The "Durimprove" research project: Improvement of the fatigue life of welded structures in high strength steel grades

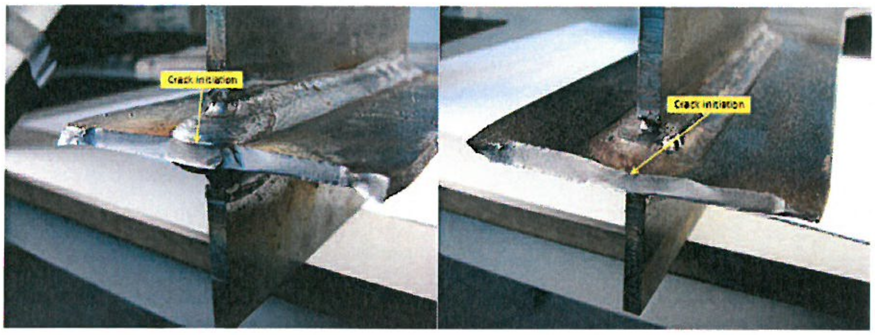

Fig. 1 • Fatigue failure in a non-treated weld (left) and in a TIG-dressed weld (right). The post-weld treated joint performed better during fatigue testing.

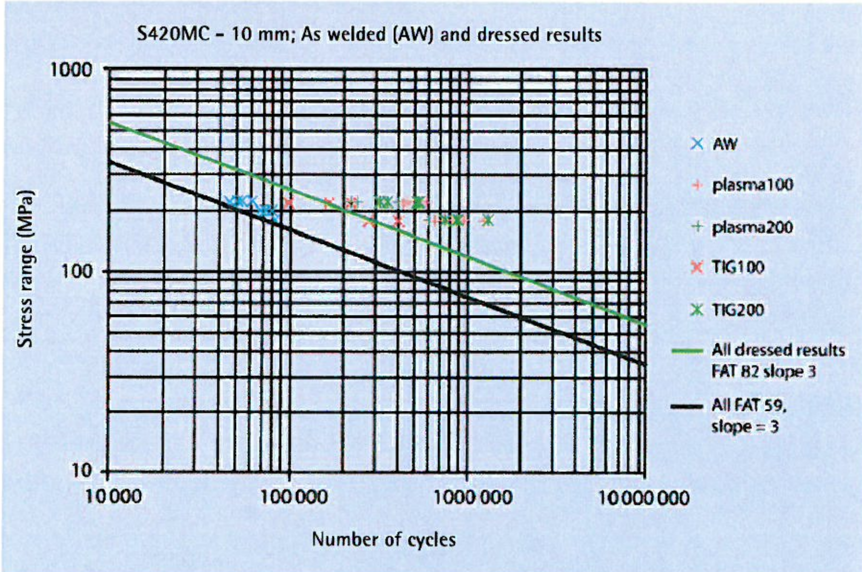

Fig. 2 • Wöhler curves of welds in the as welded condition and welds improved by TIG and plasma dressing.

Introduction

Fatigue properties of welded components can be improved by means of post-weld treatments, like tungsten-inert gas (TIG) dressing or hammering. This article describes the results obtained in the research project "Durimprove", in which the effects of post-weld treatments on welds in high strength steels (HSS) were investigated.

In this project, the Belgian Welding Institute BWI and the Belgian research center OCAS investigated methods to improve the fatigue properties of welds on high strength steels by different means. Two re-melting techniques (TIG- and plasma dressing) and one mechanical technique (Pneumatic Impact Treatment, PIT) were applied and compared. The project "Durimprove" was funded by the Flemish Government. 20 companies contributed to the project.

Requirements

In the target application field, construction equipment (i.e. agriculture machinery, ground moving vehicles, cranes, buses, general mechanical construction etc.), weight and cost savings are the goal for many manufactures; either to improve the pay load/deadweight ratio or to reduce energy consumption. The choice for high strength steels seems obvious, because thinner material can be used.

Post-weld treatment

In many applications, introducing HSS however is limited because the fatigue

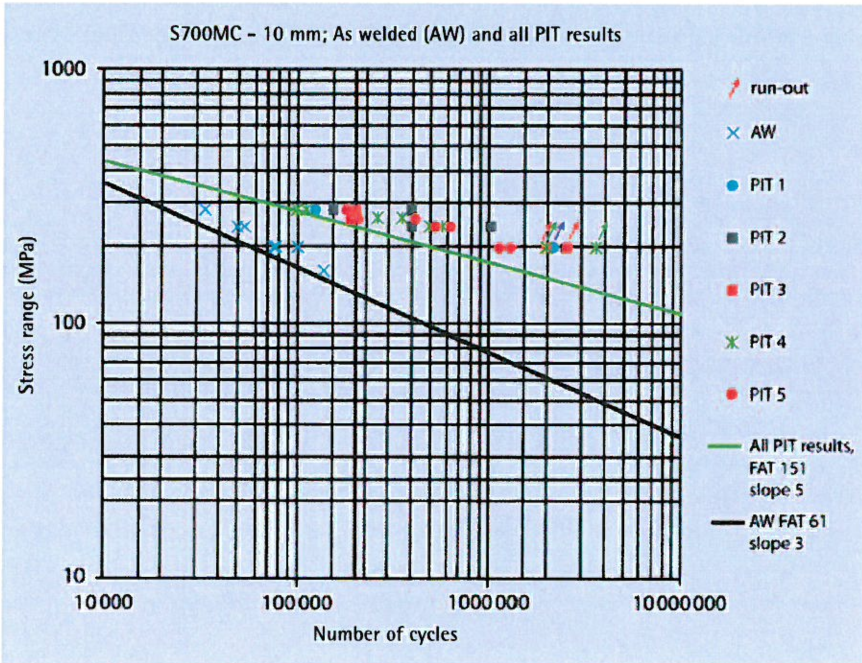

Fig. 3 • Wöhler curves for welds in the as welded condition and for welds improved by Pneumatic Impact Treatment (PIT).

Fig. 4 • Steering lever. Left: location of the steering lever at the back wheel of a potato harvester; Right: fatigue fracture of the steering lever initiated at the weld.

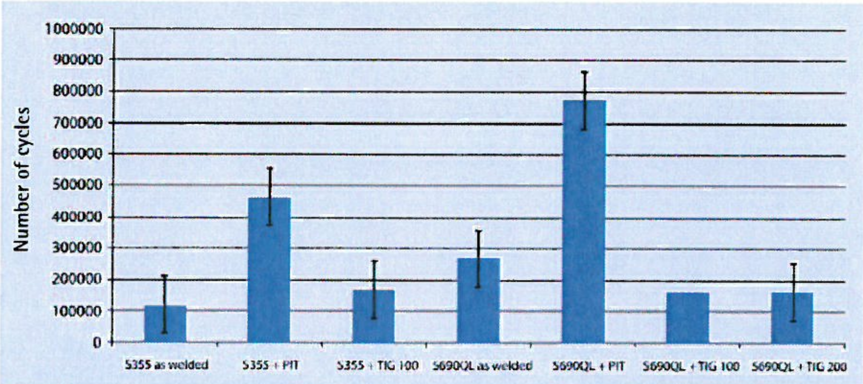

Fig. 5 • Overview of the fatigue tests: number of cycles as a funtion of the steel grade and the post-weld treatment.

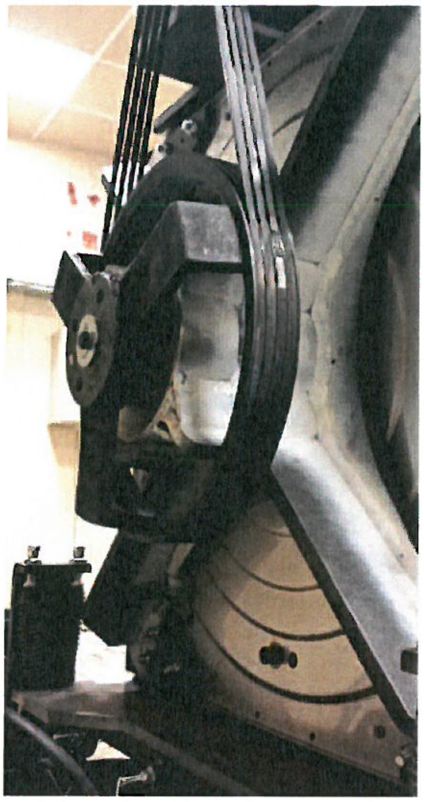

Fig. 6 • HF900 bearing house of an industrial washing machine ready for out-of-balance test.

strength of welded joints in HSS is found to be equal to the fatigue strength of welds in medium strength steels. When using thinner plates, the weight of a construction will decrease, but the lifetime might become insufficient. However, it is possible to improve the fatigue properties of welded connections by means of post-weld treatments, Fig. 1. By re-melting the weld toe, the geometrical transition from the weld metal to the base metal is smoother. This results in better fatigue properties.

Another way to improve fatigue properties is the application of a hammer treatment, which creates a smooth transition at the weld toe and introduces compressive stresses. In the "Durimprove" project, Pneumatic Impact Treatment (PIT) was used.

Wöhler curves

In an extensive generic test program, Wöhler curves were composed for non-treated welded joints (as welded) and for post-weld treated welded joints in S420MC and S700MC steel grades. The improvement obtained with TIG- and plasma dressing was equal. Therefore the results of both remelting techniques were grouped in a single curve, as shown in Fig. 2. This figure shows the Wöhler curve of longitudinal stiffeners

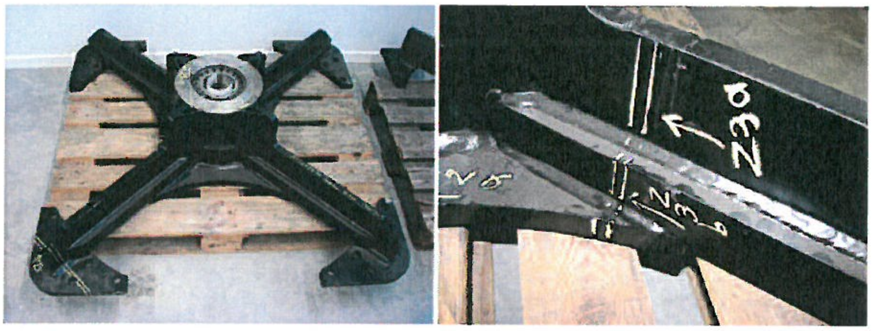

Fig. 7 • HF900 bearing house. Left: original design; Right: a detail of the critical point for fatigue crack initiation at the star-shaped reinforcement.

in S420MC in 10 mm thickness in "as welded" condition and the improved curve of TIG- and plasma dressing.

The increase of the fatigue life obtained with PIT was higher compared to the increase obtained by the remelting techniques. As an experiment, different parameters of the PIT process were applied on fatigue testing specimens. Regardless the variation of the parameters, the improvement was constant. Therefore, a single graph was composed per steel grade and per sheet thickness, as shown in Fig. 3. This graph shows the improvement obtained with PIT for welded joints in S700MC with a sheet thickness of 10 mm. The FAT-class (this is the design strength at 2 million cycles) increased with 150%. Furthermore, the new curve for PIT-treated welded joints has a smaller slope; the effect is even larger at low stress levels.

The post-weld treatments were applied on industrial components, three of them are discussed in this article.

Case 1: Potato harvester

The steering mechanism of a Dewulf potato harvester is made of S355 (Fig. 4). Several prototypes were made of the most critical steering lever, using an improved welding procedure and with different post-weld treatments. The best result was obtained with a PIT-treated steering lever made of S690QL high strength steel (Fig. 5). The life expectation increased 6.5 times compared to the original untreated steering lever in S355. The geometry of the steering lever was not changed, given the very limited space in which the lever is mounted.

Case 2: Industrial washing machine

The second case that was examined is a bearing house of an industrial washing machine of Alliance Europe. The bearing house is located at the back of the washing machine. At one side, the washing basket is mounted, at the other side the engine power is transmitted. The maximum fatigue load is reached when 15% of the maximum payload (90 kg) is present in the machine at a rotational speed of 750 rpm. This unbalance at 750 rpm is used as a fatigue test by the manufacturer, the so-called out-of-balance test (Fig. 6).

The original weight of the bearing house is 281 kg and it is composed of S235 steel. Out-of-balance tests performed in the past reached 130 hours on average, until a fatigue crack appeared in one of the four arms at the transition between the star-shaped reinforcement and the arms (Fig. 7). The ambition of Alliance was to extend the lifetime up to 500 hours without fatigue crack initiation. Weight saving as such was not a priority, as it might lead to resonance problems.

The critical welds of the original design were PIT-treated. The out-of-balance test ended at 349 hours due to the appearance of a fatigue crack. The desired 500 hours were achieved by a design change (Fig. 8). The star-shaped reinforcement was integrated in the arms. As the star-shaped part is fully integrated in the arms, no notch effect is present, which is beneficial for increased fatigue resistance. Furthermore, the additional reinforcement plates, which are present in the current design, were no longer needed.

The new design reached 500 hours in the out-of-balance test without fatigue crack initiation. The weight was lowered by 12% and 25% less welding time is required.

The case shows that the use of HSS and the use of a post-weld treatment is not always the best or only solution for increasing the fatigue life of a component. Alliance accepted the design change in their production.

Case 3: Hoists

ArcelorMittal Gent uses old and new overhead cranes made of S235. Fatigue cracks in beams of the overhead cranes occur at various critical locations. These critical

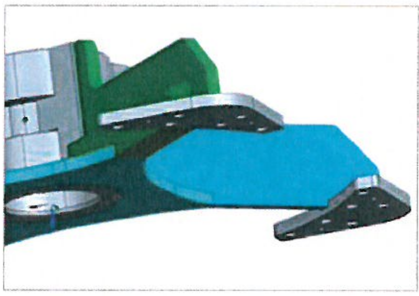

Fig. 8 • Design change of the bearing house: the star-shaped reinforcement is integrated in the arms. The additional reinforcement plates at the arms are no longer needed.

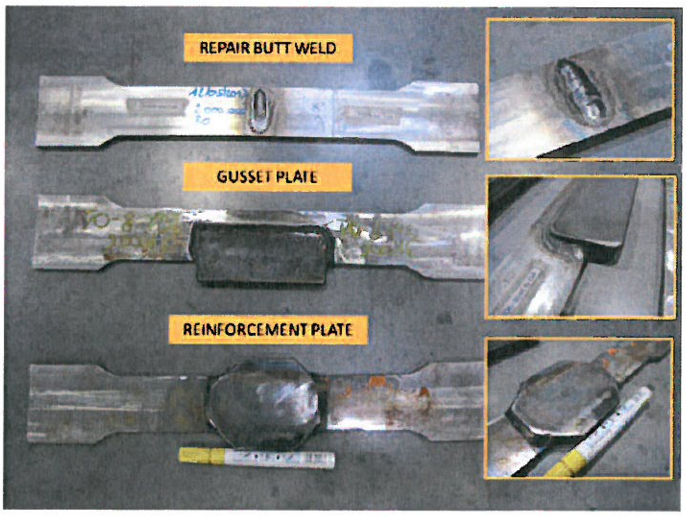

Fig. 9 • Fatigue test samples with critical weld details of overhead cranes. Top: repair butt weld; middle: gusset plate; bottom: reinforcement welded under the beams.

locations are regularly inspected and repaired if cracks are found.

Fatigue tests were performed for the three most critical weld details, in order to examine the preventive effect of a PIT-treatment on aged welded joints. It was also examined if fatigue crack initiation can be delayed on hoists which are in service for some years. The following three weld details were examined:

- **A repair butt weld**
  Fatigue cracks are removed by grinding. This is done in an X joint preparation using Manual Metal Arc Welding (MMAW). Because repair welds are always located in critical zones and because they are most often made in difficult circumstances, they remain sensitive for new fatigue cracks.
- **Gusset plate**
  This is a steel plate which connects the beams of overhead cranes with the building, for having sideway stability.
- **Reinforcement plates under beams**
  In zones where the highest bending stresses occur in the beams of overhead cranes, extra reinforcement plates are welded underneath. Fatigue cracks can initiate where the reinforcements end.

For these weld details, small-scale fatigue test specimens were manufactured (Fig. 9). First, fatigue tests were executed on the weld details for reference purposes. Second, welded joints were subjected to fatigue loads until a point at which fatigue cracks can be expected like they are in service for years. A dye penetrant test was done to detect surface cracks. If no cracks were found, a PIT-treatment was done on the aged welds. The welded joints then were further fatigue-tested. The results per weld detail are listed below:

- The original butt weld: The measurement points lie, as expected, above the design curve for butt welds specified in Eurocode III. One fatigue test was performed on an aged welded joint after PIT treatment. Despite the high stress range (225 MPa), no cracks appeared after 3M cycles and the test was ended. This measurement point is far above the design curve for butt welds specified in Eurocode III.
- PIT treated aged gusset plates were fatigue tested at R 0.1 and a stress range of 225 MPa. At this stress level the average fatigue life was three times higher than the fatigue life of new untreated gusset plates.
- Aged PIT treated reinforcement plates were fatigue tested at R 0.1 and a stress range of 225 MPa. At this stress level, the average fatigue life was 14 times higher than the fatigue life of new untreated reinforcement plates.

The outcome of this fatigue test campaign shows that a post-weld treatment of weld can be used as a preventive measure to delay fatigue crack initiation. Before applying the post-weld treatment, a dye penetrant check must be done.

Conclusion

In general, the "Durimprove" project showed that fatigue life of welds can be increased by using post-weld treatments on commodity and high strength steels. The case of the bearing house demonstrated that the use of high strength steel and post-weld treatments is not the only way to increase the fatigue life of a component. A design change led to the desired improvement of the fatigue properties. Finally, the beneficial effect of post-weld treatments was shown on old overhead cranes. Thanks to a post-weld treatment, fatigue crack initiation can be delayed. This leads to significant savings of weld repairs and inspections. Given the successful outcome of the "Durimprove" project, this knowledge will be used for highway bridges, in the frame of the European RFCS research project "Optibri" (Optimal use of high strength steel grades within bridges). The partners in this project are the University of Liege (project leader, Belgium), the Belgian Welding Institute, GRID Consulting Engineers (Portugal), the University of Combria (Portugal), the University of Stuttgart (Germany) and Industeel (Belgium). In this project, the use of high strength steel in highway bridges, designed according to ‚Eurocode III', is studied. Fatigue life of these bridges is limited by transversal stiffeners. As an extra limitation, ‚Eurocode III' does not take into account the beneficial effect of post-weld treatments on welded joints.

The effect of post-weld treatments on the fatigue properties of transverse stiffeners made in HSS will be investigated. Finally, the outcome of this project will contribute to a possible change of the Eurocode III. This will enhance the use of HSS in bridges and lead to weight savings.

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