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RESEARCH ARTICLE

Validation of A356T6 automobile wheel fatigue strength using the finite elements method

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Abstract: In this study, A356-T6 wheel bending fatigue test limits were determined using the finite element methods and compared to experimental test results. Short and long bending fatigue tests (200.000 cycles and 1.800.000 cycles respectively) were done. Simulation models was created in Ansys by defining A356-T6 S-N curve. Simulation has been performed with test parameters. Fatigue cracks started around 210.000 and 2.000.000 cycles in accordance with simulation results. In experimental test, zinc-glycerin was applied front surfaces of wheels to obtain fatigue detects. Experimental tests were done in MAKRA BUP760 – 750 machines. The initiation cycles of fatigue cracks were recorded approximately 225.000 cycles and 2.000.000 cycles in experimental tests. According to the results, it has been revealed that the experimental, and analysis datas were parallel to each other.

Keywords: Bending fatigue, A356T6, Finite Element Methods, Crack, Simulation

1. Introduction

Wheels are very important equipment for vehicles in terms of safety, aesthetics and fuel consumption. A356-T6 material is one of the most preferred aluminum alloys in automotive wheel production due to its weight advantage and high strength properties.

Among the structural castings for automotive and aeronautical applications, A356 alloy is one of the most used cast alloys due to its good balance between casting properties and mechanical behaviour after the precipitation hardening, usually obtained by T6 heat treatment. Therefore, it represents a good candidate for fatigue critical structural applications, such as automotive wheels, engine blocks, cylinder heads, chassis, and suspension components. In particular, considering wheels, it must be pointed out that they represent an engineering component playing an important role for the safety and comfort of the vehicle.[1]

In literature, there were many studies about A356 alloys with different percentages of titanium , silisium and other alloys. However, it has been clearly seen that the fatigue strength of A356-T6 alloy were higher than other alloys.

It is known that the properties of the material change according to the variability of Casting, Heat Treatment, Machining, Painting parameters. It will be more accurate that the assumptions to be obtained as a result of using the mechanical properties of the parts obtained with the optimized parameters in the current conditions in the simulation program to minimize these differences. For this reason, the S-N curve was obtained by performing fatigue tests at different stresses, starting from yield strength at 10 Hz and 20 Hz frequency, with samples extracted in accordance with ASTM E466 standard on wheels cast with optimized parameters at Döktaş. Obtained S-N curve data was added to Ansys software and executed on the design and verified by rotating bending fatigue tests. In this way, it is ensured that the data of the material with the same casting errors and heat treatment conditions are used.

2. Material and Methods

Tests were carried out on A356-T6 alloy wheels produced with LPDC method by Döktaş Dökümcülük Trade. and San. Inc. Chemical analysis tests were carried out with ARL 8820 model Optical Emission Spectrometer for the wheels to be used in this study, the chemical composition is given in Table 1. For mechanical property controls, hardness measurements were carried out in Brinell 5mm/250kg method in accordance with ISO 6506[2] standard, tensile tests were carried out in Shimadzu AGS-X 100kN device in accordance with ISO 6892[3] standard. In addition, metallographic controls were carried out with Nikon Epiphot 200 model optical metal microscope.

Mechanical properties and SDAS measurement results

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are shared in Table 2.

Table 1. Chemical composition (wt.%) of the tested Sr-modified A356 alloy

Alloy	Si	Mg	Sr	Ti	Fe	Cu,Zn,Mn	Al
A356	6.944	0.25	0,025	0,11	0,079	<0,01	Bal.

Table 2. Tensile properties, SDAS, and hardness measurements of the tested alloy

Sample area of wheel	UTS, Mpa	YS, Mpa	Elongation, %	SDAS, μm	Brinell Hardness, HB
Rim	285±5	220±5	8±2	35±5	85±10
Spoke	240±5	200±5	3±1	45±5	75±10

2.1. Defining A356-T6 S-N Curve

Fatigue test specimens were extracted from A356-T6 alloy wheels casted in Döktaş. Fatigue samples were prepared in accordance with ASTM E466[4] standard as shown in Figure 1. The tests were carried out on a Shimadzu EHF-EV200k2-040-0A model fatigue test device, the image of which is shown in Figure 3.

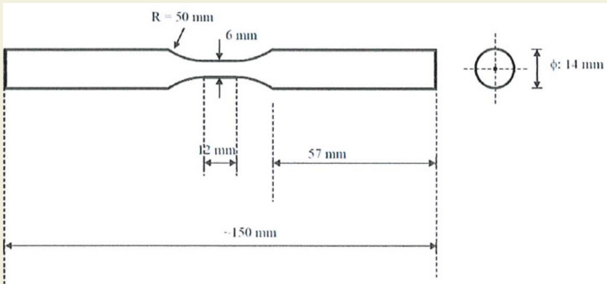

Figure 1. Dimensions of Döktaş Fatigue specimens acc.to ASTM E466

Figure 2. Fatigue specimen of Döktaş

As a result of the fatigue tests, the S-N curve in Figure 4 was obtained.

2.2. Rotating Bending Fatigue Test of Wheel;

Rotating bending fatigue test is done in MAKRA BUP machines. (Figure 5) In this dynamic test, wheel is fastened to adjustable test-bench within bolts from inner-rim flanges. Wheel is rigidly fixed from hub to test-bench using screws or fixing nuts according to standart manufacturer torque values. Rotating bending moment is applied to the wheel by creating eccentric mass which is at certain distance from wheel offset.

Figure 3. Testing configuration and fatigue specimen in testing

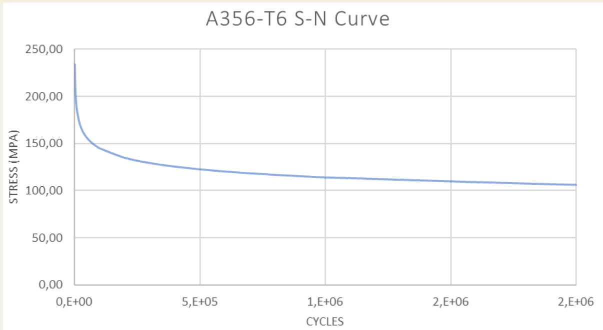

Figure 4. S-N curve of A356-T6 wheels

Figure 5. a)Scheme of the rotating bending fatigue test[5], b) testing machine

Formula for the bending moment calculation; Abbreviations appear in Figure 6.

$M_{bmax} = S^*[F_r(\mu^* r_{dyn} + d)]$

M_{bmax} = Maximum reference bending moment [Nm]

F_r = Maximum load capacity of wheel [N]

r_{dyn} = Dynamic radius of largest tyre recommended for wheel [m]

d = Inset [m]

μ = Coefficient of friction

S = Factor of safety

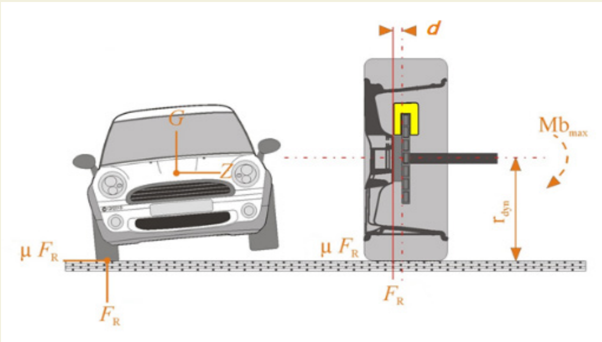

Figure 6. Bending fatigue representational image

The test is carried out with two percentage values (50 percent and 75 percent) of the max moment and on the basis of the following standards.[6] Tests performed with 75% load are considered as short tests and tests with 50% load are considered as long tests.

Short Test Cycle : 200.000

Moment of short test $0.75xM_{bmax}$

Long Test Cycle: 1.800.000

Moment of long test $0.5xM_{bmax}$

3. Simulation Design

The bending fatigue test consists of test bench and wheel. Wheel is fastened to the bench from inner-flange corners. S-N curve and mechanical properties of A356-T6 material were defined the ANSYS Workbench. 3D wheel model has created CATIA and transferred to simulation environment. Model mesh size were 5*mm*.Wheel dimension was 7Jx17H2 and offset was 50*mm*. Maximum wheel load was 700*kg*. Short bending test moment was 3716 *N.m*, long bending test moment was 2508 *N.m*. Maximum equivalent stresses found that 134.47 and 106.64 *MPa* respectively. Fully reversed model was used for fatigue life. According to fatigue life, the short and long tests were positive which means there was no any fatigue detected in test cycles. First cracks started around bolt-holes 215.000 cycles propagated to spoke regions 2.000.000 cycles in short test. In long test results, crack initiation was determined around 2.000.000 cycles and didn't propagate to spoke or other regions.

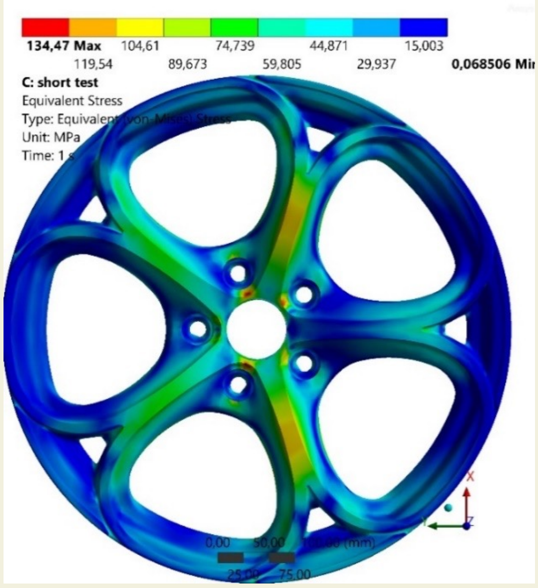

Figure 7. Maximum equivalent stress,short test

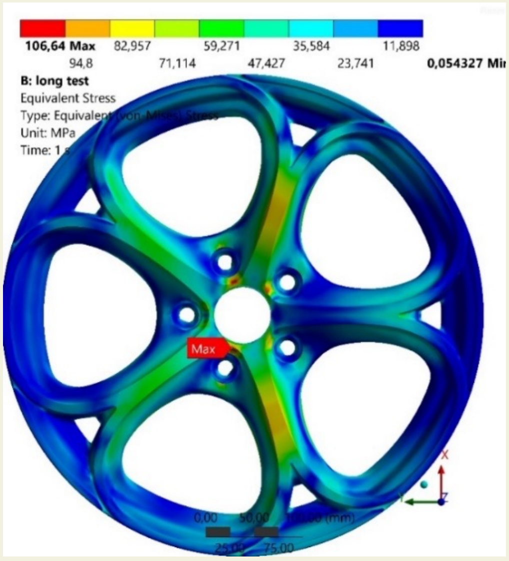

Figure 8. Maximum equivalent stress, long test

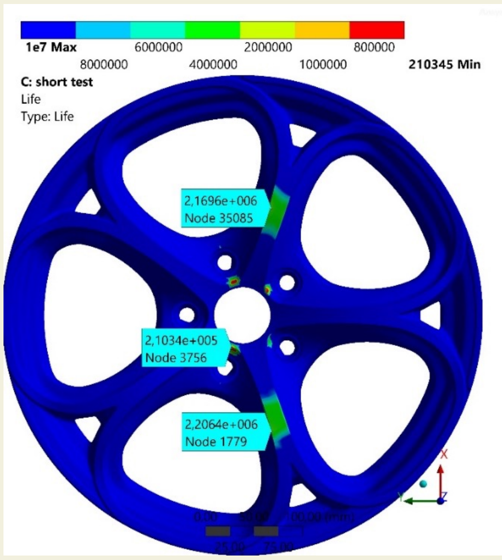

Figure 9. Fatigue life in short test

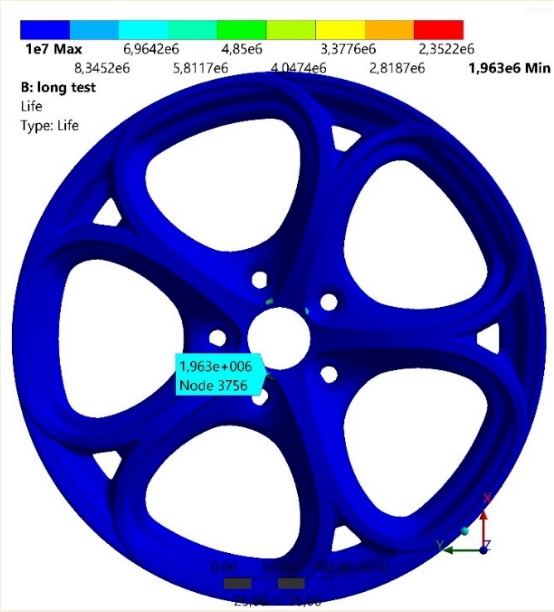

Figure 10. Fatigue life in long test

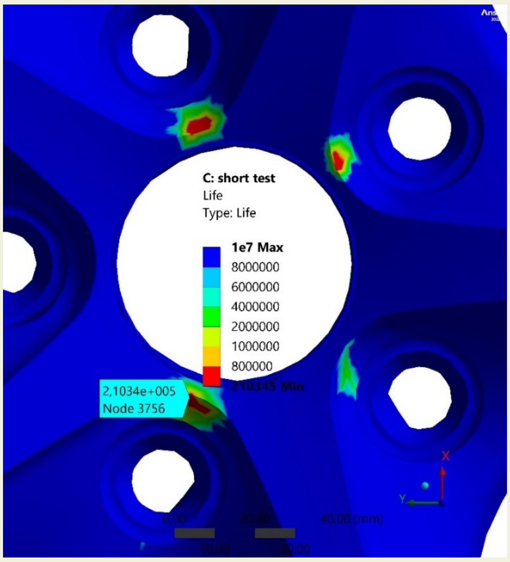

Figure 11. Fatigue life detail in short test

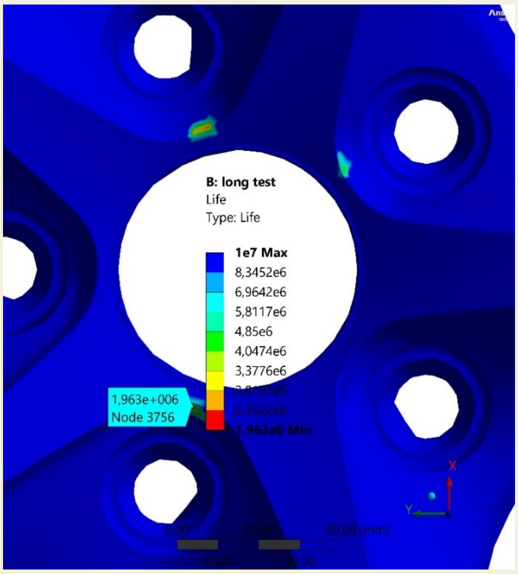

Figure 12. Fatigue life detail in long test

4. Experimental Test

A356-T6 wheel bending fatigue tests were done in MAKRA BUP 760 and BUP 750 machines in Döktaş Test Center. Zinc-gliserin was sprayed all front surfaces. Test moments and cycles were entered the test machines. In short bending fatigue test, any fatigue cracks weren't seen. Approximately 225.000 cycles cracks started around bolt-holes. After 2.100.000 cycles, cracks propagated to spoke sections. Failure occurred nearly 2.500.000 cycles. In long bending fatigue test, any crack occurred to 1.800.000 cycles. After 2.000.000 cycles, first cracks were seen around bolt-holes then spread out other bolt-holes nearly 4.000.000 and 6.000.000 cycles. Long test was performed to 10.000.000 cycles. There was no failed as occurred in short test.

Figure 13. 200.000 cycles in short test

Figure 14. 225.000 cycles in short test

Figure 15. 2.100.000 cycles in short test

Figure 16. 2.500.000 cycles in short test [fail]

Figure 17. 1.800.000 cycles in long test

Figure 18. 2.00.000 cycles in long test

Figure 19. 4.000.000 cycles in long test

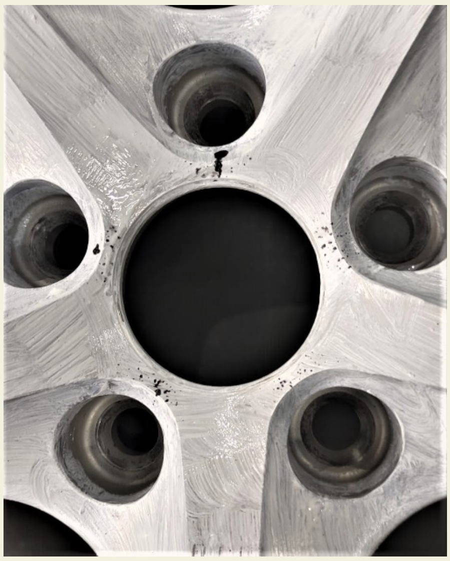

Figure 20. 6.000.000 cycles in long test

Figure 21 10.000.000 cycles in long test

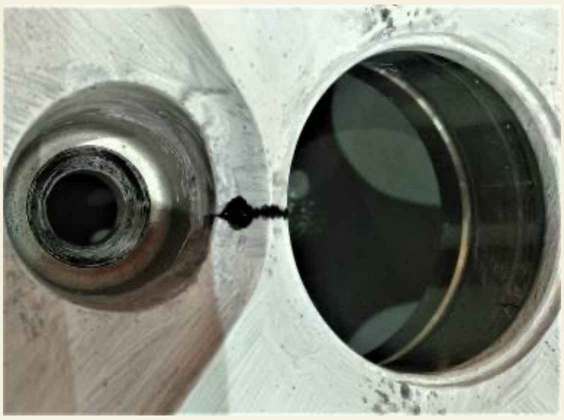

Figure 22 10.000.000 cycles in long test

5. Conclusion

A356-T6 wheel rotating bending fatigue tests were performed in simulation environment and experimentally. S-N curve of A356-T6 was defined in accordance with standard tests. Short and long rotating bending fatigue tests were considered. Simulation and experimental crack initiation cycles were calculated and recorded. The critical crack test cycles were found that 210.000 and 225.000 cycles for short test. The crack initiation of test wheels were observed around 2.000.000 cycles in simulation and experimental tests. Therefore, fatigue strength of A356-T6 automobile wheel has been validated using the finite elements method.

6. References

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