SOME OBSERVATIONS ON FATIGUE FRACTURE OF MATERIALS WITH SURFACES HARDENED BY LASER AND PLASMA NITRIDATION

P.Mazal* and I.Dlouhý†

Experimentally acquainted information on basic fatigue properties are sumarized for selected structural steels and gray cast iron, whose surfaces had been thermally treated by laser beam and plasma nitridation. The effect of the surface layer homogeneity of the laser treatment on the fatigue limit of material values is discussed as well. The homogeneity in surface hardness distribution was shown to be more important aspect than the hardness level of surface layer.

INTRODUCTION

Modern methods of surface treatment based on utilization of laser and electron beams, ion nitridation, ion implantation and similar methods are introduced into industrial practice in wide extents. Perfect utilization of these procedures of surface engineering brings necessity of detailed investigation of all regularities, by which are changes in the treated material controlled.

It is generally known that most of the homogeneous treatments producing the surface layer hardening make more difficult the cracks initiation on material surface and by that they increase resistance against fatigue fracture. However, substantial problems imposes interpretation of results, acquainted at the laser treatment. Majority of the available lasering devices and procedures are not able to ensure homogeneous covering of the whole treated surface by one laser bead. It is necessary to apply several mutually overlapping tracks in these cases. Any following bead significantly influences the previous one, however. Remarkably non-homogeneous treatment of the surface layer is produced due to this procedure. This non-homogeneous surface hardening does not enable full utilization of the capability of the laser thermal treatment, however.

* Institute of Design, Technical University of Brno, CZ 616 69 Brno, Czech rep.

† Institute of Physics of Materials, CZ 616 62 Brno, Czech rep.

EXPERIMENTAL PROCEDURES AND MATERIALS

Because of the experimental equipment the sample shape shown in Fig.1 was selected. The heat treatment was applied on surface of shallow notches only, sample sides were protected. Cyclic loading was in progress in the symmetrical alternating four point bending mode, at loading frequency approximately 120 through 150 Hz. The samples were loaded till the fracture event or the test was interrupted after 10^7 loading cycles. Fracture areas of samples were subjected to standard macro and micro fractographic observation, metallographic analysis of the microstructure was executed on selected samples.

In this work, selection of results generated for three steels and one cast iron, which represent the some group of structural materials. The group of carbon steels represents the steel ČSN 41 2060 (**CS**), steel ČSN 41 4209 (**BS**) stands for the bearing MnCr steels, structural Cr steels for the ČSN 41 4140 (**SS**) and gray irons for the ČSN 42 2456 (**GCI**). Chemical composition of used materials is introduced in the Table 1. Graphic dependences for non treated materials are marked **B**.

RESULTS AND DISCUSSION

Laser treatment (LP)

All materials used were lasered under conditions at which surface melting still did not be come. Because of laser parameters used were two mutually overlapping tracks (**LP-O**) were applied on the notch surface in the longitudinal direction (see Fig.2). Another group of samples was produced with thickness reduced on 6mm and lasered by one bead (**LP-H**). For the carbon steel was created samples with two beads on notch surface between which narrow non-lasered area was left (**LP-D**). Conditions simulating homogeneous, lightly non-homogeneous and strongly non-homogeneous laser surface treatment were obtained in such a way.

The results are presented in Fig. 3, 4, 5 and 6. From graphic presentation of the experimental results is obvious that the lasering provides considerably different values depending on degree of surface treatment homogeneity. For the carbon steel the severe decreasing of the fatigue limit even came at strongly non-homogeneous treatment (without overlapping). Significant decreasing of fatigue properties was found for lasered gray cast iron lasering (regardless the treatment homogeneity). For remaining steels slight improvement of properties at homogeneous and partly non-homogeneous laser treatment was detected. Somehow surprising is finding the fatigue limit of samples lasered by one track is lower than that of samples with two tracks (certain effect play a different thickness of the samples).

Measured depth of the layer afected by the laser fluctuates in all observed materials in range of 0.35 to 0.50mm. Maximum increase in micro-hardness after lasering was found for the carbon steel on approximately 310% of the initial value. For another materials this micro-hardness increase reached appr. 250-270%, see Fig.7. From the fractographic point of view the biggest attention was paid to samples with two laser tracks. Micro-cracks, which number in individual areas differed were observed in . surfaces of these samples in course of loading.

In case of discontinuous hardening of notch surfaces the dissimilar strain hardness and different residual tensions have deciding influence in initial stages of fatigue life. As consequence of existence of differently transformed or quite non-transformed areas stress residual tensions arise in lattice, which may stimulate quicker initiation of surface micro-cracks.

As consequence of different mechanical properties of areas nearby the surface and in combination with non-homogeneous residual tensions the initial cyclic plastic deformation concentrates in area between the tracks. Higher number of cracks, observed in ferrite-pearlite areas in comparison with martensite areas can be taken as evidence. The cracks propagation is obviously decelerated or quite blocked on interface of both hardened parts. Contingent fields of residual stress tensions in the lasered areas may even play significant role at this blocking.

Steplike fracture surface is often observed, each step corresponding to one laser track. This knowledge, together with micromorphology of fracture surfaces suggests, that the mode of lasered area failure is deciding for the magistral crack forming. Two mechanisms of surface failures are supposed in stage following the micro-cracks initiation:

(i) the nucleation of micro-cracks in the ferrite-pearlite part, where they are localized in the immediate vicinity of lasered areas, they may preferably propagate through this area (there are the highest tensile tensions),

(ii) it is possible to suppose that the existence of certain increased martensite predispositions to nucleation susceptible fatigue fracture may lead to initiation of additional cracks. Delayed propagation of these cracks may be caused by existence of the stress fields.

Both mechanisms act probably as competition ones till the moment the tension field ajanced to the lasered area is destroyed (e.g. as consequence of the nucleated micro-cracks). Preferable failure of hardened areas may be as well coherent with crack propagation rate, which is higher in low-tempered martensite than in the martensite, tempered at higher temperature.

The basic structure of the gray cast iron is pearlitic with flake graphite. Size of pearlitic colonies is in range of 10-40 μm, microscopic pores are presented in the material. The laser thermal treatment led to surface hardening to depth of appr. 0.5mm. Graphite distribution was not by the laser thermal treatment remarkably influenced.

On the fracture surfaces were found no more widespread areas with characteristic fatigue grooving. Based on fractographic observations it may be supposed that the fatigue crack propagates rather by small discontinuous jumps through suitable areas at utilization of present cavities and graphite flakes.

Plasma nitridation (PN)

Homogeneous layer hardened into depth of 0,15 to 0,30 mm was produced applying the low temperature plasma nitridation. The micro-structure of the surface layer is characteristic by very thin white layer (appr. 10 μm), formed by hard nitrides. Under this surface layer follows diffusion layer created by Fe and N compounds. Surface hardening under the white layer is remarkable lower in comparison to hardening due laser treatment - $HVm_{0.04}$ increases on 220% of initial value as maximum. The depth of hardened layer is lower than at lasering (Fig.7). Fatigue properties are in all cases comparably better that at laser hardening - see Fig.3, 4, 5 and 6 (**PN**). Observation of fracture surfaces have shown that the initiation occured in more places simultaneously, especially in vicinity of the edge with side wall of the specimen. The initiation comes in vicinity of surface under white layer. Beside thin surface layer the homogeneous distribution of hardening and residual stresses play significant role at increasing of resistance against fatigue fracture.

Nitridation (N)

The results generated on samples with surface treated by standard nitridation in the gas are introduced in the graphs of steels ČSN 41 4140 (SS) and ČSN 41 4209 (BS). This treatment applied at temperatures higher than that used in previous case. Results of fatigue tests show even more remarkable improvement than those observed at plasma nitridation. The most cracks initiate under the surface layer, usually on different inclusions and similar discontinuities (fig.8).

CONCLUSIONS

Results of fatigue tests for four materials with different surface treatments by laser, plasma nitridation and by standard nitridation were summarised. It was shown that the basic factor, which influences fatigue properties is homogeneity of the treated surface layer than its thickness and level of surface hardening. E.g. homogeneously hardened surface layer of plasma nitridated gray cast iron led to compensation of negative effect of the graphite flakes and remarkable improvement of fatigue properties. On the other side results on the same cast iron treated by the laser show, that even high hardening of surface layer may have even negative effect on the fatigue limit in combination with unsuitable basic structure. On the carbon steel significant effect of laser treatment mode (homogeneity of treatment) was shown. In case of surfaces lasered by more tracks relatively complicated way of fracture initiation at notch surfaces was observed. Surface microcracks arise obviously simultaneously in the hardened and not hardened surface parts, than the crack propagates preferably through the laser hardened part. On contrary from the laser treatment the plasma nitridation and standard nitridation had always unambiguously positive influence on the fatigue properties. At this treatment there were long period till registered cracks followed by stage of magistral crack quick propagation.

TAB.1 Chemical composition of the observed materials

mater	C	Mn	Si	Cr	Ni	Al	P	S	Fe
CS	0.59	0.66	0.35	0.24	0.09	0.021	0.014	0.024	bal.
SS	0.41	0.65	0.21	0.96	0.26	0.004	0.019	0.018	bal.
BS	0.98	1.12	0.51	1.45	0.04	0.002	0.012	0.017	bal.
GCI	2.96	0.92	1.42	0.16	0.08	0.008	0.021	0.032	bal.

REFERENCES

(1) Mazal,P. and Dlouhý,I., Scr.Metal.et Mater., Vol.28, 1993, pp.693-698.

(2) Mazal,P. et al. "Fat.Properties of Mater. with Surf.Hardened", Heat Treat.& Surface Eng., IFHT'95, Edited by M.Salehi, ISSST, Isfahan, Iran, 1995.

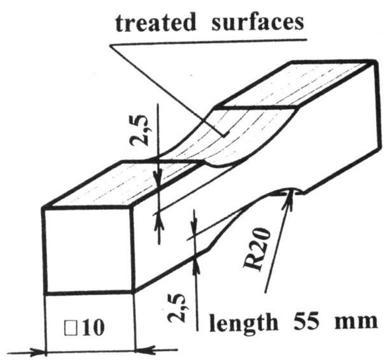

Fig.1 Test specimen geometry

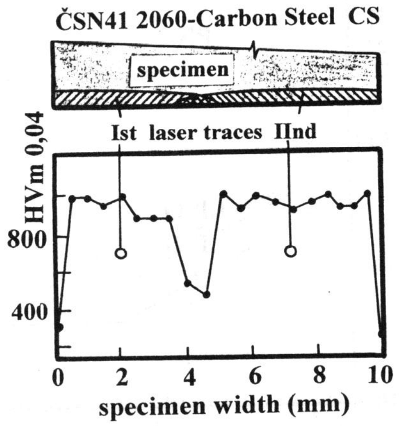

Fig.2 Micro-hardness on surface of sample with overlapping laser tracks

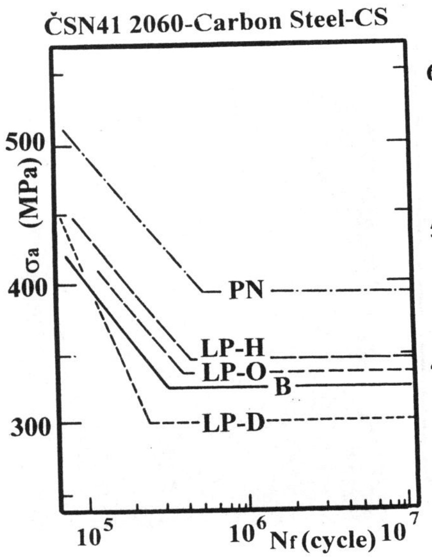

Fig.3 Dependence Nf vs. σa for carbon steel.

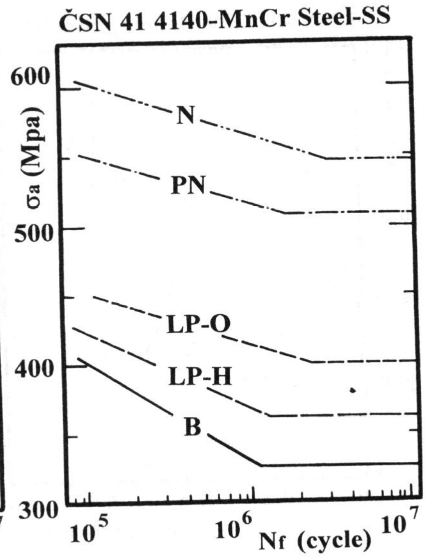

Fig.4 Dependence Nf vs. σa for structural Cr steel.

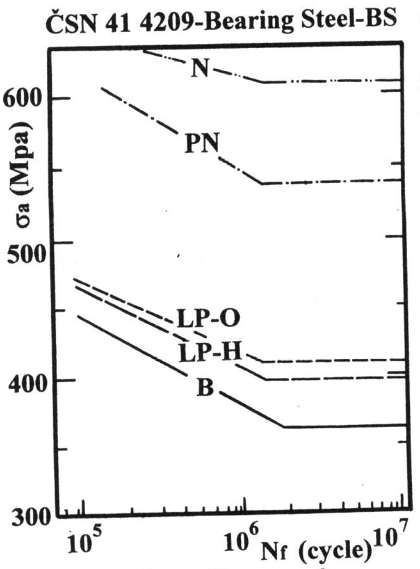

Fig.5 Dependence Nf vs. σa for bearing steel.

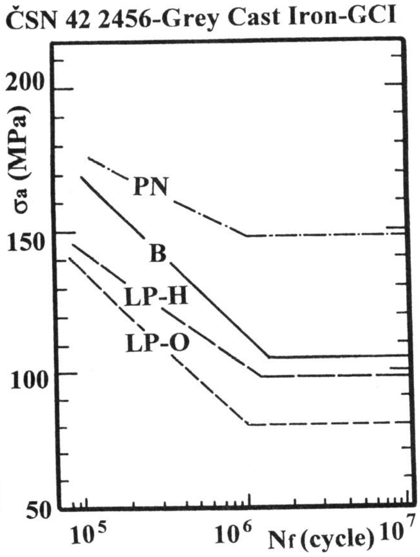

Fig.6 Dependence Nf vs σa for grey cast iron.

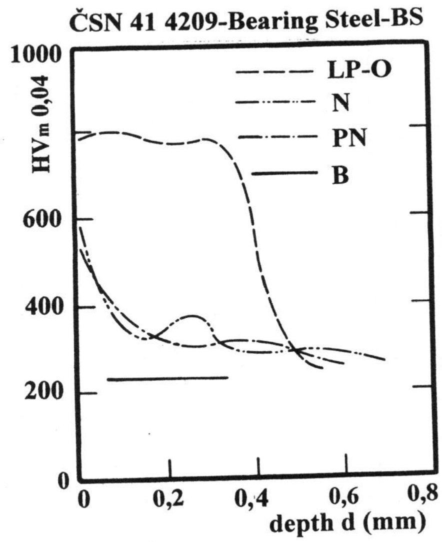

Fig.7 Micro-hardness under the surface of bearing steel.

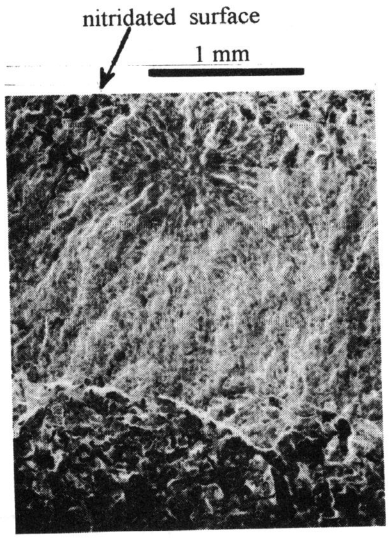

Fig.8 Micrograph of crack initiation site under nitridated surface (SS).