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METALLURGICAL AND PROCESS CHALLENGES IN FLASH BUTT WELDING OF DIFFERENT DIMENSIONS OF MICRO-ALLOYED STEEL ON CONTINUOUS PICKLE LINE

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Abstract

Flash Butt Welding (FBW) is a critical process in continuous steel production, particularly within the pickling line. While highly efficient with modernized software-driven machines, the FBW of microalloyed steels such as S355J2+N and S355MC presents significant metallurgical and process challenges. This study describes critical welding points and the complexities arising from the steel's microstructure under the influence of the Heat Affected Zone (HAZ). The study is focused on presentation of FBW tests on different thicknesses of microalloyed steels, the selection and adjustment of essential process parameters, as well as the testing and analysis of welds using various methods and metallographic analyses. Tests were conducted after the modernization of the welding machine on Pickling Line 2 at the cold rolling mill, carried out by Taylor-Winfield (TW) in 2022. The aim of the study is a holistic approach and understanding of the complex interdependencies between process parameters (defining and selecting an adequate "welding curve"), material properties, welding equipment mechanics, and the resulting weld quality, as well as the monitoring and quality control system. A poor weld poses a significant risk of strip breakage in the line and is a cause of line stoppage, which can lead to mill downtime and financial losses.

Keywords: *Flash Butt Welding, microalloyed steels, welding defects, weld testing methods*.

1. INTRODUCTION

(FBW) is a resistance welding technique widely used across various industrial sectors. This method uses a combination of heating and forging to achieve high-quality welded joints between two metal components. At HBIS Serbia's Cold Rolling Mill (CRM), the automated FBW process was enhanced through the modernization of the welding machine on the pickling line. The main goal of this upgrade was to improve weld quality, ensuring that high percentage of unbroken joints could pass through both the pickling and rolling lines. Another objective was to enable the welding of high-strength steels, including micro-alloyed steels (HSLA). Although all parameters were initially set in the software by the manufacturer, Taylor-Winfield, we concluded that a series of tests and trials were essential to determine the optimal settings. This was necessary to achieve a 100% sound weld across the full range of steel sheet dimensions and grades.

2. EXPERIMENTAL SECTION

Characteristics and Weldability of Micro-Alloyed Steels: (HSLA) are generally considered "well-weldable" due to their low carbon content. However, the presence of micro-alloying elements introduces new complexities to the (FBW) process. Consequently, the good weldability of these steels is highly dependent on the choice of welding process. This study focuses on weldability of two micro-alloyed steel grades, S355J2+N and S355MC of the same and different thicknesses. While S355J2+N exhibits good weldability with conventional welding processes (111, 135, 141...), FBW is performed without a shielding gas. Thus, the amount of inclusions becomes a critical factor affecting weld quality [1]. Micro-alloying elements, together with other alloying constituents, form highly stable oxides, nitrides, and carbides (e.g., TiN, NbC, TiC, MnO, and SiO_2). This necessitates precise optimization of welding parameters to ensure effective removal of these oxides from the weld zone. Inadequate expulsion results in brittle, glassy non-metallic films within the weld, which inhibit metallurgical bonding between the sheets. Moreover, excessive heat input during welding of these steel grades promotes grain coarsening and deterioration of mechanical properties in the (HAZ).

Weld Quality Assessment: Weld quality is primarily assessed through two testing phases. In the initial phase, samples are taken from different locations along the welded joint and prepared for bend testing. These samples are clamped in a vise and subjected to bending or punching forces to evaluate their plasticity and resistance to defects. A representative section of the welded joint is then sent to the mechanical testing laboratory. There, standardized samples are subjected to a tensile test to determine tensile strength, elongation, and the location of the fracture. The parameter optimization and testing is repeated until consistent weld quality is achieved.

Weld Integrity Testing on S355MC Micro-Alloyed Steel (3 mm to 4.5 mm)

Initial trials using the parameters established by Taylor-Winfield specialists produced inconsistent results (Figure 1, Figure 2). After performing a series of welding tests on S355MC of various thicknesses, the welding curve was modified to achieve a sound weld [2].

Figure 1: initial testing of 3mm

Figure 2: Joining 3.5mm to 3,5mm

Figure 3: confirmed good quality on 3.5mm

When initially testing the welding of 3.5 mm steel coils to other 3.5 mm coils, and 4 mm coils to other 4 mm coils, the success rate was about 85%. Failures primarily occurred next to the weld, not in the weld itself. After optimizing and fine-tuning the parameters (such as upset time and flash time), weld samples passed tensile strength testing in the mechanical laboratory with a 100% success rate. Welding thicker sheets and sheets of different thicknesses of this same steel grade will require additional tests to confirm a 100% quality weld. The successful parameters have been archived and now serve as the standard setup for welding the **S355MC** grade (see Table 1).

Table 1: Welding paameters for S355MC

	PARAMETERS - S355MC							
Thickness [mm]	Flash time [s]	Upset distance [in]	Upset current [%]	Upset time [cycles]	Gaugebar step	Ramp time [s]	Ramp distance [in]	Tap setting
3.0-3.0	14	0.13	90	19	2	0	0	5
3.5-3.5	14	0.13	90	19	2	0	0	5
3.5-4	18	0.2	90	24	2	0	0	6
4.0-4.0	20	0.2	90	24	3	0	0	6
4.5-4.5	22	0.22	90	24	2	2	0.02	7
4.5-5	24	0.25	90	28	2	2	0.02	8
5.0-5.0	26	0.25	90	28	1	2	0.02	8
5.0-6.0	26	0.25	90	28	1	2	0.02	8

FBW Parameter Testing for S355J2+N Steel

Weld tests were conducted on steel sheets of two types: joints between two sheets of 4 mm × 1240 mm, and joints between 5 mm × 1240 mm and 4.5 mm × 1240 mm sheets (Figure 4).

Figue 4: Tensile testing of welded joints.

For the 4.5mm thick sheets, setting the upset time to 14 cycles resulted in weld failure in 33% of the tested samples. For the 4mm strips, the failure rate during mechanical testing was 18.5%.

Of the 12 samples welded with an upset time of 10 cycles, only one sample failed the bend test, while the tensile test results indicated a sound weld. Based on these findings, we concluded that an upset time of 10 cycles is optimal for welding 4 mm thick material. For the 5mm thickness, out of 12 welded samples, six (50%) failed completely during testing, and two exhibited cracking. Tensile test results remained consistent despite varying the upset time. Specifically, three samples failed with an upset time of 16 cycles, and three failed with an upset time of 12 cycles.

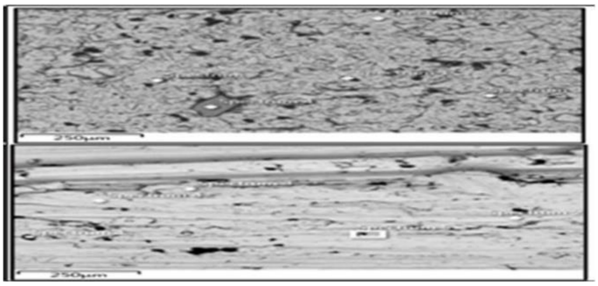

Figure 5: SEM analysis

All failed samples were subsequently analysed using SEM and EDS to identify the cause of fracture and to compare them with a sound weld sample. Detailed examination confirmed a significantly higher concentration of non-metallic inclusions along the fracture line in the failed welds.

3. RESULTS AND DISSCUSION

Some samples welded with identical parameters exhibited good performance in tensile and bend tests, with fractures occurring outside the weld joint. EDS analysis showed these samples still contained inclusions, though smaller and less dense (Figure 6), confirming that slight reductions in oxide formation and inclusion size significantly improve mechanical properties. Our tests demonstrated a strong interdependence between transformer tap setting, upset distance and flash time. Adjusting the transformer tap alone, without corresponding upset distance adjustment, was ineffective at fully expelling oxides from the weld center, resulting in trapped inclusions [3]. Increasing flash time promotes greater heat dissipation into the base material, reducing the temperature gradient at contact surfaces, combined with a large upset distance, this can cause excessive deformation. Conversely, very short flash times produce high temperature gradients that, when paired with a large upset distance lead to grain elongation perpendicular to deformation direction as well as formation of cold spots.

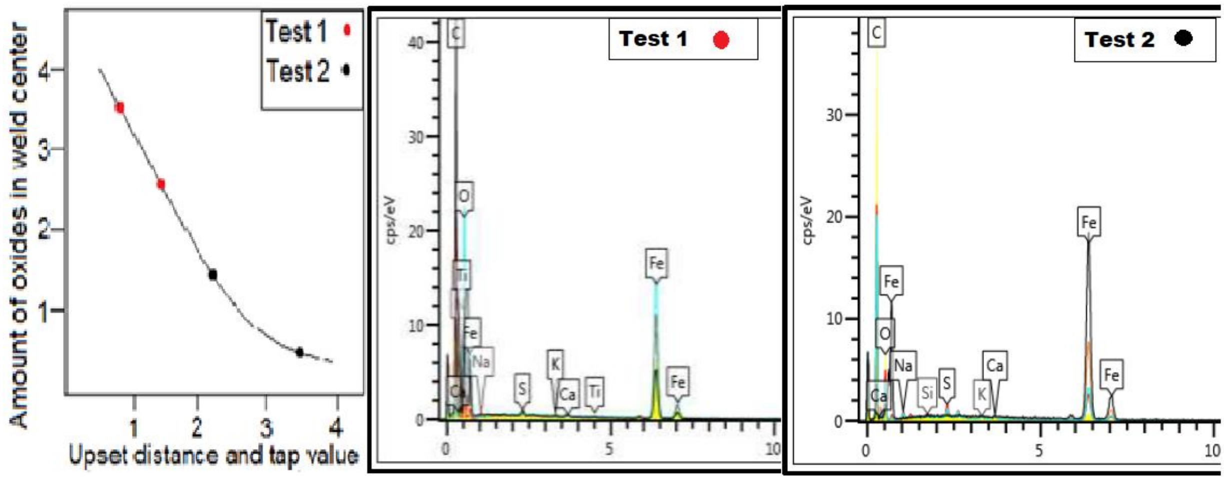

Figure 6: Interdependance of tap settings and upset distance on the amount of nonmetallic inclusions.

Uneven Heat Distribution and Plasticization in Dissimilar Joints. Further welding and testing were performed on dissimilar joints joining 5 mm and 4.5 mm thick sheets. Initially, most samples failed due to brittle fracture along the weld. Increasing upset distance and adjusting tap settings improved results, but consistent quality remained challenging. Optimizing parameters for the thicker sheet risks overheating or local melting of the thinner side, while optimization for the thinner sheet can cause insufficient plasticity on the thicker side, leading to cold welds or fusion defects [4].

4. CONCLUSION

Modernization of the welding machine on the D2 line at HBIS cold rolling mill, combined with thorough testing and parameter optimization, has significantly improved welding of micro-alloyed steels. For S355MC, success reaches 100% across nearly all dimensions. For S355J2+N, sound welds occur in 83% of 4 mm strips but are rare and inconsistent for 5 mm strips. Further testing is required to optimize parameters for these challenging welds. Further testing may consider the use of shielding gas to effectively mitigate oxidation-related defects.

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