INFLUENCE OF SHOT PEENED ON FATIGUE BEHAVIOUR OF SUSPENSION ARM USING STRAIN-LIFE APPROCAH

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SUPERVISOR'S DECLARATION

I hereby declare that I have checked this thesis and in my opinion this thesis is satisfactory in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering.

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I hereby declare that the work in this thesis is my own except for quotations and summaries which have been duly acknowledged. The thesis has not been accepted for any degree and is not concurrently submitted in candidate of any other degree.

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ABSTRACT

This project describes the influence of shot peened on the fatigue behaviour of suspension arm using strain-life approach. The main objectives of this project are to predict the fatigue life and identify the critical location, to investigate the effect of shot peened treatment and to select the suitable materials for suspension arm. Aluminium alloys are selected as a suspension arm materials. The fatigue life predicted utilizing the finite element based fatigue analysis code. The structural model of the suspension arm was utilizing the SolidWorks. The finite element model and analysis were performed utilizing the finite element analysis code. In addition, the fatigue life was predicted using the strain-life approach subjected to variable amplitude loading. The three types of variable amplitude are considered in this project. TET10 mesh and maximum principal stress were considered in the linear static stress analysis and the critical location was considered at node (6017). From the fatigue analysis, Smith-Watson-Topper mean stress correction was conservative method when subjected to SAETRN loading, while Coffin-Manson model is applicable when subjected to SAESUS and SAEBRKT loading. From the material optimization, 7075-T6 aluminium alloy is suitable material of the suspension arm compared to 6082-T6. As a conclusion, shot peened treatment was capable to improve the fatigue of the critical location. The significant of this project is to reduce the cost before developing the prototype.

ABSTRAK

Projek ini menerangkan tentang pengaruh tembakan "peened" terhadap jangka hayat lesu ke atas "suspension arm" menggunkan pendekatan tegangan-hayat. Objektif utama projek ini adalah untuk meramalkan janka hayat lesu dan mengenal pasti lokasi kritikal, menyiasat kesan rawatan tembakan "peened" dan memilih bahan yang sesuai untuk "suspension arm". Aluminium alloy telah dipilih sebagai bahan untuk "suspension arm". Ramalan jangka hayat dibuat menggunakan unsure terhingga bedasarkan kode analisis lesu. Model struktur "suspension arm" dibuat menggunakan "SolidWorks". Selain itu, analisis jangka hayat lesu diramal menggunakan analsis tegangan-hidup apabila dkenakan bebanan amplitude berubah. Dalam projek ini, tiga jenis bebanan amplitude berubah diambil kira. Unsur TET10 dan prinsip tekanan maksimum diambil kira dalam analysis linear pegun. Daripada keputusan yang didapati, pembetulan tegasan min Smith-Watson-Topper adalah kaedah yang konsevatif apabila dikenakan bebanan SAETRN, manakala model Coffin-Manson boleh diguna pakai apabila dikena bebanan SAESUS dan SAEBRKT. Daripada pengoptimuman bahan, aluminium alloy 7075-T6 adalah sesuai digunakan berbanding 6082-T6. Kesimpulanya,"tembakan peened" berupaya untuk memperbaiki jangka hayat pada lokasi yang kritikal. Kepentingan projek ini adalah untuk mengurangkan kos sebelum prototaip dimajukan.

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LIST OF SYMBOLS

ε_e	Elastic component of the cyclic strain amplitude
c	Fatigue ductility exponent
$\frac{\Delta\varepsilon}{2}$	Strain amplitude
N_f	No of cycle to failure
ε'_f	Fatigue ductility coefficient
b	Fatigue strength exponent
E	Modulus of elasticity
σ_o	Local mean stress
σ_{max}	Local maximum stress
σ'_f	Fatigue strength coefficient

LIST OF ABBREVIATIONS

Al	Aluminium
CAD	Computer-aided design
CAE	Computer-aided engineering
SWT	Smith-Watson-Topper
FE	Finite element
FFM	Finite element modeling
SAETRN	Postive mean loading
SAESUS	Negative mean loading
SAEBRKT	Bracket mean loading
MBD	Multibody dynamics
LFC	Low fatigue cycle
TET	Tetrahedral
SAE	Society of Automotive Engineers

CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

In automotive industry, aluminium (Al) alloy has limited usage due to their higher cost and less developed manufacturing process compared to steels. However, Al alloy has the advantage of lower weight and therefore has been used increasingly in car industry for the last 30 years, mainly as engine block, engine parts, brake components, steering components and suspension arms where significant weight can be achieved Kyrre (2006). The increasing use of Al is due to the safety, environmental and performance benefits that aluminum offers, as well as the improved fuel consumption because of light weight.

Suspension components, along with wheel rims and brake components are unsprung masses, which make weight reduction important for ride quality and response as well as for reducing the total vehicle weight. Every automotive suspension has two goals, passenger comfort and vehicle control. Comfort is provided by isolating the vehicle's passengers from road disturbances like bumps or potholes. Control is achieved by keeping the car body from rolling and pitching excessively, and maintaining good contact between the tire and the road.

In this project, the material used for the suspension arm is a 6082-T6 aluminium alloy, which has good formability and corrosion resistance as well as high impact and fatigue strength Kyrre (2006).

1.2 PROBLEM STATEMENT

One of the important structural limitations of an aluminium alloy is its fatigue properties. This study is aimed at the automotive industry, more specifically a wrought aluminium suspension system, where safety is of great concern Kyrre (2006). Most of the time to failure consists of crack initiation and a conservative approach is to denote the component as failed when a crack has initiated Kyrre et al. (2005). This simplification allows designers to use linear elastic stress results obtained from multibody dynamic FE (finite element) simulations for fatigue life analysis.

The suspension arm is subjected to cyclic loading and it is consequently exposed to fatigue damage. In most cases, fatigue damage initiates at the surface due to localized stress concentrations caused by machining marks, exposed inclusions or even due to the contrasting movement of dislocations. Shot peening is extensively used for the above purpose as it produces near surface plastic deformation leading to the development of work-hardening and high magnitude compressive residual stresses. Work hardening is expected to increase the flow resistance of the material and thus reduce crack tip plasticity Rodopoulus et al. (2004)

In the suspension arm, uncertainty is related to loads expected given to the car component due to individual driving styles and road conditions. Therefore, the prediction of fatigue life is less accurate even under controlled laboratory conditions. Hence the numerical simulation is implemented because of cheap and easy to perform as well as provide insight to the mechanism of shot peening during the impact of the shot on the component surface. The finite element based shot peening enable the designer to carry out the parametric study of the process Rahman et al. (2007).

1.3 SCOPE OF STUDY

This study is concentrates on the strain-life approach under variable amplitude loading. Numerical simulations are used to determine the effect of shot peening on the fatigue life of the suspension arm. The scopes of study are as follows:

i. Structural modeling
ii. Finite element modeling (FEM).
iii. Fatigue analysis.
iv. Surface treatment analysis.

1.4 OBJECTIVES OF THE PROJECT

The main objective of this project is to conduct the finite element based fatigue analysis for aluminium suspension arm under variable amplitude loading. The overall objectives are:

i. To predict the fatigue life of suspension arm using strain-life method and identify the critical location.
ii. To investigate the effect of shot peening on the fatigue life of the suspension arm.
iii. To optimize the material for the suspension arm.

1.5 OVERVIEW OF THE REPORT

Chapter 1 gives the brief the content and background of the project. The problem statement, scope of study and objectives are also discussed in this chapter.

Chapter 2 discusses about the fatigue life prediction methods, fatigue life prediction in variable amplitude loading, strain-life method and shot peened treatment.

Chapter 3 presents the development of methodology, finite element modeling and analysis, fatigue life prediction technique and linear elastic analysis.

Chapter 4 discusses the result and discussion of the project. The discussion aims is to determine the predicted facts and correlate them with the current international researches on the field of the fatigue mean stress effects.

Chapter 5 presents the conclusions of the project. Suggestions and recommendations for the future work are put forward in this chapter.

CHAPTER 2

LITERITURE REVIEW

2.1 INTRODUCTION

The purpose of this chapter is to provide a review of the past research related to the shot peening, fatigue life method, variable amplitude loading and strain-life method.

2.2 FATIGUE LIFE PREDICTION METHOD

In general, fatigue life refers to the ability of a component to function in the presence of defect for a given loading. In practice, the predominant failure mode is fatigue and hence, the term fatigue life analysis was used to describe the analysis of the fatigue performance.

Rahman et al. (2007) were studied about finite element based durability assessment in a two- stroke free piston linear engine component using variable amplitude loading. Authors discussed the finite element analysis to predict the fatigue life and identify the critical locations of the component. The effect of mean stress on the fatigue life also investigated. The linear static finite element analysis was performed using MSC. NASTRAN. The result was capable of showing the contour plots of the fatigue life histogram and damage histogram at the most critical location.

Kyrre (2006) was investigated the fatigue assessment of aluminium suspension arm. Fatigue life prediction from finite element analysis has been discussed. Although the methods can be used for all structural alloys, author focuses on aluminium alloys in automotive structures. The software package nSoft was used for fatigue life prediction and Fedem is used for the dynamic simulations. The author concluded that the dynamic finite element analysis was very computationally intensive. The model must therefore be simple, possibly confined to separate sections of the vehicle. Then the accuracy what was required for static analysis required, since small inaccuracies in peak stresses affect the life prediction can be determined significantly. This was shown for a mesh typically used in static strength evaluations. The mesh was converted using higher order elements and compared to the initial mesh. The new mesh proved to be much more conservative in fatigue life predictions. He applied the Smith-Watson-Topper (SWT) parameter and Morrow mean stress correction and found that stress-life was better correlation at high fatigue life, but the strain-life method must be used if plastic overloads are observed.

Conle and Mousseau (1991) used the vehicle simulation and finite element result to generate the fatigue life contours for the chassis component using automotive proving ground load history result combine with the computational techniques. They concluded that the combination of the dynamics modeling, finite element analysis is the practical techniques for the fatigue design of the automotive component.

S.K. et al. (2005) were conducted the fatigue life prediction of suspension arm using finite element analysis of surface topography. They concluded that fatigue strength of the structure is highly depending on the surface quality. Current methods to predict fatigue life rely on empirical relations between geometric surface parameters and observed endurance lives. The uncertainty associated with these methods is typically high, since parameters based on geometrical averages can fail to describe important characteristics of surface topography. Then they proposed a new approach where detailed finite element analysis of surface topography is used as a foundation for fatigue life prediction.

Kim et al. (2002) studied a method for simulating vehicles dynamic loads, but they add durability assessment. For their multibody dynamic analysis they use DADS and a flexible body model. The model was for a transit bus. For their dynamic stress analysis, MSC. NASTRAN was used. The fatigue life was then calculated using a local strain approach. From the fatigue life, it was found that the majority of the fatigue damage occurred over a frequency range that depend on terrain traveled (service or accelerated test course). This showed that the actual service environment could be simulated instead of using an accelerated testing environment.

Nadot and Denier (2003) have been studied fatigue phenomena for nodular cast iron automotive suspension arms. They found that the major parameter influencing fatigue failure of casting components are casting defects. The high cycle fatigue behaviour is controlled mainly by surface defects such as dross defects and oxides while the low cycle fatigue is governed by multiple cracks initiated independently from casting defects.

2.3 VARIABLE AMPLITUDE LOADING

When components are subjected to variable amplitude service loads, additional uncertainties arise, whether the loading in laboratory tests related to the loads that could be expected to appear. Traditionally this problem is solved by using the simplifying assumption of damage accumulation, and constant amplitude tests in laboratory are transformed to variable amplitude severity by the Palmgren-Miner rule which says that a load cycle with amplitude *Si* adds to the cumulative damage *D*, a quantity (*1*/Ni). Here, Ni denotes the fatigue life under constant amplitude loading with amplitude *Si* and n_i is the number of load cycles at this amplitude.

$$\mathrm{D} = \sum_{i=1}^{m} \frac{n_i}{N_i} \qquad (2.1)$$

The lack of validity of this accumulation rule has been demonstrated in many applications and in consequence its usage will introduce uncertainties which must be compensated for by safety factors. One possible way to diminish the deviations from the damage accumulation rule is to perform the laboratory experiments closer to the service behaviour with respect to the loads. A method for establishing a Wohler curve based on variable amplitude loads has recently been developed and is presented in a parallel paper Johannesson et al. (2005). The use of this method should be customized to each specific application by performing laboratory tests with load spectra covering different service requirements. One idea is that service measurements are used to establish a few reference load spectra for use in laboratory tests. Based on the resulting variable amplitude Wohler curve, fatigue life can be predicted for load spectra similar to the reference types.

Svensson et al. (2005) was conducted the fatigue life prediction based on variable amplitude tests-specific applications. Three engineering components have been tested with both constant amplitude loading and different load spectra and the results are analysed by means of a new evaluation method. The method relies on the Palmgren-Miner hypothesis, but offers the opportunity to approve the hypothesis validity by narrowing the domain of its application in accordance with a specific situation. In the first case automotive spot weld components are tested with two different synthetic spectra and the result is extrapolated to new service spectra. In the second case, the fatigue properties of a rock drill component are analyzed both by constant amplitude tests and by spectrum tests and the two reference test sets are compared. In the third case, butt welded mild steel is analyzed with respect to different load level crossing properties and different irregularity factors.

Nolting et al. (2008) was investigated the effect of variable amplitude loading on the fatigue life and failure mode of adhesively bonded double strap (DS) joints made from clad and bare 2024-T3 aluminum. They concluded that the fatigue life of a variable amplitude loading spectra can be calculated with reasonable accuracy using an effective stress range vs. life fatigue curve. The effective stress range vs. failure life curve is dependent on the bond geometry and therefore this curve must be developed for each component geometry of interest. The effective stress range versus life fatigue curve should be used to predict the fatigue life of clad specimens if the failure mode of the clad specimens is expected to be adhesive failure.

Molent et al. (2007) was evaluated the spectrum fatigue crack growth using variable amplitude data. This paper summarizes a recent semi-empirical model that appears to be capable of producing more accurate fatigue life predictions using flight load spectra based on realistic in-service usage. The new model described here provides an alternative means for the interpretation of full-scale and coupon fatigue test data, and can also be used to make reliable life predictions for a range of situations. This is a very important capability, particularly where only a single full-scale fatigue test can be afforded and should lead to more economical utilization of airframes.

2.4 STRAIN-LIFE METHOD

The fatigue strain-life approach involves the techniques for converting the loading history, geometry, and materials properties (monotonic and cyclic) input into a fatigue life prediction. The operations involved in the prediction process must be performed sequentially. First, the stress and strain at the critical region are estimated, and the rainflow cycle counting method Matsuishi et al., (1968) is then used to reduce the load-time history based on the peak-valley sequential. The next step is to use the finite element method to convert the reduced load-time history into a strain-time history and also to calculate the stress and strain in the highly stressed area. Then, the crack initiation methods are employed to predict the fatigue life. The simple linear hypothesis proposed by Palmgren, (1924) and Miner, (1945) is used to accumulate fatigue damage. Finally, the damage values for all cycles are summed until a critical damage sum (failure criteria) is reached.

In order to perform fatigue life analysis and to apply the stress-strain approach in complex structures, Conle and Chu (1977) used the strain-life result which is simulated using three-dimensional models to evaluate the fatigue damage. After the complex load history was reduced to an elastic stress history for each critical element, a neuber plasticity correction method was used to correct the plastic behavior. Elastic unit load analysis using strength of materials and an elastic finite element analysis model combined with a superposition procedure of each load point's service history was proposed. Savaidis (2001) verified that the local strain approach is suitable for a fatigue life evaluation. In this study, it is consider that the local strain approach using the Smith-Watson-Toper (SWT) strain-life model is able to represent and to estimate the parameters. These include mean stress effects, load sequence effects above and below the endurance limit, and manufacturing process effects such as surface treatment and residual stresses, and also stated by Juvinall and Marshek (1991).

2.5 SHOT PEENED TREATMENT

The increased use of aluminium (Al) alloys in automotive industry is due to the safety, environmental and performance benefits that aluminum offers, as well as the improved fuel consumption because of light weight. Al alloys have advantages such as good corrosion resistance, high melting point, good formability and good thermal conductivity. However the hardness and wear resistance of Al alloys is lower than steel, hence the surface treatment should be done to increase the fatigue life of Al alloys. Mechanical surface treatment such as nitriding, shot peening, hot and cold rolled are often used to increase the fatigue life of high strength Al alloys Novovic et al. (2004). Shot peening is well established cold working process widely used in automotive and aircraft industry. In shot peening, the surface component is hit repeatedly by large numbers of shot. The component undergoes large plastic deformation and thus compressive residual stress is useful for fatigue life of the component Harada and Mori (2005).

Shot peening is a widely used method for improving the fatigue life and stress corrosion resistance of components. The process involves the firing of hard steel balls, under controlled velocity onto the critical zone of the surface of the component. The improvement in fatigue behavior of the component is usually a consequence of: (i) the strain hardening of surface layers which increases the yield stress of the material, (ii) the compressive residual stresses in surface layers induced by the shot peening and (iii) the final surface finish quality and structural changes. The effect of these factors varies with the original structure, with the strengthening method (for example, the modification to the surface finish can have a detrimental effect), with the strength or the hardness of the material, with the geometry of the workpiece and with the applied stress. The quality and effectiveness of peening depends on several parameters, including: the type and size of shots, shot peening intensity, surface coverage (shot peening time) and the properties of the material (Farrahi et al., 1995; Eleiche et al.,2001).

Farrahi and Ghadbeig (2005) carried out an investigation into the effect of various surface treatments on fatigue life of a tool steel. The effects of nitriding, nitrocarburizing and shot peening on fatigue behavior of AISI D3 cold work tool steel were investigated. The authors found out the shot peening is the best treatment to improve the fatigue life of AISI D3 tool steel.

2.6 CONCLUSION

This chapter is about the summary of journals or works those others people have done that related to this project. The works were discussed about fatigue life prediction method, variable amplitude loading, strain-life method and shot peened treatment. The next chapter is about the methodology of the project.