Influence of various welding

This chapter presents the influence of various welding related parameters on fatigue behavior of weld joints. Attempts have been made to explain how (residual stress, mechanical properties and microstructure) fatigue performance is affected by variation in welding parameters.

Keywords: Welding parameters, welding procedure, edge preparation, welding process, welding consumable, cleanliness, flux, electrode diameter, post weld heat treatment

29.1 Parameters related with welding

There are many aspects related with welding which influence the fatigue performance of a sound (defect free) weld joint such as welding procedure, weld bead geometry, weld joint configuration and residual stress in weld joint. These parameters affect the fatigue performance in four ways a) how stress raiser in form of weld continuities are induced or eliminated, b) how do residual stresses develop due to weld thermal cycle experienced by the metal during the welding, c) how are mechanical properties such as strength, hardness, ductility and fracture toughness of the weld joint influenced and d) how is the microstructure of the weld and HAZ affected by the welding related parameters.

29.1.1 Welding procedure

Welding procedure includes the entire range of activities from edge preparation, selection of welding process and their parameters (welding current, speed), welding consumable (welding electrode and filler, flux, shielding gas), post weld treatment etc needed for development of a weld joint. Following sections describe effect of various steps of welding procedure on the fatigue performance of the weld joints.

Edge preparation

There are two main aspects of edge preparation which can influence the fatigue performance of a weld joint a) cleanliness of faying surface and b) cutting of faying surface of base metal to be welded by fusion arc welding process. Surface and edge of the plates to be welded are cleaned to remove the dirt, dust, paint, oil, grease etc. present on the surface either by mechanical or chemical methods. Use of chemical approach for cleaning the surface using hydrogen containing acid (sulphuric acid, hydrochloric acid etc.) sometimes introduce hydrogen in base metal which in long run can diffuse in weld and HAZ and facilitate crack nucleation & propagation (by HIC) besides making weldment brittle (Fig. 29.1). Further, improper cleaning sometimes leaves impurities on faying surface, which, if are melted or evaporated during the welding then these impurities can induce inclusions in weld metal. Presence of inclusions in weld metal acts as stress raiser for nucleation and growth of cracks and so weakens the joint and lowers fatigue performance. Cutting of hardenable steel plates by thermal cutting methods such as gas cutting also hardens the cut edge. These hardened edges can easily develop cracks in HAZ under the influence of the residual stresses caused by weld thermal cycle associated with welding.

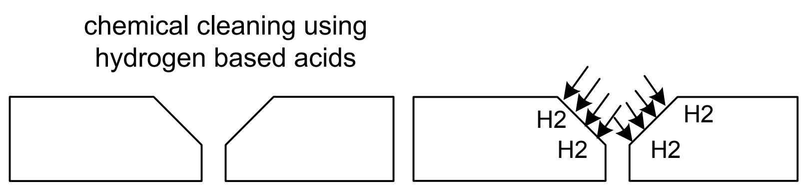

Fig. 29.1 Hydrogen based chemical cleaning can introduce hydrogen in weld

29.1.2 Welding process

Welding process affects the fatigue performance in two ways a) net heat input per supplied during welding affects cooling rate and the so weld-structure and b) soundness / cleanliness of the weld. Arc welding processes use heat generated by an arc for melting of the faying surfaces of the base metal. Heat generation from welding arc (VI) of a process depends on welding current (A) and welding arc voltage (V) while net heat supplied to base metal for melting is determined by welding speed (S). Therefore, net heat supplied to the faying surfaces for melting is obtained from ratio of arc heat generated and welding speed (VI/S). Net arc heat supplied to base metal falls over an area as determined by arc diameter at the surface of base metal. Net heat input per unit area of the base metal affects the amount of the heat required for melting. Higher the net heat input lower is cooling rate (Fig. 29.2). High cooling rate results in finer grain structure and better mechanical properties hence improved fatigue performance while low cooling rate coarsens the grain structure of weld which in turn adversely affects the fatigue life. However, high cooling rate in case of hardenable steel tends to develops cracks and harden the HAZ which may deteriorate the fatigue performance of the weld joints.

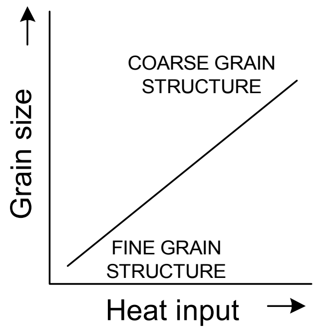

Fig. 29.2 Schematic diagram showing effect of heat input on cooling rate and grain structure of the weld

Each arc welding process offers a range for net heat input capacity which in turn affects the cooling rate and so the grain structure and fatigue performance accordingly. For example, shielded metal arc welding possess provides lower net heat input unit area than gas tungsten arc welding for developing sound weld joints.

Impurities in the form of inclusion in weld are introduced due to interactions between the molten weld metal and atmospheric gases. However, the extent of contamination of the weld metal by atmospheric gases depends on the shielding method associated with the particular welding process to protect the “molten weld”. Each method has its own approach/mechanism of protecting the weld. GTA welding offers minimum adverse effect of weld thermal cycle and cleanest weld in terms of lowest oxygen and nitrogen content in the weld metal as compared to other welding process. On contrary SAW welding results in high oxygen concentration in weld while self shielded arc welding process produces weld joints with large amount of oxygen and nitrogen as impurities in the weld metal. These gases in turn result in inclusions and porosity in the weld and so degrades their fatigue performance. Therefore, selection of welding process affects the fatigue performance appreciably.

29.1.3 Welding consumables

Depending upon the welding process being used for fabrication of a fusion weld, variety of welding consumables such as welding electrode, filler wire, shielding gas, flux etc. are applied. The extent up to which the factors related with welding consumables influence the fatigue performance is determined by the fact that how following characteristics related with welding are affected by welding consumables:

a) net heat input

b) cleanliness of the weld metal
c) residual stress development
d) microstructure and chemical composition
e) mechanical properties of the weld joints

Effect of each of above aspects related with welding has already been described under separate headings in previous section. In following section, influence of welding consumable on each of the aspects will be elaborated.

a) Electrode

Electrode diameter, and its material affect the arc heat generation (due to variation in area over which is heat is applied and amount of heat generated (as per welding current and arc voltage) which in turn governs weld thermal cycle and related parameters such as cooling rate, solidification rate, peak temperature and width of HAZ. Large diameter electrodes use high welding current which in turn results in high net heat input. Composition of the electrode material affects the solidification mechanism of the weld metal, residual stress in weldment and mechanical properties of the weld metal. Electrode material similar to that of base metal results in epitaxial solidification and otherwise heterogeneous solidification through nucleation and growth mechanism is followed. The difference in thermal expansion coefficient and yield strength of electrode metal with respect to base metal determines the magnitude of residual stress in weld and HAZ region. Larger is the difference in thermal expansion coefficient of two (base metal and weld metal) higher will be the residual stresses. Further, low yield strength weld metal results in lower residual stresses than high yield strength metal. Development of tensile residual stresses in general lowers fatigue life of weld joints. Further, according to the influence of the solidification mechanism, microstructure and residual stress on mechanical properties of weldment, fatigue performance is governed. The equiaxed solidification mode, fine grain structure, compressive residual stresses improve the fatigue performance of the weld joints.

b) Coating material and flux

Presence of low ionization potential elements like Na, K, Ca etc. (in large amount) lowers the heat generation as easy emission of free electrons from these elements in coating material in the arc gap improve the electrical conductivity by increasing the charge particle density which in turn reduces the electrical resistance of arc column and so heat generation for a given current setting. Additionally, the basicity index of the flux or coating material on the electrode affects the cleanliness of the weld. In general, flux or coating material having basicity index greater than 1.2 results in cleaner weld than that of low basicity index. Thickness of the coating material on the core wire in SMA welding affects the contamination of the molten weld pool by influencing the shielding capability from atmospheric gases. Thicker is flux coating on the core wire better is protection due to release of large amount of inactive protective gases from thermal decomposition of coating materials and so cleaner is weld. However, increase in thickness of flux layer in SAW lowers the cooling rate of weld metal during the solidification and increases the protection from atmospheric contamination. Effect of both these factors on fatigue performance of the weld is expected to be different e.g. low cooling should adversely affect the mechanical properties and fatigue performance while cleaner weld should offer better fatigue performance owing to absence of stress raisers in form of inclusions.

c) Shielding gas

The effect of shielding gas (helium, argon, carbon dioxide, and mixture of these gases with oxygen, helium and hydrogen) on fatigue performance of the weld joint is determined by two factors:

a) **Effect of shielding gas on the arc heat generation**: The shielding gas affect the heat generation in the arc gap due to difference in ionization potential of different shielding gases. The variation in heat input in turn affects the cooling rate and so resulting microstructure and mechanical properties of the weld. High ionization potential shielding gas in general burns the arc hotter which in turn leads to lower net heat input higher cooling rate thus finer structure and improved mechanical properties produce enhanced fatigue performance of the weld joint. Addition of oxygen, hydrogen and helium in argon increases the arc heat generation and penetration capability of the arc.

b) **Effect of shielding gas on the cleanliness of the weld**: Shielding capability of each of the above mentioned gases to protect the molten weld pool from atmospheric gases is found different. Helium and argon provide more effective shielding than carbon di-oxide and other gases and hence they result in better fatigue performance of the weld joints. As carbon dioxide tends to decompose in arc environment to produce Co and O_2. Presence of oxygen arc zone can contaminate the weld metal.

29.1.4 Post Weld Heat Treatment

Weld joints are given variety of heat treatments (normalizing, tempering, stress relieving, Q &T, T6 treatment) for different purposes ranging from just relieving the residual stress to manipulating the microstructure in order to obtain the desired combination of the mechanical properties. In general, post weld heat treatment operation relieves the residual stresses and improves the mechanical properties; these in turn result in improved fatigue performance of the weld joints. However, improper selection of type of PWHT and their parameters like heating rate, maximum temperature, soaking time and then cooling rate, can deteriorate the microstructure and mechanical properties, induce unfavorable softening or hardening of HAZ, tensile residual stresses and cracking in HAZ. As a result, unfavorable PWHT can adversely affect the fatigue performance of the weld joint.

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