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Stabilizing Flash Butt Welding of Varied Chemistry Steels during End-To-End Coil Joining

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Abstract

Flash butt welding (FBW) is extensively used for joining front end of incoming hot rolled coil to the tail end of the previous coil in pickling and tandem cold rolling mill (PLTCM). Improper welding causes failure in the cold rolling strands in the later stages. Hence, it is of paramount importance to establish a sound weld line by selecting the right welding process parameters. Optimizing the process parameters largely depends on the thickness and chemistry of the steels because slight variations in steel chemistry can cause weld failures. Recently, during flash butt welding of hot rolled Interstitial Free (IF) steel from TSK (Steel A) in the cold rolling mill (CRM) of TSJ (Steel B), adjustments had to be made in the welding parameters to enable smooth cold rolling. The flash butt welded TSK coils showed oxides of Fe, Mn, Al and Ti on fractured surfaces with the standard TSJ welding parameters. Back up study suggested that higher Mn, Al and Ti levels in the TSK coils were possibly responsible for greater volume fraction of oxides at the weld zone. Since, flash butt welding is done without the use of shielding gas, oxidation of the molten pool happens at the abutting edges. Improper process parameters can lead to the entrapment of oxides at the fusion line causing failure initiation. Therefore, this called for a change in welding parameter from the set value. Increasing the flashing length and upset length enabled in removing the excessive oxides formed during the flashing stage and prevented failure of the welds. The downstream end has hence been stabilized.

Key words: Flash butt welding; Oxidation; Interstitial free steel; Cold spot/penetrators.

1.0 Introduction

Flash butt welding (FBW) is an electrical resistance autogenous welding process used extensively in coil to coil joining in PLTCM to maintain the continuity of cold rolling process. This process enables the reliable joining of coil ends possessing large cross-sectional area with very high productivity. After FBW, the welded coils undergo severe deformation (up to 80%) during cold rolling, wherein degree of deformation is dependent on the final thickness requirement. While undergoing deformation for thickness reduction, premature failure of defective welds can occur at any of the cold rolling mill strands leading to huge losses in productivity and repair. FBW is also extensively employed in the production of wheel rims, rail to rail joining, wire rod joining [1-3]. Previous researchers have reported that flash butt weld parameters play a vital role in determining the weld quality. Ziemian et al. studied the weld quality using ultrasonic C scan technique for welds fabricated by varying parameters namely tap setting, flashing time, upset time and upset dimension. The authors concluded [4] that upset dimension and flashing distance played a critical role in producing defect free joints. In another study, flash butt welds of 590MPa wheel rim steel showed a direct relation between failure percentage and flashing allowance. A small drop in the hardness of heat affected zone was also observed [5-6] with increasing flashing distance. Studies on upset current 'ON time' showed [7] decrease in peak hardness at the weld and heat affected zone due to decrease in cooling rate. Increasing the upset pressure was found [8] to have a direct correlation with hardness and tensile properties. Ichiyama et al. showed [9] that pre-heating pulses can be effective in reducing the number of defects. The effect of Si and C on the defect formation was also investigated. It was observed that increase in Si percentage exponentially increased the defect percentage in flash butt welds. Flash butt weld defect such as penetrators, cold spots and oxide inclusions were investigated [10] by Rasanen et al. Penetrator/cold spot is the region at the fusion line where there is no metallurgical bonding. Localized arcing at the flashing stage results in the formation of uneven butting surface. If sufficient upset pressure is not applied during upsetting stage, the uneven craters are retained and cause failure. It was also observed [10] that the presence of oxide inclusion at the weld line can lead to failure. Apart from welding parameter, the material property can also lead to failures at the heat affected zone. Flash butt welding of material with high YS to UTS ratio can lead to heat affected softening resulting in thinning and failure during wheel rim forming operations [3, 11]. Previous studies showed flash butt welds to have poor toughness at the fusion line. This was attributed to the formation of Goss, rotated Goss and rotated cube texture components. A direct correlation between Goss texture and upset pressure was observed. As the upset pressure was increased, the Goss texture component's intensity also increased. This indicates that the texture inherited at the fusion line is deformation texture and not transformation texture [12-13]. Post weld heat treatment above A3 temperature was found to be effective in eliminating the texture and improving the toughness [14-15]. Heat distribution in resistance upset butt welding was studied using modelling and experimental analysis. It was observed [16] that there can be localized hot spots that arise as a result of localized variation in contact resistance due to contamination, oxides and non-uniformity of the butting edges.

Flash butt welding of IF-HS steel has not been reported before. This work correlates the effect of steel chemistry and optimization of welding parameters for obtaining defect free welds.

2.0 Materials and Experimental Procedure

Extra low carbon steel processed through RH degasser and hot strip mill (HSM) having a thickness of 4.5mm was used in this study. Steel A had higher Mn and Al wt. % compared to steel B **(Table 1)**. Flash butt welding of 1200mm wide hot rolled sheets was carried out on the flash butt welder.

Flash butt welder has the following parameters the flashing current, upset current on time, upset length, and upset pressure. The schematic of the stages/platen movement is given in **Fig. 1**. In this experiment, the upset current on time and upset pressure were kept constant and the flashing length and upset length were varied. Once the flashing current is switched on, arcing occurs between the two surfaces which results in material removal because of the electric field created. During this process, there is incremental displacing of the movable jaw again the surface to be joined. Once sufficient heating is achieved the two sheets are forged against each other for a preset upset length. During upsetting, there is a final welding current (upset current on time) that is kept on in order to maintain the edges at the plastic state to obtain a defect free surface.

Table 2 summarizes the welding parameters altered in this study. Parameter set 1 was the existing one being used at PLTCM to weld steel B. Parameter 2 and Parameter 3 were tried out to achieve improved weld joint performance for Steel A. Welded joints were subjected to Ericson Cupping test to evaluate their performance. Imperfect joint resulted in failure at the weld line as shown in **Fig. 3a**. The sample were polished and etched using 4% Picral followed by 2% NITAL to reveal the microstructures. Microstructure analyses were carried out using Leica optical microscope. FEG-Scanning electron microscopy with EDS was used to analyze the fractured surfaces.

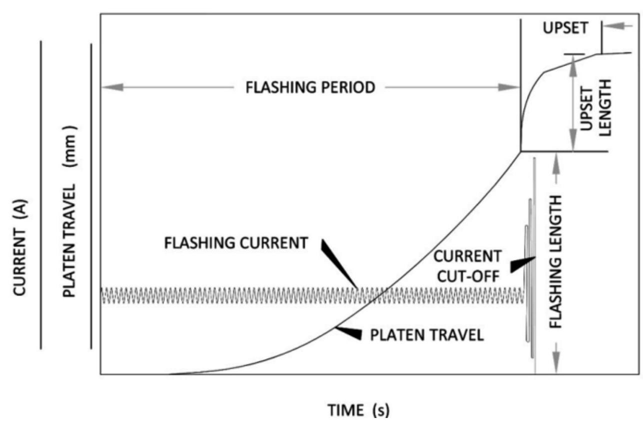

Fig. 1 : Schematic of flash butt welding process

Table 1 : Chemistry of steels in Wt.%

Steel	C	Mn	S	P	Si	Al	Nppm	Nb	Ti
A	0.0033	0.1	0.007	0.008	0.005	0.07	25	0.001	0.05
B	0.0021	0.061	0.011	0.018	0.005	0.04	19	0.001	0.05

Table 2 : Welding parameters

Parameter Set	Flashing distance (mm)	Upset distance (mm)	Upset current on time (s)	Failure percentage for Steel A (%)
1	15	4.5	0.5	90
2	15	4.7	0.5	50
3	18	5	0.5	0

3.0 Results and Discussion

3.1 Weld Microstructure

Stereo-microscope image of a flash butt weld joint's cross section is shown in **Fig. 2a**, wherein the fusion line, heat affected zone and the parent material can be seen. The high strength intestinal free steel has a complete polygonal ferrite microstructure **(Fig. 2d)**. Post flash butt welding, no alteration in phases formed at the fusion line and the heat affected zone was observed but an increase in grain size at the fusion line and the heat affected zone (ASTM grain size number 6 to 3.5) compared to the parent material **(Fig. 2(b,c))**. The grain growth can be attributed to the high temperatures (~1400 °C) experienced at the abutting edges [6].

3.2 Weld Failure Analysis

The steel B could be welded at all three parameters, whereas Steel A was not weldable with parameter sets 1 and 2. Weld failures (splitting of welds during Erichsen cupping test) and the scanning electron microscopy images of the associated fracture surfaces are shown in **Fig. 3**. It can be observed from **Fig. 3a** that the weld failed without any deformation for Steel A welded using parameter set 1. SEM analysis of the fractured surface showed the presence penetrators containing oxides of Fe-Mn-Al-Ti at the butting surface **(Table 3)**. Penetrators are detrimental to the weld and can initiate failures during subsequent cold rolling process.

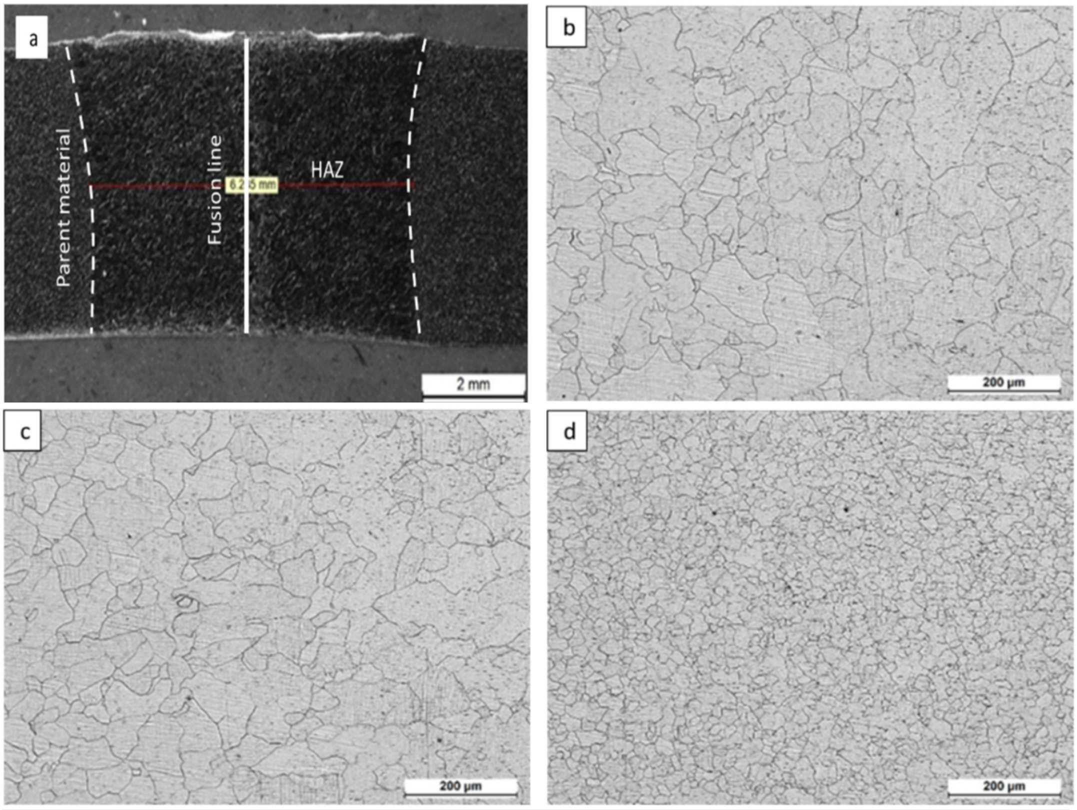

Fig. 2 : Optical image of a) Stereo of FB weld, b) Fusion line, c) Heat affected zone, and d) parent material

Table 3 : Normalized mass concentration (%)

Sl. No.	O	Al	Si	Ti	Cr	Mn	Fe
1	27.85	13.37	---	8.78	0.58	10.74	38.68
2	21.55	4.58	0.14	7.99	1.07	11.66	46.43

Table 4 : Normalized mass concentration (%)

Sl. No.	O	Al	Si	Ti	Mn	Fe
1	13.39	13.06	0.10	11.58	8.73	62.13
2	8.44	8.33	0.06	14.90	9.54	58.74

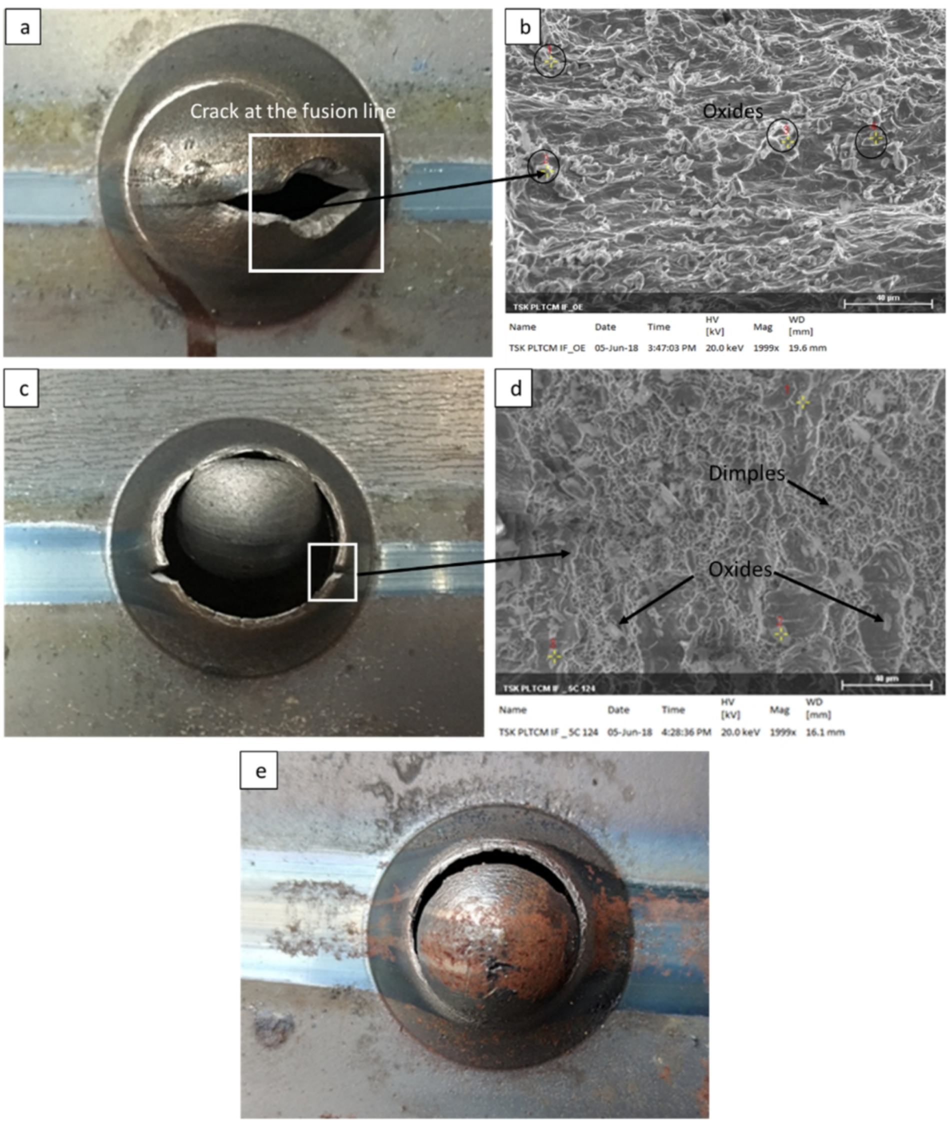

Fig. 3 : Steel A failure analysis (a, b) Parameter 1, (c, d) Parameter 2, and e) Parameter 3

As we increased the upset length as shown in parameter set 2, fusion at some cold points was observed but still there was entrapment of the oxides at the fusion line (**Fig 3d** and **Table 4**). Presence of higher Mn and Al in steel A can lead to the formation of higher weight percentage of viscous oxides, which makes it difficult to extrude them during the upsetting stage. The presence of dimples on the fractured surface indicated better metallurgical bonding of the abutting edges compared to Parameter 1 (for Steel A).

Parameter 3 yielded a defect free surface. Simultaneous increase in flashing length and upset length helped in achieving sufficient temperature to keep the oxides viscous at the faying surfaces and increase in upset length helped in the removal of these oxides from the fusion line resulting in a defect free weld as shown in **Fig. 3e**.

3.3 Mechanism of Weld Failure

Presence of cold spots, penetrators and/or entrapment of the oxide inclusion at the fusion line can lead to failure of flash butt welds. In FBW, the flashing stage results in the formation of craters on the abutting surfaces. These craters are formed as a result of violent localized arcing during this stage. In case, the upsetting length is not sufficient to remove these craters form the fusion line, they can be seen on the fractured surface as regions of 'no fusion'. The schematic of the weld defect and SEM image of the fractured surface is given in **Fig. 4 a, b**. Presence of cold spots is detrimental to weld strength and results in premature failure of the joint. Oxide entrapment is a result of insufficient heat input and upset pressure **(Fig. 4c, d)**. Therefore, a sufficient heat input should be maintained to

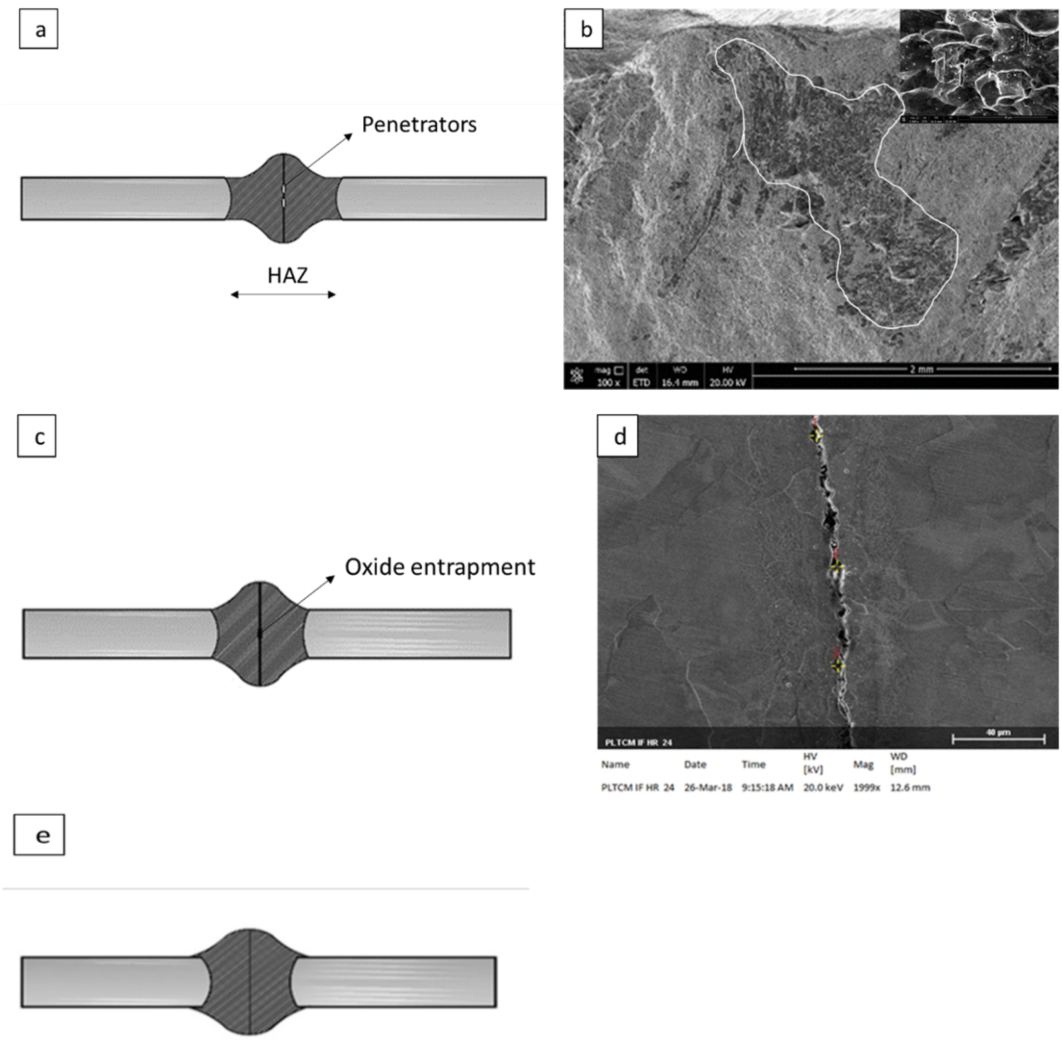

Fig. 4 : Schematic of flash butt weld defects and corresponding SEM images.

keep the oxides in a viscous state, which enables their easy removal during upsetting. Hence, a simultaneous increase of flashing and upset length (Parameter set 3) resulted in defect free welds with the best joint quality **(Fig. 4e)**. Additionally, it was observed during other welding trials (not reported here) that further increase in flashing length lead to softening of the heat affected zone, which resulted in failure caused as a result of thinning during the cold rolling of these welded coils.

4.0 Conclusion

1. Flash butt welding parameter such as upset length and flashing length play a critical role in determining the joint quality.
2. Alternation in steel chemistry required renewed optimization of welding parameters. An increase in weight percent of oxidizable elements namely Mn, Al and Ti in steel A lead to entrapment of oxides at the weld zone.
3. Formation of penetrators and/or entrapment of oxide inclusion at the fusion line of flash butt weld resulted in failure of the weld during Erichsen cupping test.
4. Simultaneous increase in flashing length and upset length resulted in effective removal oxides from the fusion line during upsetting stage.

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