Distribution of residual stresses in welded high strength structural steel beams

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Abstract

Aim of this research was to observe the effective distribution of residual stresses in welded beams of high strength structural steels after welding them with two sequences, using two different types of sections and two different steels.
S355J2G3 was welded as hole section and in the first series the butt welds were welded first, so that shrinkage was not hindered by the steel plates of the beam. In the second series the fillet welds were welded first and the butt welds was not last so that they could not shrink easily, and cause high tensile residual stresses.
S890QL was observed as double-T section and the welding sequences were the same.
The results confirmed what was thought, high residual stresses were found in the butt welded beams, but their magnitude was much lower than the yield limit in the S890 QL steel.

Riassunto

Lo scopo del lavoro è stato quello di osservare la distribuzione delle tensioni residue in travi realizzate con due tipi di acciai altoresistenziali, mediante due differenti procedure di saldatura.
Una prima serie di campioni con sezione cava (scatolati) di acciaio S355J2G3 è stata saldata di testa, in modo che il ritiro dei piatti non venga ostacolato.
Nella seconda serie di prove le saldature sono state eseguite prima ad angolo e successivamente di testa in modo da ostacolare il ritiro della saldatura, provocando in tal modo un notevole aumento delle tensioni residue.
Per quanto concerne l'acciaio S890QL è stato utilizzato nella realizzazione dei giunti saldati a doppia T con le stesse modalità di saldatura utilizzate nelle prove precedenti.
I risultati ottenuti hanno evidenziato un elevato valore degli stress residuti nelle travi saldate di testa; tali valori sono risultati sempre notevolmente al di sotto del carico di snervamento dell'acciaio S890QL.

INTRODUCTION

Many articles deal with the interaction of phase transformation residual stresses (RS) and due to hindered shrinkage of the warm zones RS. A systematic research above the effective RS amount and distribution is not so easy to find, whereas RS at the yield limit are often expected.
In this paper an investigation is performed in order to define the RS distribution and see whether they reach the yield limit.

SPECIMEN PREPARATION

Welded beams of two different geometries were used as specimens to observe RS generation in the high strength steels S355J2G3 and S890QL.
Regarding the steel S355J2G3 a hole section beam was chosen , where the upper and lower plates were welded with a three-layer V-weld seam, the other plates were unified with three-layer fillet weldings. The weldings were made using the MAG technology, and the butt-weld was post-treated with the TIG-dressing technology to reduce the notch effect of the seam.
Regarding the steel S890QL a double T profile was executed, with the same parameters and using the TIG dressing method. The supply of the filler material was carefully controlled during the welding of each specimen to create a reproducible flat seam with minimized notch geometry.
The generation of two different RS states was reached by using two different welding sequences (A and B).
The A-Series specimen was assembled using the sequence shown in fig.1, the butt-weld was finished as the first step of the beam construction. Subsequently it was treated with the TIG-technology and only after the fillet weldings were executed.

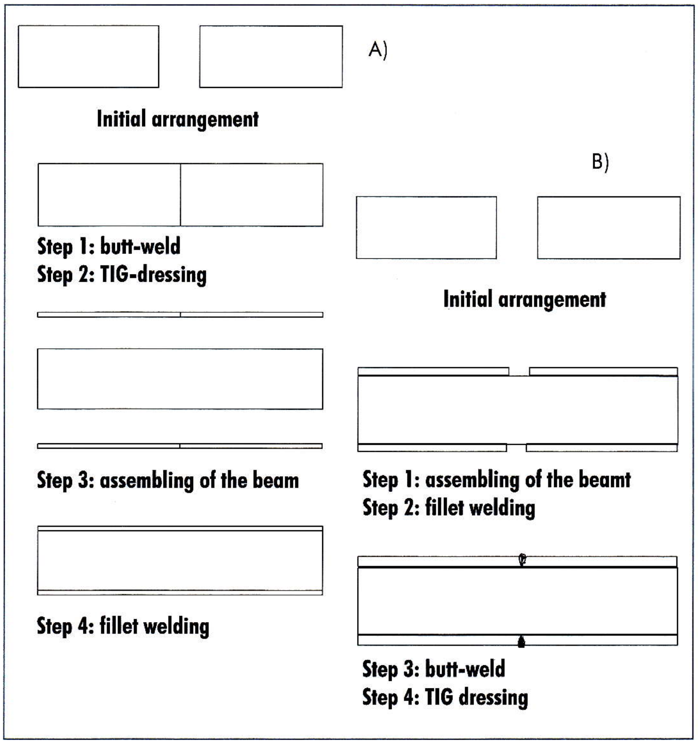

Fig. 1-2: Assembling and welding sequences of series A, left, and B, right.

This sequence allowed the warmed up regions due to the butt-weld to shrink easily and their movement was not hindered. The B-Series specimen was welded following the steps in fig.2, the fillet weldings were performed as the first step, only then were the upper and lower plates united and the transverse and longitudinal (only for the hole section profile) movement was strongly hindered so that high tensile residual stresses could be expected.

The heat input was controlled and equal for both type of models.

The lattice strains were measured by means of X-rays using Cr-K· radiation and the {2,1,1}-lattice planes of the α-Fe. The residual stresses were calculated then with the $\sin^2 \psi$ Method using the elastic constant $\frac{1}{2}s_2=6{,}08\cdot 10^6$ mm². The residual stresses were measured on a line transverse to the butt weld at different distances from the centre of the seam. The thickness of the welded plates was 10 mm; the dimensions of the investigated beams reached 800x120x100 mm.

RESULTS OF THE INVESTIGATION

3.1. Results of the measurements on the hole section beam

Fig. 3 shows the scatterbands and the mean values of the longitudinal and transverse residual stresses in both types of specimen. As expected the RS in both directions are higher, at the significant sites in the B solution where the butt weld was welded last and the free transverse and longitudinal movement was strongly hindered.

At the welding centre line the RS are compressive and then increase till 400 MPa.

The transverse RS in the B specimen reach the yield limit, whereas the longitudinal RS are of lower magnitude, but with strong peaks just at the critical sites, due to effect of the two middle plates, which also hinder longitudinal shrinkage.

In the A-Series the longitudinal stress distribution is as reported by [1] for low heat input, which means a maximum near the welding centre line, two minima nearby with values oscillating between the compression and tensile zone. The transverse RS are completly in the compression region with values between –200 and –400 MPa.

3.2 . Results of the measurements on the double T section.

The scatterbands of the transverse RS and the mean values are reported in fig. 4.

The distributions show, as expected, a significant difference

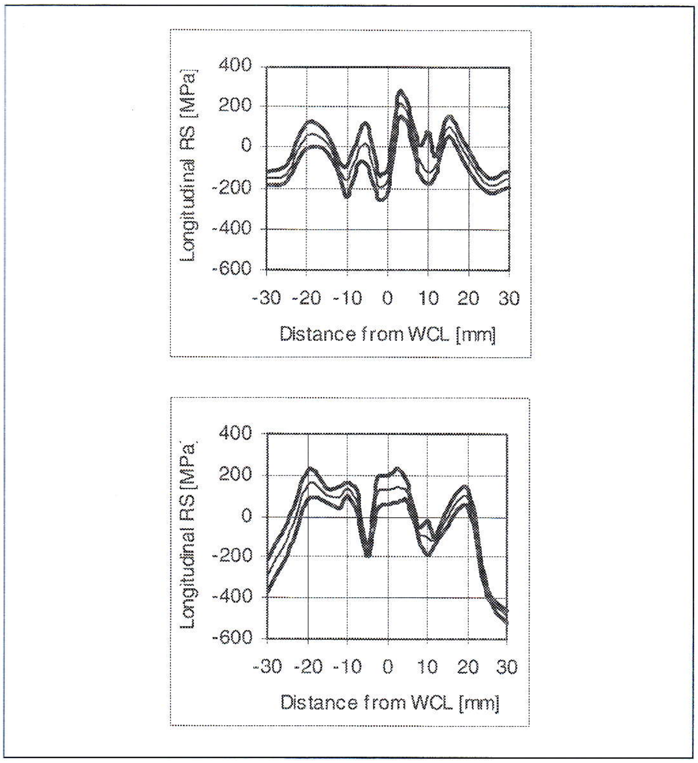

Fig. 3: Scatterbands and mean values of the longitudinal residual stresses at different distances from the weld centre line; top A solution, bottom B-solution. (Width of the weld seam ±14 mm).

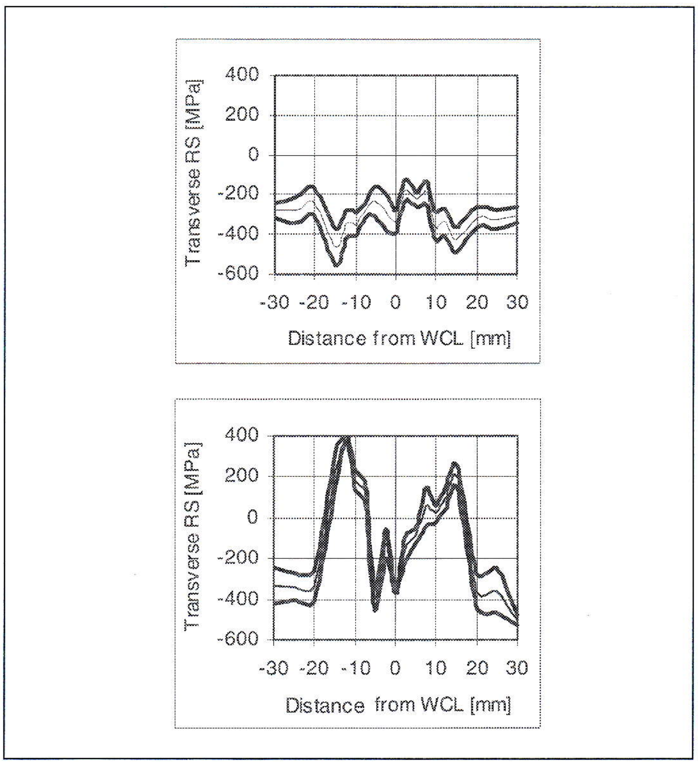

Fig. 4: Scatterbands and mean values of the transverse residual stresses at different distances from the weld centre line; top A solution, bottom B-solution. (Width of the weld seam ±14 mm).

in magnitude between the two specimens. In type B, the RS rise to higher values, near the yield limit of the material.
The longitudinal RS distribution as shown in fig. 5, is very similar for both specimens, because in this profile, opposite to the hole section, it can be assumed that longitudinal shrinkage is hindered in the same way.

Compressive longitudinal RS can be found in the centre of the seam with maxima in the HAZ.
The transverse RS distribution, fig. 6, shows a quite different magnitude characteristic, with RS peaks of about 600 MPa.

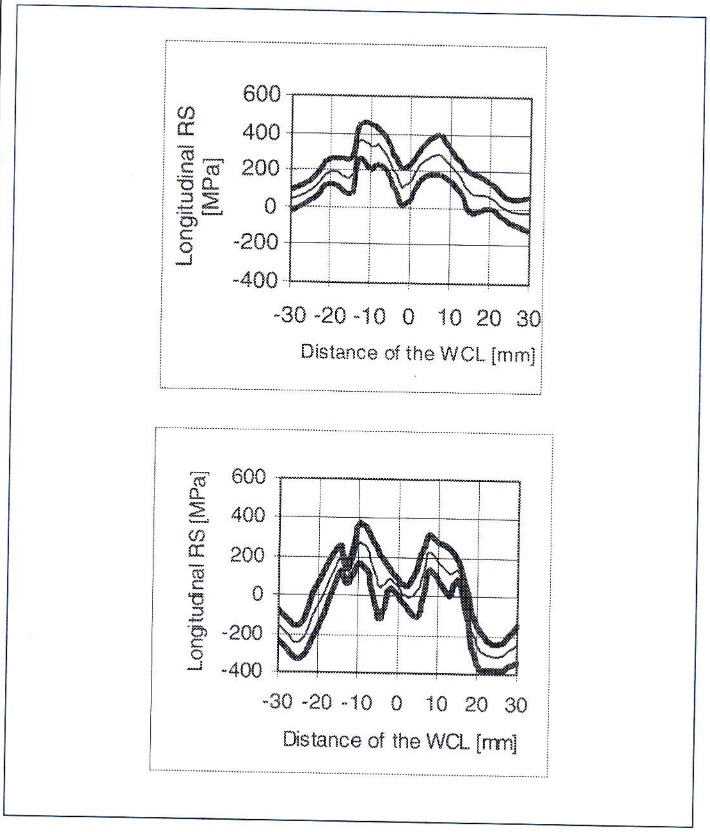

Fig. 5: Longitudinal residual stress distribution for the double T profile in S890QL, specimen B, top, and in S890QL, specimen A, bottom. (Width of the weld seam ±14 mm).

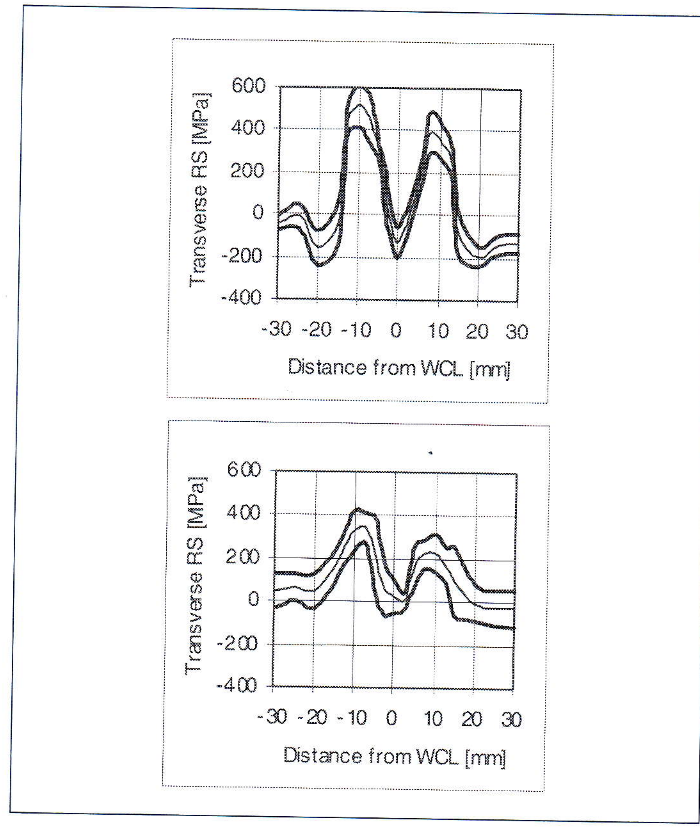

Fig. 6: Transverse residual stress distribution for the double T profile in S890QL, specimen B, top, and in S890QL, specimen A, bottom. (Width of the weld seam ±14 mm).

CONCLUSIONS

As experted, the RS distribution due to different welding techniques changes evidently.
The transverse RS arise at the critical sites of the butt-welds and in the S355J2G3 steel reach the yield limit.
By contrast, in the double-T section of the S890QL the RS distribution is quite similar in form, but with a higher RS magnitude in the B series, which did not reach the yield limit. In the transition zone of the welding seam values of only 600 MPa, much lower than the 890 MPa yield limit, were reached. This is probably caused by the TIG dressing technique, which acts as a relief post treatment on the butt-weld even if the low values of the A series are not reached.
The longitudinal RS are only influenced in the case of the hole section, where they show persistent high values, much lower than the yield limit, in the HAZ.

Totally compressive RS were found in the A solution, where no hindered transverse shrinkage is experted.
To conclude, RS at the yield limit were determined in the lower strength steel S355J2G3, whereas RS much lower than the yield limit were measured in the high strength structural steel S890QL.

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