Grain refinement methods

In this chapter, three grain refinement methods namely mechanical vibrations, electromagnetic forces, arc oscillation used for refining the structure of weld metal have been described. Further, two commonly observed metallurgical discontinuities in weld metal namely banding and segregation have also been explained.

Keywords: grain refinement, Mechanical vibration, magnetic arc oscillation, micro-segregation, banding,

34.1 Mechanical vibrations and Electro-magnetic force

Both these methods are based on use of external excitation force to disturb solidifying weld metal so as to create more number of the nucleants in weld metal. The external disturbance causes forced flow and turbulence in the viscous semi-solid weld metal carrying dendrites and nucleants which in turn can result in a) fracture of partially melted grains of the base metal, b) fragmentation of solidifying dendrites and c) improved distribution of chemical composition and the nucleants (Fig. 34.1). The fractured dendrites are pulled out of partially melted grains present in the weld and act as nucleants for solidifying weld metal a [illegible] e same composition in solid state.

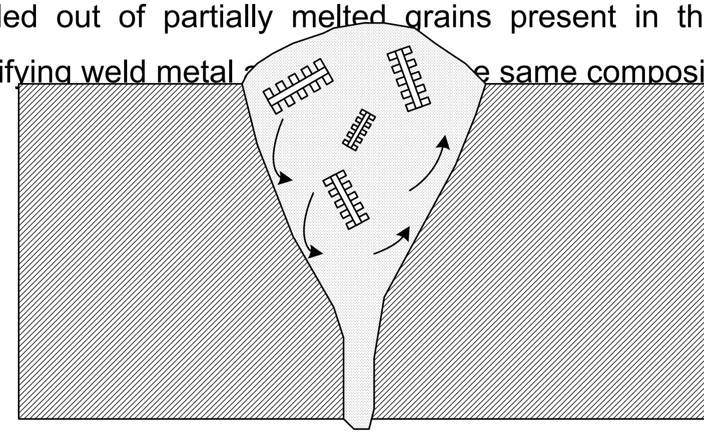

Fig. 34.1 Refinement using external excitation force

34.2 Magnetic Arc Oscillation

Arc composed of charged particles can be deflected using magnetic field. Arc oscillation affects the weld pool in two ways a) reduction in the size of weld pool and b) alternate heating and cooling of weld (similar to that of arc pulsation) as shown in Fig. (34.2). A combination of above two factors leads to rapid cooling which in turn reduces grain size owing to increased nucleation rate and reduced growth rate. As increase in cooling rate of the solidifying weld metal decreases the effective liquid to solid state transformation temperature which is known to increase the nucleation rate and lower the growth rate

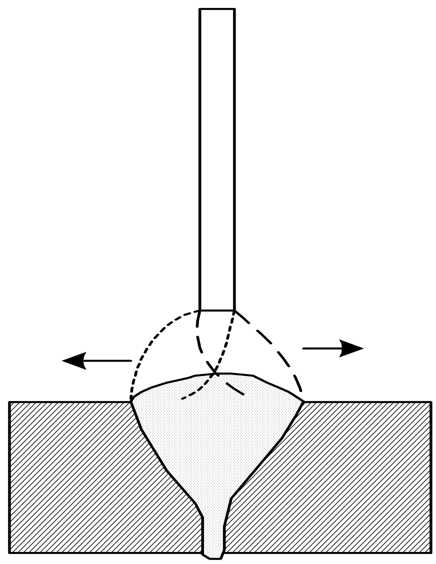

Fig. 34.2 Arc oscillation due to electromagnetic filed around welding arc.

34.3 Welding Parameter

Heat generated (kJ) by the arc is obtained from the product of welding current and arc voltage (V.I) for given welding conditions such as type, and size of electrode, arc gap, base metal and shielding gas (if any). While the exact amount of heat supplied to base metal for melting the faying surfaces is significantly determined by the welding speed. Increase in welding speed for a given welding current and voltage results in reduced heat input per unit length of welding (kJ/mm) which is also termed as net heat input for sake of clarity. Cooling rate experienced by the weld metal and heat affected zone is found inversely proportional to net heat input (Fig. 34.3). High the heat input lowers the cooling rate. Low cooling rate results in a) increased solidification time (needed to extract complete sensible and latent heat from the molten weld pool) and b) high effective solid to liquid state transformation temperature. Longer solidification time permits each grain to grow to a greater extent which in turn produces coarse grain structure. Further, high heat input causing high effective liquid solid transformation temperature produces low nucleation and high growth rate which in turn results in coarse grain structure. Increase in welding current or reduction in welding speed generally increases the grain size of weld metal as it increases the net heat input and lowers the cooling rate experienced by the weld metal during solidification.

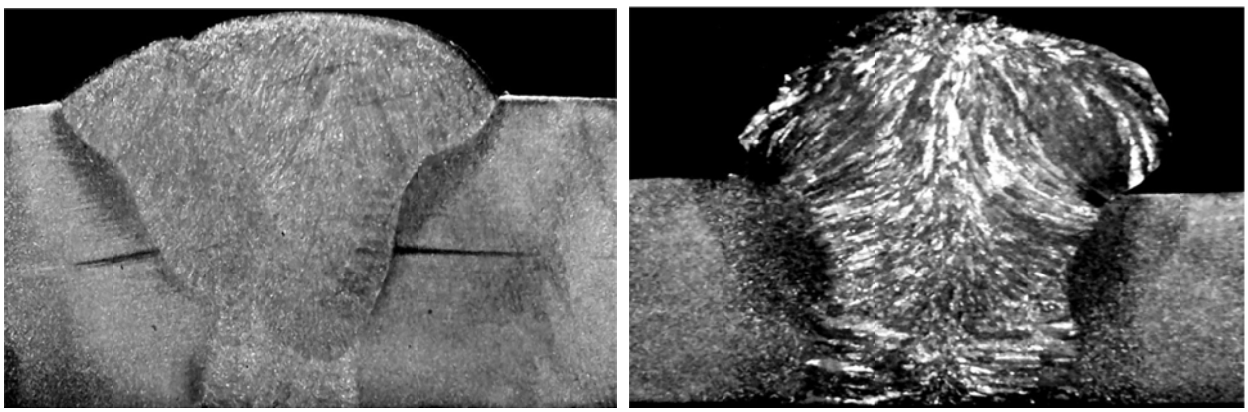

Fig. 33.4 Macro-photographs of weld joints produced using a) 3.0 kJ/mm and b) 6.0 kJ/mm heat input with help of submerged arc welding.

34.4 Typical metallurgical discontinuity of the weld

Due to typical nature of welding process, common metallurgical discontinuities observed in the weld are banding and micro-segregation of the elements. In the following section these have been described in detail.

34.4.1 Micro-segregation

Micro-segregation refers to non-uniform distribution of elements in the weld which primarily occurs due to inherent nature of solidification mechanism i.e. transformation of high temperature alpha phases first from liquid to solid by rejection of alloying elements into the liquid metal thereby lowering solidification temperature. Except planar mode, other modes of solidification namely cellular, dendrite and equiaxed involve segregation. Therefore, inter-cellular, inter-dendritic and inter-equiaxed region is generally enriched of alloying elements compared to cells (Fig 33.4).

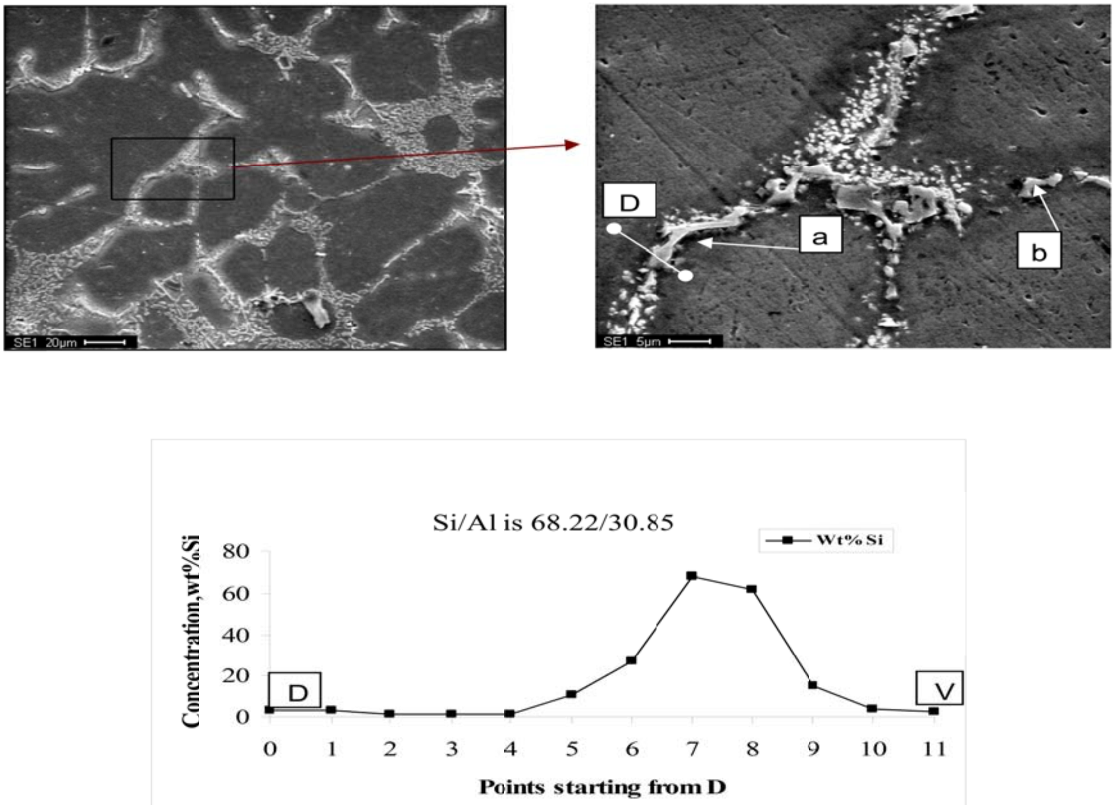

Fig. 34.4 Segregation of alloying elements at grain boundary

34.4.1 Banding

Welding arc is never in steady state as very transient heat conditions exit during arc welding which in turn lead to severe thermal fluctuations in the weld pool therefore cooling conditions varying continuously during the solidification. Variation in cooling rate of weld pool causes changing growth rate of the grain in weld and fluctuating velocity of solid-liquid metal interface. Abrupt increase in growth rate decreases the rate of rejection of alloying elements in liquid metal near the solid-liquid metal interface due to limited diffusion of alloying elements while low cooling rate increases the rejection of elements near the solid liquid metal interface as long time available for diffusion to occur. This alternate enrichment and depletion of alloying elements produces band like structure as shown in Fig 34.5. This structure is known to adversely affect fatigue and notch toughness properties of weld joints.

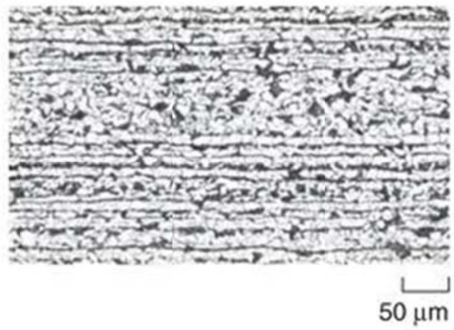

Fig. 34.5 Typical micrograph of steel showing banded structure (S Kou, 2003)

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