Assessment and Comparison of Fatigue Life for Heavy Truck Wheel Rim Rnder Fully Reverse Loading for Aluminium Alloys

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Abstract: This study presents fatigue life prediction under fully reversed loading. Tires are the most important part for any vehicle. The rim is the outer edge of a wheel, holding the tire. It makes up the outer circular design of the wheel on which the inside edge of the tire is mounted on vehicles. Present rims are manufacturing using aluminium alloys. The proposed study replaces the magnesium alloys with aluminium alloys because magnesium alloys will have high impact and fatigue strength so that they can with stand vibrations and shock loading better compared to aluminium alloys. The objective of this study is to simulate the fully reversed loading for the fatigue life analysis for heavy vehicle truck wheel rim. The finite element method (FEM) was performed on the rim model to observe the distribution of stress and damage. The fatigue life simulation was performed and analyzed for materials Al alloy (Al35T6 recent material for forged wheels) with ALMG alloys (AL6082, AL6060). When using the loading sequences is predominantly tensile in the nature; the life of mounting in Goodman approach is more conservative. When the loading is predominantly tensile in nature, the life of the component in Morrow approach is more sensitive and is therefore recommended. It can be concluded that material AL6082 gives constantly higher life than other material for given loading condition.

Keywords: Fatigue life; fully reversed loading; heavy truck wheel rim; total-life; crack-initiation; FEM.

1. Introduction

   The importance of wheels and tyres in the automobile is obvious the wheel along with tyre has to take vehicle load providing cushioning effect and cope with steering control the various requirements for automobile control were it should be strong enough[1]. It should be lightest as possible. Material should not deteriorate with weathering and age. There are three types of wheels pressed steel disc wheel, wire wheel, light alloy (cast or forged wheel) ,light alloy cast or forged wheel is recent type whose use is ever increasing in both road and sport vehicles. Moreover light alloys are better conductors of heat which helps the wheels dissipate any heat generated by tyres are breaks and thereby run cooler. lighter wheels can improve handling by

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reducing unstrung mass , allowing suspension to follow the terrain more closely and thus improve grip, however not all alloy wheels are lighter than their steel equivalents. Reduction in overall vehicle mass can also help to reduce fuel consumption. Better heat conduction can help dissipate heat from the brakes , which improves braking performance in more demanding driving conditions and reduces the chance of brake failure due to overheating. There are competitions among materials and manufacturing processes, due to cost performance, and weight. This is a direct result of industry demand for components that are lighter, to increase efficiency, and cheaper to produce, while at the same time maintaining fatigue strength and other functional requirements by using finite element approach fatigue life of wheel rim estimated for stress/strain life .The dimensions which are considered in this mentioned in Table 1. and the model shown in Figure 1.

Table 1. Dimensions of Rim

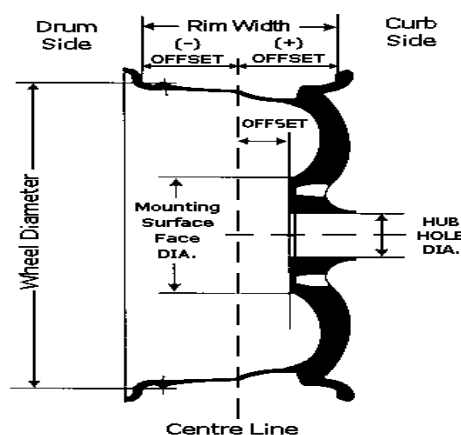| Outer diameter	450 mm
Hub hole diameter	150 mm
Bolt hole diameter	20 mm
Rim width	254 mm

Figure 1. Model of Rim

2. Finite element based fatigue analysis

The fatigue analysis is used to compute the fatigue life at one location in a structure. For multiple locations the process is repeated using geometry information applicable for each location. Necessary inputs for the fatigue analysis are shown in Figure 2. The three input information boxes are descriptions of the material properties, loading history and local geometry. All of these inputs are being discussed in the following sections.
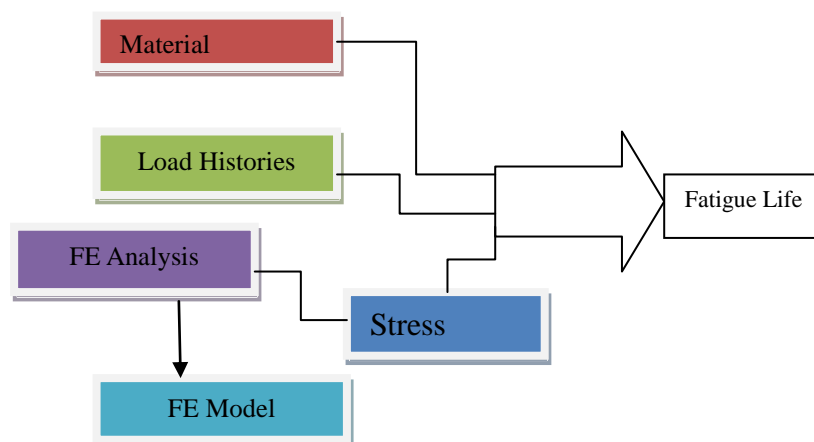

Figure 2. Fatigue Analysis Prediction Strategies

Material information-cyclic or repeated material data Load histories information-measured or simulated load histories applied to a component. The term "loads" is used to represent forces, displacements, accelerations, etc. Geometry information-relates the applied load histories to the local stresses and strains at the location of interest. The local stresses and strains information are usually derived from the finite element (FE) results. An integrated FE based durability analysis is considered a complete analysis of an entire component. Fatigue life can be estimated for every element in the finite element model and contour plots of life. Geometry information provided by FE results define how an applied load is provided by FE for each load case applied independently. Data provided for the desired fatigue analysis method. The schematic diagram of the integrated finite element based fatigue life prediction analysis is shown in Figure 3. The physical and cyclic properties for the materials are mentioned in Table 2.
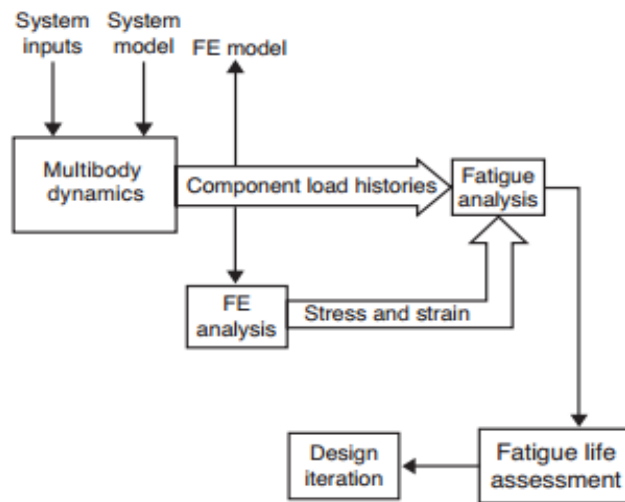

Figure 3. The Finite Element Based Fatigue Analysis Cycle

Table 2. Physical and cyclic Properties

Physical and Cyclic Properties	AL356T6	AL6082	AL6060
Yield strength(mpa)	291	307	215
Ultimate tensile strength(mpa)	303	330	240
Elastic modulus(gpa)	78	70	70
Fatigue strength coefficient(s_f)	666	486.8	376.5
Fatigue strength exponent(b)	-0.117	-0.07	-0.084
Fatigue ductility exponent(C)	-0.610	-0.593	-0.537
Fatigue ductility coefficient(e_f)	0.09	0.209	0.157
Cyclic strain hardening exponent(n)	0.063	0.064	0.038
Cyclic strength coefficient (k)	430	443.9	0.038

2.1. Fatigue analysis methods

Analysis of fatigue can be carried out by one of the three basic approaches i.e., the total life

(stress-life) approach and crack propagation approach, the crack initiation approach and crack propagation approach. The total-life (stress-life) approach was first applied over a hundred years ago and consider nominal elastic stresses and how they are related to life. The crack-initiation (stress-life) approach considers elastic-plastic local stresses and strains. It represents more fundamental approach and is used to determine the number of cycles required to initiate a small engineering cracks. Crack-propagation or linear elastic fracture mechanics (LEFM) approach is used to predict how quickly pre-existing cracks grow and to estimate how many loading cycles are required to grow these to a critical size when catastrophic failure would occur. First two methods are used in this study are briefly discussed these two methods in the following sections.

2.1.1. Stress life method

The fatigue total-life(S-N) approach is usually used for the life prediction of components subjected to high cycle fatigue, where stresses are mainly elastic. This approach emphasizes nominal stresses rather than local stresses. It uses the material stress-life curve and employs fatigue notch factors to account for stress concentrations, empirical modification factors for surface finish effects and analytical equations such as modified Goodman and Gerber equations are given below.

$$\frac{\sigma_a}{S_e} + \frac{\sigma_m}{S_u} = 1 ; \ \frac{\sigma_a}{S_e} + \left(\frac{\sigma_m}{S_u}\right)^2 = 1 \tag{1}$$

Where σ_a, Se, σ_m and S_a are the alternating stress in the presence of mean stress, alternating stress for equivalent completely reversed loading, the mean stress and the ultimate tensile strength, respectively. The Basquin showed that alternating stress verses number of cycles to failure (S-N) in finite life region could be represented as a log-log linear relationship. Basquin equation was then used to obtain the fatigue life using the material properties listed in Table 4.2. S-N approach uses to estimate the fatigue life for combined loading by determining an equivalent axial stress using one of the common failure criteria such as Tresca, von-mises, or maximum principal stress. The S-N equation is mathematically given b Where $S_{e,}$ σ'_f, $2N_f$ and b are the stress amplitude, the fatigue strength coefficient, the reversals to failure and the fatigue strength exponent, respectively[2].

$$S_e = \sigma'_f \left(2N_f\right)^b \tag{2}$$

Where Se, $\sigma'f$, 2Nf and b are the stress amplitude, the fatigue strength coefficient, the reversals to failure and the fatigue strength exponent, respectively as graph shows in Figure 4 comparison between the three materials with respect to S-N behaviour. It can be seen that these curves exhibit different life behaviour depending on the stress range experienced. From the figure, it is observed that in the long life area (high cycle fatigue), the different is lower while in the short life area (low cycle fatigue), the difference is higher. An important aspect of the fatigue process is plastic deformation. Fatigue cracks are initiated from the plastic straining in localized regions. Significant localized plastic deformation is often present, total-life approach doesn't account for plastic strain. Main advantage of this method is that it accounts for changes in local mean and residual stresses. In the crack initiation approach the plastic strain is directly measured and quantified. The total- life approach does not account for plastic strain. One of the main advantages of this method is that it accounts for changes in local mean and residual stresses. In

strain-life when the load history contains large over loads, significant plastic deformation can exist, particularly at stress concentrations and the load sequence effects can be significant. In these cases, the crack initiation approach is generally superior to the total life approach for fatigue life prediction analysis. However, when the load levels are relatively low such that the resulting strains are mainly elastic, the crack initiation and total life approaches usually result in similar predictions The fatigue crack initiation approach involves the techniques for converting load history, geometry and material properties (monotonic and cyclic) input in to the fatigue life prediction.. In this study, it was observed that the local strain approach using the Smith-Watson-Topper (SWT) strain-life model is able to represent and to estimate many factors explicitly. These include mean stress effects, load sequence effects above and below the endurance limit and manufacturing process effects such as surface roughness and residual stresses. The fatigue resistance of metals can be characterized by a strain life curve. These curves are derived from the polished laboratory specimens tested under completely reversed strain control. The relationship between the total strain amplitude ($\Delta\varepsilon/2$) and reversals to failure (2Nf) can be expressed in following form that represents the typical total strain-life curves [3, 4].

$$\frac{\Delta\varepsilon}{2} = \frac{\sigma'_f}{E}\left(2N_f\right)^b + \varepsilon'_f\left(2N_f{}^c\right) \tag{3}$$

Where, N_f is the fatigue life; σ'_f is the fatigue strength coefficient; E is the modules of elasticity; ε'_f is the fatigue ductility coefficient and c is fatigue ductility exponent.
Morrow (1968) suggested that mean stress effects are considered by modifying the elastic term in the strain-life equation by mean stress (σ_m) [5].

Where, σmax is the maximum stress and εa is the strain amplitude.

$$\varepsilon_a = \frac{\sigma'_f - \sigma_m}{E}\left(2N_f\right)^b + \varepsilon'_f\left(2N_f\right)^c \tag{4}$$

Smith (1970) was introduced another mean stress model which is called SWT mean stress correction model. It is mathematically defined as reference 6.

$$\sigma_{max}\varepsilon_a E = \left(\sigma'_f\right)^2\left(2N_f\right)^{2b} + \sigma'_f\ \varepsilon'_f E\left(2N_f\right)^{b+c} \tag{5}$$

Where, σmax is the maximum stress and εa is the strain amplitude
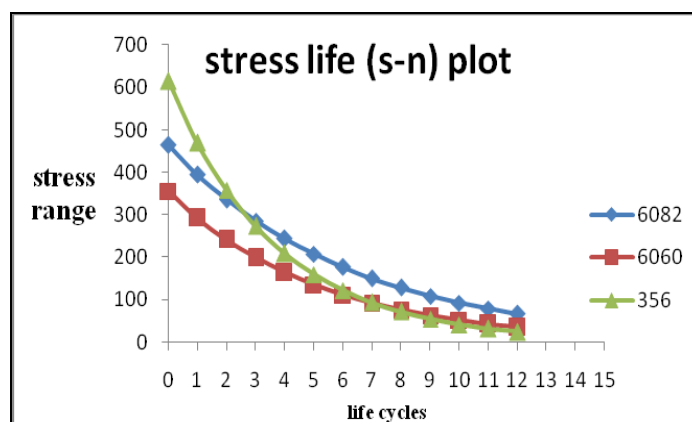

Figure 4. Stress-life (S-N) plot

Figure 5 represent the stain life curve indicates the different fatigue life behaviour for both materials. It is plotted based on the Coffin-Manson relationship. From the figure, it can be seen that in long life area (high cycle fatigue) the difference is lower while in the short life area (low cycle fatigue) the difference is higher. Figures 6 and 7 Show the other strain life curves this are based on Morrow and SWT models, respectively.
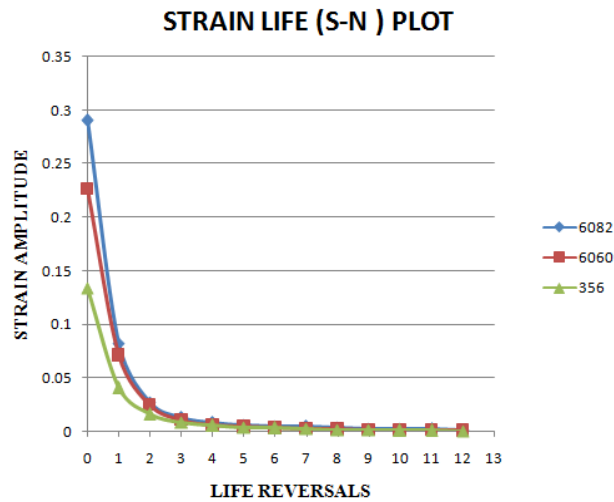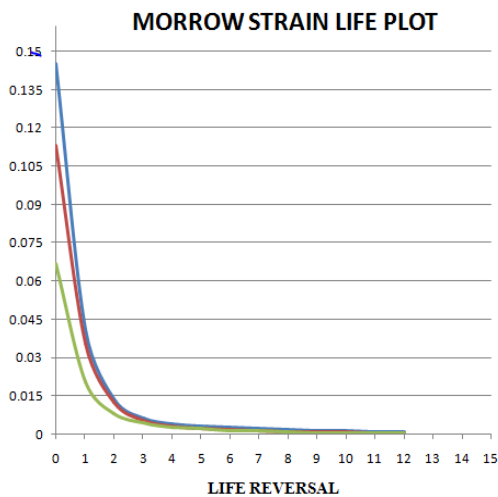

Figure 5. Strain-life (S-N) plot

Figure 6. Morrow Strain-life (S-N) plot
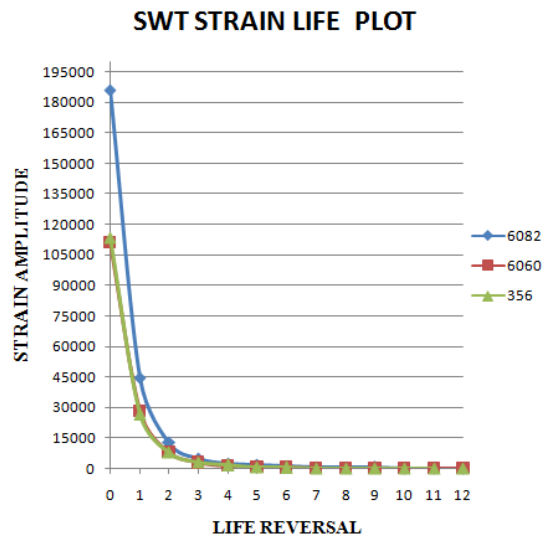
Figure 7. SWT Strain-life (S-N) plot

3. Loading information

Loading is another major input for the finite element based fatigue analysis. Unlike static stress, which is analyzed with calculations for a single stress state, fatigue damage occurs when stress at a point changes over time. There are essentially four classes of fatigue loading, with the ANSYS Fatigue Module currently supporting the first three. In this study we have taken first type of loading :
• Constant amplitude, proportional loading
• Constant amplitude, non-proportional loading
• Non-constant amplitude, proportional loading
• Non-constant amplitude, non-proportional loading

Constant Amplitude, fully reversed loading within the fatigue Module uses a "quick counting" technique to substantially reduce runtime and memory we can see in Figure 8. Loading is of constant amplitude because only one set of FE stress results along with a loading ratio is required to calculate the alternating and mean values is the classic, "back of the envelope" calculation describing whether the load has a constant maximum value or continually varies with time. The loading ratio is defined as the ratio of the second load to the first load (LR = L2/L1). Loading is proportional since only one set of FE results are needed (principal stress axes do not change over time) Since loading is proportional, looking at a single set of FE results can identify critical fatigue locations for this constant amplitude fully reversed loading determined the stress life analysis and strain life analysis by selecting the required analysis in fatigue tool for stress life analysis we can obtain the solution for goodman, gerber equation in stress life analysis and swt., morrow in strain life analysis[7].
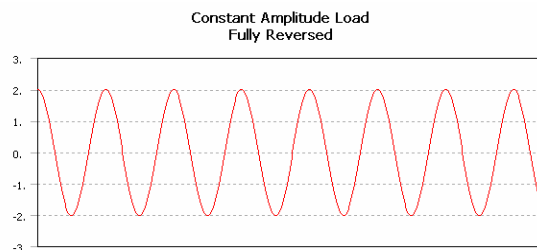

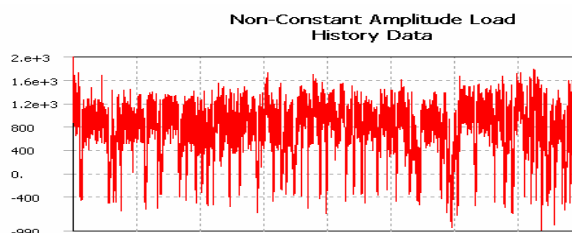**Figure 8.** Constant amplitude, proportional loading (Fully Reversed)

Figure 9. Nonconstant amplitude loading

4. Finite element analysis

Numerical techniques are necessary to stimulate the physical behavior and to evaluate the structural integrity of the different designs. The objective of the current study is to calculate the

fatigue life for a wheel rim of a heavy vehicle using total life and crack initiation methods, to investigate the effect of mean stress on fatigue life and the probabilistic nature of fatigue on the S-N curve via design criteria [7, 8].

5. Results and discussion

The linear static finite element analysis was performed . The equivalent vonmises stress contours and critical locations shown Figures10, 11 and 12. It was clearly observed that the front part (i.e wheel axle location) was found to be areas of high stresses. Figures 13-18 describes life and damage values of alloy wheel for different materials mentioned above . And Figure 18 shows the fatigue sensitivity of the loading histories Vs Available life. Based on the above figures the best material can be easily chosen. The Tables 3 and 4 show the result of Total life approach and crack initiation for different equation.
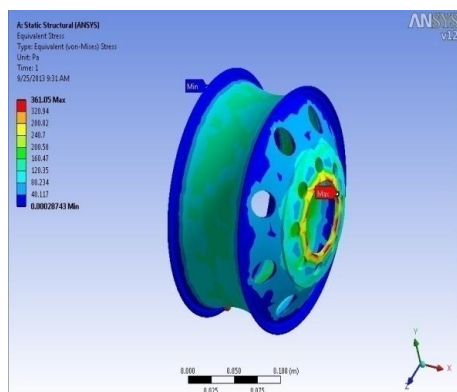
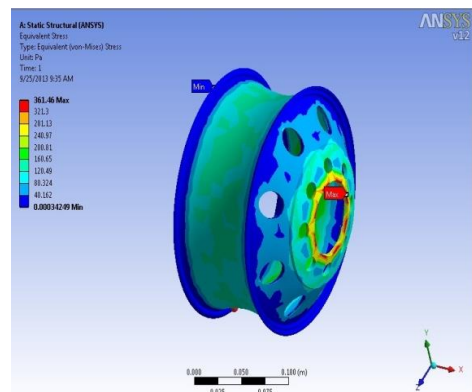
Figure 10. Vonmises Stress for Al 356T6
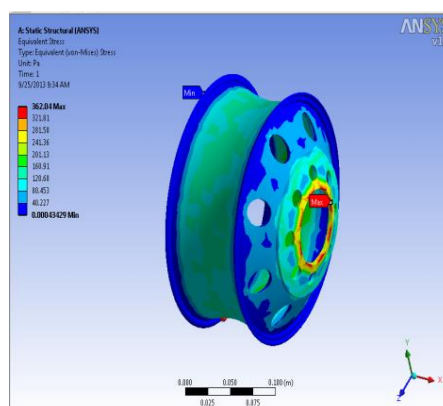

Figure 11. Vonmises Stress for Al6060
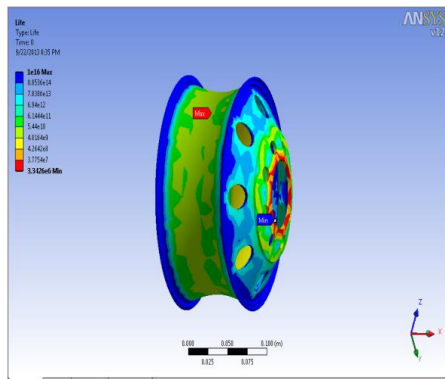

Figure 12. Vonmises Stress for Al6082

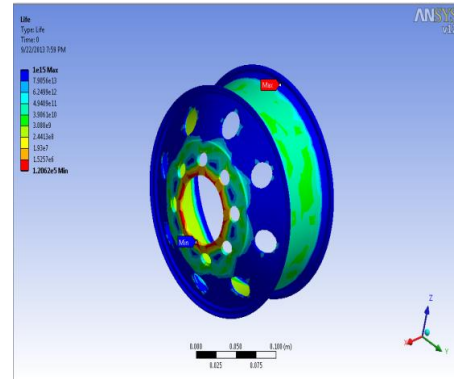**Figure 13.** Life of Al356T6

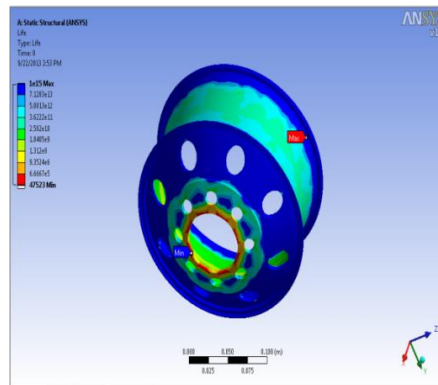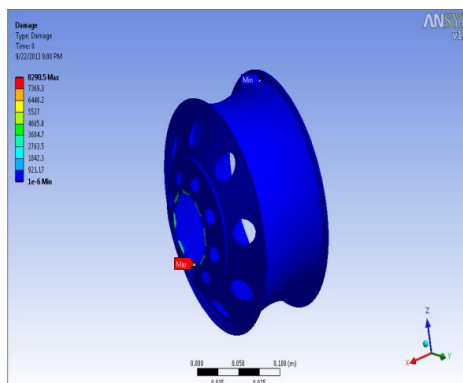**Figure 14.** Life of Al6060

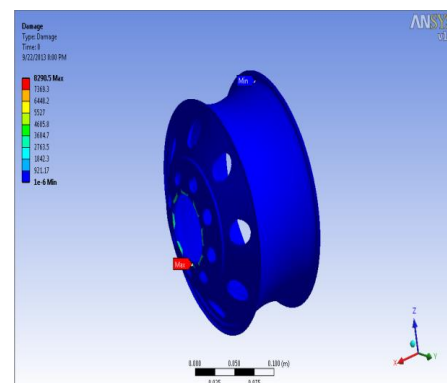**Figure 15** Life of Life of Al6082

Figure 16. Damage of Al356T6

Figure 17. Damage of Al6060

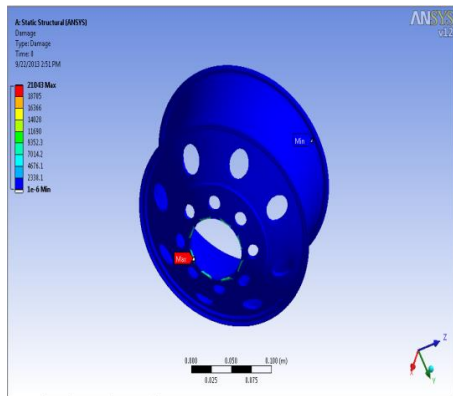J. P. Karthik, D. Manoj Kumar, and J. Ranga Raya Chowdary
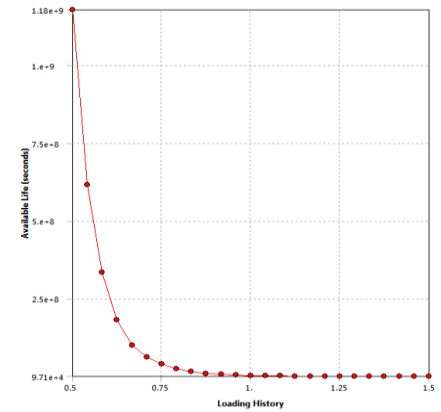

Figure 18. Damage of Al6060

Figure 19. Fatigue Sensitivity

Table 3. Predicted fatigue life using total-life approach

Materials / Loading History	Fully Reversed loading in MPa		
	No Mean	Goodman	Gerber
AL 356 T6	$9.16*10^5$	$3.92*10^5$	$9.5*10^5$
AL6060	$10.8*10^5$	$6.56*10^5$	$8.71*10^5$
AL6082	$12.54*10^5$	$12.02*10^5$	$12.52*10^5$

Table 4. Predicted fatigue using crack initiation approach

Materials / Loading History	**Fully Reversed loading in MPa**		
	No Mean	Morrow	SWT
AL 356 T6	$110.98*10^5$	$54.02*10^5$	$122.59*10^5$
AL6060	$149.8*10^5$	$50.02*10^5$	$123.59*10^5$
AL6082	$520.5*10^5$	$196.41*10^5$	$240.77*10^5$

6. Conclusions

The fatigue life was estimated based on palmgren-Miner rule which is non-conservative SWT correction and Morrows methods, and damage rule can be applied to improve the estimation. In fully reversed loading conditions good man approach for AL356T6 is more sensitive. All the three results are uniform for the material AL6082 in total life approach. While looking at the damage results damage value is more for all AL356T6 compared to other materials. While considering fatigue sensitivity life of the AL6082 is more compared to other alloys. In crack initiation approach results of the alloy AL6082 is more compared to other alloys. For the materials AL356T6, AL6060 in the crack initiation approach SWT results are approximately equal. Morrow equation result for the material AL6060 was $50.025*10^5$ MPa which is sensitive.

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