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An Evaluation Study on Fatigue Life of U-shape Aluminium and Structural Steel Fatigue Sensor

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Abstract: ***Fatigue is the most widely recognized reason for failure in metal structures. Fatigue is not a new phenomenon, it has confounded researcher for more than 200 years. The issue with fatigue makes attention with the applications of metal in various structures. In recent years, impressive efforts have been made for the development of analytical and additionally numerical models for the better estimation of fatigue life for critical component structures. Developing a fatigue damage detection sensor to monitor the structural damage accumulation of critical mechanical or structural components working under cyclic loads before any fatigue failure occurs. The practice of designing structures to take into account fatigue is highly abstruse since the actual loading history of the structure is not known and cannot be accurately predicted. In this way, there is a requirement for a device which would monitor fatigue damage and provide a reliable estimate of remaining fatigue life of a specific structure altogether to provide a warning of impending fatigue failure, it is called fatigue sensor. The main objective of this study is to analyze and an evaluation study on fatigue life of U-shape Aluminum alloy and Structural steel fatigue sensor. As simulation tool for the purpose of this paper, the finite element software is ANSYS Workbench. Based on numerical results, the maximum fatigue life was at U-shape radius (r = 20 mm) Aluminum alloy and Structural steel, the minimum fatigue life was at U-shape radius (r = 5 mm) Aluminum alloy and Structural steel.***

Keywords: ANSYS Workbench Software, Fatigue life, U-shape fatigue sensor.

1. Introduction

Fatigue is the progressive, localized, and permanent structural change that occurs in a material subjected to repeated or fluctuating strains at nominal stresses that have maximum values less than (and often much less than) the tensile strength of the material. Fatigue may culminate into cracks and cause fracture after a sufficient number of fluctuations. Predicting the fatigue life of a metal part is complicated because materials are sensitive to small changes in loading conditions and stress concentrations and to other factors. In addition to material properties and loads, the design analysis must take into consideration the type of applied loading (uniaxial, bending, or torsional), loading pattern (either periodic loading at a constant or variable amplitude or random loading), magnitude of peak stresses, overall size of the part, fabrication method, surface roughness, presence of fretting or corroded surface, operating temperature and environment, and occurrence of service-induced imperfections [1].

The practice of designing structures to take into account fatigue is highly abstruse since the actual loading history of the structure is not known and cannot be accurately predicted. Therefore there is a need for a device which would monitor fatigue damage and provide a reliable estimate of remaining fatigue life of a particular structure in order to provide a warning of impending fatigue failure [2]. In the last twenty years, networks have changed the way in which people and organizations exchange information and coordinate their activities. In the next several years, we will witness another revolution; as new technology increasingly observes and controls the physical world. The latest technological advances have enabled the development of distributed processing, using tiny, low cost, and low-power processor that are able to process information and transmit it wirelessly. The availability of micro sensors and wireless communications will enable the development of sensor networks for a wide range of applications, rather than the limited applications of sensor networks today [3].

The fatigue sensor in this system is designed with various parallel arms, every delicate to various levels of fatigue. The arms of the sensor are intended to be conciliatory and intended to fail prematurely but progressively as the sensor experiences the same fatigue cycles as the component structure it is joined to. The arms have "engineered notches" with unique geometry which are intended to fail after going through an exact number of fatigue cycles. The most critical design parameters for the application of the proposed Fatigue Damage Sensor are the design of the “notch radius” which concentrates the stress around the notch area. The fatigue endurance limit of each notched beam of the fatigue damage sensor in all cases must be selected lower than the fatigue endurance limit of the real mechanical components or structures [4].

2. Fatigue as a Phenomenon in the Material

Fatigue occurs when the material is exposed to a repeated stress cycles varying over time. Thus it is a process of time; it starts with slip formation that grows until it reaches a critical size that will cause fracture in the material. Slip formation is enhanced by the stress concentration due to internal defects or external hole in a plate as a notch. When a load is applied in cyclic form, this fluctuation will open up and close micro cracks. As the load cycles increase, the crack length will increase for each application of the load. When the crack reaches its critical length, fracture will occur [5].

2.1 Factors that Effect on Fatigue Life

There are many factors that affect fatigue life of engineering structures and components. The details of most important factors which affect the fatigue life of structure are as follows:

1. Stress state: Depending on the complexity of the geometry and the loading, one or more properties of the stress state need to be considered, such as stress amplitude, mean stress, biaxiality, in-phase or out-of-phase shear stress and load sequence.

2. Geometry: Any discontinuity in the geometry of the structure has a great influence on the fatigue strength. Generally, the geometric discontinuities in the form of notches and variation in cross section throughout a part lead to stress concentrations. In most of the crack models the stress concentration is considered to be a major factor which makes a crack to appear and it is the stress concentration location where fatigue cracks initiate.

3. Surface quality: Surface roughness cause microscopic stress concentrations that lower the fatigue strength. The compressive residual stresses can be introduced in the surface by e.g. shot peening to increase fatigue life. Laser peening and ultrasonic impact treatment also give rise to surface compressive stresses and it increase the fatigue life of the component. This improvement is normally observed only for high cycle fatigue.

4. Material Type: Fatigue life, as well as the behavior during CL, varies widely for different materials. Different analytical approaches are available in order to deal with different material models. Thus, the changes in the materials used in parts can also improve fatigue life [6].

5. Residual stresses: In many engineering components residual stresses are produced as a result of metal forming processes. Welding, cutting, casting, and other manufacturing processes involving heat or deformation can produce high levels of residual stresses. As a result of high level tensile residual stresses the fatigue life of the component decrease.

6. Size and distribution of internal defects: It is commonly observed that the cracks appear due to the discontinuities in the structures at the micro level. In general, casting defects such as gas porosity, non-metallic inclusions and shrinkage voids can significantly reduce the fatigue strength.

7. Direction of loading: Although in the case of isotropic materials the direction of loading has no significant effect on the fatigue strength but for non-isotropic materials, fatigue strength depends on the direction of the principal stresses.

8. Grain size: In most of engineering components grain size has a direct impact on the fatigue life of the component. For most metals, smaller grains yield longer fatigue lives, however, the presence of surface defects or scratches will have a greater influence than in a coarse grained alloy.

9. Environmental conditions: Environmental conditions have a strong impact on many physical phenomenon which are mostly related to the surface of the structures. Environmental conditions can cause erosion, corrosion, or gas-phase embrittlement, which all affect fatigue life. Temperature also has some influence on the fatigue strength of a component and in general higher temperatures decrease fatigue strength [7].

Materials and Methods

3. Problem Description

This study is based on analyzing and an evaluation study on fatigue life of U-shape Aluminum alloy and Structural steel fatigue sensor. As simulation tool for the purpose of this paper, the finite element software is ANSYS Workbench. The sensor comprises of the different U-shaped arms radius parallel with an axial load on the construction and boundary conditions as fig 1. The dimensions of U-shape fatigue sensor are illustrated in table 1.

Table 1: The dimension of U-shape fatigue sensor

Length	*Width*	*Thickness*
300 mm	70 mm	2 mm

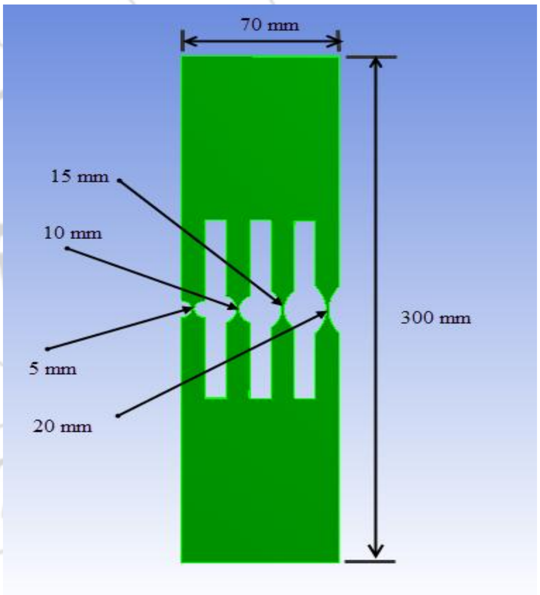

Figure 1: The U-shape fatigue sensor model

4. Mathematical Formations

In most laboratory fatigue testing, the specimen is loaded so that stress is cycled either between a maximum and a minimum tensile stress or between a maximum tensile stress and a specified level of compressive stress. The latter of the two, considered a negative tensile stress, is given an algebraic minus sign and called the minimum stress.

Applied stresses, The mean stress, S_m, is the algebraic average of the maximum stress and the minimum stress in one cycle[1]:

$$S_m = \frac{(S_{max} + S_{min})}{2} \quad (1)$$

The range of stress, S_r , is the algebraic difference between the maximum stress and the minimum stress in one cycle:

$$S_r = S_{max} - S_{min} \quad (2)$$

The stress amplitude, Sa, is one-half the range of stress:

$$S_a = \frac{S_r}{2} = \frac{(S_{max} - S_{min})}{2} \quad (3)$$

During a fatigue test, the stress cycle is usually maintained constant so that the applied stress conditions can be written $S_m \pm S_a$, where S_m is the static or mean stress and Sa is the alternating stress equal to one-half the stress range. The positive sign is used to denote a tensile stress, and the negative sign denotes a compressive stress [1].

The relationships between ultimate strength and endurance limit for Aluminum and steel can be defined as [8]:

For Steel:

$$S_{e'} = 0.5\, S_{ut} \;\; \text{for } S_{ut} < 200 \text{ Kpsi (1400 Mpa)}$$
$$S_{e'} = 100 \text{ Kpsi (700 Mpa) for } S_{ut} \geq 200 \text{ Kpsi (1400 Mpa)} \quad (4)$$

For Aluminum:

$$S_{f'} @ 5\,E{+}8 = 0.4\, S_{ut} \;\; \text{for } S_{ut} < 48 \text{ Kpsi (330 Mpa)}$$
$$S_f @ 5E{+}8 = 19 \text{ Kpsi(130 Mpa) for } S_{ut} \geq 48 \text{ Kpsi (330 Mpa)} \quad (5)$$

A corrected fatigue strength or endurance limit for the particular application can be obtained [8]:

For Steel:

$$S_e = C_{load}\, C_{size}\, C_{surf}\, C_{temp}\, C_{reliab}\, C_{miscellan}\, S_{e'} \quad (6)$$

For Aluminum:

$$S_f = C_{load}\, C_{size}\, C_{surf}\, C_{temp}\, C_{reliab}\, C_{miscellan}\, S_{f'} \quad (7)$$

The stress-life approach or the S-N curve approach is a standout amongst the most utilized techniques for defining fatigue life of materials. The general property representation is S-N curve. Rotating stress versus log number of cycles to failure [9].

The S-N equation is [10] :

$$\log S(N) = \log a + b \log N \quad (8)$$

5. Results and Discussion

The material properties of Aluminum alloy 2024-T3 and Structural steel which used for the fatigue sensor are illustrated in table 2.

Table 2: The Material Properties of Aluminum alloy 2024-T3 and Structural Steel

Properties	*Aluminum alloy*	*Structural steel*
Density	2.77 g/cm3	7.85 g/cm3
Young's Modulus	71 GPa	200 GPa
Poisson's Ratio	0.33	0.3
Shear Modulus	28 GPa	76.9 GPa
Yield Strength	345 Mpa	250 Mpa
Ultimate Strength	483 Mpa	460 Mpa

Based on the numerical simulation by using ANSYS workbench, the results showed that the fatigue life was at Aluminum alloy U-shape radius (r = 20 mm) high and fatigue life at Aluminum alloy U-shape radius (r= 5 mm) low, because the stress concentration is high at low U-shape radius that indications to failure happened firstly at U-shape when it has a low fatigue life, as shown in fig 2.

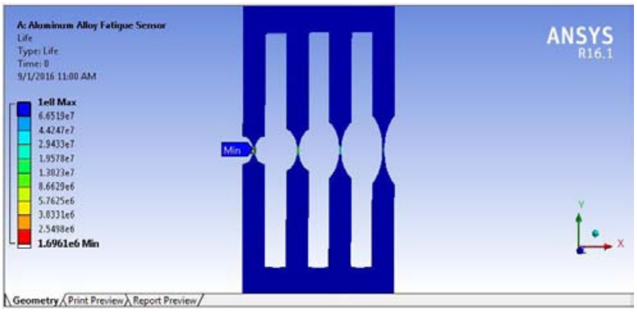

Figure 2: The Fatigue Life of U-shape Aluminum alloy Fatigue Sensor

As illustrated before, the results shown that the fatigue life was at Structural steel U-shape radius (r = 20 mm) high and fatigue life was at Structural steel U-shape radius (r= 5 mm) low, because the stress concentration is high at low U-shape radius that indications to failure happened firstly when it has the low life, as shown in fig 3. The table 3 shows the comparison between Fatigue life of U-shape Aluminum alloy and Structural steel fatigue sensor, the maximum fatigue life at the low radius (r = 5 mm) for Aluminum alloy and Structural steel were 8.893e+06 cycle , 3.452e+05 cycle , respectively.

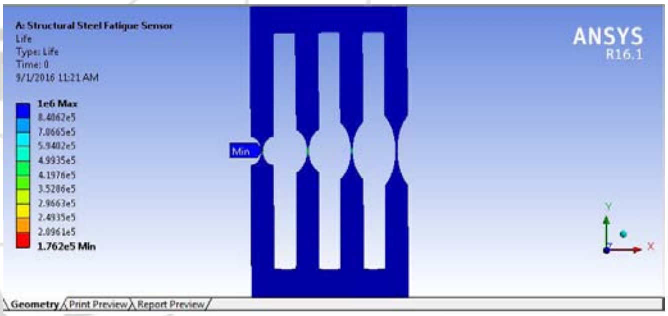

Figure 3: The Fatigue Life of U-Shape Structural steel Fatigue Sensor

Table 3: Comparison between the Fatigue Life of U-Shape Aluminum alloy and Structural Steel Fatigue Sensor

Fatigue life	*r =5 mm*	*r =10 mm*	*r =15 mm*	*r =20 mm*
Aluminum alloy	8.893e+06	9.766e+06	2.0353e+07	5.351e+07
Structural steel	3.452e+05	2.082e+06	5.587e+07	3.402e+06

The minimum fatigue life at low radius (r = 5 mm) for Aluminum alloy and Structural steel were 8.893e+06 cycle, 3.452e+05 cycle, respectively. The maximum fatigue life at high radius (r = 20 mm) for Aluminum alloy and Structural steel were 5.351e+07cycle, 3.402e+06 cycle, respectively. That is indicated the U-shape radius (r =20 mm) has the best fatigue life compared with the U-shape radius (r = 5 mm). All these details can show in fig 4.

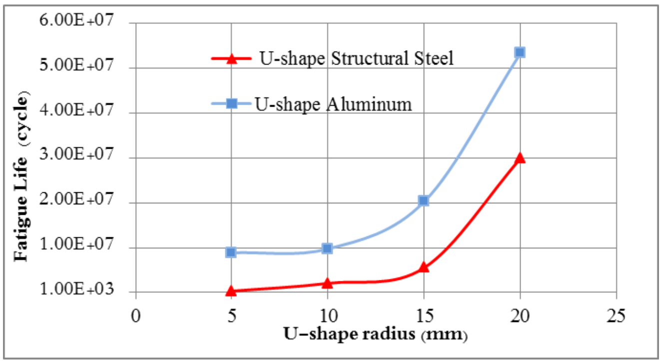

Figure 4: The Fatigue Life Vs U-shape Radius Aluminum alloy and Structural steel

6. Conclusion

In this paper provides the outline of the U-shape fatigue sensor, which has been analyzed with ANSYS workbench software. The key benefits of this U-shape fatigue sensor are generally summed up as being small in geometry, with a simple design, ease of preparation, low cost, and a lack of necessity for the permanent connection of complex gauging and recording devices. On the other hand, the common drawbacks for the application of this fatigue sensor in actual products are high environmental sensitivity, low reliability, low stability, as well as low repeatability. The fatigue sensor can be installed onto surfaces of fatigue sensitive areas and also can be embedded within weakness delicate areas of dangerous mechanical parts, for example, bridge way, aircraft and so on.

Based on the results, the maximum fatigue life was at U-shape radius (r = 20 mm) Aluminum alloy and Structural steel, the minimum fatigue life was at U-shape radius (r = 5 mm) Aluminum alloy and Structural steel.

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Author Profile

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