Failure Mode Analysis of Automotive Final Drive Gears

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Abstract. After repeated complaints from customers about failure, the crown and pinion assembly of the vehicle was analyzed by standard metallurgical methods. Standard material composition of the part was confirmed by chemical analysis. Tooth contact analysis was done to understand the contact and sequence of failure. Micro hardness test was done to understand about the hardness of the specimen. The nature of fracture is studied by subjecting the specimen to micro-structural study. It was found that the effect of combination of low case hardness and improper composition was augmented by improper alignment while assembling caused premature failure of the component.

Keywords: Failure analysis · Material · Testing · Gear

1 Introduction

Life expectancy of any mechanical system dependents on the life of its critical components. In the power train of an automobile, gears are critical components. Gears in power train should carry high loads at high speeds with minimum size and weight. In gears, tooth bending fatigue has been one of the most common fatigue failure modes. Tooth bending fatigue results in progressive damage to gear teeth which ultimately result in complete failure of the gear [1] (Fig. 1).

In this work a pair of crown wheel and pinion, from the final drive of a passenger car, was tested to find out the cause of their failure. The final drive transmits power from the transmission box to the live axles through the differential unit. The crown pinion transmits power from the propeller shaft to the crown wheel which carries the differential assembly in a carrier. Often combinations of two or three types of stresses are applied to a gear tooth [2]. Also, complex phenomena of failure are involved for surface hardened components during their working life; therefore a deeper comprehension of the damaging mechanisms is necessary to prevent the failure [3].

En353 (15 Ni Cr 1 Mo12) [for heavy- duty applications] and En 207 (20Mn Cr1) [for medium applications] are the two common billet materials used to manufacture these gears.

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Fig. 1. Failed crown and pinion

2 Tests and Analysis

2.1 Visual Inspection

From standards, the life expectancy of the failed part should have been between 150000 km and 200000 km. During visual inspection, cold weld on the edge of the broken tooth of the gear were found. There were indications showing that the crown wheel and pinion were relatively new. The pinion had sub case fatigue initiated by fine cracks. Large fragments have been removed from the teeth. The gear also had fatigue beach marks.

The drive members were subjected to macro examination using a stereomicroscope for pitting failure. Gear teeth pitting is characterized by the presence of small pits on the contact surfaces.

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2.2 Chemical Analysis

Chemical analyses were done at two different locations on the gear. Portions of the specimen, at the damaged portion and at where the surface was good, was cut using abrasive cut off wheel and chemical analysis was carried out. The chemical analysis would help to identify the variation in the basic composition of the material by comparing with the manufacturer standards.

The EDX analysis [5] done on new component and failed component are shown in Figs. 2 and 3 respectively. It was learnt that En353 was used to manufacture the parts. The carbon equivalent (CE) for the failed component was found to be 0.77. From the chemical analysis it was understood that one of the reason of failure was wrong selection of material. Also, the manufacturer had changed the composition by increasing percentage of manganese. This reduced the carbon content which resulted in low core hardness. This modification also contributed to premature failure of components. Tables 1 and 2, respectively, shows chemical analysis result for new and failed components.

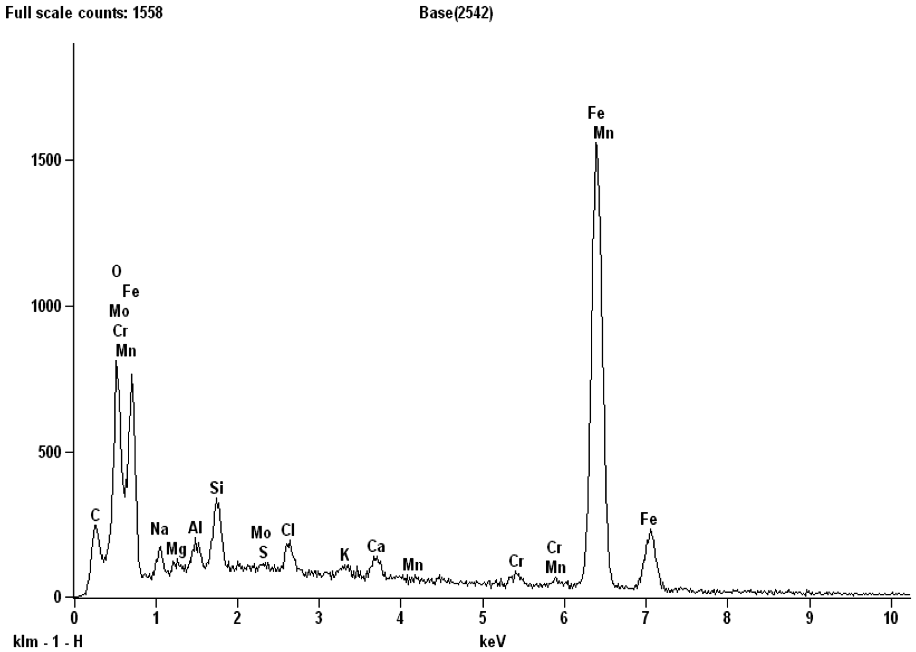

Fig. 2. EDX analysis done on good surface

Table 1. Chemical analysis done on good surface

Element	Net counts	Net counts error	Weight %	Atom %	Formula	Compound %
C	1653	±159	16.71	39.87	C	16.71
O	5423	±663	10.86	19.45	O	10.86
Na	1038	±300	1.76	2.20	Na	1.76
Mg	423	±192	0.35	0.41	Mg	0.35
Al	1210	±363	0.87	0.92	Al	0.87
Si	2763	±390	1.71	1.74	Si	1.71
S	185	±204	0.13	0.11	S	0.13
Cl	1477	±405	1.07	0.87	Cl	1.07
K	417	±183	0.33	0.24	K	0.33
Ca	967	±195	0.85	0.60	Ca	0.85
Cr	547	±177	0.75	0.41	Cr	0.75
Mn	241	±195	0.50	0.26	Mn	0.50
Fe	27135	±879	64.13	32.91	Fe	64.13
Mo	0	0	0	0	0	0
Total			100.00	100.00		100.00

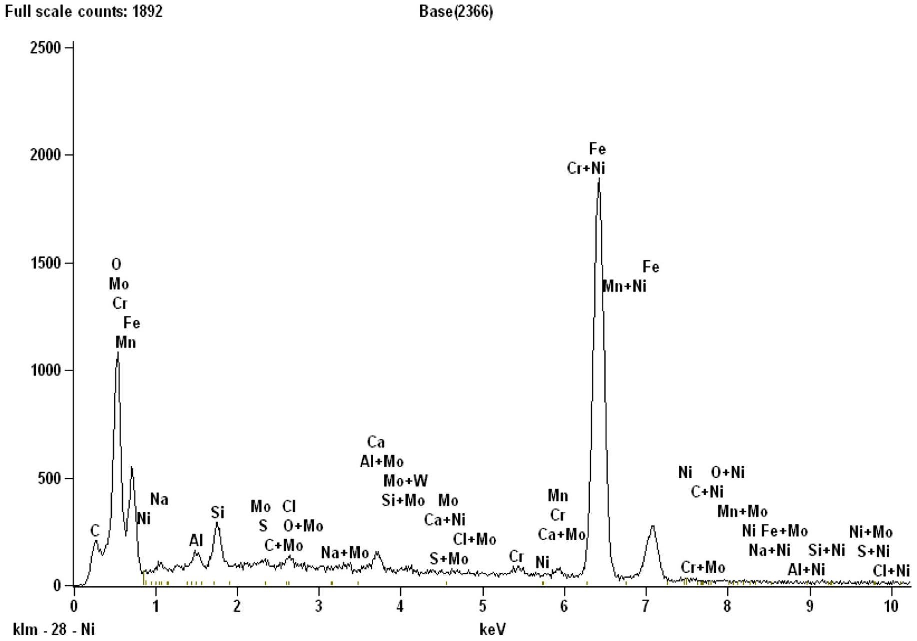

Fig. 3. EDX analysis of damaged surface

Table 2. Chemical analysis done on damaged surface

Element	Net counts	Net counts error	Weight %	Atom %	Formula	Compound %
C	1240	±150	11.05	29.08	C	11.05
O	8142	±684	13.17	26.03	O	13.17
Na	448	±132	0.73	1.00	Na	0.73
Al	666	±165	0.45	0.52	Al	0.45
Si	2037	±204	1.17	1.31	Si	1.17
S	344	±201	0.22	0.21	S	0.22
Cl	538	±198	0.36	0.32	Cl	0.36
Ca	1378	±405	1.09	0.86	Ca	1.09
Cr	458	±189	0.56	0.34	Cr	0.56
Mn	453	±213	0.85	0.49	Mn	0.85
Fe	32623	±969	69.94	39.50	Fe	69.94
Mo	305	0	0	0	0	0
Ni	120	±185	0.41	0.32	Ni	0.41
Total		100.00	100.00		100.00	

2.3 Tooth Contact Studies

Surface contact fatigue is the most common cause of gear failure. It results in damage to contacting surfaces which can significantly reduce the load-carrying capacity of components, and may ultimately lead to complete failure of a gear [4]. It has been shown that corrosive wear at tooth fillet can cause pitting, intense localized plastic strain and folds leading to crack formation [6]. The contact and sequence of failure of the gear can be studied by tooth contact study. In this analysis, the failed pinion was revolved on crown wheel by referring the index number given in block cone face of the crown wheel and the shank of the pinion. The gear ratio is 6.1 and the index number of failed teeth of crown wheel is 14, 15, 16 and 26. Table 3 shows tooth contact analysis of crown wheel and pinion.

The failed pinion did not affect all the teeth of crown it mate with. For the failure to occur in all the identified teeth, it is learnt, the crown wheel might have revolved at least six times after the initial failure. The sequence indicates a fairly gradual progression of the damage which ended with the cold weld. The mode of failure of crown wheel is by partial uprooting. The gear teeth have been chipped off from all around the edges of crown wheel. It is revealed that a partial mating between the pinion and crown wheel could have happened due to improper alignment. The misalignment might have developed a high stress between the teeth in contact. This increased load might have resulted in the characteristic teeth chipping.

The sequence in which the failed tooth of the pinion mated with crown wheel is represented in the table given below. Also shown is the level of damage observed during visual inspection. The sequence in which the fracture in crown wheel has occurred is 14, 26, 15, and 16.

Table 3. Tooth contact analysis of crown wheel and pinion

Revolution of crown wheel	Sequence of contact of failed pinion teeth with crown wheel indicating the level of damage						
1	2	8	14 (damaged)	20	26 (damaged)	32	
2	6	12	18	24	30	36	
3	3	9	15 (damaged)	21	27	33	
4	1	7	13	19	25	31	37
5	4	10	16 (damaged)	22	28	34	
6	5	11	17	23	29	36	

2.4 Micro Hardness Test

Micro Vicker's hardness test was done on a sample specimen taken from the crown wheel and the data obtained is shown in Table 4. The hardness values measured from the specimen at varies points are given in the table given below.

Case carburized material has varying hardness from the case to the core. Micro hardness survey gives a better picture on this. For the failed gear, core hardness was measured near the center of base of the damaged tooth. The measured hardness is 276.6 HV, whereas the desired core hardness is between 317 and 401 HV. This means that the failed part had very low case hardness. It can be concluded that the low hardness also contributed to the premature failure (Figs. 4, 5 and 6).

Table 4. The hardness values of crown wheel

S. no	Distance from the surface (mm)	Micro Vickers Hardness (HV 1 kg)
1.	0.1	428.3
2.	0.3	449.8
3.	0.5	453.1
4.	0.7	404.8
5.	0.9	401.3
6.	1.1	439.5
7.	1.3	393.5
8.	1.5	386.1
9.	1.7	382.6
10.	1.9	373.4
11.	2.1	341.5
12.	2.3	340.3
13.	2.4	331.7
14.	2.5	275.7
15.	2.6	293.3
Core hardness	276.6, 283.0, 291.5 HV 1	

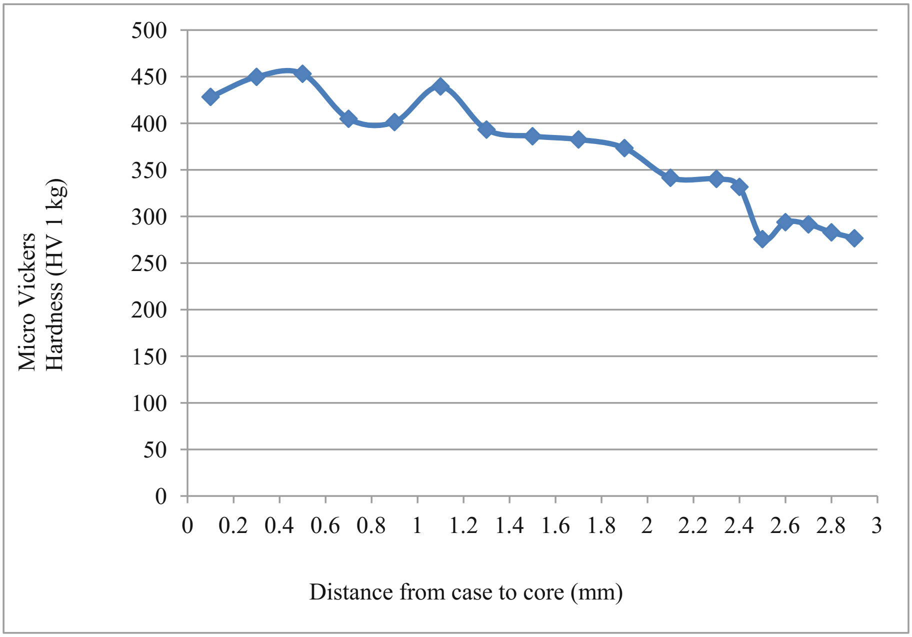

Fig. 4. Micro hardness graph

Fig. 5. SEM image of the failed part

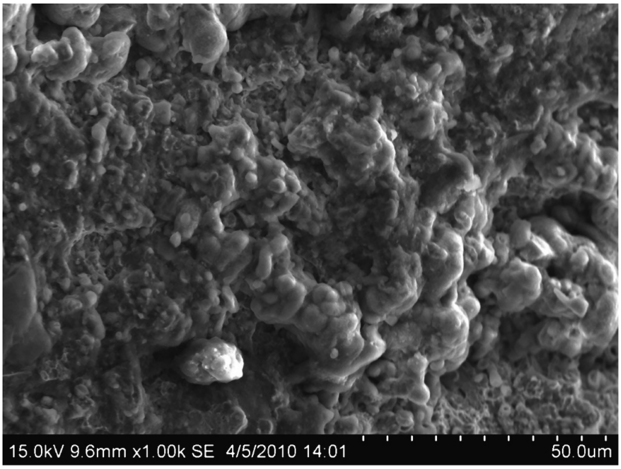

Fig. 6. SEM image of original part

3 Microstructure

Fractography would reveal the nature of fracture in a component. A portion of the failed part was cut and is subjected to micro structural study using scanning electron microscope [SEM]. The case and core micro structure of the failed component are shown below. The study revealed that the mode in which the fracture has occurred is highly brittle in nature. This is evident by the cleavage facets. The SEM images of the specimen are shown in the following figures.

4 Conclusion

The extensive study shows various parameters played their role in different ways causing premature failure of the component. The study implies wrong selection of material as the major cause of failure of the component. Moreover, the manufacturer modification in the selected composition also played an important role. Usage of improper material composition resulted in poor core hardness. Low hardness has resulted in premature failure of the gear. Low case hardness when augmented with misaligned parts assembly has caused severe pitting of the gear teeth.

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