Effect of Vibratory Weld Conditioning on Residual Stresses: A Review

M.VykuntaRao
Department of Mechanical Engineering
GMR Institute of Technology, GMR Nagar, Rajam Andhra Pradesh State, India
P. Devi Prasad
Department of Mechanical Engineering
Aditya Institute of Technology and Management, Tekkali A.P. India
P. Srinivasa Rao
Department of Mechanical Engineering
Centurion University of Technology and Management, Odisha State, India

Abstract-In fusion welding process, because of uneven heating and cooling cycles residual stresses are induced within the material. Vibratory weld conditioning is non-thermal and energy efficient method in which the specimen is vibrated during welding. In this a periodic energy is given to the specimen, this periodic force influences the weld pool and leads to the formation of Refined grain structure so that there will be decrease in the residual stresses. This paper presents the effect of vibratory weld conditioning on residual stresses.

Keywords: Vibratory weld conditioning, Residual stresses, welded joints, post weld vibration.

INTRODUCTION:

In the fusion welding process, the welded specimens are subjected to local non-uniform heating and cooling cycles. Non-uniform heating and cooling cycles causes the residual stresses in the weldments. Residual stresses reduce the fatigue life of welded structures. To reduce the residual stresses there are several methods available such as design considerations, material considerations, preheating, welding procedure, welding sequence, post weld heat treatment, natural ageing, and peening and vibratory stress relief. Vibratory stress relief is a non-thermal method in which the vibration energy with different frequencies is imparted to the weldments during welding.

LITERATURE SURVEY:

Reduction of residual stresses in welded joints are of prime importance. The reduction of residual stresses is achieved by subjecting the specimen to vibrations. The vibrations which are given to the specimen are broadly categorized into two types. Firstly, post weld vibratory treatment, in which the vibrations given to the specimen during cooling that is after completion of welding Munsi et al., (2001, Munsi et al., (2000). Second one is the vibrations given to the specimen during welding.

In the post weld vibration technique, the time period of first five seconds of vibrations has more influence on the reduction of residual stresses. Subsequent vibration after this time period has little or no influence on the reduction of residual stresses. Effect of time of vibration on the reduction of residual stresses during post weld vibration is investigated by the Munsi et al., (2001). Authors investigated that during the post weld vibratory technique, when the applied stress is less than the 230MPa, influence of time of vibration on the reduction of residual stresses is very small. If the applied stress is more than 230MPa, increase in time of vibration will redistribute the residual stresses. Zhu et al., (2005) was given two different vibrational frequencies in the electro slag welding of base metal BB503. The distribution of residual stresses is measured by blind hole drilling method. From the metallographic study, the part of the specimen which is vibrated at 0.6g vibrational frequency is found to have a smaller grain size compared to 0.3g vibrational frequency. Vibratory weld conditioning can form low residual stresses which may be half of the yield stress. Effect of pulsed gas tungsten arc welding parameters on the residual stress of the weldments investigated by the Tseng and Chou, (2002). Autogenous gas tungsten arc welding was performed on SUS 304 and SUS310. Residual stresses can be minimized with the increase in the pulse frequency and amplitude ratio in the pulsed gas tungsten arc welding.

Vibrations given to the specimen during welding are of two types. One is random vibration method and the other is harmonic vibration. In the random vibration method, white noise method is the one in which welded specimen is vibrated to different frequency levels. Another one is the filtered white noise which confirms to the natural frequency of the welded specimen. The noticeable improvement through the application of the stated two modes of vibrations is that the tensile residual stresses near the bead are reduced [Aoki et al., (2005)]. The harmonic load is another method to decrease the residual stresses [Aoki et al., (2007)]. Near the weld bead reduction in residual stress is observed in the Rolled and high tensile strength steel when it is vibrated at a frequency of 20 Hz, 30 Hz and 40 Hz. Kuo et al., (2007) investigated the effect of steady state vibrations on microstructure, δ-ferrite content and residual stresses of 304 stainless steel specimens. In these 304 stainless steel specimens are welded by using gas tungsten arc welding under steady state vibrations like 0Hz and 39.4 Hz which is a sub resonant frequency. Because of these steady state vibrations of 39.4Hz, dendrite arm of δ-ferrite content becomes short and very fine which results in fine grain structure. Due to this the residual stresses got reduced from 262 to 206 MPa.

The most common methods to reduce the residual stresses is heat treatment or annealing. Heat treatment process can be used effectively for small sized components. But, for large components these methods are not suitable due to the furnace size limitation. Vibratory stress relief is one kind of mechanical method of relieving residual stresses. In this the vibrations are given to the component by an eccentric circulating electric motor. The basic phenomenon in VSR is that, the cyclic stresses will be given to the component, which will be more than the yield strength. The time at which the component is vibrated depends upon the weight and its recrystallization temperature.

Rao et al., (2004) applied the vibratory welding on the magnetic levitation transport system. Eccentric recirculating motor was attached to the one end of the rail. Rigid clamps were used to clamp the motor to the rail. Vibrations were controlled by varying the speed of the motor. The running speed of the motor was controlled by computer. For 15-20 minutes the rail was vibrated at its natural frequency. Residual stresses were measured through the hole drilling method. Authors concluded that with the vibratory stress relief, average principle stresses were reduced by 30% when compared to without vibration.

Finite element technique is another effective method to measure the residual stresses. 3-D finite element method is used by Akbari and Sattari-Far, (2009) to investigate the influence of weld heat input on the development residual stresses in a dissimilar pipe joints made of A240-TP304 stainless steel and A106-B carbon steel. In the stainless-steel part, residual stresses distribution can be reduced by reducing the heat input compared to carbon steel. The thermo-mechanical behavior in weldments can also be analyzed by FEA using thermal elasto-plastic analysis. Because of localized heat and rapid cooling at the toe of the butt weld joint, tensile residual stresses can be decreased and fatigue performance of welded structure can be improved (Teng and Chang, (2004)). It is possible to predict fatigue crack initiation life in weldments by combining the finite element analysis with strain life equation (Teng et al., (2002)). Weld geometry parameters like toe radius and flank angle influenced the fatigue crack initiation life. It is always possible to increase the crack initiation life by increasing the toe radius and decreasing the flank angle. Fatigue crack initiation life of butt welded joints can also be increased by reducing the residual stresses through preheating process. Finite element technique can also be extended to investigate the thermo-mechanical behavior of residual stresses in various types of welding sequences in single-pass, multi-pass butt welded pipes and circular patch welds. In this regard, large tensile stresses appear near the bead and compressive stresses occur away from the bead (Teng et al., (2003)).

Munsi et al., (2001) investigated the influence of dynamic torsional shear stress on the residual stresses. Authors also observed that there is partial reduction of residual stresses in the welded shafts. In some cases, where the cold work or shrinkage was involved, the authors observed that there is redistribution of residual stress state due to the applied shear stresses. Because of vibratory stress relief, residual stresses in the welded steel plates of D6AC and D406A can be decreased to zero stress point (Sun et al., (2004)). Effect of vibratory welding on multi pass girth butt welded pipes was investigated by Xu et al., (2007). Authors observed that the residual stresses at the outer surface and axial distortions were less influenced by Vibratory weld conditioning. With the VWC, sensitiveness to fatigue failure decreases. Effect of vibratory weld conditioning on the residual stresses and transverse contraction distortions in the multi pass welding of A105 forging steel was observed by Xu et al., (2006). Vibration accelerations of 0.6g were selected for study and it was observed that reduction in transverse contraction and reduction of residual stress is more with VWC compared to normal welding. Rao et al., (2007) evaluated the effectiveness of vibratory stress relief by using cyclic loading on 304L stainless steel welded structure. The authors established a relationship between the reduction of residual stress and amplitude of dynamic stress.

Zhao et al., (2008) developed finite element model for the simulation of vibratory stress relief after welding and observed the influence of load amplitude, vibration time on the reduction of residual stress. Authors concluded that, for non-resonant vibratory stress relief, if the load amplitude is not proper, residual stress cannot be decreased and further it develops the new residual stresses. Vibration time is not a significant factor in vibratory stress relief. Fatigue life can be decreased with the increase in vibration time. Sun et al., (2004) explored the distribution of residual stresses in the marine shafting of $35^{\#}$ bar steel with and without vibratory stress relief. The tensile properties of marine shafting of $35^{\#}$ bar steel compared before and after vibration. Authors found that by applying vibrations macro residual stresses were decreased by around 48% in the $35^{\#}$ bar steel and the tensile properties also got modified.

Sattari-Far and Farahani, (2009) investigated the effect of weld groove shape and weld pass number on residual stresses in butt welded pipes using finite element technique. authors considered pipe joints of 6 mm and 10 mm thickness, weld groove shapes of X1, X2, u and V. Authors observed that in case of 6 mm thick plates residual stress distribution had not at all influenced by weld groove shape. In thin pipes with the increase of pass number, the residual stresses were found to be decreased. Kwofie, (2009) developed a stress relaxation model for vibratory stress relief by means of matlab/simulink program. Strain sufficiency, yield stress and starting strain solidifying rate on the adequacy of the VSR treatment might be clarified. Authors observed that Vibratory stress relief was an uneven deformation phenomenon. During vibration material was experienced different cyclic stress - strains. Authors concluded that developed model helps in developing the standardized methods for the evaluation of Vibratory stress relief in real time.

Residual stress reduction in large structures is difficult by means of thermal stress relief. Authors found that VSR is an alternative method to heat treatment. Rao et al., (2005) investigated the influence of VSR on the welded structures. Residual stresses were measured by the hole drilling method on weld bead before and after Vibratory stress relief treatment. Authors concluded that after VSR treatment, in the drum hoist machine the average principal stresses decreased by 56% and 31 % decrease in the stainless steel 304L plate.

CONCLUSIONS:

- After VSR treatment, in the drum hoist machine the average principal stresses decreased by 56% and 31 % decrease in the stainless steel 304L plate.
- With the Vibratory weld conditioning, with the increase of pass number, the residual stresses were found to be decreased in thin pipes.
- With the applications of vibrations macro residual stresses were decreased by around 48% in the $35^{\#}$ bar steel and the tensile properties also got modified

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