Estimation of Vickers hardness uncertainty for a heterogeneous welded joint (S235JR+AR and X2CrNiMo17-12-2)

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Abstract. When talking about tests that include measurements, the uncertainty of measurement is an essential element because it is important to know the limits within the obtained results may be assumed to lie and the influence the measurement technological system elements have on these results. The research presented in this paper focuses on the estimation of the Vickers hardness uncertainty of measurement for the heterogeneous welded joint between S235JR+AR and X2CrNiMo17-12-2 materials in order to establish the results relevance and the quality assessment of this joint. The paper contents are structured in three main parts. In the first part, the initial data necessary for the experiment is presented in terms of the welded joint and technological means characterisation. The second part presents the physical experiment development and its results and in the third part the uncertainty of the measurements is calculated and a results discussion is undertaken.

1. Introduction
The technological developments are characterized by the continuously enhancing of the performance of instruments, driven by ever higher requirements of the industry. In a modern society, whether we relate to the quality of products or services, a great emphasis is placed on quality. Metrology, as a part of the infrastructure of a modern society, ensures that the measurements normally used in manufacturing activities and product exchanges can be trusted. The result of a specific measurement will be reported in terms of value and uncertainty in order to be understandable and relevant to their users [1, 2, 3].

Nowadays, in industrial and commercial applications, it is necessary to provide an interval that can be attributed to the quantity of the measurement, in which the measurement result may be expected to encompass on a large distribution of values [2, 3, 4]. The ideal method for evaluating the uncertainty of the result of a measurement should be universal, more exactly to be applicable to all kind of measurements [2, 3, 4]. The quantity used to express the uncertainty of a measurement must be: internally consistent – must derive from the components and the subcomponents that contribute to it – and transferable – it should be able to use the uncertainty evaluated from one result in the evaluation of the uncertainty of another measurement, in which the first one is a component of the second [2, 3, 5].
1.1. Objective
The main objective of the research presented in this paper is the determination of the Vickers hardness uncertainty of measurement for the heterogeneous welded joint between a structural steel – S235JR+AR (EN ISO 10025) – and a stainless steel – X2CrNiMo17-12-2 (EN ISO 10028-7) – in order to establish the results relevance and the quality assessment of this joint.

1.2. Research program
The research program consisted of the following activities: mechanical cutting of the necessary samples, grinding and polishing of the samples in order to obtain a good quality of the surfaces, chemical attack with Nital 2% for S235JR+AR part, chemical attack with oxalic acid 10% for X2CrNiMo17-12-2 part, Vickers hardness measurement using HV 0.2 method, registering and processing of the experimental data in order to calculate the uncertainty of the measurements, results check in order to see if they lie within the limits required by the regulations and presentation of the relevant conclusions.

2. Initial data
2.1. Welded joint
The base materials used for the welding structure are the S235JR+AR and X2CrNiMo17-12-2 steels, with the dimensions of 100 mm x 120 mm x 15 mm. The filler material used in the experiments, in form of flux cored wire with a diameter of 1.2 mm, was T 23 12 LPM 1/C1. The chemical composition for the basic materials is presented in table 1, and for the filler material in table 2.

| Material | Chemical elements [%] |
|----------|------------------------|
| S235JR+AR (EN ISO 10025) | C 0.17 Mn 1.40 P 0.035 S 0.035 Si 0.55 Cr 0.012 Ni 0.026 Mo 0.026 |
| X2CrNiMo17-12-2 (EN ISO 10028-7) | C 0.030 Mn 2.00 P 0.045 S 0.015 Si 1.00 Cr 16.5...18.5 Ni 10...13 Mo 2...2.5 |

| Filler material T 23 12 LPM 1/C1 | Chemical elements [%] |
|----------------------------------|------------------------|
| C 0.04 Si 0.65 Mn 0.60 P 0.019 S 0.009 Cu 0.133 Ni 12.54 Cr 22.85 Mo 0.162 Nb 0.025 N 0.026 |

The joint between the two steels was executed using a V type groove, selected in accordance with SR EN 9692/1, and the welding process was conducted with a ceramic root support and two technological plates (used for priming the arc and the final crater) using a gas mixture M21 (82%Argon+18%CO₂). The welding parameters are shown in table 3.
Table 3. Welding parameters.

| Welding parameter               | Value |
|---------------------------------|-------|
| Welding amperage $I_s$ [A]      | 160   |
| Welding arc voltage $U_a$ [V]   | 28    |
| Feed rate of welding wire $v_a$ [m/min] | 9.2 |
| Gas discharge, Ar 82% +18%CO$_2$, $D_g$ [l/min] | 18 |
| Welding speed $v_s$ [cm/min]$^a$ | 102.85 |
| Heat input $Q$ [KJ/mm]$^b$      | 2.61  |

$^a$Value calculated with equation 1.

$^b$Value calculated with equation 2 in accordance with SR EN 1011/1 [11].

\[ v_c = \frac{L_c}{t_s} [cm/min] \] (1)

\[ Q = k \cdot \frac{I_s U_a}{v_s} \cdot 10^{-3} [kJ/mm] \] (2)

, where $k$ - thermal efficiency, $I_s$ - welding amperage, $U_a$ - welding arc voltage, $v_s$ - welding speed.

The groove designed and the sample obtained after the welding process are presented in figure 1.

Figure 1. The designed and obtained welded joint:
1 – S235JR+AR steel, 2 – X2CrNiMo17-12-2 steel, 3 – ceramic root support, 4 – the filling of the groove, 5 – the obtained welded seam

2.2. Technological means

The technological means used for the experiment consists of: an EVOLUTION TR 100 cut-off machine, an universal grinding machine, a Vector and Alpha Beta polisher Buehler, a Shimadzu HVM-2TE micro Vickers hardness tester and a computer with a special software for hardness data recording.

The welded joint was cut using a cut-off machine for metallographic samples, EVOLUTION TR 100 (see figure 2), with the following characteristics: engine power - ISGEV brand, two poles 220/380/50 Hz, 3-phase protection IP 55; isolation class F (according to IEC standards) 2.2 kW; maximum speed of the shaft 2800 rpm; maximum diameter of the grinding wheel 300 mm.

After cutting, the samples were subjected to a grinding process, followed by a polishing process made with a Vector and Alpha Beta polisher Buehler (see figure 3).

For measuring the mean diagonal of indentation and the hardness a Shimadzu HVM-2TE micro Vickers hardness tester and a computer were used. This Vickers hardness tester has the following
characteristics: magnification of 400X; fully automated with on-screen footprint; measuring range: 98.07, 245.2, 90.3, 980.7 mN, 1.96, 2.942, 4.903, 9.807, 19.61 N (HV 0.01, 0.0025, 0.05, 0.1, 0.2, 0.3, 0.5, 1); effectively measuring range: 250 μm (at 40).

3. Physical experiment

3.1. Experiment setup
For measuring the Vickers hardness values, there were established three directions of measurement, two longitudinal and one transversal as it can be seen in figure 5 and 6. For the longitudinal direction, a total of 25 hardness values were measured, 5 measurements for each zone of interest, such as: X2CrNiMo17-12-2 side, HAZ near the X2CrNiMo17-12-2 steel, welded seam, HAZ near S235JR+AR and S235JR+AR. For direction C were measured 20 values of Vickers hardness.

For the Vickers hardness measurement was selected the HV 0.2 method.

Figure 2. EVOLUTION TR 100 cut-off machine. Figure 3. Vector and Alpha Beta polisher Buehler. Figure 4. Shimadzu HMV 2TE micro Vickers hardness tester.

Figure 5. Longitudinal direction of measurement: A and B.

Figure 6. Transversal direction of measurement: C.
3.2. Experimental results

After the hardness measurement process, the data presented in tables 4 and 5 was obtained. The measurement was done in accordance with the tree directions – A, B and C – previously established.

Table 4. Vickers hardness values for the longitudinal directions of measurements.

| Measuring points | X2CrNiMo17-12-2 | HAZ near X2CrNiMo17-12-2 L | Welded seam | HAZ near S235JR+AR | S235JR+AR |
|------------------|-----------------|-----------------------------|-------------|---------------------|----------|
| Direction A      |                 |                             |             |                     |          |
| HV 0.2 values    |                 |                             |             |                     |          |
| d[mm]            | 0.0424          | 0.0422                      | 0.0422      | 0.0432              | 0.0426   |
| Direction B      |                 |                             |             |                     |          |
| HV 0.2 values    |                 |                             |             |                     |          |
| d[mm]            | 0.0444          | 0.0426                      | 0.0426      | 0.0426              | 0.0426   |

Table 5. Vickers hardness values for the transversal direction of measurements.

| Measuring points | Welding seam – Direction C |
|------------------|-----------------------------|
| HV 0.2 values    |                             |
| d (mm)           |                             |
| 0.0462           | 0.0446                      | 0.0452        |
| 0.0452           | 0.0452                      | 0.0452        |
| 0.0446           | 0.0446                      | 0.0446        |
| 0.0462           | 0.0462                      | 0.0462        |
| 0.0452           | 0.0452                      | 0.0452        |
| 0.0462           | 0.0462                      | 0.0462        |
| 0.0452           | 0.0452                      | 0.0452        |
| 0.0462           | 0.0462                      | 0.0462        |
| 0.0452           | 0.0452                      | 0.0452        |
| 0.0462           | 0.0462                      | 0.0462        |
| 0.0452           | 0.0452                      | 0.0452        |
| 0.0462           | 0.0462                      | 0.0462        |
| 0.0452           | 0.0452                      | 0.0452        |
| 0.0462           | 0.0462                      | 0.0462        |
| 0.0452           | 0.0452                      | 0.0452        |

4. Vickers hardness uncertainty calculation

In this paper we are trying to evaluate the uncertainty of the Vickers hardness measurement. To express this uncertainty the measured must be fully described.

For the calculation of the Vickers hardness uncertainty the following steps were undertaken: description of the measured, HV 0,2; identifying uncertainty sources for the Vickers hardness and classify them to Type A and B; calculation of the standard uncertainty; calculation of the combined uncertainty; calculation of the expanded uncertainty, U, reporting the result.

There are a lot of factors that can influence the result of a measurement, some of the most important factors and their sources are presented in table 6. All the sources of uncertainty presented in table 6 are evaluated using a Type B standard uncertainty. The standard uncertainty is evaluated using scientific judgment based on the available information on that input quantity [2].
The information can include: previous measurement data, knowledge of the proprieties and behaviour of relevant materials and instruments, manufacturer specifications; data provided in calibration, uncertainty assigned to reference data [2].

**Table 6.** Influencing factors for Vickers hardness test.

| Factor            | Source of uncertainty and type of evaluation |
|-------------------|-----------------------------------------------|
| Test specimen     | preparation - Type B                          |
|                   | shape, size and thickness - Type B             |
|                   | parallelism - Type B                           |
|                   | surface aspect - Type B                       |
|                   | test force, F - Type B                        |
|                   | measurement for the diagonal of indentation , d - Type B |
| Testing means     | angle, a - Type B                              |
|                   | duration of total force application, T – Type B|
|                   | indentation velocity, c - Type B               |
| Test environment  | temperature - Type B                          |
|                   | dirt, dust scale and grease - Type B           |
| Operator          | knowledge and experience                      |

*Certified value of the CRM (certified reference material) are: \( X_{CRM} = 200 \) HV 0.2; \( u_{CRM} = \pm 0.5 \) HV.

The machine uncertainty is presented in table 7.

**Table 7.** Machine uncertainty for 200 HV 0.2.

| Type of component       | Value                      |
|-------------------------|----------------------------|
| Linear Repeatability    | 0.06 µm                    |
| Force                   | 1.961 N, tolerance ±0.15   |
| Resolution              | 0.005 µm, tolerance ± 0.004|
| Indenter Angle          | 136°, tolerance ±0.5°      |

The uncertainty of the Vickers Hardness values was calculated using the prescriptions of the JCGM100:2008, using the equation 3 for the standard uncertainty [2, 3] and equation 4 for the corrected expanded uncertainty [2, 3].

\[
u(x) = \sqrt{\frac{\sum_{i=1}^{n}(x_i - \bar{x})^2}{n-1}}
\] (3)

where \( x_1, \ldots x_{in} \) - hardness measurements, \( \bar{x} \) – the average of the hardness, \( n \) – number of measurements

\[
U_{corr} = k \sqrt{u_{CMR}^2 + u_H^2 + u_{\bar{x}}^2 + u_{ms}^2 + u_b^2}
\] (4)

where \( k \) - coverage factor (\( k=2 \) for 95% confidence level), \( u_{CMR} \) - uncertainty of the mean value calculated by the calibration laboratory, \( u_H \) -the uncertainty of \( \bar{H} \) (mean value of users machine on CRM), \( u_{\bar{x}} \) -the uncertainty of \( \bar{x} \) (measurements on a material), \( u_{ms} \) – standard uncertainty according to the resolution of the measuring system, \( u_b \) – standard uncertainty of the determination of the standard deviation.
After the calculation of the value for the corrected expanded uncertainty, the following has been obtained: $U_{\text{corr}} = \pm 16.34$.

In figures 7 and 8 the hardness values measured by the machine and the result of the Vickers hardness measurement with the corrected uncertainty for the longitudinal directions are presented. Figure 9 presents the same data for the transversal direction.

Figure 7. Direction A - Vickers hardness measurement.

Figure 8. Direction B - Vickers hardness measurement.
5. Conclusions
An increase of the hardness values can be observed near the carbon steel, in the heat affected zone, that are higher than in the base material, S235JR+AR. Differences between the measurements in each zone of interest can be observed, if we analyse the variation of hardness measured on the longitudinal directions. To properly analyse the uncertainty of each zone of interest, the standard uncertainty was calculated. In the analysed case, the uncertainties of Vickers measurement gave a quantitative indication of the result quality, which can be added to the final result of the measurement.

A coverage factor, $k=2$, which provides a level of confidence of approximately 95% was used for expressing the expanded uncertainties which are based on standard uncertainties.

The result obtained show the rage given by a certain measurement of Vickers hardness on the sample used and depends on the machine, environment and operator.

6. References
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