of this comparison show that already small changes in strain and thereby very short lengths of cracks are displayed by the coating. Thus, the progress of

crack formation, growth and fracture can be well observed with the luminescence coating which makes this method very interesting for continuous monitoring of fatigue loaded components.

Practice example

The crack luminescence method was also tested on butt welds and fillet welds. Fatigue damage was caused in cyclic tensile tests. The tests were also monitored by permanent strain measurement and video capture. All tests showed an early detection of the crack. Figure 9 shows a butt weld before and after the application of the fluorescing layer. Strain gauges and crack luminescence coating were applied on both sides due to the unpredictable location of the occurring crack.

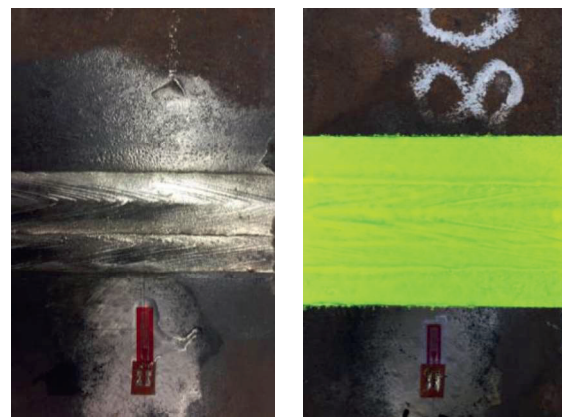


Fig. 8. Butt weld without and with fluorescing coating

An example of a tests on those butt welds is shown in Figure 10. Three different stages of the crack formation are shown. After 410 000 cycles a blinking is visible at the later point of rupture which is the edge of the weld.

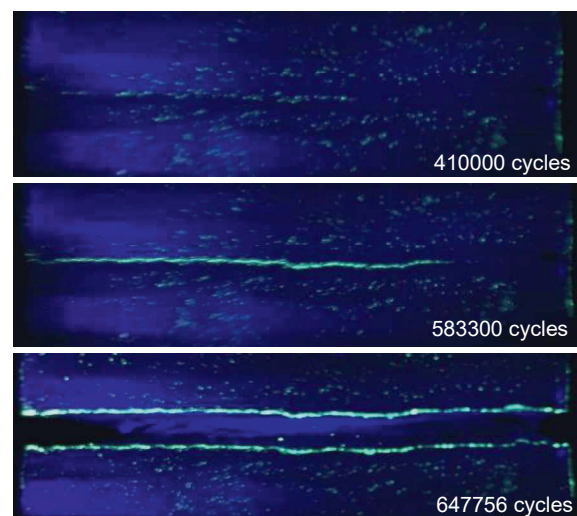


Fig. 9. Steps of crack formation (butt weld)

Figure 11 shows the evolution of strain where three specific times are marked. The first mark

"a" refers to the point of time (410000 cycles) when the maximum strain starts to decrease (see Figure 10 and 11). The brightness and blinking of the crack consistently increases. The mark "b" refers to the point of time (583300 cycles) when the maximum strain is decreased by 5 % (see Figure 10 and 11). After 647 756 cycles the specimen fractured (see Figure 10 and 11).

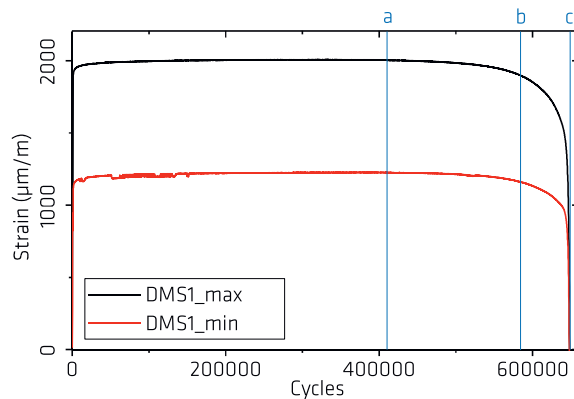


Fig. 10. Evolution of strain (butt weld)

The coating was also tested on fillet welds. Figure 12 shows the application of the fluorescing coating and the strain gauges. The strain gauges were applied close to the weld's edge for a sensitive detection of very small changes in strain.

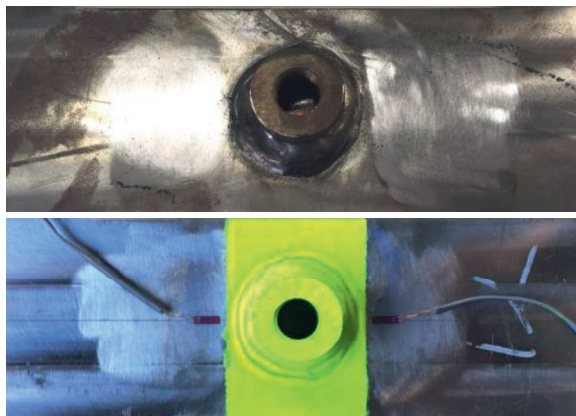


Fig. 11. Fillet weld without and with fluorescing coating

In Figure 13 the test setup is depicted. UV-lamps permanently irradiate the covering layer of the luminescent coating at the weld. The number of cycles is also captured in the video to simplify the synchronization with the measured strain. The specimens were loaded with a testing frequency of 10 Hz.



Fig. 12. Test setup

In Figure 14 the crack formation is shown at a fillet weld. First blinking began after about 130 000 cycles which got better visible after 150 000 cycles. After 250 000 cycles the crack reached a significant length and at 274 084 cycles the specimen fractured completely.

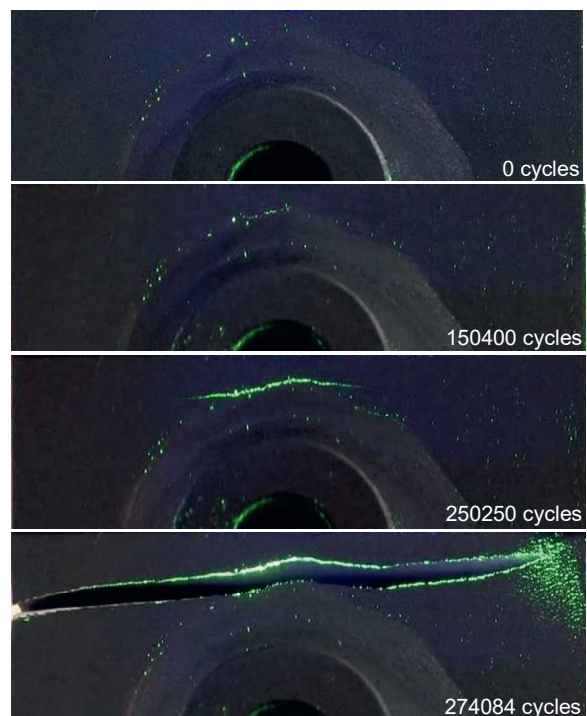


Fig. 13. Steps of crack formation (fillet weld)

In Figure 15 the evolution of strain is depicted. The mentioned steps of the crack formation from Figure 14 are marked in the graph. After a change of about 50 $\mu\text{m/m}$ (which corresponds to 4 % decrease of the maximum strain) in the maximum strain when the curve begins to fall, a blinking of the occurring crack was clearly visible.

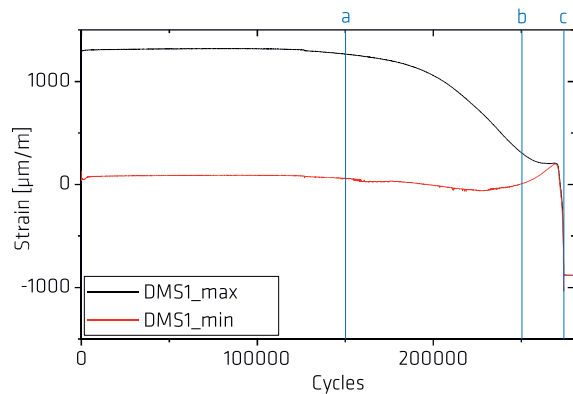


Fig. 14. Evolution of strain (fillet weld)

After 250 000 cycles (stage “b”) the value for maximum strain decreased significantly from about 1300 to 300 $\mu\text{m/m}$. Stage “c” marks the fracture of the specimen. A very sensitive reaction of the strain measurement and the luminescence coating are observed. In order to detect a crack the sensitivity of the strain measurement always depends on the location of the strain gauges. The closer they are to the occurring crack the faster they show changes in strain.

Also noticeable at some fillet weld specimens were the formation of a second crack at the opposite edge of the weld which was only visible with help of the crack luminescence. Red-white penetrant testing (Figure 16) and microscopic examination proved later the existence of the second crack.



Fig. 15. Red-white penetrant testing

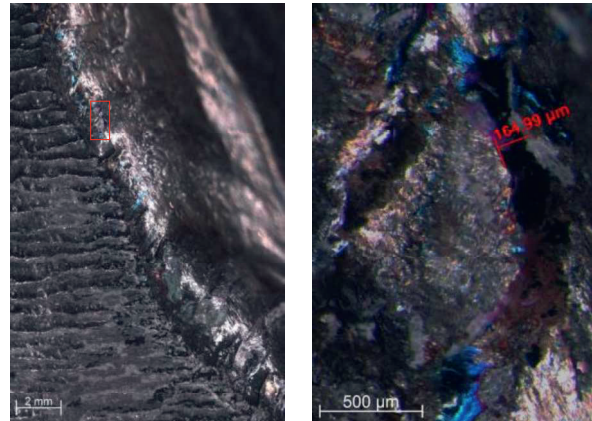


Fig. 16. Microscopic examination

Conclusion

The researches show a very high sensitivity of the crack luminescence which are in good agreement with the strain measurements. This method detects the cracks without knowing the location in advance where the crack occurs. The light emission of the coating makes continuous monitoring possible. So far the crack luminescence was just tested under laboratory conditions but next steps are industrial applications where weather resistance is more important. The crack luminescence is a promising approach to support the inspection of stressed and by fatigue damage endangered construction parts.

References

- [1] H. A. Richard, M. Sander, Ermüdungsrisse – Erkennen, sicher beurteilen, vermeiden, 26 ff (2009); ISBN: 978-3-8348-0292-7
- [2] M. Medianpour, Risslumineszenz - Ein neues Verfahren zur Detektion und Überwachung von Ermüdungsrisse, VSVI-Seminar Brücken- und Ingenieurbau, Braunschweig (2015)