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Metallographic characterization of the heat affected zone in welded joints with multiple defects

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Abstract

This paper is based on extensive research about the influence of multiple different welded joint defects on the integrity of welded structures. In this particular case, the focus was on the heat affected zone and its different sub regions - up to this point, it was observed as a whole, with homogeneous mechanical properties along its cross-section. Due to the need to describe its behaviour in more detail, it was concluded that metallographic characterisation of the heat affected zone is necessary. Metallographic tests have provided a detailed insight into the micro-structures with the heat affected zone, which would be difficult to predict in this case, due to specific conditions, i.e., a welding technology which was adopted with the purpose of deliberately causing a number of defects in the welded joint. This would result in a more realistic distribution of mechanical properties along the heat affected zone, which in turn would provide more accurate input data for numerical simulations, since the use of finite element method will be the next step in this research.

Keywords: multiple welding defects; metallography; structural integrity; heat affected zone

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1. Introduction

During welding, various types of defects can occur in the weld metal and the heat affected zone, and this is a commonly encountered issue in practice [1-3]. Presence of defects can lead to failures in welded structures, by directly compromising their structural integrity, since these defects will more often than not cause stress concentration, thus weakening the structure. Examples of the most common defects (as defined by relevant standards) that occur in welded joints include incomplete root penetration, plate misalignment, undercuts, excess weld metal, etc.

Autors of this paper analysed the effects of such defects on the integrity of welded joints, assuming the presence of more than one type of defect. Previous work involved investigating of how geometry affected the stress and strain states in welds. [4-8]. This particular analysis will mainly focus on micro-structures of welded joint regions, in order to provide additional insight into the behaviour of each individual zone. Welded joint defects can often occur in the form of groups, and multiple types of defects can appear simultaneously. SRPS EN ISO 5817 standard defines the acceptable dimensions of such defects, but only takes individual defects into account [9]. Since combinations of defects have significant effect on stress concentration, as well as the way in which the welded joints deform under load, it was necessary to consider all contributing factors. In this case, the mechanical properties of the heat affected zone were largely affected by the presence of defects, in the sense that their values were lower than expected. This was the main motivation for the micro-structure analysis stage of the research - to try and figure out how the micro-structures themselves affected the HAZ, since mechanical properties of each welded joint region are directly influenced by them.

This is especially important when taking into account the prominent heterogeneity of welded joints and their regions - base metal, weld metal and the heat affected zone. The HAZ is particularly sensitive to this, having several subregions with very different grain sizes, depending on whether its subregions are closer to the base metal or the weld metal/fusion line [10, 11]. The goal here was to determine if the grain size in these subregions was different compared to cases where there are no defects present.

2. Preparation of specimens for microstructural analysis

Due to aforementioned reasons, it was necessary to analyse the micro-structures of all three welded joint regions in detail, and in accordance with relevant standards. A number of specimens, cut out of steel S275 welded plates were used for this purpose. This analysis included metallographic preparation of test surfaces, using sandpaper of various granulation levels (P240-P1200), and in the next stage, these surfaces were polished using diamond paste with ~1µm size. Polished specimens were then etched in a 5% Nital solution (a mix of nitric acid and alcohol), in order to make every individual welded joint region clearly visible on the specimen surface. Images of welded joint cross-sections were made using standard microscope, with magnification ranging from 20 to 100 x.

3. Microstructures in welded joint regions

This section will present the results of the extensive microstructural analysis of all three welded joint regions, starting with the base metal. micro-structure of hot-rolled base metal (S275 steel) sheets consists of ferrite base and pearlite colonies which form microstructural bands, as can be seen in figure 1. Most of the ferrite grains have an almost equiaxed shape as can be seen in figure 1. Shape of ferrite grains is not elongated (in the rolling direction), which indicates intensive recrystallization during cooling from the hot rolling temperature. Microstructural bands might be observed even in the heat affected zone (HAZ), which is a consequence of alloying elements segregation during solidification process. As can be seen, there were no significant anomalies in the micro-structure of the base metal, as expected. Next, results for the heat affected zone are shown, in figure 2. Heat affected zone is characterized by a heterogeneous micro-structure, which might be divided into subregions. micro-structure of HAZ next to the base metal (BM) is similar to micro-structure of BM (ferrite/pearlite), but significantly finer grained, as is shown in Figure 3.

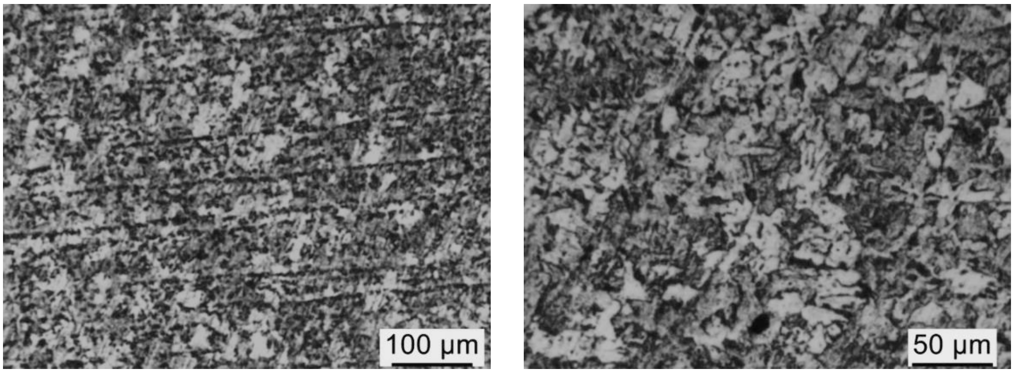

Figure 1. micro-structure of base metal: a) 50X magnification and b) 100x magnification

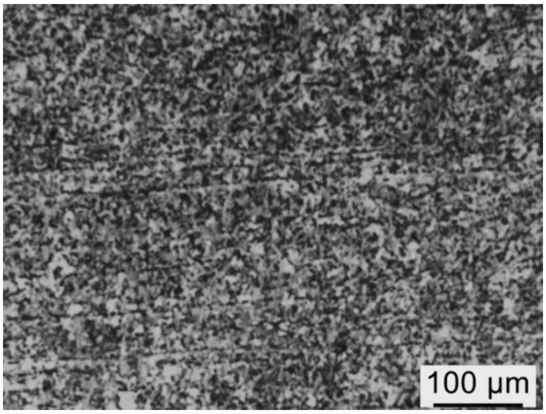

Figure 2. Microstructural banding in heat affected zone

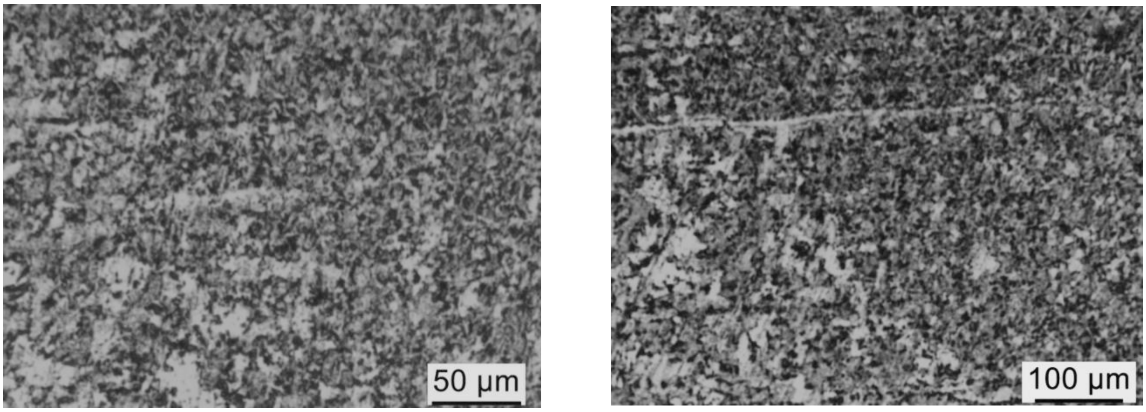

Figure 3. micro-structure of HAZ next to the BM: a) specimen 1 and b) specimen 2

Fine grained micro-structure provides higher mechanical properties than those which characterize BM, and HAZ micro-structure significantly changes towards the fusion line, which is manifested in the form of significant grain coarsening. Additionally, non-equilibrium ferrite morphologies, needle and plate like morphologies have occurred, and can be seen in Figure 4.

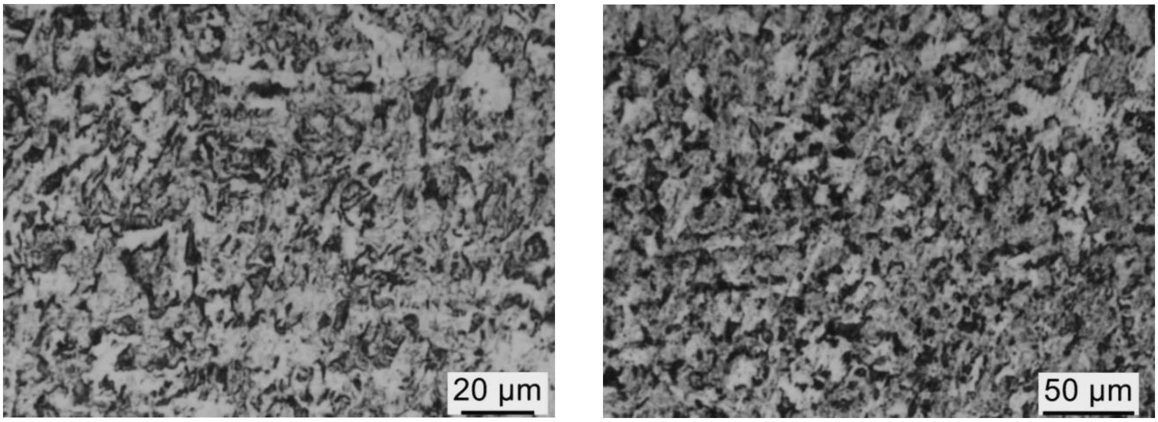

Figure 4. HAZ micro-structure in region of intensive grain growth towards the fusion line

In the fusion line region, cooling of steel from the austenite region had occurred at a high rate which caused the forming of bainitic and Widmanstatten ferritic morphologies (Figure 5). Those morphologies are characterized by high dislocation density, which leads to increase of yield stress. They are considered unfavourable in the case of low-alloyed structural steels, and their increased presence, compared to expected distribution of such micro-structures in the HAZ, implies improper heat input, which is a common cause for a number of welded joint defects.

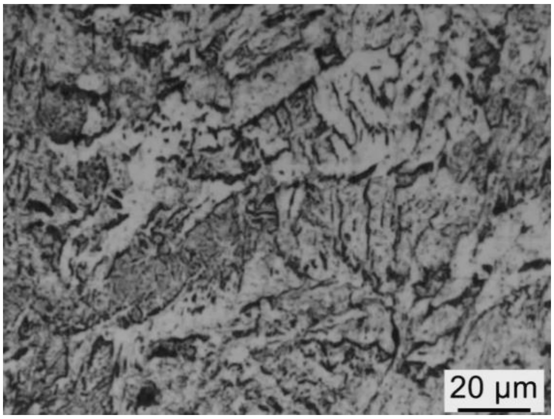

Figure 5. Microstrucure at the fusion line

Micro-structure of weld metal in all of the specimens is heterogeneous. In the weld face region, bainitic morphologies, accompanied with Widmanstatten morphologies and pearlite are dominant in micro-structure, as a consequence of higher cooling rate (Figure 6). Toward the root region of WM, micro-structure was formed under influence of heat input caused by multilayer welding technology. Each pass caused tempering of the previous one which is followed by lower cooling rate. In this way, micro-structure in weld root region consists of ferrite and pearlite (Figure 6b). Observed micro-structure is similar to micro-structure of base metal. For this welded joint region, the distribution and percentage of the aforementioned micro-structures was not as important as in the case of the HAZ, since the weld metal was considerably stronger than the base metal (overmatched welded joint).

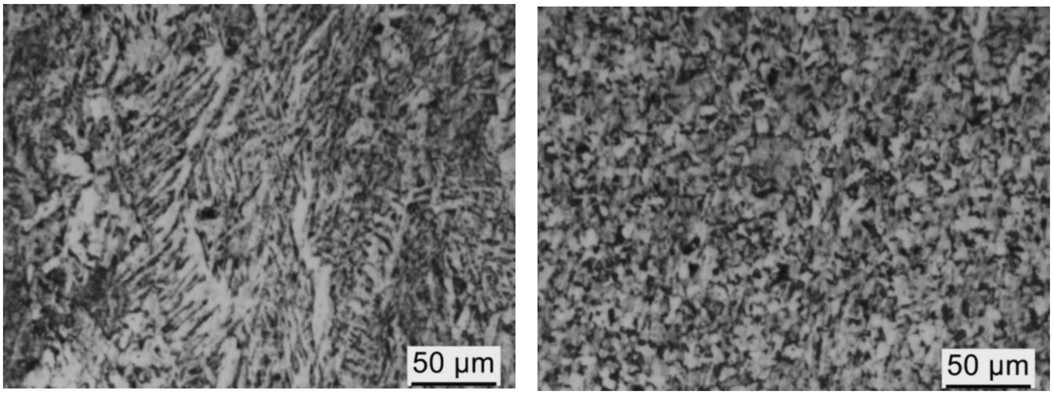

Figure 6. micro-structure of weld metal in region of: a) weld face and b) weld root

4. Discussion

As can be seen from the results that were presented, there was no noticeable differences in the micro-structures of all three welded joint regions, compared to what is typically obtained when analysing welded joints without defects. The amount of bainitic and Widmanstatten morphologies was slightly increased, and their distribution was more irregular than expected, but this did not affect the overall micro-structure of the HAZ and WM in any meaningful way.

Initially, it was assumed that the irregular heat input, which was necessary in order to produce the required welded joint defects, could not only cause the increase in presence of coarse-grain morphologies - but also have the opposite effect. The possibility of grains in the HAZ not growing as much as expected due to insufficient heat input in certain parts of the weld was considered. However, analysis of existing micro-structures had confirmed that this was not the case.

The presence of welded joint defects did have a negative effect on heat input during welding, but rather than affecting the grain size, its influence was reflected in irregular HAZ geometries. Heat affected zone widths were measured for a total of five specimens, and are shown in table 1. It should be noted that the fifth specimen was made without any defects, and used as a reference.

Table 1. Heat affected zone width for each S275 welded joint specimen.

Specimen number	Weld face width	Weld root width
1	0.7 mm	3.7 mm
2	1.7 mm	2.9 mm
3	1.7 mm	5.1 mm
4	1.0 mm	3.3 mm
5 (no defects)	1.9 mm	3.3 mm

Hence, it can be seen that the presence of defects had a considerable effect on HAZ width, as there is noticeable deviation from the dimensions obtained for the “undamaged” specimen. In certain cases, the widht of defective specimens was over 50% greater than the regular one, and all four weld face widths were actually smaller than the regular (1.9 mm). This suggests a consistently decreased heat input in the area around the weld face. Weld root results are more random, in the sense that some specimens had HAZ width less than or equal to the regular specimen, while some were much wider.

5. Conclusion

Since heat input during the welding has considerable influence on the potential forming of multiple types of welding defects, the resulting micro-structures of the base metal, weld metal and heat affected zone were investigated, in order to determine if there were any unexpected micro-structures (or their distributions).

As for individual welded joint regions, the following was observed:

- Micro-structure found in the base metal represented a balance mix of ferrite and pearlite, as expected, whereas a fine-grain ferritic-pearlite micro-structure was observed near the heat affected zone.
- Heat affected zone consisted of mainly ferrite and pearlite near the fusion line, with larger grain size compared to the BM. Bainitic type micro-structures were also detected, but did not have any unusual effects on the results as a whole.
- Weld metal was characterised by a dominantly pearlitic micro-structure, with bainitic morphologies

While the above results indicated that there was nothing out of the ordinary when it comes to micro-structures in the welded specimens that were analysed, heat input did affect the width of the HAZ. Weld face HAZ widths were smaller than expected, due to decreased heat input, which was necessary in order to produce the required defects. As for the root HAZ width, the results were less uniform, due to different types of defects that were produced there, compared to the weld face.

Acknowledgements

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