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Failure investigation of a tie rod end of an automobile steering system

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Abstract

A failure analysis of a tie rod end of a sports utility vehicle (SUV) steering mechanism has been carried out in this study. The tie rod end is composed of two parts fitted together: a threaded part and an embracing part. Failure took place in the threaded part which is made of AISI 8620 steel. The vehicle had been in service for approximately two years and accumulated less than 30,000 km. An evaluation of the failed part was undertaken to determine the cause of failure and assess its integrity. Visual examination, photo documentation, chemical analysis, hardness measurement, and metallographic examination were all conducted. The failure surface was examined with the help of a scanning electron microscope (SEM) equipped with EDAX facility that determines chemical composition at desired locations within the part. Results indicated that the tie rod end had failed by fatigue with a crack initiation at the throat (minimum) area of the threaded part due to material deficiency and improper heat treatment.

Keywords: Fatigue; Crack initiation/propagation; Material property

1. Introduction

Tie rods connect the center link to the steering knuckle on automobiles with conventional suspension systems and recirculating ball steering gears, Fig. 1. On automobiles with MacPherson strut suspension and rack-and-pinion steering gears, tie rods connect the end of the rack to the steering knuckle, Fig. 2. A tie rod consists of an inner and an outer end as shown in both previous figures.

Tie rods transmit force from the steering center link or the rack gear to the steering knuckle, causing the wheels to turn. The outer tie rod end connects with an adjusting sleeve, which allows the length of the tie rod to be adjustable. This adjustment is used to set a vehicle's toes, a critical alignment angle, sometimes referred to as the caster and camber angles.

A vehicle's steering and suspension systems should be checked regularly, at least once a year along with a complete wheel alignment. A worn tie rod end, due to rubbing and wearing, can cause wandering, erratic

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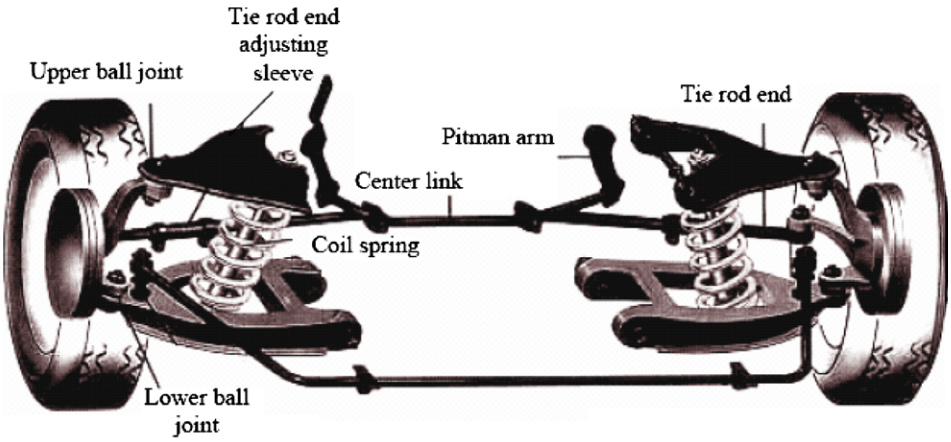

Fig. 1. Conventional suspension.

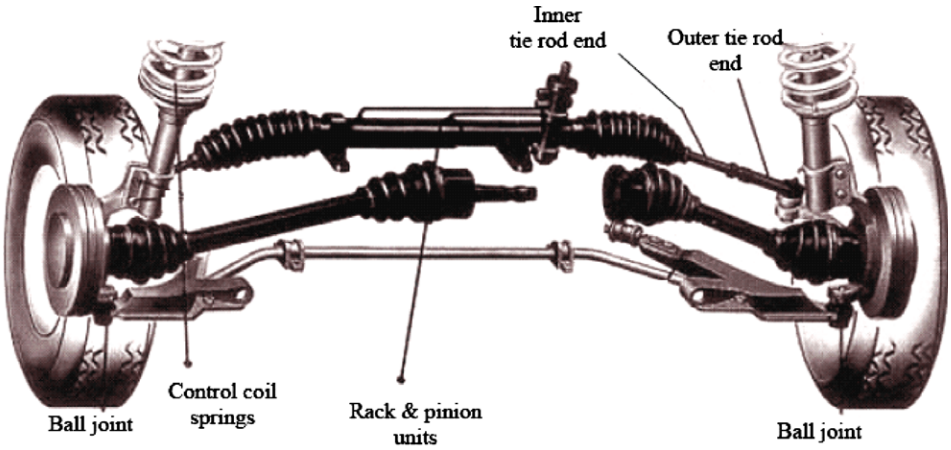

Fig. 2. McPherson suspension with rack and pinion.

steering and excessive tire wear. If tie rod replacement is necessary, a wheel alignment is also required because tie rod replacement disturbs the toe setting.

Tie rods may fail in many different ways, and except for a slight increase in noise level and vibration, there is often no indication of difficulty until total failure occurs. In general, each type of failure leaves characteristic clues, and detailed examination often yields enough information to establish the cause of failure. The general types of tie rod failure modes include fatigue, impact fracture, wear and stress rupture [1]. Several causes of tie rod end failure have been identified. These include poor design, incorrect assembly, overloads, inadvertent stress raisers or subsurface defects in critical areas, use of incorrect materials and/or manufacture process, and improper heat treatment [2]. Tie rods in automobile suspension are generally robust and reliable components. However, problems do occur particularly due to manufacture error or driver misuse [3].

The case under investigation involves failure of the outer part of an automobile tie rod. It was brought for analysis by the investigation bureau of the Ministry of Interior over a legal dispute between the driver of an SUV and a local car dealer who sold him the vehicle. The vehicle was driven for nearly two years and had registered less than 30,000 km. The driver claimed that while he was driving the vehicle, a sudden bang was heard and he lost control of the vehicle and hit the median rail guard of the highway. The vehicle was damaged and the driver, though still conscious, was slightly injured. He believed that there was something went suddenly wrong with a mechanical component of the vehicle and that caused the accident. The local car dealer, on the other hand, disagreed with the driver's scenario on grounds that the manufacturer produced thousands

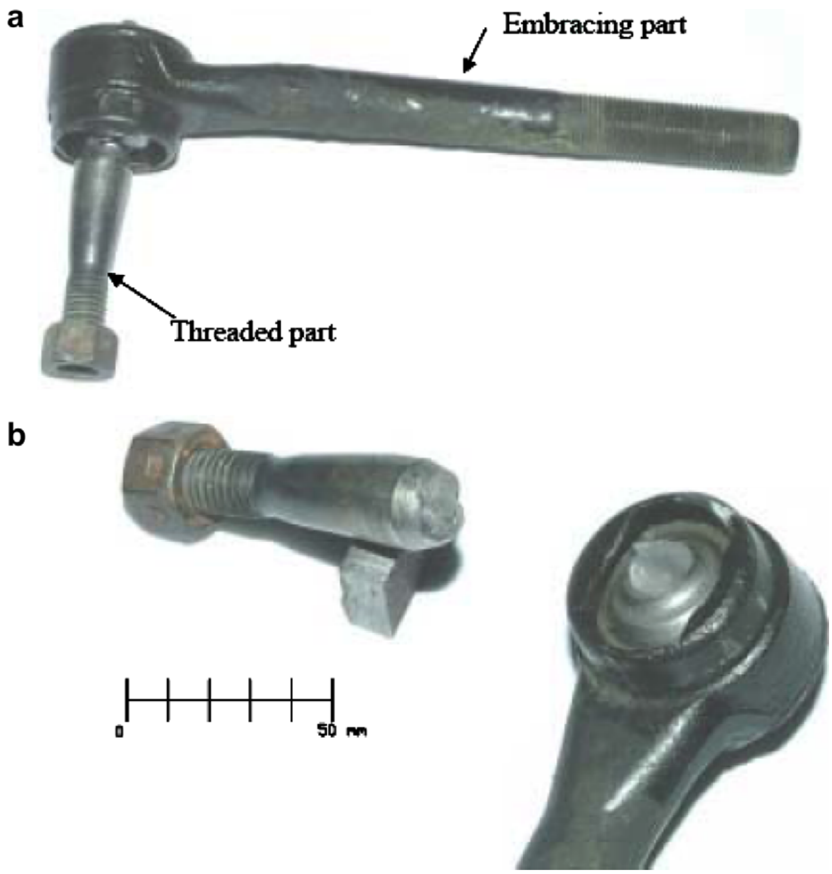

Fig. 3. Parts of fractured tie rod end (a) assembled and (b) separated.

of such vehicles every year and they were, and still are, running fine all over the world without any reported serious failure. The dealer attributed the accident to careless driving behavior that resulted in a loss of control over the vehicle, which in turn hit the guard rail and led to vehicle damage. To settle the dispute, it was decided to undertake a thorough failure analysis investigation of all components of the steering mechanism to determine the cause of failure. All steering components were found intact though badly bent, except for the outer tie rod end which was fractured at the throated area of its threaded part. The embracing part of the outer tie rod end, however, was intact, except for two scars at its rim that could have happened when the threaded part broke into two pieces. The general appearance of the parts of the failed tie rod end is shown in Fig. 3a, where the two fragmented pieces of the threaded part were brought together to show how the tie rod end appeared before failure. Fig. 3b shows the two fractured parts separated. Fig. 4 gives the visual appearance of the embracing part and one fragment of the threaded part, both facing up. It is clear that fracture took place at the throat area of the threaded part where stress is expected to be high due to reduced cross sectional area and stress concentration. Further examination of the threaded part was conducted to determine the exact cause of failure.

2. Experimental procedure

The failed threaded part of the tie rod end was inspected visually and macroscopically taking care to avoid damage of fractured surface. The failed threaded part of the tie rod end was ultrasonically cleaned prior to microscopic examination, photo documentation, chemical analysis and hardness measurement at the fracture surface and away from it. Scanning electron microscope (SEM) equipped with EDAX facility and an optical microscope were both used in the investigation.

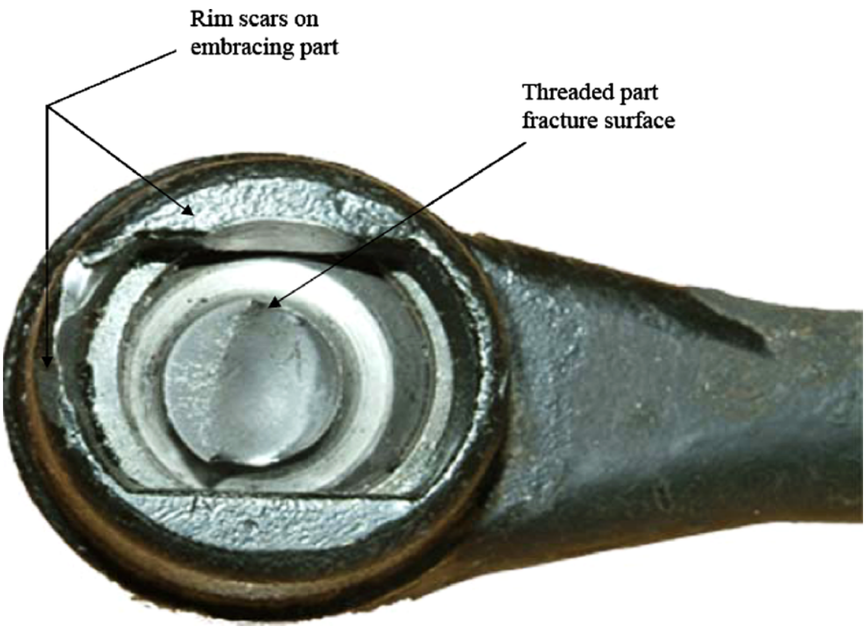

Fig. 4. Threaded part fracture surface and rim scars on embracing part.

3. Results and discussion

Chemical analysis using atomic absorption spectrophotometry was carried out at several locations of the failed threaded part of the tie rod end and the average values of the test results are given in Table 1 along with the specified chemical composition. Spectrum analysis revealed that the threaded part material was AISI 8620 steel which is usually used for main automobile steering components. The low percentage of manganese and of chromium in the tested sample suggests that the final hardness of the part would be substantially reduced. On the other hand, the high percentage of nickel in the tested sample would result in lower toughness thereby compromising the mechanical property that is required to withstand impact loads resulting from bumpy roads. The surface hardness of the fractured tie rod end was measured to be 45.6 HRC. This suggests that the tie rod was not hardened properly, since hardness of tie rods, in general, is expected in the range of fifties for such applications.

It is evident from Fig. 4 that there exist two distinct areas on the fracture surface; one is smooth while the other is relatively rough. This is a typical fatigue fracture where crack originates at the edge of the smooth area and propagates towards the rough area, which represents final failure. On the other hand, the smooth area of the fracture surface is dominant as seen in Fig. 4. This indicates that the tie rod end took some time to break from the instant of crack initiation till complete fracture; i.e. a high cycle fatigue failure case. This proves that

Table 1
Chemical composition of failed threaded part of tie rod end and AISI 8620 steel

Element	Failed tie-rod end	Specified chemical composition of AISI 8620 steel	Comment
% C	0.195	0.18–0.23	Within range
% Si	0.238	0.20–0.35	Within range
% Mn	0.580	0.70–0.90	Low
% Ni	1.654	0.40–0.70	High
% Cr	0.089	0.40–0.60	Low
% MO	0.214	0.15–0.25	Within range
% S	0.017	$\leqslant$0.040	Within range
% P	0.009	$\leqslant$0.035	Within range

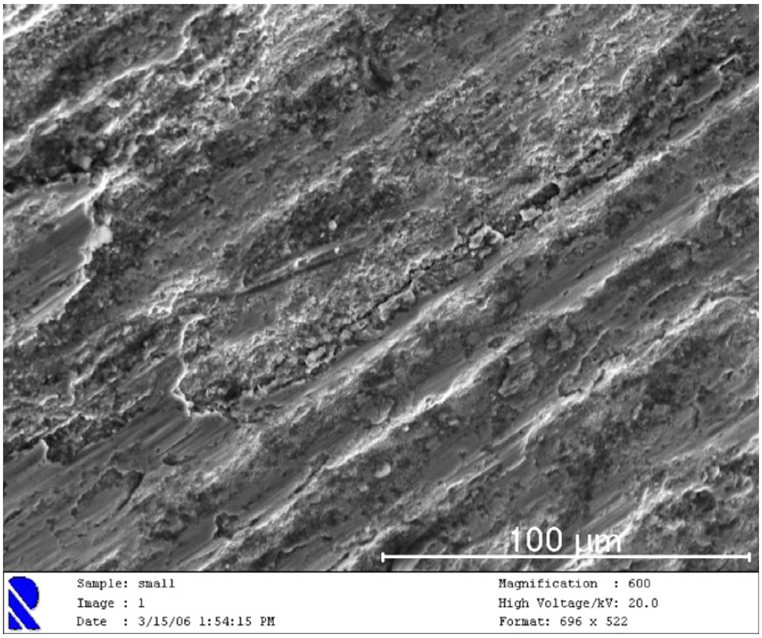

Fig. 5. SEM micrograph showing crack propagation region.

the cause of the SUV accident was a lack of strength and low resistance to impact loads in the material of the threaded part of the tie rod end that initiated a crack and then took some time to reach complete separation.

A specimen from the fractured surface was metallographically prepared and observed in a scanning electron microscope (SEM). Significant fatigue cracks were observed at the smooth area of the fracture surface. The origin of cracks was at the edge of the smooth area of the threaded part throat, suggesting that the stresses were highest at this region. Fig. 5 shows crack propagation on the fracture surface. Beach marks can be observed clearly which is a typical feature of fatigue failure [4].

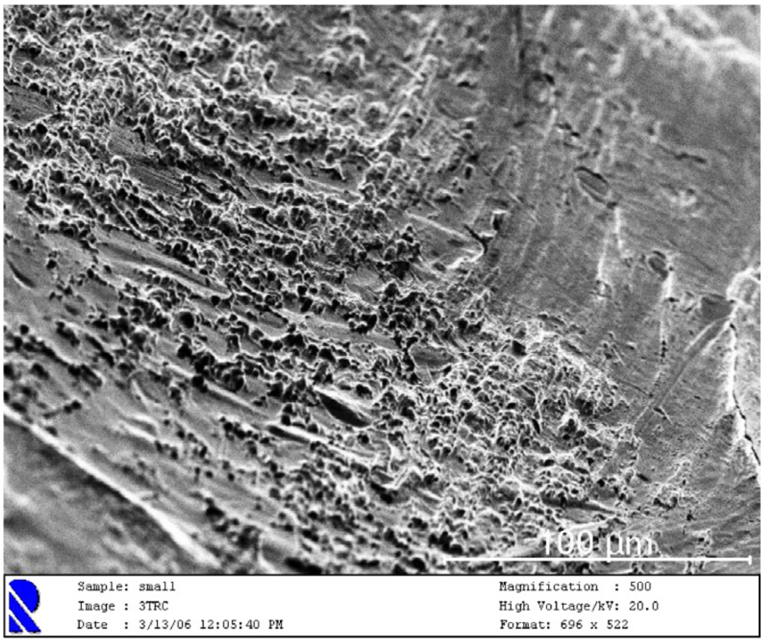

Fig. 6. SEM micrograph showing typical brittle fracture observed in final stage of crack propagation zone.

The origin of the crack was surrounded by beach marks. Also, the fracture surface at the fatigue region had a smooth appearance with a rippled beach mark pattern which indicates that fatigue had initiated at one point of the circumference and then grown across the fracture area. A small area has a rough, jagged look where the last portion of the throat broke away. No corrosion media were found on fracture surfaces.

Brittle fracture was observed in the final stage at crack propagation as seen in Fig. 6. Fig. 7 shows the micrography of the rough area of the fracture surface where variation of grain size combined with shallow dimples is evident. The light lines surrounding the grains in the figure indicate intergranular cracking that

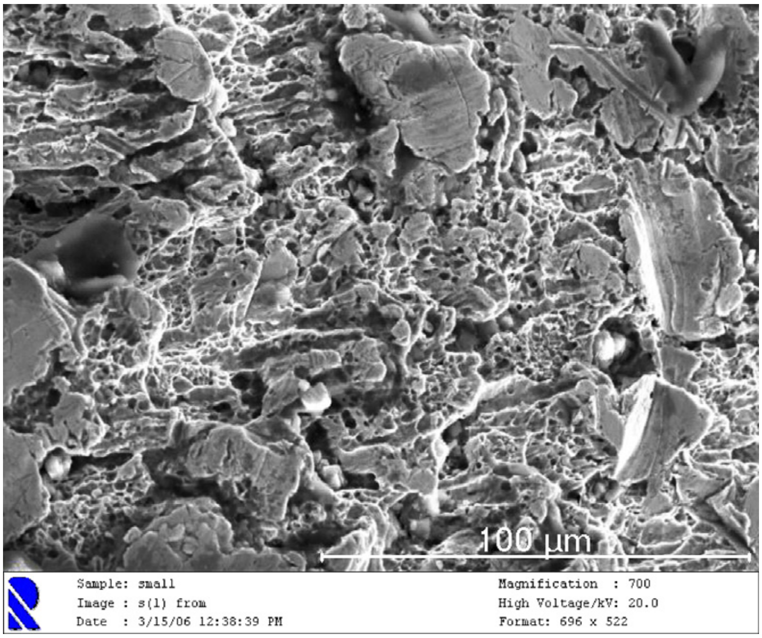

Fig. 7. SEM micrograph of the last portion of fracture surface to break away.

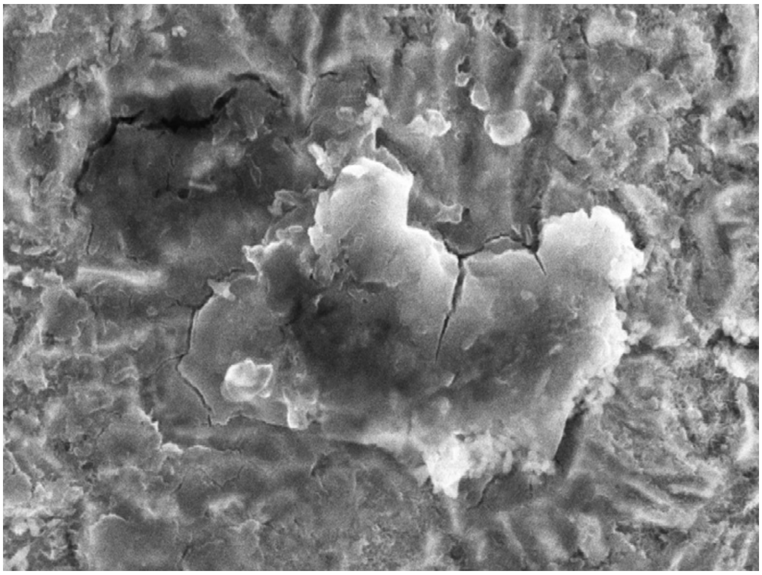

Fig. 8. Close-up showing both intergranular and transgranular cracking.

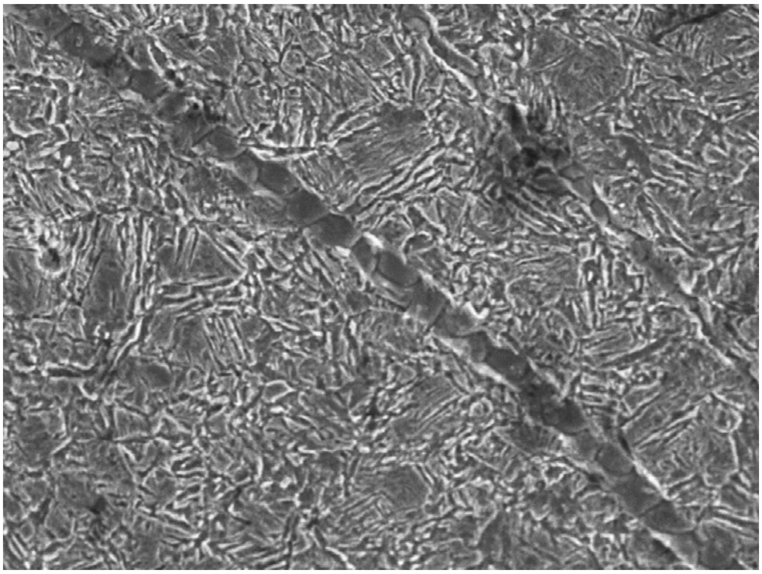

Fig. 9. Micrograph of thread part showing Pearlite (Finger prints Matrix) and α–Ferrite (sample was etched with 2% Nital).

is usually observed with brittle fracture. A close-up of such grains revealed both intergranular and transgranular cracking at some locations as shown in Fig. 8.

Quantitative chemical analysis was carried out by EDAX attached to SEM on the fracture surface to verify the presence of any other associated components. No presence of any detrimental foreign elements was observed.

Metallographic view of a sample cut from the threaded part after polishing and etching with 2% Nital solution is shown in Fig. 9. As shown, the microstructure consists of pearlite (finger print appearance) and ferrite (which appears dark). This is typical of unhardened low carbon steel. No abnormality was observed in the microstructure.

From the above observation, it can be ascertained that failure was caused by high stress concentration at the throat area mainly due to inadequate chemical composition which contributed to reduction in material strength and lack of toughness. Under the cyclic loading produced from driving the SUV on regular and bumpy roads, fatigue cracks had initiated at these stress concentration points, namely the throat, leading to fracture of the part at the instant when the local stress exceeded the material strength. It should be mentioned, as well, that every so often, the increased noise and vibration due to crack propagation go unnoticed till failure unexpectedly occurs. In order to further improve the durability of the tie rod end to stand the applied loads, it is suggested to increase the cross-sectional area of the threaded part throat and to enlarge the fillet radius.

4. Conclusion

This study was conducted on a failed tie rod end of a SUV. Spectrum analysis and hardness measurement revealed that the failed part was AISI 8620 steel. The composition and hardness did not conform to the specified standard. Fractographic features indicated that fatigue was the main cause of failure of the tie rod end. On the fracture surface of the threaded part of the rod, the crack initiation region and beach marks could be clearly identified. It was observed that the fatigue crack originated from destructive areas in the vicinity of the throat and propagated from there. Failure analysis results indicate that the primary cause of failure of the tie rod was likely material deficiency. Formation of the crack initiation and propagation together with a final rupture within the fractured area supported this hypothesis and are, thus, in agreement with the claim of the SUV driver that the accident took place as a result of incompatible mechanical part, in this instance, the tie-rod end.

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