The impact of welding technology on the manufacture of metal baskets

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Abstract. The submitted paper is closely connected with the challenging complex of problems relating to degradation of the anti-corrosion parts. The given anti-corrosion parts are represented by welded Cr-Ni steel baskets, which are also known as “hardening baskets”. The given “hardening baskets” are commonly used for embedding of the bearing parts to be quenched and tempered. Based on the utilisation, the mentioned welded metal baskets, which are made of X8CrNi25-21 steel, are exposed to the long-term cyclic thermal loading in the furnace. Relating to the manufacture of “hardening baskets” and investigation, the significant attention was paid to the effect of the used welding electrodes on the performance and quality of the welded joints. The weldability of austenitic X8CrNi25-21 steel has the considerable effect on these three phenomena: susceptibility of this material to the crack initiation, precipitation of chromium carbides in microstructure and occurrence of the intermetallic phases. The main objective was to evaluate the structure of welded joints produced by welding technology and the main features of their damage in order to compare the impact of individual filling materials on the quality of welds in the cage baskets as well as to evaluate the hardness course. In addition, evaluation of the macrostructure as well as microstructure changes was based on static tests. The results of evaluation are reflected in the recommendation of the most appropriate welding filling material. All aspects, which could lead to the occurrence of the critical states, were subjected to the complex investigation in the terms of the structural properties and moreover, there is also the final recommendation for possible elimination of the undesired phenomena.

1. Introduction
More complex constructions are made of steel by joining parts that are often non-joinable using welding technology [1, 2]. In order to achieve a high weld quality, we need keep these following conditions: to add the appropriate filling material (reinforcement) to the base material, to select a suitable welding method as well as welding conditions that must comply with the applicable European standards [3, 4]. The used production technologies significantly influence the properties of the materials [4, 5]. Due to cyclic thermal stress in the production process, the service life of the welded parts is reduced [6–8]. The main objective of the experiment was to find out the primary reason of premature failure of quenching baskets.

Based on structures from metallographically prepared samples of prepared welds, which were welded using two determined types of electrodes, microstructures were investigated [8, 9]. From the microstructures, it is possible to obtain information on an optimal filling material for welding of the stainless steel quenching baskets [10]. Since the welded baskets serve for embedment of the components that are quenched and subsequently tempered, the material from which they are made is subjected to
long-term thermal cyclic stress [10]. Therefore, during the quenching and tempering process, there is the occurrence of welds damage and deformations of the baskets [11].

2. Material and methods
In the heat treatment process, steel baskets are used for quenching and tempering to store heated components in a furnace. These baskets are made of Cr-Ni austenitic steel and they are welded in corners at four specific sites as it can be seen in figure 1. During their use, critical states and their degradation occur and therefore, they lose their functionality to such an extent that they cannot longer be used (figure 2). Mechanical-thermal cyclic loading causes premature cracking in operating conditions, resulting in economic losses.

3. Production of stainless steel basket
The steel quenching baskets are produced according to the drawn technical documentation – the individual parts are prepared by cutting technology, then they are punched and subsequently welded. Electric arc welding of all joints takes about 45 minutes. This means that the welder has to produce 10 pieces of quenching baskets during the working shift. The bottom part of the basket is joined with the material representing side walls in the predetermined sites throughout the whole circumference and after that the whole piece can be welded to the useable shape. Further operation is known as reinforcing the corner welds with bent reinforcing components which are made of refractory anticorrosive material, and the final operation of production includes welding of handles to the side walls of quenching basket. Commonly, the baskets are welded with ASP-308L ASKAYNAK electrodes as well as ASP-310R INTHERMA electrodes. These types of electrodes are used to weld stainless Cr-Ni steels. The main objective of the experiment was to find out the primary reason of premature failure of quenching baskets.

4. Experimental part
In the experimental part of this work, materials for the production of welded parts were investigated from the metallurgical as well as technological point of view. Further, the quality of welded joints in the corner sites of the quenching baskets was evaluated. The experiment was based on the study of microstructures of the starting material and randomly selected undamaged and damaged sites from the weld and its surrounding areas. On the basis of microstructures of metallographically prepared samples, it is possible to obtain information on optimum additive material for arc welding of anti-corrosive baskets which are commonly used in the production of bearing.

The quenching baskets are made of X8CrNi25 stainless steel with a relatively high Cr and Ni content. The chemical composition of the material is shown in table 1 and mechanical and physical properties are given in table 2.
Table 1. Chemical composition of X8CrNi25 stainless steel.

|     | C     | Si    | Mn   | Cr     | Ni     | P     | S    |
|-----|-------|-------|------|--------|--------|-------|------|
| max.| 0.20  | max. 1.00 | max. 1.50 | 24.0–26.0 | 19.0–22.0 | max. 0.045 | max. 0.030 |

Table 2. Parameters of mechanical properties for X8CrNi25 stainless steel.

|                  | Yield strength $Re$ (MPa) | Tensile strength $Rm$ (MPa) | Young modulus $E$ (GPa) | Ductility $A5$ (%) | Contraction $Z$ (%) |
|------------------|--------------------------|-----------------------------|-------------------------|-------------------|-------------------|
|                  | 210                      | 500–700                     | 180–200                 | 35                | 45                |

4.1. Microscopic evaluation
Using light microscopy, the structure of the starting material of Cr-Ni steel was studied and it led to confirmation that it was austenitic steel. Grains of austenite are small and fine with the clear visible boundaries (figure 3) and with relatively high occurrence of slip lines and twins. Due to the nature of the structure, it can be assumed that the sheet of metal material was annealed in the range from 950 to 1000 °C, while the cooling medium was represented by water. The dissolution annealing was used to dissolve chromium carbides in austenite.

Figure 3. Austenite microstructure.

It is important to point out, that if there is a large number of twins in austenitic Cr-Ni steel, the given steel becomes sensitive to temperature changes. For austenitic steel, the heterogeneity in grain size and the occurrence of different phases can cause stress in the microlocalities and it is the reason for the initiation of the failure.

4.2. Microstructure of welds and heat affected area
On the basis of a macro-structural study of the non-etched and etched material sample in the area of the corner weld, there is the appearance of defects, such as bubbles, cracks, cavities and contractions as it can be seen in figures 4 and 5. As it was mentioned in the text hereinbefore, the material for production of baskets is commonly welded with these two types of electrodes:
- ASP-308L ASKAYNAK – this electrode was designated as sample 1 - 308;
- ASP-310R INHERMA – this electrode was designated as sample 2 - 310.
The occurrence, morphology and arrangement of non-metallic inclusions, the degree of plastic deformation of the individual structural phases and the effect of the heat treatment on the structure were studied and evaluated on the basis of the observed microstructure of the longitudinal sections of metallographically prepared material. In relation to the cross-sections, non-metallic inclusions, porosity, and microcracks throughout the cross-section were analyzed.

4.3. Micro-purity of the starting material
The micro-purity of the material represents the content of non-metallic inclusions in the structure of austenitic steel and it was evaluated according to STN EN 10247. Regardless of the type of the selected electrode, pollution of selected weld areas was the same. The presence of oxides and non-formable silicates has been identified in the welds (figure 4).

![Figure 4. Microscopic evaluation of the micro-purity of the material and the surrounding weld area (sample 1 - 308).](image)

In some welds of the investigated material (e.g., sample 1 - 308), the occurrence of cracks was identified in the area which is between two welded sheets. The character of the crack, which is ruptured in the metallographic section, indicates an interdendritic failure from the area of the non-welded area of the weld (figure 4). The cracks in this investigated material sample are spread over the boundaries of the deformed grains after thermal or mechanical stress.

![Figure 5. Microscopic evaluation of the micro-purity of the material and the surrounding weld area (sample 2 - 310).](image)
The occurrence of non-welded joints in some weld areas shows that the correct predetermined time and speed in the shift of electrode was not kept – there was short time interval for perfect welding of the material. These defects can arise, for example, in the case of increasing labor productivity, which means more weldments in shorter time (figure 5).

As it can be seen in figure 6, the weld was not sufficient in the surrounding weld area of the metal. Cold joints as internal defects of welds are often caused by non-compliance with the welding mode and it leads to the heterogeneity of the material's chemical composition.

![Figure 6. Imperfect weld of quenching basket with the description of specific areas (sample 1 - 308).](image)

If there is the unwanted defect in the welds of quenching baskets and subsequent exposition to temperature cycling changes, the premature changes and degradation states can be predicted. The weld metal formed by both electrode 308 and 310 had elongated grains of varying size. The undesirable heterogeneity of the weld structure and its surrounding leads to stress-strain states. Minor inclusions (on the base of the oxides) are present in the heat affected area as well as in the weld structure and it can be attributed to the occurrence of delta ferrite in this microstructure.

In the following metallographically prepared microstructures (figure 7), attention has been paid to selected weldments, using electrode 310. In this case, the heat affected area between the weld metal and the starting structure was not distinctive. Moreover, the weld metal had lengthened austenite grains with fine inclusions and with delta ferrite occurring, but it was in the lower extent than it is described for the above-mentioned microstructures.

![Figure 7. Imperfect weld of the quenching basket (sample 2 - 310).](image)

From the microstructural evaluation of randomly selected areas of welded metal sheet, it can be seen that the arc welding technology with Cr-Ni electrode has been correctly selected. Welds, which were made with the ASP-310R INTHERMA electrode (Sample 2 - 310), exhibited better quality in comparison with welds which were made with ASP-308L ASKAYNAK electrode.

4.4. Hardness test

Hardness was assessed for the austenitic steel weld areas where both of these electrodes were used. Using electrode 308 referring to sample 1 - 308 and electrode 310 referring to sample 2 - 310, the measured austenite hardness values are shown in a graphical way in figure 9. The Vickers method of hardness was used in the work to specify material changes due to temperature influence of the evaluated material (according to STN EN ISO 6507-1). With the mentioned electrodes, tested weld samples were
prepared and they were subjected to the hardness measurement (HV0.5) while the given measurement procedures (steps) were performed from the central part of the weld up to the starting material and the distance between the individual measurement procedures (steps) was 0.5 mm.

Based on Vickers HV 0.5 method, the hardness course was measured for cross-sections of welded joints. Testing procedure was performed from the starting material through the heat affected area to the weld metal (figure 8). The number and spacing of the indentations must be sufficient to define hardened or softer areas due to welding for the materials being compared. The hardness of the weld joint was performed on both samples.

![Testing procedure from the starting material to the weld metal.](image)

**Figure 8.** Testing procedure from the starting material to the weld metal.

**Table 3.** Comparison of austenite hardness using electrodes (308 and 310).

| Hardness HV0.5 sample 1 - 308 | Hardness HV0.5 sample 2 - 310 |
|-------------------------------|-------------------------------|
| 157.7 ± 0.5                   | 156.7 ± 0.5                   |
| 148.7 ± 0.5                   | 151.0 ± 0.5                   |
| 157.0 ± 0.5                   | 162.7 ± 0.5                   |
| 152.3 ± 0.5                   | 164.7 ± 0.5                   |
| 152.0 ± 0.5                   | 172.0 ± 0.5                   |
| 152.7 ± 0.5                   | 154.7 ± 0.5                   |
| 152.7 ± 0.5                   | 162.3 ± 0.5                   |
| 150.3 ± 0.5                   | 160.3 ± 0.5                   |
| 182.2 ± 0.5                   | 180.5 ± 0.5                   |

As it can be seen from the measured hardness values in table 3, the material which was welded with ASP-310R INITHERMA electrode has a higher hardness in comparison with the material which was welded with ASP-308L ASKAYNAK electrode. It is debatable information from the aspect of its significance in relation to the strength properties of the welded material. It is important to point out that the material which was welded with ASP-310R INITHERMA electrode showed better durability and performance.
a) Figure 9. Graphic course of hardness for samples – welded with different electrodes: a) sample 1 - 308, b) sample 2 - 310.

The hardness of the austenitic steel, which was designated as sample 1 - 308 (usage of ASP-308L ASKAYNAK electrode), was lower than the hardness of austenitic steel, which was designated as sample 2 - 310 (usage of ASP-310R INTHERMA electrode), but it was uniform throughout the given area. The selection of electrode is an important factor that can have negative effect on the weld quality. If the electrode is dried insufficiently, hydrogen is released into the material and it causes the disruption of welds. The size (diameter) of the electrode affects the intensity of the electric arc and thus the energy supplied.
4.5. Fracture surfaces of welds

The tested material is defined by the chemical composition and physical state of the structure and substructure and it is also shown in the behavior of the fractures of the welded austenitic materials. Using the same welding method, these artificially created welds for quenching baskets were subjected to the tensile tests by help of HOUNSFIELD H20 K-W tensile test machine. On the basis of macroscopic observation of fracture surfaces, the character of the fracture was evaluated from the aspect of deformation occurrence, because the obtained results can be used to prevent breakage of the welded austenitic steels. Compared with the starting material, the typical feature of experimentally prepared welds and their fractures was the occurrence of so-called welds light areas that indicate the presence of certain inclusions under the interaction of hydrogen in figures 10 and 11. For this reason, there is a combined violation, because in the surroundings of the light areas, there is the initiation of the brittle fracture although there is also the indication of ductile fracture. Based on the material destructive tests, it can be assumed that during the welding process, hydrogen can be released to the weld from the electrode, causing the embrittlement of the austenitic steel. In the case of inappropriate welding parameters for a given material, the stress-strain states occur and after welding procedure, the given states can result in the residual stress which can be the reason for crack occurrence in the welds.

![Figure 10. Fracture surface of weld for sample 2 - 310.](image1)

![Figure 11. Fracture surface of weld for sample 1 - 308.](image2)

In relation to the investigation, there was the mutual comparison of the fracture surfaces of the welds, which were designated as samples 1 - 308 and 2 - 310. The sample 2 - 310 exhibited lower ratio of the light areas.

5. Results and discussion

In the presented work, the occurrence of critical states of quenching baskets was investigated. Cr-Ni austenitic steel represented the material for these high temperature welded components. The uniform microstructure and maximum approx. 4 % of delta ferrite are the condition for Cr-Ni austenitic steels to be used in the operation process while this operation process includes cyclic temperature changes. If the content of delta ferrite is exceeded there is the high susceptibility of weld to rupture (it can be also seen in Schaffler diagram). Based on the size, shape of the baskets and the overall welding time interval, the mentioned technological process will not allow the release of residual stress from previous welds on the same basket. If the company determines that one quenching basket has to be welded and made in 45 minutes, there is a presumption that uneven heat affected areas will occur in the volume of the material and they can be considered as preheating or as heat accumulation. In cooling process, uneven stresses arise in individual areas and it can cause rupture during the welding process. Residual stresses are the reason for shortening of lifetime or service life of quenching baskets, because in the operation where temperature cyclic loading occurs, critical states of deformation can occur and it can lead to superposing of further stress in local volumes of quenching baskets. Although the austenitic steel for
quenching baskets is resistant to high temperatures, the welding procedures (welds) make it to be sensitive to cyclic thermal loading. This work draws attention to the need to use high-quality electrodes because, if they are dried insufficiently, they can release hydrogen into the welds, causing the occurrence of brittle cracks. The selection of electrode is an important factor that can has negative effect of weld quality. Based on the obtained results from the tests, we recommend the ASP-310R INTERMA electrode because it shows better results in relation to hardness, structure and fracture surface, compared with ASP-308L ASKAYNAK electrode.

6. Conclusion
Based on metallographic analysis and comparison of hardness results, the suitability of filling materials for the quenching baskets as well as their stability was evaluated by means of materials science and specific scientific techniques based on the static tests. The damage of welds is caused by material fatigue due to repeated temperature cycles.

We recommend the precise and accurate selection of filling material for the welded joints of corrosion resistant stainless austenitic steel because the given joints have to withstand high mechanical-thermal cyclic loading. It is important to point out that the given recommendation can be one of the possible ways how it would be possible to achieve the high quality and increase in the durability of the quenching agents (baskets).

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