Weldability map of low alloy steels

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ABSTRACT

A weldability map has been developed for low alloy steels considering the role of carbon and the carbon equivalent of the alloying elements on hardness and hardenability. Contours of preheat temperatures are drawn based on the Seferian type of equation. On the basis of heat flow relations, heat input and the preheat temperature of the weld plate are related and transferred to the weldability map to include the heat input values and cooling time contours in the map.

***Keywords :** weldability map, carbon equivalent*

INTRODUCTION

High strength low alloy quenched and tempered steels are incresingly used in structural applications as in power plant components, chemical and oil industries. These steels have high strength and toughness; but they pose some problems in welding during fabrication. Careful considerations must be given for the selection of welding processes, hydrogen free electrodes, heat input and preheat temperature of the base plate. Apart from the above welding parameters, the steel chemistry plays an important role in the weldability of the alloy. Defects like cold cracking may result if carbon and the other alloying elements are not properly controlled and the correct welding parameters are not chosen. To assess the possibility of cold cracking carbon equivalents (CE) of the alloy steels have been proposed and IIW gives the CE as

$$CE = C + (Mn+Si)/6 + (Cr+Mo+V)/5 + (Ni+Cu)/15$$

$$= C + CEA \quad \text{.....................} \quad (1)$$

where C is the carbon in wt.% and CEA is the carbon equivalent of the other alloying elements (wt%). William [1] has given the other formulae in use and discussed the applicability of CE for welding alloy steels. Graville [2] has shown a diagram (Fig. 1), connecting the carbon (C%) and the carbon equivalent (CE%) and indicating the different regions of weldability of low alloy steels. It can be seen that there is an invalid zone in which the CE value will be less than C value.

Further, in the computation of CE, carbon, C, and the carbon equivalent of the alloying elements, CEA, are simply added though their individual contributions to the development of hardness and hardenability are different. For example, 0.8% carbon steel and the 2.25 Cr-1 Mo steel will have the same CE value of about 0.8%, but their weldability properties and preheat temperature requirements etc., will be different. Thus, mere addition of CEA to C and taking CE as a single parameter to study the weldability of alloys may not be a correct approach.

In the following analysis carbon and the carbon equivalent of the alloying elements are separately considered for the development of the weldability map and the preheat temperature contours, heat input information and the cooling time contours are incorporated to extend the utility of the map.

Development of weldability zones

Since hardness of the weld plate plays an important part in the weldability of steels, hardness developed in the Jominy test is taken as

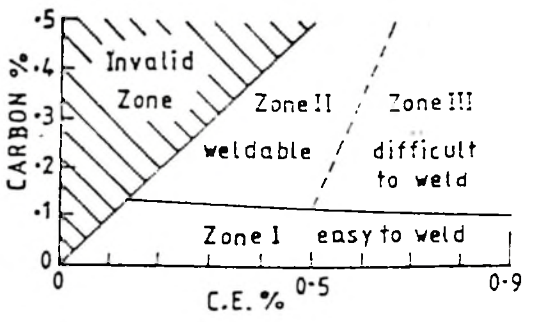

Fig 1 : Graville diagram

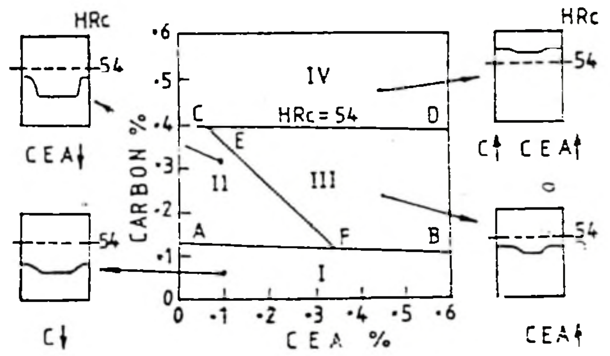

Fig 2 : Effect of C and CEA on hardness & hardenability

the basis for the demarcation of different zones for weldability consideration, as schematically illustrated in Fig. 2.

The area is divided into four zones. Hardness obtained for steels with carbon less than 0.1% is well below HRc = 35 and these steels can be easily welded. The region below the line AB represents this easily weldable condition and HSLA steels lie in this zone even though their CE values may range from 0.5 to 0.9%. This area is indicated as ZONE I. On the other hand, steels with C>0.4% have hardness values greater than HRc = 54 and the martensite formed will be more than 50% in such cases. Thus the line CD indicates the lower limit above which the hardness will be more than 54 HRc and the material will be very difficult to weld. This area is indicated as ZONE IV. The area between these two limiting lines AB and CD is designated as ZONE II and ZONE III divided by the line EF, as indicated in the figure.

The line EF actually represents CE (= C+CEA) equal to 0.45%. William [1] has also taken 0.45% CE as the upper boundary upto which the preheating could be optional. Further, it has been shown [3] that when the CE is above around 0.45% the possibility of cracking increases rapidly. Further, this line EF also represents a preheat temperature Tp of 150°C, as per Seferian formula

$$Tp(^{\circ}C) = 350\sqrt{(CE - 0.25)} \qquad ...(2)$$

It has been shown by researchers [4,5,6] that the cracking tendency depends on the cooling rate in the temperature range of 150°C in the preheated welded joint. The cooling rate must be below 20°C/sec, so that micro-fissures can be avoided [7]. Thus the line EF gives the boundary, the right hand side of which indicates the possibilities of cracking and the left hand side indicates a relatively safe zone to weld, though precautions like preheating, proper weld procedure, hydrogen free electrodes etc are required. Thus the C-CEA diagram is divided into four zones indicating the different degrees of weldability.

Data points from heat treaters hand book are analysed for steels AISI 10xx to AISI 9xxx, and are presented in Fig. 3 on the C versus CEA coordinates. The four zones discussed are also shown along with the contours of preheat temperature calculated on the basis of Seferian Eqn. (2).

Weidability map

Fig. 4 shows the weldability map based on the above analysis. It has been pointed out that the Seferian equation (2) for preheat predicts very high temperature specially in ZONE I and ZONE III. For example, 0.8% C steel may require a preheat of around 250°C, whereas 2.25 Cr-I Moly steel may require only a preheat temperature of 150°C. So retaining the form as it is, the equation (2) is modified as

$$Tp = 350\sqrt{C+mCEA-0.25} \qquad ...(3)$$

where "m" is a constant. When CEA is zero or negligible, the Seferian equation (2) will be able to give the preheat temperature, as in the case of carbon steels. With alloy addition, Tp has to be increased but not so much as in the case of carbon steel. Hence the constant "m" is introduced and its value is taken as 0.5 for the present analysis. Thus the preheat temperature contours as per equation (3) are also shown in the map. The locations of typical low alloy steels such as AISI 4340, AISI 4130, SA 517, HY80, Cr-Moly steels, HSLA steels, Tisten steel, SAIL-MA steels etc., are shown in the map, the data taken from published literature. The preheat temperatures as predicted by eqn. (3) appear to correlate well with the values in practice.

Role of heat input and cooling rate on weldability

The cooling time t8/5 between 800°C to 500°C plays an important role in the formation of microstructure, hardness and impact strength. The time t 8/5 - (seconds) is related to the heat input rate Q (kJ / mm) and the plate temperature Tp (°C), and is given by

$$t8/5 = (6700-5\ Tp)\ Q\ [(1/500-Tp)-(1/800-Tp)]\ F2 \times 10E{-4} \qquad ...(4)$$

for three dimensional heat flow. F2 is a factor. The relation between the heat input Q (kJ/mm) and the plate temperature Tp (°C) for different cooling times is shown in Fig. 5. Simple carbon steels require very high cooling rate of about 120°C/sec for the formation of martensite and the critical cooling time corresponding to this cooling rate will be around 2.5 seconds. In the case of heavily alloyed steel like AISI 4340 the cooling rate can be around 10°C/sec. The critical cooling time will be 30 seconds. Thus, C and CEA determine the cooling time and the heat input apart from the preheat temperature.

The relation between Tp and Q with different cooling times can be transferred to the C-CEA map given in Fig. 4, as the Y-axis in latter also contains Tp scale, though not linear. Such a weldability map containing the heat input and the contours of the cooling time t8/5 is shown in Fig. 6. Locations of typical alloy steels whose heat input data are also available in the literature, are shown in the figure as closed circles.

Utility of weldabilty map

The heat input Q and the preheat temperature, Tp influence the impact toughness (Transition Temperature) and the hardness of the alloy steels. To determine the optimum zone of welding, the weldability map can be made use of, if the critical cooling time t8/5 (critical) is also known for the material, in addition to the chemical composition. As a typical example the Jackal Armour steel is considered. It is reported [8] that for the Jackal Armour steel the carbon is

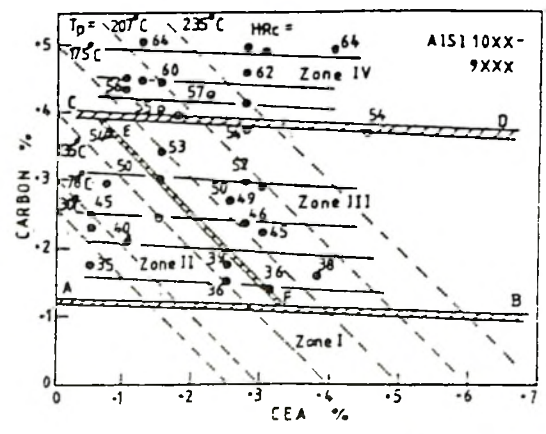

Fig 3 : Variation of HRc with C and CEA

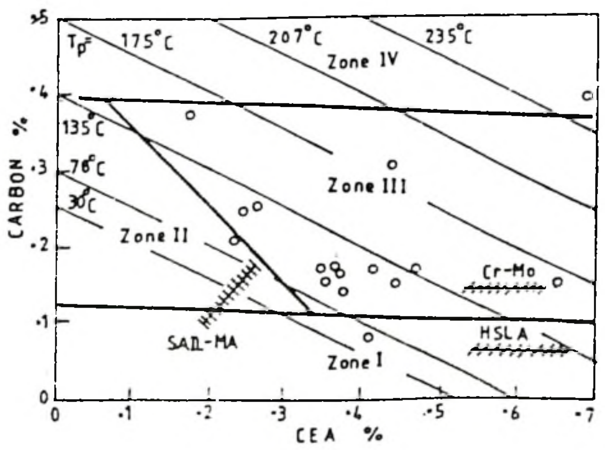

Fig 4 : Variation of HRc with C and CEA

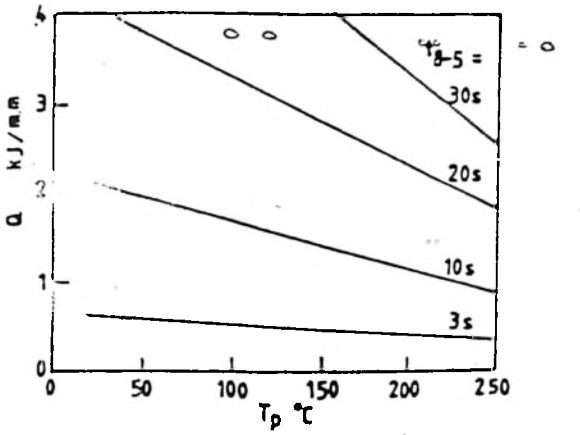

Fig 5 : Variation of Q with Tp

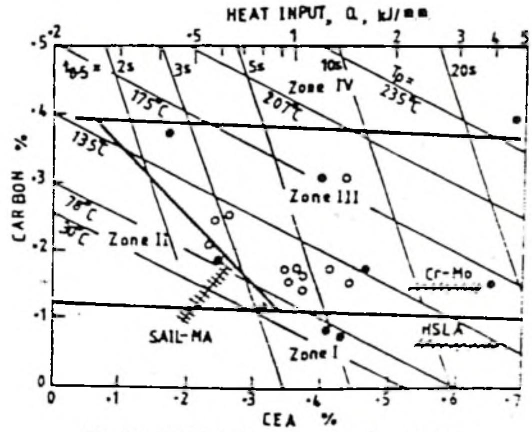

Fig 6 : Weldability Map with Q and t8-5

0.32%, CE = 0.7% and the critical cooling time is 7.1 seconds. The steel is located in the weldability map as shown in Fig. 7. The cooling time coincides with the critical cooling time and the preheat temperature is obtained as 180°C. The corresponding heat input is 1.2 kJ/mm. Thus the cooling time line and the preheat line combination gives the boundary and the zone below this boundary indicates crack prone region and the zone above indicates crack free weldability region as illustrated in the figure. However, the cooling times corresponding to the desired optimum toughness and the optimum hardness can be determined and this zone can be marked on the weldability map as shown. Welding

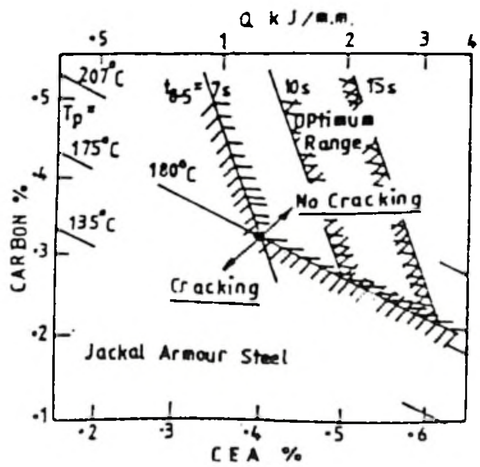

Fig 7 : Cracking and No Cracking Zones

parameters like Q, Tp, and t8-5 can be chosen from this optimum zone so that in addition to a crack free weld the desired mechanical properties can be obtained. It is reported that the preheat temperature used in the production is around 200°C [8].

CONCLUSIONS

A weldability map is developed for low alloy steels relating the carbon and the carbon equivalent of the alloying elements. Heat input information (for three dimensional flow) is also included in the map and the contours of preheat temperature and the cooling time are incorporated to enable the welding metallurgist and the engineer to choose the parameters without risking the possibility of cold cracking.

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