IJSTE - International Journal of Science Technology & Engineering | Volume 5 | Issue 12 | June 2019
ISSN (online): 2349-784X

A Review Paper on Fatigue Strength and Crack Initiation Analysis of Welded Joints of Mild Steel

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Abstract

Aim of this paper is to study about the fatigue strength of welded joints by means of fracture mechanics approach that takes into account the fatigue behavior of welded joints. The methodology helps to find out the fatigue crack propagation rate as a function of the difference between the applied driving force and the material threshold for crack propagation, a function of crack length. Failure of welded structures or machine parts causes different direct losses such as the cost of repair work, the cost of the work to avoid upcoming failure and accident compensation, and decrease in production. Joints being the weakest element in any structure/machine are possible to fail first. Therefore, it is essential to analyze the failure of those joints. Understanding a failure occurrence and its propagation will result in a better appreciation of welded joints from reliability point of view. It may be feasible that some purpose activities or failure causes may be critical and may be minimized at layout or fabrication stage main to failure minimization of such joints.

Keywords: Fatigue, Welded joint, Stress Concentration factor, Life cycle

I. Introduction

Over the last decades, numerous concepts have evolved for Fatigue analysis of welded assemblies. The traditional approach is to analyze the fatigue life based on the nominal stress concept. This concept derives the stress state at the weld seam according to a beam theory approach. The Forces and Moments acting on a certain cross section are divided by the section properties to yield the nominal membrane and bending stress. Failure of material under cyclic loading is termed as fatigue. Many engineering designs are based on the structural applications, for example, cranes, bridges, vehicles, in transportation industries etc. In such cases, fatigue analysis of welding is the major part of interest. In transportation applications such as welding joints faces the cyclic loading. Therefore such structural elements are designed on fatigue considerations. Fatigue is a very complicated process in material. The fracture of the material starts in structure and initiation of micro crack takes place. These micro cracks propagate and becomes visible as main crack. Fatigue in welding is one of the more complicated processes. During welding process, material is affected by heating and cooling as well as fusion process with addition of filler material. Welding is also affected by, containing cavities, pores, undercuts, lack of penetration etc. During welding high stress concentrations occurred. In welding, fatigue failure occurs at the welds rather than in the base metal. In fatigue analysis of welded joints different methods are used. From the viewpoint of fracture mechanics, fatigue crack initiates from the surface or near-surface defects of structure and then propagates until the structure fails. Steel materials are widely used in number of engineering applications. Now days, they are increasingly demand for structural applications. Steel materials give good mechanical and chemical properties. Many applications in the structural areas involve welded components, which have to be designed to avoid fatigue failure.

II. Literature Review

The welding of Mild Steel and its alloys has always represented a great challenge for researchers and technologists. Welding is a process that has produced low cost and high quality joints of aluminum alloys. For carrying out research work in any area, the first and an important phase is to review the available literature for the selected topic and the research problem can be formulated with clear objectives. In order to formulate the present research problem along with the methodology that could be adopted for accomplishing this research work, the selective review of the relevant literature surveyed is presented briefly in following categories.

1) Effect of Weld bead geometry profile on fatigue strength.
2) Welding joint parameter.
3) Fatigue analysis of joint.
4) Effect of materials on weld strength.

A. *Effect of Weld bead geometry profile on fatigue strength.*

V. Caccese et. al. (2006) the effect of weld geometric profile on fatigue life of laser-welded HSLA-65 steel is evaluated. Presented results of cruciform-shaped fatigue specimens with varying weld profiles loaded cyclically in axial tension–compression. Specimens with a nearly circular-weld profile were created at 133 cm/min, as part of this effort, with a hybrid laser gas-metal-arc welding GMAW (L/GMAW) process. The ability of the laser-welding process to produce desirable weld profiles resulted in fatigue life superior to that of conventional welds. Comparison of finite-element analyses, used to estimate stress-concentration factors, to the hot spot and mesh insensitive approaches for convergent cases with smooth weld transitions is presented in relation to the experimental results.

Vijay Kumar et. al. (2016) parametric study has been carried out, overlap length and gap size are selected as parameters to be varied during experimentation. The range of parameters is decided by referring literature. Design and validation of fixture is carried out for testing purpose. Specimens are prepared with greater accuracy and tests were carried out using UTM. The results obtained from experimentation are compared with result obtained from simulation. Various design parameters are considered and effect of these parameters on tensile strength of lap welded joint is discussed. Analytical design procedure was adopted for designing fixture to hold the specimen. The specimen dimensions were finalized and specimens were prepared by varying overlap length and gap size.

K. V. Sastry et. al. (2015) conducted a simulation analysis of weld joint by varying its weld bead size. The T – joint Structural and fatigue analysis are done in solid works simulation. By observing the structural analysis results, all the joints are withstanding the applied pressure as the analyzed stress values are less than the yield strength of steel. The finite element analysis is used for the analysis of joints in the plane – stress condition, under static load. Fatigue analysis is done to analyze the fatigue usage by applying cyclic loading. By observing the analysis results, the fatigue usage is more for Butt Joint, so the life of the Butt Joint is less than other two joints.

Akkas et. al. (2013) experimental study has been performed to obtaining a relationship between the values defining bead geometry and the welding parameters and also to select optimum welding parameters. The welding parameters such as the arc current, arc voltage, and welding speed which have the most effect on bead geometry are considered, and the other parameters are held as constant. Four, three, and five different values for the arc current, the arc voltage, and welding speed are used, respectively. So, sixty samples made of St 52-3 material were prepared. The bead geometries of the samples are analyzed, and the thickness and penetration values of the weld bead are measured. Then, the relationship between the welding parameters is modeled by using artificial neural network (ANN) and neuro fuzzy system approach. Each model is checked for its adequacy by using test data which are selected from experimental results. Then, the models developed are compared with regard to accuracy. Also, the appropriate welding parameters values can be easily selected when the models improve.

P. J. Mistry et. al. (2016) analyzed the effect of welding arc current, voltage, welding speed, and the contact tube to work distance on weld bead geometry such as weld penetration, weld bead width, and height of reinforcement. It is essential to assess the effect of process parameters on specific bead geometry and shape relationships. The result of this study helps in improved understanding of applying control methods in forecasting the quality of Weldments during electric arc welding. The weld bead shape of a welded joint determines the mechanical properties of the joint. Weld joint is considered to be sound and economical if it has a maximum penetration, bare minimum bead width, reinforcement and dilution. Enhancement in voltage will increase bead width, penetration, and reinforcement. Voltage has a positive effect while welding speed has a negative effect on weld bead width. The relationship between current, voltage, speed and contact tube to work distance with penetration, bead width, reinforcement height, WRFF, WPSF and dilution is explained. It is evident that a correct fine-tuning of welding process parameters yields a sound weld.

Yajima et. al. (2011) evaluated the toughness against unstable brittle fracture from fatigue crack, which is initiated and propagated from the surface of the butt-welded joints of heavy-thick steel plates. Centre-notched small size tension test specimens were made from butt-welded joints of 70 mm heavy-thick steel plates and employed for the tests using this plate thickness as the specimen width. In this paper, the test results are evaluated and investigated. When the tested electro gas-welded joint is applied to a large welded structure such as a mega-container ship, the allowable surface fatigue crack length along the welded bead is determined to be about 100 mm, when a nominal yield stress (460 N/mm2) is applied to the structure at -10 °C.

B. *Welding Joint Parameter*

R.S. Sharma et. al. (2009**)** conducted fatigue analysis of advanced high strength steels (AHSS) that are essential to meet the demands of safety and fuel efficiency in vehicle. Fatigue tests show that TRIP:MS combinations exhibited excellent fatigue life, with fractures occurring in the base metal region of mild steel at values approaching the tensile strength of mild steel The fusion zone was free of defects such as cracks, porosity, voids, inclusions and others.

Hongtao Zhang et. al. (2014) Studied about Traditional gas metal arc welding process, that was modified to change the fluid flow in the molten pool by the rotary motion of filler metal (wire) accompanied by downward feeding process. The rotary motion of the wire transfer red additional momentum in to weld pool and best owed the latter with rotating fluid flow characteristics. The rotating fluid flow of the weld pool decreased the penetration of the weld and refined the weld micro structure directly. The finer micro structure of the weld noticeably increased the tensile strength of the weld metal.

M Nagy et. al. (2017) focused on the application of numerical simulation to the design of welding parameters for the circumferential laser welding of thin-walled exhaust pipes from the AISI 304 steel for automotive industry. Using the developed and experimentally verified simulation model for laser welding of tubes, the influence of welding parameters including the laser velocity from 30 mm.s−1 to 60 mm.s−1 and the laser power from 500 W to 1200 W on the temperature fields and dimensions of fusion zone was investigated using the program code ANSYS. Based on obtained results, the welding schedule for the laser beam welding of thin-walled tubes from the AISI 304 steel was suggested.

Chaudhari et. al. (2014) the effects of welding process parameters of Gas Metal Arc Welding (GMAW) on tensile strengths are found out..The GMAW process is an important in many industrial operations. Experiments have been conducted as per central composite design matrix to find the effect of process control parameters: voltage, wire feed rate, welding speed and gas flow rate on tensile strength. The tensile testing of the welded joint is tested bya universal tensile testing machine and results are evaluated. MINITAB software is used to draw the direct and interactive graphs which show the effect of welding input process parameters on tensile strength.

Patel et. al. (2014) presents the influence of welding parameters like welding current, welding voltage, welding speed on ultimate tensile strength (UTS) of AISI 1030 mild steel material during welding. A plan of experiments based on Taguchi technique has been used. An Orthogonal array, signal to noise (S/N) ratio and analysis of variance are employed to study the welding characteristics of material & optimize the welding parameters. The result computed is in form of contribution from each parameter, through which optimal parameters are identified for maximum tensile strength. From this study, it is observed that welding current and welding speed are major parameters which influence on the tensile strength of welded joint.

C. *Fatigue Analysis of Joint*

Z. Barsoum et. al. (2009) a welding simulation procedure is developed using the FE software ANSYS in order to predict residual stresses. The procedure was verified with temperature and residual stress measurements found in the literature on multi-pass butt welded plates and T-fillet welds. The predictions show qualitative good agreement with experiments. The welding simulation procedure was then employed on a welded ship engine frame box at MAN B&W. A subroutine for LEFM analysis was developed in 2D in order to predict the crack path of propagating fatigue cracks. The objective was to investigate fatigue test results from special designed test bars from the frame box where all test failed from the non penetrated weld root. A subroutine was developed in order to incorporate the predicted residual stresses and their relaxation during crack propagation by ISO parametric stress mapping between meshes without and with cracks, respectively. The LEFM fatigue life predictions shows good agreement with the fatigue test result when the residual stresses are taken into account in the crack growth analysis.

F. Pakandam et. Al. (2010) they evaluated fatigue damage of different welded joints under uniaxial loading condition and its response on fatigue lifetime. The main variables influencing the fatigue life of a welded joint are: applied stress amplitude, material properties, geometrical stress concentration factor. Energy approaches were employed to evaluate the fatigue damage of various weld joints under uniaxial loading conditions. Energy-fatigue life (W-N) curves were further discussed and comported for their capabilities in assessing fatigue life of various joints through different parameters including curve slope, life data scatter, and how readily coefficients/constants are determined and employed in the energy methods. The critical plane/energy approach was found to be the most suitable energy-based approach for fatigue damage and life assessment of welded joints by offering sharper W-N curves and less life scatter. This approach also allowed employing readily available material coefficients/properties as compared with the notch stress-intensity energy approach.

Hamza Khatib et. al. (2016) estimates the fatigue life of the weld bead. The results obtained using this approach will be used to analyze the notch effects on the fatigue life of welded joints. Two joint configurations are analyzed at the end of this paper. The paper include two main parts, the first section will focus on calculating the fatigue curve (S-N) of the welded joint. These calculations are based on the local deformations approach (S-N) that requires fatigue parameters related to material strength. Determination of these parameters will be provided through a set of correlation formulas and static characterization tests. At the end of this part, the calculated fatigue curves (S-N), will be compared to other curves of three different materials in order to evaluate the accuracy of results.

F. R. Mashiri et. al. (2002) Investigation of welded thin-walled (t=4 mm) hollow sections in the manufacture of lighting poles, traffic sign supports, swing ploughs, linkage graders, trailers, and haymakers. These structures are subjected to fatigue loading. A review of current fatigue design guidelines showed that there is a lack of design rules for nodal joints made up of thin-walled (t<4 mm) hollow sections. This paper describes the tests carried out on welded thin-walled (t<4 mm) tube-to-tube T connections made up of square hollow sections under cyclic in-plane bending. Different failure modes were obtained during fatigue testing.

P. Selvakumar et. al. (2013) evaluated the fatigue performance using finite element analaysis, where the calculated stress can vary according to element sixze, type, etc. to overcome these challenges, battelle has developed a novel, mesh insensitive structural stress method. the stresses are calculated using the balanced nodal forces and moments obtained at the weld toe location from the finite element solutions. Working with industry partners, Battelle has also developed a unified master S-N curve that combines the effects of joint geometry, loading modes and thicknesses.

T. Marin et. al. (2009) presented a structural stress approach to fatigue assessment of welded joints that integrates well with finite element modeling. The implementation in a post-processor program was successful and showed the potential for becoming a useful tool for the design and assessment of welded structures subjected to fatigue. The mesh-insensitivity was confirmed; even coarse meshes provide adequate structural stress estimates so the method can be used in modeling complex structures. The procedure was applied to three different specimen geometries subjected to constant amplitude loading and predicted the correct location of the fatigue cracks. Finally, the use of the ASME master S-N curve proved to give accurate fatigue life predictions.

D. Effect of Materials on Weld Strength

Uygur et. al. (2014) evaluated effects of the shielding gas composition on tensile behavior, R=-1 fatigue response and various temperature impact result of MIG welded low carbon steel. In tensile test, the strength values are increased with increase of CO_2 content, whereas the ductility decreased. In the fatigue test, the fatigue strength and number of cycles to failure enhanced as the content of CO_2 increased. On this basis, an increase in CO_2 content causes improvement in the tensile strength where as the ductility is decreased. In the fatigue tests, S-N curves are quite similar in argon and CO_2 media, however they are shifted down and the fatigue strength is decreased CO_2 content is increased in the shielding gas.

Mitsuhiro Okayasu, et. al. (2013) they studied the fatigue and tensile properties of SPCC low carbon steel joints prepared by metal inert gas welding. the mechanical properties of the welded component in several localized regions, e.g., weld metal, heat affected zone(HAZ) and base metal, were investigated. The tensile and fatigue properties of the weld metals were high compared to the other areas (base metal and HAZ) due to the precipitated Ti containing oxide inclusions in acicular ferrite containing oxide inclusions in acicular ferrite. The fatigue strength of our samples has been analyzed to provide a direct prediction of the fatigue life with modified Goodman diagrams.

S. Bhattacharya et. al. (2013) investigation on joining C45 medium carbon steel specimens using gas metal arc welding employing 100% carbon dioxide as the shielding gas, and to find out the optimal set of process parameters utilizing the AHP. Three process parameters, weld speed, weld voltage and weld current were varied to evaluate the best combination of process parameters corresponding to an experimental run within the domain of the present work. As these process parameters have varying influence on weld quality, the AHP was employed to discover the experimental run(s) giving the desired quality of weld.

Ranjit et. al. (2016) presented fatigue analysis of a 3-D model of weld structure using ANSYS 15 FE Software. The study was carried on welding of two dissimilar materials in which SA106 and STS 304 are parent materials and M 309 is used as a filler material. Butt welded joint specimen using gas metal arc welding (GMAW) process was analyzed to cyclic loading. The specimen was modeled in ANSYS 15 Workbench. At first thermal analysis is done by giving a heat input which is equivalent to the heat generated by a GMAW welding process. In the next step, a structural analysis was carried out to obtain the mechanical response of the structural model, where the temperature history obtained from the first step was employed as a thermal load in the analysis. Then on the same specimen, fatigue analysis is conducted by applying cyclic loading.

III. TYPES OF LOADING

Welding joints are applicable in wide range of engineering approach such as structural and mechanical engineering. There are various loading condition according to change in application such as the failure of welded joint due to torsion can be seen in flange welded to the hub transmitting torque. In structural application such as bridges the joints are subjected to static as well as fatigue loading. In both the case of structural application the failure mode may be different due to change in loading condition (i.e. Reason for crack initiation in both the cases is different and life span of welded joint too. Automobile uses spot welding for joining various frame components. During a high speed collision, these welded joints are subjected to impact loading. Lot of research has shown that the some kind of welded join behaves in different manner for different kind of loading condition and by keeping the joint geometry as it is. It gives different values of strength for different kinds of loading.

A. Welding Geometry

Welding geometry is also affecting factor on the strength of the welding joint. In that, curvature radius affects on Stress concentration phenomenon. It is found that, the value of stress decreases when curvature radius increases. It is experimentally proved that, the curvature radius influenced on the variation of stress and fatigue life. A welding process having greater penetrating power calls for a narrow groove, lesser heat affected zone and distortion and lesser filler metal consumption. Due to full penetration lead to decrease in quality. The over penetration of electrode causes the melting or burning away of the base metal at the toe of the weld this resulting from fundamental difficulties in a welding operation such as cracking and porosity. In some research paper it is found that, stress also decreased by increasing welding angle. Too great travel angle results into a bead with poor penetration. The quality of the weld metal may be determined to a marked degree by the angular deposition of the electrode to the work.

B. Specimen Preparation

Lot of research has been carried out for finding the effect of varying various parameters on strength of welded joint. These parameters are loading conditions, welding defects, environmental effects and process parameters. Maximum results are obtained with the help of ANSYS software. Very less amount of work carried out experimentally. It is observed that in some literature, the researcher worked on the weld geometry in which varying the gap size and overlapping length for same plate and same loading conditions gives different tensile strength.

IV. CONCLUSION

This literature study work has discussed the modes of fatigue failure in different types of structures and preventive measures against it. As fatigue plays a vital role in applications where there is repetitive load. It helps in finding out the areas of failure and thereby accurately predicting service life of the application where the welded structure is to be used. The fatigue life of welded joints can be evaluated with higher accuracy, hence it makes possible to design with better known safety factor for fatigue. Methodology leads to design and build lighter military vehicles with proper fatigue performance. Moreover, it enables vehicles with better supportability characteristics and to be owned at a reduced cost.

V. FUTURE WORK

As a part of future work, fatigue tests will be conducted to determine the effect of start-stop positions of weld seams and also with further weld joint geometries. For welding simulations to decrease the cost of thermo mechanical models, model simplifications and reduction improvements will be performed.

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