NATURE OF COMPRESSIVE RESIDUAL STRESSES AND ITS MEASURMENT TECHNIQUE: A REVIEW

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ABSTRACT:-

Residual stresses are stresses that remain in a solid material after the original cause of the stresses has been removed. Residual stress may be desirable or undesirable. Residual stresses can occur through a variety of mechanisms including inelastic deformations, temperature gradients during thermal cycle or structural changes means phase transformation. Heat from welding may cause localized expansion, which is taken up during welding by either the molten metal or the placement of parts being welded. When the finished well-meant cools, some areas cool and contract more than others, leaving residual stresses. Another example occurs during semiconductor fabrication and micro system fabrication when thin film materials with different thermal and crystalline properties are deposited sequentially under different process conditions. The stress variation through a stack of thin film materials can be very complex and can vary between compressive and tensile stresses from layer to layer. Compressive residual stresses most of the time causes of crack propagation, according to the type of loading. That's why it is important to know nature of Compressive residual stresses in material as well as in component.

Keywords : Neutron Diffraction , plasticity induced crack closure (PICC), hammer peening, Contour Method.

I. INTRODUCTION

Residual stresses or locked-in stresses can be defined as those stresses existing within a body in the absence of external loading or thermal gradients. In other words residual stresses in a structural material or component are those stresses which exist in the object without the application of any service or other external loads.

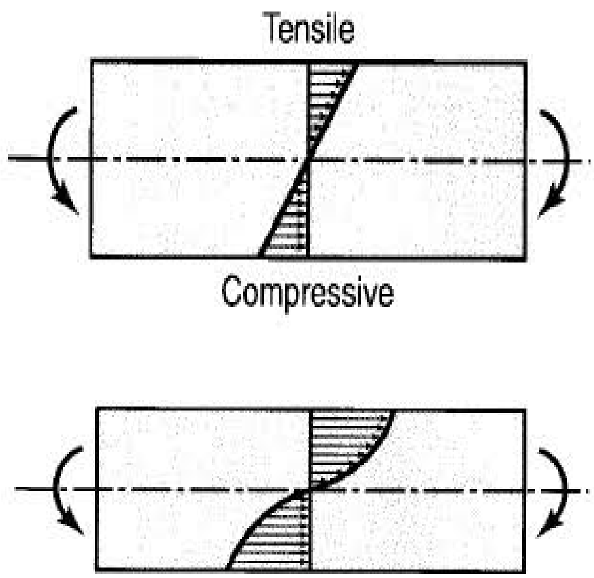

Figure 1: Schematic of generation of compressive residual stress during bending of Beam.

Residual stresses are referred to stresses remaining in a structure in the absence of external mechanical or thermal loads. Such stresses are induced where a stress gradient exists in a body and the stresses are larger than elastic limit. Upon removal of external forces and to maintain the permanent deformation caused by the stress raiser, a self-balanced system of internal forces (residual stresses) remains in the structure. Therefore, residual stresses are usually local (next to the location of the stress concentration) and bounded by large elastic region. Residual stresses are caused by most manufacturing process such as welding, machining, and forming; or are intentionally produces by processes like penning and auto frottage.[1]

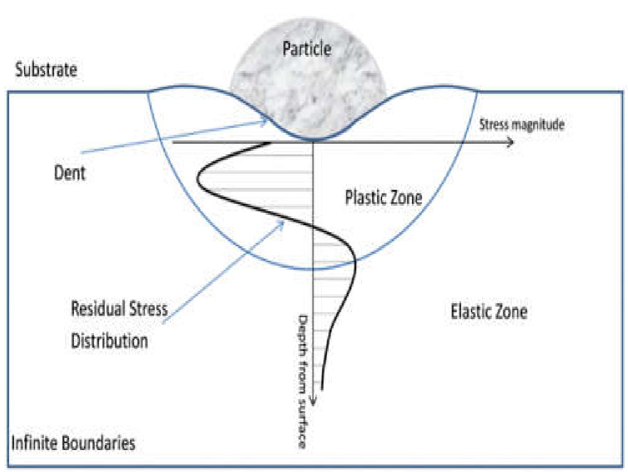

Figure 2: Schematic of compressive residual stress on surface of component.

II. TECHNIQUES USED TO MEASURE RESIDUAL STRESSES

There are many techniques used to measure residual stresses, which are broadly categorized into

a. Destructive,
b. Semi-destructive and
c. Non-destructive techniques.

These technique depends on the information required and the nature of the measurement specimen. Factors include the depth/penetration of the measurement (surface or through-thickness), the length scale to be measured over (macroscopic, microscopic or microscopic), the resolution of the information required, and also the composition geometry and location of the specimen.

A) Destructive Techniques:

Destructive techniques result in large and irreparable structural change to the specimen, meaning that either the specimen cannot be returned to service or a mock-up or spare must be used. These techniques function using a "strain release" principle; cutting the measurement specimen to relax the residual stresses and then measuring the deformed shape. As these deformations are usually elastic, there is an exploitable linear relationship between the magnitude of the deformation and magnitude of the released residual stress. Destructive techniques include:

- Contour Method – measures the residual stress on a 2D plane section through a specimen, in a uni-axial direction normal to a surface cut through the specimen with wire EDM.
- Slitting (Crack Compliance) – measures residual stress through the thickness of a specimen, at a normal to a cut "slit".

B) Semi-destructive Techniques:

Similarly to the destructive techniques, these also function using the "strain release" principle. However, they remove only a small amount of material, leaving the overall integrity of the structure intact. These include:

- Deep Hole Drilling – measures the residual stresses through the thickness of a component by relaxing the stresses in a "core" surrounding a small diameter drilled hole.
- Centre Hole Drilling – measures the near-surface residual stresses by strain release corresponding to a small shallow drilled hole with a strain gauge rosette. Centre hole drilling is appropriate for up to 4 mm in depth. Alternatively, blind hole drilling can be used for thin parts. Center hole drilling can also be performed in the field for on-site testing.

Ring Core – similar to Centre Hole Drilling, but with greater penetration, and with the cutting taking

- place around the strain gauge rosette rather than through its centre.

C) Non-destructive Techniques:

The non-destructive techniques measure the effects of relationships between the residual stresses and their action of crystallographic properties of the measured material. Some of these work by measuring the diffraction of high frequency electromagnetic radiation through the atomic lattice spacing (which has been deformed due to the stress) relative to a stress-free sample. The Ultrasonic and Magnetic techniques exploit the acoustic and ferromagnetic properties of materials to perform relative measurements of residual stress. The Stress system uses an electromagnetic measurement system. Non-destructive techniques include:

- Neutron Diffraction - a proven technique that can measure through-thickness but which requires a neutron source (like a nuclear reactor).
- X-Ray Diffraction - a limited surface technique with penetration of a few hundred microns only.
- Ultrasonic - an experimental process still in the works.
- Magnetic - Can be used with very limited sample dimensions.

III. RELIEF OF RESIDUAL STRESSES

Though these residual stresses are harmful so its removal also important. Following are some methods to remove these residual stresses.

A. Thermal method

The thermal method involves changing the temperature of the entire part uniformly, either through heating or cooling. When parts are heated for stress relief, the process may also be known as stress relief bake. Cooling parts for stress relief is known as cryogenic stress relief and is relatively uncommon.

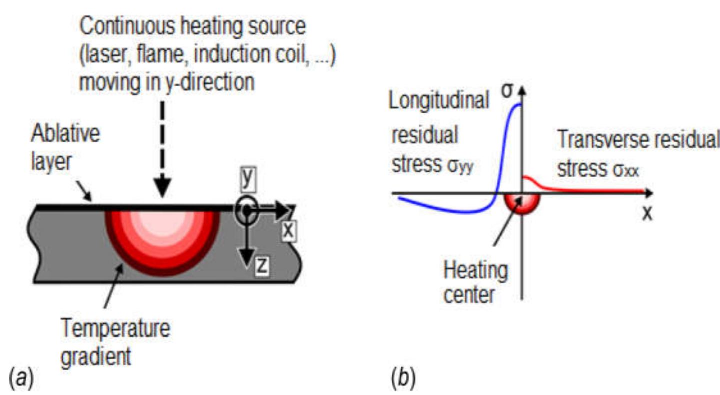

Figure 3: Schematic of residual stress due to heat treatment on surface of component.

A. Stress relief bake

Most metals, when heated, experience a reduction in yield strength. If the material's yield strength is sufficiently lowered by heating, locations within the material that experienced residual stresses greater than the yield strength (in the heated state) would yield or deform. This leaves the material with residual stresses that are at most as high as the yield strength of the material in its heated state.

Stress relief bake should not be confused with annealing or tempering, which are heat treatments to increase ductility of a metal. Although those processes also involve heating the material to high temperatures and reduce residual stresses, they also involve a change in metallurgical properties, which may be undesired. For certain materials such as low alloy steel, care must be taken during stress relief bake so as not to exceed the temperature at which the material achieves maximum hardness

B. Cryogenic stress relief

Cryogenic stress relief involves placing the material (usually steel) into a cryogenic environment such as liquid nitrogen. In this process, the material to be stress relieved will be cooled to a cryogenic temperature for a long period, then slowly brought back to room temperature.[2]

IV. EFFECT OF COMPRESSISVE RESIDUAL STRESS ON CRACK PROPOGATION

As per considering welded joints failure happened sue to tensile residual stresses. So managing these stresses is very much important work to increase life of welded components. The hammer peening process is well known as one of the methods to improve the fatigue life of welded joint by generating compressive residual stress filed near the weld toe where recognized as the fatigue crack initiation site. However there is few research work which related with the fatigue crack estimation in the compressive residual stresses field. In order to improve effect of compressive stress on surface crack propagation, a fatigue test was carried out by the bench mark method.[2]

As a result of it, when compressive stress is induced in the surface of the base metal by the hammer peening , the fatigue crack propagation rate in the length direction is much slower that when peening is not applied.[2]

V. EFFECT OF COMPRESSIVE RESIDUAL STRESS ON THE CORNER CRACK

Other methods can be applied for measure compressive residual stresses detection are like plasticity induced crack closure (PICC) concept and three dimensional (3D) finite element methods (FEM) are used to study the effect of compressive residual stress field on the fatigue crack growth from a hole.

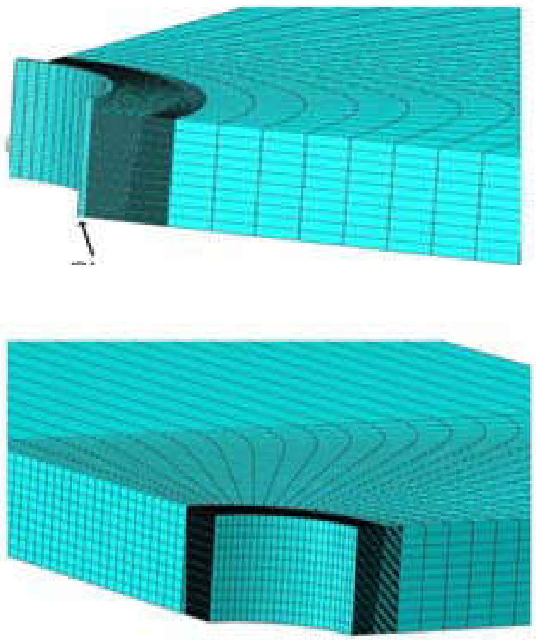

Figure 4: Sleeve (Figure from reference [9]).

As a result of above experimentation are that, Increasing number of elements around the crack tip region would give rise to increase in captured crack opening stress levels at all portion of the crack tip. Higher opening stress levels are observed at the surface and at the bore region due to plane stress conditions. Applying compressive residual stress to the model using cold work simulation, results in approximately 45% increase in normalized opening stress values. Plane stress condition at the free surface give rises to front-turning-inward for no residual stress condition. Compressive residual stress decreases this effect.[9]

VI. COMPRESSIVE RESIDUAL STRESSES MEASURMENT TECHNIQUES

There are many methods and techniques to measure the compressive residual stresses. Here one of the useful technique is given which is X ray diffraction method.

x-ray diffraction:-

Figure shows the diffraction of a monochromatic beam of x-rays at a high diffraction angle (2θ) from the surface

of a stressed sample for two orientations of the sample relative to the x-ray beam. The angle ψ, defining the orientation of the sample surface, is the angle between the normal of the surface and the incident and diffracted beam bisector, which is also the angle between the normal to the diffracting lattice planes and the sample surface. Diffraction occurs at an angle 2θ, defined by Bragg's Law: $n\lambda = 2d \sin \theta$, where n is an integer denoting the order of diffraction, λ is the x-ray wavelength, *d* is the lattice spacing of crystal planes, and θ is the diffraction angle. For the monochromatic x-rays produced by the metallic target of an x-ray tube, the wavelength is known to 1 part in 105. Any change in the lattice spacing, *d*, results in a corresponding shift in the diffraction angle 2θ. Figure shows the sample in the $\psi = 0$ orientation. The presence of a tensile stress in the sample results in a Poisson's ratio contraction, reducing the lattice spacing and slightly increasing the diffraction angle, 2θ. If the sample is then rotated through some known angle ψ, the tensile stress present in the surface increases the lattice spacing over the stress-free state and decreases 2θ. Measuring the change in the angular position of the diffraction peak for at least two orientations of the sample defined by the angle ψ enables calculation of the stress present in the sample surface lying in the plane of diffraction, which contains the incident and diffracted x-ray beams. To measure the stress in different directions at the same point, the sample is rotated about its surface normal to coincide the direction of interest with the diffraction plane. Because only the elastic strain changes the mean lattice spacing, only elastic strains are measured using x-ray diffraction for the determination of macro stresses. When the elastic limit is exceeded, further strain results in dislocation motion, disruption of the crystal lattice, and the formation of micro stresses, but no additional increase in macroscopic stress.

Although residual stresses result from non uniform plastic deformation, all residual macro stresses remaining after deformation is necessarily elastic. The residual stress determined using x-ray diffraction is the arithmetic average stress in a volume of material defined by the irradiated area, which may vary from square centimetres to square millimetres, and the depth of penetration of the x-ray beam. The linear absorption coefficient of the material for the radiation used governs the depth of penetration, which can vary considerably. However, in iron, nickel, and aluminium-base alloys, 50% of the radiation is diffracted from a layer approximately 0.005 mm (0.0002 in.) deep for the radiations generally used for stress measurement. This shallow depth of penetration allows determination of macro and microscopic residual stresses as functions of depth, with depth resolution approximately 10 to 100 times that possible using other methods. Although in principle virtually any inter planar spacing may be used to measure strain in the crystal lattice, availability of the wavelengths produced by commercial x-ray tubes limits the choice to a few possible planes. The choice of a diffraction peak selected for residual stress measurement impacts significantly on the precision of the method. The higher the diffraction angle, the greater the precision. Practical techniques generally require diffraction angles, 2θ, greater than 120°.[10]

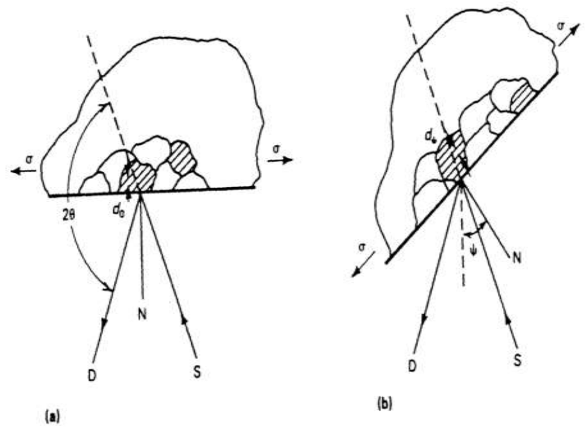

Figure 5 : Principles of x-ray diffraction stress measurement (Figure from reference [10]). (a)ψ = 0. (b) ψ = ψ (sample rotated through some known angle ψ). D, x-ray detector: S, x-ray source; N, normal to the surface.

VII. CONCLUSION

From the above review, two conclusions can be obtained. First is that compressive residual stresses are introduced in the surface of base metal affects the fatigue crack propagation rate in both the base metal and welded joint also. Second is that if the origin of compressive residual stresses are obtained properly then, it quit easy to find there effect and also we can compensate their hazards effect. Also the sources of errors will be estimated precisely and parametric study on sizes causing compressive residual stresses.

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