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Fatigue Analysis of Alloy Wheel for Passenger Car under Radial Load

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Abstract:-The alloy wheels of passenger cars are intended for better heat conduction and improved aesthetics appearance over steel wheels. The alloy wheels are lighter than steel wheels. In order to achieve better quality, the study of alloy wheel is necessary. The manufacturers carry out a number of wheel tests to ensure that the wheel meets the safety requirements and higher comfort level. Thus, simulations of alloy wheel were carried out for specific design through realistic loading conditions. Skoda Octiva passenger car alloy wheel was used for simulation. In this study, stress distribution of alloy wheel is evaluated by using finite element analysis. S-N curve was generated for aluminum alloy material. The radial fatigue test is carried on specimen according to industrial standards. The wheel was checked for fatigue life cycle and improvement in the material. An attempt has been made by conducting study to suggest a suitable safety for reliable fatigue life prediction.

Keywords: 1 finite element analysis technique 2. Radial fatigue test 3. Life cycle

1. INTRODUCTION

Alloy wheels were first developed in the last sixties to meet the demand of racetrack enthusiasts who were constantly looking for an edge in performance and styling. It was an unorganized industry then. Since its adoption by OEM's, the alloy wheel market has been steadily growing. Today, thanks to a more sophisticated and environmentally conscious consumer, the use of alloy wheels has become increasingly relevant. With this Increased demand came new developments in design, technology and manufacturing processes to produce a superior with a wide variety of designs. In the fatigue life evaluation of aluminium wheel design, the commonly accepted procedure for passenger car wheel manufacturing is to pass two durability tests, namely the radial fatigue test and cornering fatigue test. Since alloy wheels are designed for variation in style and have more complex shapes than regular steel wheels, it is difficult to assess fatigue life by using analytical methods. For this simulations of alloy wheel for specific design and improvement is carried out through realistic loading conditions.

i. Types of wheel (material)

Steel and light alloy are the foremost materials used in a wheel rim however some composite materials together with glass-fibre are being used for special wheels.

A. Wire spoke Wheel

Wire spoke wheel is an essential where the exterior edge part of the wheel rim and the axle mounting part are linked by numerous wires called spokes. Today's automobiles with their high horse power have made this type of wheel manufacture obsolete. This type of wheel is still used on classic vehicles.

B. Steel Disc Wheel

This is a rim which practices the steel made rim and the wheel into one by joining (welding), and it is used mainly for passenger vehicles especially original equipment tires.

C. Light Alloy wheel

These wheels are based on the use of light metals, such as aluminum and magnesium has come to be popular in the market. This wheel rapidly become standard for original equipment vehicle in Europe in 1960's and for the replacement tire in United States in 1970's. The advantages of each light alloy wheel are explained as below.

ii Aluminium Alloy Wheel

Aluminium is a metal with features of excellent lightness, thermal conductivity, physical characteristics of casting, low heat, machine processing and reutilizing, etc. This metal main advantage is decreased weight, high precision and design choices of the wheel.

iii) Magnesium alloy Wheel

Magnesium is about 30% lighter than aluminium and also admirable as for size stability and impact resistance. However its use is mainly restricted to racing, which needs the features of weightlessness and high strength. It is expansive when compared with aluminium

iv) Titanium alloy wheels
Titanium is an admirable metal for corrosion resistance and strength about 2.5 times compared with aluminium, but it is inferior due to machine processing, designing and more cost. It is still in developed stage.

v) Composite material wheel
The composite material wheel is different from the light alloy wheel, and it is developed mainly for low weight. However this wheel has inadequate consistency against heat and for best strength.

2. DESIGN AND FATIGUE ANALYSIS OF ALLOY WHEELS

After analysing the working condition of wheel, there are two major loads i.e. direct load (Radial load due to weight of vehicle) and tangential load (due acceleration torque or braking torque)

Table No 1: Material Properties

	Aluminium A356.2	**Aluminium 7075-T6**
Ultimate Tensile Strength (S_{ut})	250 MPa	570 MPa
Tensile Yield Strength (S_{yt})	230 MPa	503 MPa
Modulus of Elasticity orYoung's Modulus (E)	72.4 GPa	71.7 GPa
Poisson's Ratio	0.33	0.33
Density (ρ)	2810 Kg/ m^3	2700Kg/m^3

The wheels for passenger cars need satisfy two testing industrial standards. They are as follows
1. Bending Endurance Test
2. Radial Endurance Test

2.1 Bending Test

The bending moment to be imparted in test shall be in accordance to following formula
$M = ((\mu * R) + d) * F * S(1)$
According to the Japanese Industrial Standards (JID D 4103)
μ = 0.7
d = 37 mm = 0.037m F= 4414.5 N

Bending Moment M = ((μ * R) +d) * F*S
= ((0.7*0.1904) + 0.037) * 4414.5*1.5
M = 1589 N-m

Table No 2. Loading Coefficient specified according to the Standards.

Division of wheel	Light alloy wheel	
	Coefficient S	Specified number of revolutions
Wheels under 100 mm in offset	1.8	10^3
	1.5	10^5
	1.35	25 x 10^3
	1.33	10^3
	1.26	10^3
	1.1	10^3

2.3 Radial Endurance Test

The radial load to be imparted in test shall be in accordance with following formula:
Fr = F *k

Angular Velocity

Angular Velocity is calculated by using the formula. From relation

$V = r * \omega$

Maximum Speed of the car is 80 km/hr = 22.22m/s

$V = r * \omega$

$22.22 = 0.1904 * \omega$

$\omega = 116.70$rad/sec

2.1To find out Tensile Stress developed in rim

The Alloy wheel has Five Spokes,

$2\alpha = \frac{2\pi}{5}$

$\alpha = 0.628$ rad

$= 35.98^{\circ}$

1. Mass of rim per mm of circumference (m)

Radius = 175 mm

Mass of rim per mm of circumference (m) = Wt / Circumference

(m) $= \frac{2800*166*36}{1000*1000} = 0.016$Kg/m

2. Evaluation of Tensile Stress

By using S Timoshenko's equations, We get

$f_1(\alpha) = 0.7992$

$f_2(\alpha) = 0.00302$

$\sigma = 1.371\ N/mm^2$

Table no.3 Alternating Stresses at Various Cycles for aluminium alloy A356.2

Cycles	Alternating Stresses (MPa)
10	468.01
20	419.16
50	362.32
100	324.50
200	290.63
2000	201.51
10000	156.00
20000	139.72
100000	108.16
200000	96.87
1000000	75

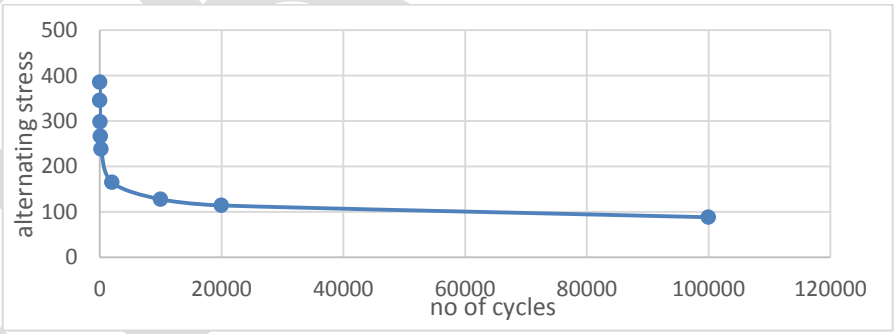


Figure 1 shows the graph of alternating stresses at various cycles for aluminium alloy A356.2. It is obtained from Equation (5).

Table no.4 Alternating Stresses at Various Cycles for Aluminium 7075-T6

Cycles	Alternating Stresses (MPa)
10	1067.08
20	955.70
50	826.00
100	739.87
200	662.64
2000	459.45

Cycles	Alternating Stresses (MPa)
10000	355.69
20000	318.56
100000	246.62
200000	220.88
1000000	171.00

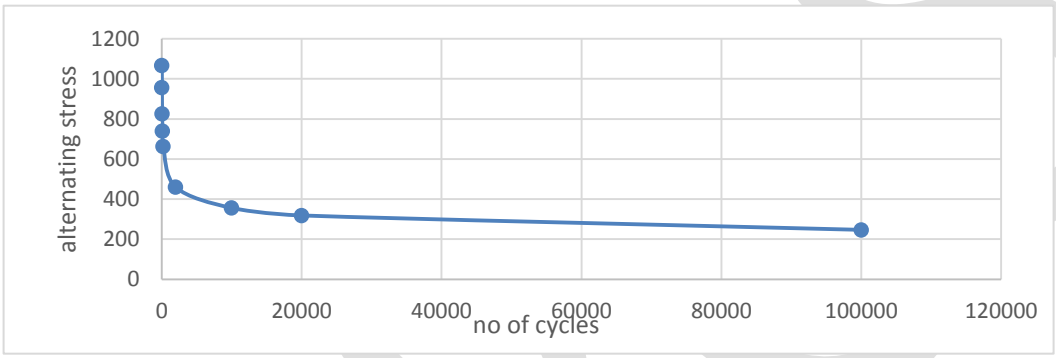


Figure 2 shows the graph of alternating stresses at various cycles Aluminium 7075-T6. It is obtained from equation (5)

3.1 MODELLING

Dimension of alloy wheel is take trough reverse engineering and by using the CMM technique. The CMM scanning was done by use Faro Scanning machine for complex part. The digital variner caliper is used measure the hole diameter and other dimension. Through CMM partially dimension recovered. The CMM scanning machine can generate rough geometry in unigraphics software and using this dimension model is built in Solidworks Software.

Figure 3 Cad model of alloy wheel

3.2 Meshing of alloy wheel

ANSYS is high performance finite element pre and processor for major finite element solvers. Which allows engineers to analyze design conditions in highly interactive and visual environment? ANSYS support the direct use of Cad geometry and existing finite element models, providing robust inter-operability and efficiency. Three-dimensional meshes created for finite element analysis consist of tetrahedral, pyramids, prisms or hexahedra. Advanced automation tools within ansys allow user to optimize meshes from a set of quality criteria change existing meshes through fine meshing. The total numbers of element formed are 62768 and total numbers of nodes formed are 112044. Table 5.2: Mesh information of Alloy wheel

Figure 4 Meshed model of alloy wheel

3.3 Applying of Boundary Conditions

Boundary Conditions:

1. Input Force: Radial force 9.93KN is applied on wheel
2. Pressure of 0.303MPa is applied to rim surface.
3. Rotational velocity of 116.7 rad/s is given.

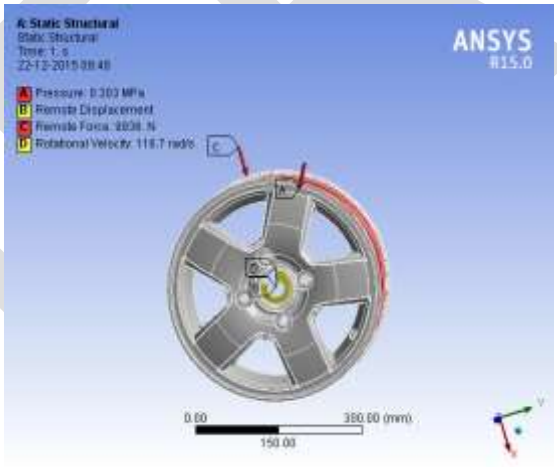
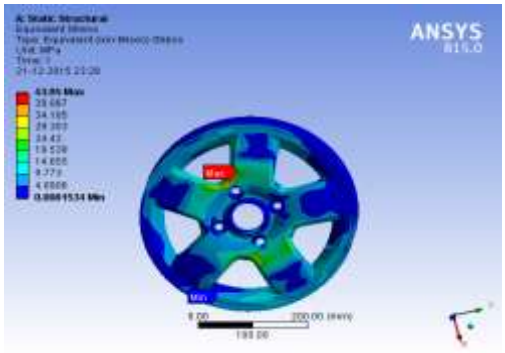
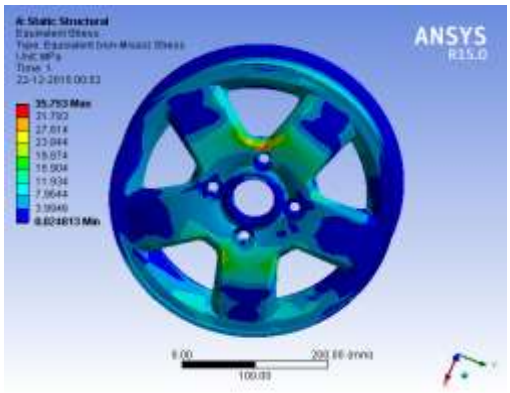
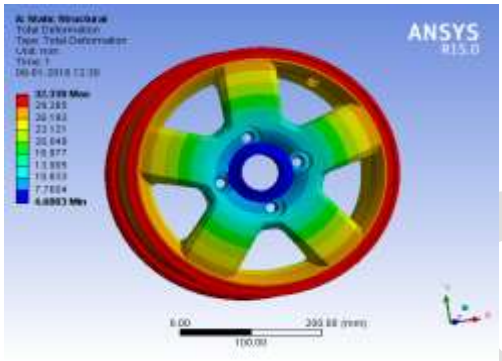
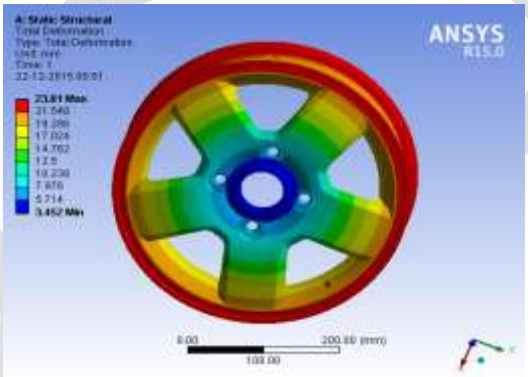
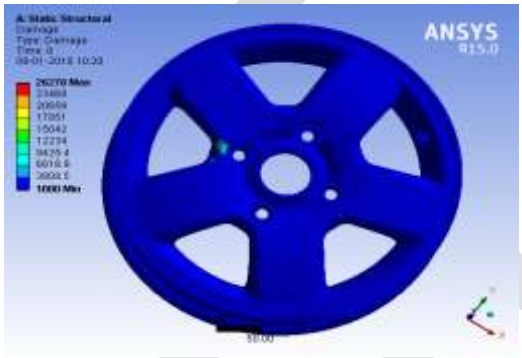
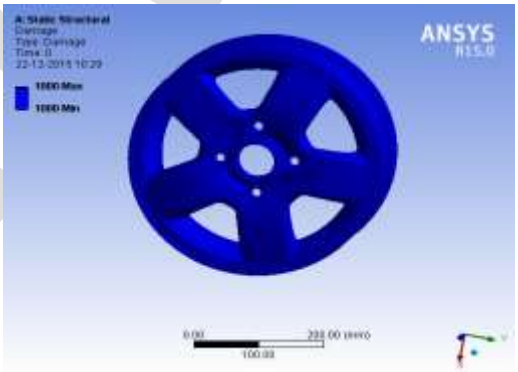
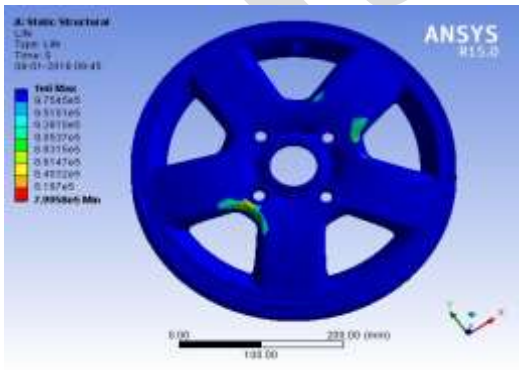
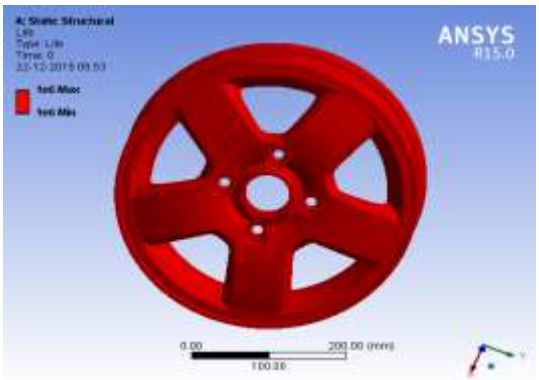
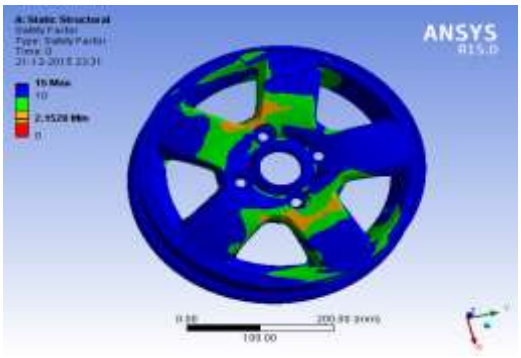
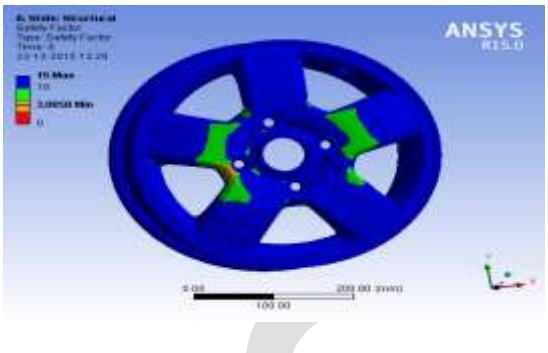
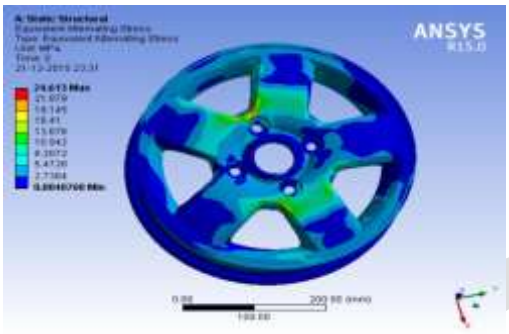
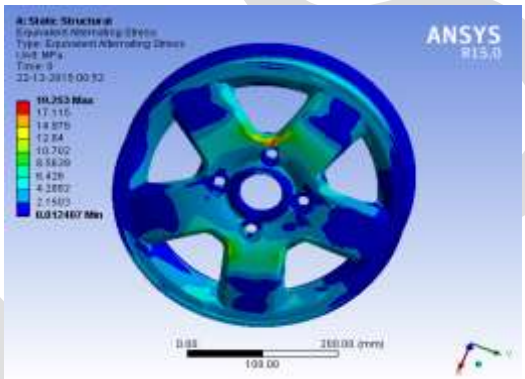


Figure 5 Constraining & Appling Boundary condition

Table 5 Comparison of Simulation Results for A356.2 & 7075-T6 alloy Wheel

Aluminium A356.2 Alloy Wheel	Aluminium 7075-T6 Alloy Wheel

1. Equivalent stress	**1. Equivalent stress**
	
2. Deformation	**2.Deformation**
	
3. Damage Analysis	**3. Damage Analysis**
	
4. Fatigue Life Cycle	**4. Fatigue Life Cycle**
	

5.Factor of Safety	**5.Factor of Safety**
	
6.Alternating Stress	**6.Alternating Stress**
	

4. FATIGUE ANALYSIS OF ALLOY WHEEL BY EXPERIMENTAL METHOD

A typical test setup according to standard of the radial fatigue test is shown in the figure equipped with a driven Rotatable drum. The drum axis is parallel to the axis of the test wheel which presents smooth surface wider than the section width of the loaded test tyre section width. The test wheel and tyre provide loading normal to the surface of drum and in line radially with the centre of test wheel and the drum. The test wheel is fixed to the hub by nuts with a suitable torque specified by vehicle or wheel manufacturer. The total weight of a car is balanced with a vertical reaction force from the road through the tyre. This load constantly compresses the wheel radially while the car is running, the radial load becomes a cyclic load with the rotation of the wheel. Hence, the evaluation of wheel fatigue strength under radial load is an important performance characteristic for structural integrity.

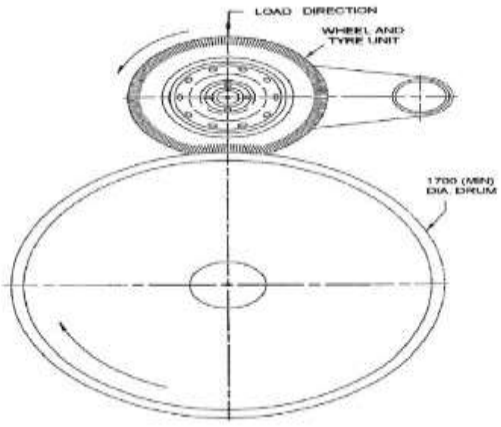


Fig 6 Layout of test setup radial fatigue test

Test Condition : The test condition shall be as follows:

Radial load The radial load shall be in accordance with the formula :

Fr = F. K

Where, Fr : radial load (kN)

F the maximum value (generally in accordance with JIS D 4202) of maximum loads(10^5)of the tires applied to wheel.

Table No 6 Accelerated test factor for specified no of revolutions

Division of wheel	Light alloy wheel	
	Coefficient K	Specified number of revolutions 10^4
Wheels 17.5 or under in nominal rim diameter	2.25	50(10^4)
	2.2	10^3
	2.0	10^3
	1.8	10^3
	1.4	10^3

Test termination: -The test shall be terminated in either of the two following circumstances:

a) Inability of wheel to sustain load

b) Propagation of a cracks existing prior to test or new visible stress-caused cracks penetrating through a section of wheel

4.1 Radial fatigue Testing Machine.

The durability of the wheel is important for the safe operation of vehicle .Therefore, it is necessary to examine a wheel for both strength and fatigue life cycles. Fatigue test is carried for radial load. Figure 9 shows radial fatigue testing machine. The alloy wheel mounted on assembly, bolt are fixed. Then machine is started, initial radial load of 3.998KN is given. The Driver drum speed is setup for 80Kmph which makes alloy wheel to rotate. After minimum five lakh cycles the machine is stopped and checked for cracks and again its started.

According to JIS D4103 for Radial Fatigue Test

Radial Fatigue Test / No. of Cycles= 9932N/ 850000 cycles.

Wheel size = 14 inches

Flange shape = J

Rim width = 7 inches

Offset = 37mm

Weight= 9.8-10 kg

Figure 7 Radial Fatigue Testing Machine Setup

Table 7 .Experimental Fatigue test Results

Test RFT	
Test Load/ Weight(N)	9930.4
Nut torque (initial)	110 N-m
Test Cycles	8.5x 10^5
D.P.T. result	Crack initiation from 8.15 lakh Cycles

5. RESULT AND DISCUSSION

Table 8 Results for Radial Fatigue Test

Parameters	**Aluminum A356.2**	**Aluminum7075-T6**
Von Mises Stresses	43.95 MPa	35.75MPa
Displacement	32.33mm	23.81mm
Factor of Safety	2.1528	3.085
Life of alloy wheel	7.995 x 10^5	1x 10^6

The Radial fatigue life cycle of alloy wheel was found out. A comparison is made for both Aluminium A356.2 and Aluminium 7075-T6 material used for alloy wheel. The existing components which are made of steel are slowly phased out by replacing with Aluminium alloys having comparable better properties. The maximum Equivalent stress (Von Mises stress) developed in Aluminium A356.2 alloy wheel is 43.95MPa and minimum stress was 0.008Mpa.For Aluminium 7075-T6Equivalent stress (Von Mises stress) developed are 35.75 MPa and minimum stress was 0.024MPa.The alloy wheel also needs to satisfy Automotive Industry Standard,According to AIS 073 (P1 &P2) maximum radial load given is 75kN and wheel size 12-24inch.The wheel passes minimum no of life cycle under radial load according to AIS 073 (P1 & P2) & IS9436.

Table No 9 Comparative Results A356.2 Alloy Wheel

Material A 356.2	**Fatigue Life Cycle**
Simulation results	Radial fatigue life 7.995 x 10^5cycles
Experimental results	Experimental found 8.15 x 10^5 cycles

6 CONCLUSION

1. The Stress developed in alloy wheel for aluminium 7075-T6 less as compared to aluminium A356.2 alloy wheel. The maximum stress induced in the alloy wheel for aluminium A356.2 was 43.95 MPa and for aluminium 7075–T6 alloy wheel is 35.5 MPa.
2. The safety factor was higher in case of aluminium 7075-T6 as compared to Aluminium A356.2 alloy wheel.
3. The fatigue life alloy wheel of Aluminium A356.2 is 7.9985 x 10^5 cycles and that of Aluminium 7075-T6. alloy wheel is 1 x 10^6 cycles.
4. Aluminium 7075- T6 grade are best suitable for alloy wheel

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