# MAGNETIC PROPERTY EVALUATION OF CREEP DAMAGED Cr-Mo STEEL COMPONENTS USED IN POWER PLANTS

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## INTRODUCTION

Magnetic properties of steel are sensitive to the total volume of magnetic inclusions in the material [1]. These magnetic inclusions may be precipitates or microscopic voids. When a material is subjected to an elevated temperature under stress for extended periods, slow plastic flow of material occurs which eventually leads to microscopic voids, cavities and finally macroscopic cracking. This process is known as creep damaged. Depending on the strain rate within the material, the creep process can be divided into three categories. In the early stage of the creep process known as primary creep, the material deforms rapidly with time. But this strain rate gradually decreases and becomes independent of time. This stage of creep process is known as secondary, or steady state, creep. In the final stage which is known as tertiary creep, the strain rate again increases with time and deformation continues until the material fails.

Early detection of creep damage is a major cause of concern for components which have experienced high temperature and pressure over an extended period and are, therefore, susceptible to failure. Presently, detection of creep in service exposed components is restricted to the use of replication techniques [2] which are time consuming, relatively expensive and can not assessed on-site. As magnetic properties are highly sensitive to the structure of materials [3,4], the magnetic properties of the materials may be expected to change with the level of creep damage. The aim of the present work is, therefore, to investigate the properties of a creep damaged service exposed Cr-Mo steel by means of magnetic measurements.

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## MATERIALS

The materials under study were 1.25Cr-0.5Mo steel welded flanges which had been removed from service in a fossil fuel power plant. The materials had experienced accelerated test conditions of 40 MPa at 600°C simulating 3700 hours of service. Scanning electron micrographs of the sample showed early stages of creep damage including formation of small isolated spherical cavities [5]. Two specimens cut from the upper (AB) and two from the lower (CD) portions of the flange were taken for the present study. The two specimens from each portion were taken from diametrically opposite regions of the flange. A schematic showing the position of the specimen in the flange is given in Fig. 1.

## EXPERIMENTAL

Two types of magnetic measurements, hysteresis and micromagnetic Barkhausen emissions, were studied on service aged Cr-Mo steel. Measurements were made on material distant from the welded regions to find the influence of creep on the parent metal. Hysteresis parameters were measured using the computer controlled portable Magnescope with a quasi-dc magnetic field excitation [6].The Barkhausen parameters were determined using a surface probe at a frequency of 8 Hz and an amplitude of 30 Oe magnetizing field. Barkhausen signals were monitored by a digital storage oscilloscope (Lecroy, Model 9314M) and the number of events were measured by a universal counter (HP, Model 5316B).

## RESULTS

The measured magnetic hysteresis parameters for four different specimens A,B,C,D are given in Table-I and the coercivity and remanence of the specimens are plotted in Fig. 2. The specimens which were taken from the upper portion of the flange (AB) exhibited higher coercivity and remanence than the others. The Barkhausen waveforms

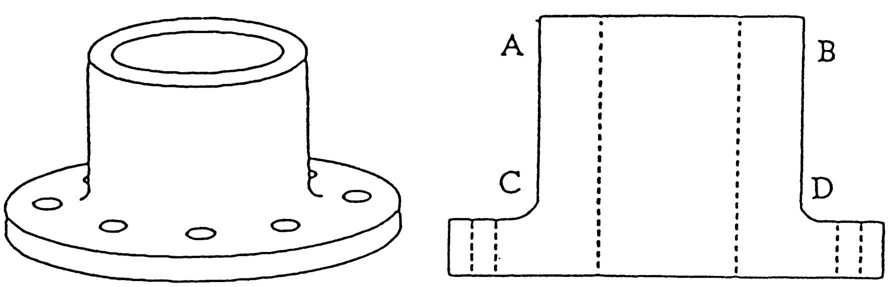


Fig. 1. Schematic diagram showing the position of the specimen cut out from a service exposed flange.

Table-I: Magnetic hysteresis parameters of creep damaged Cr-Mo steel.

| Specimen # | Coercivity (Oe) | Remanence (kG) | Hysteresis loss ($10^3$ ergs/cc) |
|---|---|---|---|
| A | 6.24 | 8.81 | 24.96 |
| B | 5.67 | 8.58 | 22.24 |
| C | 4.86 | 8.00 | 19.27 |
| D | 4.81 | 7.69 | 19.05 |

for the specimens A,C and B,D are shown in the Fig. 3 and 4 respectively. The Barkhausen parameters are given in Table-II. It is clear from the Barkhausen waveforms that the specimens C and D have higher Barkhausen activity than the specimens A and B. In Fig.5 the root mean square (RMS) and the peak voltages of Barkhausen signal are plotted.

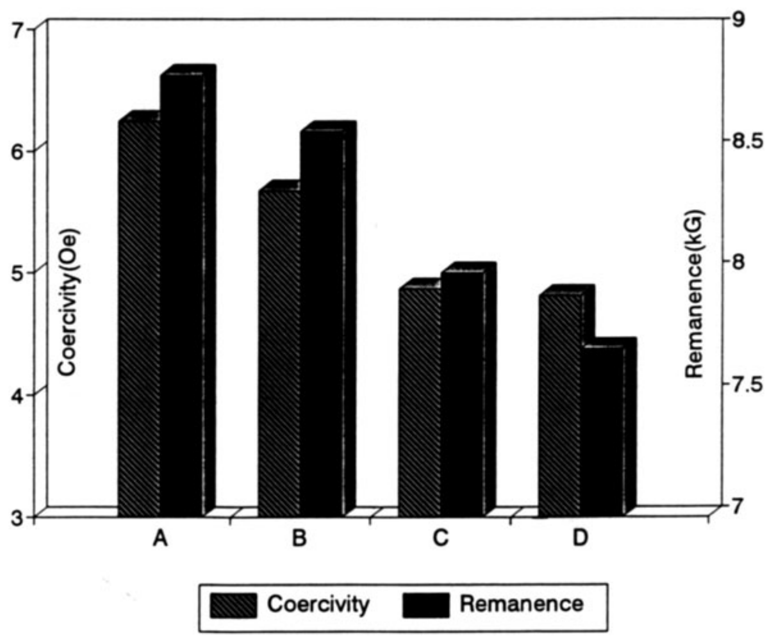


Fig. 2. Variation of coercivity($H_c$) and remanence ($B_r$) for different creep damaged specimens.

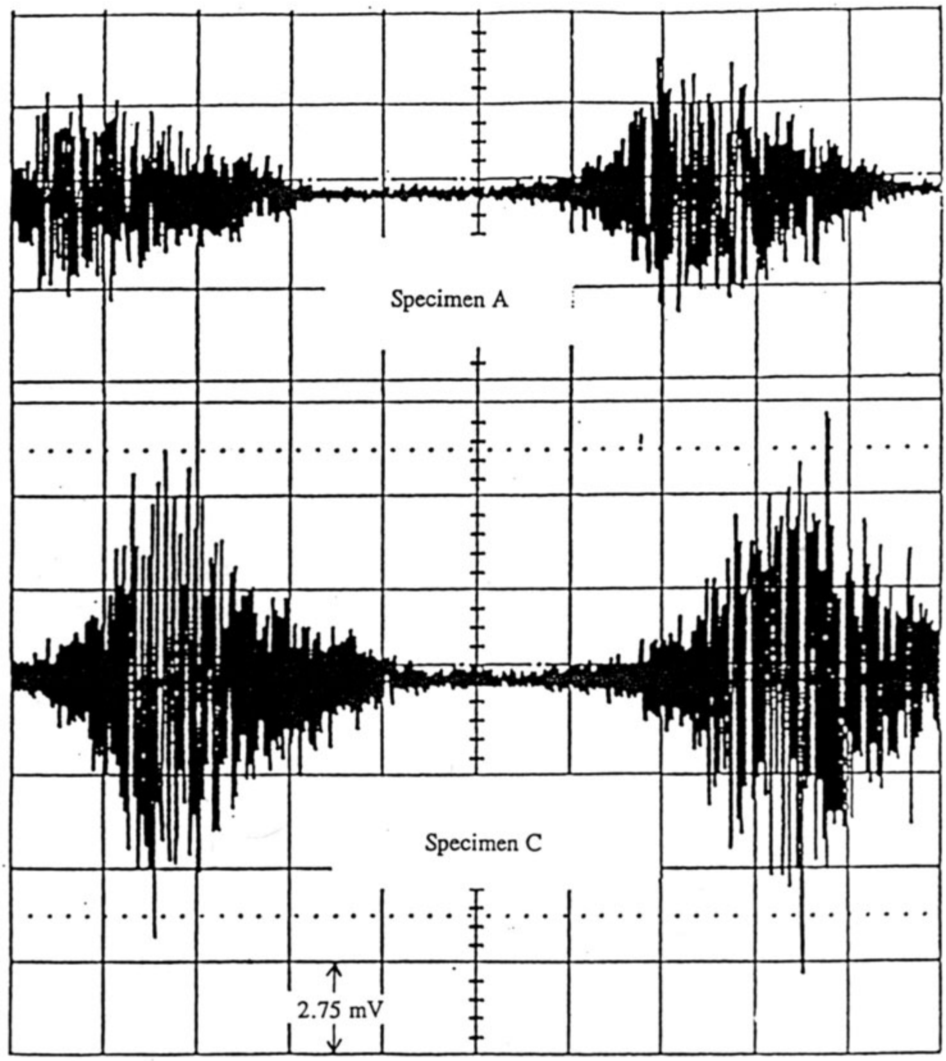


Fig. 3. Magnetic Barkhausen waveforms for the specimens A and C. The applied magnetic field amplitude was 30 Oe with a frequency of 8 Hz.

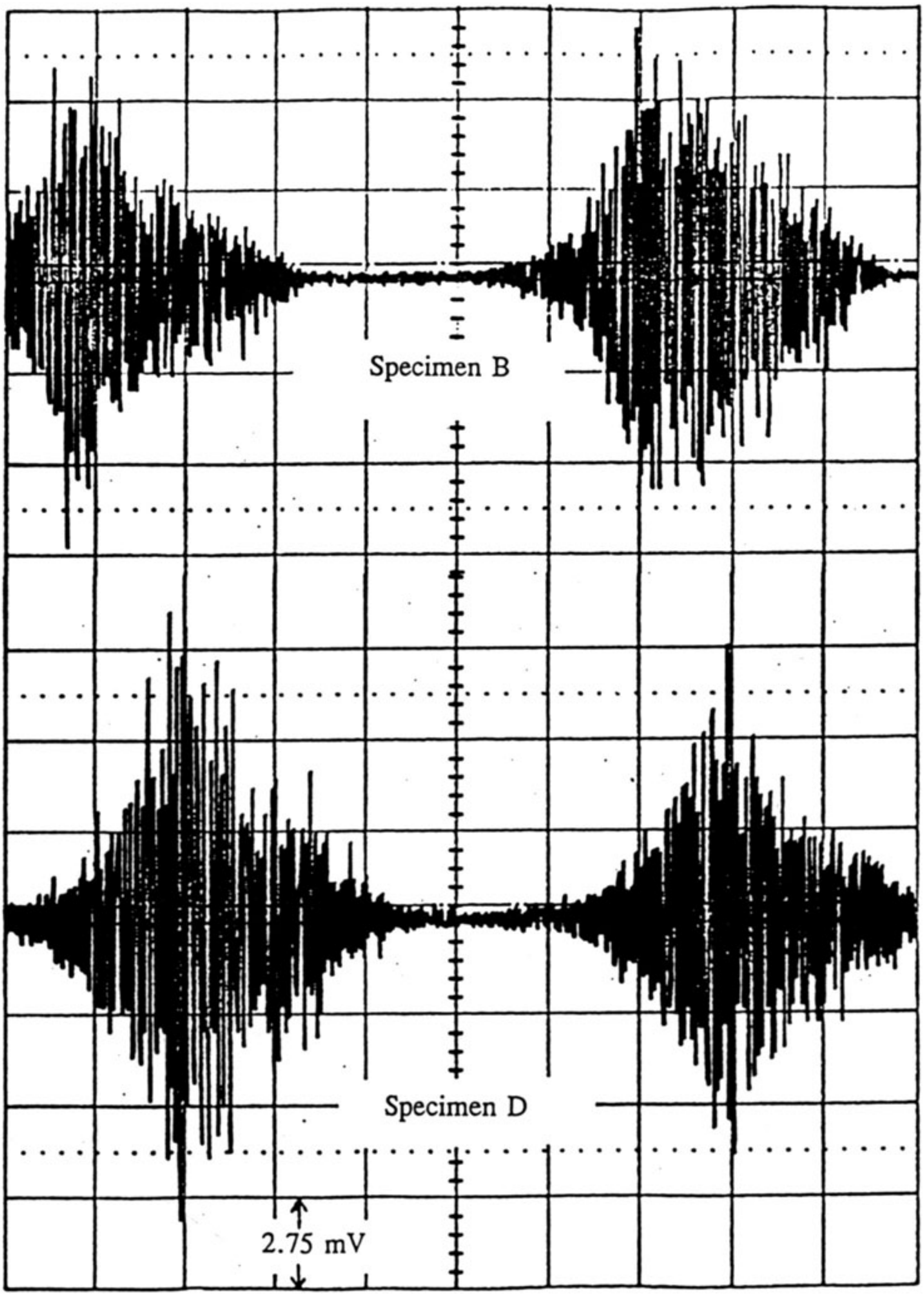

Fig. 4. Magnetic Barkhausen waveforms for the specimens B and D. The applied magnetic field amplitude was 30 Oe with a frequency of 8 Hz.

Table-II: Barkhausen parameters of creep damaged Cr-Mo steel.

| Specimen # | No. of Events/Cycle | RMS Voltage(V) | Peak to Peak Voltage(V) |
|---|---|---|---|
| A | 2003 | 0.54 | 3.85 |
| B | 2324 | 1.02 | 6.51 |
| C | 1946 | 1.18 | 8.25 |
| D | 2132 | 1.12 | 9.17 |

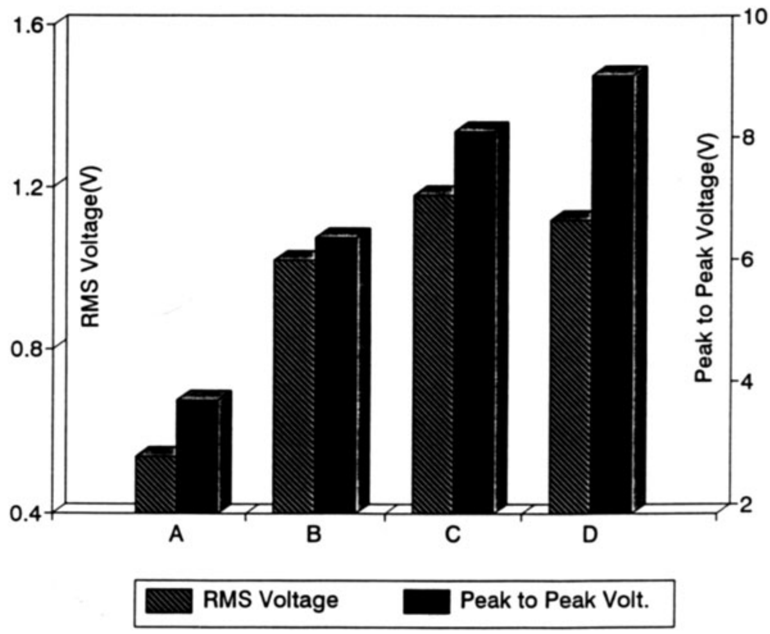


Fig.5. RMS and peak to peak voltage of Barkhausen signal for specimens A, B, C and D.

## DISCUSSION

In the creep process impurities are segregated in the materials and these migrate towards the grain boundaries. Due to the plastic flow of materials, dislocations also build up and move towards the grain boundary. This accumulation slowly causes cavities at the grain boundaries. Thus in the creep process two microstructural effects occur in the material: (a) the defect density (impurities, dislocations) inside the grains decreases and (b) cavities are nucleated and developed at the grain boundaries.

When a domain wall interacts with non-magnetic inclusions or voids, the magnetostatic energy is reduced [7] and therefore these defects act as pinning points during domain wall movements. As the defect density within the grains decreases in the creep process, the domain wall experiences less pinning forces. Therefore a creep damaged specimen should have lower coercivity. The nucleation and growth of cavities at the grain boundary during the creep process introduces local demagnetization fields in the vicinity of the cavity, and this results in a decrease of remanence in creep damaged specimens.

Barkhausen emissions are caused by irreversible domain wall movements in the presence of an alternating magnetic field. As the defect density decreases during creep, the domain wall can travel farther distance without pinning forces. Thus, the Barkhausen jump amplitude is higher in creep damaged specimens, resulting in higher Barkhausen activity.

In the present study, C and D specimens which were taken from the lower portion of the flange, exhibited lower coercivity and remanence compared with the specimens A and B from the upper portion. As creep damage reduces the coercivity and remanence, it follows that the lower portion of the flange experienced a higher level of creep damage. The observed higher Barkhausen activity in C and D specimens also indicates a higher level of creep damage in the lower portion of the flange. Results show that the specimens B and D have lower coercivity, remanence and higher Barkhausen activity than the corresponding specimens from A and C. Thus the BD side of the flange probably has higher level of creep damage than the AC side.

## CONCLUSION

Magnetic properties of service exposed Cr-Mo steel have been measured non-destructively. A good correlation between magnetic hysteresis and Barkhausen parameters has been observed. Coercivity and remanence were expected to decrease and Barkhausen activity was expected to increase with the level of creep damage. Results of the present study indicate that the lower portion of the flange had experienced more creep damage than the upper portion of the flange. Among each portion of the flange, specimens from the BD side had experienced higher levels of creep damage compared with the corresponding specimens on the AC side. The present work demonstrates that magnetic non-destructive techniques can be useful for detecting the presence and extent of creep damage in steel components.

## ACKNOWLEDGEMENTS

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