Repair of Fatigue Cracked CT-specimens Using Adhesively Bonded CFRP Lamellas

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Introduction

Current investigations from the Federal Highway Research Institute in Germany show that today about 15% of German bridges are in urgent need of refurbishment or have to be replaced. Similar conditions can be observed in many other European countries. One of the main reasons for this is an increase of heavy-duty traffic in the last three decades, which clearly exceeds the traffic load forecast used in the 1960s. The methods of crack repairing already established in steel bridge constructions include repair welding and the drilling of the crack tip, sometimes in combination with a reinforcement using bolted steel profiles. In a national research project, the effectiveness of currently used crack repair methods and adhesively bonded CFRP lamellas is compared regarding the remaining lifetime of fatigue damaged steel structures. Selected results are presented in this paper.

Material Properties

The mechanical behaviour of the adhesive bond between the joining partners CFRP and steel is one of the essential requirements for a successful reinforcement with CFRP laminates. For the determination of the mechanical characteristics as well as the adhesion properties of different adhesives, various experimental investigations are carried out, in particular on lap shear specimens. The shear strength of the adhesively bonded CFRP-steel joints is determined in quasi-static tests and the time-dependent deformation behavior under continuous load is determined in creep tests. For this purpose, a lap shear test, modified from EN 14869-2, is used, where a CFRP coupon is inserted in the overlap area [1]. Based on the results of these experiments, two adhesives are selected for further investigations taking into account the mechanical properties as well as other adhesive-specific properties like glass transition temperature, processability and curing time.

Crack Repair and Retrofitting Using CFRP

To study the influence of adhesively bonded CFRP-reinforcements on the remaining lifetime of fatigue damaged steel structures, experimental investigations are carried out on CT-specimens (compact tension). Drilling of the crack tip, repair welding and single-sided bonding of prestressed and non-prestressed CFRP lamellas as well as combinations of these methods are considered. The lamellas of the prestressed specimens, which are bonded with Epoxy 1 are prestressed with 5 kN, Epoxy 2 with 3 kN respectively. Fig. 1 shows the geometry of the sample and the detail pictures during the repair process of the established procedures realized in the project.

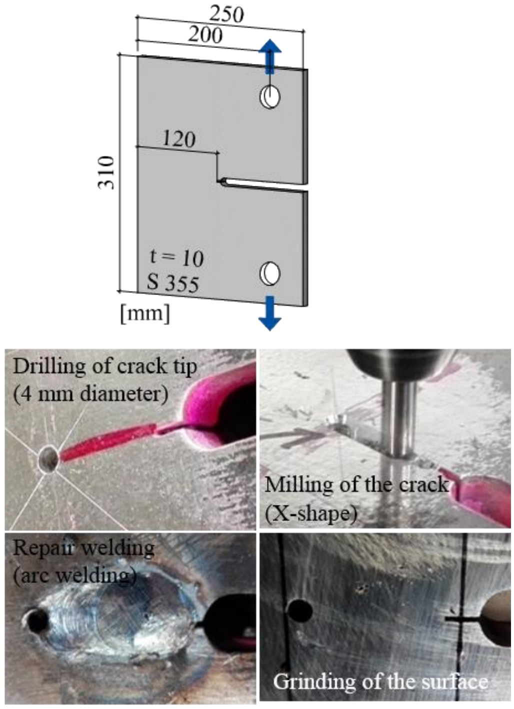

Fig. 1. Top: Geometry of the CT-specimen; Bottom: Procedures of repair methods

Before the joining process the steel surface is blasted and the surfaces of the lamella and CT sample are thoroughly cleaned with acetone to improve the adhesion of the adhesive layer. In case of applying a prestressed lamella a pretensioning system developed for this purpose at the KIT Karlsruhe is used [2]. The test specimens cure for at least 7 days at room temperature.

The tests are performed in three phases: The first phase includes the cyclic loading of the undamaged specimen at a frequency of 14 Hz, a stress ratio of R = 0.5 and a force amplitude of 10 kN and is stopped when a 20 mm long initial crack has formed. In the second phase the crack repair methods are executed as described above. This is followed by a third phase with cyclic loading of the strengthened specimen until the crack has grown to a total length of 40 mm. Using crack propagation gauges, the progression of the crack tip is recorded during the tests.

The determined remaining lifetimes (after the third test phase) for specimens strengthened by prestressed or non-prestressed single-sided bonded CFRP lamellas are shown in Fig. 2.

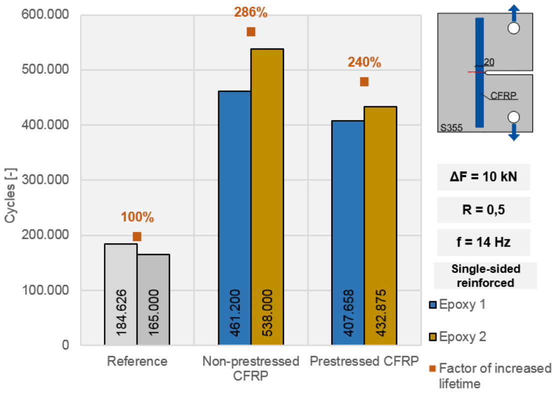

Fig. 2. Remaining lifetime of CT-specimens strengthened by prestressed or non-prestressed single-sided bonded CFRP lamellas

Compared to the reference experiments without any repair measure, the remaining lifetime can be increased by 186% using a non-prestressed CFRP lamella. Prestressing of the lamellas however leads to a slightly less increase in the number of sustainable cycles. This is probably caused by the application of a single-sided reinforcement. Due to prestressing, a tensile force is introduced only on one side of the 10 mm thick steel plate, which causes a secondary bending moment of the specimen and leads to a higher stress intensity at the crack tip on the non-reinforced side during loading.

For an additionally drilled crack tip the results of the remaining lifetime are shown in Fig. 3.

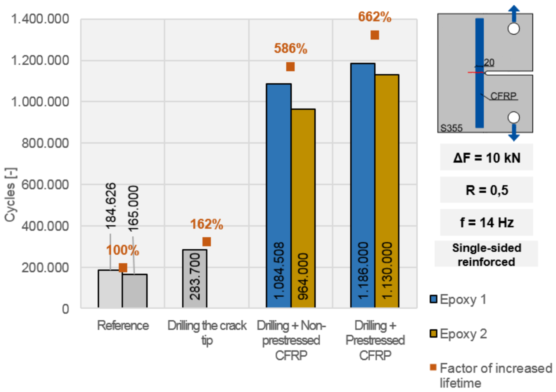

Fig. 3. Remaining lifetime of CT-specimens with drilled crack tip and strengthened by single-sided bonded CFRP lamellas

Compared to the reference experiments, the remaining lifetime resulting from only drilling the crack tip increases by 62%. The further application of a prestressed lamella leads to an increase in the number of sustainable loading cycles by about 500 percentage points. Due to a new crack initiation phase a pretension seems to lead to a higher remaining fatigue life compared to a non-prestressed CFRP lamella. This is probably why the results show no negative influence of single-sided reinforcement. To investigate this phenomenon in detail further experiments are needed.

In Fig. 4, the remaining lifetimes for a rehabilitation combining repair welding, a drilled crack tip and adhesively bonded CFRP lamellas are shown. The results also prove the great potential of the innovative strengthening method using CFRP. By the application of a non-prestressed lamella an extension of the remaining lifetime of an additional 386 percentage points can be achieved compared to repair welding (incl. drilling the crack tip). The application of the preload force leads to a 391 percentage points higher remaining lifetime compared with non-prestressed CFRP lamellas. Results of fatigue tests on center notched steel specimens only strengthened by double-sided prestressed CFRP lamellas show even higher remaining lifetimes compared to single-sided applications. With double-sided repairs a negatively acting secondary bending moment does not occur.

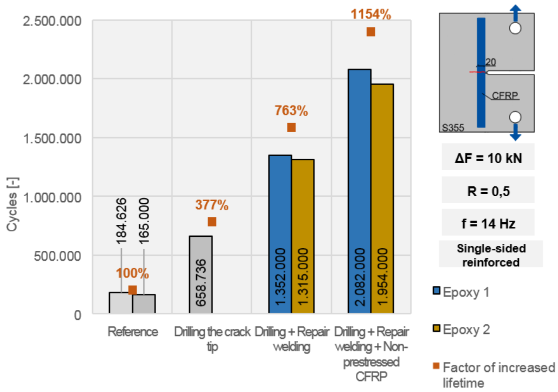

Fig. 4. Remaining lifetime of CT-specimens strengthened by repair welding (incl. drilling the crack tip) and single-sided bonded CFRP lamellas

Conclusions and Outlook

The presented experimental results of fatigue tests on CT-samples demonstrate the great potential of adhesively bonded non-prestressed and prestressed CFRP lamellas to strengthen fatigue damaged steel components. By bonding a non-prestressed CFRP lamella across a fatigue crack the remaining lifetime can be increased by 186% compared to an unstrengthened specimen. In combination with repair welding and drilling the crack tip, the number of sustainable cycles can be increased by a factor of up to 11. A dependence of the adhesive stiffness on the effectiveness of the strengthening method can be shown partly and is confirmed by investigations on center-notched steel specimens [3].

Acknowledgements

The IGF research project (IGF-No. 19032 BG/ DVS-no. 09.072) of the "Research Association on Welding and Allied Processes of the DVS, Aachener Straße 172, 40223 Düsseldorf" has been funded by the AiF within the program for sponsorship by In-dustrial Joint Research (IGF) of the German Federal Ministry of Economic Affairs and Energy, based on an enactment of the German Parliament.

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