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FATIGUE LIFE EVALUATION OF TWO TYPES OF STEEL LEAF SPRINGS

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ABSTRACT

Multi-leaf and parabolic spring is one of the important components in automobile. This type of spring has different design and material apply to them, but had been used for the same vehicle. The objective of this study is to analyze and evaluate the capability of parabolic spring to replace the multi leaf in suspension system. Finite element analysis had been performed to analyze the stress distribution and behavior both type of springs. Then, time histories service loading data was analyze and damage area was simulated to predict the fatigue life of the components. Finally, comparison between simulation and experimental result had been made for validating purpose. Multi leaf can hold much more load then parabolic spring, but in terms of material usage and space requirement, parabolic spring has the advantages. Stress distribution patent for both spring was vary, where for multi-leaf, the stress was concentrated at the center part, while for parabolic, stress was distributed well at the both side of the part. The outcome from the study hopefully will help in further work on development of suspension system.

Keywords: Heat treatment, Microstructure, Hardness, Low alloy steel

INTRODUCTION

Multi-leaf and parabolic spring are widely used in automotive and became one of the vital component in suspension system. Even have different shape, design and material assign to it, and both type of spring still utilized for the same purpose. These springs serves to absorb and store energy and then release it (SAE, 1980). During the operation, the stress must not exceed a certain maximum in order to avoid settling or premature failure. In terms of shape and design, multi-leaf spring consist of 7 leave and have equal thickness for all individual leaf, but for the parabolic, the spring was thicker at the center part and decrease parabolically towards spring eye and consist of two individual leaf (Fukui *et al.*, 1874; Grip *et al*., 1986) Due to uniform thickness for all leaf, multi-leaf spring is relatively much easier in manufacturing, but used much more of material. Parabolic leaf springs required relatively little space but on the other hand their production is costly (Grip *et al*., 1986). Both types of springs are subjected to cyclic compression and tension loading in variable amplitude when vehicle was drove on the road. In industry, most of the manufacturers only manage to perform constant amplitude loading for the fatigue life prediction. This is due to time consuming and additional cost that relatively high to perform the variable amplitude loading (VAL) fatigue test. This paper presents the evaluation of multi-leaf and parabolic spring using Finite element analysis (FEA)-based approach. The stress distribution and behavior was studied and compared for both type of spring. VAL signal also utilized to simulate the fatigue test.

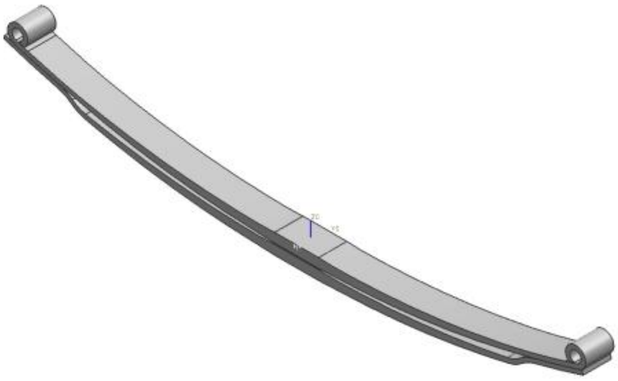
This paper presents the fatigue life prediction based on finite element analysis and variable amplitude loading. Data collection of service loading was carried out and this data was used as an input in the simulation. Critical areas were obtained from the FEA. Finally, the life of this parabolic spring can be predicted, showing the total life within the acceptable limit.

METHODOLOGY

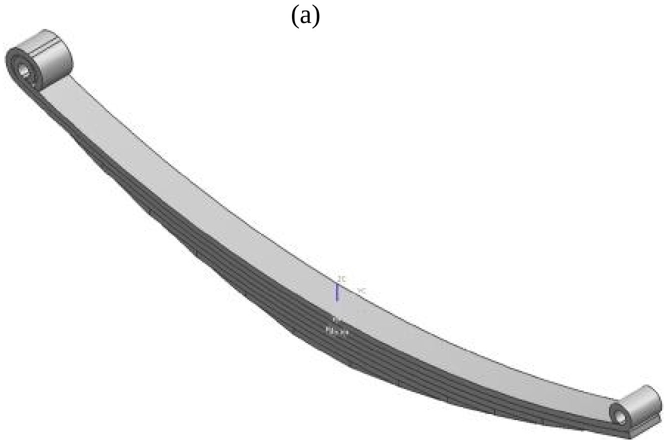
Multi-leaf and parabolic spring was modeled using commercial software and all the specification was accordingly followed the relevant drawing standard. For the FEA simulation, 20-nodes hexahedral element was used. Both model of springs was partition into several part to get more accurate geometry and easier to mesh. Boundary condition was set according to real static load test which is the front eye was allowing only rotational at y axis and the rear eye was constrained in y and z translation and x and z rotation, allowing free x translation and y rotation (Kammerdtong *et al.;* Qin *et al.*, 2002).

Using finite element analysis, high stress patent and deflection behavior of both springs can be studied. Also, this FE model will be used in fatigue analysis in next step of study. These types of springs were used in the same model of trucks. Multi-leaf was used earlier and then was replaced by the parabolic spring.

Contact at each leaf also been defined. All leave was constrained at 2nd degree of freedom to represent the clip hat holds that to spring together. Finally, vertical load was applied at the center part of the spring. In this study, several assumptions have been made i.e. the chosen material was homogenous, no interleaf friction was defined. To reduce he complexity of simulation, shackle and bush was not model together, only represent by boundary condition and shot peening stress effect and nip stress also omitted. The material that had been used for the multi leaf was SAE5160H and SAE6150 for parabolic spring which is low carbon alloy steel normally used for the spring fabrication. The chemical composition for both steel is shown in Table 1.



(a)



(b)

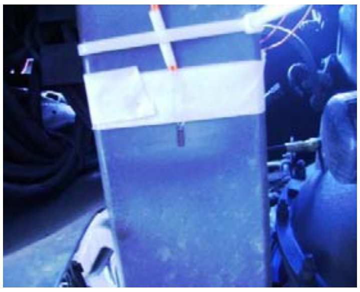
Fig. 1. Geometry schematic of (a) multileaf spring and (b) parabolic spring

Table 1: Chemical composition of steel spring

Material	Element (wt%)			
	C	Mn	Cr	V
SAE5160	0.56	0.75	0.70	-
SAE6150	0.48	0.70	0.80	0.15 (Min)

SoMat eDAQ data acquisition system as illustrated in Fig was used to collect strain data. Strain gauge had been attached to the parabolic spring of a truck. In this study, both left and right side spring was attached with the strain gauge. Then truck was driven on a public road in Malaysia with average speed of 60-70 km per hour. The collected data was sampled at 200 Hz ad containing 17000 discrete data points, thus, it gave 86 seconds of total record length.

(a)



(b)

(c)

Fig. 2. :SoMat eDAQ data acquisition set up, (a) strain gauge on leaf spring (b SoMat eDAQ, (c) laptop for operating the eDAQ

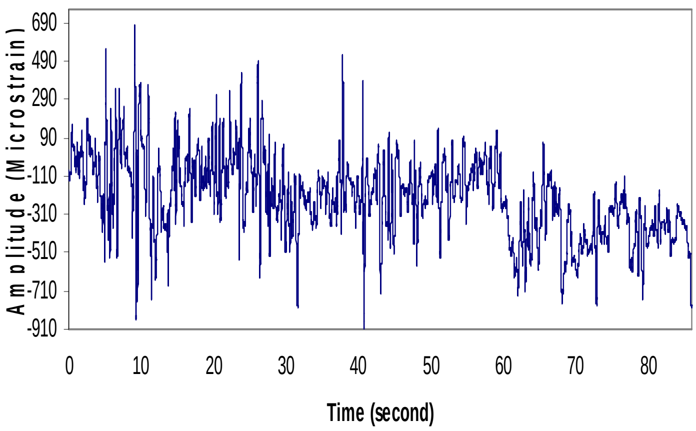
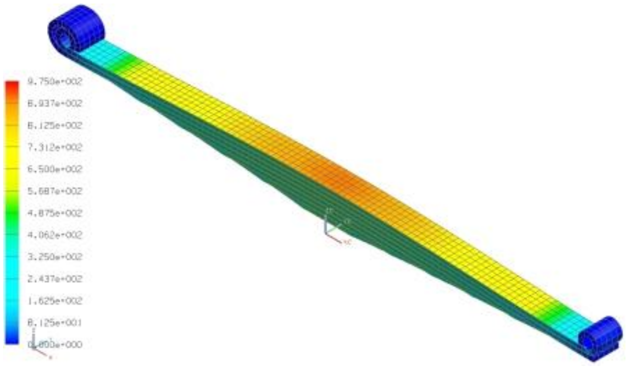


Fig. 3. : Variable amplitude loading signal which was collected from the data collection work

The range of amplitude of the collected data (as shown in Figure 1) is at -910 µE minimum and 760 µE maximum. The collected strain loading was then used as an input for FEA-based fatigue simulation. In this simulation, the Morrow approach had been used for correcting the damage calculation with considers the mean stress effect. In a case of the loading being predominantly compressive, particularly for wholly compressive cycles, the Morrow model provides more realistic life estimates (Dowling, 1999).

RESULTS AND DISCUSSION

The stress distribution for both multi-leaf and parabolic spring is shown on Figure 4. The combination of boundary condition gives a maximum stress at the center of multi-leaf, while the stresses were distributed from the center towards spring eye for the parabolic spring. The thickness patent of both spring contribute to the different high stress area.



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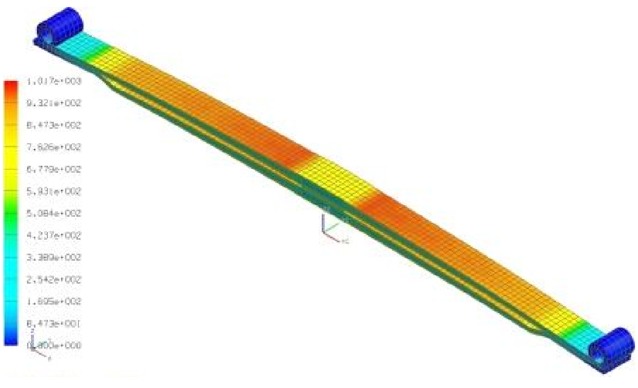


(b)

Fig. 4. : Stress distribution areas on a particular component: (a) multi-leaf spring, (b) parabolic spring

Figure 5 shows the load versus stress graph for both springs. The different at the initial was around 15% but it decrease when the load is increase. Resulting from the graph, found that stresses occur more on parabolic spring then multi-leaf spring when the same loading was applied. This is due to number of leaf and total weight of both springs is different and multi-leaf taking advantage on that.

Graph of load versus deflection was illustrated in Figure 6. Deflection of the spring was increase gradually in linear manner. This is resulting from linear static analysis that performed in simulation. This method of simulation was chosen to simplify and reduce the computational time consume. As shown in Figure, multi-leaf deflects up to 22% more than parabolic spring. The deflection was measured from the spring seat, which is the center part

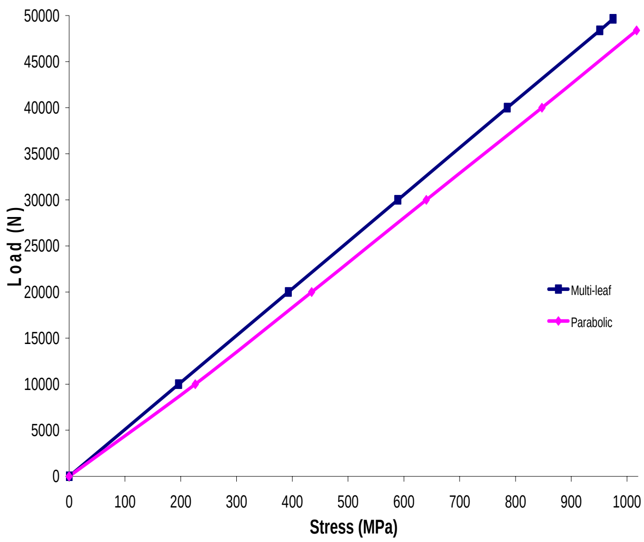


Fig. 5.: Load vs. Stress graph of multi-leaf and parabolic spring

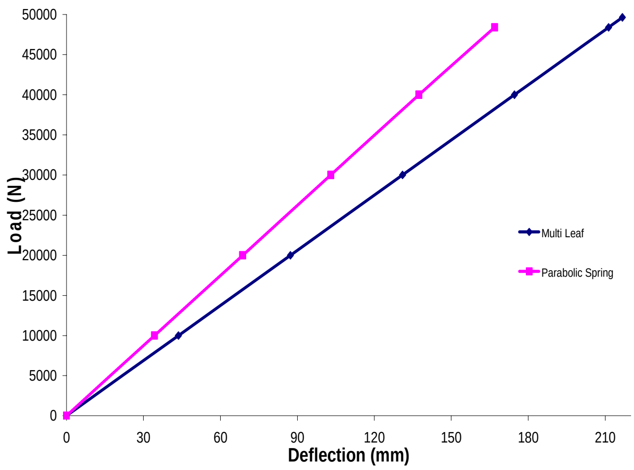


Fig. 6. : Load vs. deflection graph of multi-leaf and parabolic spring

of the spring. In order to obtain the better result, non-linear analysis is preferable (Qin *et al.*, 2002; Liu, 1988). In non-linear analysis, a large deformation of the geometry will be taken account during the simulation. For multileaf spring, SAE5160H steel has been used meanwhile SAE6150 steel was utilized for the parabolic spring

Table 2. : Fatigue simulation results of damage and cycle prediction

	Multileaf spring	Parabolic spring
Highest damage value	7.937×10^{-5}	9.121×10^{-5}
Lowest cycle value	4.649×10^{3}	3.982×10^{3}

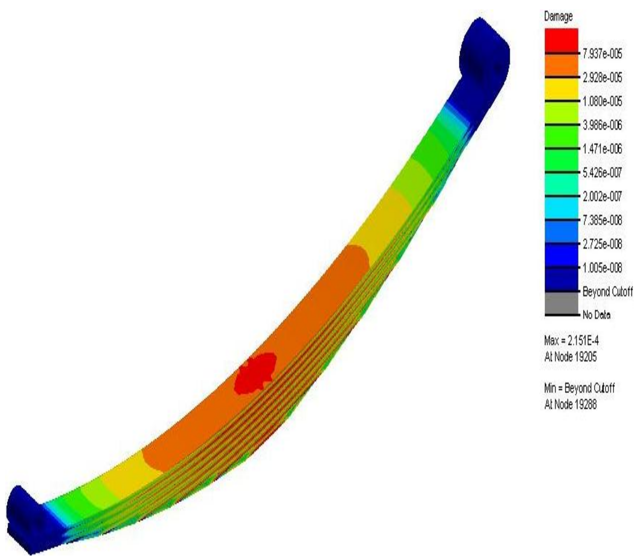
Damage analysis of engineering components loaded under variable amplitude loading spectra requires involvement of phenomenological factors to address the effects of loading sequence (Varvani *et al.*, 2005). For strain-based fatigue life prediction, this rule is normally applied with strain-life fatigue damage models, such as the Coffin–Manson relationship (Coffin, 1954; Manson, 1965), i.e.

$$\varepsilon_a = \frac{\sigma'_f}{E}\left(2N_f\right)^b + \varepsilon'f\left(2N_f\right)^c \qquad (1)$$

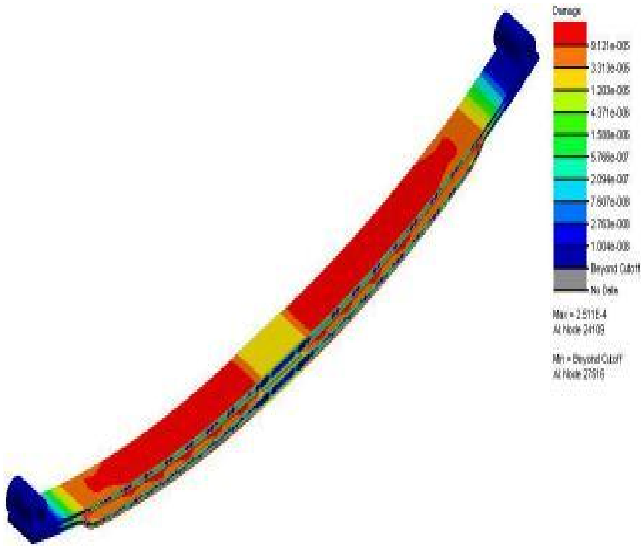
and meanwhile, the Morrow (1968) stress mean correction model has been used in this study due to the loading being predominantly compressive, particularly for wholly compressive cycles

$$\sigma_{max}\varepsilon_a = \frac{\left(\sigma'_f\right)^2}{E}\left(2N_f\right)^{2b} + \sigma'_f\varepsilon'f\left(2N_f\right)^{b+c} \qquad (2)$$

In Figure 7, damage area can be found when spring was applied with random loading and this image was correlated well with the FEA stress distribution area.



(a)



(b)

Fig. 7.: Load FEA-based fatigue prediction: (a) Multi-leaf spring, (b) Parabolic spring

For the parabolic spring, it occur from spring seat towards the spring eye was where the high damage occur. For both springs, the eye itself didn't show significant or no damage at all. The eye only experiencing rotational movement, where the magnitude deflection was relatively small compared to the critical area. As simulated in FEA, high damage occurs at the center part of multi-leaf spring. This shows that multi-leaf tend to fail at the center. Moreover, there are center hole at the high damage area that increase the potential of failure.

CONCLUSIONS

Evaluation on multi-leaf spring and parabolic spring using FEA-based was presented. Finite element modeling and analysis has been performed to study the stresses distribution and behavior of the springs. The SAE 5160 H and SAE 6150 spring steel were considered in this study.

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