

## Comparison of Residual Stress in High Strength Steel Sample before and after Laser Welding

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The paper deals with the evaluation of residual stress in high strength steel sample measured by x-ray method before and after laser welding. Data were collected and processed in program Matlab, where surfaces of stress distribution in the sample were created. Polynomial functions were fit to the data to achieve smoother curves and a better understanding of results. Finally, results of residual stress in the welded sample were compared to those in the non-welded sample for determining the effect of welding on residual stress. Nowadays, the use of high strength steels is being developed, yet their use is sometimes limited by their fatigue critical welds. One common problem associated with welding is the formation of residual stress. Heating, melting and cooling of the weld and non-uniform temperature distribution are causing plastic thermal strain formation, which results in permanent deformation and residual stress near the weld and its heat-affected zone and can be high enough to cause cracking without any applied loads. The welding-induced tensile residual stresses have a harmful effect on fatigue lifetime of structures, corrosion resistance and other mechanical properties. On the other hand, compressive residual stress can improve the fatigue resistance of the material.

**Keywords:** residual stress, laser welding, X-ray method, high strength steel Domex.

### 1 Residual stress determination

Calculation of residual stress requires the introduction of many simplifications due to a vast number of variables included. These assumptions enable a mathematical description of the processes, but also simplify their physical nature; calculation of the stress is complicated nevertheless. Therefore, the residual stresses, despite huge progress in computer science and good results in the simulation of the process, are still largely determined by application of experimental measurements [1].

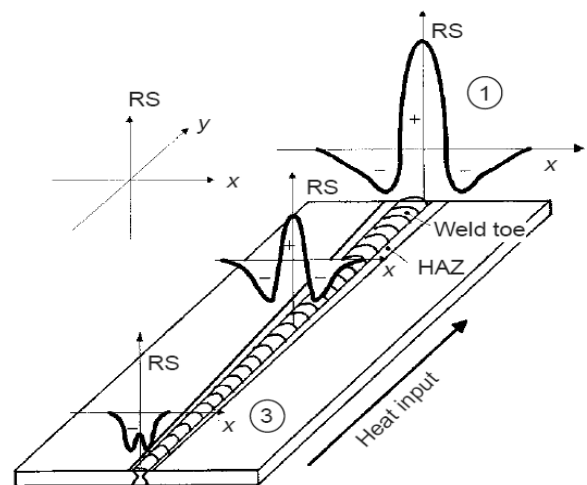
Traditionally, residual stresses can be measured by destructive or non-destructive methods. The former contains for instance cutting and hole-drilling techniques, the latter neutron and x-ray diffraction techniques. X-ray diffraction method obtains strains through a change of micro-structural crystal lattice spacing in the material; and from this quantity, the total stress can be acquired [2,3]. When x-ray beam is cast over a solid material, it is sprinkled by the atoms forming the material. The diffracted (sprinkled) waves lead to interferences and the beam can be collected to reach the diffraction intensity peak according to the Bragg's Law (Eq. 1) [2].

$$2D_0 \sin \theta_0 = n\lambda \quad (n = 1, 2, 3 \dots) \quad (1)$$

Where:  $D_0$  is the original distance between lattice planes of adjacent crystal surfaces at the non-stress state,  $\theta_0$  is original diffraction angle between the x-ray beam and crystal surface at the non-stress state,  $\lambda$  is the wavelength of the x-ray beam,  $n$  is the order of diffraction.

However, the x-ray beam can penetrate into the material usually not deeper than 40  $\mu\text{m}$ , hence this method assumes plane-stress condition i. e., stress perpendicular to the surface is assumed to be zero. For many applications, particularly where fatigue failure is involved, this is not a serious disadvantage [4-6].

A number of factors influence residual stress in a welded structure. Shrinkage of the weld metal, thermal expansion and contraction of the base metal, quenching effects, phase transformation and fixtures of the structure being welded are the most important [7-9].



**Fig. 1** Influence of heat input on transverse residual stress distribution (RS = residual stress)

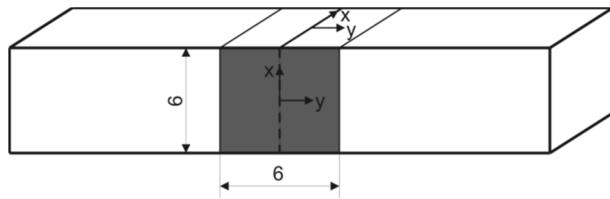
The diagram in Fig. 1 shows the influence of increasing heat input on the distribution of transverse residual stresses along a line perpendicular to the weld seam.

In the case of low heat input (Curve 3 in Fig. 1), one can see a reduction of tensile residual stress or even compressive residual stresses. In the case of high heat input (Curve 1), one can expect a buildup of high tensile stresses across the weld seam. On account of this fact, welding the sample by means of laser technology was selected.

Laser welding has become popular recently owing to high power density, which has the possibility of focusing the beam power to a very small spot diameter resulting in a small heat-affected zone. This is a huge perquisite in

contrast to the conventional welding processes, e.g. arc welding as it means also lower distortions, residual stresses and strains [10-13].

## 2 Measurement results

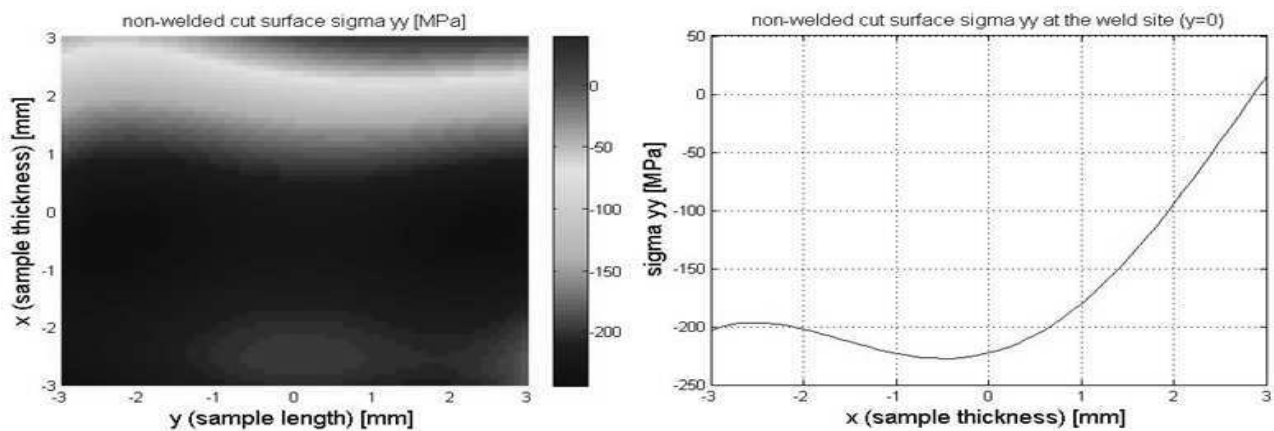


**Fig. 2** Schematic representation of a measured sample – highlighted cut surface (transverse)

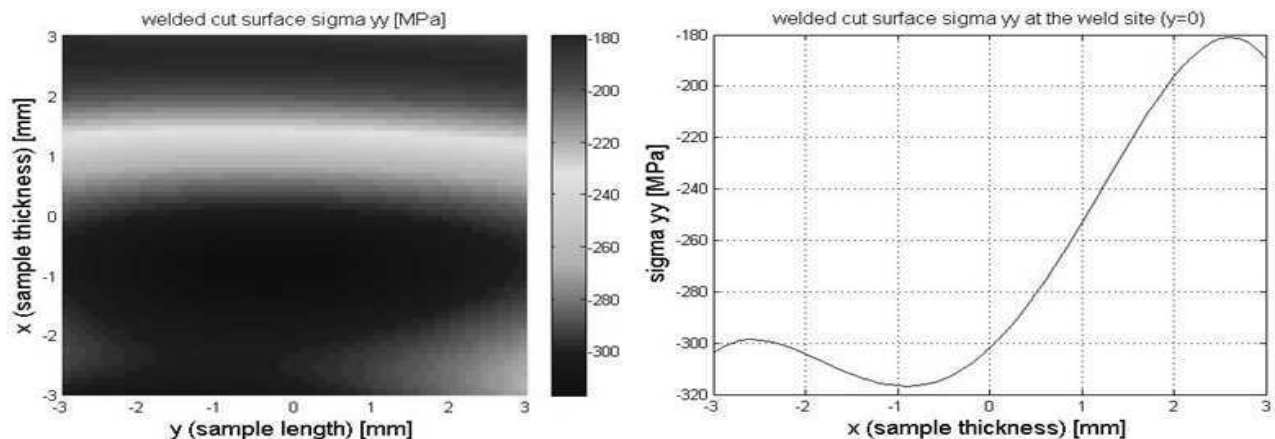
The measurement of residual stress in a sample (Fig.2) from high strength steel Domex 700 MC was carried out. Domex 700 MC is a hot-rolled, low-alloy high

strength sheet steel with 700 N/mm<sup>2</sup> yield strength. The sheet was welded by laser and then cut into individual samples. The measurement of transverse residual stress was conducted first in base metal sample and subsequently in welded sample on the cut surface (highlighted according to Fig. 2) with dimensions (6×6) mm [14].

In Fig. 3a), there is a distribution of normal residual stress in “y” direction on non-welded cut surface. In the direction to the inside of the material (“x” coordinate from 3 to -3) stabilization of the cutting process (sawing) was achieved resulting in compressive stresses. The tension stresses (red area above zero) or unloaded condition (about zero) changed to the compressive stresses in a direction of the band saw blade crossing into material. In Fig. 3b), there is distribution of normal residual stress in “y” direction along a line y = 0 on non-welded cut surface.



**Fig. 3** a) Distribution of normal residual stress in “y” direction on the non-welded cut surface and b) distribution of normal residual stress in “y” direction on the line y = 0 on non-welded cut surface



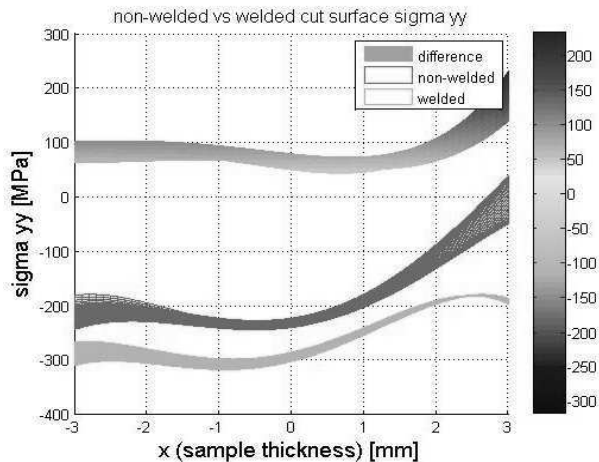
**Fig. 4** a) Distribution of normal residual stress in “y” direction on welded cut surface and b) distribution of normal residual stress in “y” direction on the line y = 0 on welded cut surface

In Fig. 4a), there is distribution of normal residual stress in “y” direction on welded cut surface. There can be seen compressive stresses, values of which are decreasing towards the weld surface (i.e. the largest compressive stresses above -300 MPa are at the weld root). This is due to the fact, that the weld face has a more pronounced cooling compared to the weld root, so at the weld face, there is a greater tendency for tension stresses formation than that of the root. Considering a size of the

stresses, it can be assumed that the measured sample was somewhere in the first part of the weld (see Fig. 1). The beginning of the weld takes longer to cool, because it is still heated by continuous welding. In Fig. 4b), there is distribution of normal residual stress in “y” direction along a line y = 0 on welded cut surface.

In Fig. 8, there is comparison of normal residual stress in “y” direction on non-welded and welded cut surface. There can be seen an influence of welding as a process,

whose thermal effect increases compressive stresses in a given sample, which can be considered as a positive phenomenon.



**Fig. 5** Comparison of normal residual stress in “y” direction on non-welded and welded cut surface

### 3 Conclusion

The aim of this paper was to conduct experimental measurement of residual stress in high strength steel sample before and after laser welding by X-ray method, process the data and compare and evaluate the results. Residual stress was determined in transverse and longitudinal direction across the sample thickness before and after laser welding; data was processed in program Matlab, where surfaces of stress distributions were created and smoothed by polynomial functions.

Results showed the compressive character of normal residual stress both in transverse and longitudinal direction after laser welding due to the low heat input typical for this technology. This fact is favourable as compressive residual stress can enhance fatigue resistance of the material, which will be verified in later research.

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