Fatigue performance of weld joints

This chapter presents various approaches commonly used for enhancing the fatigue performance of weld joints namely reducing stress raiser, improving mechanical properties and inducing compressive residual stresses. Methods of improving fatigue behavior of weld joints based on above approaches have been elaborated.

Keywords: Improving fatigue performance, stress raiser, compressive residual stress, TIG dressing, shallow hardening, shot peening, overloading

30.1 Improving the fatigue performance of the weld joints

The performance of welded joints can be improved using multi-pronged approach which includes enhancing the load carrying capability of the weld by improving the mechanical properties of the weld, reducing the stress raisers, developing favorable compressive residual stresses. The basic principles of these approaches have been presented in following sections.

30.1.1 Increasing load carrying capacity of the weld

Load carrying capability of the weld joints can be enhanced by selecting proper electrode or filler metal and proper welding procedure so to obtain the desired microstructure and mechanical properties of the weld joints. Efforts are made to achieve the fine equiaxed grain structure in weld with minimum adverse affect of weld thermal cycle on the heat affected zone. These factors are influenced by electrode material composition, net heat input during welding and presence of nucleating agents in weld metal to promote heterogeneous nucleation so as to get refined equiaxed grain structure in the weld metal. Inoculation involving addition of the element like Ti, V, Al and Zr are commonly used in steel and aluminium welds to realize the fine equiaxed grain structure. Additionally, application of external excitation techniques such magnetic arc oscillation, arc pulsation and gravitational force method can also be used for grain refinement of weld metal. Selection of proper welding parameters (welding current, speed) and shielding gas also help to refine the grain structure of the weld by reducing the net heat input for developing weld joints. In general, fine equiaxed grain structure is known to enhance the load carrying capacity of weld joints and fatigue performance of the weld joints. Post weld heat treatment namely normalizing also helps to a) enhance fatigue performance of weld joints, b) refine the structure and c) relieve the residual stress. Surface and case hardening treatments like carburizing and nitriding also help to increase the fatigue performance of the weld joints in two ways a) increase the surface hardness up to certain depth and b) inducing compressive residual stresses.

30.1.2 Reducing stress raisers

First stage of fatigue crack nucleation is largely influenced by the presence of the stress raisers on the surface of engineering component subjected to fatigue loading. These stress raisers in the weld joints are mostly found in the form of ripples present on the surface of weld in as welded condition, sharp change in cross section at the toe of the weld, cracks in weld metal and heat affected zone, inclusions in weld, too high bead angle, excessive reinforcement of the weld bead, crater and under-fill (Fig. 30.1).

In order to reduce adverse effects of stress raisers on fatigue performance of weld joints, it is necessary that stress raisers in form of poor weld bead geometry and weld discontinuities are reduced as much as possible by proper selection of the welding parameters, consumable, manipulation of welding arc and placement of molten weld metal (Fig. 30.2). Presence of inclusions and defects in the weld metal can be reduced by re-melting of small amount of weld metal near toe of the weld using tungsten inert gas arc heat (Fig. 30.3). This process of partial re-melting weld bead to remove defect and inclusions especially near the toe of the weld is called TIG dressing. TIG dressing is reported to increase the fatigue life by 20-30% especially under low stress fatigue conditions. The TIG dressing also disturbs the system of residual stress by the re-melting a small portion of weld and HAZ.

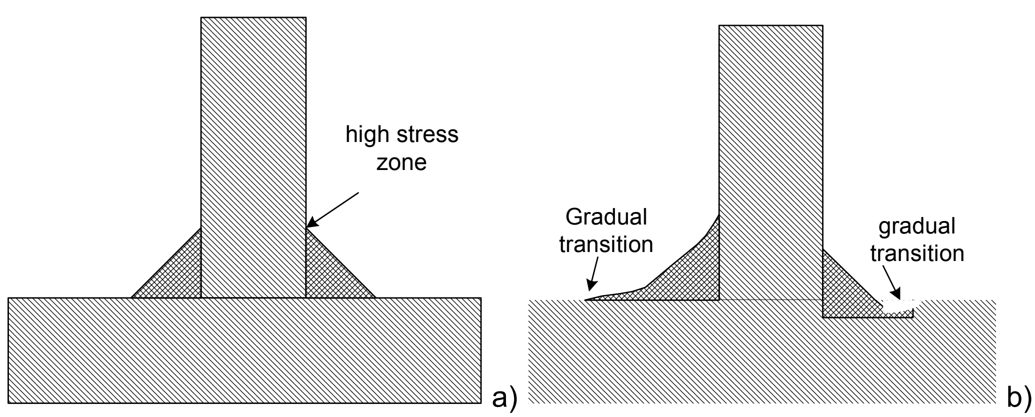

Fig. 30.1 Reducing stress concentration at toe of the weld a) toe with sudden change in cross section causing high stress concentration and b) providing some fillet at the toe of the weld by grinding

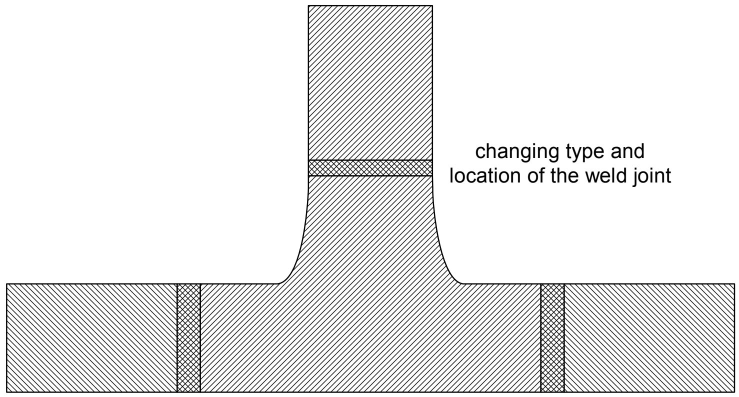

Fig. 30.2 Schematic diagram showing change on joint configuration from fillet to butt joints

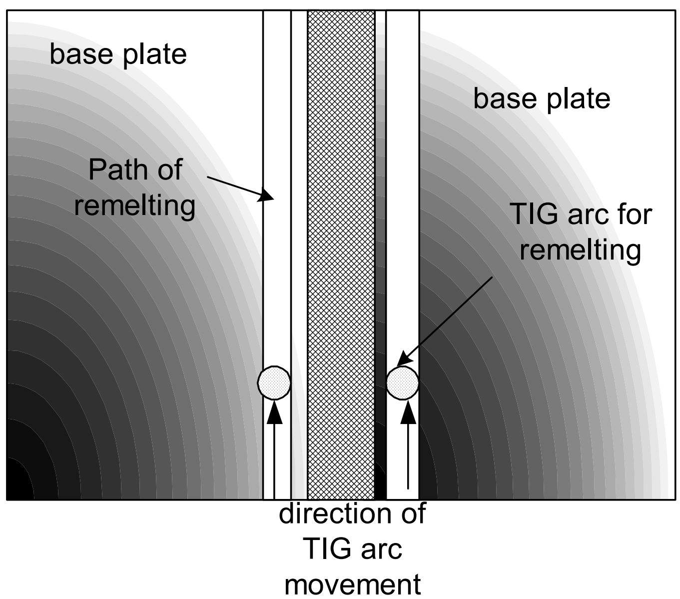

Fig. 30.3 Schematic of TIG dressing

Controlled removal of material from the toe of the weld by machining or grinding in order to give suitable fillet so as to avoid abrupt change in cross section of the weld is another method of enhancing the fatigue life of weld joints by reducing the severity of stress raisers.

Further, attempts should be made to reduce the weld bead angle as low as possible so that transition in cross-sectional area from the base metal to the weld bead is gradual to produce a weld joint without stress concentration (Fig. 30.1). Weld joints with machined, ground and flushed weld bead offer minimum stress concentration effect and hence maximum fatigue life. Additionally, efforts can be made to relocate the stress raisers away from the high stress areas by redesigning of components. For example, fillet weld can be replaced with butt weld by relocating the weld through redesign of component (Fig.30.2)

30.1.3 Developing compressive residual stress

This method of improving the fatigue performance of the weld joints is based on simple concept of lowering the effective applied tensile stresses by inducing compressive residual stress. This type of stress to some extent neutralizes/cancels the magnitude of externally applied tensile stress. Therefore, this method is found effective only when fatigue load is tensile in nature and its magnitude is lower than yield strength. Moreover, this method marginally affects the fatigue performance of the weld joints under low cycle fatigue conditions when fluctuating loads and corresponding stresses are more than yield strength of weld. Improvement in fatigue performance of the weld joint by this method can vary from 20-30%. There are many methods namely shot peening, overloading, spot heating, and post-weld heat treatment, which can be used to induce compressive residual stress. All these methods are based on principles of differential dimensional/volumetric change at the surface layer and core of the weld by application of either localizing heating or stresses beyond yield point.

a) Shot peening

In case of shot peening, high speed steel balls are directed towards the surface of the weld joint on which compressive residual stress is to be developed. Impact of shots produces indentation through localized plastic deformation at the surface layers of weld and HAZ while metal layers below the plastically deformed surface layers are subjected to elastic deformation. Material further deeper from the surface remains unaffected by shots and plastic deformation occurring at the surface. Elastically deformed layers tend regain their dimensions while plastically elongated surface layers resist any come-back. Since both plastically and elastically elongated layers are metallurgically bonded together therefore elastically elongated under-surface metal layer tends to put plastically elongated surface layer under compression while elastically elongated under-surface layers come under tension. Thus, residual compressive stresses are induced at shot peened surface. Presence of tensile residual stress below the surface is not considered to be much damaging for fatigue life as mostly fatigue failures commence from the surface.

b) Overloading

This method helps to reduce the residual stresses by a) developing the opposite kind of elastic stresses and b) relieving the locked in strain using plastic deformation by overloading the component under consideration.

c) Shallow hardening

Shallow hardening improves the fatigue performance in two ways a) increase in the hardness of surface and near surface layers which in turn delays crack nucleation stage of fatigue fracture and b) development of residual compressive stress at the surface reduces adverse effect of the external tensile stresses on all stages of fatigue fracture hence improve the fatigue performance. However, under external compressive loading conditions, residual compressive stresses will deteriorate the fatigue performance of welds.

References and books for further reading

- John Hicks, Weld Joint Design, Abington Publishing, 1999, 3rd edition, England.
- S. J. Maddox, Fatigue strength of welded structures, Woodhead Publishing, (1991)
- R S Parmar, Welding engineering & technology, Khanna Publisher, 2002, 2nd edition, New Delhi.
- Welding handbook, American Welding Society, 1987, 8th edition, volume 1 & 2, USA.

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