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An Effect of Surface Laser Hardening on Deformations and Fatigue Properties of 42CrMo4 Steel Specimens

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Abstract. Laser hardening is an advanced method of surface heat treatment with wide possibilities of industrial applications. Considering the fact that this technology is fairly new and is being developed, knowledge about effects on properties of materials treated by this technology are still limited, particularly from the viewpoint of mechanical and particularly fatigue properties. As a dependence of numerous parameters of the treatment, basic material and its state and also size of treated pieces or specimens, not only substantial changes of microstructure in the surface and subsurface layers occur, but also residual stresses and connected deformations. Results of an experimental investigation of effects of laser treatment with selected parameters on deformations and fatigue resistance of relatively small samples of 8 x 8 mm cross section are presented and discussed in this work. Effects of surface speed of the laser beam was evaluated, then effects of fixation of the specimens to rigid supporting steel plate on changes of deflection caused by the laser treatment and eventually, changes of the deformations after releasing the specimens from the supporting plate. Results are in a good agreement with residual stress measurements. Fatigue tests indicated possibilities of favourable effects of laser treatment on fatigue resistance. Results are discussed considering an occurrence of inclusions in the material, residual stresses and fatigue damage mechanisms.

Introduction

Laser surface hardening belongs to advanced methods of surface treatment of structural steels with a great potential to improve various surface properties like wear, corrosion or fatigue resistance and consequently with a wide industrial application possibilities. The technology is fairly new and so, further investigations have to be performed in order to gain a comprehensive knowledge about effects of laser hardening applications with specific parameters in specific cases of basic materials and conditions of use.

As regards fatigue strength of materials treated with this technology, recently published results show that fatigue resistance can be either reduced or increased, even considerably, depending on numerous parameters of basic material and laser hardening parameters. Effects of laser treatment on existing cracks, either short surface or subsurface or long cracks at conditions of fatigue loading represent a specific field of problems [1, 2]. Particularly residual stresses and their distribution in surface and subsurface layers play an important role [3]. Compressive residual stresses in general reduce mean stress of cyclic loading and therefore can result in a growth retardation or even complete arrest of short surface or subsurface fatigue cracks [4].

Particularly during last two or three years, results of new investigations have been published, which concern either favourable or unfavourable effects of laser hardening in combinations with some other types of surface treatment like coating, shot peening etc. [5]. Note that a significant, positive effect of laser hardening using previous generation of lasers in a combination with subsequent surface polishing on fatigue strength in a high cycle regime and fatigue limit was shown and described at SVÚM already several years ago [6].

This contribution contains results of a partial study of effect of laser hardening of relatively small specimens on their deflections caused by surface residual stresses and on fatigue resistance of 42CrMo4 steel.

Experiments

Experimental material was a low-alloy 42CrMo4 steel suitable for both heat treatment and surface heat treatment. The material was obtained in both available versions of chemical compositions, namely 42CrMo4 and 42CrMoS4, the latter with guaranteed range of sulphur content, usually higher than in the version 42CrMo4. The guaranteed range of sulphur content in 42CrMoS4 steel is between 0.020 and 0.040 % with ± 0.005 % tolerance in a final product. Chemical composition of the steel according to the material sheet of the provider – Bohdan Bolzano s.r.o. company is in the following Table 1 [7].

Table 1 Chemical composition of 42CrMo4 steel

Element	**C**	**Si**	**Mn**	**P**	**S**	**Cr**	**Mo**
Weight %	0.38-0.45	max. 0.40	0.60-0.90	max. 0.025	max. 0.035	0.90-1.20	0.15-0.30

According to the delivery sheets, the steel was heat treated. Actual strength corresponded to the values declared. Metallographical analyses, however, showed considerable microstructure inhomogeneity, atypical for heat treated state (Fig. 1). Therefore, before continuing in the experimental programme, the material was heat treated again with the same target values of strength, but homogenous microstructure (Fig. 2).

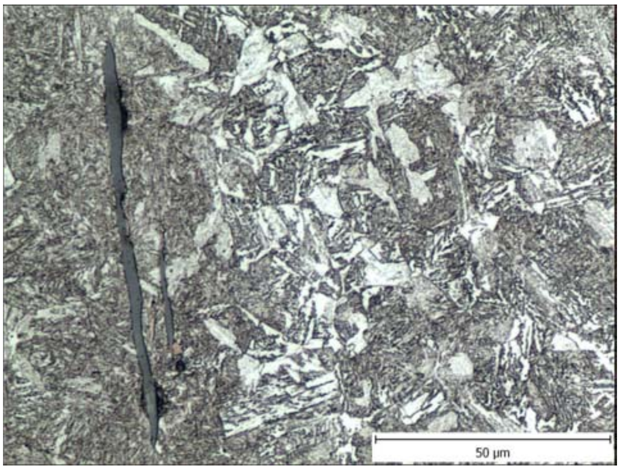

Fig. 1 Original inhomogeneous microstructure of 42CrMo4 steel with impurities and inclusion

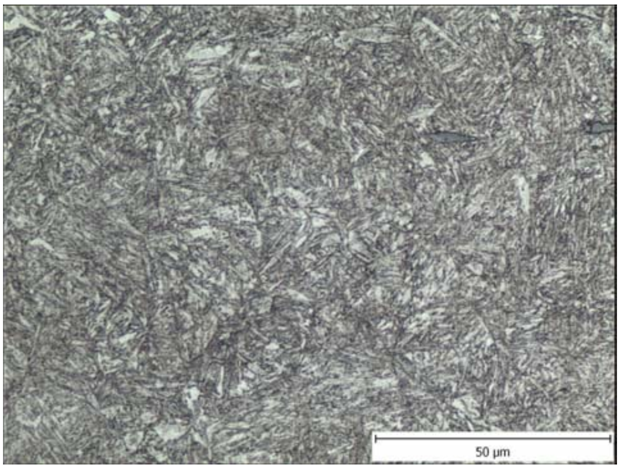

Fig. 2 Homogeneous microstructure of tempered martensite after additional heat treatment

In the next step, specimens for fatigue tests under three point bending were manufactured from both the steels. Cross section of the specimens was 8 x 8 mm, total length 140 mm. Reference specimens for fatigue tests of the same heat treated material, but without laser hardening were manufactured, too.

Already preliminary laser hardening indicated certain concave deflection of the specimens. It was therefore decided to weld the specimens at their ends to a supporting rigid steel plate before the laser treatment. Triplets of specimens were always welded, their total width being 24 mm. As the laser beam width was more than 25 mm, all specimens in a triplet were treated together. Parameters of the laser treatment corresponded to surface temperature 1200 ^{o}C and surface laser beam speed of

3 mm/s and 4 mm/s, respectively. Corresponding marking in diagrams is 1200/3 and 1200/4, respectively.

Deflections resulting from the laser treatment were measured using magneto-dynamic gauge Sangamo with a precision of 1 μm. A detail of the measurement of specimens welded to the plate is in Fig. 3.

Fig. 3 Measurement of deflections on triplet of specimens welded to supporting plate

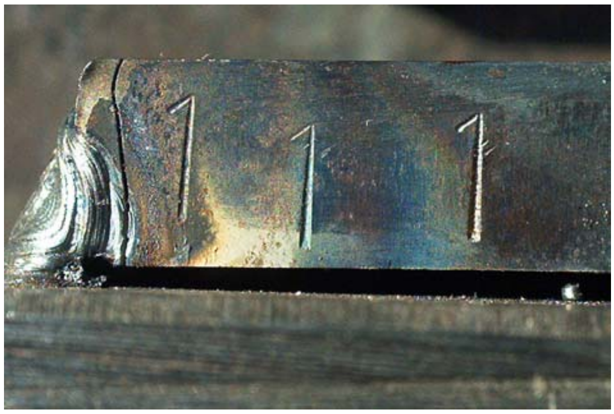

Fig. 4 Gap between the specimen and supporting plate in case of imperfect weld

Results, Discussion and Conclusions

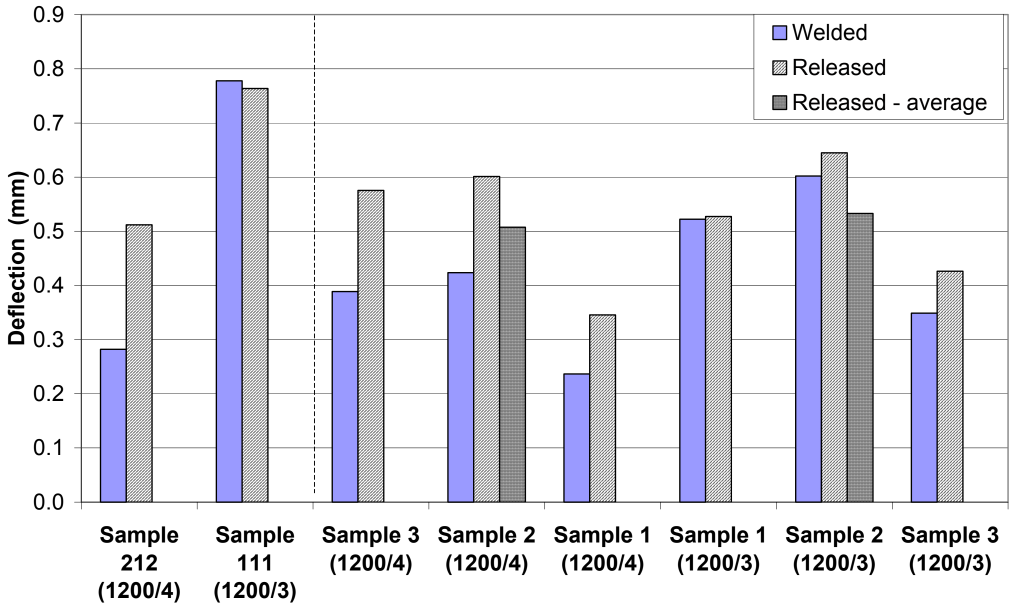

Fig. 5 Comparison of defection of laser hardened specimens welded to the plate and released

Results of the deflection measurement are shown in Fig. 5. First two specimens in the diagram, namely 212 and 111, were laser treated and evaluated separately. Specimen 212 was one of specimens treated in a couple, specimen 111 was a marginal specimen of a triplet. The next six specimens were treated as two separate triples with the different beam speeds. In both the triples, specimen 2 was the central one, specimens 1 and 3 were marginal. Several characteristics following from the diagram can be pointed out:

- The deflection values, particularly those before specimen release from the supporting plates, depend on the intensity of the specimen heating by the laser beam. Average values of deflection in case of surface beam speed 3 mm/s are significantly higher than those corresponding to the 4 mm/s beam speed. Furthermore, the highest deflection occurred in specimen 111, where there was the quite poor contact with the supporting plate (Fig. 4) and so heat flow from the specimen to the plate was rather limited.

- Deflection of central specimens in the triplets were higher than deflection of the marginal specimens. It looks that the power of the laser beam near its margins was somewhat lower as compared to its centre.
- Not easy to be explained are different deflection changes after releasing of the specimens from the supports for the different surface laser beam speeds. These changes are evidently more distinct in case of the beams speed 4 mm/s, whilst they are almost negligible for the 3 mm/s speed. Excluding the specimen 111 with the poor contact with the supporting plate, deflections after the specimen release are almost comparable for the two beam speeds.

The deflection effects are quite comparable with surface and subsurface residual stresses measured at the Czech Technical University in Prague (Ganev N. and Kolařík K.), where significant compressive longitudinal stresses around –300 MPa were evaluated particularly in case of the laser beam speed of 4 mm/s. These compressive residual stresses evidently contributed to the increased fatigue resistance and fatigue limit of the specimens laser treated with the 4 mm/s beam speed [8]. Note that there were numerous crack-like defects in the material (Fig. 1). Laser hardening does not remove the inclusions, but compressive stresses induced by the laser treatment are able to retard or even arrest physically short fatigue cracks emanating from the inclusions [9, 10].

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