Research Article

Open Access CrossMark

Static analysis for Nickel Aluminides (Ni_3Al) wheel hub using CATIA and solidworks

Abstract

Static analysis in FEA is one of the important analysis need to be done in preliminary stage of an engineering design process. It shows the static condition of a design with material used and load applied. This analysis also includes the constraints and other external features that applied during the actual application of the design. In this present study, a new material which is intermetallic Nickel Aluminides (Ni_3Al) is used to study how it affects the automotive wheel hub at static condition. Intermetallic Nickel Aluminides have been used in automotive industry with its superior characteristics such as lightweight, good resistance in high temperature and corrosion, and high oxidation. The samples were heat treated for 400°C, 500°C and 600°C and the results were compared with the existing materials in order to review the performance.

Keywords: static analysis, finite element analysis, intermetallic aluminides, automotive, CATIA, solidworks

Volume 6 Issue 4 - 2022

Halida Hanim Hafiz Afandi,[1] Intan Sharhida Othman,[1] Sivaraos,[1] T Joseph Sahaya Anand,[2] Saiful Izwan Abd Razak,[3] Ranjit Singh Sarban Singh[4]

[1]Faculty of Manufacturing Engineering, Universiti Teknikal Malaysia Melaka, Malaysia
[2]Faculty of Mechanical and Manufacturing Engineering Technology, Universiti Teknikal Malaysia Melaka, Malaysia
[3]Faculty of Engineering, Universiti Teknologi Malaysia, Malaysia
[4]Faculty of Electronic and Computer Engineering, Universiti Teknikal Malaysia Melaka, Malaysia

Correspondence: T Joseph Sahaya Anand, Sustainable and Responsive Manufacturing Group, Faculty of Mechanical and Manufacturing Engineering Technology, Universiti Teknikal Malaysia Melaka, 76100, Durian Tunggal, Melaka, Malaysia, Tel +60 16 412 7232, Email anand@utem.edu.my

Received: September 09, 2022 | **Published:** October 10, 2022

Introduction

Automotive industries demand an excellence performance at a practical cost where future cars are expected to be more lightweight, high fuel efficient as well as good autonomous driving quality. In order to achieve this goal, a highly robust material or system need to be applied where auto makers engineers are focus to explore new materials and technologies.[1] Intermetallics aluminide is a material that have a high potential to be applied in different field especially in automotive industries. It is good in both mechanical and chemical properties, high oxidation resistance and corrosion.[2] Due to these characteristics, intermetallics alloy tend to be used in harsh application for a long time. Nickel has a good mechanical properties such as ductile, hard, malleable and does not affected by water or air which makes it also good corrosion resistance.[3] Instead, Aluminium is highly malleable, lightweight and relatively ductile.[4] Therefore by merging these two metals will form an intermetallic compound with a high order crystal structure that will boost the material properties. Due to that, this study is aimed to investigate the performance of intermetallic Nickel Aluminides (Ni_3Al) as an alternating material for automotive wheel hub in terms of static analysis using CAD software.

Von mises stress theories are normally used in determining the design failure or success where it starts from the distortion energy theory. The theory can be compared with two different kinds of energies including distortion energy on a simple tension case at failure and distortion energy on actual situation.

Based on this case, the distortion energy on an actual situation will be more than the in the simple tension at failure. In order to make a material shape to deform, distortion energy is needed. During this situation, the shape of material will change but not for the volume as it remains the same.[5] The distortion energy that is required per volume will be in u_d for three dimension case will be given in the terms of the principal stress values as,

$$u_d = \frac{1+v}{3E}\left[\frac{(\sigma_1-\sigma_2)^2+(\sigma_2-\sigma_3)^2+(\sigma_3-\sigma_1)^2}{2}\right]$$

Meanwhile, the distortion energy for simple tension at failure is as follows,

$$u_{d,\text{sim}} = \frac{1+v}{3E}\sigma_y^2$$

These two equation can be equalize and simplified using the theory of distortion energy failure which will be as per below,

$$\left[\frac{(\sigma_1-\sigma_2)^2+(\sigma_2-\sigma_3)^2+(\sigma_3-\sigma_1)^2}{2}\right]^{\frac{1}{2}} \geq \sigma_y$$

$$\left[\frac{(\sigma_1-\sigma_2)^2+(\sigma_2-\sigma_3)^2+(\sigma_3-\sigma_1)^2}{2}\right]^{\frac{1}{2}} = \sigma_y$$

Left-hand side of the equation is the von mises stress. Therefore, the equation can be simplified as,

$$\sigma_v \geq \sigma_y$$

Hence, through the simplified equation design failure can be determined when von mises stress exceed the yield point of a material.

Methodology

In order to perform finite element analysis, 3D modelling of the wheel hub had been done following the actual measurement of a front wheel hub using CATIA software. The detail drawing can be seen through Figures 1&2. This drawing only requires one part and does not need any assembly drawing to attach with.

As for this study, Nickel aluminide is used for study material and carbon steel and aluminium are the existing material that needs to be compared. Different materials have different characteristics which will act differently and give different results when changes applied such as force and heat. Before generating the analysis, constraints will be chose based on the real applications. Certain parts design on the wheel hub is made for screws and nut as mechanical fasteners to glue together the parts. In automotive application, different section in a vehicle such as bumpers, brake systems, airbags and others use different fasteners as it will deal with different stress types. When suitable fasteners had been chosen, force applied need to be keyed in. The calculation for applied force can be seen as below.

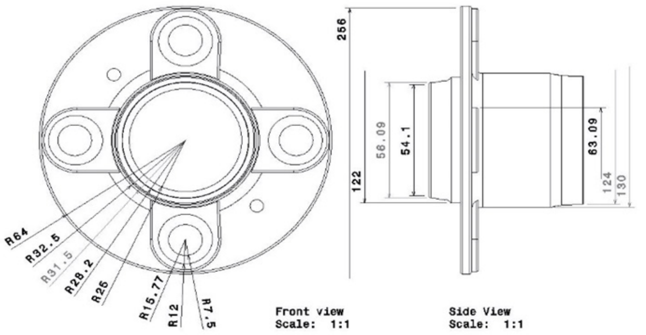

Figure 1 Detail drawing of wheel hub.

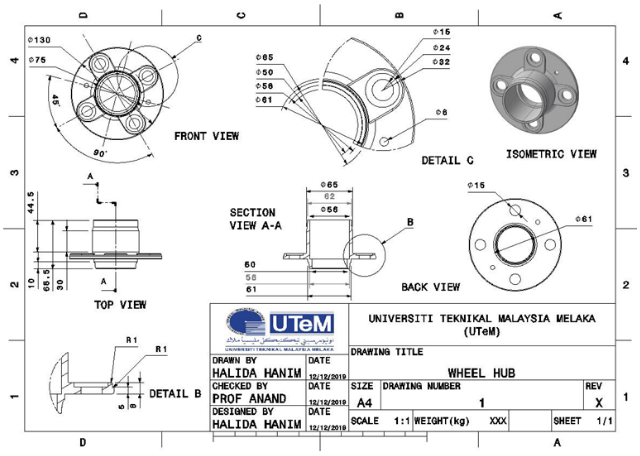

Figure 2 Detailed drawing with title block of wheel hub.

Since the wheel hub used is from Perodua Myvi car, the kerb weight of the car will be 970 kg and the weight assumed for each passenger is 60 kg.

$$Kerb\ weight\ =\ 970\ kg$$

$$Passenger\ weight\ (per\ person)\ =\ 60\ kg$$

$$Number\ of\ passenger\ =\ 4\ person$$

$$Total\ weight\ (kg)\ =\ Kerb\ weight\ (kg)\ \times\ Weight\ of\ passengers\ (kg)$$

$$=\ 970\ kg\ +\ (60\ kg\ \times\ 4\ person)\ =\ 1210\ kg$$

$$Load\ each\ hub\ (kg) = \frac{Total\ weight}{4\ \text{wheel}\ hubs} = \frac{1210}{4} = 302.5\ kg$$

Since, 1 kg = 10 N then 302.5 kg = 3025 N = 3.025 kN,

Therefore, the load received by each wheel hub is 3.025 kN.

Once force applied is inserted, temperature will be added as the application are in different temperature which are at room temperature, 400°C, 500°C and 600°C. Consequently, the analysis will be generated in order to obtain results. The above temperature is selected because a collision that happen can raise the temperature up to 500°C.[6] Therefore, 400°C and 600°C is set as upper and lower temperature. Since, this is a static structural analysis, no motion parameters are added.

Results and discussion

The results of the analysis are tabulated as below where Table 1 is the result for aluminium, Table 2 is for carbon steel and Table 3 is for nickel aluminides. The results are in a form of Von mises, yield strength and displacement**.** In finite element analysis, these three data are the main result used to describe the simulation. Since Von mises stress determine a material to yield or fracture where it will compared with yield strength to judge the material's strength where when the material reach its yield point, it will yield and considered failed. In this case, if von mises stress is more than yield strength will consider as fail and this can be referred from the introduction section.

Based on Table 1, as the temperature increase the Von mises and displacement increase. Table 2 shows when the temperature of carbon steel wheel hub rise, the Von mises and displacement value increase. As for Table 3, same pattern can be seen to the nickel aluminide wheel hub results for Von mises and displacement. The results obtain from Solidworks software, for Aluminium 6061 and Carbon steel have the Von mises value that is smaller than the yield strength which shows the designs are safe. Unfortunately, when the samples are heat treated to 400°C, 500°C and 600°C the values of Von mises exceed the yield strength. It can be seen clearly when heat is applied to the aluminium and carbon steel, the values of Von mises stress is higher than yield stress and it is not safe for hub application. Nickel aluminide samples do not have any issue with this. The value of Von mises stress for all samples are lower than yield strength value which shows this results are better compared to other two materials. The yield strength value initially at 72 740 MPa for non-heat treated sample and ends at 9 097 MPa for 600°C sample. Compared to Von mises value, the nickel aluminide samples have 3.211 MPa for non-heat treated sample and 77.93 MPa for 600°C sample.

Table 1 Static analysis result for Aluminium 6061

Annealing condition	Von mises (MPa)	Yield strength (Mpa)	Displacement (mm)
Non-heat treated	3.21	55.15	0.001369
400°C	897.4	55.15	0.2099
500°C	1090	55.15	0.264
600°C	1319	55.15	0.3194

Table 2 Static analysis result for Carbon Steel

Annealing condition	Von mises (Mpa)	Yield strength (Mpa)	Displacement (mm)
Non-heat treated	3.213	241.3	0.000488
400°C	1231	248.2	0.1033
500°C	1559	248.2	0.1308
600°C	1948	248.2	0.1598

Table 3 Static analysis result for Nickel Aluminide

Annealing condition	Von mises (Mpa)	Yield strength (Mpa)	Displacement (mm)
Non-heat treated	3.211	72 740	0.00129
400°C	47.24	7 454	0.115
500°C	71.86	8 957	0.1419
600°C	77.93	8 097	0.1701

Displacement is the changes of how much an object experience when external load of force applied. The aluminium wheel hub has a displacement of 0.001369 mm at non-heat treated sample and as for 600°C heat treated sample is 0.3194 mm. Carbon steel wheel hub obtain 0.0004882 mm of displacement at room temperature hub and 0.1598 mm at 600°C hub. As for nickel aluminide, the displacement gained is 0.00129 mm for normal hub and 0.1701 mm at 600°C of heat applied. In general, Carbon steel has the lowest displacement value compared to the other two material. As for the displacement value difference from one temperature to another, nickel aluminide has the lowest. Aluminium 6061 has the highest displacement value compared to carbon steel and nickel aluminide. This shows that carbon steel and nickel aluminide are better compared to aluminium in terms of durability. However, the displacement values are less than 1mm which almost unnoticeable unless the design is frequently running on a high temperature in a long time.

Based on the results obtain from Solidworks software, for Aluminium 6061 and Carbon steel have the Von mises value that is smaller than the yield strength which shows the designs are safe. Unfortunately, when the samples are heat treated to 400°C, 500°C and 600°C the values of Von mises exceed the yield strength. For instance, Aluminium sample has Von mises value of 897.4 MPa to 1 319 MPa at 400°C to 600°C which are more than 55.15 MPa of yield. Meanwhile, carbon steel obtain 1 231 MPa to 1 948 MPa for 400°C to 600°C which are more than 248.2 MPa of yield value. It can be seen clearly when heat is applied to the aluminium and carbon steel, the values of Von mises stress is higher than yield stress and it is not safe for hub application. Nickel aluminide samples do not have any issue with this. The value of Von mises stress for all samples are lower than yield strength value which shows this results are better compared to other two materials (Figure 3 & 4).

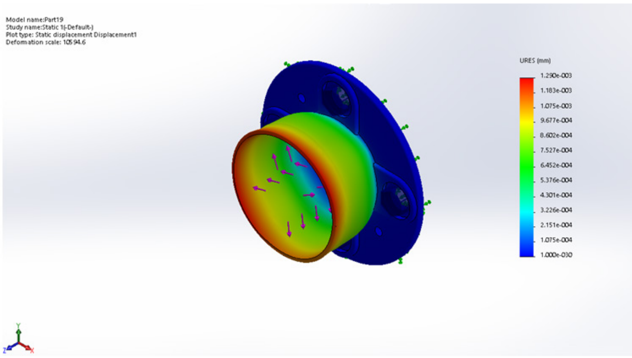

Figure 3 Displacement for Nickel Aluminide wheel hub at non heat treated condition.

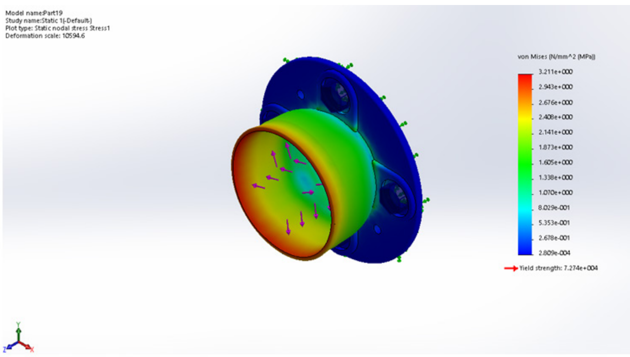

Figure 4 Von Mises distribution for Nickel Aluminide wheel hub at non heat treated condition.

The Von mises value increase as the temperature applied to the material increase. Larger Von mises stress shows the material is close to yield. If the von mises stress is greater or equal to the yield strength of the material, the subject is likely to yield. Von mises is a value that shows a material is prone to ductility or brittleness. As the temperature increase the atomic bonds tend to stretch.

A static analysis studied by Karthik A.S. et al to identify the best material for alloy wheel. The material candidates are magnesium, aluminium and titanium. Based on the results, titanium experience the least von mises stress and deformation although it is the most expensive.[7] As for this study, nickel aluminide experienced the least von mises stress at high temperature which means it has the most strength out of the other two materials. Nickel aluminide also does not deform much referring to the deformation results because of the high melting point.

The yield strength of each material have different pattern. It is better to have a material with higher yield strength[8] because the higher value is materials that can withstand a higher stress without any permanent deformation occur. In order to compare between Alumium, carbon steel and nickel aluminide, nickel aluminide has the highest value of yield strength. The result can be referred in Tables 1–3.

Von mises and yield strength value are very important in static analysis. When von Mises stress value is greater than yield strength, the part is consider fail. Meanwhile, if the value is less than or within the yield strength, it is not fail or the design is within yield criteria.[9,10] A high value of von mises value can cause failure to the components with repetitive operating condition.[8,11] Based on the results, even though at the highest annealing temperature Nickel Aluminide still has the lowest von misses value compared to aluminium and carbon steel.

Conclusion

Generally, the safest material compared at the analysis is the material that has a lower value of von mises stress than the yield strength which is the nickel aluminides. For a start, aluminium 6061 and carbon steel both have a lower value of von mises than material the yield strength but not after when heat is applied, both materials tend to have a higher von mises stress value which is unsafe for the design. In terms of displacement, carbon steel and nickel aluminides has a lower value compared to aluminium due to the higher melting point of the material. Above all, nickel aluminides shows that it able to be the best alternating material for wheel hub compared to aluminium and carbon steel.

Acknowledgements

None.

Conflicts of interest

The Authors declares that there is no Conflict of interest.

References

1. Fentahun MA, Savas MA. Materials Used in Automotive Manufacture and Material Selection Using Ashby Charts. *Int J Mater Eng*. 2018;8(3)40–54.
2. Guo JT, Sheng LY, Xie Y, et al. Microstructure and mechanical properties of Ni_3Al and Ni_3Al–1B alloys fabricated by SHS/HE. *Intermetallics*. 2011;19(2)137–142.
3. Kalpakjian S, Schmid S. Manufacturing Engineering and Technology. 4th Ed. Prentice Hall; 2001.
4. Joseph Sahaya Anand T, Sivarao, Ganesh Kumar K. Mechanical and Chemical Properties of Intermetallic Ni_3Al for Automotive Body. *Curr Res Malaysia*. 2013;2(2)61–72.
5. Guo A, Boyun Lyons William, Ghalambor. *Petroleum Production Engineering*. 2007.
6. Kumar KG, Anand TJS. A Novel Intermetallic Nickel Aluminide (Ni 3 Al) as an Alternative Automotive Body Material. *Int J Eng Technol*. 2011;11:1–9.

7. Jaspreet S, Siddhartha S. Static Analysis of Alloy Wheel Using Ansys15.0. *Int. J Res Eng Technol*. 2016;2(12):397–401.
8. Solanki VV, Patel PNS. Static Analysis and Geometric Optimization of Independent Suspension Link. *Int J Thesis Proj Diss*. 2014;2(2):47–57.
9. Li Z. Mechanical Analyses of Multi-piece Mining Vehicle Wheels to Enhance Safety. University of Windsor; 2014.
10. Ragul G, Kalivarathan G, Jayakumar V, et al. An Analytical Investigation on Design and Structural Analysis of Cam Shaft using Solid Works and Ansys in Automobiles. *Ind J Sci Technol*. 2016;9(36):1–9.
11. Verma H, Kumar S, Singh R, et al. Design and Development of the Front Wheel Hub for All-Terrain Vehicle (ATV). *J od Mech Eng*. 2020;17(1):49–62.

Citation: Afandi HHH, Othman IS, Sivaraos, et al. Static analysis for Nickel Aluminides (Ni_3Al) wheel hub using CATIA and solidworks. *Aeron Aero Open Access J*. 2022;6(4):166–169. DOI: 10.15406/aaoaj.2022.06.00157