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Experimental Stress Analysis

# LOCAL PLASTIC DEFORMATION AND ITS INFLUENCE ON RESIDUAL STRESS DISTRIBUTION AT HIGH STREGTH STEEL WELDS

Ľuboš Mráz [1], Leif Karlsson[2], Ivan Hamák[1], Pavol Mikula[3] & Miroslav Vrána[4]

**Abstract:** The effect of fatigue load and local plastic deformation on residual stress distribution of high strength 800 MPa steel cruciform welds has been studied. The residual stress distribution has been identified by neutron diffraction. Local plastic deformation has been induced by tensile loading and was measured by strain gauges. A large drop of residual stresses in the vicinity of the high strength steel welds has been recognised due to local plastic deformation at the level of 2 %. The influence of fatigue load on residual stress distribution after more than $2 \cdot 10^6$ cycles was much lower compared to the influence of local plastic deformation.

## 1. Introduction

Residual stresses are typical feature of welded joints. It is generally known that they are developed during and after welding and are the main cause of deformation and cracking either during or just after welding or under loading of welded structures. The presence of residual stresses also influence the crack propagation due to cumulative effect of external and internal force especially during cyclic loading.

All welded steel structures should withstand not only external but also internal load represented by residual stresses without any plastic deformation. Anyway, local plastic deformation can occur due to sudden unexpected load or not proper design of the structure for a given load. This deformation can reach the yield point, induce dislocations and a part of residual stress can be converted into plastic deformation and relieved. This effect is considered as the stress relaxation process.

Seungho et al. [1] have studied the influence of fatigue load on stress relaxation. They recognized that mainly first cycle can redistribute the residual stresses. They have found out that the final stress relaxation depends on the stress amplitude and on the number of loading cycles. Similar effect has been recognized by Farajian-Sohi [2].

Stress relaxation has also been identified due to ultrasonic impact treatment (UIT) [3]. According to the presented results specimens have showed UIT strengthening, which is considered as an efficient method for increase in fatigue strength of welded joints.

Byeongchoon and Sungyong [4] have proposed a fatigue life prediction model in order to predict fatigue life time due to stress relaxation.

In this paper the influence of cyclic load and local plastic deformation on weld residual stress distribute

[1] Welding Research Institute – Industrial Institute SR, Bratislava, Slovakia
[2] ESAB AB, Göteborg, Sweden
[3] Research Centre Řež, Ltd., Řež, Czech Republic
[4] Nuclear Physics Institute AS CR, v.v.i., Řež, Czech Republic

## 2. Experiments

The influence of cyclic load and local plastic deformation on residual stress distribution of high strength steel WELDOX 700 welds has been studied. Neutron diffraction method has been used in order to identify the residual stress distribution in the vicinity of the fillet weld toe. Local plastic deformation (pre-stressing) has been induced by static load. The influence of cyclic load has been studied on the test specimen subjected to $2x10^6$ cycles at a stress amplitude of 58.59 MPa.

### 2.1 Test specimen preparation

Cruciform weld test specimens have been used in this study (**Figure 1**). WELDOX700 steel thickness of 8 mm was used as parent material. Chemical composition of the parent material is given in **Table 1**. MMAW was used to prepare single pass fillet welds from both sides of test specimen using high alloyed Cr-Ni basic electrode. Chemical composition of the all-weld metal of basic electrode is given in **Table 2**.

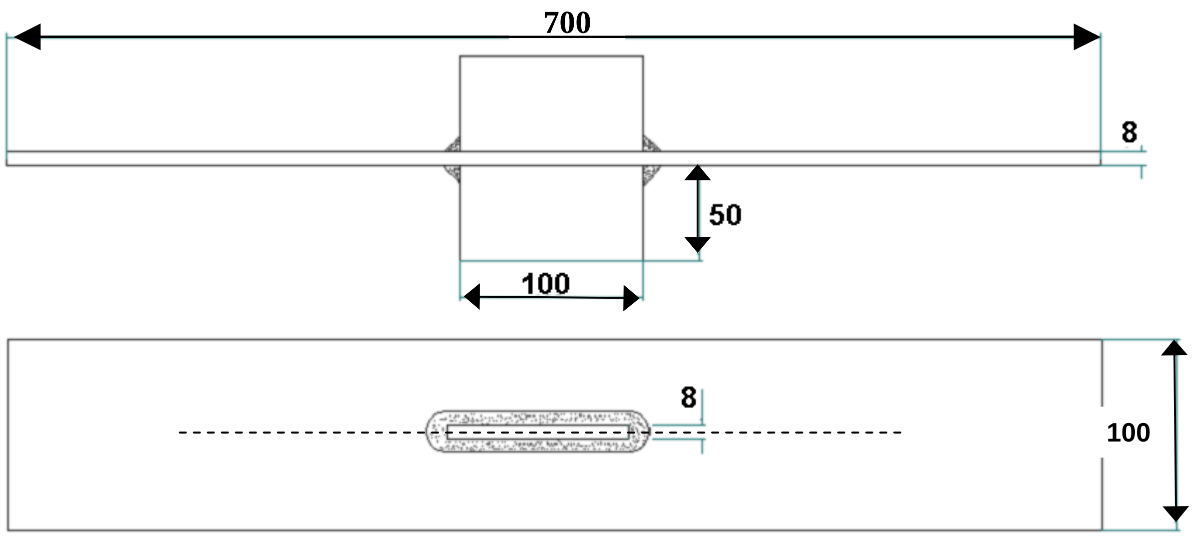


***Figure 1*** *Fatigue test specimen*

***Table 1*** *Chemical composition of WELDOX 700 parent material*

| Steel | Content (weight %) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | C | Si | Mn | B | P | S | Cr | Ni | Mo |
| Weldox 700 | 0.137 | 0.294 | 0.991 | 0.0015 | 0.0090 | 0.0014 | 0.37 | 0.041 | 0.015 |

| Content (weight %) | | | | | | | CEW |
|---|---|---|---|---|---|---|---|
| V | Ti | Cu | Al | Ca | Nb | N | (%) |
| 0.049 | 0.016 | 0.006 | 0.006 | 0.0036 | 0.021 | 0.0038 | 0.39 |

***Table 2*** *All-weld metal chemical composition of tested electrodes*

| **Type** | **Test No.** | **Content (weight %)** | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | **C** | **Si** | **Mn** | **P** | **S** | **Cr** | **Ni** | **Mo** | **Cu** | **O** | **N** |
| LTTE-CM4B | 4385 | 0,062 | 0,31 | 1,38 | 0,010 | 0,001 | 10,84 | 10,3 | 0,04 | 0,01 | 260 | 160 |

### 2.2 Fatigue load

Fatigue load has been introduced on fatigue test SCHENK equipments using a frequency of 29 Hz at the ratio R = 0.1 (ratio of minimum to maximum load). Fatigue equipment is the resonance type with a maximum load of 200 kN and 600 kN respectively. The cyclic load amplitude of Ra = 58.59 MPa (Rr = 117.19 MPa) was applied for the fatigue test specimen in order to reach $2x10^6$ cycles.

### 2.3 Pre-stressing procedure

The test specimen for identification of the local plastic deformation on residual stress measurements has been pre-stressed. The level of pre-stressing has been performed on a SCHENK tensile test machine with a capacity of 1600 kN. The elongation of a test length of 290 mm and local deformation have been measured. Local deformation has been measured using strain gauges in the vicinity of the weld toe of the fillet test weld (**Figure 2 and 3**). Local deformation behavior of the weld toe area during pre-stressing is shown on **Figure 4**.

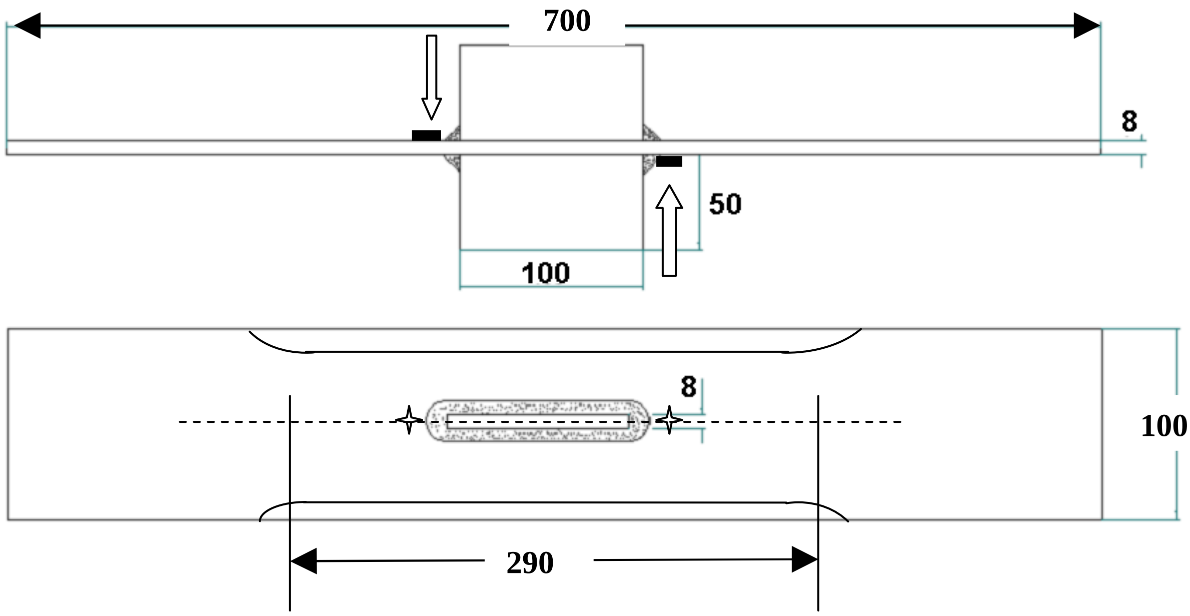


***Figure 2*** *Location of strain gauges of the test specimen*

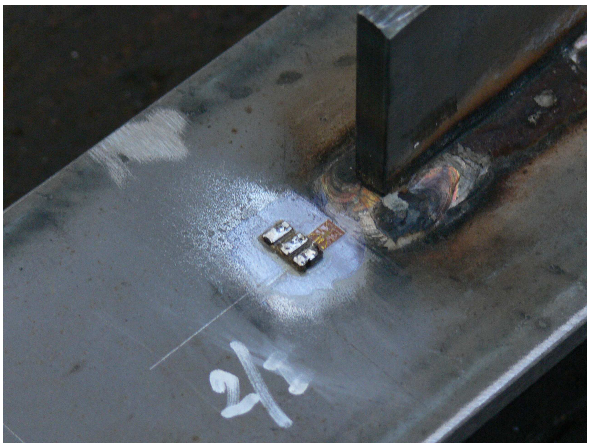

***Figure 3*** *The location of strain gauges on the test specimen*

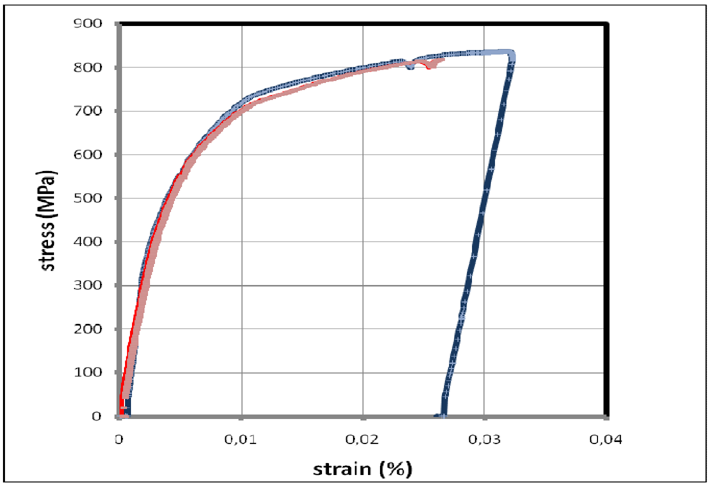


***Figure 4** Record of a local deformation in the vicinity of the weld toe*

### 2.4 Residual stress measurements

Neutron diffraction has been used for the residual stress distribution measurements in the vicinity of the test welds. The measurements were carried out at the neutron strain scanner SPN-100 installed at the medium-power research reactor LVR-15 in Řež, Czech Republic **[ 5].** The instrument has a curved Si(111) monochromator and is equipped with linear high-resolution position-sensitive detectors for fast recording of diffraction profiles. The monochromator provides a neutron beam with a wavelength of 0.232 nm. The shift in the Bragg angle (relative to that of the stress-free material) permits determination of the average lattice macro-strain over the irradiated gauge volume. The strain scanning was carried out by means of diffraction on α-Fe(110) lattice planes for $2\cdot\theta_{110} = 70^{o}$. For the evaluation of the strains it was necessary to determine the angular position $2\cdot\theta_{0,hkl}$ of the diffracted neutron beam for the strain free material. As the chemical composition of the weld is different from that of the steel, it is necessary to have strain free steel and weld metal reference material for calibration. Therefore, after carrying out the strain scanning, small cubes with a volume of about 27 $mm^3$ were cut off from the steel plates and the welds in which the strains were relaxed and the material was considered as strain free. All three components Rx, Ry and Rz have been measured. The location of the diffraction measurements is shown in **Figure 5**.

## 3. Results

Plastic deformation of 2 % has been applied for the test specimen prior to neutron diffraction in order to study the influence of high deformation single cycle. The results of neutron diffraction measurements of Rx component for all three specimen e.g. after welding without any subsequent loading (as-welded), after local plastic deformation (pre-stressed) and finally after cycling load are shown on **Figure 6**. Residual stress Rx of more than 600 MPa has been measured in the CGHAZ for the as-welded specimen. Cyclic load caused a slight drop of Rx stress in CGHAZ to a level 400 MPa. Remarkable drop of residual stress Rx has been identified after local plastic deformation. The level of 50 MPa has been measured in this region. The drop of residual stress has been observed not only in the vicinity of the weld (CGHAZ) but also in the whole region 35 mm far from the weld toe. The results support the assumption of Seungho et. al [1] that the stress relaxation depends on the level of load and number of cycles under cyclic load. According to their results the stress relaxation amount is larger when the stress amplitude is larger.

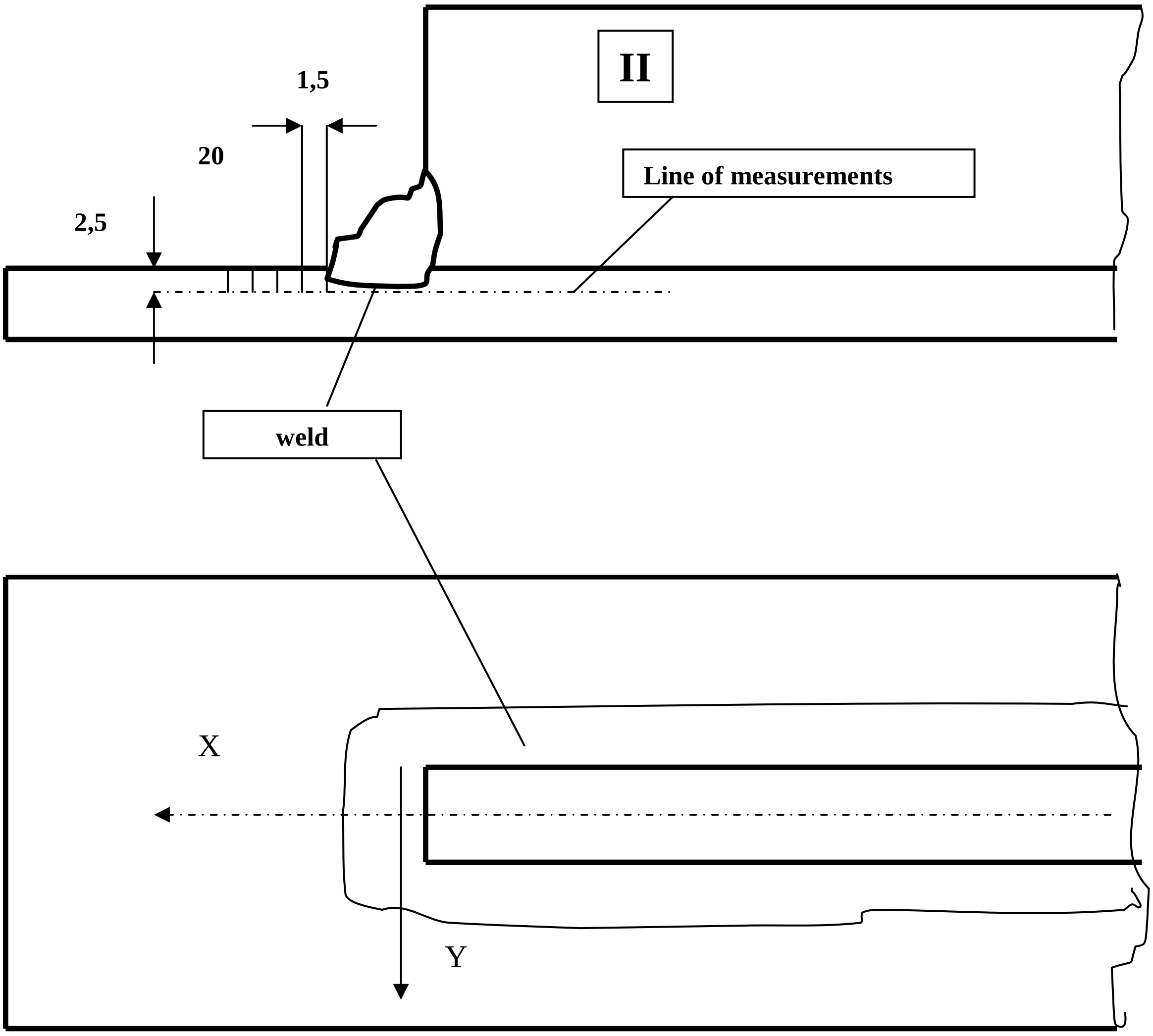


***Figure 5*** *Location of residual stress measurements*

The results of the neutron diffraction also clearly show that the stress relaxation is not only a local process but it covers the whole region in the weld metal to the distance of almost 40 mm far from the weld. It has also been recognized that the stress relaxation is far more pronounced due to local plastic deformation than due to cyclic load. Similar effect of external load has been identified also for two other stress components Ry and Rz.

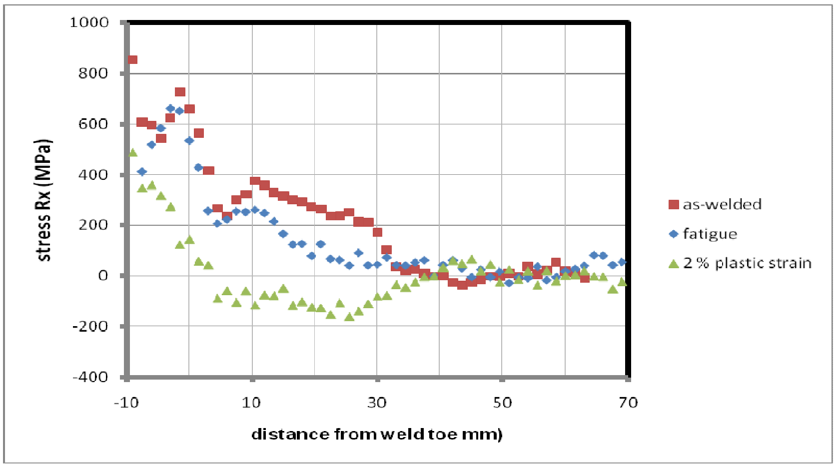


***Figure 6*** *Residual stress Rx changes in the vicinity of the CB4M test welds*

## 4. Conclusion

The influence of cyclic load and pre-stressing (local plastic deformation) on residual stress distribution (stress relaxation) of the high strength steel WELDOX 700 cruciform welds have been studied.

The results can be summarized as follows:

- residual stress component Rx oriented perpendicular to the fillet weld continuously decreases with the distance from the weld for all tested conditions (as-welded, fatigue loaded and pre-stressed),
- stress relaxation has occurred due to both cyclic or pre-stressed loads,
- stress relaxation is more remarkable after local plastic deformation than after cyclic load of the test weld,
- pre-stressing (local plastic deformation) decreased the residual stress level Rx of about 400 MPa to 600 MPa,
- cyclic load decreased the level of Rx component by about of 200 MPa,
- stress relaxation was observed in the region of approximately 40 mm far from the weld toe of both cyclic load or pre-stressed test specimens.

The influence of pre-stressing on fatigue life time will be studied in order to characterize the effect of local plastic deformation on fatigue behaviour compare to as welded condition.

**Acknowledgment**

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