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Effect of Phosphorus in the Heat Treatment of En353 Steel Gears

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Abstract: **This article deals with the effect of phosphorus in the heat treatment of EN353 steel gears. The study was initiated due to the frequent rejections of EN353 steel gears because of the bending fatigue failure occurring during its service life. For manufacturing a gear, processes like hot forging, annealing, phosphating, Molybdenum disulphide treatment, cold forging and finally carburizing treatment are undertaken. After the manufacturing process, there was an indication of white layer beneath the carburized layer in the microstructure. This was found to be due to the presence of phosphorus by the use of Energy Dispersive X-ray Spectroscopy that seemed to be detrimental to the fatigue properties. The SEM analysis was also made to confirm the presence of phosphide. The effect of phosphorus was studied and dephosphating was carried out for various time intervals before heat treatment in order to eliminate the white phosphide layer and the standard time for dephosphating was analysed. This in turn could result in the increased fatigue life of the gears as the presence of phosphide was removed.**

1. INTRODUCTION

EN 353 steel is the most common and cheapest steel which find its mechanical properties applicable in automobile applications such as heavy duty gears, shafts pinions, camshafts etc. It has a carbon content of 0.16%, and so it is neither too brittle nor too ductile because of its low carbon content and low hardness. Here in this paper we deal with case carburized EN 353 steel gears. The gear manufacturing follow steps like hot forging, which is then subjected to annealing. Phosphating is done prior to cold forging and molybdenum disulphide coating for lubrication. It is then case carburized. These gears were rejected because of the bending fatigue failure which reduced the life of gears. Therefore it is important to increase the fatigue strength of gears, to attain a high load carrying ability and improving the component reliability. The reason for the cause of failure was analyzed from the heat treated microstructure. This indicated the presence of tempered martensite and retained austenite along with a white layer beneath the carburized layer. EDS study was made on the white layer. This indicated the presence of phosphorus. Further SEM analysis was made to indicate the phosphide layer.

The effects of phosphorous content on a carburized SAE 4320 steel showed that high phosphorous levels enhance phosphorous segregation to austenite grain boundaries and considerably lower bending fatigue endurance limits. An increase in phosphorous from 0.017 to 0.031 weight percent reduced endurance limits from 1075 to 875 MPa[1]. This paper deals with the identification for the cause of failure and a remedy to overcome this phosphor presence by dephosphating. Dephospahating time was standardized by performing various trials.

2. EXPERIMENTAL WORK

This experimental work gives a detailed idea of what causes the white layer, their ill effects and by which the life of gear is enhanced by the elimination of it. Three trials were conducted and conclusions were drawn from the research papers and the experimental study. The general procedure began with the selection of desired raw material which was cut and made in the form of billet. Shot blasting was carried out and hot forging was done. Annealing was performed using pit type furnace then after which Zinc phosphating was carried out.

Table 1. Composition

Element	Percent	
	Min	Max
Carbon	0.16	0.22
Silicon	0.10	0.35
Manganese	0.80	1.10
Phosphorus	-	0.035
Sulphur	-	0.020
Chromium	0.80	1.20
Molybdenum	0.10	0.20
Nickel	1.00	1.20
Aluminium	0.02	0.05

Molybdenum disulphide coating was applied for lubrication. The gear was cold formed for a good surface finish and accuracy. Pre-machining was done and then the gear was subjected to carburizing. Carburizing was carried out at a temperature of 930°C followed by hardening at 850°C and quenching at 220°C. This was followed by hot turning and inspection. The heat treated microstructure was analyzed at 100X. Based on the micro structural observation, a white layer was found and hence three trials of dephosphating were conducted at 5, 10 and 15 minutes to standardize the dephosphating time.

3. OBSERVATION

Based on the experimental study the observations made are as follows:

3.1. Heat treated microstructure

It is clear from the microstructure that there is a white layer beneath the carburized layer.

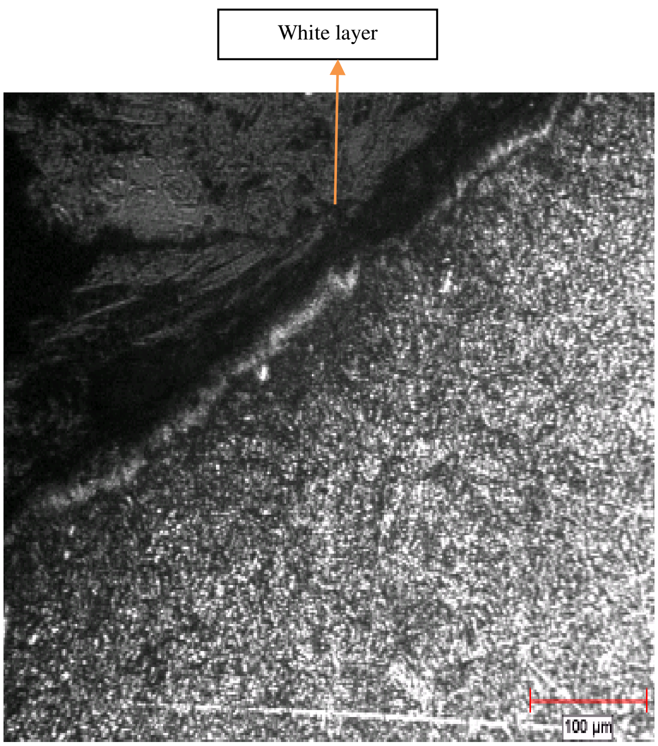

Fig. 1. Microstructure at 100x

3.2. SEM Analysis

The SEM analysis was performed on the sample and the white layer was examined further by EDAX study.

3.3. EDAX study

The EDAX study was performed over the white layer area and the observations were made where the presence of phosphorous was highlighted.

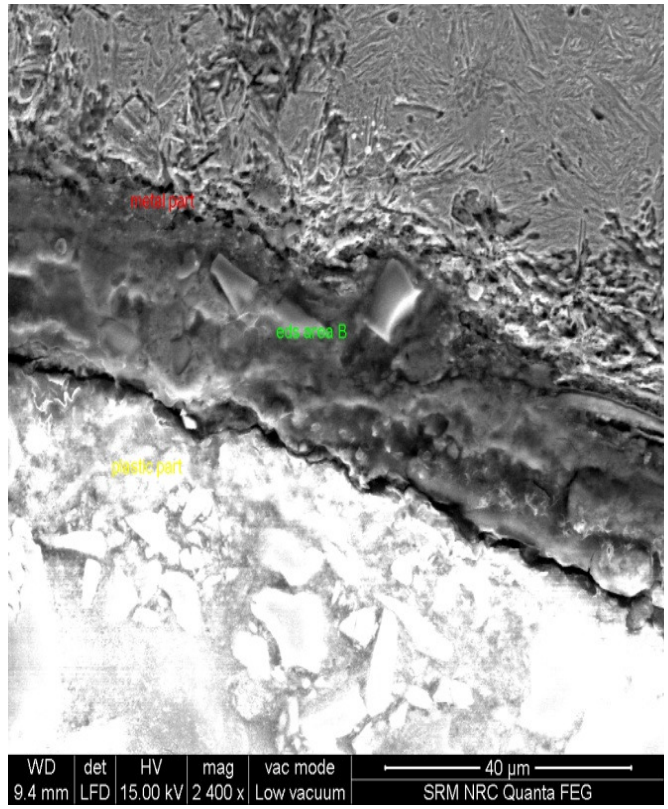

Fig. 2. SEM image

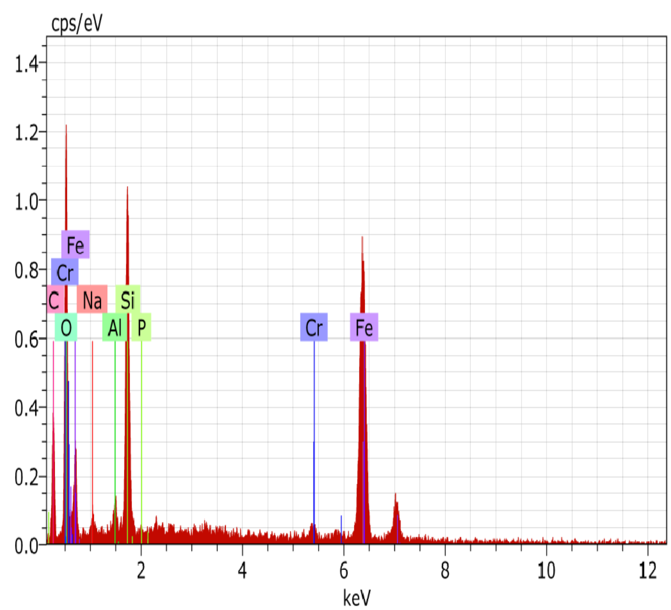

Fig. 3. EDAX image

3.4. Dephosphated microstructures

The dephosphated microstructure was observed at three trials.

3.4.1. Trial 1

Prior to heat treatment dephosphating was done for five minutes and the following microstructure was observed.

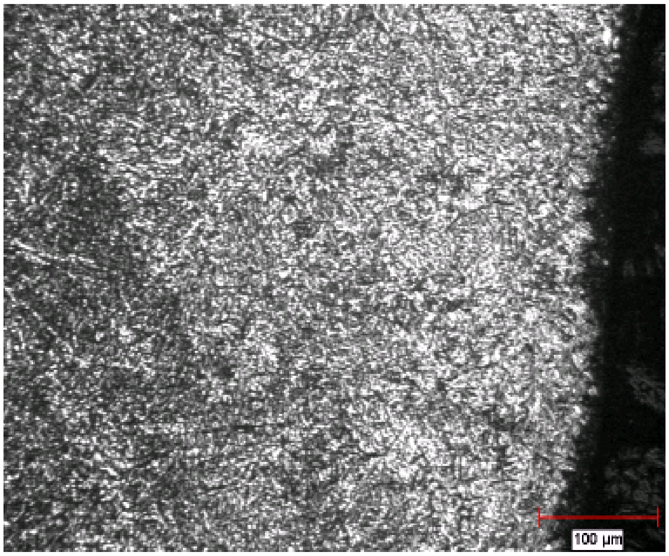

Fig. 4. Trial 1 microstructure

3.4.2. Trial 2

Before heat treatment dephosphating was done for ten minutes and the following microstructure was observed.

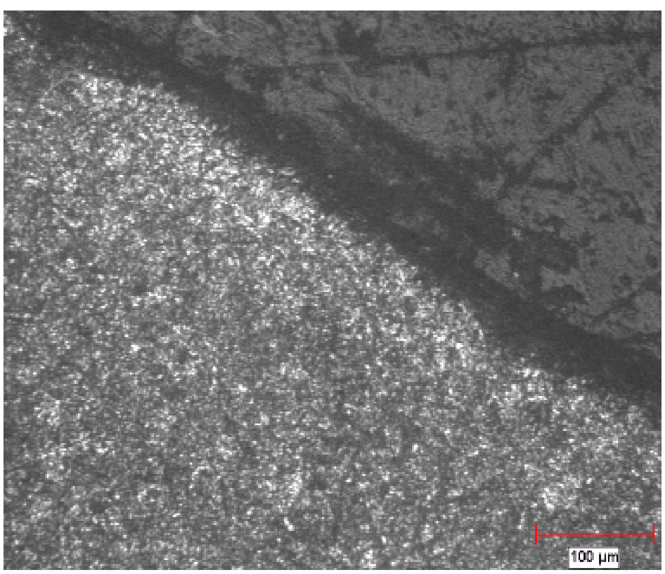

Fig. 5. Trial 2 microstructure

3.4.3. Trial 3

Prior to heat treatment dephosphating was done for fifteen minutes and the following microstructure was observed.

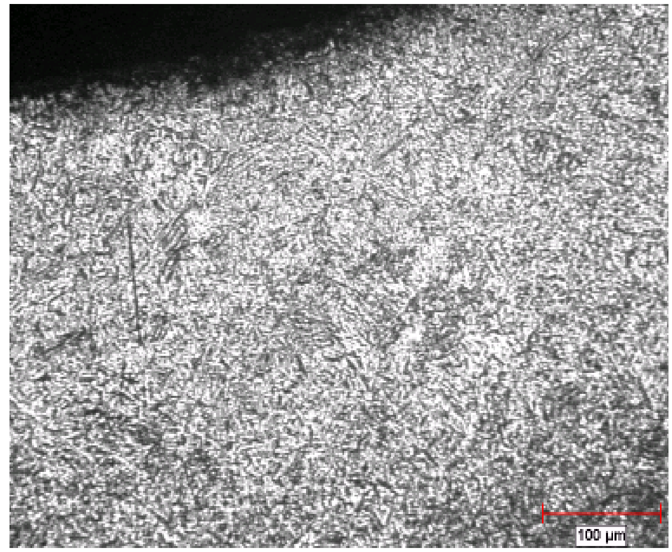

Fig. 6. Trial 3 microstructure

4. RESULTS AND DISCUSSION

On the basis of experimental data, observation and literature survey, the presence of excess phosphorus is undesirable. This is because the endurance limit is decreased. A study on the effects of phosphorous content in a carburized SAE 4320 steel showed that high phosphorous levels enhance phosphorous segregation to austenite grain boundaries. The relationship between phosphor content and endurance limit is shown below.

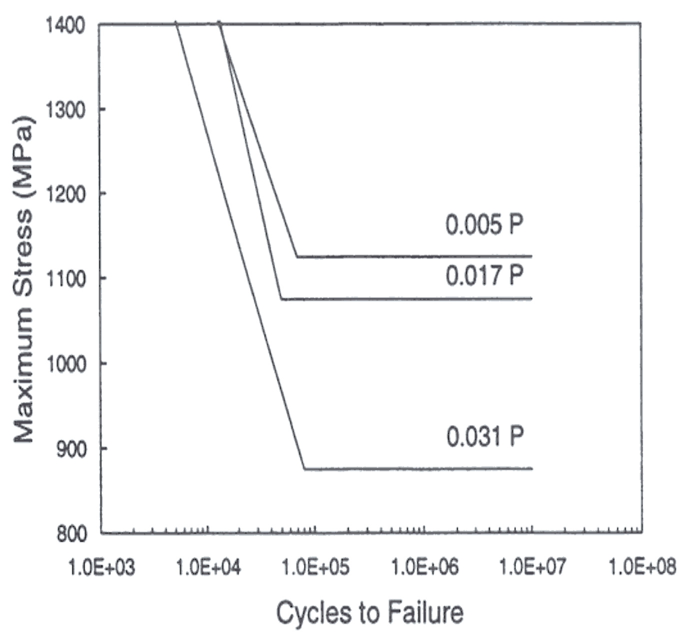

Fig.7. Effect of phosphorous content on the S-N curve of carburized steel[1]

When bulk phosphorous content exceeded 0.017 weight percent, endurance limit dropped significantly. An increase in phosphorous from 0.017 to 0.031 weight percent reduced endurance limits from 1075 to 875 MPa.

The variation of hardness with respect to phosphating and dephosphating is as follows:

Description	**Hardness (HR_C)**
Heat treated microstructure	66
Dephosphated (5 mins)	62
Dephosphated (10 mins)	62
Dephosphated (15 mins)	61

The hardness is found to decrease as the dephosphating time increases. Noted, all the hardness values fall within the desired hardness range of 58-62HR_C. Thus, dephosphating does not impair the service requirements of the gear.

The conventionally manufactured gear produced a white layer which was clear in the microstructural analysis as shown in figure 1. A SEM analysis was done on the white layer to fix the region for EDAX study. From the EDAX study, the compositional analysis indicated the presence of phosphorous which might have come from the phosphating process.

This white layer, being detrimental to the gear life was removed using dephosphating prior to heat treatment. Based on the observation it was confirmed that the white layer was removed in all the three trials. Considering the speed of production and time constraint dephosphating time of 5min is considered as the standard time.

5. CONCLUSION

The following conclusion has been drawn from the experimental result and discussions made. The dephosphating did not have any influence in the hardness and thus the process can be added inorder to eliminate the phosphor layer and hence improving the service life. Also the dephosphating has to be done prior to heat treatment as the white layer cannot be removed after carburizing.

Owing to the time constraints in an industry the dephospating time of 5 minutes was chosen in order to improve the production efficiency. Thus it is being concluded that a dephospating stage can be included for improving the fatigue life of the gear.

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