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# The refinement of the surface layer of HS 7425 high speed tool steel by laser and electric arc plasma

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## Abstract

The paper present two different techniques: laser remelting surface and plasma remelting surface of the high speed steel HS 7425. The structure of the remelted layers were examined by means of SEM – microscopy. Measurement of microhardness in remelting zone using Vickers method. The remelting zone consist of dendritic cells and columnar crystals. Increase of hardness was observed in remelted zone in comparison to the substrate of the steel. The hardness in the remelted zone increases with the increasing cooling rate.

**Keywords:** Heat treatment; High speed steel; Laser remelting; Plasma remelting; Microstructure; Microhardness

## 1. Introduction

The development of the first high-speed steels started over 100 years ago. Today in spite of competition from cemented carbide and ceramic material, high speed steels are still main material applied on cutting tools. Because high speed steels have high resistance on the impact load it applies on tools to plastic processing also. Research of high speed steels is are focused on three problems [1,2,3]:
1. substitution or content limitation of expensive alloying elements like W Mo V Co and replacement by Si Ti or Nb;
2. selection parameters and optimazation of heat treatment;
3. application of advanced surface technologies like CVD, PVD, laser treatment and plasma treatment. The laser treatment of high speed steels was subject of research conducted by work's authors [4,5]. The authors have shown advantageous influence of the Nd:YAG pulsed laser and $CO_2$ CW laser treatments on structure, mechanical and tribological properties of the steels.

A lasers devices have a very high price, therefore tests surface refinement of the steel alloys by electric arc plasma [6]. The process of crystallization of high speed steel during laser treatment is similar to the conventional crystallization of steel [5]. After solidification process created the dendritic structure [7], it can be characterized by two parameters: primary dendrite spacing ($\lambda_1$) and secondary dendrite spacing ($\lambda_2$). This structure is showed in Fig.1. (primary and secondary arms spacings). Based on the empirical studies on the stem spacing it has been shown that they depend on the gradient G and the growth rate V. The spacing between main axis of dendrites was described by equation (1).

$$\lambda_1 = \text{const}\ V^{-c}\ G^{-d} \qquad (1)$$

were: $0.2 < c < 0.5$, $0.5 < d < 0.75$ dependent coefficients from quantity of elements alloying (W, Mo, V, Co ) in steel.

The initial growth of the dendrite appears on bulges. The bulges lengthen and transform on the secondary arms dendritic. The growth of the secondary arms of dendritic does not prevent growth of the primary arms dendritic. Distance between secondary dendrites in high speed steels is function of the cooling rate T. The spacing $\lambda_2$ is described by equation (2)

$$\lambda_2 = AT^{-b} \qquad (2)$$

were: T = GV, G –gradient of temperature, V – growth rate, $30.6 < A < 47.4\ \mu m \bullet s / K$, $0.34 < b < 0.38$.

The value of A seems to be determined mainly by the solidify-cation interval, not by the concentration alloying elements [1].

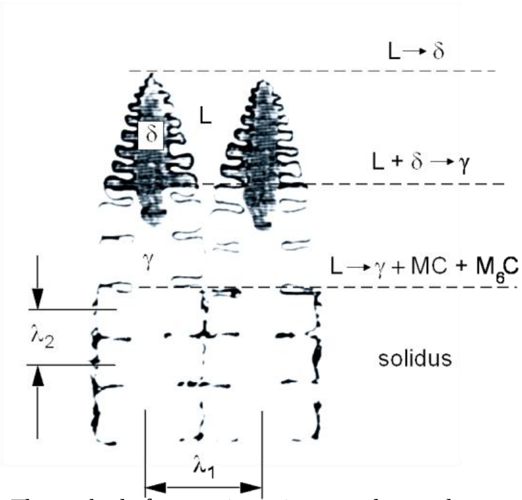


Fig. 1. The method of measuring primary and secondary spacings with solidification reaction for high speed steels [1]

The aim of the work is to study laser treatment (with using Nd YAG - pulsed, $CO_2$CW) and arc plasma electric treatment on the structure and microhardness of high speed steel HS 7425.

## 2. Material and methodology

The HS 7425 (DIN- 1.3246, EU, ISO4957- HS 7425) steel belongs to the cobaltic high speed steel group. Possessing high hardness (after heat treatment it has 66 HRC), excellent cutting properties, high red hardness and good toughness, is applied for heavy duty tools - turning and planing tools of all types, taps, twist drills and cold work tools. The chemical composition of HS 7425 tool steel listed in table 1.

Table 1.
Chemical composition of the HS 7425 steel (average %).

| C | Si | Mn | Cr | Mo | V | W | Co |
|---|---|---|---|---|---|---|---|
| 1,15 | 0,50 | 0,49 | 4,30 | 4,10 | 2,00 | 7,10 | 4,90 |

The tests were performed on conventional annealed steel. Specimens with dimensions of 25 x 25 x25 mm were remelted on the surface with using impulse laser, laser $CO_2$ as well plasma of the electric arc. The parameters of laser treatment were as follows: - laser Nd YAG pulsed, with gaussian distribution of energy $TEM_{00}$, beam defocused on the surface to the spot of about 1,5 mm, energy 30 J, work time 0,5 ms; laser $CO_2$ CW with gaussian distribution of energy $TEM_{00}$, beam diameter on sample surface 2,8 mm, power 1200 W, scanning rate 600 mm/min; arc plasma electric – current intensity 150 A, scanning rate 400 mm/min, graphite electrode - 6 mm diameter. The solidification structures were studied by SEM microscopy combined with computer system of image analysis (Multiscan). The hardness, HV0,065 was measured with Hannemen Mph 100 microhardness tester using the load of 0,065N.

## 3. Results

In the first the substrate consisted of primary and secondary carbides in the ferrite matrix (Fig.2). The primary carbides have relatively regular circle – shape. After the treatment with using laser and electric arc plasma in the specimens , the following structural zones could be distinguished: remelting zone, heat affected zone, substrate (Fig.3.).

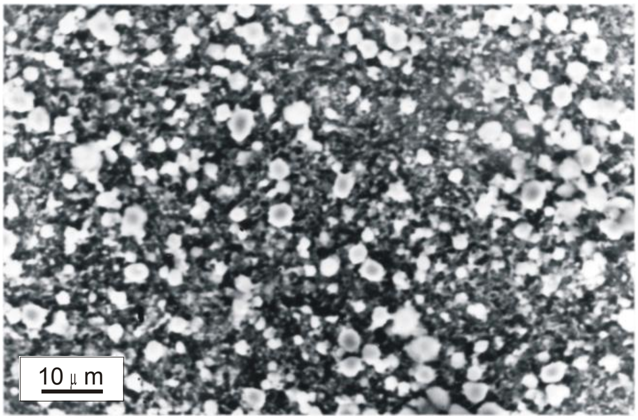


Fig. 2. Microstructure of high speed steels HS 7425 after conventional annealing, primary carbides inside ferrite matrix

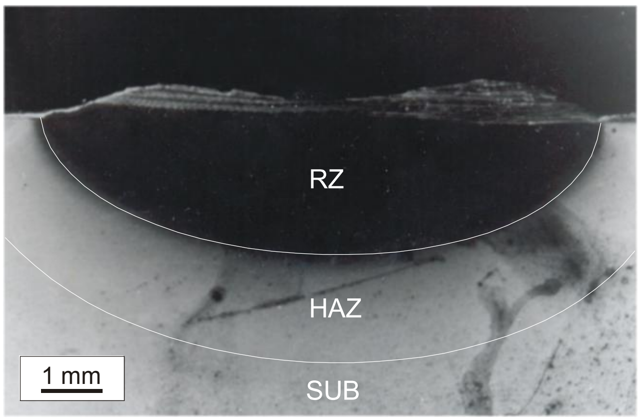


Fig. 3. The image of transverse cross-section of specimen after arc plasma treatment. RZ – remelted zone, HAZ heat affected zone , SUB – substrate.

Rapid crystallization leads to various morphologies of the remelted zone. The remelting zone consist of dendritic cells and columnar crystals. The dendritic cells orientation is depending of the direction of heat transfer and solidification velocity (Fig.4.).

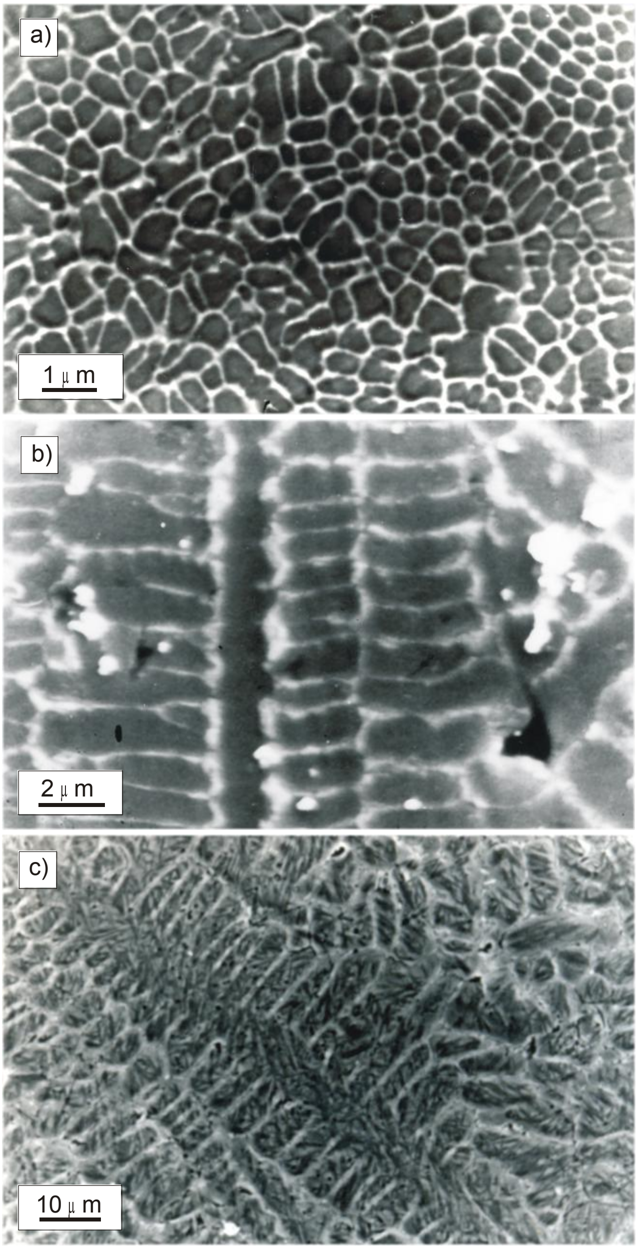


Fig. 4. The size of cell in the remelted zone in the steels after a) Nd:YAG pulsed treatment, b) $CO_2$ CW laser treatment, c) arc plasma electric treatment

The dimensions of cell were measured on the cross section of the surface remelted about total area equal $4 \cdot 10^4$ µm$^2$. Measured values of dimensions were grouped in classes according to Ryś [8]. On the basis of the dimensions distribution the average diameter of cells ($\lambda_C$) was marked. For all examined specimens the distributions of diameters of cells have the function profile logarithmic normal. Figure 5 shows the distribution of diameters of cells in the zone remelted with using Nd:YAG laser.

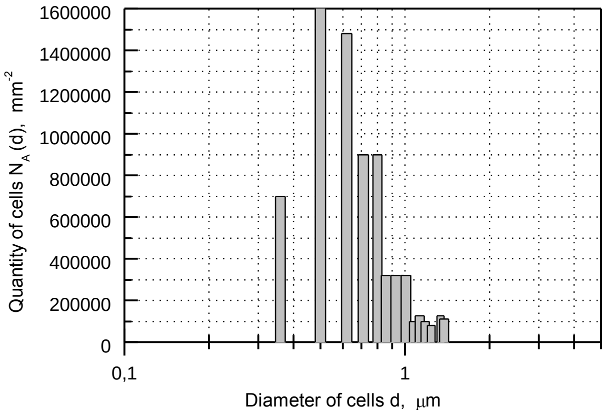


Fig. 5. The distribution of the diameter of cells in the zone Nd:YAG remelted

Accepting that $\lambda_C$ (diameter cell) is according with $\lambda_2$ (secondary spacing dendrites), on the basis of equation (2) the cooling rate in the remelted zone was calculated. For coefficients A=59 and B=0,34 according to Moris [5] the cooling rate in the remelting zone during the laser and arc plasma electric treatment of HS 7425 steel is listed in table 2.

Table 2.
The parameters of the remelted zone

| method of remelted | mean diameter of cell $\bar{d}$ ,µm | cooling rate $K \cdot s^{-1}$ | mean micro hardness of remelted zone HV0,065 | depth of remelted zone µm | width of heat affected zone µm |
|---|---|---|---|---|---|
| Nd:YAG pulsed laser | 0,5 | $1,2 \cdot 10^6$ | 1196 | 40 | 10 |
| $CO_2$ CW laser | 1,8 | $2,9 \cdot 10^4$ | 1126 | 500 | 100 |
| arc plasma electric | 5,5 | $1,1 \cdot 10^3$ | 988 | 3000 | 2000 |

Inside the dendritic cells martensite and retained austenite could be observed. The interdendritic space is filled by eutectics - carbide phase and austenite (Fig.6.). The heat treatment zone consists of plate martensite with retained austenite, at the bottom of the zone partially melted carbides was observed. In the specimens after the Nd:YAG laser melting the hardness of the remelted zone was 1196 HV0,065 (Fig.7.), but the depth of remelted zone was very small - 40 µm. (Table 2.). The microstructure formed during the Nd:YAG laser tratment is extremely refined. The cell diameter in the melted zone was about – 0,5 µm, corresponding to an approximate cooling rate of $1,2 \cdot 10^6$ $K \cdot s^{-1}$. In the case of $CO_2$ CW laser remelting microhardness of remelted zone was 1126 HV0,065 however depth of the zone is larger and has 500 μm.

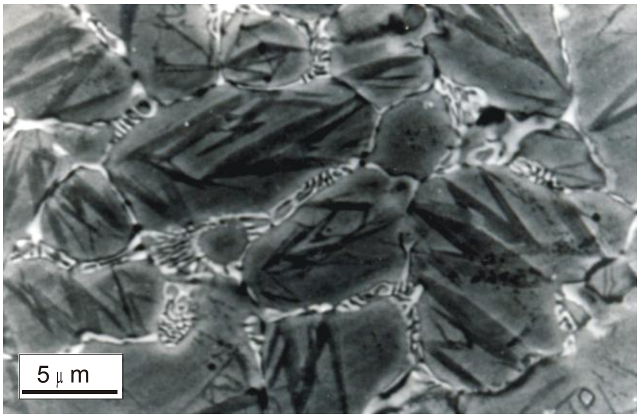


Fig. 6. The steel after arc plasma treatment, the microstructure of the bottom remelted zone, inside of the cells plate martensite and retained austenite visible

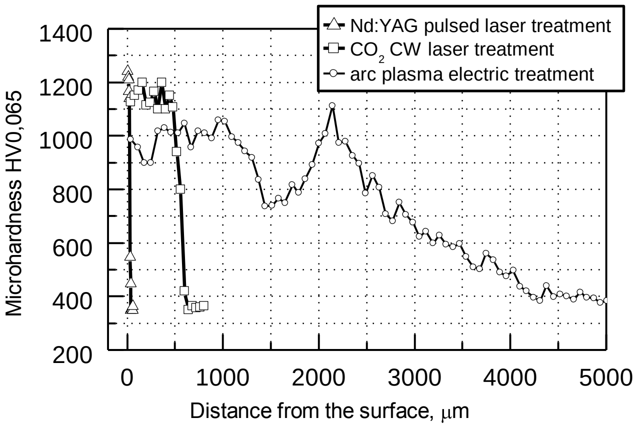


Fig. 7. Microhardness distribution on cross-section of surface layers after remelting

The highest depth (3000 μm) of the remelted zone was obtained after electric arc welding.

Microhardness in the zone varies in the range of 1100 – 670, mean microhardness is 988 HV0,065. For all specimens in the heat affected zone microhardness was observed to decrease continuously to the substrate level for this material, i.e. 386 HV0,065.

# 4. Conclusions

The investigation shows shaping of microstructure and microhardness of high speed steel HS 7425 by surface refinement with the electric arc plasma and laser treatments. After remelting with the laser and electric arc plasma the cellular – dendritic grains with carbide eutectic on the boundary could be observed. The high hardness of the remelted zone may be attributed to the crystalline scale of the dendritic cells and the columnar crystals. The hardness in the zone increases with increasing cooling rate.

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