Effect of Arc Welding Variables on Thermal Cycles during Welding

V. R. SUBRAMANIAN*

Introduction

Welding has been accepted to-day as a reliable method of joining metals and alloys. The rapid development in welding processes and techniques has kept pace with the development of sophisticated materials to meet the exacting and rigorous demands on the property requirements and reliability, to give a dependable fabrication process and procedure.

Heating incident in all forms of welding may produce changes, often of a permanent nature in the material. These may be attributed to structural transformations occurring during heating or cooling processes or take the form of residual stresses. The actual welding procedure and the associated pre-or post-heat treatment required for certain alloys, to relieve residual stresses and eliminate detrimental structural changes, necessitate great care and rigorous control. An understanding of the effects of heating and cooling during welding on the basemetal and the weld-metal will help not only in the correct choice of the process and consumables but also an appreciation of the why of the pre- and post-heat treatment given and the basis for the proper choice of the pre-and post-heat treatment to get the most optimum properties in the weldment to meet the service requirements.

Temperature Changes in Welding

During welding, the base metal adjacent to the deposited weld metal experiences rapid thermal changes and there are the consequent complex metallurgical changes in this region called the heat affected zone—'HAZ'. If we had an exact knowledge of the thermal cycles and the response of various metals and alloys to these, the resulting changes in microstructures and mechanical properties could be predicted. Unfortunately, we do not have a quantitative information. We have, however, some data on the effect of arc welding variables on the temperature distribution in the HAZ. These data will assist the welding engineer in understanding the importance of temperature effects in welding.

The factors that influence the thermal cycles in arc welding are :—

(a) The Energy input : Joules/in $= 60\dfrac{VI}{v}$

V = Arc voltage in volts
I = current in amperes
v = Travel speed in in/min.

(b) Initial temperature of base metal.
(c) Weld geometry : t, size, shape, etc.
(d) The thermal characteristics of the material, expressed as

Thermal Diffusivity $= k = \dfrac{K}{C\sigma}$

K — Thermal conductivity cal/sec/in/°C
σ — Density g/cm^3
C — Specific heat cal/gm/°C
k — Thermal diffusivity Cm^2/sec.

(e) Electrode size : This determines the effective size of the heat source.

The temperature range of significance is dependant on the material and its response. For example, in structural steel, the regions in the HAZ experiencing peak temperatures between melting point and the lower critical point, will undergo significant structural and mechanical property changes.

Fig. 1 shows the thermal cycles experienced at specific distances from the centre line of the weld, in the HAZ in an arc weld made with 100,000 J/in on

*Mr. Subramanian is Development Manager, Welding Consumables, Indian Oxygen Ltd. Calcutta.

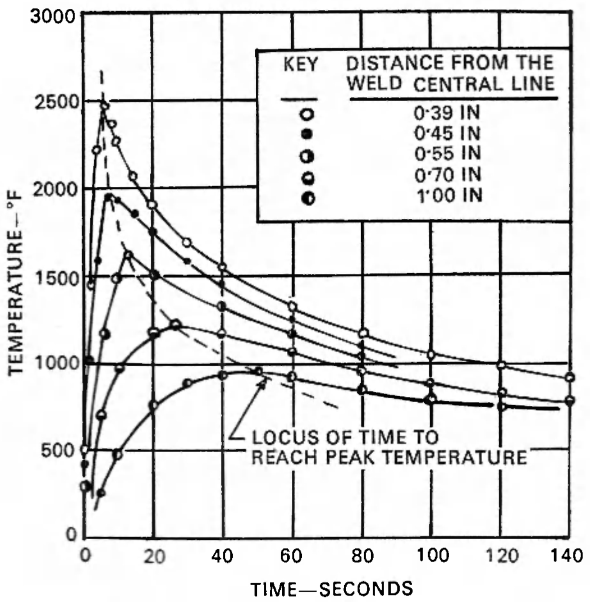

Fig. 1. Thermal cycles experienced by indicated locations in the heat-affected zone of an arc weld made with 100,000 joules/in. for ½ in steel plate at room temperature.

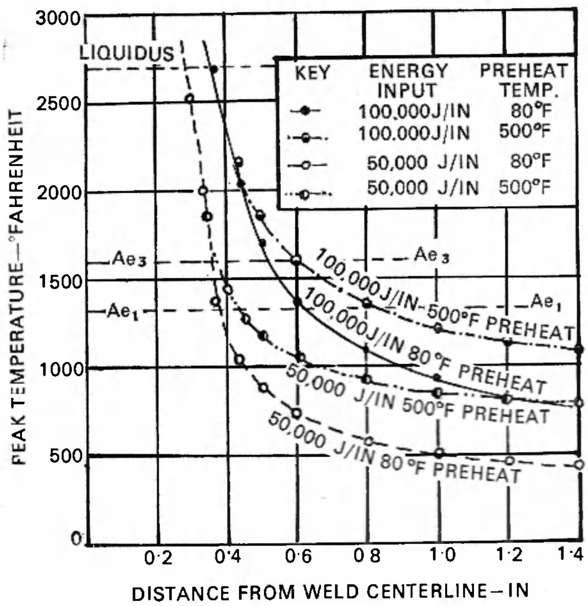

Fig. 2. Effect of energy input and preheat temperature on the peak temperature distribution in ½ in steel plate welded at room temperature with manual shielded metal-arc welding.

1/2 in. plate at room temperature. This is the typical pattern for all arc welds and the following points emerge from the curves.

(a) The peak temperature decreases rapidly with increasing distance from weld centre line.

(b) The time required to reach peak temperature increases with increasing distance from the centre-line.

(c) The rate of heating and rate of cooling both decrease with increasing distance from the weld centre line.

Fig. 2 depicts the effects of energy input and preheat temperature on the distribution of peak temperatures in HAZ of a manual arc weld in steel. The following generalisations can be made from curves.

(a) Decreasing either the energy input or the preheat temperature provides a steeper distribution of peak temperature in HAZ.

(b) Increasing the energy input increases the distance from the centreline to a point experiencing a particular peak temperature for all its values.

(c) Increasing the preheat temperature increases the distance from the weld centre line to a point that experiences a particular peak temperature by an amount which varies inversely with the peak value.

Fig. 3 illustrates the effects of energy input and a preheat temperature on the thermal cycles in the HAZ of welds in the 1/2″ steel plate using covered electrodes. For all the four cycles, the peak temperature was near the melting point. The following conclusions can be drawn from these curves.

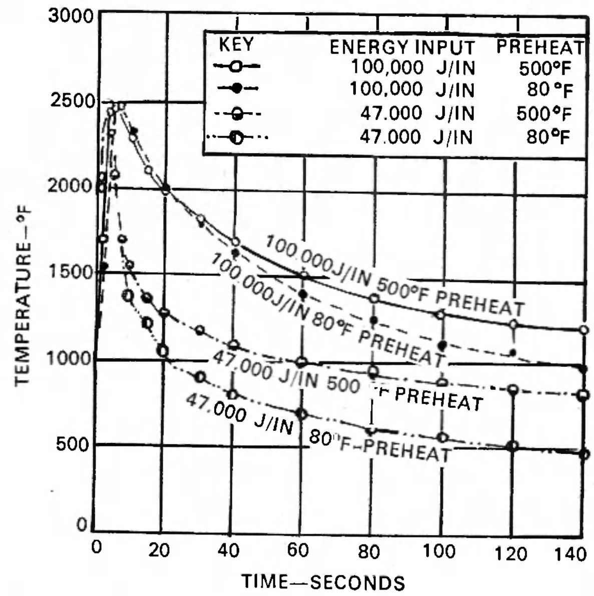

Fig. 3. Effect of initial plate temperature on thermal cycles in heat-affected zone of welds in ½ in steel plate using covered electrodes showing comparison for 100,000 joules/in. and 47,000 joules/in energy inputs.

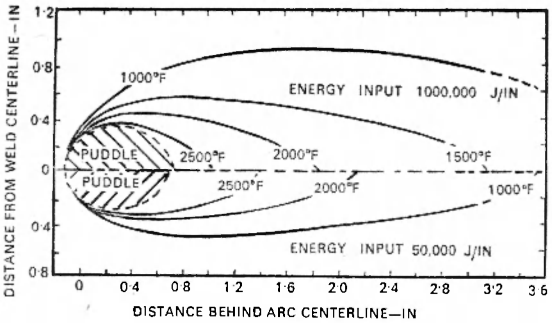

Fig. 4. Effect of energy input on temperature isotherms at surface of ½ in. steel plate (Upper portion)—100,000 joules/in 24 v. 208 amp. 3 in/min (Lower portion) —50,000 joules/in 24 v 208 amp. 6 in/min.

(a) For a given preheat, increasing the energy input causes an increase in the time of exposure to temperatures near the peak temperature and causes a decrease in cooling rate.

(b) For a given energy input, increasing the preheat temperature decreases the cooling rate but does not significantly influence the time of exposure to temperatures near the peak temperature.

It is therefore clear that by manipulating the energy input and preheat temperature, we can control the time at temperature and the cooling rate for the material in HAZ in addition to controlling the width of HAZ.

Fig. 4 shows the isotherms at the surface of 1/2 in. thick steel plate under two conditions. In the upper portion, the heat input is 100,000 J/in at 24 V, 208 amps and 3 in/min travel speed and in the lower portion, the heat input is 50,000 J/in at 24 V, 208 amp and 6 in/min. It will be noted that the HAZ is reduced by decreasing the energy input and the volume of metal heated above a temperature say 800°C is less at any instant of time. This effect becomes much more pronounced with greater speeds as encountered in automatic welding. The steepness of temperature gradient normal to the direction of welding increases at an exponential rate with increase in travel speed above 12 in/min.

Let us see the effect of plate thickness on the thermal cycle at HAZ. Fig. 5 shows the thermal cycles having peak temperatures of 1200°C for butt welds with an energy input of 47,000 J/in on three thicknesses of base material namely 1/4″, 1/2″ and 1″. The initial temperature being room temperature, it is seen from the curves that,

(a) The cooling rate tends to increase with increasing thickness.

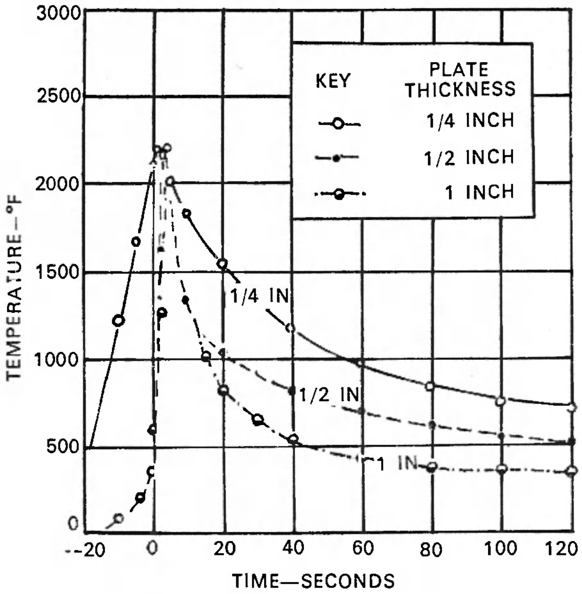

Fig. 5. Effect of plate thickness on the thermal cycles in the weld heat-offccted zone of manual shielded metal-arc welds in steel plate. Energy input—47,000 joules/in initial plate temperature 80°F.

(b) The time at elevated temperature tends to decrease with increase in thickness, In much thicker plates, the thermal flow becomes more complicated.

The thermal characteristics of the base material have the following effects on the thermal cycle during welding.

(a) The lower the thermal diffusivity, the steeper will be the distribution of peak temperatures.

(b) The higher the thermal diffusivity, the faster will be the rate of cooling for a thermal cycle with a given peak temperature.

(c) The higher the thermal diffusivity, the shorter will be the time at elevated temperature for a thermal cycle with a given peak temperature.

The width of the HAZ in a given material may be controlled by altering the distribution of peak temperatures. The more concentrated the heat source the steeper the distribution. For example, electron beam welding which has a heat flux of the order of megawatts/cm² is capable of producing welds with such steep distribution of peak temperatures that the HAZ almost disappears. On the other hand, gas welding provides a diffuse heat source at comparatively low temperatures and causes a relatively flat distribution of peak temperatures and therefore a wide HAZ. In general, conditions which provide a steep distribution of peak temperatures tend to produce rapid cooling rates in the HAZ.