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REVIEW OF FATIGUE STRENGTH EVALUATION OF LOCAL STRESSES IN WELDED JOINTS

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ABSTRACT

This paper presents a review of fatigue strength for welded joints. The keys of welded joints influencing fatigue has been introduced as well. The types of stresses affecting the weld joint is listed as well with impression to the one affecting fatigue strength. In the second part we listed the factors affecting the fatigue of weld joints. Finally, we finished with small conclusion summarising the strength and its importance in material sciences and specially in welding. Moreover, areas that require additional research are highlighted as a result of review.

Keywords: Fatigue, Weld Joint, Fatigue Strength, Residual Stress, Flaws.

1. INTRODUCTION

This phenomenon “fatigue”, It can be defined as a progressive localised process in which damage continuously accumulates in a structure or structural element because of cyclic loading, which has much less intensity than the static resistance of an observed structure or structural detail [1]. Fatigue cracks are mainly start at locations of a sudden change in the geometry, notch locations or welding [2]. where there is a restricted grow of stress (stress concentration). The smaller the notch is, the upper the stress concentration is. Ending, fatigue life is shorter. The ordinary locations in steel structures prone to fatigue where fractures made are welded joints as these are locations of high stress concentrations. Clearly, fatigue assessment is unavoidable through in design and maintenance due to the fact mentioned that welding is a primary process of connecting elements in structures.

Fatigue breaks start for the most part from the surface, as the stresses because of loads (like bowing and torsion) are by and large high at the surface contrasted with within material. The fatigue resistance of sub-surface material is likewise higher (roughly by 1.4 times) than that of the surface (Peige et al., 1996). Furthermore, the surfaces are exposed to machining and dealing with defects which go about as stress raisers. These machining tasks actuate impeding (tensile) residual stresses that can antagonistically influence the fatigue response and surprisingly the dimensional strength just as further machining. It is always a challenge to the designer to maximize the fatigue strength without any additional weight or cost increase. The fatigue strength can be enhanced by the use of controlled cold working methods. Shot peening (SP) is one such process which induces residual compressive stresses (RCS). Typical residual stress distribution developed by the SP process. The RCS reduces the tensile mean stresses due to the applied loads and manufacturing thereby it increases the fatigue strength [3].

2. FATIGUE OF WELDED JOINTS

2.1. Fatigue in General

The term of "Fatigue" was first referenced in the nineteenth century to portray the disappointment of a structure or auxiliary component exposed to cyclic loading. Examination of fatigue was first done by August Wöhler who explored the failure of train axles. He recognized that structural loading that is well beneath its static resistance doesn't cause any failure. Although, if the same case of loading has been repeated throughout a prolonged period of time, it can cause failure of the structure or basic component. In the 19th century, fatigue was a strange wonder because fatigue damage could not be recognized, and failure happened without any notice. In the twentieth century, it became realized that cyclic basic loading causes the fatigue, more specifically crack initiation, and its propagation (fracture mechanics) [4]. A sequence of fatigue improvement from 1837 to 1994 is given by Schütz [5], just as Mann [6], in his assortment of 21,075 writing sources in his four books that are worried about the fatigue issue of materials and structures from 1838 to 1990. An audit of fatigue evaluation strategies from 2002 and the elements that influence the fatigue behavior of structures and materials was made by Cui [7].

A comprehension of the fatigue effect is an essential while considering various variables that influence fatigue life and picking suitable appraisal methods. The fatigue life of a structure or basic component is estimated from the crack commencement and crack propagation phase. Cracks made by cyclic stacking as a rule happen at the surface of a basic component where fatigue harm comes as microscopic cracks in crystallographic slip planes. This stage is known as the "Crack Initiation Phase." Furthermore, Cracks propagate from confined plastic strain to naturally visible size toward a path opposite to the loading direction, which presents the crack propagation stage [4]. The Crack commencement stage additionally contain crack growth for a microscopic scope, yet it actually can't be seen by the unaided eye. It is difficult to decide the point between the periods of crack commencement and propagation. In the break commencement stage, fatigue is a surface phenomenon and relies upon material surface attributes and natural conditions, while crack spread relies upon the attributes of the material the crack is spreading through. These two stages were perceived by Forsyth [8]. which is perhaps the greatest achievement in research of fatigue of metals in the twentieth century. The component of fatigue in various materials and structures is broadly described by Schijve [4] in his book. Current fatigue hypotheses independently examined each phase of the fatigue cycle. Crack initiation speculations depend on the suspicion that fatigue cracks show up with local stress or strain fixations on the surface of the component due to various geometrical shapes like openings, notches, discontinuity, etc. Crack propagation and final fracture is structured by fracture mechanics which considers the break proliferation rate corresponding to the stress state in crack tip.

2.2. Key of Welded Joint Influencing Fatigue

2.2.1 Geometric Stress Concentration

The geometries of most welded joints present harsh surfaces and changes of segment includes that cause nearby stress focus when the joint is loaded. Consequently, they offer locales for fatigue crack initiation. A few, eminently weld surface ripples, are moderately mild and in fact ceaseless welds in which the fatigue loading acts corresponding to the weld (generally referred to as longitudinal welds in the fatigue context). as appeared in Fig. 2.1, are among the most elevated fatigue execution welded joints. Interestingly, the sharp area changes at the ends of broken longitudinal welds and the toes of any cross over welds (for example loaded at right points to the weld) present extreme stress focuses under loading typical to the weld (alluded to as cross over welds in the fatigue setting) [9].

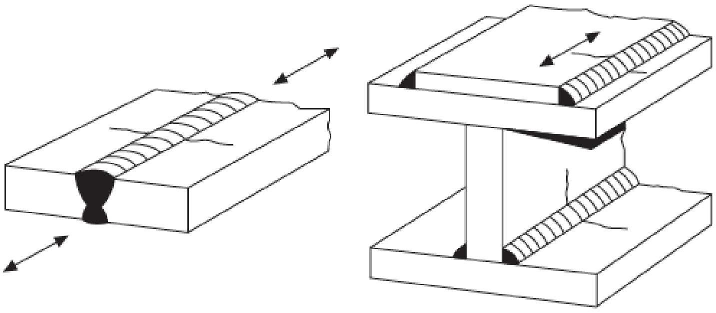

Figure. 2.1. Continuous longitudinal butt and fillet welds in which fatigue failure initiates at mild stress concentrations (weld ripples, stop/starts or the weld root)

2.2.2 Flaws

A critical component of weld toes in steel is the inescapable presence of sharp discontinuities. Undercut and cold laps are models, but more significant, on much smaller scale, are little (regularly 0.1 to 0.4 mm in depth) nonmetallic interruptions (Signes et al, 1967) [10]. The weld toe fatigue break in Fig. 2.2 has started at such a flaw. In contrast to undermine and cold laps, which can normally be dodged by control of the welding, these intrusions are an inherent feature of welds made in steel by creation curve welding measures.

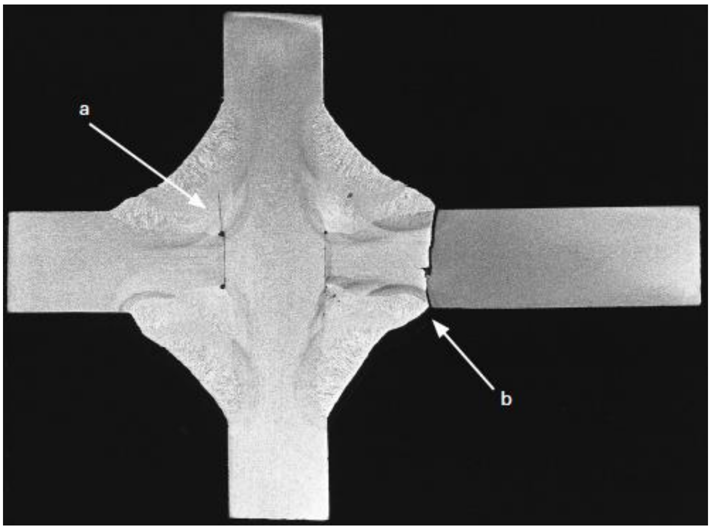

Figure 2.2. Fatigue cracking in fillet-welded cruciform joint: (a) crack growth from weld roots; (b) crack growth to failure from weld toe

A critical consequence of the consolidated effect of a serious geometric stress concentration because of the sharp area change and natural break like flaws is that fatigue cracks or break promptly start at weld toes or ends and most of the subsequent fatigue life of the welded joint might be spent essentially spreading a break. Conversely, fatigue crack initiation can occupy most of the lives of unwelded components. This is the reason the weariness execution of welded joints will in general be a lot more unfortunate than that of unwelded material. Weld toe interruptions like those described above difficult to found in aluminum alloys and they may not occur in steels welded by methods like, tungsten inert gas (TIG), laser, electron beam and friction. However, the extreme geometric stress concentration because of sharp area changes is still produced and different highlights, for example, undercut, cold laps and liquation cracks do happen. Subsequently, fatigue cracks promptly start and typically the fatigue life is still dominated by fatigue crack propagation.

This has significant implications concerning fatigue design S–N curves furthermore, the components which impact the fatigue lives of welded joints, on the grounds that those impact crack initiation can be quite different from those that influence crack growth. Aside from the flaws considered above, which are either inherent in welding or on the other hand intentionally presented as on account of cruciform or T-joints made with partial penetration filet welds, welding can present imperfections, for example, gas pores, non-metallic inclusions and even cracks. These are commonly limited, or avoided in the case of cracking, by legitimate choice of welding conditions and proper assessment. If they are present in a fatigue loaded weld, they may provide sites of fatigue cracks initiation. however, their assessment typically falls outside the extent of fatigue [9].

2.2.3 Residual Stress

Residual stresses in welding are caused by differential thermal extension and constriction of the weld metal and parent material. Residual stress levels in and close to the weld can be high, up to material yield strength size in highly constrained circumstances, which is the situation in most real structures.

Aside from welding, comparative high tensile residual stresses (alluded to as long range or limitation stresses) are probably going to be introduced during the assembly of a structure from segments, because of flawed fit-up. In contrast to welding residual stresses, it isn't commonly conceivable to relax these by stress help heat treatment. High tensile residual stresses have a critical impact on fatigue. If the residual stress is as high as tensile yield, the resulting effective stress cycles down from yield, the range being unchanged (Gurney, 1979) [11]. Also, the fatigue lives of welded joints containing high tensile residual stresses should be independent of applied mean stress for either tensile or compressive applied anxieties. This has, truth be told, been affirmed experimentally ordinarily, prominently by Fisher and co-workers (Fisher, 1997) [12]. Other issue that should be referenced is the way that residual stresses can change as result of investigation from ensuing applied loading (McClung, 2007) [13]. Indeed, relaxation of tensile welding-induced residual stress in direct proportion to the magnitude of the applied stress observed following the application of a single tensile stress cycle (Iida and Takanashi, 1997) [14].

3. TYPE OF STRESSES

3.1 Nominal Stress

The fatigue strength measurement of welded structures usually dependent on the nominal stress, σ_n, which is characterised as far as sectional forces and instants in the structure a little bit away from the welding joint, in consideration of linear elastic theory [15]. A nominal stress range versus fatigue life (S-N curve) is at that point decided tentatively for a given weld and structural geometry. The nominal stress S-N curve involves the impact of material, geometry (comprehensive of notch and size impact) and surface (comprehensive of residual stresses). It is subsequently certain that the methodology isn't appropriate for the assessment of contrasts in welding parameters, for example, size, geometrical and stress concentration impact since it is verifiably remembered for the experimentally determined S-N curve, which is adjusted to include the impact of the statistical scatter because of parameter varieties. Since the welded segment to be assessed should be like the part for which the S-N curve is determined, the nominal approach is additionally not appropriate for the evaluation of new subtleties or geometries.

The benefits of the methodology lie in the way that the results are dependable, given that the nature of the welded joint viable associates near to the given class of joint for which the curve is set up regarding welding process, weld quality and geometry. The technique additionally requires few computational efforts in the case of simple geometries. In most examples there is no change for mean stresses, in view of the assumption that there exist huge residual tensile stresses in the weld, near the yield stress of the material, which will become less with cyclic loading because of plastic flow [16].

3.2 Structural Stress

The underlying stress or strain approach for surveying the fatigue strength and administration life continues from the structural stress or strain amplitudes in the structural part and compares them with a structural stress or strain S–N curve [17]. The structural (or 'geometric') stress or strain describes the macrostructural behaviour without consideration of local notch impacts. It very well might be measured by strain gauges or determined by engineering formulae or finite component analysis. The structural stress S–N curve might be set equivalent to the nominal stress S–N curve of the parent material if the zone of the structural part comprises or consist of parent material and is free of notches. The point should be to shield the notches of a component from crack commencement and along these lines move the basic area to the notch free parent material. This can be accomplished, at any rate somewhat, by suitable design and producing measures. In general, the structural stress approach reached out to welded joints gives a sign of how quantitative explanations on fatigue strength or life might be accomplished for critical zones without turning to the notch stress or notch strain approach which requires higher expenditure [18].

3.4 Elastic Notch Stress and Stress Intensity

The notch stress for instance in the weld toe, which is as a rule numerically determined expecting linear elastic material behaviour, takes the nearby weld geometry into account. Although, exceptionally huge stress values can take place, depending on the notch radius. For a radius moving toward zero, i.e., a sharp notch, the theoretical elastic stress even becomes infinite, i.e., singular.

The fatigue conduct of sharp notches is, not withstanding, less determined by the high, restricted stress summit, however more by impacts of the material structure forestalling inordinate nearby yielding and supporting the notch root. These so called micro structural support impacts can be considered by assessing the local stress gradient, by averaging the stress about a specific distance or volume or by taking the stress at a critical distance away from the notch root, utilising in all cases material-subordinate information. The outcome is the fatigue viable notch stress [18].

The stress averaging approach initially proposed by Neuber has picked up practical significance in the methodology by Radaj [19]. who presented a correspondingly expanded invented notch radius of $r_{ref} = 1$ mm for sharp weld toes and weld roots for a real radius of zero as the most pessimistic scenario. Fig 3.1 shows the fictitious notch rounding of weld toes and roots for a cruciform joint and a butt joint. At non-combined root faces, a supposed keyhole notch is organised, setting the vertex point of the circle toward the end of the slit, for example the area of the weld root. The weld shape is normally admired; otherwise, the genuine shape having, for instance, a certain flank angle can likewise be displayed [20].

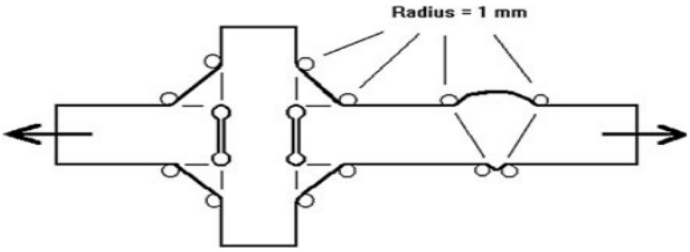

Figure 3.1. Fictitious notch rounding of weld toes and weld roots

On the other hand, the stress intensity factor can be utilised for the fatigue strength assessment at points with a stress peculiarity. The utilisation of the stress intensity factor as indicated by Irwin [21]. at cracks tips or cracks like slits is notable, for example, the non-fused root countenances of non-infiltrating welds. For the numerical examination of the last mentioned, the length of the cut can be expected as starting crack length, while an underlying crack length must be accepted at weld toes. However, a length somewhere in the range of 0.05 and 0.2 mm is expected for design purposes introducing a small defect or flaw. It ought to be noticed that the stress intensity factor is impacted by the local weld geometry, in any case, the impact decrease with expanding crack length.

A stress intensity factor can be determined likewise for sharp V-shaped notches happening at weld toes, called the notch stress intensity factor (N-SIF). The numerical assurance of these factors and their relevance to the fatigue strength assessment of welded joints have been mentioned by Lazzarin [22]. Utilising the strain energy density over a control volume around the notch, the N-SIF can be resolved with a generally coarse finite element model.

3.5 Elastic-Plastic Stress and Strain

As the elastic limit of the material is as often as possible surpassed during cyclic loading, the elastic-plastic stress considering these impacts can be viewed as another boundary for the fatigue strength assessment. They are appropriate especially for the evaluation of enormous load cycles in association with low-cycle fatigue.

Figure 3.2 represents the over-corresponding increment of the local strain ε and the under-relative increment of the local stress σ during the loading. On the other hand, approximation formulae exist for the calculation of the elastic-plastic stress and strain. Neuber's rule expects that the result of the over-relatively expanding local strain ε furthermore, the under-relatively expanding local stress σ relies upon the elastic notch stress σ_e and Young's modulus E as follows:

$$\sigma.\varepsilon = \frac{\sigma_e^2}{E} \tag{3.1}$$

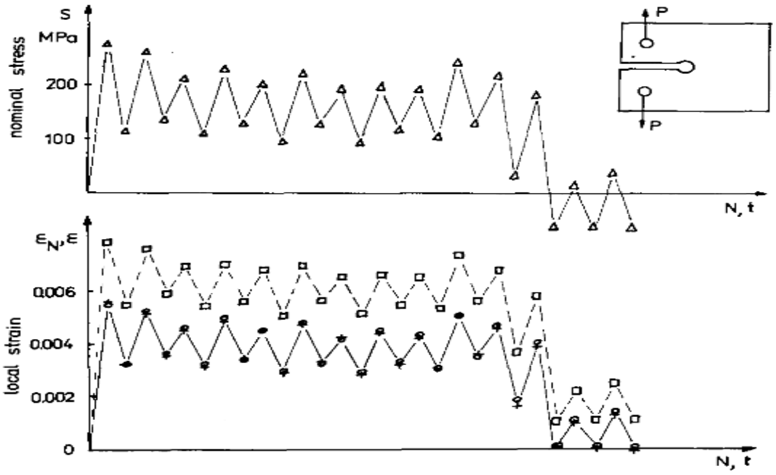

Figure 3.2. Elastic-plastic notch stress and strain during cyclic loading (+, ———) and theoretical (o, - -- --., Neuber's rule method; (o,———) energy-based method)

The equation is important for the preservation of σ and ε is the cyclic material law. it ought to be noticed that the local straining in generally sharp notches is restricted because of the encompassing elastic material. Nonlinear finite component examinations just as Neuber's standard consider this supposed macrostructural support effect. The elastic-plastic notch stress and strain are utilised all the more regularly in the fatigue strength assessment of adjusted notches in the parent material all things being equal of welded joints for the following two reasons:

1_ The weld shape is sporadic and regularly described by small defects.

2_ The material properties of the parent and weld material and the warmth influenced zone contrast from one another. the progressions happen in or near the weld toe with the most noteworthy notch stress.

Moreover, the previously mentioned material-related miniature help impacts are important [23].

4. FACTORS AFFECTING THE FATIGUE OF WELDED JOINT

4.1 Geometry, Stress and Strain Concentrations

The reactions of underlying things to the outer forces are typically described by the stresses and strains related with the forces. The overall stress response is significant, and surprisingly more so is the nearby stress rise brought about by geometrical discontinuities. The geometry of the item is significant and is one of the issues that should be addressed at the plan stage to accomplish further developed fatigue solidness.

The fundamental issue is to lessen the stress concentration element K_t in regions susceptible to fatigue. This will restrict the stress and strain response caused by the outer loads at expected break spots. The stress concentration is characterized as a local ascent of stresses because of a geometrical change or discontinuity. A more or less abrupt change in geometry is often referred to as a notch.

The stress concentration due to the notch are shown in Figure 4.1 bellow. At the left side of Figure is shown a plate with two edge notches evenly on each side. As shown, the stresses will increment at the notched segment because of the decreased cross segment; yet undeniably more significant is the stress rise cause of the local distribution of the actual notch. This effect depends on the notch radius ρ, and the cracks may appear in the root of both notches. The same thing seen in the right side of the figure, but In this we have no reduction of the cross section, but overfill of the weld metal will act as a stress riser, The stress will rise at the transition between the base plate and weld metal. This area is often referred to as the weld toe. The local geometry can be characterized by its flank angle θ and radius ρ. The stress concentration factor is defined as:

$$K_t = \frac{\sigma_l}{\sigma_n} \qquad (4.1)$$

The reader should be aware of the fact that the nominal stress can be defined in the section away from the notch or the nominal stress in the notch section. This may vary in various handbooks [24].

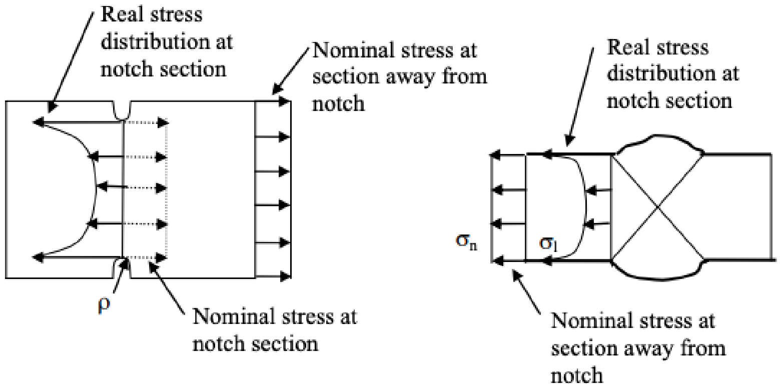

Figure 4.1. Stress concentrations at notches. Left: plate with edge notches. Right: butt joint

4.2 Material Parameters

The material sort has an enormous influence on the fatigue conduct. For example, the fatigue strength of constructions made of aluminium alloy is generally small compared to the steel structures by a factor of 2.5. The sort of material effects additionally the notch and mean pressure affectability.

Inside one material sorts the fatigue strength relies upon the material strength just for generally mild notches, though it has been observed to be practically the equivalent for structures with generally solid notch impacts including welds. This has prompted codes and suggestions where the fatigue strength of welded joints is autonomous of the material strength inside one material sort. An immediate outcome is that uncommon consideration is required when planning welded designs of high strength materials and that the higher strength can't be used in the event of high cyclic stresses, except if the notch impacts are decreased, for example by fatigue strength improvement strategies [25].

4.3 Weld Quality and Imperfections

A weld is rarely awesome and contains deviations from an ideal shape, for example, expanded flank angle, overabundance weld metal, misalignment, and so on. and anomalies like pores, undercuts, slag considerations, absence of fusion, and so on These are called defects if they are inside as far as possible given by important Standards, in any case they are called defects requiring correcting measures.

The fatigue strength of welds, where breaks start at the weld toe, is mostly impacted by the weld toe range and the flank angle, see Figure 4.2. Obviously, undercuts assume a huge part excessively here. Misalignments moreover debilitate the fatigue strength of pivotally stacked designs because of the formation of secondary bending stresses, as exemplified in Figure 4.2(a) [25].

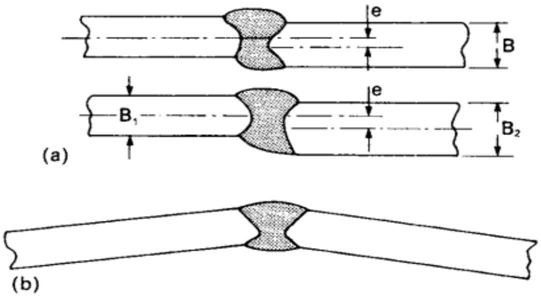

Figure 4.2. Misalignment in butt welded joints: (a) Axial: (b) Angular [26].

4.4 Residual Stress

Residual stresses are characterized as static inherent stresses present in the structural thing before the external forces are applied. The residual stresses are frequently made by the manufacture procedure. They are self-equilibrated; in case there are zones that have pliable anxieties there should be different zones that have compressive stresses. The regions exposed to tensile stresses will be more vulnerable to fatigue. The straightforward clarification of this is the mean stress impact, which has been examined previously. The presence of huge tensile residual stresses will increase the mean stress. Indeed, even compressive stresses brought about by the external forces may, when added on to prior static tensile stress, successfully go about as a tensile stress cycle in the material. The impact of residual stress is displayed in Figure 4.3 for a somewhat compressive external stress cycle [27].

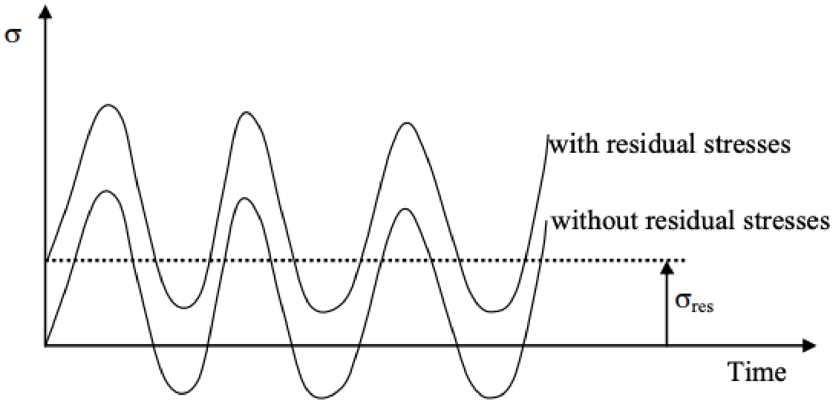

Figure 4.3. The effect of residual stresses in the stress cycles

5. DISCUSSION

Finally. From the review of fatigue strength for welded joints, we can conclude the following points: Welded structures and their components should be designed in such a way that the required fatigue strength, service life and safety are achieved with the lowest possible expense.

The fatigue strength can be further reduced by a corrosive environment. Stress relieving by heat treatment only increases strength significantly under compressive applied mean stresses.

The influence of mean strain on fatigue strength is characterised by a ratio of alternating to pulsating strain amplitude.

The influence of residual stresses, in particular the influence of residual welding stresses on fatigue strength, should be considered on three groups of components according to the condition of the manufacture:

- Welded components with high tensile residual stresses
- Welded components which are stress relieved, e.g., by heat treatment.
- Components with deliberately introduced high compressive residual stresses.

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