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# A REVIEW ON RESIDUAL STRESSES IN FIELD OF DESIGN AND ITS ROLE IN FAILURE CRITERIA

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## ABSTRACT

*Residual stresses can add to, or subtract from, the applied stresses and so when unexpected failure occurs it is often because residual stresses have combined critically with the applied stresses, or because together with the presence of undetected defects they have dangerously lowered the applied stress at which failure will occur. Consequently it is important that the origins of residual stress are understood and finding out the ways for removing harmful or introducing beneficial residual stresses.*

*Residual stresses have the some role in a structure's strength as common mechanical stresses. However, while stress due to external loads can be calculated with a degree of accuracy, residual stresses are difficult to foresee. It is, therefore, very important to have a reliable method able to measure them directly with minimum damage to the surface. Residual stresses can play a significant role in explaining or preventing failure of a component at times*

*Residual stresses is that which remains in body that is stationary and at equilibrium with is surrounding. It can be very detrimental to the performance of material of the life of component. Residual stresses are more difficult to predict than in service stresses.*

***Keywords: creep cavitations, fatigue, plastic collapse, Residual stresses(RS), unstressed condition.***

## I.INTRODUCTION

### What are Residual Stresses ?

Stresses that remain within a part after it has been deformed and all external forces have been removed. The deformation must be non uniform across the material cross-section in order to give rise to residual stresses. The deformation can result by manufacturing operations but also from thermal processes.

Residual stresses are those stresses which remain in a body when all external forces (except gravity) have been removed from it. These stresses are sometimes termed as locked-in stresses which exist in a body at rest. Since the body containing the residual stresses must be at equilibrium (if it is at rest, and subject to no externally applied forces), it is clear that the residual stresses within the body must be both positive (tension) and negative (compression) in sign to maintain the equilibrium state.

There is macro residual stresses, or those which exist in a body on a scale much larger than the micro-scale. Micro residual stresses are those which exist in a body on nearly an atom-scale, or at least on the scale of those material features which can be seen only with the aid of high-magnification microscopy. These local stresses are sometimes termed tessellated stresses. While it is true that the systematic variation of micro-stresses can, in fact, produce a macro-stress distribution across, or within, a body at rest, the engineering properties and characteristics of the material can be adequately understood by giving attention only to the macro-stresses [2].

## II. INTRINSIC NATURE OF RESIDUAL STRESSES

Since stresses are an entirely elastic phenomena, and further, since stresses are always related to only the elastic strain portion of the total the presence of residual stresses within a body must mean the presence of non-uniform distributions of elastic strains within the body. This is a very important concept in the consideration of residual stresses - they are really a manifestation of non-uniform distribution of elastic strains within the body. If this is kept in mind at all times in working with residual stresses, the effect of the stresses on the properties and characteristics of the body, as well as the remedial measures for the reduction of residual stress levels, is much more easily understood [2].

Take the example of a simple beam in bending shown in Figure 1. While deflection is low, the entire beam behaves elastically. Tensile and compressive stresses develop linearly as the distance from the neutral axis increases to the beam's outer fiber as in Figure 1(a). As the deflection builds, the outer fibers will reach the yield point and plastic deformation will begin. Under further deflection, the depth of material experiencing plastic deformation grows while the core of the beam continues to behave elastically

as in Figure 1(b). When the load is released as in Figure 1(c) , the release of elastic strain energy allows the beam to straighten to a point. The material that had been plastically deformed will not return to the same original length since it has been stretched or compressed, depending on whether the applies stress was tensile or compressive. The final result will leave the outer fibers in residual stress opposite in direction to the original applied stress as in Figure 1(d). When subsequent elastic stresses are applied, the starting point for the loading is the final residual stress state (Figure 1(d)) as opposed to the original unstressed condition. If the subsequent loading is in the same direction, the net stress on the upper fiber will have been reduced by the amount of the residual stress. On the other hand, if the subsequent loading is in the opposite direction, the net stress will increase by the amount of the residual stress. Therefore, the product application plays a significant role in determining whether or not a particular residual stress state is an improvement or detriment [1].

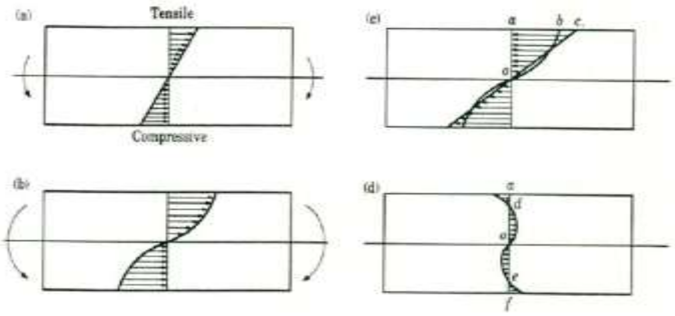


**Figure 1:** Residual stresses developed in bending a beam made of an elastic strain-hardening material (Figure from reference [1])

## III. TYPES OF RESIDUAL STRESSES

Residual stresses can be characterized by the scale at which they exist within a material. Stresses that occur over long distances within a material are referred to as macro-stresses. Stresses that exist only locally (either between grains or inside a grain) are called micro-stresses. The total residual stress at a given location inside a material is the sum of all 3 types of stresses.

**Type I Stresses:** Macro-stresses occurring over distances that involve many grains within a material. Macro-residual stresses are developed in several grains. Any change in the equilibrium of Type-1 RS will result in a change in macroscopic dimensions. Any treatment or process which causes inhomogeneous distribution of strains produces Type-1 residual stresses.

**Type II Stresses**: Micro-stresses caused by differences in the microstructure of a material and occur over distances comparable to the size of the grain in the material. Can occur in single-phase materials due to the anisotropic behavior of individual grains, or can occur in multi-phase material due to the presence of different phases.

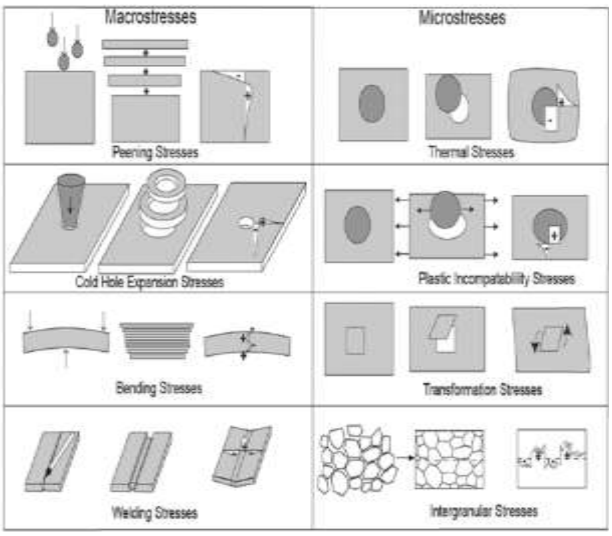


**Figure 2:** Residual stresses arise from misfits, either between different regions of a material or between different phases within the material.

(Figure from reference [3])

**Type III Stresses:** Exist inside a grain as a result of crystal imperfections within the grain. Sub-micro residual stresses are developed within several atomic distances of the grain. Formation is caused by crystalline defects such as vacancies, dislocations, etc. In real life, components have all the residual stress types.

Following figure shows some causes of generation of Residual stresses.

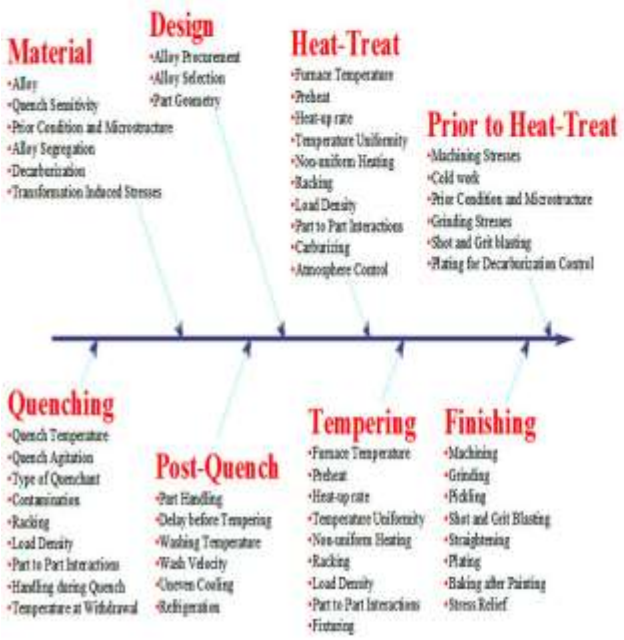


**Figure 3:** causes of residual stresses and distortion.

## IV. ORIGIN OF RESIDUAL STRESSES

In considering the origin of residual stresses, it is first necessary to specify the nature of the body in which they exist. For this purpose, the bodies containing the residual stresses can be placed into three categories: (1) mechanical assemblies of components, (2) fusion joined assemblies of components, and (3) homogeneous bodies.

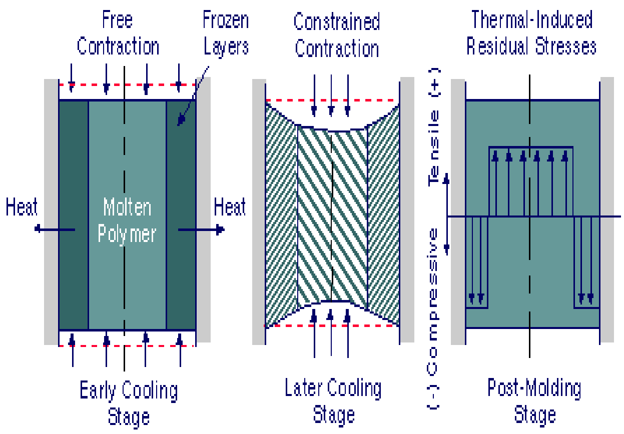


**Figure 4:** Origin of Residual stresses in component.

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**(1) Mechanical assemblies of components:**

The non-uniform distribution of the elastic strains in the body results from interference fits, misalignments, etc. Shrink-fitted, inserted dies are a typical example of bodies in this group.

**(2) fusion joined assemblies of components:**

Fusion-joined assemblies of components, residual strains result from the resistance of the assembly to the thermal contraction of the parts which were heated to produce the assembly, or to .the thermal contraction of the fusion material itself. Residual stresses in the first two categories are sometimes termed contingent stresses, because their existence is Contingent upon the presence of adjoining members.

**(3) Homogeneous bodies:**

Homogeneous materials and or bodies, the residual strains result from a non-uniform distribution of plastic deformation [2].

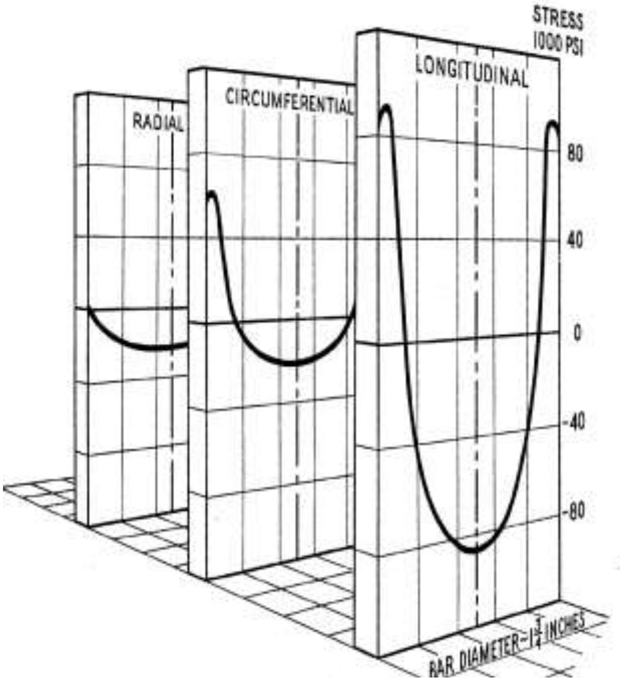


**Figure 5:** Accurate Residual Stresses Distribution. (Figure from reference [2])

Following are also some situations where residual stresses are formed, some of them discussed as:

***1. Plastic deformation:***

In a real material plastic deformation is never completely homogenous. Deformation at the atomic scale takes place by the movement of discrete line defects (dislocations) through the crystallite. Probably the simplest way to introduce a residual stress plastically into a body such as a bar is to bend it beyond the elastic limit. The resulting plastic strain misfit between the outer regions and the elastically strained interior is maintained on elastic unloading such that the bar remains permanently bent, as recorded by the strain gauge and a characteristic zigzag residual strain profile results. The compressively strained (LHS) region has tensile residual strains while the tinselly strain region (RHS) is compressively strained [3].

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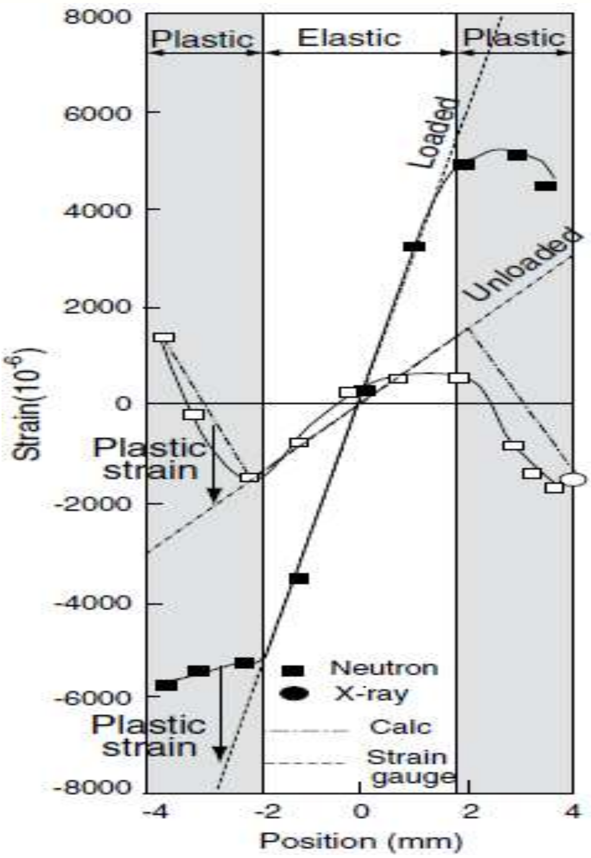


**Figure 6:** Lattice strain variation across an aluminium alloy bar loaded with a bending moment exceeding the yield point of the material (Figure from reference [3])

***2. Thermal origins:***

Thermal misfit stresses arise due to temperature gradients within a body. Consider for example, rapid cooling (quenching); the exterior which cools fastest would contract naturally due to the decrease in temperature were it not for the resistance offered by the warmer interior. This generates tensile stresses in the exterior and compressive stresses in the interior. Normally, these stresses are transient disappearing when the body as a whole reaches the same temperature. If on the other hand the gradients are sufficiently severe (thereby generating significant stresses), or the yield stress of the interior very low(due to the elevated temperature), then non-uniform plastic deformation may occur in regions where the yield stress is exceeded. Once cooled to a uniform temperature these permanent misfits generate a characteristic residual stress. This method is used commercially to introduce compressive in-plane surface stresses in thermally toughened glass. The sequence of stress profiles as the glass is cooled rapidly from above the glass transition temperature is shown in figure. Once cooled these residual stresses are not evident from the appearance of the glass, but radically affect the failure behavior of the glass leading to a characteristic mosaic crack that runs through the interior of the glass pane. Because it is the elastic strain energy that provides the energy to produce such a network of cracks, the residual stress can be estimated from the average size of the pieces [3].

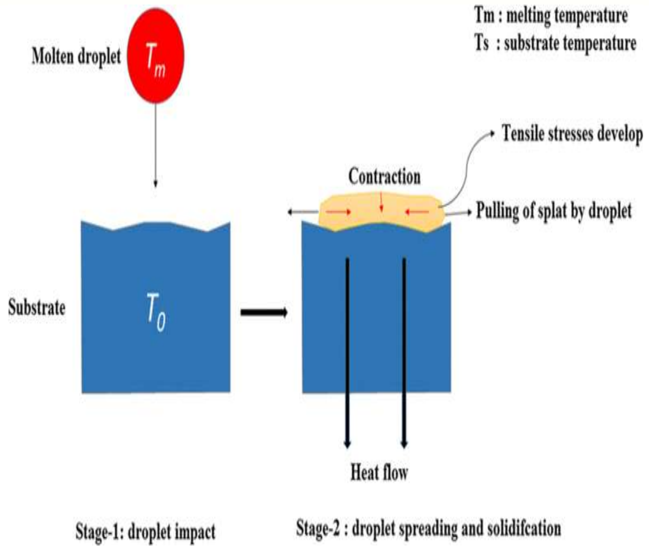


**Figure 7:** Residual stresses from Thermal origin (Figure from reference [5])

**3.** ***Phase transformation:***

Many 'smart' materials rely on solid state transformations

that occur displacively. Displacive transformations are characterized by a rapid distortion of the crystal lattice from one structure to another, thereby generating a misfit between the transformed and untransformed regions which may give rise to residual stresses as well as a sudden macroscopic shape change The most well known example

of a displacive transformation is provided by the martensitic transformation in steel. In order to minimize the residual stress (elastic energy) the marten site nucleates as lenticular plates with a twinned structure [3].

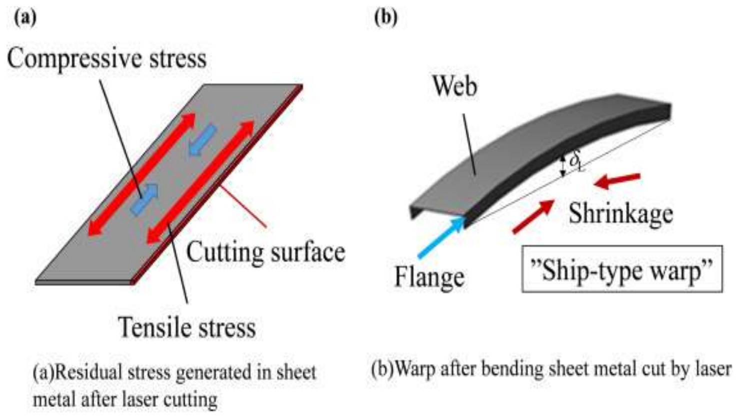


**Figure 8:** Residual stresses from Phase transformation (Figure from reference [6])

***4. Welding and other localized heat treatments:***

whenever a material is exposed to severe thermal gradients

there is an opportunity for non-uniform plastic deformation: this situation is characteristic of welding. The local thermal excursion usually causes plastic strain in the weld metal and

base-metal regions near the weld. These give rise to residual

stresses as well as to local shrinkage and distortion. It should also be borne in mind that the materials microstructure is likely to be sub-optimal locally in that the parent microstructure has usually been optimized to peak condition by careful processing, while the extreme local thermal excursion is likely to have led to a less favorable microstructure from a performance point of view. The joints are often sites of stress concentration these residual stresses are commonly a cause of cracking and premature failure of welded structures [3].

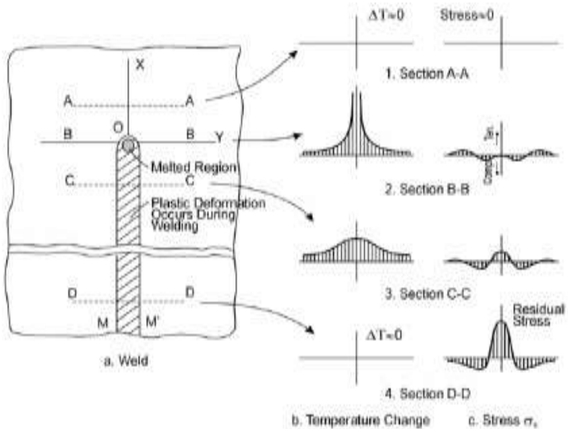


**Figure 9:** Schematic representation of changes of (*b*) temperature and (*c*) longitudinal thermal residual stresses during bead-on-plate welding. (Figure from reference [3])

## V. EFFECT OF RESIDUAL STRESSES ON FAILURE CRITERIA

***1. Plastic collapse :***

In simple terms plastic collapse occurs when the stress exceeds the yield criterion over a sub domain of the component. Engineers tend to define primary and secondary stresses based on whether they affect structural plastic collapse. The former are required to satisfy equilibrium externally and arise from imposed loading, including dead weights, internal pressures, etc although very long-range residual stresses such as fit-up stresses in pipe work are sometimes included. Secondary stresses on the other hand are shorter range stresses (weld residual stresses, etc) caused by misfit strains within the body It should be noted that in certain cases residual stresses which are self-equilibrating over the entire structure may still result in plastic collapse in the net section around a crack-like flaw. [3]

***2. Fracture :***

Common to all fast fractures is the catastrophic propagation of a crack from an initial microscopic defect or flaw. It is explained in detail in case study. [3]

***3. Fatigue and thermal fatigue:***

Fatigue is the deleterious change in properties that occurs due to the repeated application of sub-critical stresses or strains. Fatigue crack growth can be broken down into nucleation and propagation of damage (e.g. Suresh 1991). During the nucleation stage micro structural changes cause permanent damage prior to the formation of microscopic cracks. The propagation stage begins once these microscopic flaws have grown and coalesced to form dominant macroscopic cracks. These may then propagate stably prior to rapid growth leading to fast fracture. [3]

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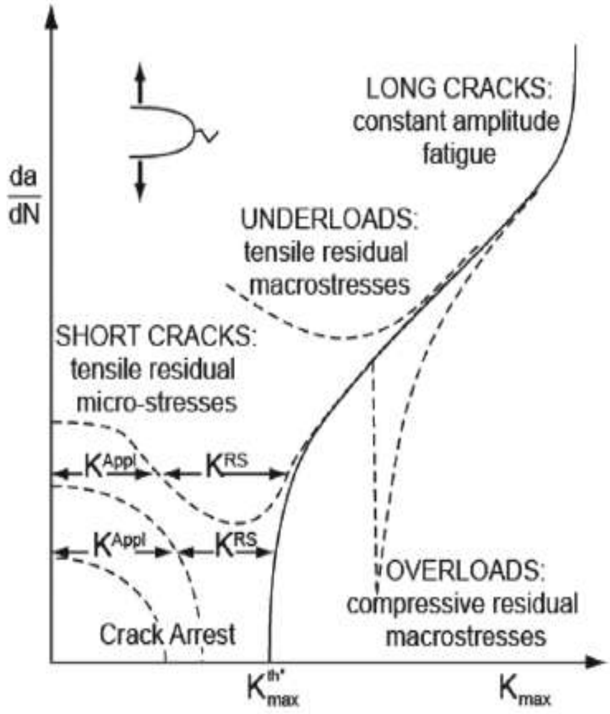


**Figure 10:** Schematic illustration of the role of residual stress on crack growth rate, d*a*/d*N*, for long and short cracks in terms of *K*max. (Figure from reference [3])

For tension–tension fatigue, local compressive residual stresses ahead of the crack-tip arise from reverse plastic flow on unloading . If a tensile overload is applied the size of the compressive zone is believed to which has been used to explain transient retarded crack growth. This effect is exploited in the use of warm pre-stressing to increase fracture toughness of cracked components. [3]

***4. Creep cavitation cracking:***

Creep, is the inelastic deformation under load of materials over long periods, that would cause only elastic deformation if imposed for short periods. This is an important deformation mechanism at elevated temperatures. If the accumulated creep strains exhaust the creep ductility of the material, cracks will initiate. The failure mode is often characterized by the growth of cavities on grain boundaries. Welds and the adjacent heat affected parent material are generally the regions most susceptible to creep continuum damage in fabricated steel structures. Creep strain and ultimately cracking can be driven by residual stresses, for example, 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. [3]

***5. Stress corrosion :***

Stress corrosion cracking is a particular worry for the oil, petrochemical and power generation industries. As a near surface phenomena, stress corrosion is particularly amenable to prevention by control of the near surface stress state and significant increases in the resistance to stress corrosion have been achieved by the various peening methods. Figure shows that in contrast to shot peening, low plasticity burnishing was found to confer good resistance under 0.5mm notched SCC and foreign object damage (FOD) testing. [3]

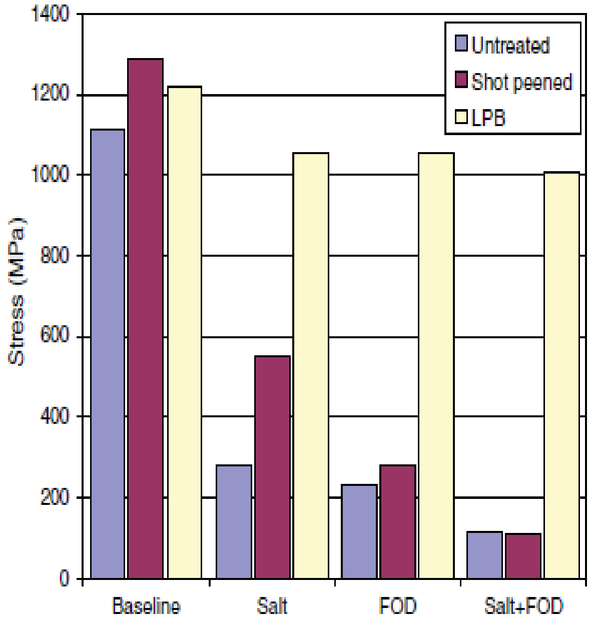


**Figure 11:** Fatigue strength at 107 cycles for 0.5mm notched SCC study of 300M steel in the presence of a neutral 3.5% salt solution for untreated, shot peened and low plasticity burnished conditions.
(Figure from reference [3])

## VI. CONCLUSION

From the above review, we can say that Residual stress (RS) is often implicated in the failure of parts or assemblies, but there has not been any quantification or statistics collected on RS induced failures. Because of the great importance of residual stress states for the strength and lifetime of surface treated components they have also to be taken into account in the case of failure analyses.

## VII. ACKNOWLEDGMENT

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