Effect of Process Variables on the Flash Butt Welding of High Strength Steel

Y. S. Kim and M. J. Kang

Abstract

This study was aimed to evaluate the quality of flash welded joints and optimize the welding process for flash butt welding of 780MPa grade high strength steel. And then the relationship between the welding process variables and the joint quality would be established. The effect of process variables between flashing and upsetting process was elucidated. Microstructure observation of the joint indicated that the decarburized band was mainly changed with upsetting process. Width of HAZ was also related to the upsetting conditions rather than the flashing conditions. Generally maximum hardness at HAZ was correlated with Ceq of steel and the empirical relationship was obtained to estimate the HAZ properties. Tensile elongation at the joint was usually decreased with increasing the initial clamping distance. Investigation of fracture surface after tensile and bending tests reveal that the origin of cracking at the joint was oxide inclusions composed of SiO_2, MnO, Al_2O_3, and/or FeO. The amount of inclusions was dependent on the composition ratio of Mn/Si in steel. If this ratio was above 4, the amount of inclusions was low and then the resistance to cracking at the joint was enough to maintain the joint performance. It was obtained that the flashing process influenced the conditions for the energy input to establish uniform or non-uniform molten layer, while the upsetting conditions influenced the joint strength. Heat input variable during flashing process was also discussed with the joint properties.

Key Words : Flash butt welding, High strength steel, Process variables, Flashing, Upsetting.

1. Introduction

Flash butt welding is one of the resistance welding processes composed of heating and forging stage. Flash butt welding commonly is employed to join metals and alloys ranging from very small sections to very large sections. The advantages of this welding process are high productivity, little or no preparation of material for welding, uniform high quality, and solid state welding. Therefore flash butt welding is widely applied in the automotive industry, steel mills, and several other engineering industries. In steel mills, the coil joining in the continuous pickling and cold rolling lines is generally accomplished by flash butt welding. The weld of uniform high quality is required to execute pickling and cold rolling of steel strip without failure. The quality of weld in steel depends on welding parameters as well as chemical compositions of steels. The present study will discuss the effects of welding process variables such as flashing and upsetting parameters as well as chemical compositions of steels

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expressed by carbon equivalent, Ceq.

2. Experimental procedure

2.1 Materials

The 780MPa grade of high strength steel was used for the present study of flash butt welding. The chemical composition of this alloy as mass contents in % is shown in Table 1. The range of the ratio of Mn/Si was 0.69~6.48 and that of the carbon equivalent (Ceq) was 0.383~0.615. Welding specimens were prepared from the 2.7 mm-thick hot rolled plate of laboratory heat and the dimension of specimen was 200 mm × 100 mm × 2.7 mm.

Table 1 Chemical composition of steel used in this study

C	Si	Mn	P
0.10~0.19	0.4~1.5	1.6~2.98	<0.05
S	S-Al	Nb	Mo
<0.01	0.03~0.05	Tr	Tr

2.2 Welding experiments

The flash butt welding simulator, which was a 1/3 scale of the real flash butt welder in the cold rolling process line, was utilized for welding experiments in this study. Primary voltage, unclamping length, flashing distance, and upset distance were the main variables for flash butt welding experiments.

2.3 Analyses

Once the flash butt welding was performed, the microstructure investigation was conducted and mechanical properties including tensile property and bending property were examined. Scanning electron microscope was also utilized for the investigation of fracture surface.

3. Results and discussion

3.1 Microstructure

A typical microstructure after flash butt welding is shown in Fig. 1. In the latter step of flashing process, the faying surface of steel is covered with molten metal and the heat is conducted back into the parent material to allow the appropriate temperature for forging at the upsetting process.

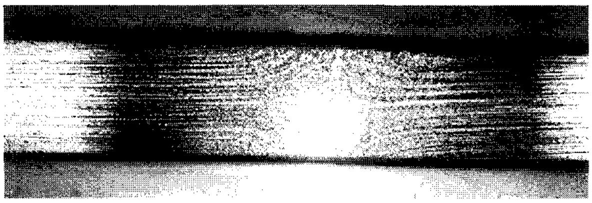

Fig. 1 Typical microstructure of flash butt weld showing metal flows

Once the proper forging temperature is achieved, the flashing process is terminated and the immediate forging process, upsetting, begins. During upsetting, the molten metal as well as residual contaminants like oxides expel and the intimate contact for bonding occurs. The initial feature of upsetting is the expulsion of molten metal from the weld area[1]. Joints are clearly solid state and the forging deformation of metal reveals the well-defined metal flows. The white band can be clearly observed at the weld line. This band is known as decarburization[2] or light area, indicating the lower hardness at the weld line compare to the HAZ as shown in Fig. 2. The maximum hardness at HAZ reaches to Hv 400 for a steel with which Ceq is 0.567. It is indicated from the maximum hardness at various peak temperatures as shown in Fig. 3 that the HAZ adjacent to the weld line reaches to temperature between 1200°C and 1300°C. This peak temperature simulation of flash butt weld reveals that the maximum hardness can be calculated with the empirical relationship;

$$Hv = 776\ Ceq - 47.5 \qquad (1)$$

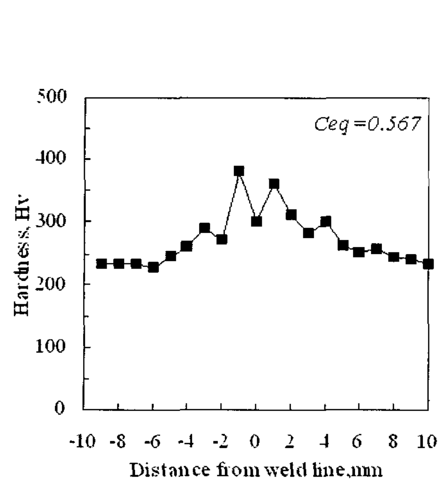

Fig. 2 Hardness distribution of a flash butt weld

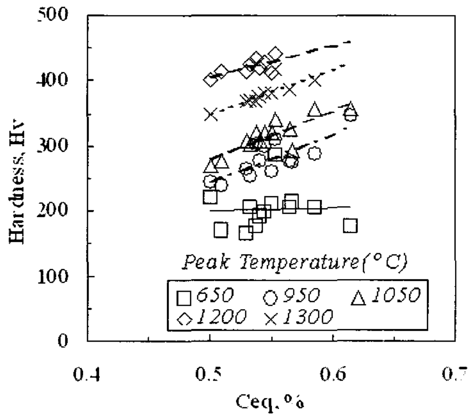

Fig. 3 Maximum hardness as a function of Ceq

3.2 Effects of flashing

It is well established that flashing is a series of bridging (short circuit), superheating, and expulsion of molten metal[1]. The primary function of flashing is to generate enough heat to produce a plastic zone that permits adequate upsetting. Therefore energy input as a function of time is a major factor in determining the temperature distribution. In most cases, energy input or flashing pattern is characterized by a period of constant velocity at the beginning for starting the flashing operation, and by a following period of accelerating flashing pattern over a large portion of the total flashing time. So that flashing rate is maintained depending on the flashing pattern until the appropriate amount of metal is flashed off and the adequate plastic zone is obtained. The current study reveals that the flashing rate affects the weld strength as shown in Fig. 4. Tensile strength of flash butt weld increases with flashing acceleration.

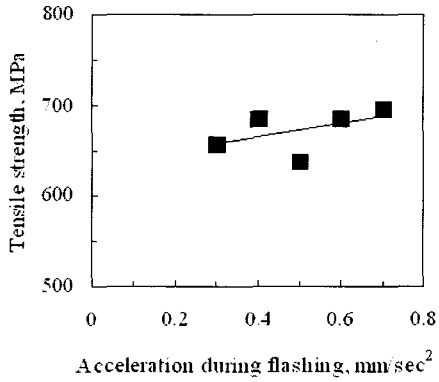

Fig. 4 Tensile strength varies with flashing rate

3.3 Effects of upsetting

If the adequate metal is flashed off and the proper temperature profile is established, bonding takes place during upsetting process. Of upsetting parameters, current was found to be significant, especially with upset distance and force. Fig. 5 illustrates the influence of upset current on the total upset distance. When the upset distance is increased, the upset current is also increased. This indicates that the metal is more deformable at a large amount of upset distance. The metallographic observations reveal that the upset distance influences the decarburazed band as shown in Fig. 6. During flashing, carbon solubility is higher in the molten metal than in the adjacent heated metal by diffusion at the liquid-solid interface. The decarburized metal is not entirely extruded during upsetting and some remains in the weld as a white zone as shown in Fig. 1. This heated plastic metal is deformed upon upsetting and remains in the weld line depending on the upset distance. The quality of the flash butt weld is greatly affected by the upset force. During upsetting, force should be sufficient to expel molten metal, oxides, or other contaminants, to close all voids.

Tensile strength is an indication of quality as shown in Fig. 7. Generally tensile strength of flash butt weld is increased with increasing upset force. However, tensile strength remains in constant with increasing upset force at high upset current. This indicates that the excessive upset current as well as upset force can be detrimental to weld quality. In other words, a large amount of upset by current and force indicates that most of heated plastic metal has been extruded, and hence welding takes place in metal where plasticity may not have been sufficient to ensure a good quality of weld.

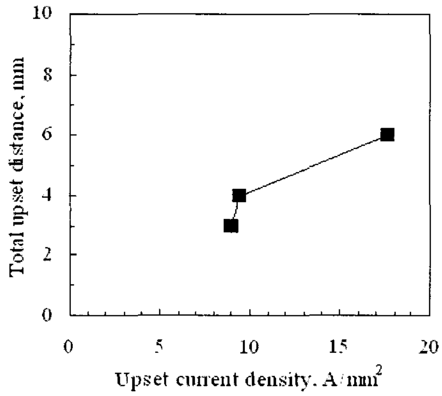

Fig. 5 Total upset distance as a function of upset current density

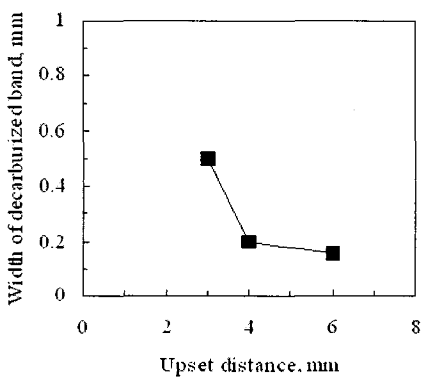

Fig. 6 Decarurized band varies with upset distance

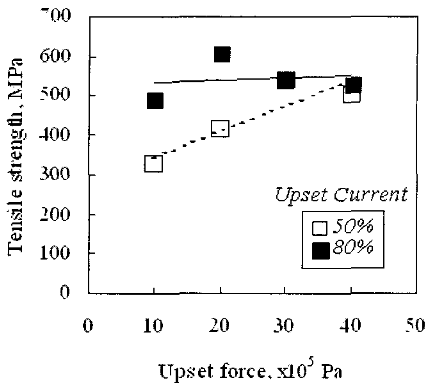

Fig. 7 Tensile strength as a function of upset force

3.4 Oxide inclusions

A Poor weld quality produced by inadequate parameters shows a brittle failure at the weld line with low tensile strength. Fig. 8 shows a fracture surface failed at the weld line after tensile test. Electron microanalysis indicates that the complex oxide inclusions composed by Si and Mn have been distributed at the fracture surface. Generally oxidation as well as decarburization occurs by reaction with carbon in the metal at the FeO scale in the initial stage of flashing. In the molten metal FeO will dissociate into [Fe] and [O], and [O] will dissolve in the decarburized layer. This dissolved oxygen will react with elements like Si, Mn, or Al to compose complex oxides like SiO_2-MnO-Al_2O_3. These oxides in the molten metal will be expelled when the appropriate parameters are applied during upsetting, and then the solid joint can be obtained. However, these oxide inclusions may be present in the weld joints that have been welded by insufficient upset force to expel them, or at too low temperature to give plasticity to the weld area. These inclusions are in various sizes but they affect the weld strength, and these are not removed or the weld quality is not improved by heat treatment like an arc welding. Therefore, flashing and upsetting parameters in the flash butt welding are very significant to reveal the good quality of welds of high strength steels.

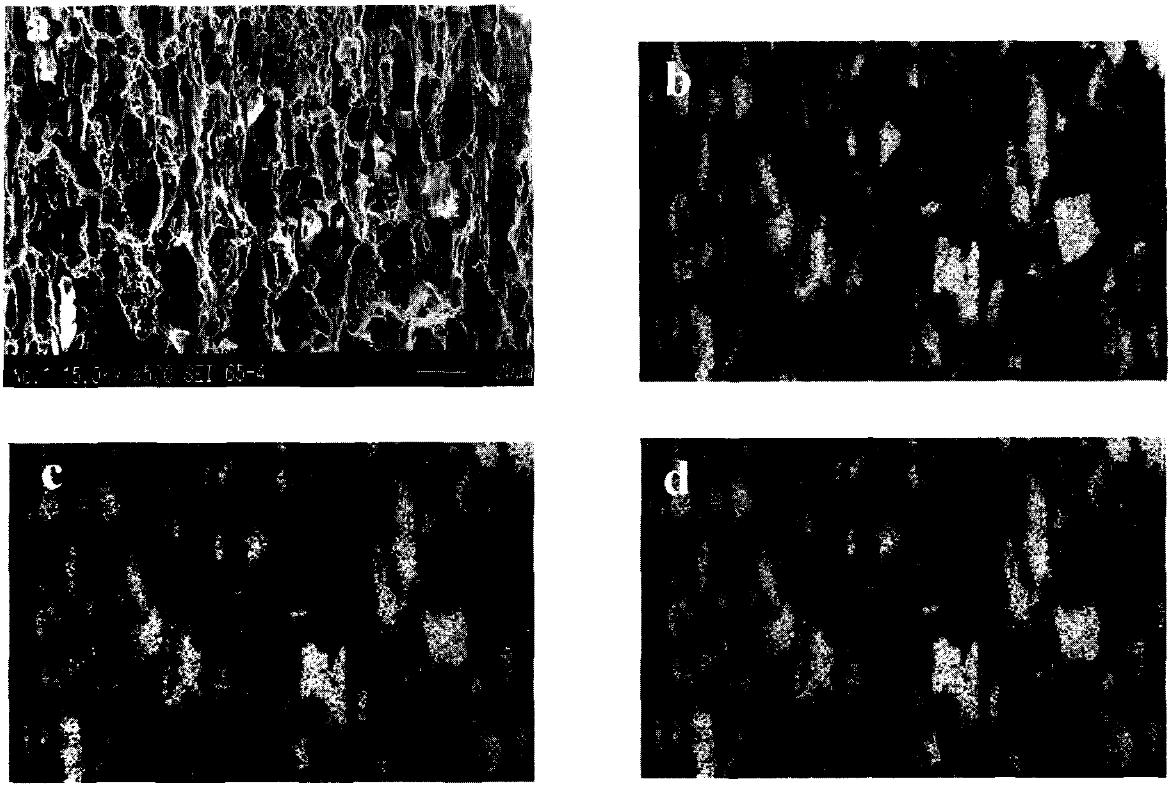

Fig. 8 (a) SEM micrograph reveals the element distributions of (b) O, (c) Si, and (d) Mn.

4. Conclusion

1. Hardness variation of HAZ was closely related Ceq, and the maximum hardness can be calculated with the empirical relationship ;

$$Hv = 776\ Ceq - 47.5$$

2. Flashing acceleration affects tensile strength of the weld

3. It is generally observed that both the decarburized layer at the weld line and the HAZ width are mainly influenced by the upset parameter.

4. Upset force as well as upset current also influences tensile strength of the weld.

5. Brittle fracture surface reveals the complex oxide inclusions that weaken the weld.

References

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