

## STANDARD AND SCANNING LASER HARDENING PROCEDURE

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### Abstract

Laser hardening is one of the most common laser applications. The standard "wide-spot" method uses a direct diode laser with a large spot which moves evenly along a treated area. The scanning method uses a small laser spot in combination with a laser scanning head, which allows very fast laser spot displacements. This technique is based on very fast laser beam sweeping which is perpendicular to main laser treatment trajectory. The fast sweeping beam acts like a continuous wide laser spot. These two laser hardening techniques are described and compared in this contribution. Experimental procedures and results examples are introduced. HPDD (High Power Direct Diode) laser with spot dimensions 6 x 12 mm was used for wide-spot hardening and a solid state disc laser with spot diameter 800  $\mu\text{m}$  and laser scanning head allowing spot displacement speed up to 21.5 m/s were used for scanning method hardening. Results comparison and main advantages or drawbacks of both the methods are discussed in this contribution.

**Keywords:** laser hardening, laser quenching, steels, laser scanning, surface treatment

### 1. INTRODUCTION

Laser usage in commercial applications rises thanks to increasing efficiency and decreasing cost of laser systems. Laser hardening [2,3,4] has proved to be a very competitive method of material processing. It differs significantly from the conventional methods of heat treatment, where the absence of a cooling medium matters. Laser radiation acts as a heat source and it heats up rapidly the surface of the workpiece under the laser spot during a short time of the laser-surface interaction. Consequently, the heat is conducted immediately into a material bulk. The workpiece can be hardened by the laser radiation only in a surface layer, approximately to one tenth of its thickness (depth of material under the laser track) and can reach very high hardness due to a very rapid heat dissipation. The maximum achievable depth of hardening is about 2 mm without melting of the surface layer (depending on a treated material, geometry of the workpiece and laser beam parameters). The main advantage of laser hardening is its speed, possibility of precise control of the entire process (e.g. according the surface temperature), high selectivity (only selected areas can be hardened, minimal heat impact against the workpiece), minimal distortion and thermal influence of the hardened part, the possibility of processing of hardly reachable places of the treated workpiece, "pure" operation (processing possible in any atmosphere, oxidation is always at an acceptable level - in comparison with other methods). Tracks must be placed side by side during hardening of the large components. A slightly tempered region with decreased hardness occurs at the point of tracks overlaps in this case. It can be complication if the processed part operates under dynamic stress. Any conventionally hardenable material can be laser hardened, but excellent results can be achieved only for proper materials, which are suitable for this type of processing. Since laser hardening is a very fast process it is important to choose material which can achieve sufficient homogenization of austenite during very short time period, preferably fine-grained materials with graphite in the form of flakes (higher rate surface/volume). Grain size of the processed materials can be affected substantially by the appropriate choice of previous treatment. Best results are achieved with annealed parts. The process proceeds very quickly, so there is no excessive grain coarsening. Advantage of laser hardening process is the possibility of selective processing of geometrically complicated components and it is well suited for small series because of easily programmable process.

Because the surface layer only is hardened, the advantage of increased resistance to surface abrasion is obtained while a flexible core is maintained. This is used especially for holders of machine tools, mechanical components, molds, matrices, bearings housings, pins, rollers, clamping tools, shafts, gears, hinges, pins, nuts, etc.

Lasers [1] with wavelengths of 800-1064 nm are used for laser hardening due to their very good absorption by metallic materials. There is not a need for a high quality beam therefore diode lasers with high efficiency (up to 50% today) and power output of several kW are used. The value of the applied power always depends on the beam profile (geometry). Spot size is normally from tenths to thousands of square millimeters. The laser spot [5] of rectangular shape (power distribution should be constant in at least one axis) is used most often. If a constant temperature distribution across the width of the track is needed, the laser beam in the shape of inverse gauss is applied. Such a beam profile can be achieved by use of special optical components (e.g. πShaper).

Laser hardening with scanner [6] is a new method of laser processing, which is especially useful for processing of small parts or hardly reachable places. Gaussian spot profile [7] with smaller size (hundreds of micrometers, maximally several millimeters) in focus is used in comparison with the standard laser hardening. It allows higher control over the process. Hardened area is heated rapidly by quick scanning of the laser beam. Even very complex regions (of limited size) can be processed as a whole piece. Gaussian beam profile is scanned perpendicularly to the direction of motion. It is necessary to choose the right amplitude, oscillation frequency and traverse speed. Burns occur at the edges of the processed area (oscillation amplitude peaks) due to the limited dynamic of the scanning optics. The burns can be eliminated by switching off the laser on the edges.

The two different methods for laser surface hardening are presented in this contribution. The aim of the work is finding suitable process parameters, comparing the final properties of hardened surfaces and presenting the main possibilities, advantages and disadvantages of both the methods.

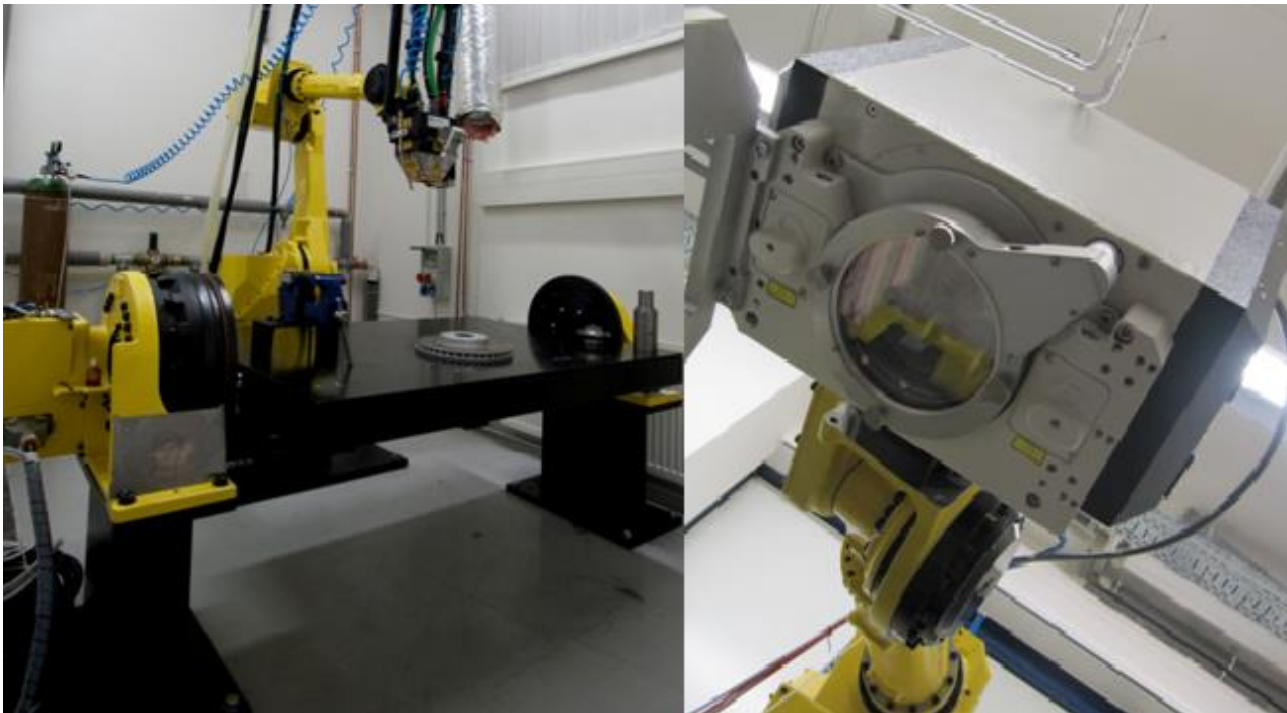
## **2. EXPERIMENTAL PROCEDURE**

### **2.1 Standard laser hardening system**

The diode laser Coherent Highlight ISL-4000L mounted on the robot Fanuc M-710iC was applied for the standard heat treatment (Fig. 1). Laser diodes emit a beam of wavelength 808 nm. Maximum laser power is 4.3 kW. Laser spot is shaped by output optics into a rectangular profile and the dimension of the spot is 12 x 6 mm. The working distance of the processing optics is 90 mm. Fanuc industrial manipulator allows motion in 6-axis. Rotary positioner is integrated in the system for the processing of rotational parts. The devices form together a highly versatile system for processing of a wide range of various workpieces.

### **2.2 Experimental – standard laser hardening procedure**

Three sets of parameters were used to demonstrate the capabilities of the Coherent laser hardening system. Samples with dimensions of 100 x 50 x 25 mm from steel grade ČSN 12050 were selected for the experiment. The first sample was processed with power of about 1 kW and low traverse speed of the laser beam over the surface. The laser beam created three 10 mm wide traces with a slight overlap (about 2 mm) on the sample surface. The second and third samples were processed with severalfold higher traverse speed. The power of 3.3 kW was used for the treatment of the second sample and the maximum power of 4.3 kW was applied for the third sample.



**Fig. 1** The device for standard (left) and scanning (right) laser hardening

### 2.3 Scanning laser hardening system

For the scanning laser hardening it is necessary to use a scanning head, which sweeps the laser beam over the treated surface. Trumpf disk laser Trudisk 8002 and 3D-scan system ScanLab intelliWELD 30 FC V (scan head) were integrated and create a system for surface heat treatment (Fig. 1). The laser emits a beam with a wavelength of 1030 nm. Spot size of 800  $\mu\text{m}$  was used for the first application tests. Maximum laser power is 5.3 kW. Working distance of the scanning optics is 544 mm and the focal length is 460 mm. The scan head is able to process an elliptical image field of dimensions 385 x 270 mm the maximum laser beam movement speed – 21.5 m/s. Movement in z axis is allowed in range of  $\pm 70$  mm. The scan head is controlled by SAMLight software.

### 2.4 Experimental – scanning laser hardening procedure

The processing procedure was based on a low speed laser beam movement in x axis (laser hardening progress axis) and high speed oscillations in y axis (perpendicularly to the direction of the laser hardening progress). The method was tested using parameters in Table 1. The amplitude from 1 to 8 mm and the oscillating frequency from 300 to 1000 Hz were the most suitable for testing. The power of 300 W was sufficient for the set of parameters. These procedures brought very similar results at those for conventional “wide beam” laser hardening. The highest measured hardness was about 550 HV. The method tests were performed on RobotSyncUnit software.

**Table 1** Scanning laser hardening – testing process parameters

Test no.	Power [W]	Wobbling frequency[Hz]	Surface hardness [HV5]	Track width [mm]
1M	200	300	400 $\pm$ 21	2
2M	300	500	550 $\pm$ 29	4
3M	300	700	520 $\pm$ 18	6

The applicability of the scanning method had been verified after the method tests. The scan head was coupled with scanning control software SAMLight. This software allows adjustment of the shape of the

processed area and a type of hatch selecting. Two different procedures were used. The first procedure - a shape and a size of the processing area were selected, and then the area was hatched with the laser beam (Table 2). The second procedure – a trajectory of a random shape was chosen and the process was performed by scanning the circle contour and moving over the trajectory with a set speed (Table 3). Tests were demonstrated on sample with dimensions of 100 x 50 x 25 mm from steel ČSN 12050.

**Table 2** Scanning laser hardening – hatching of square pattern

Test no.	Power [W]	Dimension A [mm]	Dimension B [mm]	Process time [s]	Specific energy [J/mm <sup>2</sup> ]	Surface hardness [HV5]
1	1000	10	10	4.3	21.7	663±14
2	1000	10	10	3.2	15.9	710±13
3	1000	10	10	2.8	14.1	684±18
4	1000	10	10	2.3	11.5	658±11
5	500	10	10	4.3	11.5	598±15
6	500	10	10	14.8	39.3	497±19
7	500	10	10	3.2	8.4	625±18

**Table 3** Scanning laser hardening – moving of circle pattern

Test no.	Power [W]	Length of trajectory [mm]	Circle diameter [mm]	Process time [s]	Specific energy [J/mm <sup>2</sup> ]	Surface hardness [HV5]
8	1000	20	10	10.1	50.6	494±44
9	1000	20	10	2.1	10.4	502±10
10	1000	20	10	3.4	17.1	644±17
11	1000	20	10	5.1	25.4	506±27
12	500	20	10	5.1	13.4	328±4
13	500	20	10	10.1	26.6	303±6

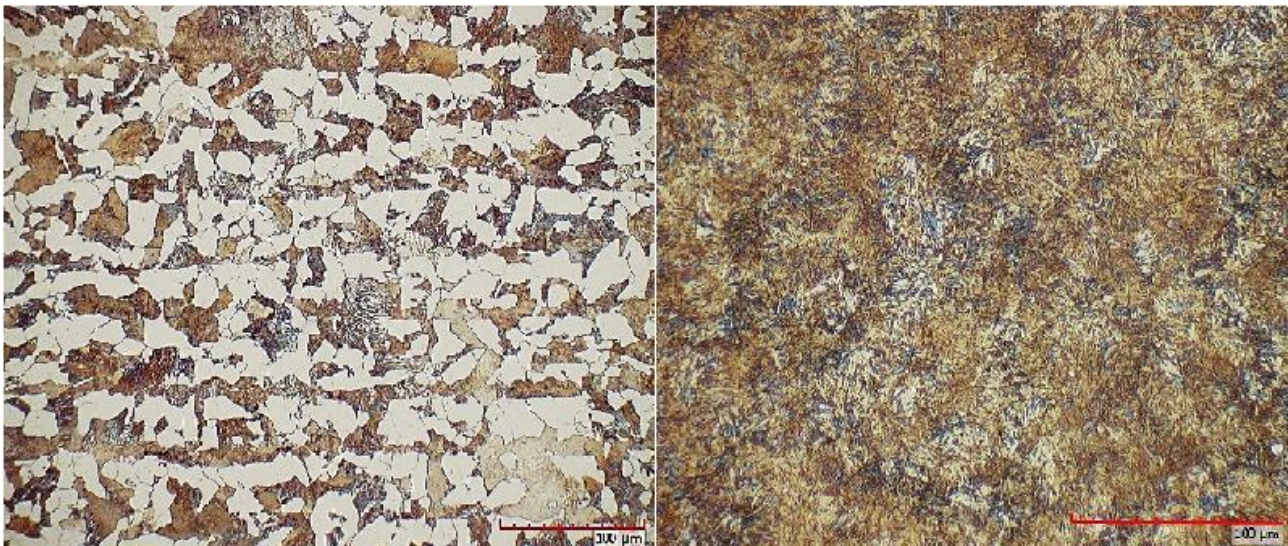
### 3. RESULTS AND DISCUSSION

#### 3.1 Standard laser hardening procedure

Surface hardness was measured on all processed samples (Table 4). Surface hardness was measured by method HV5 and individual samples differ significantly. Hardness about 492 HV was measured in the center of the trace on the 1S sample, 638 HV on the 2S and 675 HV on the 3S respectively. The hardness in traces overlap was significantly lower, about 400 HV. Processing of the 1S sample was too slow, therefore the sample warmed up to much and rapid “self-quenching” [8] couldn't take place. The result of this structure is low hardness of processed surface area. Sample of dimensions as used in this experiment should be processed with a higher laser beam velocity. Metallographic analyses were realized for structure appreciation. Ferritic and martensitic “needle-like” structure of 2S sample is shown in the figure 3.

**Table 4** Standard hardening parameters

Test no.	Power [W]	Beam profile width [mm]	Process time [s]	Specific energy [J/mm <sup>2</sup> ]	Surface hardness [HV5]	Depth of hardened layer [μm]
1S	1100	12	160	50.1	492±14	250
2S	3300	12	16	12.8	638±8	450
3S	4300	12	11	10.1	675±13	400



**Fig. 2** Ferritic structure (left), martensitic “needle-like” structure (right) – Sample 2S

### 3.2 Scanning laser hardening procedure

The scanning method is convenient especially for processing of complex workpieces. The scanner allows changing the width of the processed area easily during the process. The scanning software allows very precise control of energy distribution in the processing area and complex treating patterns can be produced. Processing time is for scanning method significantly shorter. Processing speed influences the depth of hardened layer. Spot size can be modified thanks to variscan (z axis movement). The process of laser hardening can be easily controlled according a surface temperature. This value in conjunction with time period of maintaining the temperature is the main quality quantifier. The surface temperature can be controlled (or maintained) very precisely thanks to possibility of repeated scanning in a short period of time. The repeated scanning of the processed area results in better austenite homogenization because of longer time for austenitic transformation. Following results have been obtained in comparison of two scanning methods. First scanning method is based on hatching of a square contour. Measured surface hardness of hatched area is of a satisfying value and its distribution is very homogenous (Table 2). Second scanning method uses moving of the laser circle pattern over the treated surface. This procedure does not give so satisfying results. Surface hardness is lower and it isn't distributed so uniformly (Table 3).

## 4. SUMMARY

The obtained results are of a similar quality respecting the surface hardness. Two different methods of laser hardening were presented on series of experiments. The standard method uses the high-power direct diode laser. The high process speed in combination with high laser power results in higher hardness of treated surface. This method is more favorable for processing of large plain areas but treating of small complex zones is very problematic. Creating of tempered zones in laser track overlaps is another disadvantage, which influences surface properties of processed area.

Hardening of small complex trajectories is performed perfectly by the scanning method. The scanning method advantage compared to standard laser hardening is especially a very precise and easy control of beam guiding. The main advantage is that very complex areas can be processed as a whole piece without overlaps. Thus no tempered zones are produced. Width of laser beam can be modified by changing of scanning properties. It is a great advantage against our standard laser hardening system, which has constant width of laser beam about 12 mm. We will focus on discovering of scanning system possibilities in the future.

High power diode lasers are well-established for surface treatment. Purchase cost of diode lasers is significantly lower than cost of solid state lasers of similar power, which are mostly used for scanning applications. The purchase cost difference is adequate respecting the beam quality. However the comparison introduced in this contribution has shown that high-power solid-state lasers have advantages in some special applications.

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