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FORMATION OF RESIDUAL STRESSES AT WELDING SEAMS WITH S235 AND S355

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ABSTRACT

Welding seams are often the origin of cracks under dynamic load that may give a failure of the component. Because of the high temperature near the welding seam during the welding procedure, structural changes appear, and the residual stress stage changes significantly. The cooling process depends on the thickness of the material, the kind of welding, and further parameters that influence the formation of the residual stress stages in the welding zone. If tensile residual stresses will appear the probability of getting cracking rises. In this investigation, two different materials (S235; S355) were used. The samples were MAG-welded with and without fixation. The residual stress was determined by X-ray diffraction parallel and perpendicular to the welding seam up to 35 mm distance in a step wide of 1.5 mm.

Keywords: welding; seam; residual stresses; S235; S355

1. Introduction

Residual stresses are one important fact for the durability of components. Depending on the construction of the part, welding seams are one critical zone for crack initiation under dynamic load. This may cause a failure of the part. One example is bridges that are currently under dynamic load, (see e. g. [1]). Another very sensitive situation is welded vessels that are under pressure (see e. g. [2]). At welding seams, the residual stresses are one reason for cracking in combination with hardness and microstructure. In this investigation, seams under different conditions were investigated at the base material S235 and S355. Full residual stress profiles in dependence of the distance to the seam are shown in correlation with hardness for MAG welding.

2. Basics

2.1. Welding

In this case, MAG (Metal Active Gas) welding was used. It is a common method of welding. It uses a protective gas shield against the non-wanted contact with oxygen in the ambient air. To the carrier gas argon (Ar) carbon dioxide (CO₂) and oxygen (O₂) are added. Many parameters influence the quality and therefore the residual stresses of the seam like current,

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fixed or not fixed material, the number of single passes, the shape of the seam before welding (X, V shape), etc. Therefore, all samples, all parameters are fixed.

2.2. Cos-alpha-method

Determining the residual stresses X-ray diffraction was used, especially the so-called cos-alpha method. A small X-ray beam is radiated onto the surface and because of Bragg reflection, a Debye-Scherrer ring appears (see figure 1). [3]

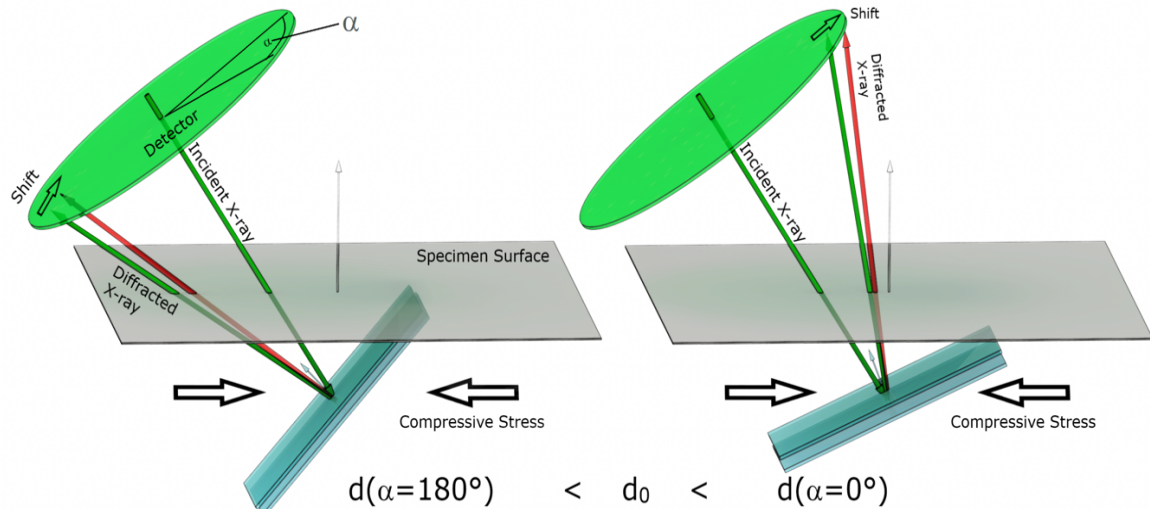


Figure 1: Arrangement of the X-ray beam, Debye-Scherrer ring (border of the green area), and detector

A second ring also appears because of backscattering in the same direction as the incident beam. The possibility to detect the whole ring is the relatively new development of area detectors called MAD. [4]

In figure 3 α is the azimuth angle of the ring. The ring shifts a little bit in the plain of the Debye-Scherrer ring. This shift is caused by changing the distance of the atomic layers because stresses are present. If there are compressive stresses, the distance is getting smaller and for tensile stresses getting larger. $\cos \alpha$ is differentiated to shift ϵ at this angle α gives a constant. Involving the material constants Young-modulus E and Poisson's ratio ν , the existing stress can be calculated. Therefore, it is called the cos- α method. For a detailed description, see [5-8].

3. Samples and Measuring

3.1. Description of the sample

The specimens are plates and have a size of 18 cm * 10 cm. The welding seam is in the middle. The thickness d of the different plates is $d = 10$ mm (S235) or 15 mm (S355). The material specifications are given in table 1:

Table 1: material specifications

label	S235JRC+C	S355J2+N
minimum tensile strength R_e (MPa)	235	355
notched bar impact work (J)	J2 = 27 J at 20°C	J2 = 27 J at -20°C
marking 1	C+C= cold formed +cold hardening	+N = normal annealed
marking 2 (used later) (Probe)	1/2 not fixed/fixed	1/2 not fixed/fixed
material nr. (DIN 10027-2)	1.0122	1.0577

The welding process was done by a skilled worker who had much experience. The two parts welded together had a V-shaped seam before welding. The specimens were welded in three layers and one at the backside.

A gas mixture of 18 % carbon dioxide and 82 % argon was used. The filler material was class ER70S-6 (AWS A5.18). The additional welding parameters given in table 2.

Table 2: welding parameters

material	S235JRC+C	S355J2+N
welding current 1. layer I (A)	94	94
welding current 2. layer I (A)	125	125
welding current 3. layer I (A)	121	121
welding voltage U (V)	16,5	16,6
effective power q_{eff} (W)	1797	1808
speed v (mm/s)	3,7	3,8

As indicated in table 2 three passes, respectively layers, were done (different step sequence from left to right):



Figure. 2: different steps of welding

3.2. Measurement Parameters X-ray diffraction

The aim is to get a profile of the residual stress on the surface in dependence on the distance to the seam. The directions of the measurements should be parallel and perpendicular to the seam. The zone influenced by welding is less than 35 mm which was determined in preliminary investigations. To get a good resolution, a minimum of 20 spots must be measured. Therefore, the diameter of the measuring spot is 600 μm determined by the aperture of the X-ray diffractometer. In this case, the different spots do not overlap. For all measurements $E = 224000$ GPa and $\nu = 0,3$ for calculating the stress were used. On the seam the material structure was very confused that not always a Debye-Scherrer ring was obtained. At least five successful measurements were done to get a value but with large errors (see figures in the next chapter).

4. Results

At first, the residual stress results for S255 are shown (fig. 3 – 6). The dotted lines are the error +/- one standard deviation. Splines are used because of the distance of the measuring spots in relation to the diameter is very small.

In figures 3 and 4, you see the residual stress distribution at the surface for S235 with the two measurement directions parallel and perpendicular to the seam. The sample was not fixed during the welding process. Significant compressive residual stresses can be detected in the seam. In the parallel direction at the border of the seam, the residual stresses are becoming tensile, and are near zero outside the seam which is the basic state of the ground material that is caused by grinding.

In the perpendicular direction only, compressive residual stresses were obtained that are at around 30 mm distance the stress of the raw material is reached. In the heat influence zone, the compressive residual stresses fluctuate but show in the blue area (16 to 22 mm) a stable plateau.

The higher residual stresses on the seam and near the seam is caused by the harder seam and the hardening near the seam.

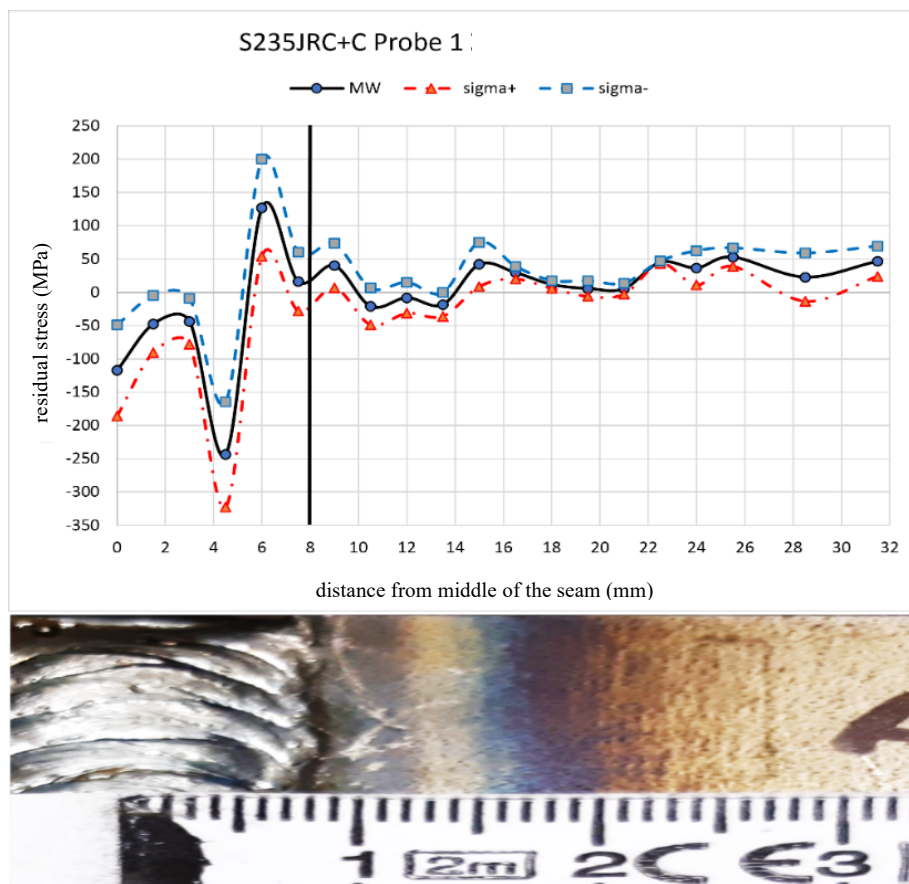


Figure 3: residual stress distribution with the measurement parallel to the seam (not fixed material)

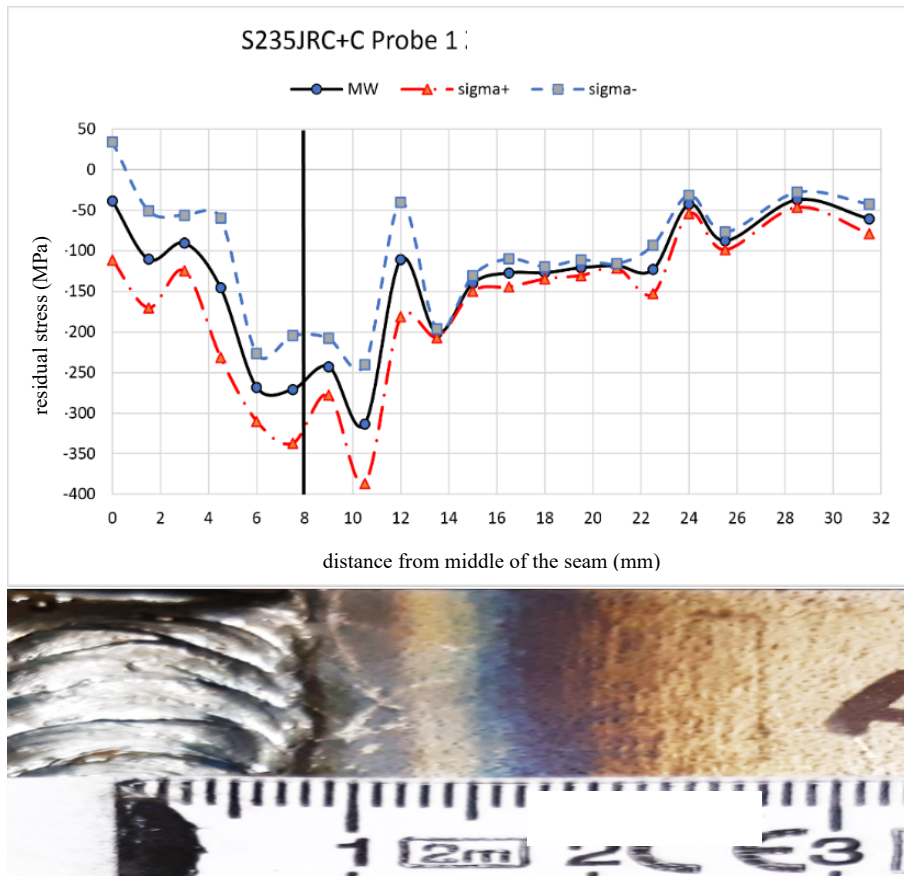


Figure 4: residual stress distribution with the measurement perpendicular to the seam (not fixed material)

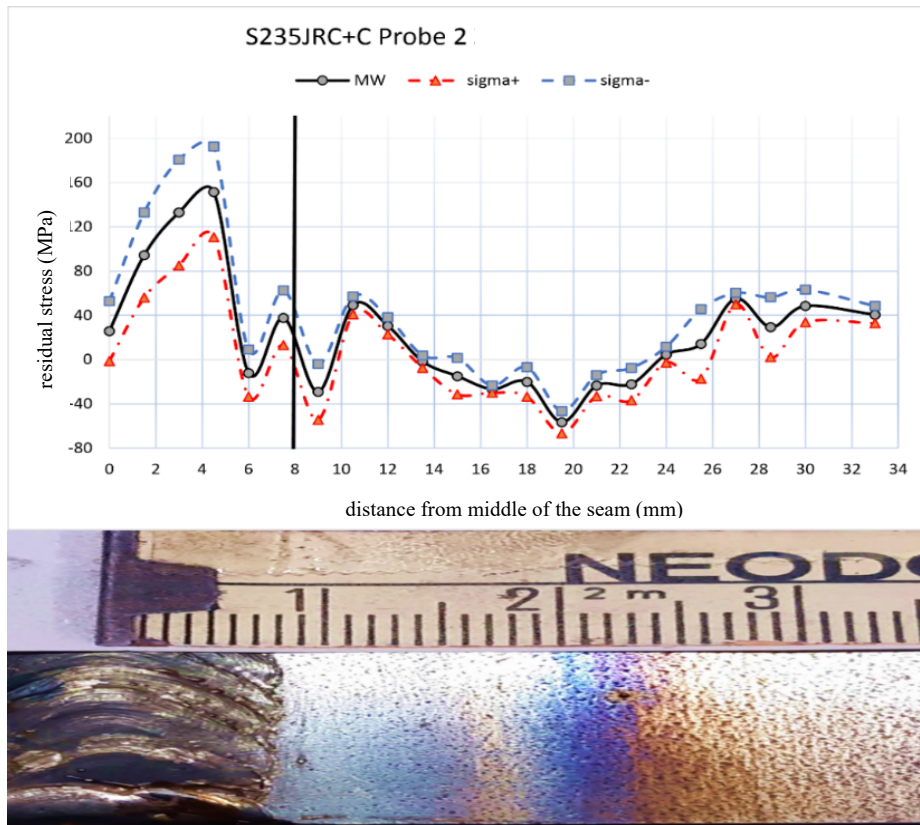


Figure 5: residual stress distribution with the measurement parallel to the seam (fixed material)

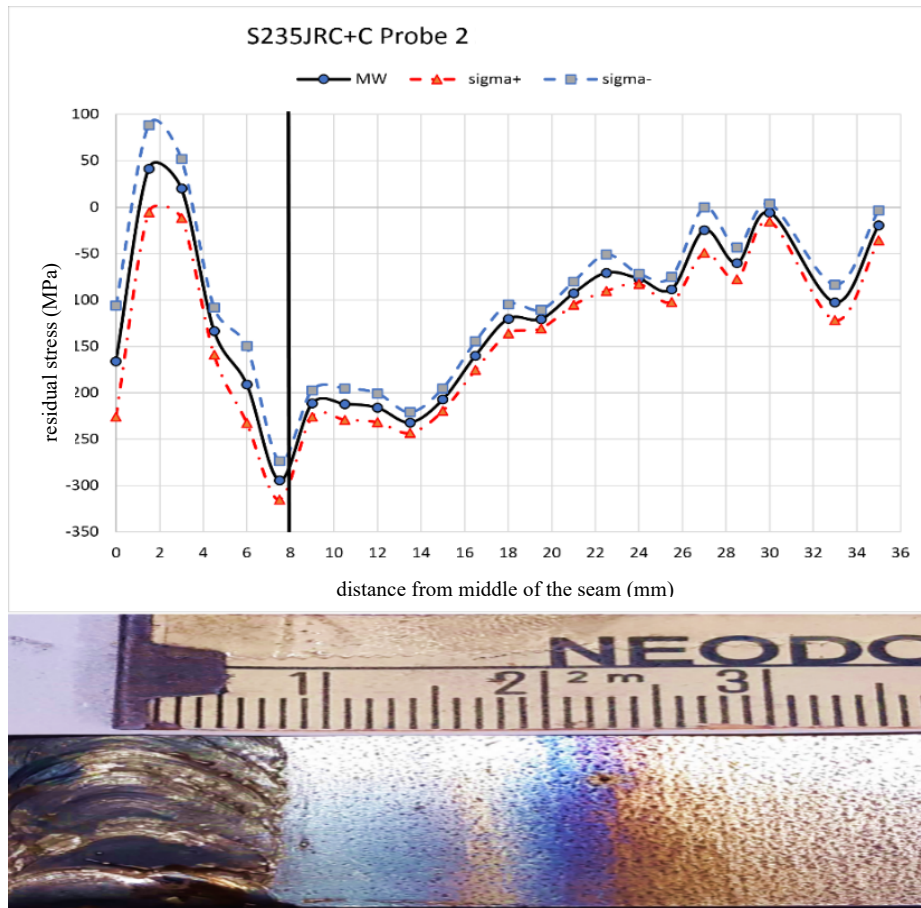


Figure 6: residual stress distribution with the measurement perpendicular to the seam (fixed material)

In the specimens that were fixed by clamping during welding more tensile stress can be detected (fig. 5 and 6). The residual stresses parallel to the seam are tensile stress and switch to compressive residual stresses in the heat influence zone. The residual stresses, perpendicular to the seam, show compressive residual stresses at the border of the seam deep that decreases with the distance of the seam. The following two figures 7 and 8 show the results of S355 specimens that were not fixed during welding.

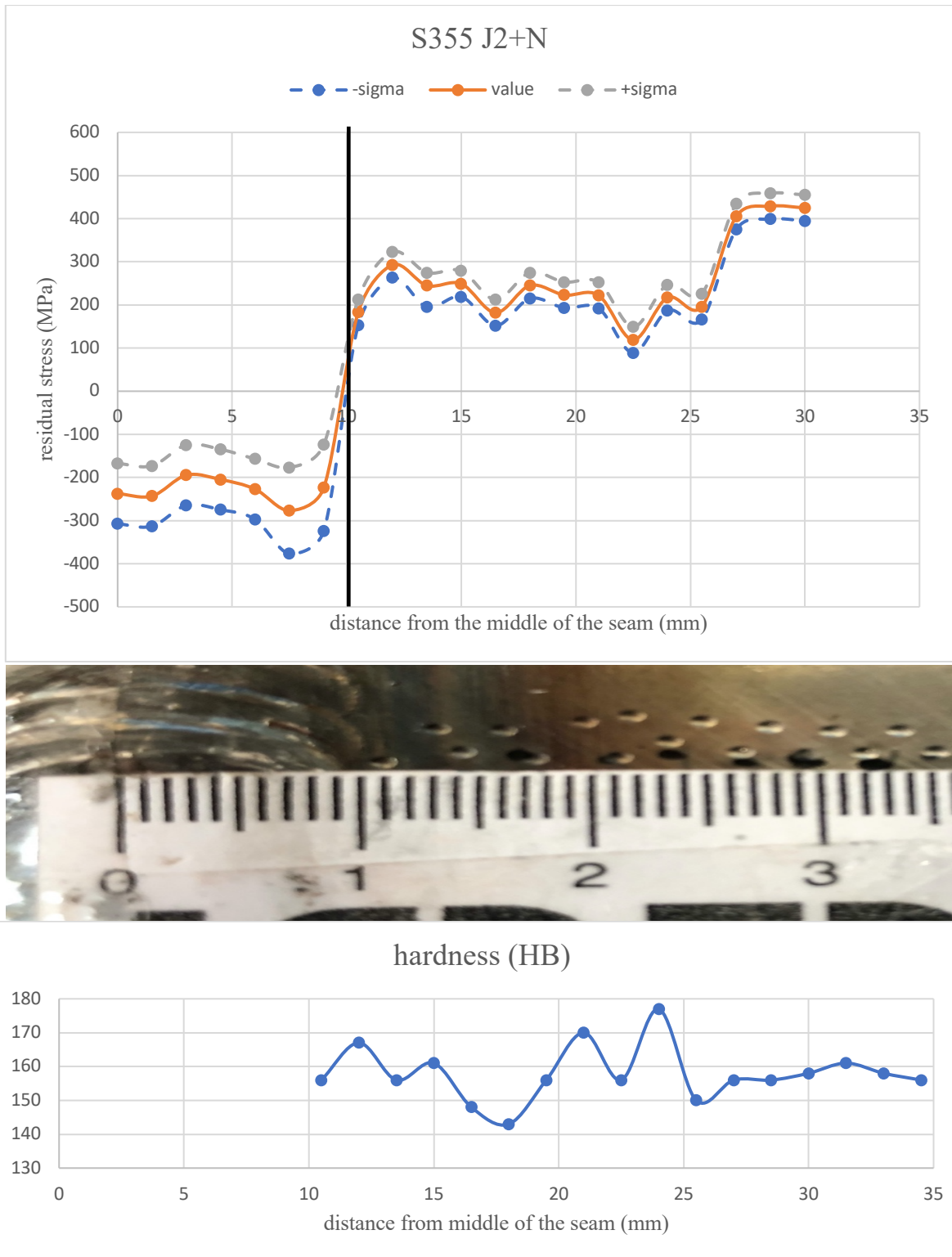


Figure 7: residual stress distribution with the measurement parallel to the seam (not fixed material) with the corresponding hardness distribution (The dotted lines above the ruler in the picture are from the hardness measurement.)

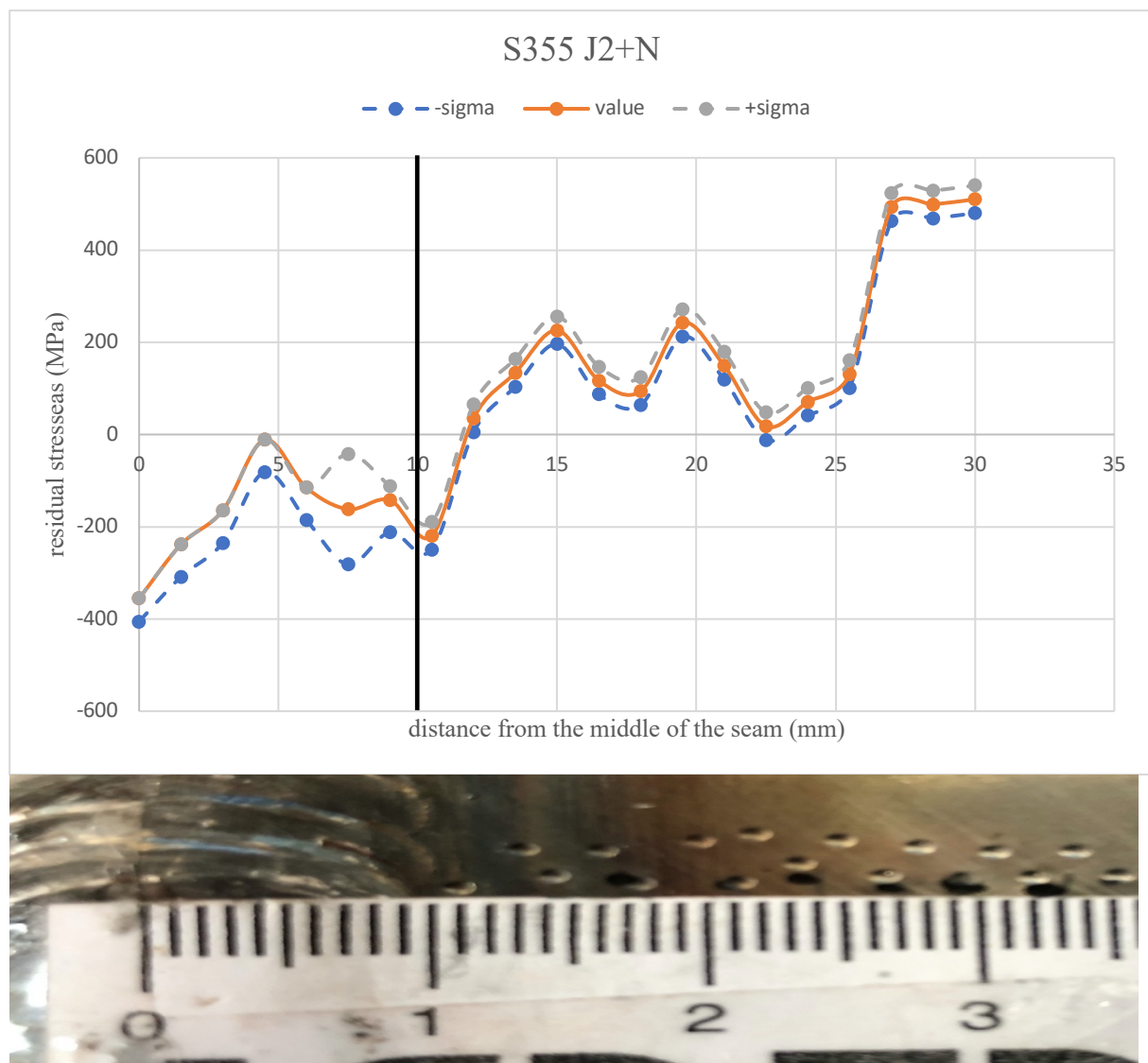


Figure 8: residual stress distribution with the measurement perpendicular to the seam (not fixed material)

The basic residual stress horizon, coming from grinding, is more than +400 MPa tensile residual stress that is existing at the area beyond 28 mm distance. In both cases, high compressive residual stresses are at the surface of the seam that flip at the border of the seam (10 mm) to fluctuating tensile level.

The hardness in the heat influence zone makes no big changes (fig. 7).

For one sample of each material, the retained austenite was measured (see. fig. 9) No big changes are expected. At S355 a little increase near the seam could be detected. The measurement was done with the same equipment as used for residual stresses. The integrated intensities of the full ferrite and austenite Debye-Scherrer ring are compared. This could be done with the same equipment. The error is +/- 1 %.

5. Conclusions

If material is welded with fixation the stress distribution in the seam is mostly compressive. It can be explained by the fact, that the base material can make a new arrangement concerning the new (boundary) conditions. If the base material is fixed or so big that material is unable to move, more tensile residual stress is expected that reduces the fatigue strength. A crack initiation may often start at the border of the seam, e. g. at S355, where a flip of the residual stress state

is. Also, notch effects can support the early start of cracks. The S355 shows in the heat influenced zone higher tensile stress compared with S235. It may be caused by two facts. The tensile strength is higher, and a higher tensile stress is possible, and the base material has been hardening by grinding because there is a stress level beginning at 28 mm distance that is significant over the normal strength of S355.

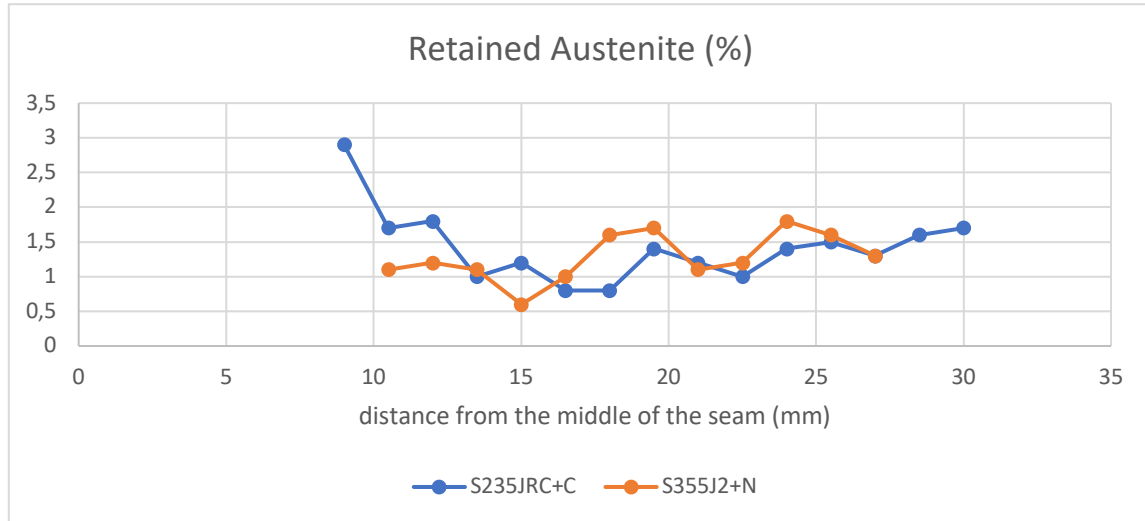


Figure 9: retained austenite distribution of two specimens S235 and S355

Big changes in hardness and retained austenite are not expected.

Creating FEM models would be helpful for predicting residual stress distributions for critical objects like bridges and other constructions where no measurement can be performed. Measurements for quality inspections at an object can be done on-site because with the new cos-alpha-method only moderate efforts are necessary.

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