

## Robot laser hardening and the problem of overlapping laser beam

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### ABSTRACT

Since 1970, many studies of various laser machining processes and their applications have been published. This paper describes some of our experience in laser surface remelting, consolidating, and hardening of steels. We focus on the problem of robot laser hardening of metals with overlapping of the hardened zone. The process of laser hardening with remelting of the surface layer allows us to very accurately determine the depth of modified layers. In this procedure, we know the exact energy input into the material. Heating above the melting temperature and then rapidly cooling causes microstructural changes in materials, which affect the increase in hardness. We identify the relationship between hardness and width of overlapping. We describe the results of previous work, research, and experience in robot laser hardening of metals. We also show the results of laser processing techniques with the problem of overlapping. Our tests were carried out on materials of DIN standard 1.2379 and 1.7225, and measurements were performed in the hardened zone of overlapping at 2 mm, 3 mm, 4 mm, 6 mm, and 10 mm. We show relationship between hardness and width of overlap for material of DIN standard 1.2379 and 1.7225. The modeling of the relationship was obtained by the 3 layers artificial neural network.

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### ARTICLE INFO

*Keywords:*

Robot  
Laser  
Hardening  
Overlapping  
Neural network

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## 1. Introduction

Different tool steels are widely used in industrial applications based on good performance, a wide range of mechanical properties, machinability, wear resistance, and cheapness [1-6]. By laser remelting the surface of the materials, we can significantly improve their wear properties better like inductive hardening. Robot laser surface [7, 8] remelting is one of the most promising techniques for surface modification of the microstructure of a material to improve wear and corrosion resistance. Laser hardening [9] is a metal surface treatment process complementary to conventional flame and induction hardening processes. A high-power laser beam is used to rapidly and selectively heat a metal surface to produce hardened case depths of up to 1.5 mm with a hardness value of up to 65 HRC. The high hardness of the martensitic microstructure provides improved properties such as wear resistance and strength. Advantages of laser hardening over inductive hardening are:

- laser is a source of energy with outstanding characteristics (contactless methods, controlled input of energy, high capacity, constant process, precise positioning),
- lower costs for additional machining,
- no use of cooling agents or chemicals,
- high flexibility,
- the process can be automated and integrated in the production process,
- superior wear resistance of hardened surface,
- selective hardening of complex geometrical shapes,
- local hardening,
- no local melting of material,
- minimal deformation,
- high accuracy,
- low heat input and thus low distortion,
- consistently high product quality due to process control.

For laser heat treatment, a CO<sub>2</sub> laser with high power continuous mode is used. Phase transformations take place in the heat-hardened zone only in the solid state. A fixed pearlite-ferrite microstructure is formed by heating austenite with a concentration gradient of graphite flakes or nodules. Non-uniform austenite is transformed by cooling to martensite and ferrite. In Fig. 1, we see a robot laser cell for hardening. This paper describes the robot laser hardening of metals by the overlapping of laser beam. The aim of the contribution is to outline possibilities of applying artificial neural networks for the prediction of mechanical steel properties after robot laser heat treatment and to judge their perspective use in this field. The achieved models enable the prediction of final mechanical material properties on the basis of decisive parameter width of overlap of laser beam influencing these properties.

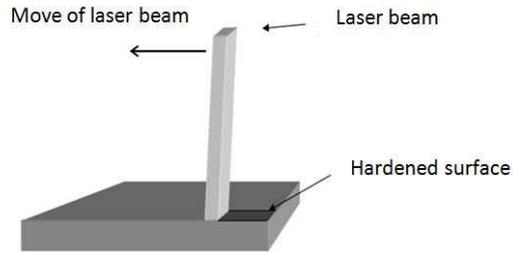


**Fig. 1** Robot laser hardened cell

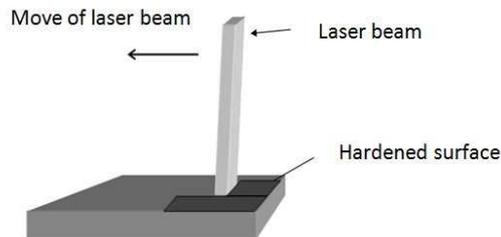
## 2. Material preparation and experimental method

### 2.1 Material preparation

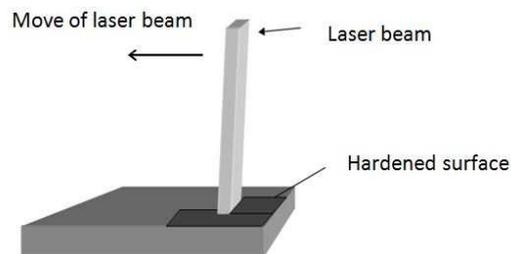
Robot laser cell can be used to provide the heat necessary for the treatment process. We use robot laser cell RV60–40 from Company Reis Robotics. As 6-axes universal robots with high path speeds and large work envelopes the RV-robots are especially suited for the high demands of path-related tasks. Laser beam have rectangle shape. We use 5×23 mm optics, F200. It means, that with this optic we hardened approximate 23 mm width. Robot laser works continuously with wavelength 700–1000 nm. Maximum power of robot laser cell is 3000 W. We hardened specimens with 1500 W output power. Robot laser hardening presents a variety of problems [10]. In previous work [11] we research how parameter of angel impact on hardness of material of DIN standard 1.7225. In this work, we were interested on problem of overlapping. We use ma-



**Fig. 2** Hardening of material



**Fig. 3** Hardening material next to hardened zone



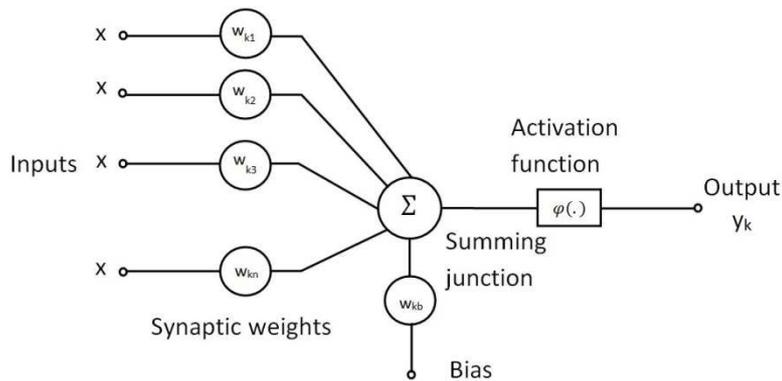
**Fig. 4** Hardening material with overlapping

material of DIN standard 1.2379 and 1.7225. Chemical composition of the material of DIN standard 1.7225 contained 0.38–0.45 % C, max 0.4 % Si, 0.6–0.9 % Mn, max 0.025 % P, max 0.035 % S and 0.15–0.3 % Mo. Chemical composition of the material of DIN standard 1.2379 contained 1.53 % C, 0.35 % Si, 0.4 % Mn, 12 % Cr and 0.85 % V. First, we hardened the materials (Fig. 2) with speed 2 mm/s and with temperature 1100 °C. Also, robot was moved linear. We use optimal parameters of robot laser cell of speed and temperature [12], which give us the best results of hardness. Very important is that robot laser cell has constant speed travel of laser beam. After this process, we hardened them again over the hardened zone, where we use different width of overlapping.

Firstly, we hardened material next to the hardened zone (Fig. 3), and then we hardened material over the hardened zone (Fig. 4) with different widths: 2 mm, 3 mm, 4 mm, 6 mm, and 10 mm. Our objective was to find a relationship between hardness and width of overlapping (Fig. 3 and Fig. 4). Material of DIN standard 1.2379 have hardness of 7 HRC and material of DIN standard 1.7225 6.5 HRC.

## 2.2 Experimental method

For analysis of the results, we used an intelligent system method, namely a neural network. Neural networks are model-less approximators, capable of performing the approximation–modelling operations regardless of any relational knowledge of the nature of the modelled problem. The relational knowledge is typically represented by the set of equations describing the observed variables and constants used to describe the system’s dependencies. The common use



**Fig. 5** The symbolic representation of the artificial neural network cell

of neural networks is the multi-dimensional function modelling [13], i. e., re-creation of the system's behaviour on the basis of the set of known discrete points representing the various states of the system. We are using the feed-forward neural networks with supervised training algorithms. The basic building element of used neural network is an artificial neural network cell (Fig. 5).

Each artificial neural network consists of a number of inputs (synapses) that are connected to the summing junction. The values of inputs are multiplied by adequate weights  $w$  and summed with other weighted input values. The training process changes the values of the weights. The sum of weighted inputs is an argument of the so called activation function which produces the final output of an artificial neural cell. In most cases, the activation function is of sigmoidal type. Artificial neural network cells are combined in the neural network architecture which is composed at least of two layers that provide communication with outer world. Those layers are referred to as the input and output layer. Between the two, there are hidden layers which transform the signal from the input layer to the output layer. They contribute significantly to the non-linearity of the neural network input-output transfer function. The process of adaptation of a neural network weights is called training. During the supervised training, the input-output pairs are presented to the neural network meaning in which each presented input value the desired output value (target value) is also known for they are both part of the training set. The training algorithm iteratively changes the weights of the neural network in order to get closer to the desired output values. Data points are consecutively presented to the neural network. For each data point, the neural network produces an output value which normally differs from the target value. The difference between the two is the approximation error in the particular data point. The error is then propagated back through the neural network towards the input, and the correction of the weights is made in the direction to lower the output error. There are numerous methods for correction of the weights. The most frequently used algorithm is called the error back propagation algorithm. When the training achieves the desired accuracy, it is stopped. From here on, the model can reproduce the given data points with a prescribed precision for all data points.

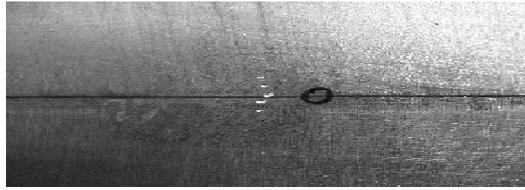
### 3. Results and discussion

#### 3.1 Material 1.2379

Table 1 summarises the results of measurements of hardness in the overlapping zone. All measurements were carried out from the left to right side of the zone. The data for laser beam overlap of 2 mm, 3 mm, 4 mm, 6 mm, and 10 mm are presented in Tables 2, 3, 4, 5, and 6 respectively. Below each table is an image showing the laser beam overlapping of hardened material.

**Table 1** Hardness of laser-hardened material with overlap of 0 mm

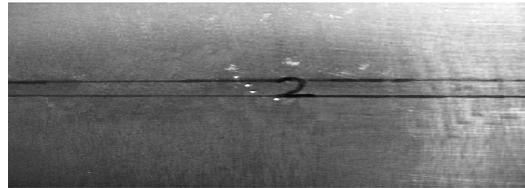
| Overlap (mm) | Hardness (HRc)                 | Direction                             |
|--------------|--------------------------------|---------------------------------------|
| 0            | 59, 59, 57, 55, 54, 50, 42, 15 | right side of the zone of overlapping |
| 0            | 58, 58, 55, 54, 53, 51, 44, 15 | left side of the zone of overlapping  |



**Fig. 6** Hardened zone with overlap of 0 mm

**Table 2** Hardness of laser-hardened material with overlap of 2 mm

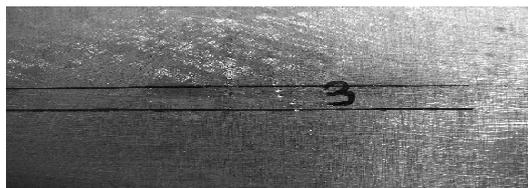
| Overlap (mm) | Hardness (HRc)         | Direction                             |
|--------------|------------------------|---------------------------------------|
| 2            | 58, 55, 50, 45, 31, 12 | right side of the zone of overlapping |
| 2            | 57, 56, 54, 51, 46, 36 | left side of the zone of overlapping  |



**Fig. 7** Hardened zone with overlap of 2 mm

**Table 3** Hardness of laser-hardened material with overlap of 3 mm

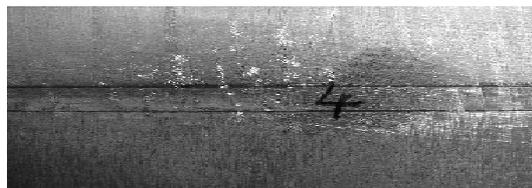
| Overlap (mm) | Hardness (HRc)     | Direction                             |
|--------------|--------------------|---------------------------------------|
| 3            | 56, 54, 52, 50, 43 | right side of the zone of overlapping |
| 3            | 52, 48, 36, 18, 14 | left side of the zone of overlapping  |



**Fig. 8** Hardened zone with overlap of 3 mm

**Table 4** Hardness of laser-hardened material with overlap of 4 mm

| Overlap (mm) | Hardness (HRc)         | Direction                             |
|--------------|------------------------|---------------------------------------|
| 4            | 55, 52, 50, 47, 40, 30 | right side of the zone of overlapping |
| 4            | 57, 54, 47, 41, 29     | left side of the zone of overlapping  |



**Fig. 9** Hardened zone with overlap of 4 mm

**Table 5** Hardness of laser-hardened material with overlap of 6 mm

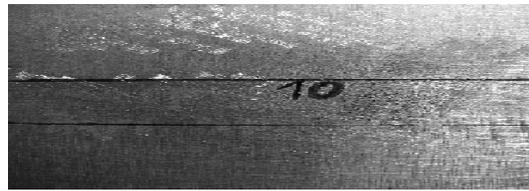
| Overlap (mm) | Hardness (HRc)     | Direction                             |
|--------------|--------------------|---------------------------------------|
| 6            | 57, 53, 48, 42, 39 | right side of the zone of overlapping |
| 6            | 56, 54, 48, 43     | left side of the zone of overlapping  |



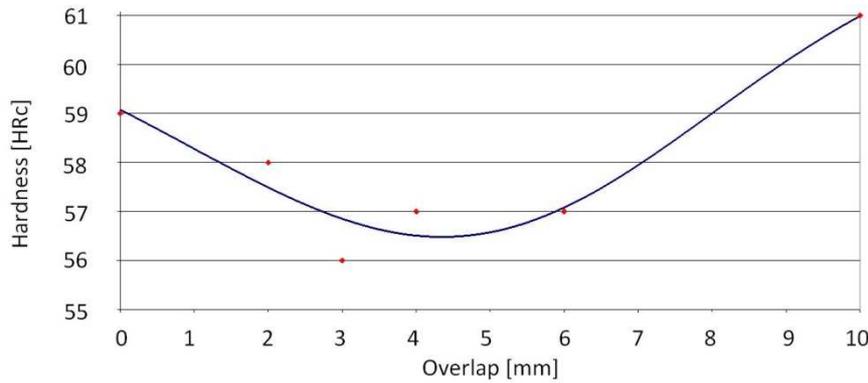
**Fig. 10** Hardened zone with overlap of 6 mm

**Table 6** Hardness of laser-hardened material with overlap of 10 mm

| Overlap (mm) | Hardness (HRC)             | Direction                             |
|--------------|----------------------------|---------------------------------------|
| 10           | 55, 52, 53, 59, 60, 60, 59 | right side of the zone of overlapping |
| 10           | 61, 61, 62, 62, 62, 61, 59 | left side of the zone of overlapping  |



**Fig. 11** Hardened zone with overlap of 10 mm



**Fig. 12** Relationship between hardness and overlap width for material of DIN 1.2379 standard. The modeling of the relationship was obtained by the three layer neural network.

Fig. 12 shows the relationship between hardness and width of overlap for a material of DIN standard 1.2379. The modeling of the relationship was obtained by the three layer neural network. We considered only the highest measured hardness. The results show that the highest hardness occurs at the maximum width of the laser beam overlap.

### 3.2 Material 1.7225

We carried out tests on the material of DIN standard 1.7225. Firstly, we hardened material without overlapping. Second, we used equal process, but we hardened material with different width of overlapping. Measurements from the overlapping zones are presented in Table 8. Measurements, from left to right, are of hardness after hardening without overlapping and after hardening with overlapping. Measurements were carried out from the soft zone towards the centre of hardened zone. Table 8 shows the hardness values for material of DIN standard 1.7225, when the overlap zone is 0, 1, 2, 3, 4, 6, 8, and 10 mm, measured from left to right.

Table 7 shows the hardness values for material of DIN standard 1.7225 without overlapping.

**Table 7** Hardness without overlapping

| Hardness (HRC)    | Direction   |
|-------------------|---|
| 7, 10, 49, 57, 57 | From the soft zone towards the centre of the hardened |

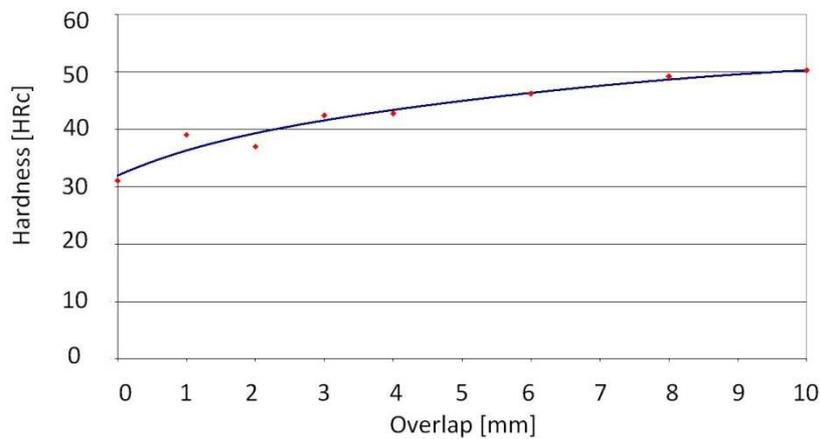
From the data in the tables we can determine the optimal hardness of hardened material in different zones of overlap. For each sample, we used 5 × 23 mm optics, F200. Robot laser hardening temperature was 1100 °C. Speed of laser hardening was 2 mm/s. Comparing data for materials of DIN standard 1.2379 and 1.7225, we can see they are quite similar. When hardened zones touch, we have hardness between 15 HRC and 59 HRC. Hardness in the overlapping zone between 2 HRC, 3 HRC, 4 HRC, and 6 HRC yields similar results; hardness is between 30 HRC and 58 HRC. Surprisingly, we find the best results in the overlapping zone 10 mm, where hardness is measured at 59 HRC (Table 6).

**Table 8** Hardness of material with different widths of overlap

| Overlap (mm) | Hardness (HRc) |
|--------------|----------------|
| 0            | 55, 43, 10     |
| 1            | 53, 30, 10     |
| 2            | 51, 14, 26     |
| 3            | 52, 28, 22     |
| 4            | 41, 22, 20     |
| 6            | 45, 32, 43     |
| 8            | 56, 40, 33     |
| 10           | 52, 39, 32     |



**Fig. 13** Hardened zone with overlap for material 1.7225



**Fig. 14** Relationship between hardness and overlap width for material of DIN 1.7225 standard. The modeling of the relationship was obtained by the three layer neural network.

Fig. 14 shows the relationship between hardness and width of overlap for material of DIN standard 1.7225. The modeling of the relationship was obtained by the three layer neural network. In Fig. 11 is presented robot laser hardened material of DIN standard 1.7225 with all overlapping. We calculated the average hardness of the overlap of the robot laser beam for a given width. We see that the hardness increases with the width of the overlap. For robot laser hardening of a given material to a sufficiently high hardness, the hardness can be increased by re-hardening the material and taking into account the width of the robot laser beam in overlapping. But in otherwise, we can decrease hardness of robot laser hardened materials flat with overlapping. This we can see on table 8. If we repeat process of hardening and use overlapping 4 mm over cone of hardening, then we can decrease hardness of hardening materials on minimum (Table 8).

## 4. Conclusion

In robot laser surface hardening of material of DIN standard 1.7225 and 1.2379, we achieved an impressive increase in the hardness of the surface layers melted, which significantly increases the wear resistance of such modified products. Experimental results have confirmed that material of DIN standard 1.7225 and 1.2379 is very favourable for laser heat treatment, since the durability and wear characteristics of the material were significantly improved after thermal laser treatment. We compared the hardness of two different materials of DIN standard 1.7225 and 1.2379 and found the optimum hardness of each hardened material. Robot laser hardening is very useful in industrial applications. In this paper, we have considered the problem of robot laser hardening in terms of the impact of the width of overlap of the laser beam zone on the hardness of the material. We use method of intelligent system, neural network for analyze experimental data. Robot laser hardening is used on mechanical components, such as torsion springs, gears, tools, dies, and in cutting-edge applications in the engineering, military, aerospace, and aviation industries. Also our very important investigate is that we can achieved decreasing and increasing hardness of materials with overlapping (we repeat process of hardening).

In the future, we hope to explore the problem of overlapping in hardened specimens as a function of several parameters for laser hardening in a robot cell. These laser parameters are power, energy density, focus distance, energy density in the focus, focal position, temperature, and speed of germination. Robot laser hardening presents many problems. In these problems, we can vary all of the above mentioned parameters (which give us a large number of combinations). Similarly, we are interested in the opposite problem, i. e., how to reduce the hardness of the hardened material.

## Acknowledgements

The present work was supported by the European Social Fund of the European Union.

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