Study of processes of steels surfaces modification with highly concentrated energy flows

R M Khisamutdinov¹, V V Zvezdin¹, I H Israfilov¹, Ruz R Saubanov¹, A A Spirin², R R Rakhimov¹

¹Naberezhnye Chelny institute (branch) of KFU, Naberezhnye Chelny, Russia
²Ford Sollers holding LLC, Naberezhnye Chelny, Russia

E-mail: irmaris@yandex.ru, rafisih88@mail.ru

Abstract. The peculiarities of steels surface layer modification under the influence of highly concentrated energies which increase the parts and tools quality have been studied. Here are the results of microstructure studies of tool steels and steel 45 samples for the analysis of strengthened steel and surface layer formation conditions. The conditions for the required quality of modified surfaces achievement using nitriding, hardening and cladding.

1. Introduction
The modern machine engineering is characterized by the complex operating conditions for machines related to vibrations, high level of effective voltage, broad temperature range, aggressive environments, etc. Specific requirements for metals surface layer must be complied with. According to the statistics, the majority of machining parts and tools (85-90%) fail due to wearing of separate parts surfaces [1].

Among the various means of metal surface layer quality improvement, the main ones are cementation, nitride cementation (carbonizing), carbonitriding, nitriding, etc.

Such courses as laser, plasma, etc, surface modification are expanding at the moment. Surface strengthening of operating areas of tools and parts is of pretentious nature both in energy parameters accuracy of the concentrated energy source, and in time-space condition of the zone where it influences the surface [2, 3].

Currently, there are numerous various methods of surface modification [7]. Their use requires adjustment of output parameters of technological complexes and time-space features so that the required surface layer quality parameters are stabilized. In the laboratory the processes of ion-plasma nitriding of parts surface, its laser and plasma hardening were studied.

This work contains the results of metallographic studies of surfaces after plasma nitriding, laser and plasma cladding and hardening. This relates to the most perspective and modern methods of hardening technologies with an opportunity to control and stabilize the tools and parts surfaces.

2. Ion-plasma nitriding of tool steels
Creation of surface layer with higher hardness, wear resistance, improved fatigue resistance and corrosion resistance is a perspective and rapidly developing course. The finished products which have already passed the mechanical and final heat treatment are subjected to nitriding.
The main purpose of this study is to control and manage the technological process parameters. The microstructure of the tool steel 4X5MФС after impulse plasma flow treatment in the nitrogen environment is shown on the Figure 1.

**Figure 1.** Microstructure of nitrided layer of the tool steel 4X5MФС.

The cores of the sample – tempered martensite, carbides, from the sample surface – nonerodible nitride zone ~5.4 micron thick; further – transition diffusion layer with nitride phase flecks after the nitriding process not only the hardness and wear resistance, but also corrosion resistance of metals increases which is especially important during extrusion dies usage [4]. This is why the purpose of the studies is to define the technological parameters influence on the microstructure values variability and metals microstructure change in the nitride atmosphere under the influence of impulse plasma flow and continuous laser irradiation.

For experimental studies an impulse plasma technological complex (IPTC) has been developed. The basis for it is a developed plasmatron with an alternating current with a power consumption up to 35 kW [5]. During this experiment, the plasma flow with a diameter of 5 to 10 mm is directed to the sample positioned in the operating booth in nitrogen gas environment. The treatment (processing) is being done almost without surface melting decreasing the heating load at the die.

A nitride layer is observed on the sample surface, this layer consists of nitride zone in the shape of a white nonerodible stripe, inner nitriding zone which consists of nitrogenous solid solution with micro-hardness starting from 1238 HV_{0.3} (0.03mm from the surface) (Fig.1).

3. **Laser and plasma hardening and cladding of steel 45**

Experimental studies have been conducted in respect to metals surface hardening in the nitrogen environment under flux and with alloyed powders of higher hardness. These include powder ПГ – CP4 – OM with micro-hardness of 55 HRC and flux AH-43 providing cladded metal acquisition with an optimal manganese, silicone and other alloy elements as well as with an optimal sulphur and phosphorus content. The Fig. 2 and 3 show steel 45 surface microstructure with a powder ПГ – CP4 – OM cladding through plasma flow and laser irradiation.

**Figure 2.** Microstructure of powder ПГ-CP4-OM layer cladded on steel 45 in nitrogen environment with a plasma flow

**Figure 3.** Microstructure of powder ПГ-CP4-OM layer cladded on steel 45 in nitrogen environment with a laser irradiation

Energy concentration is about $10^5$ W/cm², thermal impact zone in the metal acquires a segment form. Laser irradiation 0.9 mm in diameter is directed to the sample as well, transition speed is 20 mm/sec.

On Figures 2, 3 (light area) a microstructure of powder ПГ – CP4 – OM is observed, in the upper...
area — unchanged structure of steel 45. A steel 45 with powder ПГ – CP4 – OM interaction zone can be seen between them which is characterized by diffusion processes taking place in the transition zone. Micro-hardness of the powder layer (light area) cladded with plasma flow in the nitrogen environment is 514 HV0.1, and middle area after heat treatment acquired structure of a needle martensite with a micro-hardness of 1003 HV0.1. During the laser treatment is 920 HV0.1 and 1003 HV0.1 respectively. Micro-hardness was measured according to the GOST 9450-76.

Figures 4, 5 show microstructures of steel 45 samples with hardened plasma zones and laser irradiation under flux АН - 43.

![Figure 4](image1.png)

**Figure 4.** Microstructure of hardened under flux (AH – 43) zone of steel 45 with plasma flow in nitrogen environment

![Figure 5](image2.png)

**Figure 5.** Microstructure of hardened under flux (AH – 43) zone of steel 45 with laser irradiation in nitrogen environment

For the comparative analysis, microstructures and micro-hardnesses of steel 45 processed with laser irradiation in nitrogen environment under flux AH - 43 were studied in the same modes (Fig. 5). Subsurface layers micro-hardness value of martensite layer of steel 45, processed under flux is 1003 HV0.1, and with powder ПГ–CP4–OM layer cladding these values equal 1097 HV0.1.

Heat treatment of steel 45 with plasma flow in nitrogen environment under flux (AH – 43) shows ground needle microstructure of martensite layer (Fig. 3) in comparison with the microstructure of steel 45 – ПГ – CP4 – OM samples which characterizes micro-hardness reduction up to 824 HV0.1. Furthermore, a nitride layer has been identified from the sample surface, this layer consists of nitride zone in the form of a white nonerodible stripe 0,007mm thick under which a diffusion zone is located. The previously conducted analysis results for these modes show that a layer consisting of e-phase (Fe2N) forms on the steel 45 surface. The diffusion zone consists of alloyed with nitrogen matrix and incorporated nitrides of alloy elements. During hardening with laser irradiation, micro-hardness was 1003 HV0.1. Higher hardness is explained by high cooling speed of the thermal impact zone due to high density of energy and higher processing speed.
4. Laser hardening of cutter teeth made of steel P18K5F2

Figure 6. Microstructure of laser hardened layer on the tool teeth tops with micro-hardness measurements results in HV$_{0.1}$, (×500).

Chemical composition of worm cutter metal complies with the steel P18K5F2 GOST 19265-73. The part microstructure is a latent needle martensite of grade 1 GOST 8233-56, carbides. Carbide heterogeneity of the part structure corresponds to the Grade 1A of the scale 1 which complies with the requirements of the GOST 19265-73.

At the operating surface of teeth edges a surface layer hardened with a laser irradiation with nonerodible structure and carbides is observed.

Part micro-hardness is: main cutter metal - 806 – 852 HV$_{0.1}$; hardened with laser irradiation la - 961 – 992 HV$_{0.1}$.

5. Conclusion

The study findings show that the technological process of the surface layer modification is an effective method of steel wear resistance increase for extrusion dies and micro-hardness of the tool experiencing various wear types. Based on the analysis of results, main parameters of plasma flow and laser irradiation can be derived which effectively influence the technological process quality. This allows for conducting precision processing for parts and tools. This process requires use of high-accuracy laser irradiation and plasma flow positioning system [6].

References

[1] Yunusov F S, Khisamutdinov R M Shape-forming tools producing surfaces accuracy increase (monograph) // KNRTU-KAI. - 2008. – p 212.

[2] Grigoriants A G, Shiganov I N, Misyurov A I Technological processes of laser treatment: Textbook for higher education institutions/ Edited by A. Grigoriants. — M.: Publishing house of Bauman MSTU, 2006. — p 664: ill.

[3] Saubanov Ruz R, Rakhimov R R, Zvezdin V V, Israfilov I Kh Method of nanostructured modification of parts surface layer with concentrated energy flows / Materials of the 13th international science-practice conference, section 3- Saint-Petersburg; Publishing house of Polytechnic university, 2011. - pp 389-394.

[4] Arzamasov B N, Bratukhin A G, Eliseev Y S, Panayoti T A Ion chemical thermal processing of alloys in gas environments. - M: Publishing house of Bauman MSTU, 1999. – p 400.

[5] Saubanov Ruz R, Zvezdin V V, Israfilov I Kh, Rakhimov R R, Saubanov Ruisl R Invention patent №2558713, Russia, Россия, IASC H05H1/24; Application of 11.03.2014; Published: 10.08.2015; Priority 11.03.2014. Bul. №22. Impulse alternating current plasma generator device.

[6] Zvezdin V V, Khamadeev A V, Zagirov R G, Shangaraev I R Laser irradiation positioning in relation to the welding joint as a technological process quality indicator / KNRTU-KAI Bulletin, 2008. — № 3. — pp 17-21.

[7] Portnov S M, Kisaev R A, Kuznetsov I N, Israfilov I Kh, Zvezdin V V, Nugumanova A I System of parts surface heat treatment process with concentrated energy flows / «Global science potential» Saint-Petersburg: - №8. - 2011.- pp 95-100.