FAILURE PREDICTION AND ANALYSIS OF REAR AXLE HOUSING OF A COMMERCIAL UTILITY TERRAIN TRUCK

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***Abstract*— In the present study utility vehicle rear axle housing was selected to study the failure analysis experimentally and numerically. The failed rear axle housing was undertaken to check its integrity which includes a visual examination, chemical analysis, microhardness test, and metallographic tests to evaluate the failure. Failure analysis of a rear axle housing used in a utility vehicle was studied to determine stress concentration area. Based on field study strain gauges are mounted on failed parts to determine stress intensity and joint analysis were validated with Finite Element Analysis results. SEM (scanning electron microscope) was used to examine the failure zones. Under this analysis, it is seen that the rear axle housing suffered a fatigue-induced fracture. The fracture was initiated at the weld joint between the back plate and rear axle housing, where a stress concentration was created. This stress concentration was higher than the stress concentration considered at the time of design which results in the breakage of the housing into two parts. Also, stress concentration was found more on the left side as compared to the right side. Hence, all the reported failures were broken on the left side only. So, the causes of the failure of the rear axle housing were due to the defective geometric design of the rear axle housing. To avoid this failure in future the axle housing thickness is changed from 3.5 mm to 4 mm. This design change sustained the high-stress concentration which was analyzed with the help of finite element analysis.**

***Keywords*— Failure Analysis, Finite Element Analysis, Rear axle, Rear axle Housing**

I. INTRODUCTION

An axle is a cross member supporting a vehicle, on which one or more wheels turn. The Axle shaft connects the two wheels in a vehicle. The Axle shaft usually extends from opposite sides of a differential gearbox and is provided at their outer wheel ends with integral or otherwise rigid drive flanges which are connected to the wheels for transmission of driving power [1]. An axle assembly on a vehicle in the set of components allows the wheels to rotate freely. Axle sits inside the axle housing. It is held in place by bearings or bushings that allow it to rotate within the axle housing. Axle housing also supports in lubrication of the rotating axle.

Axle housing is a non- rotating member and carries the suspension seats over which the suspension springs are mounted. They are subjected to dynamic inertial loads as the vehicle moves over an uneven road surface and hence are predominantly subjected to bending during service. Bending moment distribution of rear axle housing's schematic diagram is shown in Fig. 1

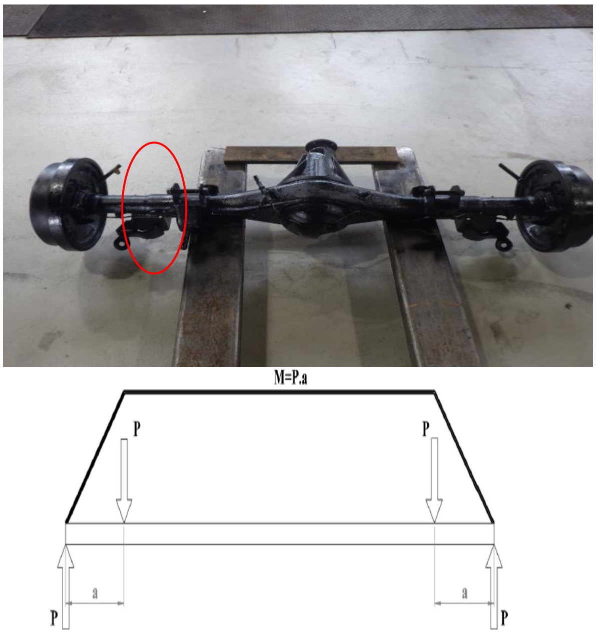

Fig.1 Bending moment distribution on the rear axle housing

II. LITERATURE SURVEY

Research on failure analysis of various components has been carried out over the years.

S.P. Raut and L.R. Raut [1] reviewed various methods used for failure analysis of shaft. The researchers discussed various tools and techniques used for analysis such as non-destructive testing, optical microscope, scanning electron microscopy, energy-dispersive X-ray spectroscopy, heat affected zone, hardness testing instruments, fatigue testing, tensile testing, etc.

Souvik Das et al. [2] conducted a failure analysis of the axle shaft of a forklift which was failed at operation within 296 hours of service. They suggested that the fracture was initiated from the martensitic case as brittle mode due to improper heat treatment process and inclusions along the longitudinal axis made the component more prone to failure. Khairul Akmal et al. [3] studied the premature failure of the rear axle due to the higher loading capacity of the heavy vehicle. The new design was developed for that rear axle model by increasing the thickness of the sheet by 7 mm to improve the fatigue life of the housing to increase the rigidity of the axle housing.

F Mujahidin et al [4] studied the axle shaft. They showed that the failure was not due to material factors but the failure occurred due to a large enough momentary shock load.

G.K. Nanawarea, et al [5] reviewed the rear axle shafts and found that they failed before completion of their warranty period. Inadequate spline root radius resulted in the failure of rear axle shafts, which results in subsequent crack growth and crack initiation was by fatigue under the cyclic loading conditions of field operation.

Osman Asi [6] has done the failure analysis of the automobile’s rear axle shaft. Results suggested that because of improper welding axle shaft fractured.

III. OBJECTIVE

The objective of this paper is to investigate, analyse the root cause of the sudden failure of rear axle housing in a running condition and to found the solution to avoid this kind of failure in future. Root cause analysis was carried out using experimental analysis and with the combination of experimental and finite element analysis, solution and recommendation are proposed.

Fig.2 shows the actual fracture of the rear axle housing

Fig. 2 Fracture of the rear axle housing at the left side

IV. EXPERIMENTAL ANALYSIS OF REAR AXLE HOUSING

For analysis, the failed rear axle housing was taken from the field. The sample was cleaned with acetone for removing dirt to perform a visual examination. After that, the sample was prepared for metallographic analysis. The transverse specimen was made from the cut section end of the failed rear axle housing for conducting Microscopic examination. The sample was polished by standard metallographic techniques to produce a scratch-free surface. The polished sample was etched in with etchant 3% Nital solution (3ml nitric acid and 97ml ethyl alcohol) and etched as well as unetched samples were observed under an Optical Emission Microscope. The hardness of the different locations of rear axle housing was measured in the Vickers hardness tester. A 50 kgf of the load was applied during testing, and a few numbers of indentations were made to measure the hardness of the rear axle housing.

The experimental investigation includes the following analysis of the failed rear axle housing-

A. Visual Analysis

B. Chemical Analysis

C. Hardness measurement

A. Visual Inspection:

Beam housing / rear axle housing failed from the left side & fractured into two pieces from the end of the weld joint of the backplate & beam housing. Fracture initiated from the end of seam weld on backplate at 13 to 14 mm below tube seam weld. At fracture initiation, clear beach marks are observed. No hit or dent mark or other damage was found near fracture initiation. The fracture can be determined as brittle when the surface is seen flat, a mixture of ductile and brittle when the surface has a moderate degree of roughness, ductile when the surface is more on the rough side.

The broken component shows a moderate degree of roughness, so it must be a combination of a ductile and brittle type of fracture. As shown in Fig. 3.

Fig. 3 Rear axle housing broken piece

B. Chemical Composition:

Chemical composition of the failed axle housing containing 0.11% Carbon, 1.18% Manganese, 0.01% Phosphorus, 0.02% Sulphur, 0.04% Silicon and 0.02% Aluminium. Whereas raw material BSK-46 contains 0.12% Carbon, 1.4% Manganese, 0.03% Phosphorous, 1.03% Sulphur, 0.1% Silicon, and 0.3% max Aluminium [8]. Failed component material is BSK-46 only as indicated by the observed values. Hence, no deviation is observed in the raw material. Therefore, the failure is not attributed to improper raw material. According to chemical composition analysis by Optical Emission Spectroscopy, the rear axle housing was manufactured using BSK-46[8].

The metallographic microstructure is shown in Fig. 4 for the rear axle housing. It shows an element mainly formed by uniformly distributed ferrite & perlite. The presence of uniform perlite indicates that the material suffered a heat treatment of quenching & tempering.

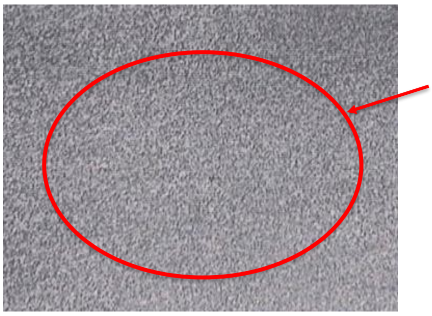

Fig. 4 Microstructure of the material

SEM (scanning electron microscope) was used to examine the fractured surface to characterize the fracture micro mechanism. The fracture surface contains ratchet marks. The ratchet marks indicate multiple origins and relatively high total stresses. Ratchet marks can result from high stress on the part or from high-stress concentrations. The combination of many ratchet marks and a small overload zone indicates that the load was light, but there were high-stress concentrations.

From these observations, it is clear that fatigue cracks have initiated at stress concentration points leading to the fracturing of the rear axle housing. The badly welded region can lead to a high-stress concentration, but can also cause fatigue crack initiation during short service time. A fatigue crack can form when the local stress exceeds the material yield strength. Since steel resistance to fatigue initiation, is proportional to its yield strength, the low properties of the steel left it open to fatigue initiation. The area of final overload fracture is small, approximately 15% of the total area, indicating that the material was adequate for the applied stresses. Fig. 4 shows a specimen under 30X magnification having flat as well as moderate roughness, which indicates the material is a mixture of both ductile as well as brittle failure.

C. Vickers hardness study:

Vickers hardness study was performed using a 50 kgf load with 13 second dwell time on location backplate to beam housing weld. Table 1 shows Vickers hardness test results.

Table 1. shows there was no deviation in material thickness, leg length, maximum weld nugget hardness, concavity, maximum heat-affected zone hardness. Hence, the weld parameter of the components was within specification as per ES-PS-0522[9]. It indicates no issue in the weld parameter of components.

TABLE 1: VICKERS HARDNESS TEST RESULTS

Weld Parameters	Beam housing to weld (near fracture initiation)	Backing plate to weld (near fracture initiation)	Specified per ES-PS-0522
Maximum weld nugget hardness (HV)	295		354 HV Ma
Concavity (mm)	0.39		0.8 mm Max
Maximum heat-affected zone hardness (HV)	231	167	446 HV Max
Parent material hardness	211	214	79-91 HRB (147-190 HV)

V. STRESS LEVEL MEASUREMENTS

A Strain gauge is a sensor used to measure applied force. Its resistance varies with applied force. The force, pressure, tension, weight, etc., is converted into an electrical resistance that can then be measured. External forces result in stress and/or strain when applied to an object.

Strain gauges were mounted on the rear axle housing; to calculate the stresses in the rear axle housing mounting position was shown by the red circles in Table 2. Following are the mechanical properties of the base material of rear axle housing (BSK-46) [9]

TABLE 2: MECHANICAL PROPERTIES OF BASE MATERIAL

Specification	YS (MPa) (min)	TS (MPa) (min)	Elongation% (min)
BSK-46	451	490-627	21

Contact stresses calculated as, Stress = Young's Modulus/Strain.

Therefore, Stress on the left side is **261.58 MPa**

and Stress on the right side is **216MPa**

Fig. 5 Mounting of strain gauges on the axle housing to measure contact stresses

Strain gauges mounting position were shown by the red circles in Fig. 5. With this strain gauge arrangement, stress values are received in the running condition on the rear axle housing.

VI. FINITE ELEMENT ANALYSIS OF REAR AXLE HOUSING

Using Finite Elements Analysis (FEA) it is possible to find the locations of high stresses suffered by the analysed element and their values. Specific conclusions can be drawn in this way and reach possible solutions to avoid the recurrence of these kinds of failures. In this analysis, the rear axle housing was geometrically modelled as shown in Fig. 6 Hexagonal elements with a size of 2 mm were used in the FE mesh. The mesh had a total of 25277 elements. The size of the elements and mesh was selected after performing a series of iterations with the same loads and using different mesh sizes. It was noted from the iterations that the values of the stresses in the element varied considerably, for elements smaller than 2 mm, making it high values related to singularities caused by small elements. For elements bigger than 2 mm the stresses were not represented as the size of the elements were higher than the contact region. Following are the loading, boundary, and contact conditions of the model:

1. A fixed contact in zone A (end of the rear axle housing)

2. Lateral load B & C, assumed constant in this analysis to simplify the modelling, with a value of 5100 N and applied on the backplate.

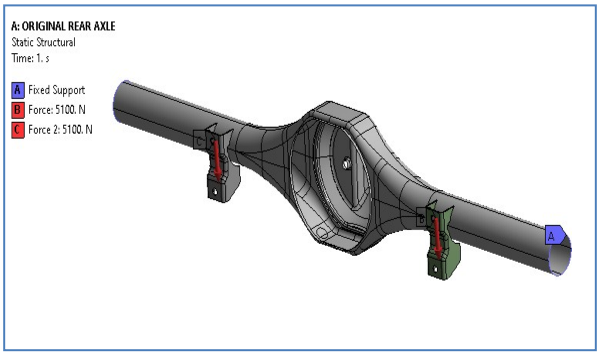

Fig. 6 Loading condition in ANSYS

The analysis and calculations of maximum stresses were performed with and without the backplate, to highlight the places of higher stresses in the element. It is observed that there is no major change in the readings after removing the jack mounting plate from the welding joint. After this trial the trial by changing the thickness of the material from 3.5 mm to 3.7 mm, 4 mm and 4.2 mm.

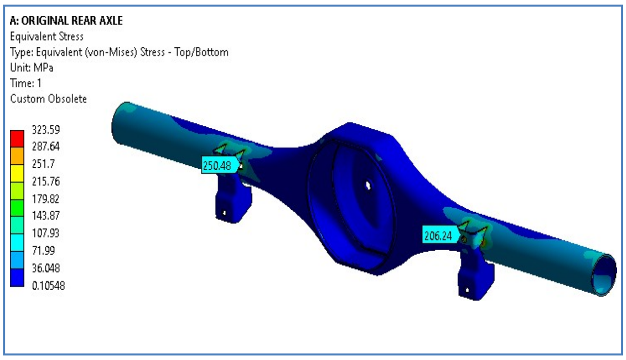

Fig. 7. Von Mises stress plot for 3.5 mm thickness

Fig. 7. shows the stress distribution of the original rear axle housing with 3.5 mm thickness. Left side stress distribution (250.48MPa) is higher than the right-side stress distribution (206.24 MPa) by 21%.

For analysis increased the thickness from 3.5 mm to 3.7 mm and it was giving the following which is shown in Fig. 8.

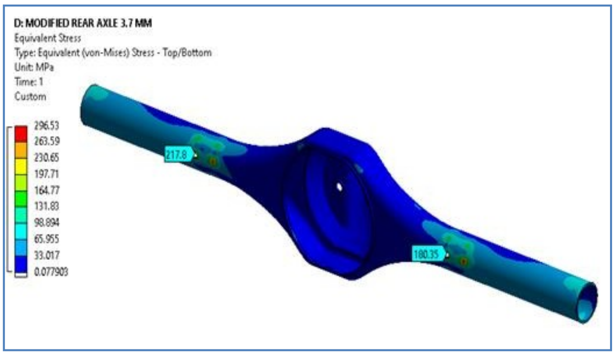

Fig. 8. Von Mises stress plot for 3.7 mm thickness

Left side stress distribution reduced up to 217.8 MPa from 250.48 MPa and right side stress distribution reduced up to 180.35 MPa from 206.24 MPa. The thickness is from 3.7 mm to 4 mm and it is given the following which is shown in Fig. 9.

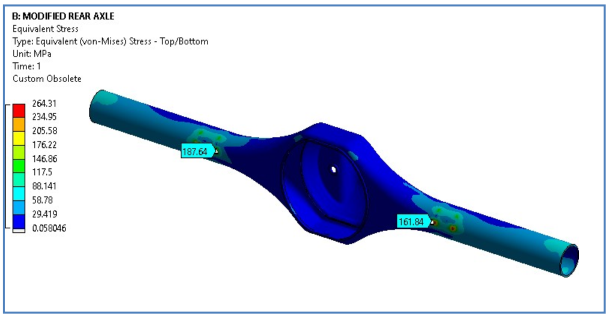

Fig. 9. Von Mises stress plot for 4 mm thickness

Left side stress distribution reduced up to 187.64 MPa from 217.8 MPa and right side stress distribution reduced up to 161.84 MPa from 180.35 MPa. The thickness from 4 mm to 4.2 mm was given which is shown in Fig. 10.

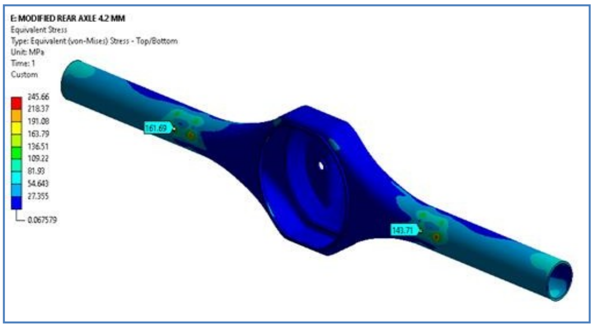

Fig. 10 Von Mises stress plot for 4.2 mm thickness

Left side stress distribution reduced up to 161.69 MPa from 187.64 MPa and right side stress distribution reduced up to 143.71 MPa from 161.84 MPa.

TABLE 3: COMPARISON OF EXPERIMENTAL AND NUMERICAL RESULTS

Sr. No.	Contact stresses on rear axle housing with strain gauges (MPa)	Contact stresses on rear axle housing for 3.5 mm thickness with FEA (MPa)	Per cent error
1	261.58	250	4.42%
2	216	206.4	4.44%

The comparison of experimental and numerical results is carried out and is shown in Table 6. The FEA results are compared with the physical test results showing a 5% error in both results which is negligible.

Table 3 shows when the thickness was 3.5 mm, left side contact stress was 250.48 MPa and right side contact stress was 206.24 MPa at which axle housing was failed. To avoid the failure, axle housing thickness was increased from 3.5 mm to 3.7 mm, 4 mm & 4.2 mm and gets the respective left side and right side contact stress values. When thickness increased to 3.7 mm, contact stresses decreased by 13% but 3.7 mm thickness material is not available in the market. Hence, 3.7 mm thickness is not feasible from the production point of view.

Then thickness increased to 4.2 mm and contact stresses decreased by 33%. If 4.2 mm thickness material is used for production it will increase the weight of the axle housing by 20% which will affect the vehicle performance. So, 4.2 mm thickness is not acceptable. Then thickness changed to 4 mm and checked contact stresses, which was decreased by 24% and weight increased by 14%. 4 mm thick raw material is also available in the market. Hence from cost, manufacturing and performance-wise 4 mm thickness is the optimized thickness. Therefore, 4 mm thickness for rear axle housing is proposed.

TABLE 4: PERCENT DECREASE IN STRESS WITH RESPECT TO THE ORIGINAL STRESS BASED ON FINITE ELEMENT ANALYSIS

Housing Thickness	Left side Von mises stress	Right side Von mises stress	Percentage decrease in stress with respect to 3.5 mm thickness
3.5	250.48	206.24	NA
3.7	217.80	180.34	13%
4	187.64	161.84	24%
4.2	161.69	143.71	33%

CONCLUSION

The failed rear axle housing of a utility vehicle is studied to check its integrity which includes a visual examination, chemical analysis, photo documentation, microhardness test, and metallographic tests to evaluate the failure. Spectrum analysis and micro-hardness measurement revealed that the failed axle housing material was BSK-46 steel. The composition, microstructure, hardness values of the raw metal were found to be satisfactory and within the specification. The fracture was initiated at the weld joint between the backplate and rear axle housing, where a stress concentration was created.

The material used in the manufacture of the rear axle housing was appropriate for this kind of application. However, less thickness of the rear axle housing element allows the formation of stress concentrators which further reduce the life of the element. Therefore, the causes of the failure of the rear axle housing were due to the Defective geometric design of the element thickness.

To a reduction in contact stresses on the rear axle housing element, a geometric design change of the element was proposed. FEA was done on 3.7 mm, 4 mm and 4.2 mm thickness. Finally, 4 mm thickness was selected. This was an optimized thickness from manufacturing, cost and vehicle performance. Therefore, in the proposed design, the thickness of the rear axle housing beam was increased by 0.5 mm. This rear axle element was modelled using the same loading and boundary conditions applied for the failed element. In the proposed case the maximum stresses were observed on the section of the element, with the highest value of 187.64 MPa approximately (24% improved as compared to the original one).

Finally, we concluded to modify rear axle housing geometry, reduce the contact stresses and avoid such types of failures.

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