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Fatigue Analysis of Steering Knuckle using Finite Element Simulation: Technical Note

S. Madhusudhanan[a], I. Rajendran[b] and B. Raguganeshkumar[c]

Dept. of Mech. Engg., Dr .Mahalingam College of Engg. and Tech., Pollachi, Coimbatore, India
[a]Corresponding Author, Email: madhufea@gmail.com
[b]Email: irus_rajendran@yahoo.co.in
[c]Email: ragumech31@gmail.com

ABSTRACT:

Steering knuckle is a prominent component of an automobile steering system. It is subjected cyclic loads from the suspension system during its service life. The Spheroid Graphite (SG) iron is the most commonly used material for manufacturing the steering knuckle. Fatigue behaviour is therefore a key consideration in its design and performance evaluation. Geometric modelling and stress analysis of such steering knuckle using finite element analysis software is carried out. Then the fatigue life of steering knuckle made from SG iron has been evaluated under the different load conditions and the results have been compared.

KEYWORDS:

Steering knuckle; Fatigue life; Spheroid graphite iron; Finite element simulation

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1. Introduction

The steering knuckle is a part of the vehicle's steering and suspension system which undergoes time-varying loading during its service life. This system provides a means where the driver can place his vehicle accurately where he wants it to be on the road. This system also keeps the vehicle stable on course regardless of irregularities in the surface over which the vehicle is travelling. Any failure in these components results immediately in loss of the orientation of the vehicle. This work is focussed on the strut of the steering knuckle which is mainly used in the steering system of the front wheel drive vehicles. This McPherson strut steering knuckle system [1] consists of a strut mount at the top, ball joint at the bottom, and a steering arm on the side. The wheel spindle fits through a hole in the centre. Since it is connected to the steering parts and strut assembly restraint, pavement applies cyclic loads to the steering knuckle through the strut mount, ball joint and steering tie rod. Steering knuckle can be made up of cast iron, aluminium, Spheroid Graphite (SG) Iron and the Austempered ductile iron.

The multi-axial deformation leads to a fatigue life damages in the steering knuckle. Elastic unit load analysis using strength of material and elastic finite element (FE) analysis combined with a stress-life analysis were reported in literature [2-7]. The technique of material as a a design variable for vehicle body and stiffness improvement techniques [8,9] and its significance have been found to be efficient design enablers combination in the vehicle design. In this paper, finite element (FE) simulation of SG Iron steering knuckle is carried out to determine its faigue life. The fatigue life calculation uses a stress-life (S-N) curve and the factor of safety (FoS) is calculated using Goodman criterion. This approach is apt to identify the critical areas as well as non-damage ares of the knuckle with a view to enhance its design and reduce its weight.

2. FE modelling

The CAD model of the streering knuckle was developed and then the IGES format of its geometry was imported into ANSYS Workbench for FE discretization and solving. A schematic flow of the steps involved in the analysis methodology is presented in Fig. 1. The geometry was discretized using tetrahedral finite elements of type SOLID186. An element size of 3mm, as the minimum thickness of the knuckle geometry, was used to give a better quality mesh. Fig. 2 shows the mesh of steering knuckle FE model. The number of nodes and elements in the developed FE model are 70323 and 41067 respectively.

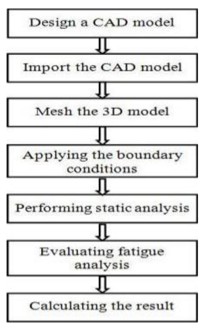

Fig. 1: Analysis methodology

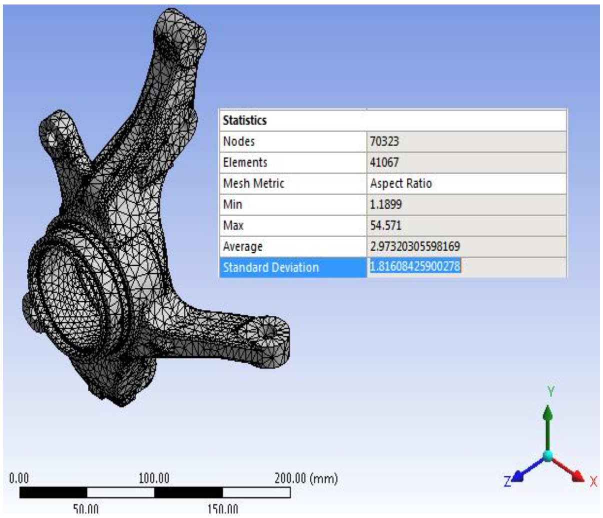

Fig. 2: FE mesh of the steering knuckle

The SG Iron material properties assigned are as follows, E = 1.6×10^5 MPa, ν = 0.28, G = 68.5 GPa, ultimate tensile strength σ_u = 620 MPa and endurance strength σ_e = 558 MPa from experimental results and used for analysis. For the cast SG Iron steering knuckle in service while the loading is applied to the strut joints through struts. The four hub bolt holes are connected to the wheel assembly. The boundary conditions and the applied loading are shown in Fig. 3. To verify the model with the specified boundary conditions, other alternatives were analyzed by switching the loading and boundary conditions and also by releasing any one of the fixed points to ensure that the critical locations remained as the same.

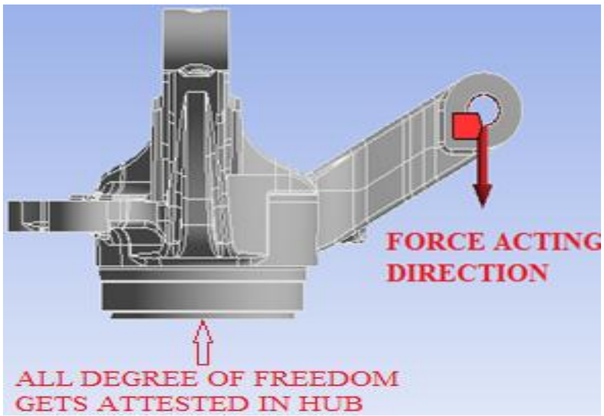

Fig. 3: Schematic of applied loading and boundary conditions

3. Results and discussion

The FE model has been solved for an applied load of 45 kN using ANSYS Workbench version 16. From the FE simulation results, the post-processed fringe plots for total deformation, fatigue damage, fatigue life, FoS and equivalent stress of the SG Iron steering knuckle component in Fig. 4 to 8 respectively. The maximum von mises stress observed in the FE simulation is 549.53 MPa. The predicted fatigue life is 1072 cycles. The FE simulation results are validated through hand calculation on the basis of a cantilever beam of length 75mm, width 34mm and depth 24mm representing a fracture at the arm portion of the steering knuckle as shown in Fig. 9.

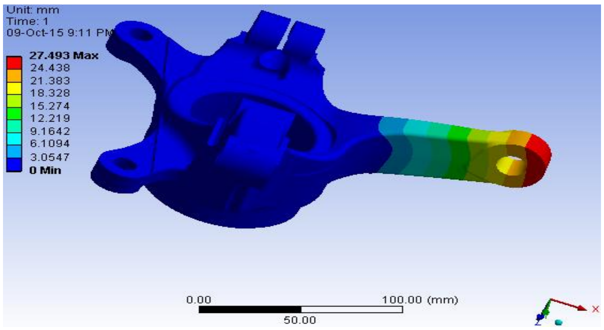

Fig. 4: Total deformation

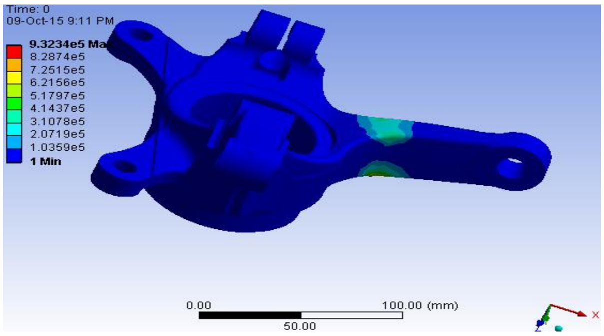

Fig. 5: Fatigue damage

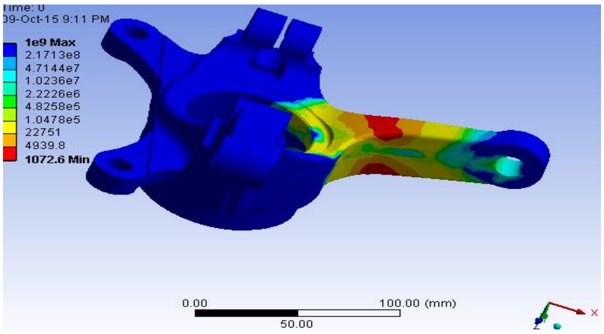

Fig. 6: Fatigue life

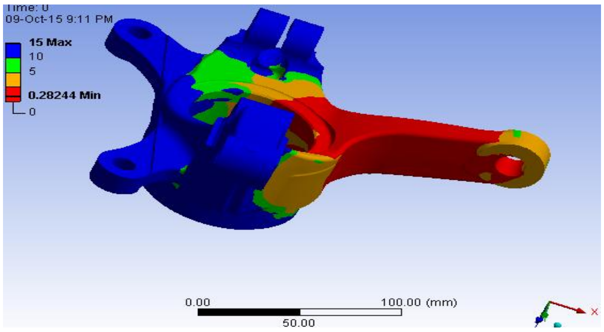

Fig. 7: Safety factor

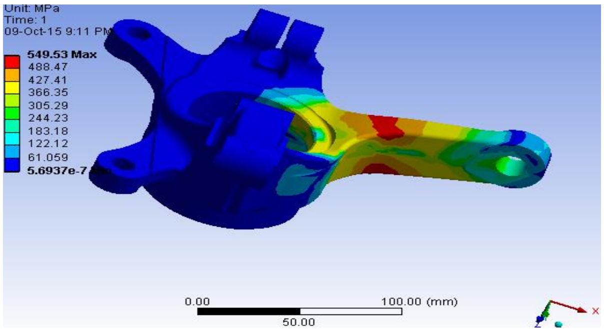

Fig. 8: Equivalent stress

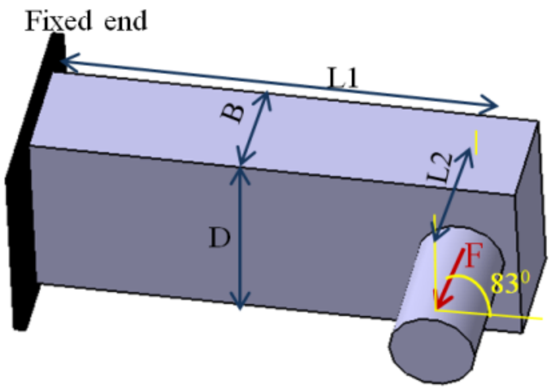

Fig. 9: Beam cross section

The bending stress in extreme surfaces of the beam cross section is calculated using,

$$\sigma = MY / I \tag{1}$$

Substituting M_x=411.3 kN-mm, M_y=3.3×10^3 kN-mm, y=17 mm and I=78.6×10^3 mm^4, the calculated values are σ_x = 88.95 MPa and σ_y = 724.44 MPa. The shear stress due to the applied normal load can be obtained by,

$$\tau_{xy} = Tr / J \tag{2}$$

Substituting T=759.22×10^3 kN-mm, r =17mm, J=471.1 ×10^3 mm^4, the calculated value is τ_{xy} = 51.57 MPa. The von mises stress of the section is calculated using,

$$\sigma_{vm} = \sqrt{\sigma_x^2 + \sigma_y^2 - \sigma_x \sigma_y + 3\tau_{xy}^2} = 690\text{MPa} \tag{3}$$

The mean and alternating stresses based on the FE simulation results can be obtained using:

$$\sigma_m = 0.5(\sigma_{\max} + \sigma_{\min}) \tag{4}$$

$$\sigma_a = 0.5(\sigma_{\max} - \sigma_{\min}) \tag{5}$$

Substituting σ_{max} = 549.53 MPa and σ_{min} = 5.69×10^{-7} MPa from Fig 8 into Eqns. (4) and (5), the calculated values are σ_m=274.76 MPa and σ_a=274.75 MPa. The fatigue life can be determined using,

$$\sigma_n = \sigma_e \left(\frac{N}{10^6}\right)^{\frac{1}{3}\log\frac{\sigma_e}{0.9\sigma_u}} = 1064 \text{ cycles} \tag{6}$$

The fatigue damage can be determined using,

$$Damage = \frac{total\ life\ cycle}{available\ life\ cycle} = \frac{10^9}{1064} = 9.3984\times10^5 \tag{7}$$

The factor of safety can be obtained by below equation

$$\frac{1}{FoS} = \frac{\sigma_a}{\sigma_e} + \frac{\sigma_m}{\sigma_u} \tag{8}$$

Substituting the values, the calculated FoS is 1.06. The deflection of the beam subjected to point load (F=45 kN) over a span of (L=75mm) is given by,

$$\delta = FL^3 / (3EI) \tag{9}$$

The calculated deflection is 5.31 mm. A summary of the FE simulation results validated with hand calculation are given in Table 1.

Table 1: Result data

Result	FE simulation	Hand calculation
Von mises stress (MPa)	549.53	690
Displacement (mm)	27.5	25.3
Life	1072.6	1064
Damage	9.328×10^5	9.39×10^5
FoS	0.28	1.06

4. Conclusion

The fatigue analysis of SG iron steering knuckle was carried out virtually using FE simulation. The results were tabulated and the theoretical calculation was also carried out for the same load condition of 45 kN. The SG Iron material steering knuckle with stand the load up to 45 kN and then the fracture will occurs at above 47 kN. Further work will be directed towards the weight reduction on the non-damage areas identified through the FE simulation results.

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