New Weldable Steels For High Input Welding

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In a C-Mn steel weldment, the most sensitive area is the HAZ (heat-affected zone). HAZ is that portion of the base metal lying next to the fusion line of weld, which had not melted but whose mechanical properties or microstructures have been altered by the heat of welding.[1]

When a C-Mn steel is subjected to any fusion welding process such as arc welding, the area adjacent to the fusion boundary gets heated above AC_3 temperature and, as a result, transforms to fcc austenite structure. The austenite grains grow and then, on cooling after the passage of the heat source, the austenite begins to decompose, firstly from regions of highest stored energy, that is, austenite grain boundaries. The actual transformation products depend on several factors such as plate chemistry, cooling rate, and inclusion type, size and distribution.

The HAZ cooling rate is determined by the heat input rate during welding and the plate thickness. Heat input rate (also called Arc Energy) for an arc process is given by the formula :

$$\text{Arc Energy} = \frac{V \times A \times 60}{S \times 1000} \text{ Kilojoules per mm}$$

where V = arc voltage,
A = welding current,
S = welding speed or arc travel speed (mm/min.).

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For a given plate thickness, higher the heat input rate slower is the HAZ cooling rate. For a given heat input rate, the HAZ cooling rate increases with plate thickness.

For low welding heat inputs, the transformation product in the HAZ is martensite of low toughness and high hardness. As heat input increases, resulting in a decrease in cooling rate, less hard microstructures are formed, i.e. bainite or aligned ferrite/carbide aggregates, which have better toughness[2]. Further increases in heat input give rise to coarser microstructures with a resulting fall in toughness. The unfavourable effect of high welding heat input is further aggravated by the increase in austenite grain size during the weld thermal cycle, which increases hardenability and encourages the growth of colonies of larger transformation products. It may be pointed out that the prior austenite grain size close to fusion boundary has been found to be around 100 μm at heat input level of 3 kJ/mm and over 300 μm for an electroslag HAZ at 20 kJ/mm.

These metallurgical phenomena have till now stifled the growth of high heat input welding processes such as multi-wire submerged-arc, electrogas and electroslag, which otherwise offer considerable economic advantages in many areas of metal fabrication due to their high weld deposition rates. Where these processes are used, it is usually necessary to normalise the welds to make them attain adequate levels of toughness. Normalising is a must, for example, in the case of electroslag welded joints even though it is expensive and time-consuming. Normalising is, however, impracticable for large, heavy structures which would deform or even collapse under their own weight during this operation.

Realising these facts, many steelmakers, especially in Europe and Japan, have been addressing themselves to the problem of developing steels which would not suffer a significant degradation of HAZ toughness properties during high heat input welding. In fact, some of them have already introduced in the market these new grades of weldable steels[3] suitable for high heat input welding without the necessity for postweld heat treatment.

There are two metallurgical approaches possible to minimise loss of toughness, namely :

(i) to restrict austenite grain growth during the thermal cycle ;

(ii) to provide nuclei which will ensure the decomposition of austenite at the upper end of the transformation temperature range, thus preventing the formation of bainitic and martensitic transformation products. Sufficient nuclei should also be formed to prevent transformation products growing too large before impinging on one another, i.e. a fine grained structure must be developed.

Since some years, it has been recognised that the presence of small second phase particles provide an effective method for restraining grain growth. Work of Kanazawa and the co-workers[4] on the efficacy of several precipitate species in a C-Mn-Si-Al steel had demonstrated that among all precipitate types, TiN is more effective than any other in restricting austenite growth even at the low cooling rates typical of high input processes such as electroslag welding.

The new class of weldable steel for high heat input welding is thus a Ti-treated steel containing controlled addition of Ti and N (around 0.02% Ti and 0.008% N). It is preferably produced by the continuously cast method since the fairly rapid cooling rate associated with it ensures a fine dispersion of TiN. The presently available TiN steels have one drawback, namely, that they do not have high strengths in heavy sections, although Japanese steelmakers can offer thinner sections[5] with tensile strengths exceeding 800 N/mm^2. These steels are quenched and tempered, but as their strength increases their resistance to high heat input welding decreases.

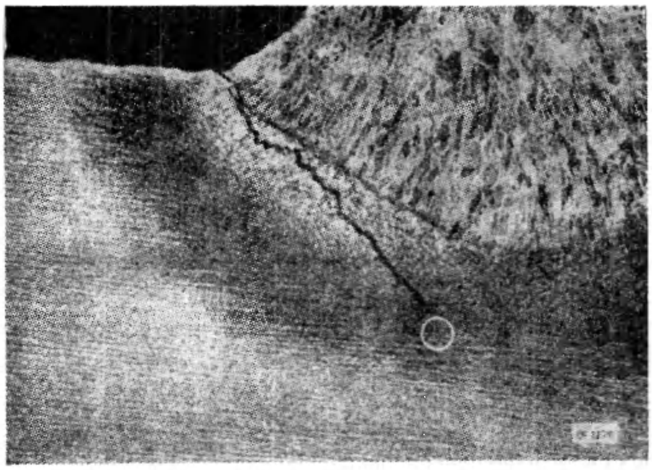
In one investigation, a conventional boiler quality steel plate having a carbon equivalent value of 0.33%

$$\left(\text{carbon equivalent } \% = C\% + \frac{Mn\%}{6} + \frac{V\% + Cr\% + Mo\%}{5} + \frac{Ni\% + Cu\%}{15}\right)$$

and thickness of 80 mm, when welded by the electroslag process at a heat input rate of 87 kJ/mm, developed a coarse austinite structure of maximum grain diameter $\sim$ 0.7 mm in the HAZ. This transformed on cooling to give coarse lamellar transformation products of low toughness. To obtain satisfactory toughness, the weldment had to be normalised. Stress-relief treatment alone was not effective as it hardly alters the microstructure.

On the other hand, a TiN steel of 0.33% carbon equivalent of 70 mm thickness welded by the electroslag process at the same heat input of 87 kJ/mm had an essentially ferrite/pearlite HAZ microstructure (i.e. the same constituents as would be expected after normalising), with only a narrow band of coarse-grained austenite. Also the HAZ toughness of the TiN steel in the as-welded condition exceeded that of the conventional steel in the stress-relieved condition.

In another investigation, 30 mm thick plates of similar composition, one of them Ti bearing and the other Ti free, were welded by the electrogas process at



Region of grain growth in the HAZ of a weld in which a hydrogen-induced crack has occurred.

heat input of 22.9 kJ/mm. The HAZ Charpy data determined at the fusion line were as follows :

Steel type	Absorbed energy J (Charpy test) 25°C	0°C	—25°C	— 50°C
Ti-bearing	120	80	45	20
Ti free	60	35	25	12

Weld metal

Weld metal deposited by high input welding also suffers from reduced toughness when conventional flux-wire combinations are used for the submerged-arc process and conventional wires are used for the electroslag/electrogas process. This known fact has also restricted the growth of these processes all these years.

A major break-through in the welding consumable field has been made by Oerlikon Buehrle of Switzerland[6] by developing a Ti-Mo-B flux-cored wire and a special agglomerated basic flux for submerged-arc welding TiN steel to provide excellent HAZ and weld metal toughness in the as-welded condition using heat input rate of 6 kJ/mm, which is quite high for the conventional welding practice. This combination has given impact value of around 85 J at—20°C for the three-wire submerged-arc process and around 170J at—20°C for the single wire process. The same flux-cord wire when used in the consumable guide electroslag process at heat input of 39 kJ/mm has given a Charpy value of around 80 J at—20°C for the weld deposited in 35 mm plate.

Microstructural data on the high input welds such as those described above are also very revealing. A typical electroslag weld metal made with Ti-Mo-B flux cored wire and an alumina basic electroslag flux in 25 mm t C-Mn-Nb-Al plate shows a fine, predominantly bainitic type of microstructure, with no ferrite nucleated at prior austenite grain boundaries.

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