International Journal on Emerging Technologies **10**(2): 165-168(2019)

ISSN No. (Print) : 0975-8364
ISSN No. (Online) : 2249-3255

A Study on Approaches for Measuring Residual Stress

Basavaraj Kawdi

Department of Mechanical Engineering,
BKIT, Bhalki (Karnataka) INDIA.

(Corresponding author: Basavaraj Kawdi)
(Received 02 April 2019, Revised 01 June 2019, Accepted 10 June 2019)
(Published by Research Trend, Website: www.researchtrend.net)

ABSTRACT: Fatigue Stresses are important factors in shaping engineer parts and structural members. Residual stresses play momentous role in maintaining desired fatigue strength. Many different procedure and different approaches are used in measuring residual stress by specific methods which have grew over several years The Practical application of these have greatly benefited from development of Complimentary technologies in the field of material cutting full field deformation measurement techniques numerical methods and computing methods. These matching technologies have stimulated advances not only in accurate & reliable measurement but also in the range of application. The purpose of this review is to classify the different methods and to provide an overview of some of the recent advances in the area of residual stress measurement and act as a summary document to aid technique selection between destructive, semi destructive and non-destructive techniques for residual stresses. For each method scope, physical limitation, advantages and disadvantages are summarized. In the end this paper indicates some promising directions for future developments.

Keywords: Residual stresses, destructive methods, semi critical methods, non-destructive methods

I. INTRODUCTION

Engineering properties of materials and structural components, notably fatigue life, distortion, dimensional stability, corrosion resistance, and brittle fracture can be considerably influenced by residual stresses [1, 11]. Such effects usually bring considerable expenditure in repairs and restoration of parts, equipment, and structures. Accordingly, residual stresses analysis is a compulsory stage in the design of parts and structural elements and in the estimation of their reliability under real service conditions. Systematic studies had shown that, for instance, in welding, residual stresses might lead to a drastic reduction in the fatigue strength of welded elements. In multicycle fatigue (N > 106 cycles), the effect of residual stresses are compared with the effect of stress concentration [3, 4]. Surprisingly significant are the effect of residual stresses on the fatigue life of welded elements with regard to relieving of harmful tensile residual stresses and introducing beneficial compressive residual stresses in the weld toe zones. Currently, the residual stresses are one of the main factors determining the engineering properties of materials, pats, and welded elements, and should be taken into account during the design and manufacturing of different products. Although successful progress has been achieved in the development of techniques for residual stresses management, considerable effort is still required to develop efficient and cost-effective methods of residual stress measurement and analysis as well as technologies for the beneficial redistribution of residual stresses.

Residual stresses can 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 [2, 5]. They can also be produced by service loading, leading to inhomogeneous plastic deformation in the part or specimen.

Residual stresses are generated during most of the manufacturing processes involving material deformation, heat treatment, machining or processing operations that transform the shape or change the properties of a material. They are originated from a number of sources and can be present in the unprocessed raw material, introduced during manufacturing or arise from in-service loading [13].

II. CLASSIFICATION OF RESIDUAL STRESS MEASURING TECHNIQUES

During the past years many different methods for measuring the residual stresses in different types of components have been developed [6, 8]. Techniques to measure Type I residual stresses may be classified as either destructive or semi destructive or non-destructive as shown in Fig. 1.

The destructive and semi destructive techniques are dependent on inferring the original stress from the displacement incurred by completely or partially relieving the stress by removing material. These methods rely on the measurement of deformations due to the release of residual stresses upon removal of material from the specimen. Sectioning, contour, hole drilling, ring-core and deep-hole are the principals destructive and semi destructive techniques used to measure residual stresses in structural members. Non-destructive methods include X-ray or neutron diffraction, ultrasonic methods and magnetic methods. These techniques usually measure some parameter that are related to the stress. Therefore the assessment of fatigue-related damage become increasingly important since many structural components, e.g. bridges, aircraft structures or offshore platforms, need to be inspected periodically to prevent major damage or even failure [7, 9]. For inspection in the field or on large constructions, small, mobile and easy to handle devices are essential in addition to cost minimization and short measuring time.

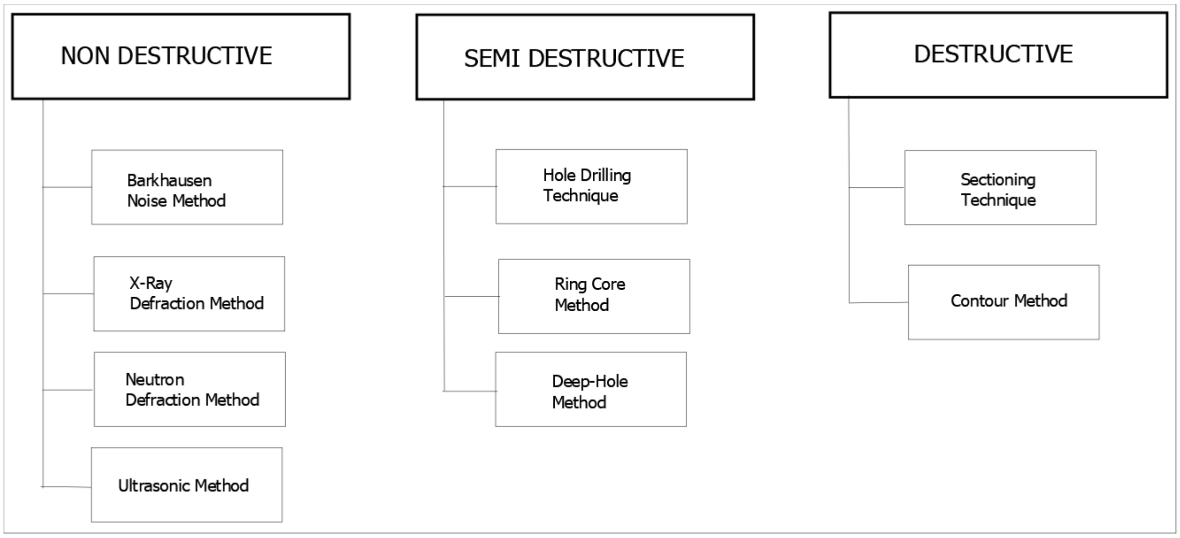

Fig. 1. Residual stresses measuring techniques.

A. Hole-drilling technique

The hole-drilling method, which is relatively simple and fast, is one of the most popularly used semi destructive method of residual stress evaluation which can provide the measurement of residual stress distribution across the thickness in magnitude, direction and sense. It has the advantages of good accuracy and reliability, standardized test procedures, and convenient practical implementation. The damage caused to the specimen is localized to the small, drilled hole, and is often tolerable or repairable. The principle involves introduction of a small hole (of about 1.8 mm diameter and up to about 2.0 mm deep) at the location where residual stresses are to be measured. The hole-drilling method is, in comparison to other residual stresses measuring techniques, is a common, cheap, fast and popular method [10]. It is applicable in general to all groups of materials. Firstly, the materials should be isotropic and the elastic parameters should be known. Secondly, the analyzed materials should be machinable, *i.e.* the boring of the hole should not perturb the measured strain. The method determines macro residual stresses. Most of the in-depth evaluation algorithms provide a solution to determine an elastic plane stress state. However, to avoid local yielding because of the stress concentration due to the hole, the maximal magnitude of measured residual stress should not exceed 60-70% of local yield stress. The local resolution of the method is dependent on the equipment used.

B. Deep hole method

The deep hole method is a further variant procedure that combines elements of both the hole-drilling and ring-core methods. In the deep-hole method, a hole is first drilled through the thickness of the component. The diameter of the hole is measured accurately and then a core of material around the hole is tampered out, relaxing the residual stresses in the core. The diameter of the hole is re-measured allowing finally the residual stresses to be calculated from the change in diameter of the hole. The deep-hole method is classified as a semi destructive method of residual stresses measurement since a hole is left in the component, the diameter of the hole can be quite small and could coincide with a hole that needs to be machined subsequently. The main feature of the method is that it enables the measurement of deep interior stresses. The specimens can be quite large, for example, steel and aluminum castings weighing several tons.

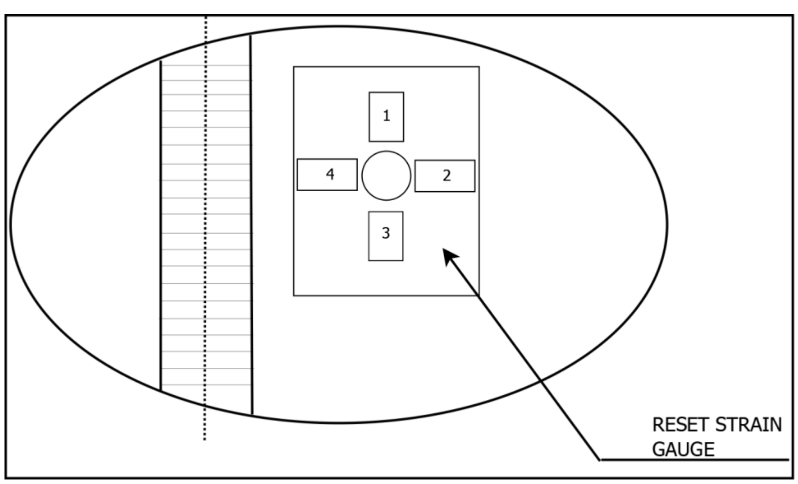

Fig. 2. Schematic illustrations of the application of hole-drilling methods for residual stress measurement.

C. Sectioning technique

Sectioning technique is a destructive method that relies on the measurement of deformation due to the release of residual stress upon removal of material from the specimen. It has been used extensively to analyze residual stresses in structural carbon steel, aluminum and stainless steel sections. The sectioning method consists of making a cut on an instrumented plate in order to release the residual stresses that were present on the cutting line. For this, the cutting process used should not introduce plasticity or heat, so that the original residual stress can be measured without the influence of plasticity effects on the cutting surface. The strains developed during the cutting process are generally measured using electrical or mechanical strain gauges. In general, the strips of material released by the sectioning process may exhibit both axial deformation and curvature, corresponding to membrane and bending (through thickness) residual stresses, respectively.

D. Contour method

The contour method provides higher spatial resolution, while the sectioning technique is easier to apply since almost no calculations are needed. The method has found a number of applications: for example, carbon steel, welded T-joint, quenched and impacted thick plates, cold-expanded hole and Aluminum alloy forging. It offers improvements over conventional relaxation methods of measuring residual stresses. The theory of the contour method is based on a variation of Bueckners elastic superposition principle.

The method was first published in detail in 2001, where the contour method was numerically verified by 2D finite element (FE) simulation and experimentally validated on a bent steel beam having a known residual stress distribution. The potential of the contour method was later demonstrated on a 12-pass TIG BS4360 steel weld to measure a complex 2D stress variation across the weld section. The result obtained from the contour method was in excellent quantitative agreement with the outcome measured by a completely different technique called non-destructive neutron diffraction.

E. X-ray diffraction method

The X-ray method is a non-destructive technique for the measurement of residual stresses on the surface of materials. X-ray diffraction techniques exploit the fact that when a metal is under stress, applied or residual stress, the resulting elastic strains cause the atomic planes in the metallic crystal structure to change their spacing [12]. X-ray diffraction can directly measure this inter-planar atomic spacing; from this quantity, the total stress on the metal can then be obtained. Since metals are composed of atoms arranged in a regular three-dimensional array to form a crystal, most metal components of practical concern consist of many tiny crystallites (grains), randomly oriented with respect to their crystalline arrangement and fused together to make a bulk solid. When such a polycrystalline metal is placed under stress, elastic strains are produced in the crystal lattice of the individual crystallites. In other words, an externally applied stress or one residual within the material, when below the yield strength of the material, is taken up by inter-atomic strains in the crystals by knowing the elastic constants of the material and assuming that stress is proportional to strain, a reasonable assumption for most metals and alloys of practical concern can be made.

Moreover, in the case of a nanostructured material, it is not easy to use diffraction techniques because of the difficulty involved in analyzing the shape of the nanomaterial diffraction peak [11]. It is difficult to pinpoint the peak location or to determine the peak shift in order to study the macroscopic stress due to severe plastic deformation for many materials. For this reason, mechanical methods are the only techniques known for the study of residual stresses in all kinds of surface nanostructured materials without the effect of nanostructure. The speed of measurement depends on a number of factors, including the type of material being examined, the X-ray source, and the degree of accuracy required. The gauge volume is a trade-off between the need for spatial resolution within the expected strain field and the time available for data collection. With careful selection of the X-ray source and test set-up speed of measurement can be minimized. New detector technology has also greatly reduced the measurement time.

F. Neutron diffraction method

Neutron diffractions method is very similar to the X-ray method as it relies on elastic deformations within a polycrystalline material that cause changes in the spacing of the lattice planes from their stress-free condition. The application of neutron diffraction in solving engineering relevant problems has become widespread over the past two decades. The advantage of the neutron diffraction methods in comparison with the X-ray technique is its lager penetration depth. In fact the X-ray diffraction technique has limits in measuring residual stresses through the thickness of a welded structure. On the other hand, a neutron is able to penetrate a few centimeters into the inside of a material, thus it can be applied widely to evaluate an internal residual stress of materials. It enables the measurement of residual stresses at near-surface depths around 0.2mm down to bulk measurement of up to 100mm in aluminum or 25 mm in steel.

III. CONCLUSION

The non-destructive residual stresses measurement methods have the obvious advantage of specimen preservation, and they are particularly useful for product quality control and for measurement of valuable specimens. However, these methods commonly require detailed calibrations on representative specimen material to give required computational data. The diffraction methods such as X-ray and neutron diffraction can be applied for the polycrystalline and fine grained materials as well as metallic or ceramic. However, they cannot be used for large welds because of limited space available on most beam lines or X-ray diffractometers or for nanostructured materials because of the difficulty involved in analyzing the shape of the nanomaterial diffraction peak. The advantage of the neutron diffraction method in comparison with the X-ray technique is its ability of larger penetration depth as x-ray method is limited for the measurement of residual stresses on the surface of materials. However, the relative cost of application of neutron diffraction method, is much higher, mainly because of the equipment cost and it is not recommended to be used for routine process quality control in engineering applications.

Conflict of Interest: Nil

REFERENCES

[1]. Totten, G. (2012). "Handbook on residual stress". SEM, Bethel 2012; **1**: 417. ISBN:978-0871707291;

[2]. Trufyakov, V., Mikheev, P., Kudryavtsev, Y. (2009).

"Fatigue Strength of Welded Structures". London: Harwood Academic, **100**.
[3]. Anawa, E.M. and Olabi, A.G. (2008). "Control of welding residual stress for dissimilar laser welded materials", *Journal of materials processing technology,* **204**, 22-33.
[4]. Macherauch, E. and Kloos, K.H. (2013). "Origin, Measurements and Evaluation of Residual Stresses", *Residual Stresses in Science and Technology*, 3-26.
[5]. Lachmann, C., Nitschke-PagelTh and Wohlfahrt, H. (2012). "Non- destructive characterization of fatigue processes in cyclically loaded welded joints by the Barkhausen noise method", Stanford University: 2nd International Workshop on Structural Health Monitoring.
[6]. Lu, J. (2013). "Handbook of Measurement of Residual stresses". SEM, Bethel 2013, ISBN: 978-0132557382; **1**, 319-322.
[7]. Olabi, A.G. and Hashmi, M.S.J. (1996). "Stress relief procedures for low carbon steel welded components", *Journal of Materials Processing Technology*, **56**: 552-562.
[8]. Kandil, F.A. and Lord J.D. (2004). "A review of residual stress measurement methods", a guide to technique selection. NPL Report MAT;(A), 1-4.
[9]. Milbradt, K.P. (2011). "Ring-method determination of residual stresses". *Proc SESA*. **9**(1): 63-74
[10]. Kiel, S. (2012). Experimental determination of residual stresses with the ring-core method and an online measuring system". *Exp. Tech.* **16**(5): 17-24.
[11]. Li, C., Z.Y. Liu, X.Y. Fang and Y.B. Guo (2018). "Residual Stress in Metal Additive Manufacturing", Procedia CIRP, **71**, 348-353.
[12]. Vladimir, Ivanovitch, Monine, João da Cruz Payão Filho, Rodrigo Stohler Gonzaga, Elisa Kimus Dias Passos and Joaquim Teixeira de Assis (2018). "X-Ray Diffraction Technique for Residual Stress Measurement in NiCrMo Alloy Weld Metal", *Advances in Materials Science and Engineering,* 1-10.
[13]. Basavaraj, K. and N. Shanmukh (2015). "Stress Analysis and Evaluation of Fatigue Characters of Pre-Stressed Hole". *International Journal on Emerging Technologies,* **6**(2): 17-23.

How to cite this article: Kawdi, Basavaraj (2019). A Study on Approaches for Measuring Residual Stress. *International Journal on Emerging Technologies*, 10(1): 165-168.