Investigate the magnetic behaviour of thermal treated carbon steel

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Abstract. The present paper investigates the utilization of the magnetic hysteresis loops and Barkhausen Noise for the non-destructive characterization of annealed and quenched carbon steels samples. The resulting magnetic properties were further evaluated by examining the microstructure of the samples by using scanning electron microscopy.

1. Introduction
Steel is a composite ferrous metal alloy with varying mechanical properties with a wide range of applications. Industry’s needs for the enhancement of its mechanical properties has led to the development of new alloys of steel with composite microstructures. It is known that exposing steels to high heat affects their mechanical properties (e.g. tensile strength, yield point), as well as their physical and chemical properties (e.g. change of crystal structure) [1-2].

Several methods have been developed in the recent years for the non-destructive testing of various grades of ferromagnetic steels [3-14]. It is well known that the magnetic non-destructive methods are influenced by the microstructural features of the examined materials [15-40].

The scope of the present paper is the documentation of changing parameters in the magnetic properties of micro-alloyed, high strength steel samples, which have been submitted to a predefined temperature annealing above the austenitic temperature, followed by quenching in oil, and the correlation of those with the respective changes in mechanical properties.

2. Experimental procedure
Micro-alloyed carbon steel were investigated with the chemical composition shown in Table 1. Before the annealing the as-received sample was cut, according to the ASTM E8 Standard (figure 1). Before the annealing process, the surface of these specimens was cleaned, degreased and dried. Then, the as-received sample was heated up to 891 °C for 5 hours and subjected to quenching in oil.

| Table 1. Chemical composition in % wt of the examined steel |
|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| C     | 0.31  | Si    | 0.28  | Mn    | 0.57  | Al    | -     | Cu    | -     | P     | 0.020 |
|       |       |       |       |       |       |       |       |       |       | S     | 0.020 |
|       |       |       |       |       |       |       |       |       |       | Ni    | 0.93  |
|       |       |       |       |       |       |       |       |       |       | Cr    | 0.19  |
|       |       |       |       |       |       |       |       |       |       | Mo    |       |
|       |       |       |       |       |       |       |       |       |       | Fe    | Balanced |

Figure 1. As received sample.

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Metallographic specimens were prepared according to the standard procedure from the as-received and heat-treated samples and etched with 2% nital solution. Microscopic examinations were carried out by JEOL JSM 6100 Scanning Electron Microscopy (SEM), which is equipped with a Noran TS 5500 Microanalyzer for EDS analysis. Additionally, both Vickers micro-hardness and uniaxial tensile tests were performed, in order to investigate the variations in the mechanical properties of the samples.

For the Magnetic Barkhausen noise (MBN) measurements, a triangular shaped magnetic field produced by a generator was applied on the surface of the samples by an electromagnet. The discrete changes in the resulting local magnetization (MBN) were sensed at the ends of a receiving coil as voltage pulses. The MBN profile measurements were recorded.

3. Results
The microstructure of the as-received sample consisted of non-equiaxed polygonal ferrite and perlite grains (figure 1a). After annealing and quenching, a fully martensitic microstructure was revealed (figure 1b). Some acicular ferrite was still present in the microstructure. The high annealing temperature increased the austenite volume fraction, which then transformed to martensite upon quenching in the oil.

![Figure 1. Microstructure of the (a) as received and (b) the annealed samples.](image)

Microstructural changes influence the mechanical properties. The strength values of the annealed sample were higher than the strength of the as-received steel. The higher strengths of the quenched steel are known to be due to the presence of the harder martensite phase (figure 2). The increment of the yield strength and the diminishment of both the elongation and the ductility were also pronounced.

Microstructural changes and variations in the mechanical properties were also affect the magnetic properties of the materials and corresponding MBN profiles. A double-peak MBN profile was observed in the as-received sample. The narrower and higher peak in the MBN profile of the as-received sample indicated that an increased amount of reverse magnetic domain walls were moved in a limited range of input voltage, over shorter displacements, within the ferrite-perlite matrix. A very small peak size it was noticed at a position close to the lower excitation voltages in the MBN profile of the as-received sample. This was associated with the existence of higher amounts of magnetically soft ferrite in the untreated sample.

However, the peak’s height in the MBN profile of the quenched samples were reduced and its position was also shifted to excitation voltage, as compared to the as-received sample. This was associated with the restricted displacement of domain walls in the hard martensite structure, which act as strong pinning during the magnetization procedure. The peak’s position increased with the increase in the yield and ultimate tensile strengths of the examined steels. Thus, when the microstructure is dominated by high dislocation density, due to the presence of martensite phase, a single-peak MBN profile was observed.
Figure 2. Stress – Strain curves of the samples.

Figure 3. MBN profile of the samples.
4. Conclusions

A micro-alloyed carbon steel sample was intercritically heat treated on a constant temperature and oil quenched in order to obtain fractions microstructures. The obtained results show the indirect relationship between the magnetic and mechanical properties of the investigated steel samples, in which this results reveal the effect of microstructure on them.

5. References

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