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The stability of laser marks on electrical steel surfaces investigated by fatigue test

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Kulcsszavak: logisztikai lézerkód, helyi felkeményedés, örvényáramú kiolvasó jel, lakk-bevonat, homokszórás
Keywords: logistic laser code, local hardening, eddy current reading out signal, lack-coating, sand spray

Összefoglalás

Lágymágneses acéllemez felületét jelölő lézerkarcok stabilitásvizsgálata fárasztással. Lézerek alkalmazása széles körben elterjedt a felületmódosító eljárásokban, rendszerint a mechanikai, illetve a mágneses tulajdonságok javítása céljából. Ám közleményünkben olyan lokális felületmódosításról van szó, amelynek célja felületi jelek, kódok létrehozása lézerrel. A lézerkarcok logisztikai kódként való alkalmazhatóságának feltétele a jelek termikus és mechanikai stabilitása. Közleményünk a lágymágneses acéllemez felületét jelölő lézerkarcok mechanikai stabilitásvizsgálatával foglalkozik. Az acéllemezek felületére, logisztikai azonosíthatóságuk céljából, CO_2 lézerrel, 100 – 400 W teljesítménnyel felvitt „karcok" örvényáramú (Fluxset) kiolvasó szondával mérhető jeleinek alak és intenzitás szerinti stabilitását vizsgáltuk összehasonlítva a mechanikai fárasztás előtt és után mért jeleket. Az *1. ábra* szerint Oerlikon OPL 2000 CO_2 lézerrel megjelölt próbatesteteket nulla-kezdésű, 30 Hz frekvenciájú, húzó-lengő igénybevétellel, 500 000 ciklusszámig fárasztottuk egy Instron 8511 típusú vizsgálógéppel. Vizsgáltuk a lézerkarcolt felület környezetének szövetszerkezetét és mikro-keménységét (*2. – 4. ábrák*), valamint azt is, hogy fárasztás mellett a kiolvasott jel alakját és intenzitását befolyásolja-e a felületkezelés: a lakkozás, illetve a homokszórás (*5. – 7. ábrák*) Megállapítottuk, hogy az alkalmazott mechanikai fárasztás, illetve a felületi lakk-bevonat nem befolyásolja a lézerkarcok örvényáramú kiolvasó jeleinek alakját és amplitúdóját.

Introduction

Lasers and their applications are often used in the surface modification technologies. The goal of these treatments can be either the mechanical or the magnetic modification of the surfaces or the production of codes for various logistic processes.

Recently, type of marking was applied for the detection of thermal induced stresses, as well as to produce bar codes on low carbon steel surfaces [1]. The physical basis of the reading out is the local phase transformations or local modifications in the stress field around individual marker. The stress evolution is the consequence of the rapid heating and the subsequent cooling processes during the laser beam-metal interaction. The thermal and mechanical stability of markings (marker – marking - mark) has of a primary importance for any application (particularly in the case of magnetic reading out technique) [2].

The appropriate reading out is usually based on magnetic or classical eddy-current phenomenon. In this paper fatigue tests were carried out on laser scribed soft magnetic sheet, in order to determine the stability of laser scribed marks against the periodic loading. The marking were carried out using CO_2 laser irradiation. A special Fluxset sensor was applied for the reading out, which is based on eddy current measurements,[3].

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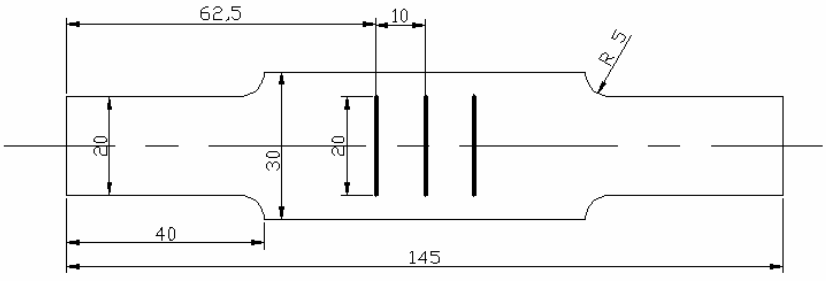


Fig.1: ***The shape and dimensions of the sample***

1. ábra. ***A próbatest alakja és méretei***

Experimental

Samples_were prepared from fully processed electrical steel sheets. (Chemical composition in wt%: Si=1, C~0.003, P=0.095, Al=0.16, Mn=0.36, S=0.006)

The sheets were cowered with a lack layer (arising from the production process). For the investigation of the magnetic properties and the possible structural changes in the samples, the coating layer was removed using sand

spraying equipment. Oerlikon OPL 2000 CO_2 laser equipment was used for the scribing (wavelength of 10,6 μm, work-ing in continuous regime). The applied power densities are 150, 200 and 400 W respectively. 1200 mm/s scanning velocity and the 1 mm laser spot diameter was applied during the scribing process.

The laser marks were placed parallel and perpendicular to the rolling direction. As an example, the geometrical parameter of the specimen is depicted in *Fig 1*.

Reading out experiments were carried out on the samples before and after the fatigue test with a special eddy current sensor [Fluxset]. The fatigue test was carried out using an Instron 8511-type fatigue machine. The number of cyclic loading was 500 000, the maximum in the applied force was 2400 N, the minimum was 0 N. The frequency of the fatiguing force was 30 Hz.

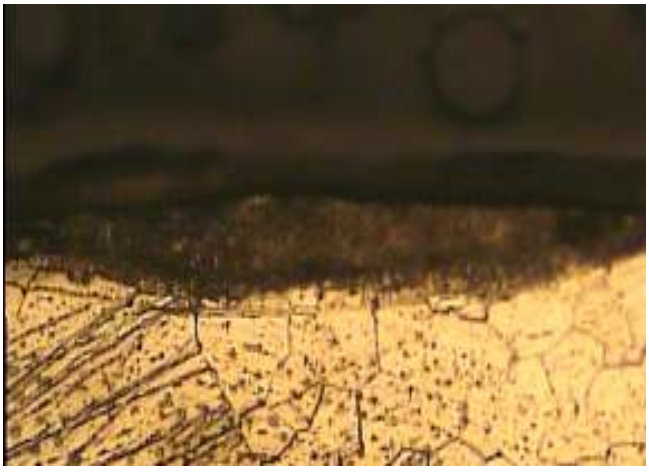
Results and discussion

Metallographic and micro-hardness characterization

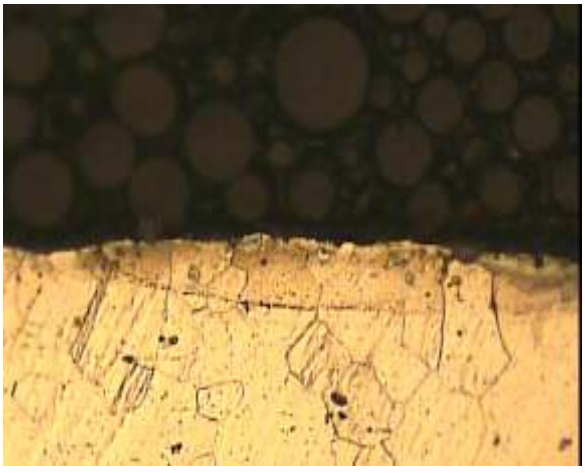
The purpose of metallographic analysis and micro-hardness measurement was to reveal the actual extension of the individual heat affected zones.

The laser scribing represents rapid local heating and subsequent rapid cooling in the surface layer of the irradiated sheet. The regulation of energy density is necessary avoiding the local surface melting (overheating effect). On the order hand, the energy input should be sufficiently high enough to rise the local temperature resulting in a local structural change, which is the basis of the code formation. In the case of carbon steels the pulse-like temperature increase ensures the activation energy or the carbon dissolution and homogenization in the austenite phase. As a consequence of the entrapped C atoms (metastable solid solution formation) together with the heat shock induced (stresses arising from the misfit between the heat affected and unaffected zones) a net resistance increase takes palace. This is the physical basis of the reading out. The carbon content of the applied specimens is low, consequently only the redistribution of the alloying elements (Si, Mn, Al) is involved in the short-time diffusion process during the period of irradiation.

Except the negligible grain coarsening, no structural change can be observed within the heat affected zone as *Fig. 2 B* shows. When the heat accumulation is high enough besides the grain coarsening other type of phase transformation may also occur, but this case is not involved in the present experiments. Nevertheless, the actual heat accumulation also depends on the surface quality of the absorbent sheet. In our case, the surface was covered by lacquer layer, (electric insulation). The efficiency of energy absorption is better in the presence of layer. The lens-shape heat treated zone can be observed in *Fig. 2 A* and *B*.



A)



B)

Fig. 2: *Optical micrograph of the cross section of laser marked sheets;*

A) *400 W laser power;* ***B.)*** *400 W laser power, sand sprayed surface*

2. ábra. *A lemez mikroképe a lézerkarc keresztmetszetében;*

A.) *lézer-teljesítmény: 400 W;* ***B.)*** *lézer-teljesítmény: 400 W, a felület homokfúvózva*

In *Fig. 3* and *Fig. 4* the micro-hardness data versus the distance (measured from the surface) can be seen. Two conclusions can be drawn from the Figs. First: the hardening effect near to the surface or in the centre of the heat affected zone is higher for the coated surface as a consequence of more effective heat accumulation. Second: in spite of the absence of carbon in this type of (soft magnetic) steel sheets, there is still a detectable mechanical hardening in both samples which can be the consequence of the solute redistribution inside the heat affected zone. The lower hardening in the case of sand sprayed surface can be attributed to the lower absorption ability of the sand sprayed surface.

The maximum in hardness is around the centre of the irradiated zone (mark). It means that the mechanism responsible for the hardness increase is associated primarily with the final temperature and on the time of incubation necessary for the solute redistribution as well.

Nevertheless, the contribution of the additional macroscopic stresses evolution to the net hardness increase can also not be ruled out.

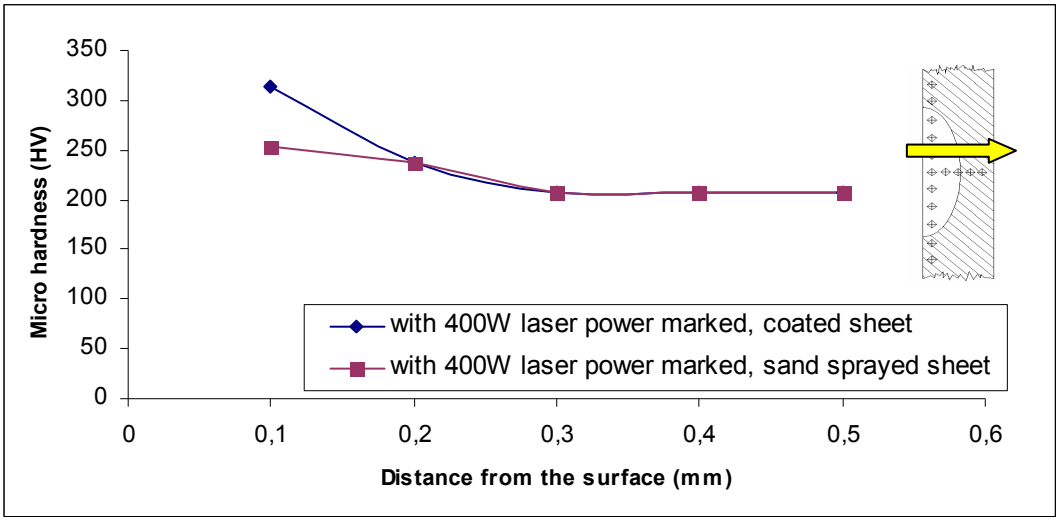


Fig. 3: *The micro-hardness distribution versus the distance. The measuring direction is perpendicular to the surface*

3. ábra. *A mikrokeménység változása a felületre merőleges irányban mérve*

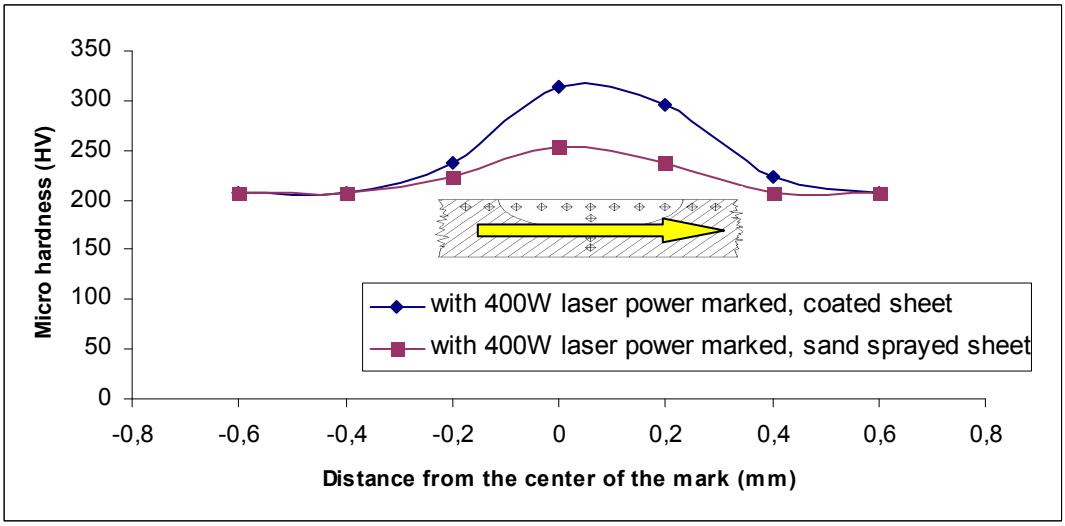


Fig. 4: *The micro-hardness change versus the distance. The measuring direction is parallel to the surface*

4. ábra. *A mikrokeménység változása a felület mentén a lézerkarcra merőlegesen*

Results of reading out

In *Fig. 5* can be seen the reading out signal versus the distance. In the case of coated surfaces the intensity of the reading out signal is much higher than that of the sand sprayed surfaces. Again, the reason is the lower absorption ability of the sand sprayed surfaces.

The stability of the laser scribed codes against the periodic, mechanical vibration was measured, applying fatigue machine. This loading type seems to be suitable for the simulation of usual loading associated with the applied production technologies of the soft magnetic sheets. The readability of codes was determined before and after the cyclic loading experiments comparing the amplitude and the shape of marks. The results of this comparison are illustrated in *Fig. 6* and *7.*

According to the present investigations the applied cyclic loading has no significant influence on the readability of the signal, so the laser scribed markers are stable enough against this loading type in the investigated soft magnetic, fully processed sheets. It is also remarkable that successful scribing can be applied even this type of lacquer coatings is missing.

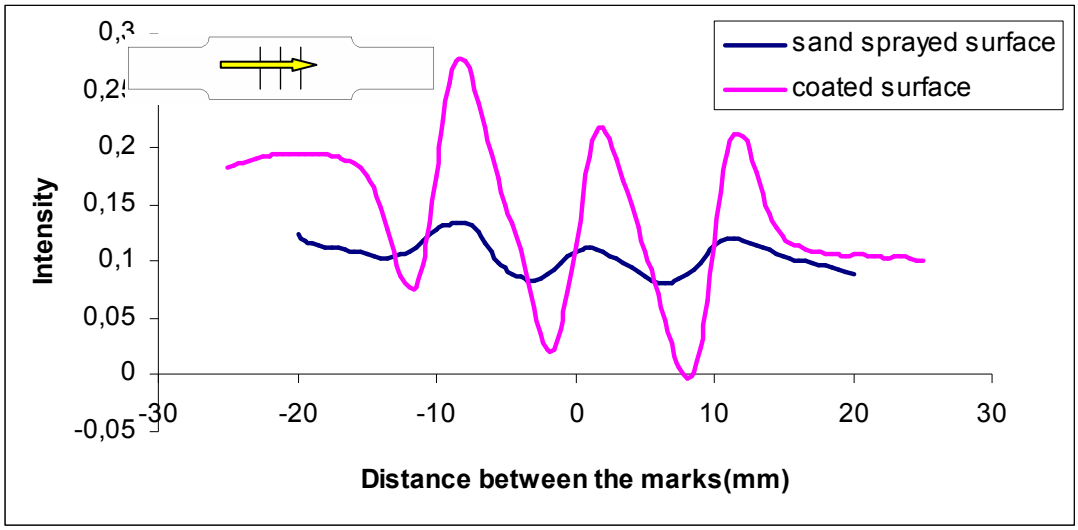


Fig. 5: *The reading out signal in case of coated and sand sprayed surfaces applied 100 W laser power*

5. ábra*. A felületi bevonat, illetve a homokszórás hatása a 100 W teljesítménnyel készült lézerkarcok kiolvasási jelének erősségére*

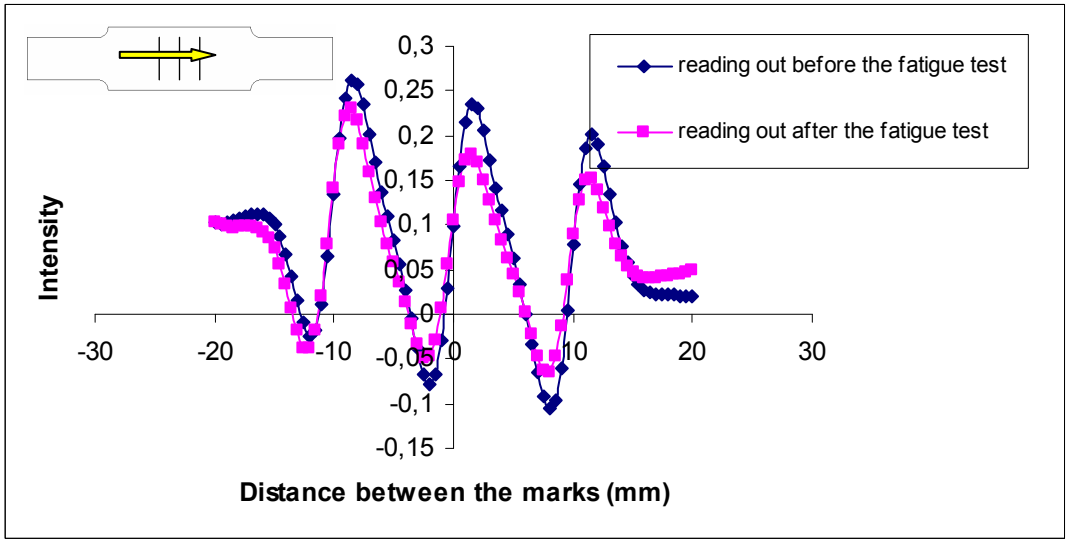


Fig. 6: *The shape of reading out signals produced on coated surface by applying 150 W laser power before and after the fatigue test. The marks were perpendicular to the direction of cyclic loading*

6. ábra. *A 150 W teljesítménnyel készített lézerkarcok fárasztás előtt és után, a felületi bevonaton át, mért kiolvasási jelének alakja és erőssége. A lézerkarcok a ciklikus terhelés irányára merőlegesek*

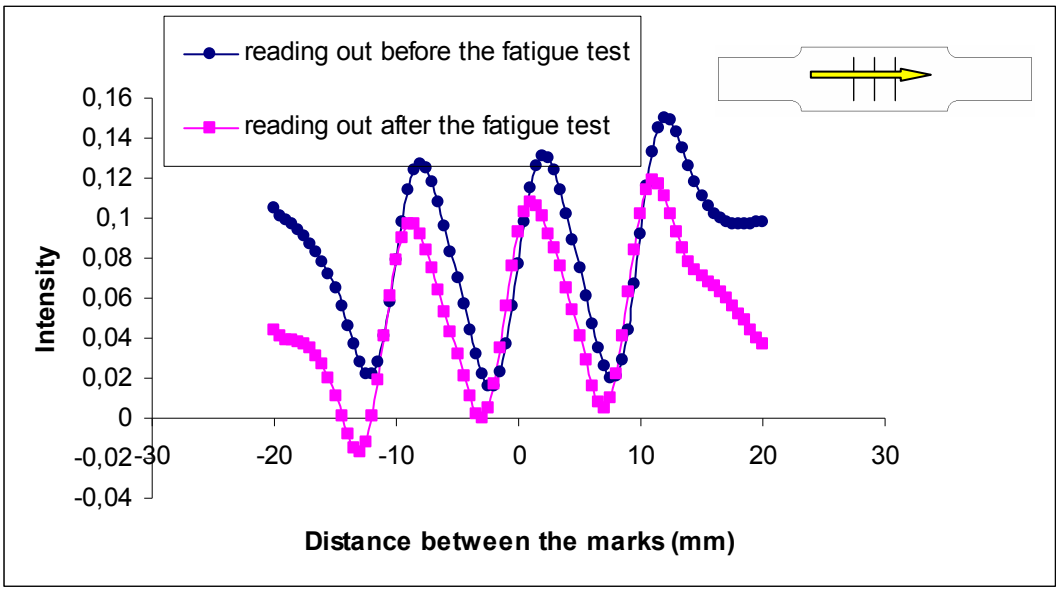


Fig. 7: *The shape of reading out signals produced on sand sprayed surface by applying 150 W laser power before and after the fatigue test. The marks were perpendicular to the direction of cyclic loading*

7. ábra. *A 150 W teljesítménnyel készített lézerkarcok fárasztás előtt és után homokszórt felületen mért kiolvasási jelének alakja és erőssége. A lézerkarcok a ciklikus terhelés irányára merőlegesek*

Conclusions

The mechanical stability of markings was investigated in the samples after the irradiation with various power densities. It can be observed, that the presence of lacquer layer has no detectable influence on the readability of laser codes. Neither the shape nor the amplitude of the individual markers have changed due to the applied fatigue loading. Removing the lacquer layer, the absorption is decreasing.

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