IOP Conference Series: Materials Science and Engineering

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To cite this article: Shwetabh Suman *et al* 2017 *IOP Conf. Ser.: Mater. Sci. Eng.* **263** 062074

IOP Conf. Series: Materials Science and Engineering **263** (2017) 062074 doi:10.1088/1757-899X/263/6/062074

Impact and modal analysis for different alloy wheel compositions

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Abstract: Wheels are an important component in the vehicle. The strength of the Alloy wheel rim is an important property of the Alloy wheel, which plays an important part in determining the overall performance of the vehicle, the structural integrity of the rim and the life of the Alloy wheel rim. With the advent of new Alloy wheel materials, new options are available to replace the conventional Aluminium Alloy wheels with new ones. The new Alloy wheel rim material and design need to be tested virtually for optimizing the appropriate design and material and the optimised wheel in virtual mode can be tested experimentally for the performance in real-time conditions before they can be used in the vehicles. The work in this project includes doing the impact and modal analysis for different alloy wheel compositions. From the results obtained, the optimum alloy wheel is suggested, which can be considered with further experimental validation.

1. Introduction

Wheels are critical and one of the most important part of an automobiles. It decides many parameters like, safety, stability, performance and fuel economy. The safety of passengers is of great concern, the manufacturers give very much importance for passenger's safety. Stability depends on how tires behave while turning, cornering and tire pressure. Performance of vehicle measures by many parameters and tire grip is one of them. Resistance offered by wheels are due to friction, drag produced due to tread design and gaps between the wheels. Drags produced by the wheels contribute to 5% of the total drag in case of trucks. As speed increases the tire rolling resistances increases at a faster rate. Coefficient of rolling resistance (f_R) can be determined experimentally. f_R is determined by rolling tires either on the inner or outer periphery, on a drum. f_R differs considerably from on-road tests.

We know that the mechanical properties of cast aluminium alloys are strongly influenced by the metallurgical and microstructural features. The main parameters, which help to understand their mechanical behaviour are (1) shape & the size of grains, (2) dendritic arm spacing (DAS), (3) the microstructural characteristics of the phases and the presence, (4) the amount, the size and the shape of porosity and (5) the defects [1,2]. Silicon, manganese and a small percentage of chromium improve fatigue strength [3]. Increased titanium concentration imparts good mechanical properties to the alloy. Increased concentration of magnesium in aluminium alloy increases the fatigue strength [4].

In dynamic simulation, the prediction of a wheel failure is based on the condition that fracture will occur if the maximum strain energy density exceeds the total plastic work and based on the fracture strain criterion. [5]. The validated numerical model has been employed for estimating the fatigue life of the wheel. Multiaxial fatigue criteria have been adopted, namely the sines criterion and matake criterion. According to Deepak et al. [6], when aluminium combines with water vapour in the atmosphere it releases hydrogen gas.

$$2Al+3H_2O \rightarrow 6H^+ + Al_2O_3$$

Liquid aluminium dissolves hydrogen in it, as aluminium alloy solidify concentration of liquid hydrogen reduces. As solidification progress release of hydrogen takes place and as a result porosity defects result in aluminium alloy. This reduces the strength of the alloy wheels. This can be controlled by de-gassing process. Argon gas is allowed to pass through the molten metal. Also, the mechanical properties are affected by microstructure. Presence of excessive dendritic structure reduces the mechanical properties such as hardness, impact strength and tensile strength. [7]

Impact location on the wheels greatly influenced the plastic strain distribution as observed by Robert Shang et al. 20 % reduction in the striker Kinetic energy help in simplify the modelling. [8]
C. Bosi et al., [9] casted Al-10Si-0.6Cu aluminium alloy and then observed the rotating bending fatigue behaviour and microstructural analyses for the rims of the car wheel. The wheel design influences the microstructure of the alloy, the cooling rate during solidification and the consequence have important effect on the wheel fatigue performances. Also, F. Ballo et al. [10] used the rotary bending fatigue test of the wheel in finite element method. Strains measured at different location of the wheel experimentally has been used to validate the FE model. Also, the analysis is performed considering the deformation values at the most stressed areas. Both of the methods identify the same region as the most critical for the damage nucleation. [12]

2. Material and Methods

Based upon the literature survey, the following alloys were taken for analysis work:

- Conventionally used Al-12%Si alloy
- Aluminium alloy 5052 (Mg 2.5, Cr- 0.25 Al- 97.25)
- Aluminium 6061 (Si-0.6, Cu-0.25, Mg-1.0, Cr-0.25, Al- 97.9)
- Ti-5 Al-2.5 Sn Alloy
- Ti-13 V-11 Cr-3 Al Alloy
- Mg-AZ31B Alloy (Al-3, Zn-1, Mn-0.2, Mg-95.8)

Table 1. Alloy composition

Alloy	**Si(%)**	**Mg(%)**	**Fe(%)**	**Cu(%)**	**MN(%)**	**Ti(%)**	**Others**
Al-10% Si	**10-11.5**	**0.1-0.2**	**0.2**	**0.2**	**0.1**	**0.2**	**0.05**
Al-12% Si	**11.5-13**	**0-0.2**	**0.2**	**0.2**	**0.1**	**0.2**	**0.05**

The model of the 20 inches alloy wheel as shown in Figure 1 was created in CATIA. This model was then imported to ANSYS. In ANSYS, the properties for different alloy wheel materials were input, which were to be taken into consideration for analysis. For Impact analysis, the case of a road bump occurrence during driving was considered. When the tyre hit the bump, the force that the bump exerts on the wheel is assumed to be acting normal to the wheel rim surface. Other parameters considered for the Impact analysis are as stated below:

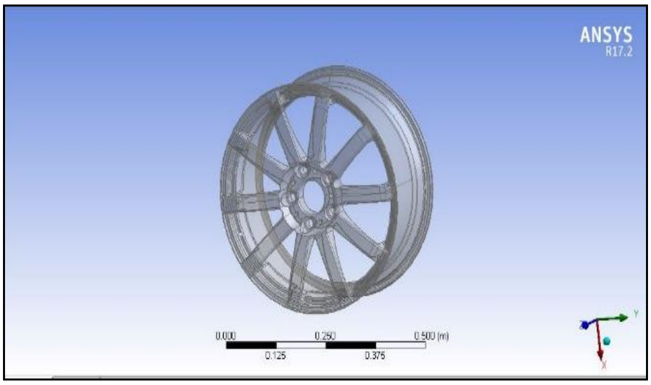

Figure 1. Model of Alloy wheel

Table 2. Alloy properties

Alloys	Density (Kg/mm^3)	Young's Modulus (MPa)	Compressive Yield Strength (MPa)	Compressive Ultimate Strength (MPa)
Al-12% Si	2.6573e-006	71016	144.79	296.47
Al-5052	2.685e-006	70327	89.632	193.05
Al-6061	2.7126e-006	68948	55.158	124.11
Mg-AZ31B	1.7715e-006	44816	151.68	255.11
Ti-5	4.4841e-006	1.1032e+005	861.84	930.79
Ti-13	4.844e-006	1.0342e+005	1172.1	1241.1

1. Time of bump contact = 0.1s
2. Speed of vehicle = 120km/h = 33.32m/s
3. Wheel velocity normal to bump = 60km/h
4. Wheel final velocity normal to bump = 0
5. Bolt hole normal force = 2224N
6. Wheel is fixed to the hub

3. Results of Impact Analysis

The deformation in the wheel due to the impact force and the equivalent Von-mises stress generated were determined in ANSYS and presented in Figure 2-7 and the values are given in Table. 3.

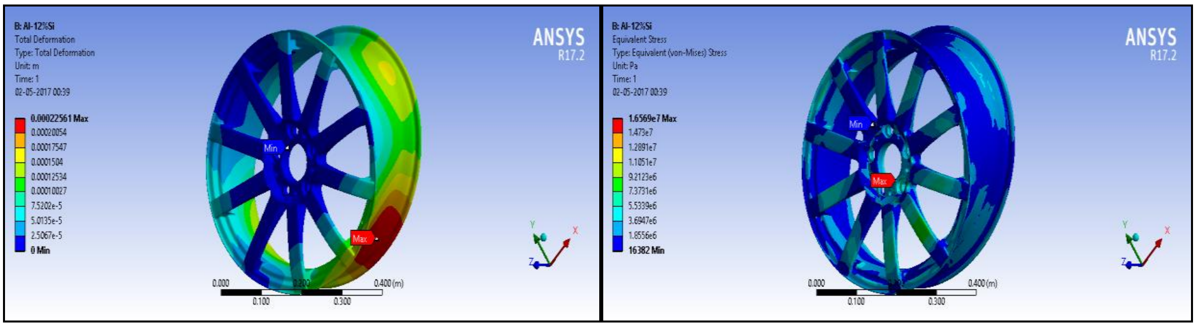

Figure 2. Deformation and equivalent stress in Al-12%Si alloy

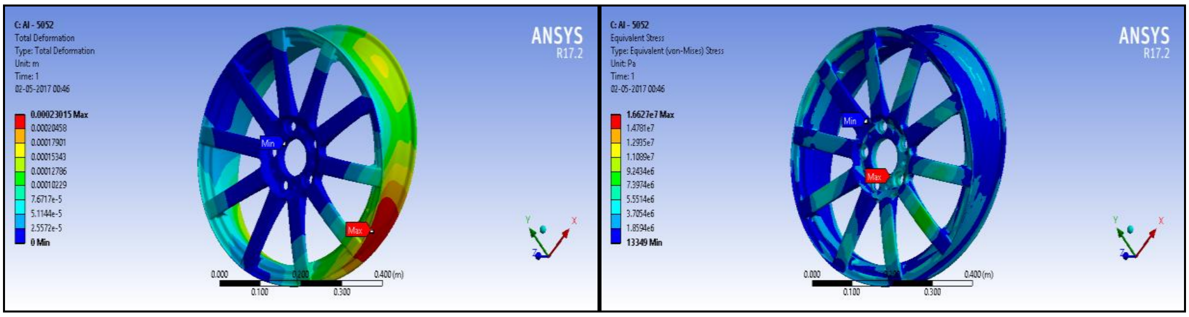

Figure 3. Deformation and equivalent stress in Al-5052 alloy

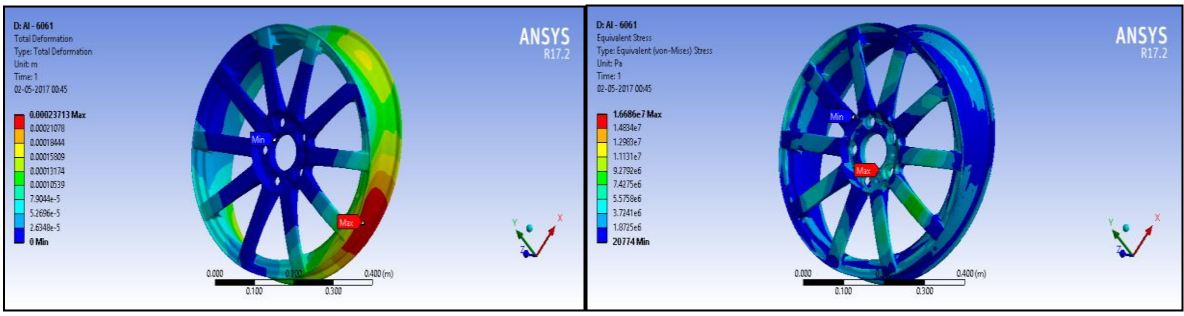

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Figure 4. Deformation and equivalent stress in Al-6061 alloy

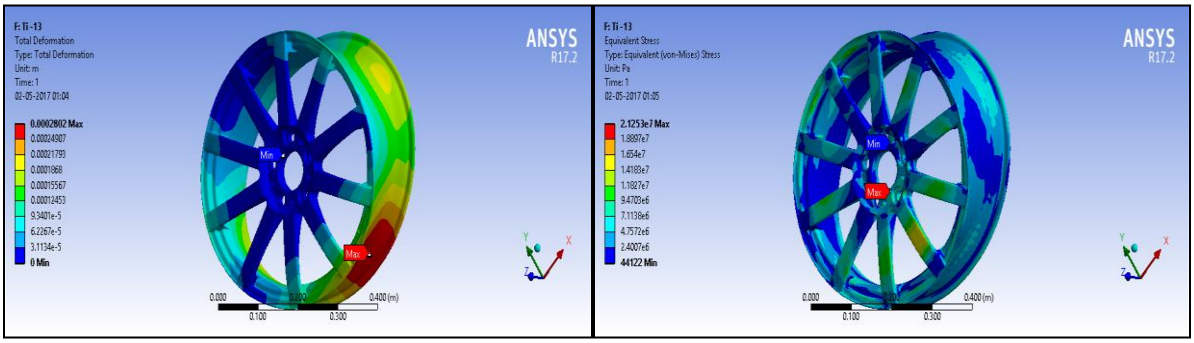

Figure 5. Deformation and equivalent stress in Ti-13 alloy

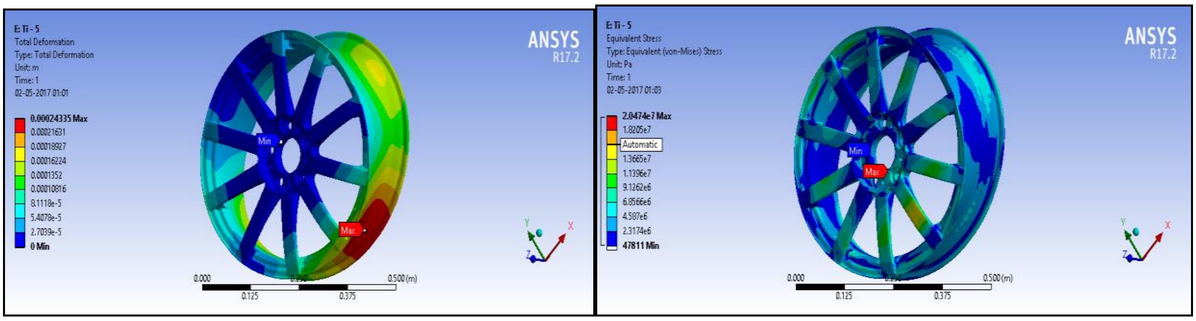

Figure 6. Deformation and equivalent stress in Ti-5 alloy

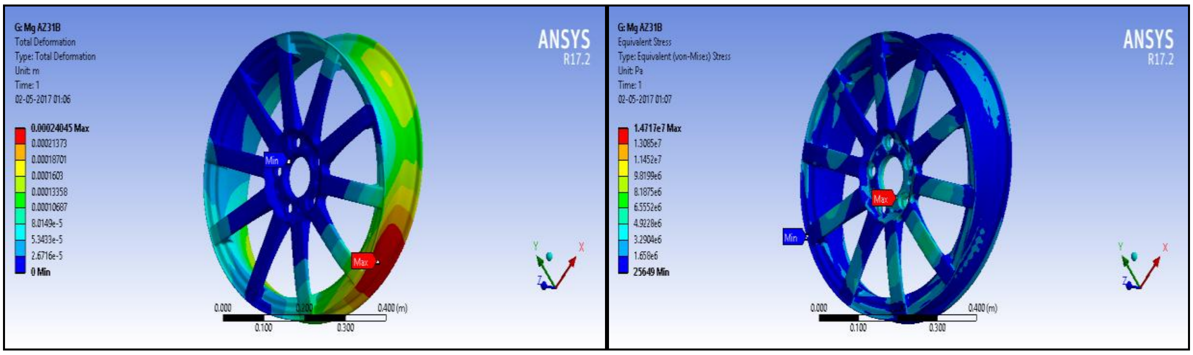

Figure 7. Deformation and equivalent stress in Ti-13 alloy

Table 3. Results of Impact analysis

Alloys Results	Al – 12%Si	Al-5052	Al-6061	Ti-5	Ti-13	Mg-AZ31B
Deformation (mm)	0.22561	0.23015	0.23713	0.24335	0.2802	0.24045
Equivalent Stress (MPa)	16.569	16.627	16.686	20.474	21.253	14.717

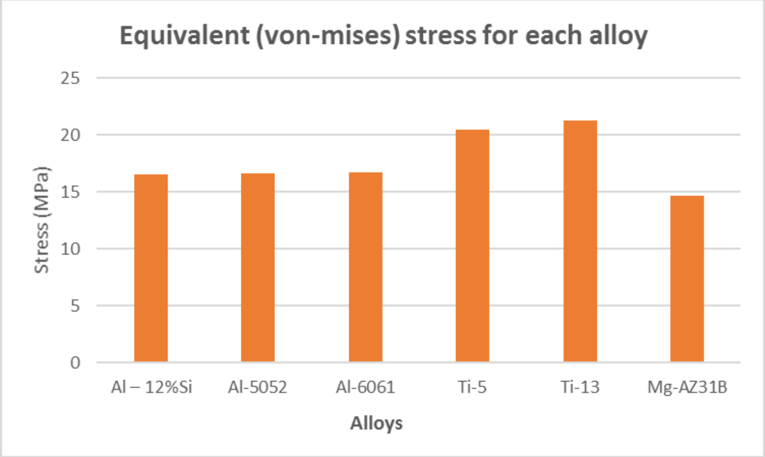

Figure 8. Comparison of Von-Mises stress for every alloy material

The results of the Impact analysis obtained are as tabulated in Table 3. Also, the Von-mises stress graph for the equivalent stress is shown in Figure 8. From the table, we can see that for nearly the same deformation values, we are getting different Von-mises stress values for every alloy. The highest equivalent stress value (21.253 MPa) is obtained for Ti-13 alloy and the least value (14.717 MPa) is obtained for Mg-AZ31B alloy. Thus, since for nearly the same deformation i.e. 0.2 mm, Mg-AZ31B alloy has the minimum equivalent stress value. Therefore, for conventional Aluminium alloy wheel (Al-12%Si alloy), Mg-AZ31B alloy wheel can be a suitable replacement.

IOP Conf. Series: Materials Science and Engineering **263** (2017) 062074 doi:10.1088/1757-899X/263/6/062074

4. Results of Modal Analysis

The first six mode shapes for Al-12% Si alloy, Ti 13 alloy and Mg Az 3 are shown in Figure 9-17.

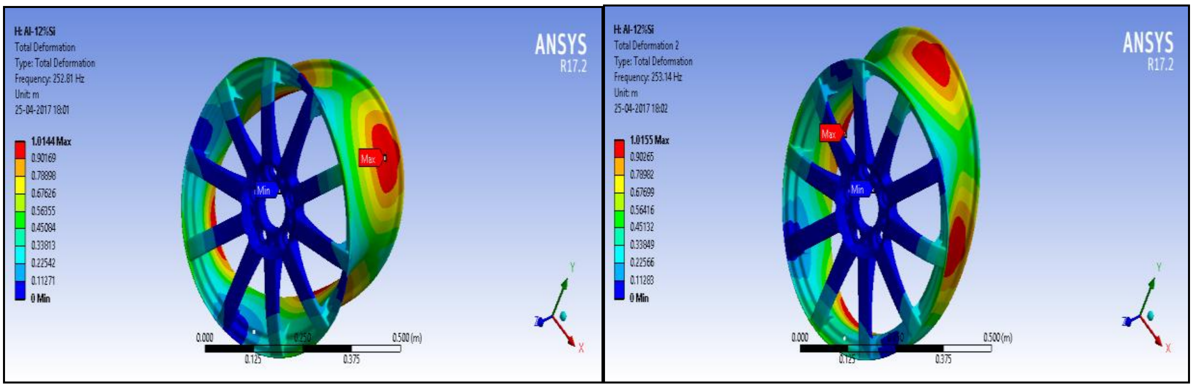

Figure 9. Mode shapes 1 and 2 for conventional Al-12%Si alloy

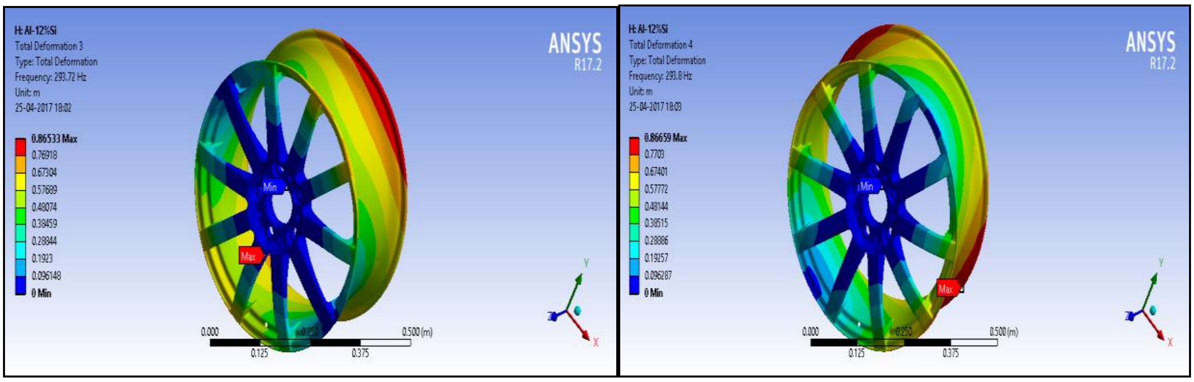

Figure 10. Mode shapes 3 and 4 for Al-12% Si alloy

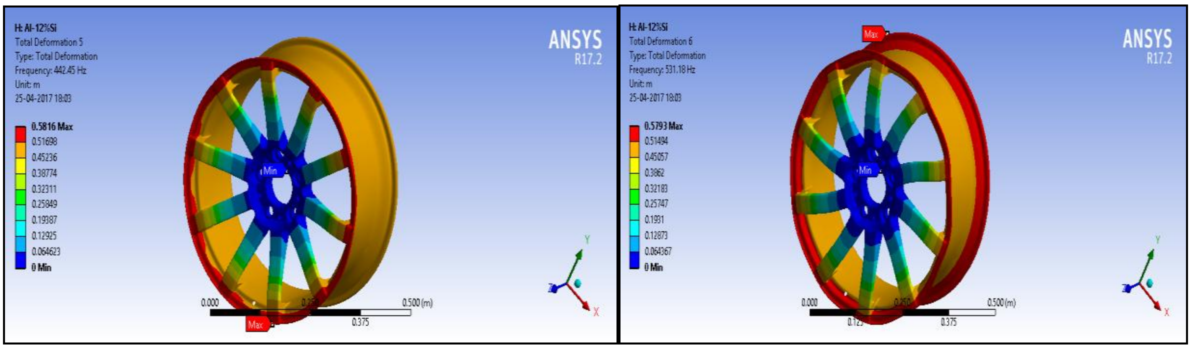

Figure 11. Mode shapes 5 and 6 for Al-12%Si alloy

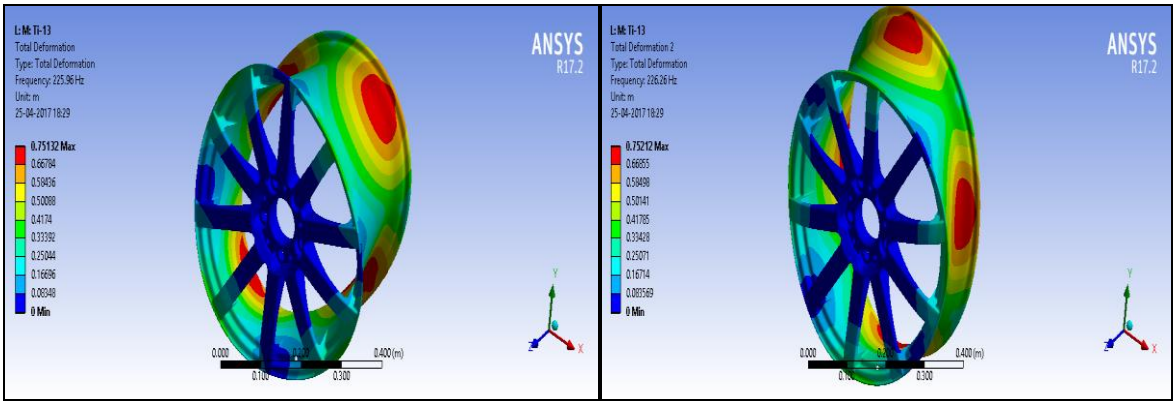

Figure 12. Mode shapes 1 and 2 for Ti-13 alloy

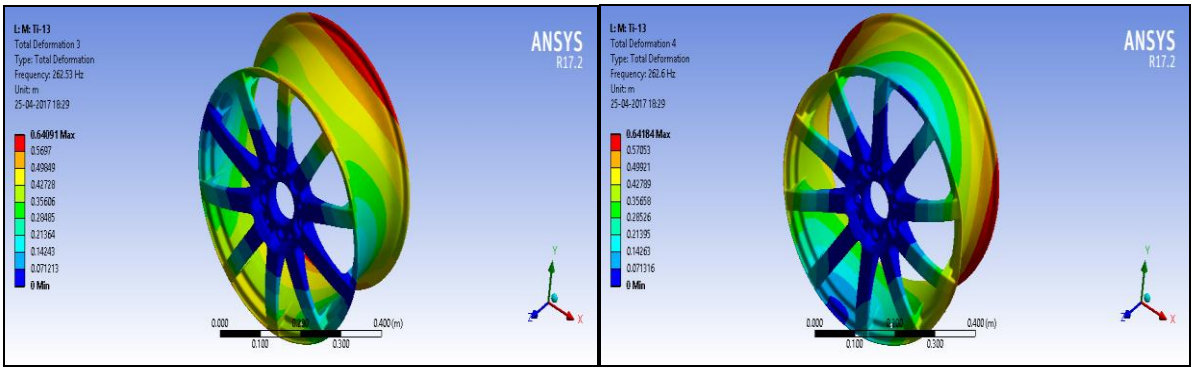

Figure 13. Mode shapes 3 and 4 for Ti-13 alloy

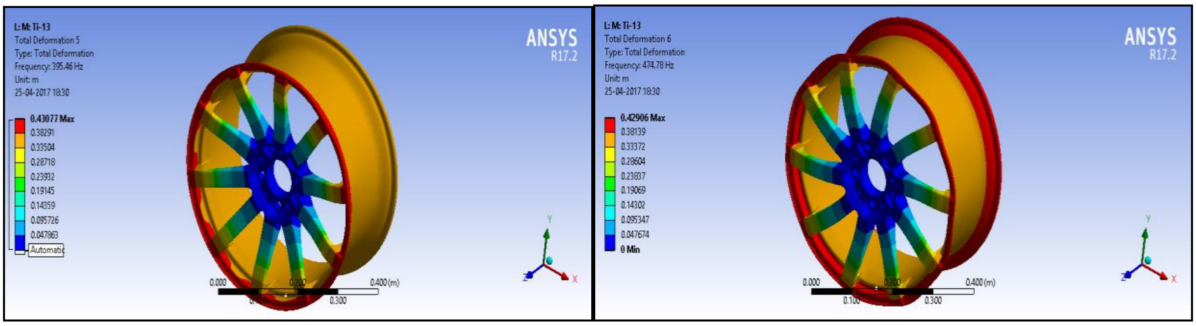

Figure 14. Mode shapes 5 and 6 for Ti-13 alloy

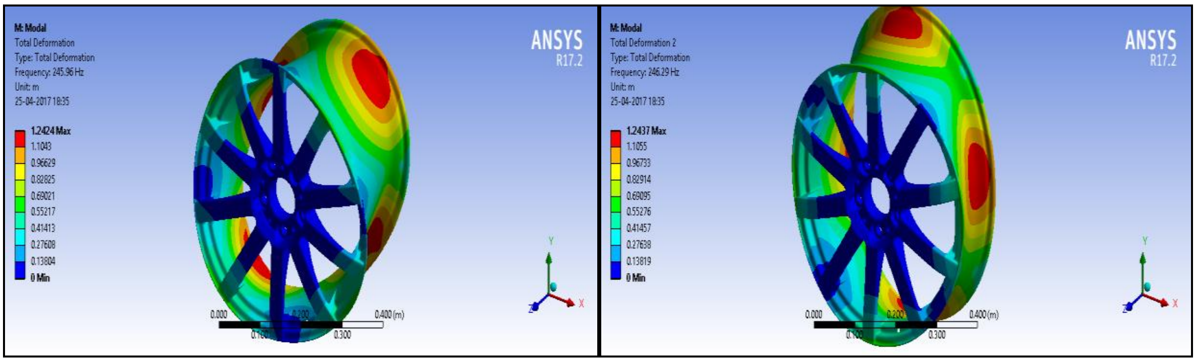

Figure 15. Mode shapes 1 and 2 for Mg-AZ31B alloy

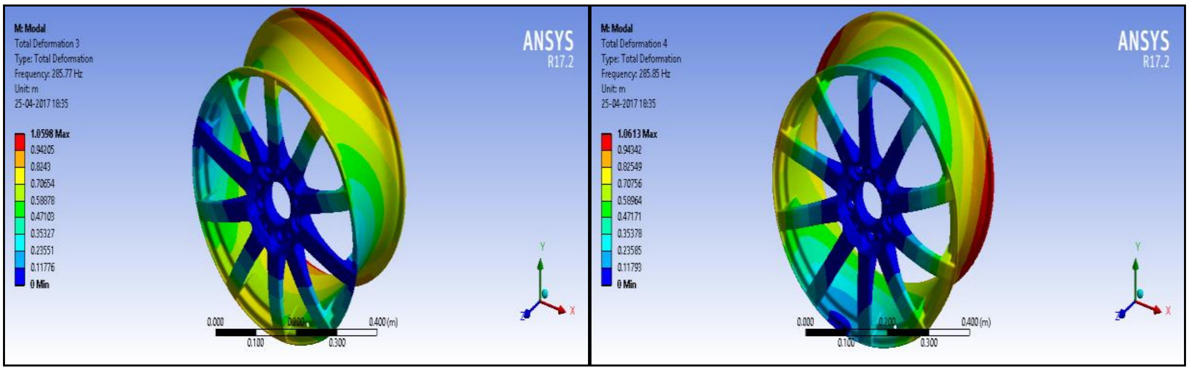

Figure 16. Mode shapes 3 and 4 for Mg-AZ31B alloy

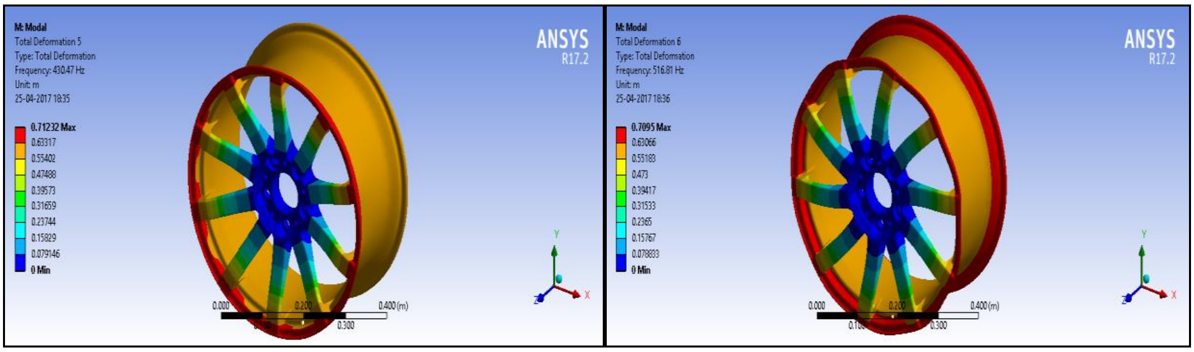

Figure 17. Mode shapes 5 and 6 for Mg-AZ31B

A maximum of 6 modal shapes were taken. The modal frequencies obtained for each alloy from ANSYS are tabulated as shown in Table.4 and compared using bar chart in Figure 18.

Table. 4. Frequencies of 6 mode shapes for all alloys.

Al-12%Si	
Mode	Frequency [Hz]
1	252.81
2	253.14
3	293.72
4	293.8
5	442.45
6	531.18

Al-6061	
Mode	Frequency [Hz]
1	246.54
2	246.87
3	286.44
4	286.52
5	431.48
6	518.02

Al-5052	
Mode	Frequency [Hz]
1	250.28
2	250.61
3	290.78
4	290.86
5	438.02
6	525.87

Ti-13	
Mode	Frequency [Hz]
1	225.96
2	226.26
3	262.53
4	262.6
5	395.46
6	474.78

Ti-5	
Mode	Frequency [Hz]
1	242.55
2	242.88
3	281.8
4	281.88
5	424.5
6	509.64

Mg-AZ31B	
Mode	Frequency [Hz]
1	245.96
2	246.29
3	285.77
4	285.85
5	430.47
6	516.81

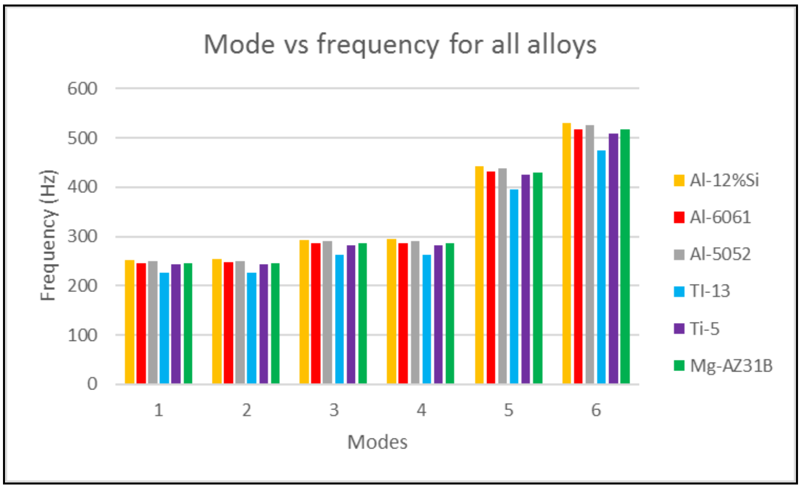

Figure 18. Comparison of Modal frequencies for each modes of alloys

From Figure 18, it can be clearly seen that the minimum Modal frequency for all modes, among the different alloys is obtained for Ti-13 alloy, next least is obtained for Ti-3 and then for Mg-AZ31B alloy. The highest Modal frequencies are obtained for Al-12%Si for all modes.

5. Conclusion

- From Impact analysis results, Al-12%Si, Al-5052, Al-6061, the deformation is approximately the same i.e. 17MPa and 0.23mm, Ti-S alloy has highest deformation of 0.28 and Ti-13 and Mg-Az31B have 0.24 mm deflection. The equivalent stress value of Al-12% Si standard alloy, Al -5052 and Al -6061 alloy have almost equal value of 16.6 N/m^2, whereas the titanium alloys have higher values of 20.4 and 21.25 N/m$^{2.}$. The least stress value of 14.7 N/m^2 were absorbed in Mg-AZ31B alloy. a can also be used as they contain chromium (0.25%) which may increase the fatigue life of the wheel.

- From Modal analysis results, it is seen that the least frequencies are obtained for Ti-13. Thus, it can be concluded that since Ti-13 has the least values of mode frequencies as compared to all other alloys (approximately **10.6% less**), thus because this is distinctly away from the wheel frequency will result in longer life.
- It can be suggested that **Mg-AZ31B** is the best alloy material with less deformation, equivalent stress and almost equal frequency for all modes that of conventional Al-12% alloy can be a good alternate for substitution of the conventional AL-12% Si wheels. **Ti-13** can be suggested when the failures are because of resonance. But, this alloys need to be tested and analysed experimentally further for fatigue life using appropriate setups before they can be used in place of conventional Aluminium alloy wheels.

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