MECHANICAL PROPERTIES INVESTIGATION OF CARBON STEEL BY ATOMIC FORCE MICROSCOPY AND MAGNETIC FORCE MICROSCOPY

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1. Introduction
Mechanical properties of material (like steel, alloys and etc.) depends not only from constitution elements, but from their 3D uniform distribution. However, material uniformity on macro- and nanosize level could be very different. Macro uniformity is average uniformity of many different nano units.

We have utilized the atomic force microscopy (AFM) technique in analyzing carbon steel material processed by milling in attempt to show that changes in material that occur at the nanometer level might be indicative of some structure-disrupting processes that are related to to mechanical properies

2. Method and material
In our study we used the SPM (Scanning Probe Microscope) system JSPM-5200 (JEOL, Japan) and magnetic material coated cantilevers from MicroMasch, type NSC36/CoCr (coated with 60 nm of chromium and 20 nm of cobalt). First, AFM was operated in tapping mode, in cupola air environment which is located in environmental room control (air, light, vibration, magnetism, temperature and pressure). In order to obtain the topography image, based on which the magnetic properties of surface layers were examined we use MFM (Magnetic Force Microscopy). Magnetic properties evaluation is based on the magnetic force gradient image that is the principle of the MFM method. This image shows the qualitative distribution of magnetic field within the scanned area, pointing to local distribution of carriers of magnetic properties. The image is obtained with two-pass technique that uses initial scan of one sample line to obtain topography image while the second pass is conducted with a gap distance of few tenths of nanometers in order to obtain only magnetic component of the force acting upon the cantilever [1].

The technique is based on an extremely sensitive force measurement system that utilizes the distance dependence of all intermolecular and interatomic interaction, whether they are polar or non-polar. The attractive or repulsive intermolecular force interacts with a cantilever-based sensor tip that is bent proportionally to 1) force vector direction and intensity, and 2) stiffness of cantilever (determined by cantilever material and geometry of cantilever mass). During scanning, cantilever is brought in close proximity to the sample, close enough to be bent by the forces originating in the material. The cantilever responds to these forces, behaving like a spring, and being bent according to Hook’s law: $x = F/k$, where $k$ is bending rigidity (or effective spring constant) of the cantilever while $x$ is deformation and $F$ is intermolecular force that is being measured. Many different cantilevers are being produced today with varying geometries that yield spring constants from 0.01 N/m to 50 N/m or more. This range allows force measurement of materials that can be as sensitive as biological material (cells, biomolecules – DNA, collagen etc.) but also as hard as metal surfaces.

In this paper we conducted characterization of carbon steel, which is composed of the following chemical composition: 0.7% C, 0.20% Si, 0.7% Mn, 0.025% P, and 0.028% S. Its physical properties (DIN C60) are: hardness 243 HB and tensile strength 690-780 MPa. After the preparation, machining and conducting SPM measurements, the metallographic microscope examination showed that the specimen surface had a pearlite and ferrite structure.
3. Experimental Results

Black areas (the magnetic fingerprint of matter) on nanometer scale, (Fig.2) shows absence of magnetic (Fe) and paramagnetic (Mn) atoms in steel. Black areas are place where diamagnetic materials (C, Si and S) are concentrate. Non-homogeneity of steel indicates a guideline in early crack event, when sample is exposed to mechanical stress.

4. Discussion

The AFM/MFM scans show that the distribution of material does not have to be consistent. The existence of “magnetic holes” in materials structure, suggests that material is not homogenous and that accumulation of non-magnetic carbides most probably (or/and silicon, phosphors, sulfur) contributes to existence of non-magnetic structures. The presence of carbides points to existence of significantly altered mechanical properties (tensile strength, ductility etc.). This technique yields mapping of surface magnetic properties that could depict possible crack initiation spots.

Now we are in quantitatively investigation how these magnetic surfaces correspond to structure and material integrity and strength and what type of impurities, besides the carbon-based ones, it can point to.

5. Conclusion

In this study we have shown that, combining AFM/MFM results it is possible to obtain the distribution of ‘magnetic carriers’ of materials in nanometer range. Investigation structural property on nano scale we may know better mechanical properties of material.

7. Acknowledgements

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8. References