A Review on the examination of the Residual Stresses present in the Welded Joints

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Abstract - *Residual stresses have a significant influence on the functional properties and reliability of service life. It plays a critical role in failure mechanisms like fatigue, wear, fracture, buckling, and distortion. Generally, chassis are manufactured by welding to reduce the weight of the chassis. Hence there is a lot of stress concentration at the welded joint region. These stresses can lead to the reduction of strength and fatigue life of the joint. The residual stress in a welded joint can augment with the externally applied load and cause structural failure. This paper reviews the investigations done on the residual stresses present in the welded joints.*

Key Words: Residual stresses, X-ray diffraction method, Neutron diffraction method, Finite element analysis.

1. INTRODUCTION

Transport is of great significance in routine life. Different mobility requirements are necessary in order to serve different needs in the form of distances, terrains, passenger load etc. During the operation of vehicles, the welded joints are subjected to huge cyclic stresses. Fatigue characteristics of a material are directly governed by several factors like cyclic stress state, temperature, the geometry of specimen, surface quality, material type, residual stresses, size and distribution of internal defects and grain size of the material. Among these factors, the common defect encountered in the vehicle is residual stress which may arise during welding. It is a common method used in the production of massive structures.

Welding is a complex and challenging process to model. It involves transient heat generation by different welding processes, melting and solidification of materials, and large plastic strain cycles which are generated over large temperature intervals. These variable cooling rates in different regions of the weld along with the strains associated with metallurgical phase transformations give rise to local variation in shrinkage resulting in welding-induced residual stresses.

The thermal energy applied results in irreversible elastic-plastic deformation and consequently gives rise to the residual stresses in and around fusion zone and heat affected zone (HAZ). It is fact that structural integrity of components is significantly affected by the residual stresses when subjected to thermal and structural loads.

Fig -1: Failure of welded joint

Presence of residual stresses may be useful or harmful for the structural components depending on the nature and magnitude of residual stresses [2]. The residual stress in a welded joint can augment with the externally applied load and cause structural failure.

2. DEFINITION OF RESIDUAL STRESSES

The stresses that are present inside a component when no peripheral loads are applied is called Residual stresses or thermal stresses [9]. Residual stresses can also be defined as the stresses that remain within a material or body after manufacture and material processing in the absence of external forces or thermal gradients. They can also be produced by service loading, leading to inhomogeneous plastic deformation in the part or specimen [7].

3. CLASSIFICATION RESIDUAL STRESS MEASURING TECHNIQUES

Based on structural integrity the residual stresses are classified or termed as Type I termed as continuum long-ranged stresses generally originates from misfit that emerge form peening, nitriding and welding; Type II termed as grain-scale stresses generally emerges due to variation in sub-grain scale stresses or grain to grain anisotropy and Type III stresses arises due to coherence at interfaces, dislocation and precipitation or due to crystalline defects. Residual stresses can be measured by several different methods and by the combination of various techniques [9] are as following:-

Table -1: Classification of residual stress measuring techniques

RESIDUAL STRESS MEASURING TECHNIQUES		
Non-Destructive	**Semi-Destructive**	**Destructive**
X-ray diffraction	Hole-drilling	Contour method
Neutron diffraction	Ring-core method	Sectioning-technique
Ultrasonic method	Deep-hole method	

4. REVIEW OF LITERATURE

In order to understand the interaction between the welding procedures and its effect on residual stress leading to distortion, several research works have been performed using experimentation and numerical simulations.

Dongpo Wang, Hai Zhang, Caiyan Deng, Baoming Gong [10], studied the consequence of residual stresses on the fatigue behavior of T-joint with the help of Numerical Simulation under coupled stress and energy failure criterion. The welding process was simulated using 3D thermos-mechanical FE model in ANSYS. The parameters assumed for performing the numerical simulation were the fatigue threshold and fatigue limit of the material. It was observed that residual stresses were very high after performing the welding process and the local peak value reached the value of yield stress of the material.

P. Ferro, F. Berto, N.M. James [1], analyzed the impact of multipass welding on the residual stress field near the weld toe developed a 2D numerical model of multipass welding considering all the physical, mechanical and thermo-metallurgical phenomena. A comparative study in terms of residual stress distribution and dimensions of different zones like heat affected zone (HAZ) and fusion zone (FZ) between single pass and multipass welding was carried out near the weld toe region. The analysis of the butt-welded joint was simulated for a fixed plate thickness using numerical code SYSWELD and the interpass temperature was maintained at 100°C. The microstructure of both single pass and multi-pass welding contained a mixture of ferrite –perlite and banite, in which the most predominant phase in the HAZ was banite. It was also observed that there was a decrease in the width of HAZ and FZ with an increase in the number of passes. This decrease in width lead to metallurgical phase formation which helped in lesser distortion and improved static-mechanical properties of multipass welded joints of the same thickness as compared to single pass welded joint. Asymptotic nature of local residual stress filed was observed near weld toe region in the case of multipass welding.

I.I. Ahmed, J.A. Adebisi, S. Abdulkareem, A.H. Sherry [5], investigated the profile of surface residual stresses developed during girth welding of low carbon martensitic stainless steel (MSS) pipe using sin2ψ X-ray diffraction method. In order to determine the peak value of Bragg angle at the every measurement location Gaussian curve fitting method was used.

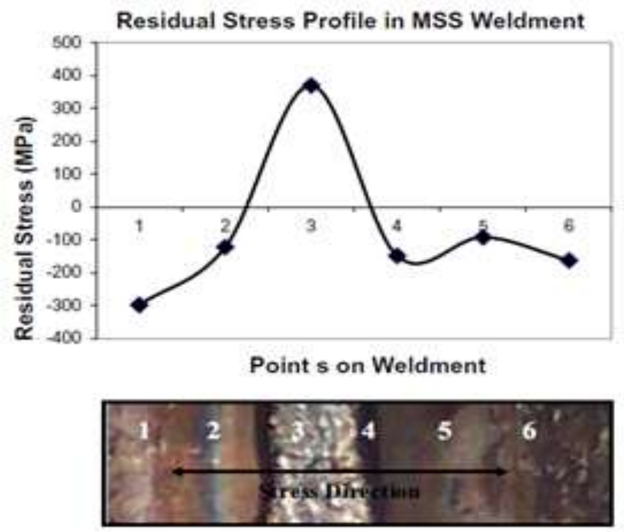

Fig No 2: - Residual stresses profile in martensitic stainless steel weldment [5]

Compressive residual stresses were observed at some parts on both the sides of the weldment near the heat affected zone, while tensile residual stresses were seen in the weldment. It was concluded that tensile residual stresses in the Heat affected zone may act as a crack opener and may give rise to stress corrosion cracking (SCC) leading to failure in the MSS.

Jonas Hensel, Thomas Nitschke-Pagel, Joana Rebelo-Kornmeier, Klaus Dilger [4], proposed a model for studying the combined effect of residual stresses and fatigue crack growth in welded steel plates. The authors made longitudinal weld for creating high tensile residual stresses in the axial direction. X-ray diffraction sin2ψ method for surface residual stresses and neutron diffraction were used to determine residual stresses near crack tip at different stages of fatigue life. It was observed that there was degradation in the residual stresses in the absence of fatigue cracks. It was also noted that propagating cracks lead to a redistribution of residual stresses.

Kimiya Hemmesi, Majid Farajian, Mirko Boin [8], studied welding residual stresses on a tube specimen made of S355J2H with the help of numerical analysis done with the help of SYSWELD software and also compared the computational results with the with the results obtained from X-ray diffraction (XRD) and Neutron diffraction methods. It was concluded that the high compressive residual stress field at the weld toe and its vicinity was due to the combined effect of low temperature and phase transformation concerning fatigue.

Takuya Nagai, Ryu Kasai, Reiichi Suzuki, Masahito Mochizuki and Tetsuo Suga [3], investigated the behavior of residual stresses in fillet welded lap joints made from sheet metal by varying steel type, welding wires of different transformation points and steel plate thickness. The authors subsequently carried out a Thermo-Elastic-Plastic analysis under simulated welding fabrication condition. X-ray diffraction technique was used to analyze residual stress near weld toe and at the topmost surface of the weldment. Validation of the residual stress was done by using Finite Element Analysis. The welding tests both experimental and analytical were executed with constant deposition rate and a good match of results were observed.

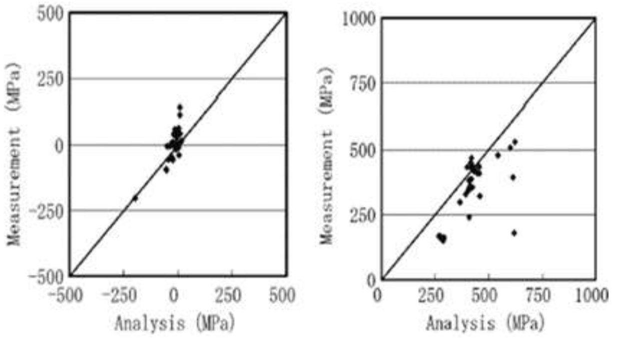

Fig No 3: - Correlation diagram of residual stresses by Experimentation and Analysis [3]

It was observed that the weld toe region of higher strength steel plate had greater compressive residual stresses. It was also found that the high rate of heating and cooling in the arc welding process had an adverse effect on the mechanical restraint conditions leading to the tensile residual stress becoming equivalent to yield stress in the weldment and HAZ region.

Vladislav Baniaria, Mária Blatnická, Michal Šajgalík, Milan Vaškoa, Milan Sága [6], measured welding residual stresses in highest strength steel plates using X-ray diffraction technique and also validated the results with a numerical simulation using MATLAB. Samples were prepared from square plates with notch without pre or post-processing in order to measure the tangential and normal stresses near the welded joint. The residual stresses were measured at three different locations near the weldment and the measured values were imported into MATLAB in order to verify the measured values. The results showed a decrease in compressive stress along the cross-section of the rolled surface produced during welding.

W. Woo, G. B. An, V. T. Em, A. T. De Wald and M. R. Hill [11], determined residual stress distribution through the thickness of 80 mm thick ferritic steel plate neutron diffraction method and results obtained were validated by using contour method. Longitudinal Tensile stresses were seen in the centerline of the welded zone within 10 mm depth from the topmost surface. While transverse compressive stresses were observed after a depth of 10mm thickness. It was also seen that the weldment had high strength and lower fracture toughness as compared to the base metal hence it was concluded that the area near the weldment is more threatened by fractures.

L.N. Brewer, M.S. Bennett, B.W. Baker, E.A. Payzant and L.M. Sochalski-Kolbus [12], examined distribution of residual stresses generated during Friction stir welding (FSW) of Oxide dispersion strengthened steel MA956 using three different welding conditions as 500 rpm/ 25 mm per minute (mmpm), 400 rpm/ 50 mmpm and 400 rpm/ 100 mmpm. FSW was done using polycrystalline cubic boron nitride (PCBN) tool of 25 mm diameter of MS 80 grade with a plunger force of 17.8 kN kept constant. Measurement of residual across the weldment, heat affected zone and base metal were done at an increment of 5mm using X-ray diffraction and neutron diffraction technique. Residual stress profile using X-ray diffraction and neutron diffraction method showed good agreement. The longitudinal stresses were seen at the weldment, while compressive stresses were seen in the heat affected zone and the base metal. It was observed that lowest heat input zone had largest tensile stresses and there was decrease in longitudinal tensile stresses in the heat affected zone with increase in depth. It was concluded that the not only the welding condition but also the nature and microstructure of the material affect the magnitude and distribution of the residual stresses.

Tsuyoshi Shiozaki, Yoshikiyo Tamai, Toshiaki Urabe [13], studied the effect of residual stresses on fatigue strength of hot rolled high strength steel sheet in order to examine the relationship between residual stresses and fatigue strength of punched specimens subjected to heat treatment after punching holes on the sheet. Wet abrasive cut-off machine was used for preparation of samples. To measure the stress concentration a 10 mm hole was punched at the center and the residual stresses were measured using sin2 ψ method was used. To measure the hardness of the specimen Vickers hardness test was used. Fatigue testing was conducted in 30 Nm capacity Schenk type testing machine under plane bending displacement control. It was observed that the rollovers which were next to edges of the holes had tensile residual stresses whereas the burnish zones of the holes were induced by compressive residual stresses. There was an increase in fatigue strength by 10% after heat treatment done at 823 K for one hour as compared to the as-punched specimen.

5. CONCLUSIONS

The identification of the residual stresses at the initial stage is essential for taking remedial actions. From the literature reviewed the causes responsible for the various weld failures due to the presence of residual stresses are summarized are as follows:-

a. Generally after performing any welding process there a rise in the residual stresses causing the local peak value to become equivalent to the yield stress of the material.

b. The Tensile residual stresses present in the HAZ generally gives rise to stress corrosion cracking which leads to failure of the welded joints.

c. The behavior of residual stresses under the cyclic load states that degradation in residual stresses is generally observed when the sum of load stresses and residual stresses overcome the yield stress of the material.

d. The rate of heating and cooling in an arc welding causes an adverse effect on the mechanical restraint conditions in and the weld zone causing tensile residual stress to become equivalent to the yield stress of the material.

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