Solid Phase Bonding of High Carbon Manganese Steel Rails

N. K. Sarkar*

INTRODUCTION

Solid phase bonding is undoubtedly the first welding process to be used by man. The general phenomenon of this process is quite similar to the primitive method of forge welding and also to the Electric Resistance Butt Welding pr ocess. The Term "Pressure Welding" is often used as a synonym for solid phase bonding since almost all the solid state processes require pressure. The source of heating may be either gas mixture, electricity or open hearth fire.

This process has been widely used in many of the advanced countries for the joining of rail ends due to various techno-economical considerations. Oxyacetylene gas mixture is used for heating the rail ends. The gas pressure welded joints have the advantages not only of high strength and reliability but also adaptability for field work. It is hardly surprising therefore that Indian Railways too had gone for this method for joining of rail ends.

Since for the first time, the portable welding equipments had been imported on the Railways, we had to standardise the process after carrying out a lot of test weld joints. My paper therefore brings out the principle, mechanics and metallurgy of the process for the gas pressure welding of rail joints.

PRINCIPLE AND MECHANICS OF THE PROCESS

In this process, the component ends are butted squarely against each other under pressure and the joint is heated at a temperature below the solidus range (Fig.1). The temperature does not exceed the solidus temperatures of the metals being welded at the begining or3 at the end of the welding process, but may due to the mutual diffusion of the components, exceed the solidus range temporarily during the process. The welding temperature renders easy plastic flow where upon the application of pressure causes the welding surfaces to come into close contact and be joined with smooth upsetting. Since the abutting faces do not reach the melting point of the metal, the mode of welding is different from that of the fusion type of welding.

* The author is from Konkan Railway Corporation Ltd.
New Bombay

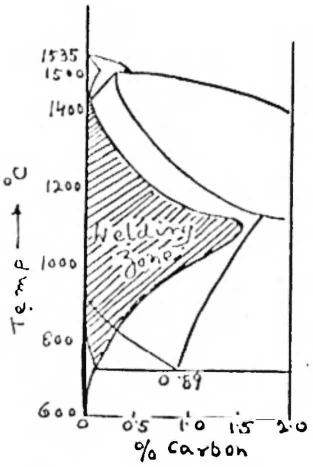

Fig 1 : Shows the Welding Zone

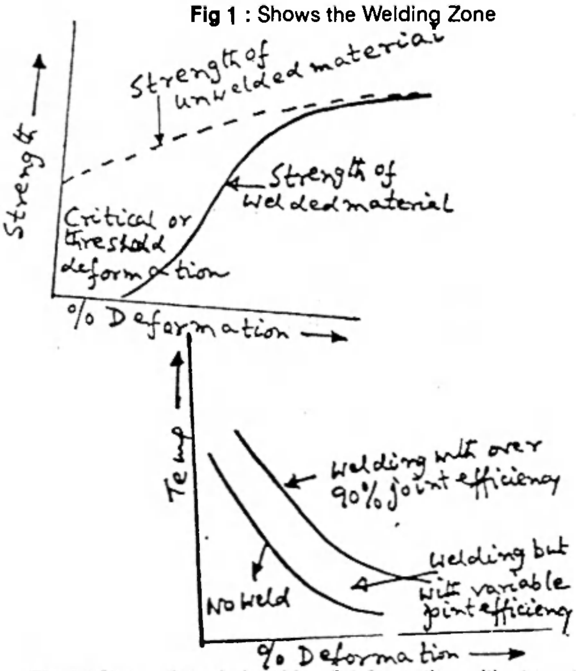

Fig 2 : Shows the relationship of deformation with strength as well as temperature

When there is a transformation metal, i.e. allotropic modification, bonding can be affected at considerably lower temperature, because of the increase in the rate of difusion, which accompanies such transformation of phase change.

The mechanism of this process involves in surface deformation, dispersal of surface films, diffusion and recrystallisation. There is critical or threshold deformation below which no weld is made and above the critical value, the joint strength rises to a value which is closer to or equals that of the cold worked metarial (Fig.2). Increase in the temperature reduces both the critical deformation and that required for optimum strength. At temperature not far away from the melting point, strong welds may be made with about 10% deformation.

It is generally considered that during deformation of the surface, the oxide film or the hardened surface layer produced by scratch-brushing fractures and exposes areas of clean metal, which bond to the opposite surface whenever two clean areas come into contact. At elevated temperature, oxide is dispersed partly mechanically and partly by solution in the metal.

Rails are normally coated with a film of iron-oxide. It may also have a layer of absorbed gases and it may be contaminated with oil grease or other non-metallic inclusions either partially or completely. Oxide and oil films hinder pressure welding.

Recrystallisation occurs during welding at elevated temperatures. Gas pressure welds made at temperatures above the upper critical showed continuity of grain growth accross the interface but may still be brittle due to oxide inclusions or other causes. However, increasing the welding temperature which favours recrystallisation also favours the elimination of other defects. Welds made below the recrystallisation temperature are unlikely to have parent metal ductility. Whereas above the recrystallisation temperature, the ductility of weld improves.

The diffusion rate also increases during the process of recrystallisation. Thus a metal which has no transformation but has a high recrystallisation temperature may still be bonded at relatively low temperature. It is evident that the surface diffusion plays an important role in modifying the shape and size of upset formed at t he interface relating to the temperature.

Metallurgical Consideration

The following 3 grades or rails covered by IRS specification No. T-12-88 are used on Indian Railways:

I shall be covering the first two grades of rails only. The rail steels being carbon steel (carbon equivalent being more than 0.70%) of high hardenability is quite prone to thermal cracking. These cracks usually appear at temperatures close to the solidus and are caused by the locked-up stresses developing due to the constrained contraction of rail steel. The source of heat in the gas pressure welding process is a multiple nozzle arrangement of oxyacetylene torch designed to conform to the contour of the rail section to be welded. Carbursing or redusing flame is to be used for heating due to very high carbon equivalent. The carbon monoxide and hydrogen formed due to the reaction of the oxygen and acetylene gas mixture avoid the "scale" formation and clean the surfaces of the rails.

The pressure weld in rail steel is usually characterised by large grain size thereby size increase in the cross section in the region of the weld seam where "upsetting" has occured. The greatest single factor in controlling the strength of the weld is the degree of "upset". The increase of area at the interface that occurs with the application of pressure is the means by which interfacial oxide is dispersed and intimate

Grade	C%	Mn%	Si%	S%	P% (C+Mn/6 +Cr/5)	Cr% Kg/ sq.mm.	CE%	UTS
710	0.45 0.60	0.95 1.25	0.04 0.50	0.05 max	0.05 max	-	0.71	72
880	0.60 0.80	0.80 1.30	0.70 0.50	0.05 max	0.05 max	-	0.85	90
1080	0.70 0.82	0.75 1.05	0.15 0.30	0.035 max	0.035 max	1.0	1.1	110

contact obtained. A properly adjusted oxyacetylene flame in conjuction with a high butting pressure is sufficient to prevent oxidation during welding. There may be failures due to heating and/or pressure not having been sufficient to squeeze out all the rail end surface. The rail ends therefore require special preparation - not only absolutely square but also little rough surface to an extent.

The cooling rate after the heating is over, is low for the rail section. Therefore the rails is successfully pressure welded and little difficulty is experienced from martensite formation. Pressure welds in alloy and high carbon rail steels are hardly ever used in the as-welded condition, since air cooling from weld temperature may result in considerable hardening of the weld metal and HAZ. Normalising, on the other hand renders maximum uniformity of structure and properties.

Welding Of Rail Joints

The welding technique consists of the following six operations :

- Preparation of the rail ends.
- Rail clamping
- Rail heating and upsetting
- Trimming of upset metal
- Normalising
- Grinding and finishing.

Rail And Preparation

In order to make a sound and straigth weld, it was necessary that the abuting faces of the rail ends should match squarely. If the abutting faces of the rail ends had any gap, there was a possibility of a film of iron oxide being formed during heating of the rail ends. This oxide film would result in lack of bonding which may ultimately lead to premature failure of the joint in service. The rail ends were prepared by grinding and filing followed by cleaning by the carbon, tetrachloride to remove the traces of oil, grease, rust etc.

Rail Clamping

The rail ends to be welded were pressed against each other at an initial pressure, obtained through the hydraulic press. This also resulted in minimising the gap between the rail ends prior to heating.

Rail Heating And Upsetting

After the initial butting pressure was applied, the burner was fitted around the junction of rail ends to be welded. As uniform and concentrated heat was required to keep the core of the rail sections at the welding temperature without overheating the external surface, the burner was designed to have a contour similar to that of the rail section. Oxyacetylene gas mixture was used for heating the rail ends. When the temperature reached about 1200 deg C, the butting pressure was increased to 30-35 MPA. At about 1250 deg C, "upset" started forming. the extent of upset was about 30mm. The total time taken for heating was about 5 minutes and 30 seconds. Fig. 3 shows the heating of rail ends in progress.

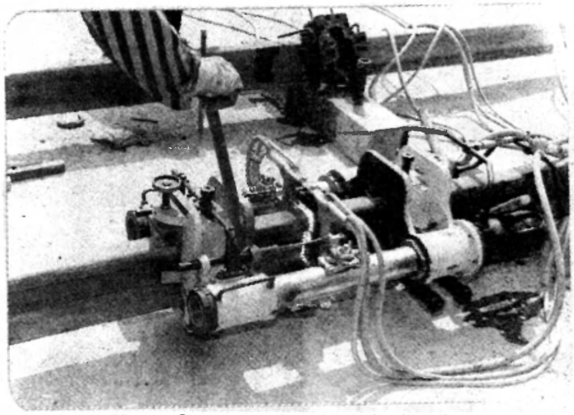

Fig 3 : Shows the heating of railends

Trimming of Upset Metal

After completion of heating, the trimmer was placed on the rail within 15 seconds. By the same time, the burner was also removed from the weld seam. Trimming of upset metal was done within next 10 seconds, otherwise the upset metal become cold. The upset metal had to be removed not only for smooth traffic but also for removal of burnt metal if any. Fig. 4 shows the completed joint ready for trimming.

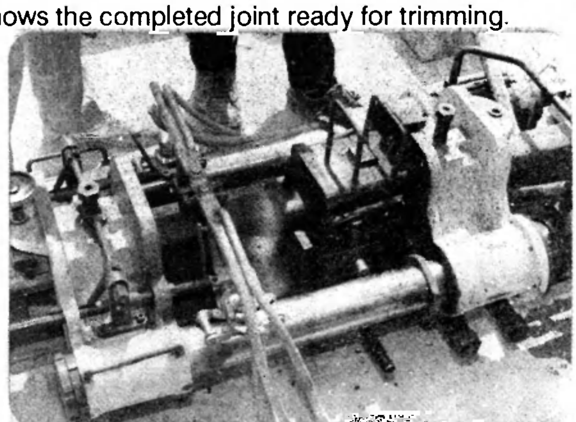

Fig 4 : Shows the completed joint ready for trimming

Normalising

After completion of trimming, the weld seam normalised at about 900 deg C with the use of same heating burner.

Grinding & Finishing

After the joint had cooled, the upset metal left after triming was ground to achieve the stipulated dimensional tolerances. This was done with the surface grinder over a width of 35mm. Care was taken to avoid localised over-heating of the rail while grinding.

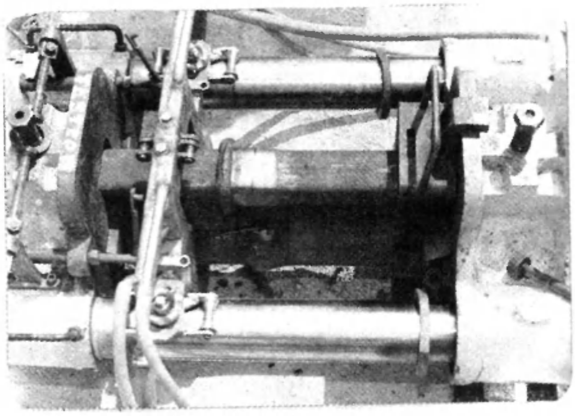

Fig 5 : Showing the presence of crack at the rail head

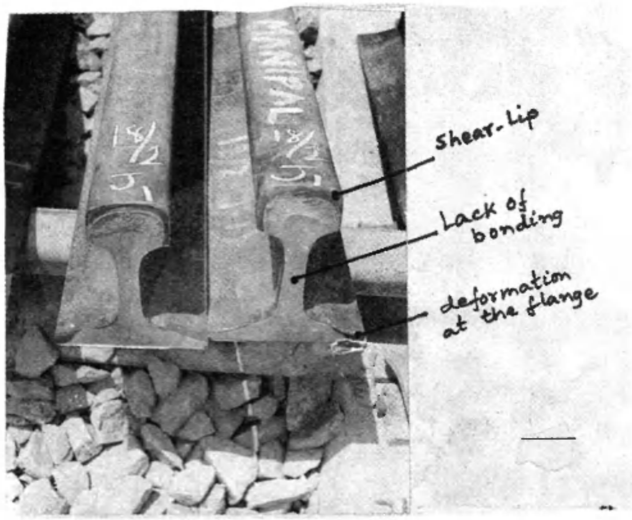

Fig 6 : Showting the defects at the fractured face of one joint

Quality Control & Testing

To judge the quality of the welded rail joints, full section bend tests were carried out to find out the breaking load, deflection and the fracture characteristics.

Initial test weld joints did not give satisfactory bend test results due to lack of bonding, cracking, oxide inclusions and improper upsetting etc. Fig.5 shows the presence of cracks on one joint. It was observed that most of the joint had the formation of shear-lip at the surface due to uneven heating of outer surface and the core of the rail section (Fig.6). The plastic deformation of the external surface was faster. This had led us to concentrate the heat to the joint so that the interior is heated properly without overheating the external surface. The flange ends were found to be twisted and deformed during the initial test weld joints. After proper controlling the heating at the flange, the deformations were eliminated. The end preparations were also improved to ensure that the gap at the flanges did not exceed 0.05 mm to avoid the welding defects.

Fig 7 : Showing a good joint

During the experimental stages, we had come accross some inherent manufacturing defects in the rail which had also lowered the breaking loads. Since no filler material was used during the welding, quality of the parent rail directly affected the weld joint quality. It was therefore decided to carry out ultrasonic testing of the rails prior to welding and of the rail joints after welding.

Parameters for welding of Rail Joints		
1. Gap between the rail ends	: For foot : For head	- 0.05 mm max - 0.10 mm max
2. Gas Pressure (MPA)	: Oxygen : Acetylene	- 0.12/0.15 - 0.04/0.05
3. Gas volume (cu.m/hr)	: Oxygen : Acetylene	- 3.6/3.7 - 4.6/4.7
4. Butting pressure (MPA)	: (i) Initial (ii) Final	- 16 to 18 - 30 to 35
5. Heating details	: (i) Heating zone : (ii) Temperature : (iii) Time	- 10/14 mm - 1250oC (approx) - 5'30" (approx)
6. Normalising details	: (i) Temperature : (ii) Time	- 880/900 C - 2'30" (approx)
7. Total Upset	: 30mm (approx)	-

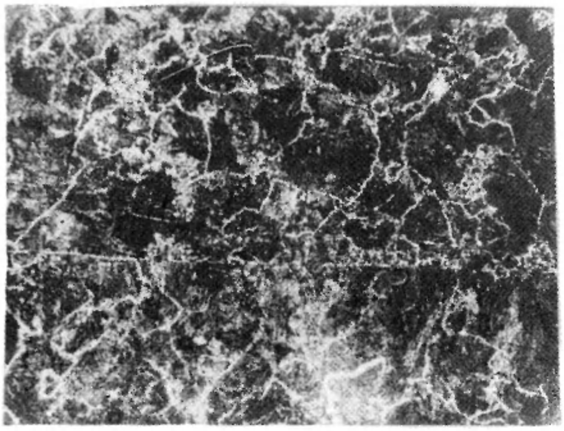

Fig 9 : Photomicrographic showing the grain structure of HAZ

Under static bend test, the welded joints which had been normalised after welding, gave better strength and ductility, since this process was to be extensively used for the first time on Indian Railways on higher strength Carbon-Manganese rails, we did not have any acceptable criteria. Therefore the criteria used for the Flash-Butt Welding process, one of the rail welding processes commonly used on the Indian railways are followed. The experimental test results showed that best results were obtained by using the welding parameters as given in Table - 1 Fig. 7 shows one good weld joint.

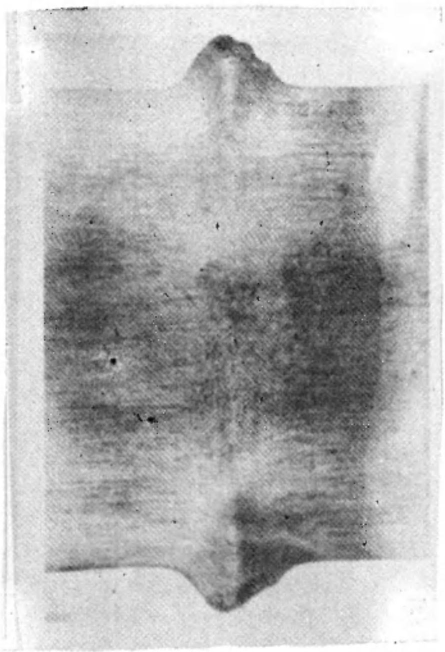

Fig 8 : Photomacrograph Showing the flow lines in one joint

Fig. 8 shows a photomacrograph one of the longitudinal sections of a welded joint, which has macro etched with 5% Nitric Acid. The flow lines observed were characteristic of solid phase bonding of rail joints due to use of pressure below the fusion temperature. Fig. 9 shows the photomicrograph showing medium to coarse grains of pearlite within the continuous ferrite network at the Heat Affected Zone.

CONCLUSIONS

From the foregoing, it may be observed that the design of the burner was of paramount importance to get uniform and controlled heating of rail ends. It was necessary that the heat supply be proportional to the dimensions of rails being welded so that the rate of temperature rise was uniform throughout the sections i.e. the interior of the rail sections had attained bonding temperature without overheating the external surface.

The rail end preparations also had to be very critical to avoid the oxide inclusion as well as to eliminate the deformation of flange ends. Reducing flame was also necessary for heating the rail ends, having very high carbon equivalent to avoid oxidation.

Normalising of rail joints immediately after trimming of up-set were necessary to obtain best strength and ductility of the rail welded joints.

References

1. "The Metallurgy of Welding, Brazing and Soldering" by J. F. Lancaster.
2. Oxyacetylene Pressure Welding by A. R. Lytle.
3. Oxyacetylene Pressure Welding of rail joints by N. K. Sarkar and K. N. Gupt.