Residual Stress Measurement Techniques: A Review

Nasir Khan[1],

Research Scholar Amity University,
Gwalior

Dr. Anshul Gangele[2]

Professor ,

Amity University Gwalior

Abstract

Compressive residual stresses are desirable because it decreases the speed of crack initiation and prolong fatigue life but at the same time residual stresses are having negative effects on the distortion, corrosion resistance, dimensional stability and brittle fracture of the component. Residual stress also plays a vital role in with respect of fatigue strength of material. Because of these effects maintenance cost and service life of the components declines. Therefore it is of interest to investigate the residual stress. There are so many methods have been developed so far for the measurement of the residual stress such as Destructive or non-destructive. Mechanical methods (Destructive and Semi destructive) based up on measurement of deformations due to release of residual stresses up on deduction of material from specimen and Nondestructive technique measures some parameters that are related to stresses. The main objective of this work is to analyze Residual stress measurement techniques which is most commonly used in industry and academia are considered: x-ray and neutron diffraction, hole-drilling, sectioning, Barkhausen, eddy current and ultrasonic methods. Out of all destructive techniques, hole-drilling is utmost used method due to well-established, cheap and simplicity. For non-destructives techniques X-ray diffraction is the furthermost used technique, because of it's widely availability, versatility, wide range of materials and macro and micro residual stress measuring. This paper gives the information of the recent advancement in the residual stress measuring techniques to help researchers on selecting their techniques hang on upon their applicability and the availabilities of those techniques. This paper represents physical limitation, scope, advantages and disadvantages for each technique. This paper also represents promising directions for future developments.

Key words: - Residual stress, Fatigue Life, Corrosion Resistance, Hole-Drilling Method, X-Ray diffraction

1. INTRODUCTION

Residual stress may arise in almost every step of the processing. The origin of residual stresses in a component may be classified as Mechanical, Thermal and Chemical. Mechanically generated residual stresses are because of manufacturing process like welding, machining grinding and shot Peening, due to non uniform plastic deformation. Thermally generated residual stresses are due to non uniform heating and cooling like quenching.Chemically generated residual stresses are due to chemical reaction and phase transformation. Residual stresses are those stresses, which exist even after removal of the external load in the material. Residual stresses are having negativeeffects on thedistortion, fatigue life, corrosion resistance, dimensional stability and brittle fracture of the component. Residual stress also plays a vital role in with respect of fatigue strength of material. Because of these effects maintenance cost and service life of the components declines. Therefore it is of interest to investigate the residual stress.

2. CAUSES OF RESIDUAL STRESSES

Following are the main cause of existing of the residual stresses:

- Non uniform heating and cooling of metal in and adjacent of weld region
- Volume shrinkage of metal in weld during solidification
- Micro structural change of metal

It is nearly impossible to avoid the generation of the residual stresses in the component but it may be possible to relieve the residual stress. The stress-relieving methods includes

- Vibratory stress relieving
- Peening of weld area
- Post weld heat treatment

Residual stresses may also be minimized if proper measures are taken during welding, such as preheating.

3. RESIDUAL STRESSES IN WELDING

Welding is the most prominent process for joining large components into complex assemblies or structures. A necessary condition for welding is that the two or more surfaces to be joined must be brought in to intimate contact. When fusion takes place, the joint is achieved by melting of two or more workpiece material in a localized region. In contrast, the solid state joining processes rely on plastic deformation of the surface asperities along the contact surface representing the original weld interface or the impending weld joint.

4. FRICTION STIR WELDING (FSW)

Friction stir welding (FSW) was invented by Wayne Thomas at TWI, and the first patent application was filed in the United Kingdom in December 1991 (2). The material which is difficult to weld by fusion welding because of their solidification characteristic can be easily welded by FSW. The Shipbuilding and Marine industries were the first industry sectors to adopt this process commercially, but now Aerospace industry, Automobile industries, Construction industries and

High speed trains are using this process commercially. Welding residual stresses are due to non-uniform cooling and heating of specimen.

5. RESIDUAL STRESS MEASURING TECHNIQUES

There are so many methods have been developed so far for the measurement of the residual stress. Residual stresses measuring technique may be classified as Destructive or Semi destructive or nondestructive [1]. Mechanical methods (Destructive and Semi destructive) based up on measurement of deformations due to release of residual stresses up on removal of material from specimen. However Non destructive technique measures some parameters that are related to stresses.

5.1 Destructive techniques

5.1.1 Hole-Drilling Technique

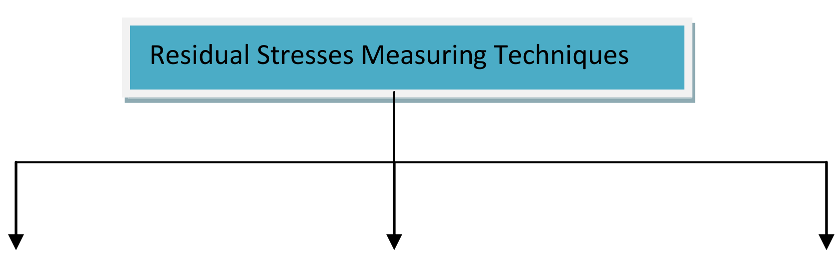
The most widely used modern technique for measuring residual stresses is Hole drilling method. It is relatively simple and quick. The steps of measuring residual stresses are following [3].

Step I. A special three element strain gauge rosette is installed on the test part at the point where residual stresses are to be measured.

Step II. The gage grids are wired and connected to a multi-channel static strain indicator

Step III. A precision milling guide is attached to the test part and accurately centered over a drilling target on the rosette

Step IV. After Zero-balancing the gage circuits, a small, a shallow hole is drilled through the geometric center of the rosette.



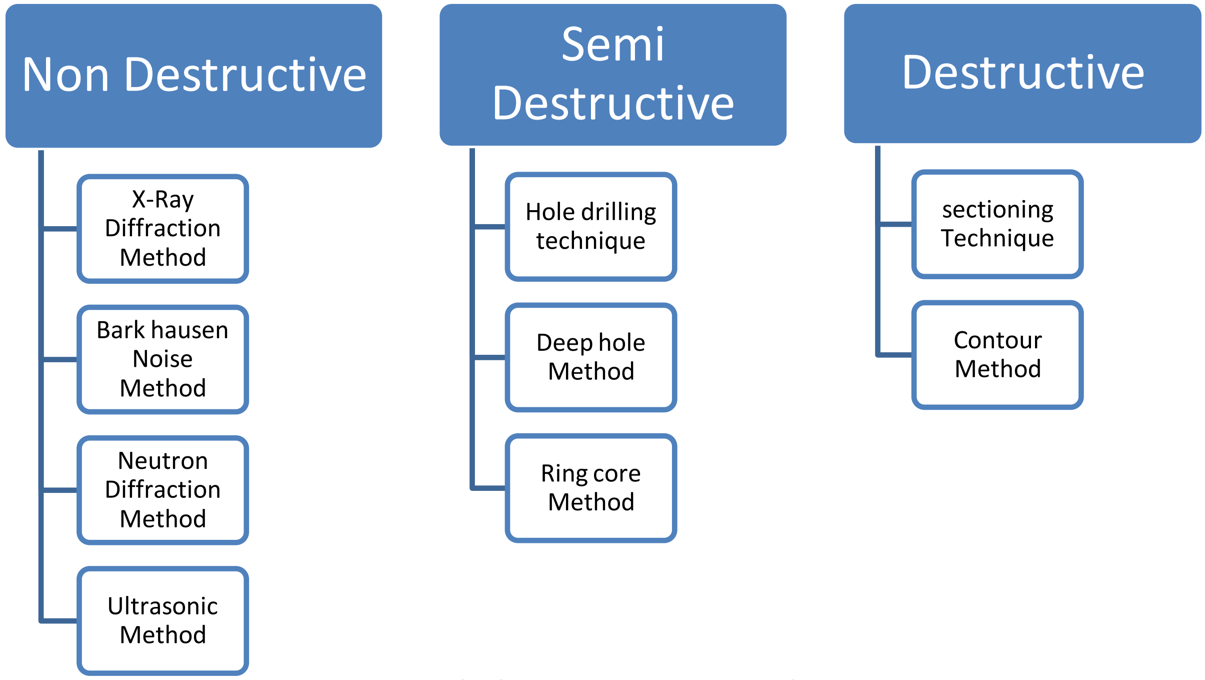


Fig.1. Residual stresses measuring technique.

Step V. Readings are made of the relaxed strain, corresponding to the initial residual stress.

Step VI. Using special data-reduction relationships, the principal residual stresses and their angular orientation are calculated from the measured strains.

Hatamleh et al. investigated peening effect on the residual stresses in FSW Joint of 2195 and 7075 aluminum joint. Surface residual stress measurement were acquired using x-ray diffraction method. Measurements of the through thickness bulk residual stresses were obtained using the contour method. The deepest compressive residual stresses were obtained with multiple layers of laser peening, and increased proportionally as the number of peening layers increased for AA 2195. For AA 7075, little change was noticed in the residual stresses as the number of peening layers increased. Interestingly, laser peening was shown to have less of an effect on residual stress near the edges of the weld joint where significant softening occurred.

As these materials are age-hardenable, theirproperties can change with time. Linton et al. [2] used the neutron diffraction technique to measure the residual stresses around a FSW in a7xxx alloy and to determine how these residual stresses changed with time. It was found that the residual stresses associated with the weldnugget decreased, while those associated with the heat-affected zone increased with time. This is in contrast to strength and hardnessvalues that increased in all regions of the weld with time.

Hole-drilling method is one of the most convenient methods for residual stress measurement. Min et al. [3] used the theory of moiré interferometry and incremental hole-drilling for non-uniform residual stress measurement is introduced. Three dimensional finite element method is constructed by ABAQUS to obtain the coefficients for the residual stress calculation. Experimental result shows that MIIHD is effective for both non-uniform in-depth and in-plane residual stress measurements.

A study of residual strains in aluminium-based dissimilar friction stir welds (FSWs) was performed byJun et al. [4] anovel approach that will be referred to as the Eigenstrain Reconstruction Method (ERM) The strain distributions evaluated by the angle-dispersive synchrotron X-ray diffraction were used to obtain the eigenstrain distributions by ERM. In order to build the FE eigenstrain model that forms the essential part of ERM implementation, the analysis of microstructure and diffraction peak profile (i.e., intensity and FWHM) was performed to understand the material mixing that occurred in the weld zone. The ERM approach allowed the approximate determination of the complete stress and strain state everywhere in the component. The resulting description is continuous, complete and consistent, in terms of satisfying the equilibrium, compatibility and boundary conditions. It is concluded that ERM is a powerful tool for the analysis and use of full-field residual stress and strain distributions in engineering components and structures.

Single and double sided partial penetration friction stir butt welds, in a rolled, quenched and tempered steel (RQT-701), were produced by Barnes et al. [5] at The Welding Institute (TWI) under controlled process conditions. The residual strain distributions in the longitudinal and transverse directions have been measured using energy dispersive synchrotron X-ray diffraction. The measured strains were indicative of longitudinal tensile residual stresses at levels greater than the 0.2% yield stress of the parent metal in both the single and double pass welds. In both cases, the maximum tensile strain was found in the parent metal at the boundary of the heat affected zone (HAZ). Microstructural analysis of the welds was carried out using optical microscopy and hardness variations were also mapped across the weld-plate cross-section. The maximum hardness was observed in the mixed bainite/martensite structure of the weld nugget on the advancing side of the stir zone. The minimum hardness was observed in the HAZ.

John et al. [6] conducted on near-threshold fatigue crack growth in friction stir welded aluminum alloy 7050-T7451 and a titanium alloy Ti–6Al–4V. Tests were conducted on weld coupons as a function of specimen geometry and stress ratio to understand the effects of residual stresses in the heat affected zone (HAZ) of the alloy. The crack growth results show that residual stresses play a key role in the crack growth parallel to the weld-path in the HAZ. Although friction stir welding process induced low residual stresses in the welds, they are found to produce large effects on the near-threshold fatigue crack growth. In general, the magnitude of the shift in the fatigue threshold in the friction stir welded coupons is a function of microstructure, residual stresses and specimen geometry. However, for a constant microstructure, fatigue thresholds at low stress ratios, were specimen geometry dependent. The thresholds were either higher or lower than those of the parent material. At high stress ratio, the differences due to the specimen geometry vanish. Stress ratio studies show that the center-crack tension geometry is less sensitive to the residual stress effects compared to the compact tension geometry.

Staron et al.[7] made attempt to reduce tensile residual stresses in the weld region. The residual stress states of FSW joints in 6.3 and 3.2mm thick Al-sheets (AA2024) that have been welded under mechanical tensioning were analyzed. The results show that large compressive stress can be induced in the weld by applying mechanical tensioning during welding.

Staron et al. [8] the influence of a coolant applied during welding of Al sheets on the residual stress state of the FSW joint was investigated. Liquid CO2 coolant was applied near the weld seam for rapid cooling of the weld zone. The residual stresses across the weld were measured by neutron diffraction. Three sheets were produced, one without cooling, and two with cooling, where two different distances of the coolant nozzles from the FSW tool were chosen. The results show that, by applying a coolant, the magnitude of the tensile stress in the center of the weld can be reduced significantly.

Arora et al. [9] reported the computed strains and strain rates during FSW of AA2524 from a three-dimensional coupled viscoelastic flow and heat transfer model. The strain rates are integrated along a streamline to estimate the accumulated strains experienced by the material. The computed strains and strain rates were in the ranges _10 to 5 and _9 to 9 s_1, respectively.

Using synchrotron X-ray diffraction the residual stress distribution has been measured in a series of AA7449-W51 Aluminium friction stir welds that had been tensioned to different loads during welding. By modifying the stress accumulation path, the application of a tensioning stress has reduced the tensile magnitude of the final residual weld stresses. Altenkirch et al. [10] studied the residual stresses were minimized when the applied load is ~35% of the room temperature yield stress of the parent material. Subsequent sectioning of the weld into shorter test lengths, as might be necessary for weld testing, resulted in a progressive and significant relaxation of the residual stress field. The effect of tensioning on the weld component distortion also has been investigated.

6. SUMMARY

Hole-drilling method is one of the most commonly used technique to measure the residual stresses. There was a strong correlation between the residual stress and the hardness distribution in the larger samples. However, less distinct correlation was identified in the dogbone samples where most of welding residual stress was released due to short length. Additional investigations will be aimed at the effect of compressive stresses on fatigue crack propagation. Moreover, modelling of the residual stress distribution in Al sheets welded under mechanical tensioning is in progress.

7. REFERENCES

[1]. Hatamleh et al. Journal of Materials Processing Technology 209 (2009) 4822–4829.

[2]. Linton et al. Acta Materialia 56 (2008) 4319–4327.

[3]. Min et al. Acta mechanicasinica vol-19 no-6, Dec-2003.

[4]. Jun et al. Materials and Design xxx (2009) xxx–xxx.

[5]. Barnes et al. Materials Science and Engineering A 492 (2008) 35–44.

[6]. john et al. International Journal of Fatigue 25 (2003) 939–948.

[7]. Staron et al. Physica B 350 (2004) e491–e493.

[8]. Staron et al. Appl. Phys. A 74 [Suppl.], S1161–S1162 (2002).

[9]. Arora et al. Scripta Materialia 61 (2009) 863–866.

[10]. Altenkirch et al. Materials Science and Engineering A 488 (2008) 16–24.