Enhancing the material properties of EN24 pinion material by heat treatment process

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Abstract. The failure analysis was carried out on a failed pinion gear which is used for power transmission system in the automobile sector. The pinion gear is made of case carburized steel with low nickel and chromium content and it also has undergone extensive corrosion due to an environmental problem. The teeth are badly damaged and corroded at the surface. However, the crack has occurred due to stress and it is found only in certain places. To improve the corrosion resistance, nickel and chromium content are added and also heat treatment is carried out. The mechanical properties and wear resistance are improved in EN24 steel when compared to failure gear and EN24 steel before heat treatment.

1. Introduction
A Wear and fracture of gears is the major problem in all industries. The failure occurs due to chemical composition and material selection etc. Wear has been defined as the material removed from solid surfaces, which causes the failure of industrial components. Many investigators investigate the wear for many years but wear could not be avoided but it was minimized. The wear and wear rate extensively depend on chemical composition, microstructure, surface properties of materials and the load level. At the time of contact between the disc and the pin heavy wear occurs in low load level. As the result, high wear rate occurs and after some period of time, wear mode changes to steady.

The process of heat treatment is carried out by heating the base material above critical temperature and then cooling with salt water, air and oil. The purpose of the heat treatment is to increase the strength, to change the grain size, to modify the structure of the base material and to relieve the internal stress in the material after hot and cold working processes.

In this experiment, gas nitriding process was carried out on EN24 steel at 515°C for 180 minutes followed by oil quenching at 535°C for 60 minutes and tempering at 250°C for 90 minutes.

2. Literature Review
The pinion is the critical component in power transmission systems in the automobile sector. The study concludes that the failure is due to the compromise made by the manufacturer in raw material composition because nickel and chromium costs are high, which is evident by the presence of low nickel and chromium content.
Bhat et al. [1] studied the strengthening and apparently intrinsic brittleness of secondary hardening steel. Finally, the enhancement of toughness from the partial substitution of silicon by aluminum is considered. Bhaumik [2] analyzed the failure of an intermediate gearbox of a helicopter. The gear had fractured into pieces. The broken pieces of the gear were examined to identify the mode of fracture. The hardness survey of the gear tooth was carried out using a microhardness tester. The results indicate that the fatigue cracks initiated at the gear.

Das et al. [3] analyzed the failure for the fracture of the pinion. The fracture resistance of the material was reduced by the presence of elongated sulphide particles. Misalignment also led to the generation of high stress. Finally, the results indicated that the fracture was caused by fatigue and the fatigue crack initiated from one of the pinion teeth. Enver et al. [4] conducted abrasive wear tests on a wear cup model device. Corrosion tests were undertaken in a 10% H₂SO₄ solution at a temperature of 56°C. Finally, the result determines that the boride layer had toothed structure and the structure was homogeneously distributed over the surface.

Jiwang Zhang et al. [5] enhanced the microstructure, mechanical properties and fracture behavior by using a heat treatment process. Finally, the austempering temperature is decreased and yield strength and tensile strength of the Austempered Ductile Iron (ADI) is increased. A decrease in both elongation and impact energy are found. Khorsand et al. [6] investigated the fatigue test and wear test for wear, tensile and compression mode. Finally, the result shows that fatigue strength increased and wear decreased by heat treatment processes.

Kiyoshi Funatani [7] enhanced the effective use of materials and to achieve the desired properties of the component, bake hardening technology is used to improve body strength. Various corrosion resistant coatings are used for panels and case hardening is used to improve hardness. This paper presented an overview of the materials as well as the heat treatment and surface technologies. Liu sheng-Fa et al. [8] investigated the new developed Mn-Cu alloyed by optical microscope, scanning electron microscope and performance measurements. Finally, the results indicated an improvement in the wear resistance, performance and fatigue behavior of the alloy.

Myounggu Park [9] analyzed the failure of a bevel gear installed on a turbojet engine. There is no surface defect on the failed bevel gear. The reason for failure is improper surface heat treatment. As a result, tooth bending fatigue was caused by improper case hardening. Siti Khadijah Alias et al. [10] enhanced the strength and hardness properties. Samples are prepared and polished according to ASTM standards. The result depicted that paste carburized samples provided a significant improvement in both tensile strength and hardness values compare to uncarburized samples. Ugur Cavda et al. [11] analyzed the powder metal compacts prepared by mixing iron powder. The compacts used a conventional sintering furnace. The results showed that, in carbonitrided samples, there is highest bending strength and in boronized samples, there is highest surface hardness and the densities increased by heat treatment processes.

3. Experimental Setup

The experimental investigation is conducted on failure pinion case-carburized steel. The following methodology is used to analyze and improve the tribological properties.

3.1. Visual examination

Visual examination is done on the fracture surface of the failed pinion, after cleaning with acetone, figure 1 shows the presence of cracks on the edge of a spur gear tooth. In a failed pinion gear, the front side of the spur gear tooth had a smooth surface, while the other side had a rough surface due to improper contact during operation. Small pieces were cut from the failure pinion and prepared for metallographic examination.
3.2. Material identification

Material identification is carried out using an optical emission spectrometer. The failure pinion indicated that the pinion material was case carburized steel and its chemical composition is shown in Table 1. The chemical elements show that there is a lack of nickel and chromium content. Then the alternative material is EN24 steel. The chemical composition of EN24 steel is shown in Table 2.

Table 1. Chemical composition of steel.

| Elements    | Composition % |
|-------------|---------------|
| Carbon      | 0.16          |
| Silicon     | 0.25          |
| Manganese   | 0.78          |
| Chromium    | 1.03          |
| Nickel      | 1.212         |
| Molybdenum  | 0.124         |
| Vanadium    | 0.005         |
| Sulphur     | 0.023         |
| Phosphorous | 0.014         |
| Aluminium   | 0.030         |
| Cobalt      | 0.002         |
| Copper      | 0.237         |
| Niobium     | 0.003         |
| Titanium    | 0.003         |
| Tungsten    | 0.01          |
| Antimony    | 0.004         |
| Tin         | 0.015         |
| Iron        | Remainder     |
Table 2. Chemical composition of EN24 steel.

| Elements          | Composition % |
|-------------------|---------------|
| Carbon            | 0.447         |
| Silicon           | 0.255         |
| Manganese         | 0.483         |
| Chromium          | 1.023         |
| Nickel            | 1.360         |
| Molybdenum        | 0.211         |
| Vanadium          | 0.025         |
| Sulphur           | 0.013         |
| Phosphorous       | 0.017         |
| Aluminium         | 0.005         |
| Copper            | 0.122         |
| Titanium          | 0.004         |
| Tungsten          | 0.040         |
| Vanadium          | 0.025         |
| Iron              | 95.99         |
| Lead              | 0.005         |

3.3. Hardness

The hardness of the core and case of the failed pinion (base material), before and after heat treatment of EN24 steel are measured using a Rockwell hardness with 150 kg load, was found to be 30-40 RC, 42-50 RC before heat treatment (BHT) and 60-50 RC after heat treatment (AHT). The surface hardness locations are shown in figure 2. The hardness values at the different locations of the specimen are plotted as a graph as shown in figure 3. The graph shows that the hardness value is different between BHT and AHT and hardness value of AHT is higher than that of BHT.

Figure 2. Rockwell hardness sample location.
3.4. Vickers Hardness Test
Micro hardness measurements with 200 g load, is performed on the carburized steel and the readings are taken at least five times. The hardness sample location is shown in figure 4 and the results are shown in figure 5. In the failed pinion, hardness of the surface was different for inner tooth and outer tooth. From figure 5, it has been found that the hardness value goes on decreasing with increase in depth. The comparative results of BHT and AHT shows that the hardness values are higher in case of AHT.

3.5. Microstructural examination
The microstructure of the failed gear tooth showed a dark etched area close to the pinion surface clearly indicating that, the pinion material was surface hardened and the microscope image is shown in...
the below figure 6. The high carbon content present in the case caused faster etching, and therefore it was confirmed that the pinion material was case carburized which is clear from the figure 7.

![Microscopic image of failed gear tooth](image1)

**Figure 6.** Microscopic image of failed gear tooth - magnification: 20x.

![Microstructure examination](image2)

**Figure 7.** Microstructure examination of failed gear tooth - magnification: 60x

The fractured sample was prepared for the micro-examinations. The microstructure at different locations of the fracture was determined by sectioning samples from the cracked surface both in the longitudinal and transverse directions as shown in figure 8 and figure 9.

![Edge of gear](image3)

**Figure 8.** Edge of gear.
Similar micro cracks were also observed at the corners of the tooth of the failed pinion, with one of the micro cracks initiating from the fillet of the failed pinion. Figure 10 shows the core with coarse tempered martensite and figure 11 shows the case with erosion due to corrosion and the microstructure is fine tempered martensite of the alternative material EN24 steel after heat treatment.

3.6. Wear-Test (Pin on Disc Method)
Wear test has been conducted on the pin on disc with a load capacity of 1 kg and 2 kg respectively in figure 12 and figure 13.
From figure 12 and figure 13, it is clear that the wear rate in case of BHT is higher than that of AHT. The same condition is seen in both the cases of 1 kg and 2 kg loading. From the results, it is clear that the heat treatment of the material increases the wear properties.

4. Conclusion
The failure analysis of pinion is made up of case carburized steel with low nickel and chromium content and also it has undergone extensive corrosion due to an environmental problem. The failure analysis of pinion shows the teeth are badly corroded at the surface. However, the crack is due to stress corrosion cracking and found only at certain places. High nickel and chromium content steel (EN24) are selected to overcome the failure. The gas nitriding process improves the mechanical properties of steel. The mechanical properties such as hardness, wear and tensile are improved when compared to case carburized steel and EN24 steel before heat treatment.

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