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A Review on Finite Element Analysis Approaches in Durability Assessment of Automotive Components

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Abstract: This research describes the majority of interesting findings in the use of the Finite Element Analysis (FEA) based fatigue for automotive components in a form of review write-up. Thus, the theoretical background related to the fatigue life prediction using FEA is presented which is the main subject of this research. The challenge for FEA-based software developers is to deliver reliable fatigue-analysis tools because over designing components is no longer a viable option. Combination between a fatigue model based on the crack initiation, the crack growth and the crack closures are performed with consideration of cycle sequence effect together with finite element results, which lead to the prediction of fatigue life under spectrum or service loadings.

Key words: Fatigue failure, fatigue life, finite element analysis, lower suspension arm, variable amplitude loading

INTRODUCTION

In automotive design, durability evaluation of components based on experimental assessments is time-consuming and expensive, so analytical approaches that include limited number of component verification tests have gained more attention. Structural components such as a lower suspension arm might be strong enough to withstand a single applied load. But what happens when the component operates over and over, day after day? To predict component failure in such cases requires what's called fatigue or durability analysis. A vehicle can be considered as a compound structure made with many mechanical components subjected to complex cyclic loading as a consequence of their normal use (Curiel *et al*., 2006). Active vehicle suspensions have attracted a large number of researchers in the past few decades and comprehensive surveys can be found in the papers produced by Karnopp (1995), Hrovat (1997) and Hrishikesh and Nam (2004).

The start of a fatigue failure is a strictly local process and it is also one that depends on the dynamics of the system. The time history of stress or strain, at the exact location where a crack is going to start, is the critical factor. This is precisely why finite element analysis is important in this discipline. The term finite element was introduced by Clough (1960). Using Finite Element Analysis (FEA) an analyst can choose any location within a model and concentrate attention on it, using the intrinsic ability of the technique to bring in dynamic effects. For that reason, the Finite Element Method (FEM) has become a reliable tool for the numerical solution of a wide range of engineering problems. Results are important in calculating and verifying safe part lifetimes. In the past, durability analysis was largely the province of research Fluctuating loads can cause failure which takes place when cracks initiate. In classic structural analyses, failure predictions are solely based on the material strength or the yield strength.

Durability analysis goes beyond this, evaluating failure based on repeated simple or complex loading. Hence, the objective of the stress analysis was to obtain the complete three dimensional stress and strain distributions at a potential failure site, facilitating fatigue life predictions. Fatigue durability is influenced by a number of factors (Plaskitt and Musiol, 2002), such as stress or strain range, mean stress, surface finish and quality, surface treatments and cycle sequence effects.

In this research, the authors focused on the different fatigue analysis attitudes with FEA or without FEA, on to the automotive components. By getting an idea regarding the other attitudes in this field, the authors work may lead to a novel finding, which can give a good effect in the field of fatigue related FEA for the scientists and

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engineers. It is important for the further development of fatigue life assessment and FEA technology and knowledge.

The researchers which they used the fatigue related FEA packages to get the fatigue life as a final target for there works. Currently, most of researchers used the models contained in commercial packages, which they are most useful to get life estimation under constant amplitude loadings, instead of variable amplitude loadings. Thus, the main benefit of this paper is to get reasonable results under service loadings for fatigue life prediction by combine finite element analysis with one of the fatigue models which take into consideration the sequence effect on components fatigue life.

ELEMENTS IN LIFE ESTIMATION

For many years the fatigue analysis process has been thought based on the logic shown in Fig. 1. In this overview the three input parameters, i.e., geometry, materials and loading, are regarded as having similar functions. In practice, most of the durability analysis follows the model produced by Bishop and Sherratt (2000) as shown in Fig. 2. The geometry and loading are initially used together in order to produce a stress-time (σ-t) or strain-time (ε-t) history at a point of which it is likely to be critical. The material properties are then introduced in order to estimate the fatigue lives. The only material properties which are needed in the first step are the things like Young's modulus and the elastic-plastic stress-strain curve, which they are not true fatigue properties. Thus, the actual cyclic material properties should be determined in order to implement the fatigue life calculations.

The step from overall geometry and generalized loading, to a detailed map of local stress and strain in a component, has traditionally required toward the use of a variety of techniques. If the loading is fluctuating with time, as it always will be in the case of fatigue, a further set of uncertainties enters. Using the meaningful FEA technique, it gives tighter control over the move from general geometry and loading to local parameters and allows dynamic factors to be dealt with more analytically. A diagrammatic model in Fig. 3 describes another life estimation process, emphasizing the importance of FEA in a situation where analysis at precise locations is essential.

The role of a fatigue calculation varies according to the component, the loading and the situation in which the component are to be used. A component with simple geometry and simple loading which is to be used in a situation where failure would cause only minor inconvenience may be manufactured and put into service purely on the basis of a calculation. This is particularly so if only small numbers of the article are to be made. If the situation is more complex and the penalties for wrong estimates are higher, verification of the calculation by testing becomes necessary (Bishop and Sherratt, 2000).

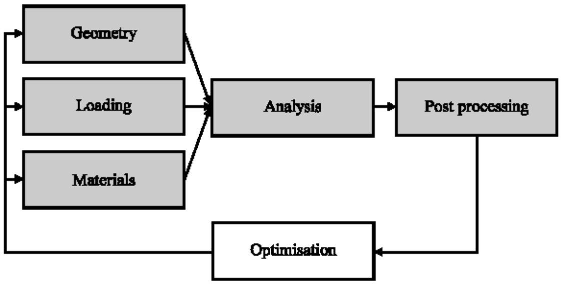

Fig. 1: Conventional view of the fatigue life assessment procedure

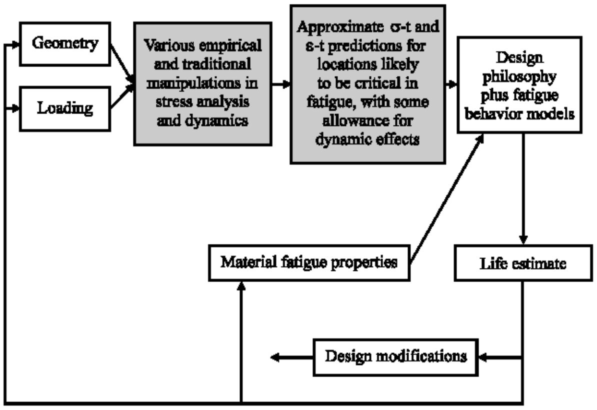

Fig. 2: An alternative schematic beyond fatigue

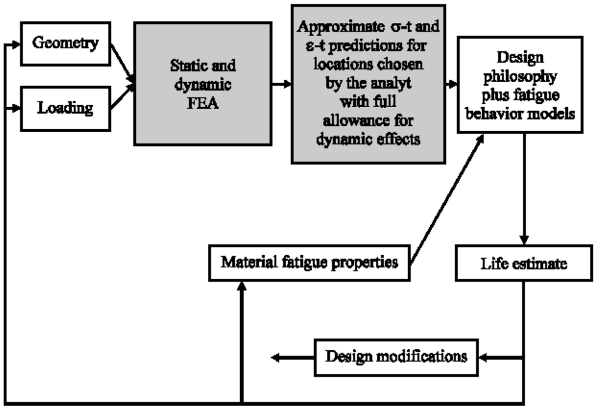

Fig. 3: A diagrammatic flow of life estimation scheme using FEA

A more typical situation is a component with complicated geometry and multiple loads is to be produced in large numbers. For this case, it requires the minimum weight and it also to be used in a safety-critical application. Prototype components or full-scale assemblies should be tested under a specific loading which is as close as possible to an expected loading in service. However, it seems to be an expensive operation in the case of durability assessment. In addition to this expense, a significant drawback with this type of testing is that it cannot be undertaken until a prototype exists. If a design problem is then occurred it is likely to be difficult and expensive to rectify. The more accurate and reliable the life prediction process becomes the less likely it is that late modifications will be needed. The main contribution of FEA based fatigue tool is then to enable reliable fatigue life calculations to be done at the design stage of a development process, long before tests are possible.

Though many low-cycle fatigue data have been published with the application of different components with or without FEA techniques, a few of low cycle fatigue research for the automotive components, for example in the case of a lower suspension arm, have been conducted with different attitudes as illustrated in this literature review. In this research, they did mention on the use of vehicle simulation which lead to the finite element results for generating the fatigue life contours for the chassis components using automotive providing ground load history results combined with the computational techniques. It was concluded that the combination of the vehicle dynamics modeling, FEA and fatigue analysis are seems to be the viable techniques for the fatigue design of the automotive components.

In another study, Devlukia and Bargmann (1997) conducted the fatigue assessment of a suspension arm using the deterministic and probabilistic approaches. The strength reduction effect due to the surface roughness was accounted for by representing the surface as a collection of notches and making use of Neuber's rule. It was concluded that the residual stress demonstrated a more pronounced effect under constant amplitude loading as compared to variable amplitude loading. The cumulative damage potential under the variable amplitude loading sequences of the long duration on a simple specimen data and strain-life method was conservative by a factor of two. After that, Ringsberg and Lindback (2001) developed a strategy for fatigue life prediction of Rolling Contact Fatigue (RCF) crack initiation. It combines the elastic-plastic Finite Element (FE) analysis, the multiaxial fatigue crack initiation models used together with the critical plan concept, the fatigue damage summation calculations and the comparison of results from numerical analysis and experiments. The strategy and evaluation methodology can be used for fatigue life predictions of RCF crack initiation caused by low-cycle fatigue and ratcheting failure.

Experimental investigation to rationalize and quantify the low cycle bending fatigue strength of steel bars under variable amplitude loading histories has also been performed by Liu (2001). By examining the microstructure of the tested specimens, the random low cycle bending fatigue life is highly dependent on the orientation angles of the material grain. Based on this observation, a physical model was established in order to explain the various failure patterns of the test specimens. A more accurate formula for describing and quantifying the low cycle bending fatigues strength of A36 steel bars under general loading histories was also established and formulated from this study.

A work from Haiba *et al.* (2002) has been seen as another FEA application in fatigue life estimation. They estimated the fatigue lives of metallic material in both time and frequency domain methods under FEA. Comparison between several approaches to fatigue life prediction using a real automotive engineering case study has also been performed. In addition, the study was taking into account the optimisation based on fatigue life which requires accurate relative distribution rather than exact values. Haiba *et al.* (2002) used a multibody dynamics (MBD) solution. William (2002) also modeled a vehicle on a computer with MBD simulation software package and combined the related work with physical laboratory tests for the purpose of optimizing durability testing. The intention of the research by William (2002) was to mirror as close as possible the behavior of a physical vehicle on a road test simulation in order to determine its durability characteristics under varying road conditions. The results from this research bode well for increasing connection between the virtual and real worlds of durability testing. Another research by Haiba *et al.* (2003) introduced a new structural optimization algorithm based on fatigue life. The paper investigates the effects of different assessment strategies on the predicted fatigue life of a lower suspension arm, the properties of which are modified to generate different degrees of interaction between the arm natural frequencies and the frequency range of the applied forcing functions. The results of this investigation were used to derive a new form of structural optimization algorithm which is more robust and efficient.

Ridnour (2003) predicted mechanical failures before they occur and determined the useful life of M1101 High Mobility trailer (HMT) that is normally towed behind a High mobility multi-purpose Wheeled Vehicle. For the analysis, the experimental data was taken from a HMT traveling over several test courses. The data was used to validate a computer simulation and also to determine the feasibility of life consumption monitoring. Multivariate regressions and principal component analysis were used to determine which sensors most accurately reflect the loads on the drawbar at the failure point. Regression and dynamic models were made after the proper decimation and filtering of the data was determined. The models that have been developed were used to predict the fatigue life of the trailer surge brake. The fatigue life prediction is divided into two parts: initiation and propagation. The fatigue crack initiation life prediction uses a multiaxial local strain approach and failure is assumed to occur when the crack has reached 2 mm in length. The fatigue crack propagation life prediction uses the FLAGRO software for which this software was developed by NASA. The results showed that the simulation can be modified to represent of the tested vehicle also. In addition, the fatigue life and durability of the vehicle can also be predicted with a model and data obtained from some sensors which have been placed on the vehicle components.

In different situation, Kim *et al*. (2003) analyzed the hydroforming process of an automobile lower arm using finite element program of HydroFORM-3D in order to accomplish its proper design and the process control. An optimum process trial was then proposed through the numerical simulation to select a suitable internal hydraulic pressure level and the axial feeding displacement path. This work showed that the FEM program of HydroFORM-3D provided valuable information regarding to the forming process and was also dramatically improved the potential of the hydroforming process. Though the computer-aided design approach was proposed in this study, the designer can improve the design efficiency, as well as to avoid expensive and time-consuming trial-and-error and extensive process design experience.

Williams *et al*. (2003) proposed a method that ensures the data used in the derivation of the fatigue parameters is appropriate and indicative of the material physical behavior. The use of this method allowed the accurate derivation of the fatigue parameters and thus allowed the use of fatigue simulation software in order to shorten the product development cycle by reducing the number of iterations in the design and test cycle.

A study by Yoon *et al*. (2003) showed the development of an acceptable testing method for steel pipe under axial Low Cycle Fatigue (LCF) testing. The plastic buckling of thin wall pipe under monotonic and cyclic loading was studied by theoretical, numerical and experimental means. In the case of monotonic compression, the FEA showed good agreement with experimental results and theoretical predictions were more conservative than other means of assessing buckling criterion. Under cycling loadings, the buckling strain was much less than that of monotonic compression. Using FEA, a non-buckling region that permitted successful for LCF testing has been found.

Then, Fatemi and Zoroufi (2004) did an experimental and analytical work using FEA, the durability assessment and also an optimization analysis. They developed methodologies that can be applied to a wide range of automotive and other components. Some of the findings are the FEA simulation for cyclic loadings which is important for fatigue damage analysis. The life prediction based on local approaches, i.e., the Morrow's mean stress parameter provided better predicted fatigue lives than the Smith-Watson-Topper's (SWT) mean stress parameter.

Nadot and Denier (2004) has then studied the fatigue phenomena for automotive suspension arms using high cycle fatigue conditions which it behavior has been controlled mainly by surface defects. For this case, the effect from LCF was governed by multiple cracks which was independently initiated from casting defects. A methodology was then proposed in order to define the maximum defect size allowed in a casting component. It was correlated with the empirical method that proposed by Murakami (1993) and also to determine the evaluation of the fatigue limit with the defect size and a multiaxial endurance criterion based on the Dang Van model (1993). The junction between these two approaches gave a concurrent tool for the fatigue design of casting components.

Abdullah (2005) worked on the novel approach of fatigue data editing technique, called Wavelet Bump Extraction (WBE), to summarise the load history. This algorithm was later used, to obtain fatigue lives under VA loadings for the experimental and predicted method. For the predict process, four strain-life fatigue damage models have been used, i.e., Coffin-Manson, Morro, SWT and Effective Strain Damage (ESD). The correlated fatigue lives between the ESD model and experiments were distributed around the 1:1 line and within the range of ± a factor of 2. However, the correlation points produced from the data of the three other strain-life models were located outside the range of ± a factor of 2.

In different work and scope by Sun *et al*. (2005), the displacement-controlled low cycle fatigue testing has been performed using the Sn-8Zn-3Bi and Sn-37Pb solder joints on lap shear samples. The test amplitude was varied whilst the frequency was kept constant at 0.2 Hz and the failure was defined as a 50% load reduction. The finite element modeling was used for the analysis and the results were then compared to the experimental data. The average lifetime for the Sn-8Zn-3Bi solder joints was 17% longer compared to the Sn-37Pb solder joints. The locations of the maximum equivalent stress from the FE simulation were found to be at the two opposite corners of the solder joints, coinciding with the experimental observations of crack initiation.

In a case study by Xianjie (2005), he investigated the cyclic strain low cycle fatigue and cyclic stress ratcheting failure of carbon steel 45 with quenched and tempered treatment. The tests for this cyclic strain low cycle fatigue with or without mean strains were carried out in order to investigate the effect of the mean strain on low cycle fatigue behavior. The evaluation equation of fatigue damage was then proposed based on the symmetric cyclic strain LCF testing results and the equation was used to evaluate the effect of the fatigue damage on the ratcheting failure under different cyclic stressing. Yi-Ming *et al.* (2006) analyzed the experimental fatigue life of the sleeve-pin-shaft connection specimens under cyclic axial and pure torsional loading. Crack initiation and crack initiation life have been predicted using FEM. The FE code used is ANSYS. Has been found from the results that among the four stress-based parameters and three strain-based parameters, the corresponding critical plane parameter (FS parameter) predicts the crack initiation life within reasonable deviation bands. The FS parameter also effectively predicts the locations of crack initiation.

In a study by Zoroufi and Fatemi (2006), the fatigue behavior of vehicle suspension components (forged steel and cast aluminium steering knuckles) were investigated under constant-amplitude load-controlled fatigue tests. Three of the finite element models of the knuckles were analysed using linear and non-linear methods. The nominal stress, the local stress and the local strain life prediction approaches were then employed and compared to the experimental results in order to evaluate the accuracy and validity of these approaches. It was observed that among the contemporary life prediction procedures used in the automotive industry, the local strain approach using linear elastic FEA results in conjunction with Neuber-corrected stresses were reasonable. In addition, it has been found that the results were close to those obtained on the basis of non-linear elastic-plastic FEA.

A recent research by Hasegawa *et al.* (2007) exposed the fatigue properties on extruded AZ31 bar under uniaxial loading by both strain and stress controlled conditions. The fatigue life evaluation method has been discussed together with the analysis of cyclic stress-strain behavior. The SWT model makes an excessive forecast for fully reversed stress controlled test, especially fatigue life is smaller. A new model has been derived by adding a correction term of $-\sigma m/2E$ to the Manson-Coffin type equation.

$$\frac{\Delta\varepsilon_t}{2} = 0.0149\left(2N_f\right)^{-0.178} + 0.410\left(2N_f\right)^{-0.691} - \frac{\sigma_m}{2E} \qquad (1)$$

Then, Hurley *et al.* (2007) focused on the application of numerical models for predicting LCF initiation lives. A series of FE simulations of the strain control specimens were run using the Mroz user-subroutine to demonstrate how the stabilized hysteresis loops may be modeled with sufficient accuracy using this method. Then a number of fatigue initiation criteria have been developed based on the strain control testing. For comparison purposes, three different fatigue parameters were utilized for predicting notch fatigue lives, i.e., Walker, SWT and the total strain energy density. At the room temperature, these three models led to accurate predictions of fatigue lives, but led to less accurate predictions at lower stresses/longer lives. At higher temperature values, the accuracy of the purely plasticity-based finite element and the Neuber models for predicting the mechanical response in notched specimens was shown to be questionable due to inaccurate results of predicting.

Recently, Mrzyglod and Zielinski (2007) developed an optimization algorithm which can be used for structures such as the suspension arm with the application of high-cycle load conditions. This work has been concentrated on the fatigue of material (multiaxial criteria of high-cycle fatigue), parametric optimization of structures and application of finite element method by using ANSYS®. The main process of fatigue optimization was preceded by the testing of methods of structure optimization and the preparing the tools for improving the efficiency of the optimization algorithm. The fatigue optimization methodology can then be applied to any case of structure subjected to high-cycle loads.

Rahman (2007) developed general procedures for durability assessment and optimization of safety-critical free piston engine components. The durability assessment process was performed using the condition of FEA and the fatigue life analysis. The FEA technique has been used to predict the fatigue life and the identification of the critical locations the specific components by using MSC Software. The durability assessment results were significant to be used for improving the specific component design at the early developing stage. The results showed that the predicted fatigue life appears to be more conservative for the tensile mean stress than the compressive mean stress. It has been shown that the crack-initiation approach of the Morrow's mean stress correction method gave the most conservative results for all loading conditions and various materials.

FATIGUE LIFE ASSESSMENT METHOD

The FE analysis results define the stress-state for a component given the specific loading condition. The most common FE analysis method used in conjunction with the fatigue analysis is to apply each load independently as a unit load case. The inputs for the FE analysis are the component geometry with FE model, the boundary conditions and the loading information. The location and direction of each load input define the loading information. The FE method assumes that the component behavior and material properties are linearly elastic. The FE based durability analysis can be considered as a complete engineering analysis for the components. The fatigue life can be estimated for every element in the FE model and the contour plot of life or damage. A more comprehensive treatment of fatigue mechanisms and cyclic behavior can be found in Suresh (1998), Socie and Marquis (2000), Skallerud and As (2002) and Kulkarni *et al*. (2003). The FEA- based durability analysis helps to eliminate unnecessary tests by allowing the engineer to check out the fatigue performance analytically and to optimize the selection of the material, manufacturing process and geometry, within the constraints of total cost and loading environment.

The strain-based approach to fatigue problems is widely used at present for correlating with low-cycle fatigue as in Chen *et al*. (2006). The most common application of this approach is in fatigue of notched members. When the load history contains large overloads, significant plastic deformation can exist, particularly at stress concentrations and load sequence effects can be significant. In these cases, the strain life-approach is generally superior to the stress-life approach for cumulative fatigue damage analysis (Ralph *et al*., 2000). The most common application of the strain-based approach, however, is in fatigue of notched members. In a notched component subjected to cyclic loads, the behavior of the material at the root of the notch is best considered in terms of strain. Since the fatigue damage is assessed directly in terms of local strain, this approach is called the local strain approach. Thus, it is common that the service loadings caused by machines and vehicles is evaluated using a strain-life fatigue damage approach (Tucker and Bussa, 1977; Downing and Socie, 1982; Conle and Chu, 1997; Chu, 1998; Dowling, 1999). The strain-life method has achieved the status of industry standard in the North American automotive industry (Conle and Chu, 1997). In Europe, the automotive industry shows a preference for stress-life methods (Berger *et al*., 2002).

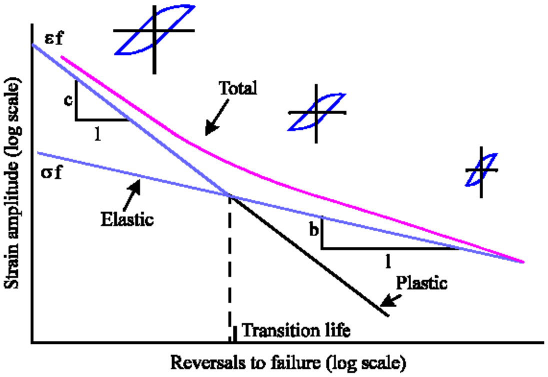

Fig. 4: Strain-life curves showing total, elastic and plastic strain components

Strain-life fatigue curves plotted on log-log scale are shown schematically in Fig. 4, where N_f or $2N_f$ is the number of cycles or reversals to failure, respectively. The strain-life curve which shown in Fig. 4 has been resolved into the elastic and the plastic strain components from the steady-state hysteresis loops. At a given life, N_f, the total strain is the sum of the elastic and plastic strains. Both the elastic and plastic curves can be approximated as straight lines. At large strains or short lives, the plastic strain component is predominant and at small strains or longer lives the elastic strain component is predominant. It is indicated by the straight-line curves and the size of the hysteresis loop in Fig. 4. The intercepts of the two straight lines at $2N_f = 1$ are σ_f'/E for the elastic component and ε_f' for the plastic component. The slopes of the elastic and plastic lines are b and c respectively. This provides the following equation for strain-life data (Graham, 1968):

$$\frac{\Delta\varepsilon}{2} = \varepsilon_a = \frac{\Delta\varepsilon_e}{2} + \frac{\Delta\varepsilon_p}{2} = \frac{\sigma_f'}{E}(2N_f)^b + \varepsilon_f'\,(2N_f)^c \tag{2}$$

Where:

$\Delta\varepsilon/2$ = Total strain amplitude = ε_a
$\Delta\varepsilon_e/2$ = Elastic strain amplitude = $\Delta\sigma/2E = \sigma_a/E$
$\Delta\varepsilon_p/2$ = Plastic strain amplitude = $\Delta\varepsilon/2 - \Delta\varepsilon_e/2$
ε_f' = Fatigue ductility coefficient
c = Fatigue ductility exponent
σ_f' = Fatigue strength coefficient
b = Fatigue strength exponent
E = Modulus of elasticity
$\Delta\sigma/2$ = Stress amplitude

One method, often referred as the (Morrow's mean-stress correction relations) replaces σ_f' with $\sigma_f' - \sigma_m$ in Eq. 2, where σ_m is the mean stress, such that:

$$\frac{\Delta\varepsilon}{2} = \varepsilon_a = \frac{\sigma_f' - \sigma_m}{E}(2N_f)^b + \varepsilon_f'(2N_f)^c \tag{3}$$

In Eq. 3, σ_m is taken to be positive for tensile values and negative for compressive values. This equation predicts the tensile mean stress is detrimental and the compressive mean stress is beneficial. Equation 3 predicts more effect of the mean stress relationship which can be derived at long lives. An alternative version of the Morrow's mean-stress where both the elastic and plastic terms are affected by the equivalent mean stress, which is mathematically given by Manson and Halford (1981)

$$\frac{\Delta\varepsilon}{2} = \varepsilon_a = \frac{\sigma_f' - \sigma_m}{E}(2N_f)^b + \varepsilon_f'\left(\frac{\sigma_f' - \sigma_m}{\sigma_f'}\right)^{c/b}(2N_f)^c \qquad (4)$$

Another the strain-life mean stress correction model was suggested by Smith *et al.* (1970), or often called the SWT parameter. This relationship was based on strain-life test data which was obtained at various mean stresses. Thus, the SWT expression is mathematically defined as:

$$\sigma_{max}\varepsilon_a E = (\sigma_f')^2(2N_f)^{2b} + \sigma_f'\varepsilon_f' E(2N_f)^{b+c} \qquad (5)$$

where, ($\sigma_{max} = \sigma_m + \sigma_a$ and ε_a is the alternating strain). This equation is based on the assumption that for different combinations of strain amplitude, ε_a and mean stress, σ_m, the product σ_{max} εa remains constant for a given life.

The main task performed during durability analysis is the fatigue life assessment of components such as engine parts, suspension parts and body structures (Bignonnet, 1999). The life of the lower suspension arm can be calculated by using the Morrow approach due to widely accepted by the automotive industry (Tucker and Bussa, 1977). The SWT approach is also widely used because it is difficult to categorically select one procedure in preference to the other (Fatigue, 2001). Suspension system arms can be fabricated using cast steel (Mahishi, 2005). In the last decade, aluminium has also found use in structural applications in mass market cars, such as brake components, steering components and suspension control arms (As, 2006). The prediction of fatigue life under variable amplitudes-despite innumerable claims to the contrary in literature (Schütz and Heuler, 1994; Schütz, 1996). Neither the Miner calculation in its many variations nor the local-strain approaches attain a sufficient accuracy, as shown in Fatemi and Yang (1998).

Several investigators have proposed methods for improving the fatigue life prediction for components subjected to variable amplitude VA loadings. Models have been derived using random vibration theory (Liou *et al.*, 1999), non-linear damage summation (Plumtree and Shen, 1990; Shang and Yao, 1999) and the adaptation of a fracture mechanics approach (Veers *et al.*, 1989; Taheri *et al.*, 2003). Methods of modifying the stress-life and strain-life approaches have also been suggested in order to predict the fatigue life of the metal structures and automobile components which are exposed to VA loadings (Conle and Topper, 1980; Yan *et al.*, 1992). A fatigue damage model for use with VA strain loadings was developed by DuQuesnay *et al.* (1993). The idea of developing this model was based on the crack growth and the crack closure mechanisms of metallic materials, particularly for steel and aluminium. It has been shown to work well for a wide range of materials, load spectra, component geometries, strain magnitudes and mean-strain effects (DuQuesnay *et al.*, 1992a, b, 1993; Topper and Lam, 1997; DuQuesnay, 2002).

The DuQuesnay's strain-life model was developed for the purpose of life to crack detection, which is based on the use of the effective strain range as the damage parameter. Using this model, the fatigue damage can be analysed based on the assumption of the short crack growth and it is because of the crack length at failure is usually less than a few millimeters. This model strain-life model is mathematically defined as:

$$E\Delta\varepsilon^* = A\,(N_f)^B \qquad (5)$$

where, E is the elastic modulus of the material, $\Delta\varepsilon^*$ is the net effective strain range for a closed hysteresis loop which is related to the fatigue crack growth, A and B are material constants and N_f is the number of cycles to failure.

CONCLUSION

Accurate calculating fatigue life requires considering every significant load in the service life. Loading complexity and resulting stress states mean fatigue analysis is more challenging than simply designing a component to withstand maximum loads. In addition, it is too computationally intensive to use finite element method in order to get the fatigue life prediction for the components which subjected to service loadings.

Several recent finite element software for fatigue life prediction purposes, using models which they are more suitable for constant amplitude loading than variable like the Morrow and the Smith-Watson-Topper (SWT) models. Thus, this study presents a review on the FEA approaches in order to solve the low cycle fatigue problem. The results of applying the Morrow and the SWT strain-life equations are still not give the perfect results. These approaches are not suitable for VA loadings because cycle sequence effects are not taking into consideration.

In a nutshell, there are many models can give more reasonable results for the fatigue life prediction by taking into consideration the sequence effect on life components. For instance, the use of the DuQuesnay model with the combination of the FEA approach in order to predict fatigue life under service loading will also be done as an effective algorithm, which leads to an alternative solution in the durability research.

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