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# *A Study on the Reduction of Vibrational Residual Stress in Manufacturing*

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### *Abstract*

*Residual stresses are tensions that persist in a solid substance after the stress source has been eliminated. Residual stress can be beneficial or harmful. Even after external forces and temperature gradients have been removed from a body, residual stresses persist. These stressors may have a negative impact on the body's service life, compromising fatigue life and dimensional stability. Various methods for stress treatment have arisen during the last few decades, including shot peening, mechanical tumbling, and Vibratory Stress Relief (VSR). This study attempts to examine VSR as a valid stress management treatment while also examining its various variations. Residual stresses can be caused by inelastic (plastic) deformations, temperature gradients, or structural changes, among other things.*

***Keywords:*** *Vibrational Residual Stress, Manufacturing, Stress Relaxation*

## INTRODUCTION

To anticipate the performance of a part, it is necessary to know how significant the residual stresses are. If an engineer assumes the service load will not exceed 30,000 psi of tension and the component has an 8,000 psi residual stress in tension, this is an illustration of the necessity of understanding the residual stress in the part. The safe service load would be decreased to 22,000 psi of tension as a result. If the residual stress was in compression, however, the same service load would be raised to 38,000psi in tension. Standard displacement or strain-gage measurements cannot be used to assess residual stresses since these methods only measure changes in stress owing to applied loads. The slitting technique, x-ray diffraction, holographic method, and strain-gage method are all examples of methods for detecting residual stresses in a component.

## STRESS RELAXATION TECHNIQUE

The stress relaxation technique is a typical approach for determining a part's residual stress. This method involves drilling a hole in the material and measuring the resulting surface stresses. The Mather-Soete Drilling Technique accomplishes this by placing three strain gauges evenly spaced around a central point, as shown in Figure. A neatly drilled hole is bored in the middle, and the variations in stress are measured. This approach is reliable, but it necessitates the use of a nice flat surface to attach the strain gauges, which takes time. For solid cylinders and tubes, as well as three-dimensional solids, there are various different ways that follow similar procedures to the Mather-Soete Technique. The relaxation approach is also used in optical and holographic technologies. The displacement surrounding the hole is measured using a laser beam in these approaches. The advantage of this technology is that it requires little setup time and that the displacements are transformed into residual stresses by software. The displacements are compared to stress states that are well-known.

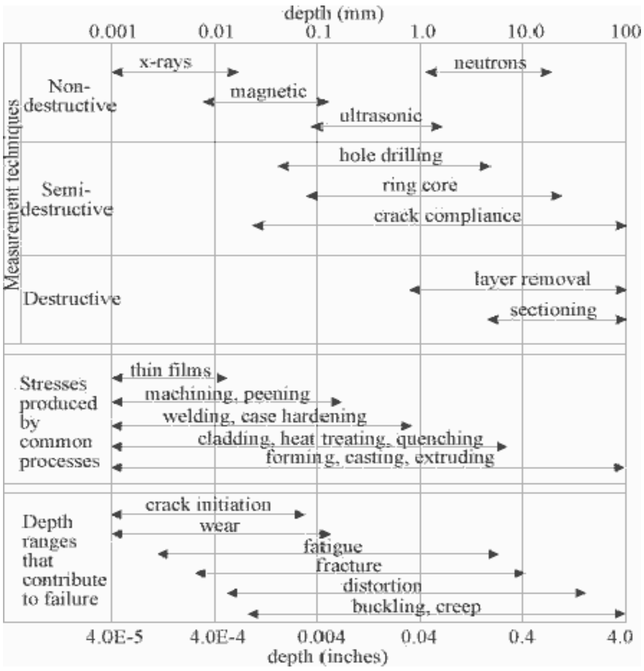


***Fig: 1 Comparison of Residual Stress Measurement Methods***

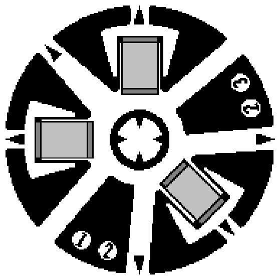

*Fig:2 Strain Gage Arrangement for Measuring Residual Stress*

**SLITTING METHOD**

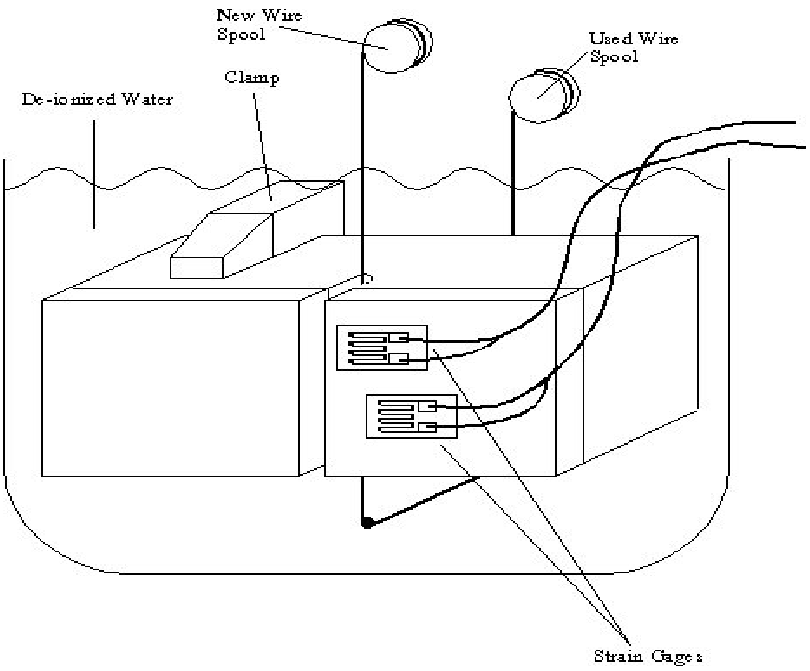


*Figure:-3 Wire EDM setup for Measuring Residual Stress*

The slitting method, like the relaxation method, involves cutting the material and measuring the displacement with strain gauges. Wire electric discharge machining (EDM), milling, or a saw blade are used to cut the slit. The wire EDM approach is used because it produces a thin slit of around 0.0035" and introduces just a modest amount of tension.

**X-RAY DIFFRACTION**

"X-ray diffraction is the most accurate and best developed method for quantifying residual stress due to various mechanical/thermal treatments," according to "x-ray diffraction is the most accurate and best developed method for quantifying residual stress due to various mechanical/thermal treatments..." The x-ray diffraction method examines the stress-induced displacements in atomic lattice structures. "By measuring the angular location of diffracted x-ray beam," the measurement is made. The change in measurement, which is the change in atomic plane spacing, is a strain that may be transformed into stress; see for additional information and equation derivation. When strain is measured in two separate directions, the stress in any direction may be determined. Only if the surface stresses are measured is this procedure non-destructive. Material is ground away to reveal the layer to be measured in order to get sub-surface tensions. The downsides of this procedure are its slowness and the fact that it is not particularly precise for heat-treated items.

## THE ESSENTIALS OF STRESS RELIEF

The two most common methods for reducing or eliminating residual stresses induced by welding are annealing (post-weld heat treatment) and mechanical treatment. The material type, heat input, heat transfer rate, thickness of the material, kind of fusion welding technique, how the material is constrained, process speed, and other parameters all influence the production of residual stresses and the stress reduction process. Because the multiple aspects involved in dealing with residual stress make a precise prediction of the stress release process difficult, organisations depend on past findings or experimental data to anticipate outcomes. The conventional way for decreasing residual stresses in welded materials is to anneal or heat treat the components. Temperature gradients are reduced when weldments are gently heated to an increased temperature, preventing the formation of additional residual stresses. The weldment is then kept at that temperature for a specific amount of time, or "soaked."

The yield point of the base material of the weldment is low enough at this increased temperature for the strained portions to plastically relax to a reduced stress state. The part is progressively cooled at the conclusion of this period to avoid introducing additional strains. The biggest issue with heat treating items is the expense in terms of time and energy. Huge weldments necessitate the use of a large oven, and there are only a handful of these furnaces scattered around the country. Large weldments may also need to be "soaked" for 40 hours or longer to decrease residual stresses to acceptable levels. Another option is to use an acetylene torch to heat treat the weld locally. This approach reduces residual tensions marginally, but it is time intensive and requires manual labour. There are a number of mechanical techniques that may be used to minimise or adjust residual stresses. Shot peening is the first process, which entails blasting a component with tiny spherical pellets.

Small deformations are caused by the pellets impacting the surface, causing compressive stresses on the surface and tensile stresses on the sub-surface of the part. These surface compressive stresses reduce the likelihood of cracking and boost fatigue resistance. Hand forgings are stress relieved by cold deformation, also called as cold working. The component is treated with a solution and then quenched. The cold component is then put between cold flat dies and decreased in thickness before being aged. Proof testing a weldment reduces residual stresses by gently plastically deforming the weld region, which results in a reduction in residual stresses. Pressure containers and pipelines are the most common applications for this technology.

## OVERVIEW OF VIBRATORY STRESS RELIEF

Vibratory stress relief (VSR) has been utilised commercially for over thirty years, but scientists and engineers have only lately studied it mathematically and mechanically. "The primary goal of VSR is to reduce and redistribute stresses to safe levels, ensuring component precision and long-term stability." VSR isn't right for every application, as we'll see later in this section, but it's great for those that don't require a change in crystal structure or mechanical characteristics. Furthermore, there are several advantages to employing VSR over heat treatment of weldments, including cost and time savings.

When compared to standard heat treatment of weldments, VSR offers several advantages, including cost and time savings, as well as environmental benefits. The first 10 cycles of VSR result in the greatest decrease in residual stress. If the resonant or sub-harmonic approaches are utilised, the VSR process will take 10 minutes, or just a few hours if the sub-resonant method is used. Furthermore, as shown in Figure 4.1 on the following page, the actuators utilised for VSR are compact and portable. Figure illustrates a single vibrational actuator, Meta-Lax, mounted on a dynamometer base that had been machined for 80 hours after welding and had less than 0.002 in distortion after production. Bonal Technologies, Inc. invented Meta-Lax, a VSR technique that they employ for both post-weld stress reduction and welding process conditioning.

Vibratory stress alleviation can be used to any application that does not necessitate a change in a part's mechanical characteristics or crystal structure. The VSR approach would be useful in applications needing dimensional stability as well as the release of residual tensile stresses that can lead to early fatigue failure and stress cracking. Tooling fixtures, welded frames, and machined parts can all benefit from stress alleviation. More VSR applications employing Meta-Lax equipment are shown in the figure.

**MODEL OF FINITE ELEMENTS**

"The finite element method is a numerical analytical methodology that may be used to provide approximate solutions to a wide range of engineering issues." In an issue involving displacement, stress, strain, or another attribute, there are an endless number of unknowns. The finite element approach works by making the analysis easier to understand. To begin, the examined form is separated into elements that are connected by nodes. The varied parameters throughout the element are then represented by an interpolation function. Polynomials are commonly used as interpolation functions because they are simple to integrate and differentiate. The degree of the polynomial is determined by the number of nodes assigned to the element. The characteristics of the individual elements are then defined using matrix equations. The attributes of the elements are then combined to form the system's equations. "The basis for the assembly technique originates from the fact that at a node, where elements are interconnected, the value of the file variable is the same for each element sharing that node," Huebner and colleagues write. The problem's boundary conditions are specified, and the system equations, which are made up of a series of simultaneous equations, are solved.

The computer model of the vibratory stress alleviation of a pre-stressed beam was created using ANSYS, a finite element modelling tool. The beam was set up as a cantilever, with the left end grounded and the right end floating in space. The beam was represented by a 2-D structural solid, the PLANE42 element in ANSYS. The PLANE42 element is a two-dimensional element made up of four nodes, each with two degrees of freedom (x and y translations). Plasticity, creep, swelling, stress stiffening, big deflection, and significant strain are all capabilities of the PLAIN42 element.

As indicated in Fig. 1, the beam's form was specified by three square components joined by eight nodes. The beam has an underformed length of fifteen inches, a height of five inches, and a depth of one unit. Because the frequency response part of the code required a value, the depth was specified as an arbitrary measurement.

Nodes 1 and 5 were fixed and had zero degrees of freedom, which were the problem's boundary conditions. To compare data to numerous other articles that employed the same material, the material parameters presented in Table were chosen to be those for the aluminium alloy 6061-T6.

***Table:1 Material Properties of Aluminum***

| Density, ρ | Modulus of Elasticity, E | Poison's Ratio, ν | Yield Strength, $S_y$ | Tensile Strength, $S_{ut}$ |
|---|---|---|---|---|
| 0.0975 $lb/in^3$ | $10x10^6$ $lb/in^2$ | 0.33 | $40x10^3$ $lb/in^2$ | $45x10^3$ $lb/in^2$ |

Several points from the stress-strain curve for aluminium 6061-T6 were taken into consideration to account for the bilinear kinematic hardening of the aluminium when it was plastically deformed, as illustrated in Figure.

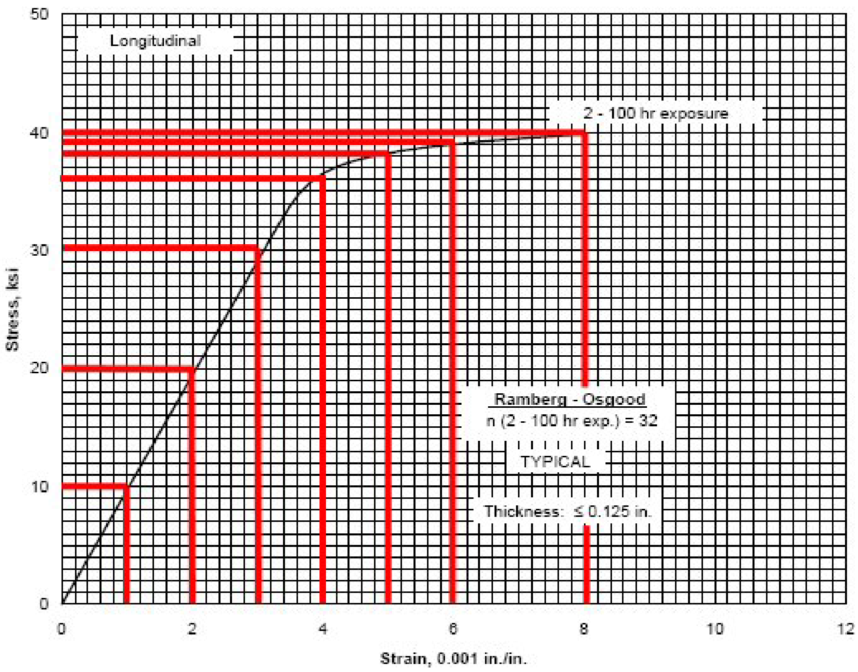


***Figure : 4 Aluminum Alloy 6061-T6 Tensile Stress-Strain Curve***

## INDUSTRIAL USE OF VSR

For economic and/or performance considerations, many modern manufacturers have removed thermal stress relief on big parts. These companies produce a wide range of products, including specialised machinery, aeroplanes, railcars, rollers and conveyors, and mining gear.

## CONCLUSION

VSR isn't appropriate for every stress-relieving situation. Parts that do not need a change in material qualities or crystalline structure are suited for the VSR process. Only a heat treatment method, like as annealing, will be effective for these modifications. VSR is appropriate for a variety of applications, including stress relief in tooling fixtures, welded frames, and machined parts where dimensional stability and fatigue life are important.

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