Experimental report

19/02/2019

Proposal: 1-02-228 **Council:** 4/2017

Title: Physical aspects of improving the fatigue strength of high strength steel welded structures

Research area: Engineering

This proposal is a new proposal

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Experimental team: Halid YILDIRIM

Local contacts: Thilo PIRLING

Samples: Welded high strength steel joins

Instrument	Requested days	Allocated days	From	To
SALSA	12	4	02/07/2018	05/07/2018
			05/09/2018	06/09/2018

Abstract:

This project will investigate the physical aspects of improving the fatigue performance (strength) of high-strength steel welded joints, such as for the use in construction equipment,transportation vehicles and lifting devices, in order to obtain significant weight reduction and improved service life.The samples will be manufactured from plate thicknesses of 5-10 mm with yield strengths of 355,700 and 960MPa.

We will examine the well-known fatigue strength improvement technique called high frequency mechanical impact (HFMI) treatment. The required beam time will be used in parallel to the approved European project Hi-Life obtained by the applicants;the project is to be conducted at Swiss Federal Institute of Technology EPFL on 10.2017-09.2019.Measurements at ILL will allow mapping the physical characterization of welds through plate thickness,which is currently not possible in Sweden due to lack of such diffraction facilities.We will develop analytical procedures to assess the benefits and limitations of the treatment method.At the end of this research work,physical behaviour of induced stress will be available for selected loading conditions to show limits of improvement method.

Physical aspects of improving the fatigue strength of high strength steel welded structures
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Experimental team:
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Instrument: SALSA, 02-07 July 2018 and 05-06 September 2018

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Scientific and Technical Approach

In recent years, high-frequency mechanical impact (HFMI) treatment has significantly developed as a novel, reliable and effective method for fatigue strength improvement technique of welded structures [1-3]. In HFMI, fatigue strength improvement is primarily achieved by imposing compressive residual stress state around the weld toe, but as well by establishing smooth transition from the parent material to the weld metal and cold-work surface region. According to our recent studies, [1-3] fatigue strength of HFMI-treated details increases as the strength (fy) of base material increases.
In the literature, HFMI studies have mainly focused on the degree of improvement in fatigue strength. However, less attention has been given to the physical characterization of the improvement method. For example, in our recent study [3], we have mostly seen root failures at the maximum applied stress, at a level much lower than the material yield strength. On the other hand, we have also observed weld toe failures when the maximum applied stress almost reaches the material yield strength. Apparently, we owe this to the relaxation of HFMI-induced compressive stress state under fully-reversed variable amplitude loading. In such cases, application of HFMI may result in almost no benefit in fatigue life in comparison to the as-welded case. Thus, the improvement method is obviously limited and dependent on the applied load conditions, which has not been systematically investigated yet. Consequently, this must be considered and investigated to develop a relation with the limitations of the applied load and the benefits of the HFMI treatment for the fatigue design guidelines.
To investigate this, residual stress state behaviour of the weld toe and root region under fatigue loading must be implemented in the finite element (FE) modelling. In connection to this, the accuracy and reliability of the model can only be proven by using accurate mapping of the induced residual stress state, especially with neutron diffraction measurements.

Aim of the work:

This proposed project aims to determine the physical aspects of improving the fatigue strength of high-strength steels for the use in welded complex structures. Particularly, to achieve the above-mentioned goal, the work focuses on the evaluation of:

- mapping the behaviour of HFMI-induced residual stress state at the welds through the plate thickness by neutron diffraction method for tested samples.
- texture analyses for both untested and tested samples to investigate grain orientation regarding the residual stress development at the welds. (could not performed within 1-02-228)

Results

In the beamtime allocation, we were able to measure 4 samples of AH36 and S690QL HFMI treated and untreated welds, as well as their two corresponding reference samples. Please see Table 1 for details. The measurements were performed at the centre line of the sample within a distance of 24 mm from the weld toe for the mid-thickness (3mm). Figure 1 shows only one example result of residual stress measurements of AH36 along the sample. Following measurements were done at the two weld toe of the four samples to map the thru thickness behaviour of residual stresses. The difference we see is that HFMI treatment

lowers the stresses at around the weld toe area. HFMI treatment changes the tensile residual stresses from the weld to the weld root area.

The required beam time within this project was used in link within the European project Hi-Life (702233) [4]. However not all the necessary tests were performed due to lacking of beam time.

Table 1. Test matrix of the project.

Sample:	Unloaded sample	Loaded sample	Sample:	Unloaded sample	Loaded sample
Reference	Measured	Not applicable	Reference	Measured	Not applicable
S1 AH36 HFMI 18	Measured	For the next time	S3 AH36 AW 14	Measured	For the next time
S2 S690QL 18	Measured	For the next time	S4 S690QL AW 14	Measured	For the next time
Texture measurements of each case	For the next time	For the next time	Texture measurements of each case	For the next time	For the next time

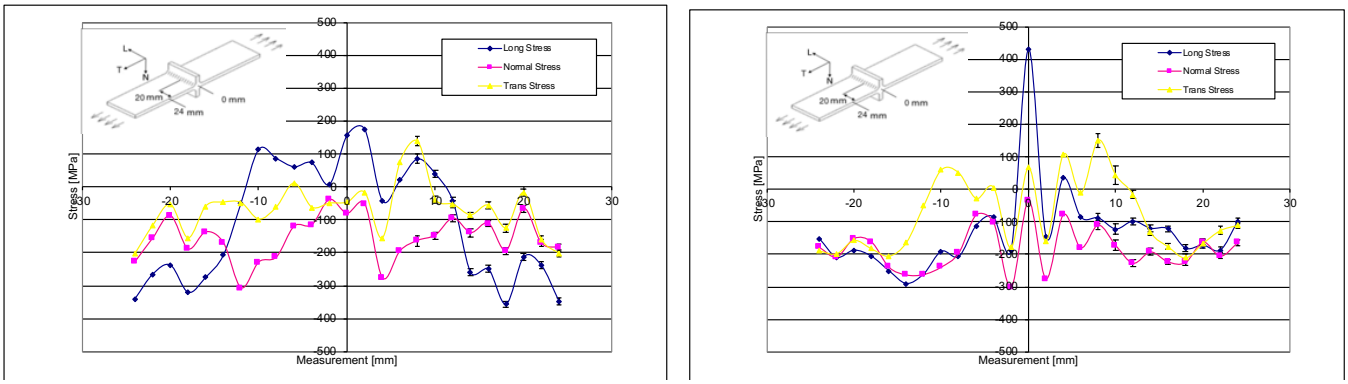

Figure 1. Residual stress distribution at the surface of untested AH36 welds at ILL. As-welded (AW) on the left, and HFMI-treated on the right. HFMI treatment changes the tensile residual stresses from the weld to the weld root area.

There is still remaining work to be done to full fill the aims of this proposed project. The next step is to perform measurements on 4 specimens at **different stages** of fatigue testing. Specimens will be tested after they are fatigue loaded. Measurements at ILL will be done at certain periods of the life time of each specimen as given in Table 1. Measurement of each specimen will approximately take 12 hours meaning that we would need 4 more days for each measurement time.

Texture measurements is also another aim in this project to precisely identify the residual stress development in relation with the grain orientation at the weld toe. For the next measurements, four samples with a size of 2x2x2 mm^3 will be cut at the weld toe along the weld seam, and they will be glued to form a test sample. For this step, both AH36 and S690QL steel types in as-welded and HFMI treated conditions will be investigated in order to differ the texture alignment of treated ones versus to conventional welds.

References:

1. Yıldırım H. C., Marquis G. B.: Fatigue strength improvement factors for high strength steel welded joints treated by high frequency mechanical impact, International Journal of Fatigue, 44, pp. 168-176, 2012.

2. Marquis G. B., Mikkola E., Yıldırım H. C., Barsoum Z.: Fatigue strength improvement of steel structures by high-frequency mechanical impact: proposed fatigue assessment guidelines, Welding in the World, Volume 57, Issue 6, pp 803-822.

3. Yıldırım HC., Marquis G B.: A round robin study of high frequency mechanical impact treated welded joints subjected to variable amplitude loading, Weld World, 57(3), pp. 437-447, 2013.

4. Hi-Life: HC Yıldırım and A Nussbaumer: Damage mechanism of High Frequency Mechanical Impact (HFMI) Treated Welded Structures under Service Loading to Increase the Fatigue Life for Lightweight Design [cordis.europa.eu/projects/702233]