Advanced Engineering P. Ltd

Experts in Metallography, Failure Investigation and RLA

Metallurgy for Industries

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Residual Stress Measurement

An introduction.

What do you mean by residual stress?:

Residual stress is defined as the stress that remains in a body that is not being subjected to external mechanical forces or thermal gradients. Residual stress exists in practically all rigid parts, whether metallic or non-metallic. They are locked-in stresses present in a component even in the absence of external load.

The maximum value of residual stress never exceeds the elastic limit of the material because stresses higher than elastic limit lead to plastic deformation and thus residual stresses greater than elastic limit are accommodated in the form of deformation/distortion of components. The residual stresses can be of either tensile or the compressive, depending upon the location and the type of the non-uniform volumetric change, which is taking place. In general, residual compressive stresses are desirable whereas residual tensile stresses are undesirable.

What causes residual stress to develop in a material?

Residual stresses can develop in a component due to plastic deformation; during thermal treatments or due to structural changes involving phase transformation, etc. Residual stresses can also arise from misfits either between different regions or between different phases within a material.

Three different factors namely – mechanical, thermal and metallurgical, often combine to produce residual stress in a component.

Manufacturing processes are the most common cause of residual stress. Virtually all manufacturing and fabrication processes such as casting, welding, machining, molding, heat treatment involving phase transformation with formation of martensite, surface hardening treatments like shot pinning, nitriding, or induction hardening; plastic deformation during bending, rolling, forging, etc. introduce residual stresses into the part.

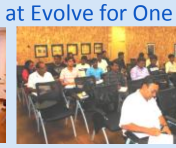
The factors contributing to development of residual stresses are: formation of deformation gradients in various sections of the part due to thermal gradients; volumetric changes arising

TCR News

- Successfully completed 2 major RLA assignments of critical piping at Thermal Power stations.
- Developed test for Determination of resistance to humid atmospheres containing sulfur dioxide as per ISO 3231 for painted components.
- Procured and installed Gamry E1010 potentiostate/ Galvanostate for electrochemical testing. This is a versatile equipment having range ±20 V and 10nA to 1 Amp. with inbuilt software for performing cyclic polarization, LPR, Tafel plots, galvanic corrosion, AC/DC Voltametry, Pulsed Voltametry, EIS, Electrochemical noise, Critical Pitting temperature Etc.

EVOLVE by TCR

- Conducted in-house training for technical staff on awareness and implementation of ISO/IEC-17025: 2017 at Evolve for One day.



- Conducted training programs of Low temperature service, two days intensive training on heat exchanger damage mechanism, inspection and failure investigation and metallurgy for engineers.
- Planned 4 trainings on in upcoming month on Non destructive testing techniques and, testing of Boiler and Gas turbine damage mechanism

Click for more information on upcoming training courses.

during solidification or from solid-state transformations; and difference in the coefficient of thermal expansion in a component made from different materials.

Classification of residual stresses:

Residual stresses can be characterized by the scale at which they exist within a material. Accordingly, there are three types of residual stress in a part:

Type I stresses: Macro stress that develops in the body of a component on a scale larger than the grain size of a material.

Type II stresses: Micro residual stresses, that vary on the scale of an individual grain. These stresses are caused by difference in the microstructure of a material.

Type III stresses: they are micro residual stresses that exist within a grain, essentially as a result of the presence of crystalline defects such as dislocations, grain boundaries & stacking faults.

Classification of techniques of residual stress measurement:

Various techniques available for measurement of residual stress in a component can be divided in to three groups namely; destructive, semi-destructive and non-destructive.

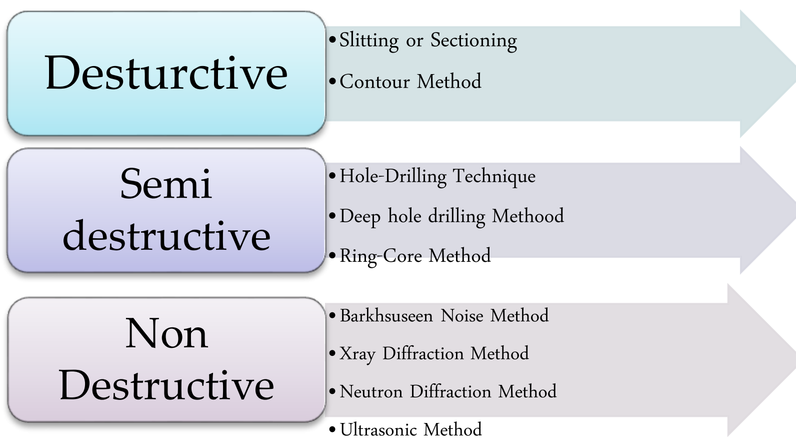


Fig.1: Classification of residual stress measurement techniques

Some techniques measure stresses resident in the part, while others measure only changes in stress from the time of application to a point after service or testing. Strain gages and diffraction techniques are quantitative in nature, and are the most widely preferred methods of residual stress analysis.

Destructive methods:

These techniques work on "strain release" principle that involves cutting the specimen in order to relax the residual stresses and then measuring the extent of deformation.

Slitting or sectioning technique: It relies on the measurement of deformation due to release of residual stress upon removal of material from the specimen. It is used extensively to analyze residual stresses in structural carbon steel, aluminum and stainless steel sections. The slitting or 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. The strains released during the cutting process are generally measured using electrical or mechanical strain gauges.

Contour Method: This method measures the residual stress on a 2 plane section through a specimen, in a uniaxial direction normal to a surface cut through the specimen using wire EDM. The contour method primarily involves four steps: specimen cutting, contour measurement, data reduction and stress analysis. It provides a 2D residual stress map on a plane of interest.

Semi-destructive methods:

Hole drilling method: The hole-drilling method is relatively simple and quick. It is one of the most popularly used semi-destructive methods of residual stress measurement. A small hole of about 1.8 mm diameter and 2.0 mm depth is drilled at the location where residual stresses are to be measured. Due to drilling of the hole the locked-up residual stresses are relieved and the corresponding strain induced on the surface is measured using suitable strain gauges. From the strains measured around the hole, the residual stresses are calculated.

Deep hole drilling method: Deep-hole drilling (DHD) is a technique that allows the measurement of residual stress fields through very thick components. 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 trepanned out, relaxing the residual stresses in the core. EDM can be used to trepan a central core around the reference hole since the cutting stresses introduced by this method are not significant. The diameter of the hole is measured again and the residual stresses are evaluated from the change in diameter of the hole. The main feature of the method is that it enables the measurement of deep interior stresses.

Ring-core method: In this method a hole is drilled in such a way that cutting takes place around the strain gauge rosette rather than through its center. In case of hole-drilling method a central hole is drilled and the resulting deformation of the surrounding surface is evaluated, the ring-core method involves measuring the deformation in a central area caused by the cutting of an annular slot in the surrounding material.

Non-destructive methods:

Barkhausen noise method: The magnetic Barkhausen noise (MBN) technique is a non destructive industrial tool to measure surface residual stresses in a component. The technique is applicable to ferromagnetic materials only, which are composed of small ordered magnetic regions called magnetic domains. It is based on the concept of inductive measurement of a noise-like signal, generated when a magnetic field is applied to a ferromagnetic material such as iron, nickel, cobalt and most steels. When magnetostrictive materials are stressed the preferred domain orientations are altered, causing domains most nearly oriented to a tensile stress to grow (positive magnetostriction) or shrink (negative magnetostriction). In materials with positive magnetic anisotropy (iron, most steels and cobalt), compressive stresses will decrease the intensity of Barkhausen noise while tensile stresses increase it. By measuring the intensity of Barkhausen noise the amount of residual stress can be determined.

X-ray diffraction: X-ray diffraction (XRD) is one of the fastest and the most accurate method to investigate the residual stress levels on the surface layer. It is a widely used non-destructive technique for the measurement of surface residual stresses up to depths of up to 30μm. It is based on the fact that when a metal is under stress (either applied or residual), the resulting elastic strains cause the atomic planes in the metallic crystal structure to change their interplaner spacings known as 'd values' . X-ray diffraction can directly measure this inter-planar atomic spacing; and from this the total stress on the metal can be calculated.

Neutron diffraction: The best residual stress measurement technique for distortion problems is neutron diffraction. It requires a neutron source. It is used to develop bulk residual stress data in thick sections. Neutrons have the advantage over X-rays that for wavelengths comparable to the atomic spacing, their penetration into engineering materials is typically many centimetres. Because of the very deep penetration of the neutron beam, data can be acquired from large volume of the component. Like the X-ray diffraction technique, neutron diffraction relies on elastic deformations within a polycrystalline material that cause changes in the spacing of the lattice planes (d values) from their stress-free value. Neutron diffraction for residual stress measurements is not widely used due to the need of expensive stationary diffractometers for neutron generation.

Ultrasonic method: In this method the ultrasonic waves (2 MHz - 10 MHz) are commonly used for the measurement of applied or residual stresses. It works on the principle that when ultrasonic waves are passed through a material, their speed is affected by the direction and magnitude of the stresses present, and this is called the acoustoelastic effect. Ultrasonic stress measurement techniques are based on the acoustic-elasticity effect, according to which the velocity of elastic wave propagation in solids is dependent on the mechanical stress.

Significance and effect of residual stresses in engineering components:

The properties such as fatigue life, distortion, dimensional stability, corrosion resistance, and resistance to brittle fracture are influenced by residual stresses. The residual stresses can be very detrimental to the performance of a material or the life of a component. The residual stress has been the cause of catastrophic brittle fracture of many engineering components. Conversely, residual stresses are at times introduced deliberately. The role of residual stress is very important when designing mechanical parts. A few representative examples of effect of residual stress on material behavior are listed below.

Beneficial effects:

Rotating components such as shafts, axles, bearings gears, etc. are subjected to cyclic loading conditions and are prone to failure due to fatigue. The introduction of residual compressive stress at the surface considerably increases the fatigue life of part subjected to cyclic loading.

The brittle materials such as glass can be toughened by introducing compressive residual stress to produce toughened glass. The rapid cooling of the glass from elevated temperature generates compressive surface stresses counterbalanced by tensile stresses in the interior. The compressive residual stresses at the surface help to prevent brittle fracture.

Pre-stressed concrete used in a wide range of building and civil structures make use of residual stresses. Counteracting the compressive pressure exerted by the load with an internally developed tensile pressure in the concrete, is the basic principle of a pre-stressed concrete.

Harmful effects:

Residual stresses in a weld joint result in the formation of cracks (hot cracking, lamellar tearing, cold cracking), distortion and reduction in mechanical performance of the weld joint.

Stress corrosion cracking (SCC) is a phenomenon which can lead to failure under the combined effect of acting or residual tensile stress in a component and a corrosive environment.

Welds and the adjacent heat affected parent material are generally the regions most susceptible to creep damage in fabricated steel structures. Creep strain and ultimately cracking can be driven by residual stresses, as a means of thermal relaxation of weld residual stress in areas with poor material creep ductility at the operating temperature and creep deformation rate.

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