

Application of pulsed heating in technologies of thermal-cycle processing of steel

I.G. Kozyr¹ and A.S. Komolikov²

¹ Leading Researcher, Lipetsk State Technical University, Lipetsk, RU

² Junior Researcher, Lipetsk State Technical University, Lipetsk, RU

E-mail: komolikov_as@niilgtu.ru

Abstract. In work features of application of concentrated streams of energy in technologies of thermal-cycle processing of metal products are considered. Examples of application of currents of high frequency at thermal-cycle processing are given. It is shown that application of concentrated streams of energy significantly reduces processing time, increases energy efficiency and allows receiving especially fine structure in the surface layers.

1. Introduction

Relevant problem of the modern mechanical engineering is creation and improvement of resource-energy saving highly effective technologies of increase in production characteristics of details of machines and the tool.

Traditional technologies of a heat treatment practically reached limits of the opportunities for modification of structure and properties of metals and alloys. There are two main types of the energy sources applied to a heat treatment: diffuse energy sources - oven heating, concentrated streams of energy - electron streams, a laser radiation, plasma jets, currents of high frequency, etc. Broader use of the technologies based on use of the high-intensity streams of energy influencing local sites of metals – concentrated streams of energy seems perspective. [1]

One of traditional technologies, hardenings of the metal products allowing receiving high production characteristics thermal-cycle processing is [2]. The consistent focus is provided on questions of perfecting of technology of thermal-cycle processing [3]. Thermal-cycle processing of details of machines and the tool finds broad application in mechanical engineering, including agricultural mechanical engineering [4,5]. The substance Thermal-cycle processing consists in cyclic accumulation of positive changes in structure of metals and alloys. At thermal-cycle processing phase and structural transformations are followed by education and annihilation of dot and linear defects, and also homogenization of chemical composition, due to dissolution and increase in dispersion of a carbide phase. For example, in steel products, $\alpha \leftrightarrow \gamma$ transformations lead to cyclic recrystallization with a thermal and phase peening which consequence significant crushing of structure is. With increase in quantity of cycles, the speed of accumulation of positive changes in structure of metals and alloys decreases. Are usually limited to 3-5 cycles. Owing to specifics of the processes happening in the conditions of cyclic influences at thermal-cycle processing there is a change of kinetics, mechanisms of process of structurization and purposeful change of a complex of properties of alloys, and, therefore, reliabilities and longevities of products, from them made [6].

One of serious shortcomings of thermal-cycle processing with use of diffuse sources is duration of process of a heat treatment and energy consumption. Use of concentrated streams of energy allows



increasing efficiency of process of thermal-cycle processing, due to reduction of time of heat treatment not less than much, considerably to increase energy efficiency and to receive highly dispersive structures up to nanometric.

The purpose of work is consideration of a possibility of increase in efficiency and energy efficiency of thermal-cycle processing of metal products, with use of concentrated streams of energy.

2. Experiment

Let's consider an algorithm of thermal-cycle processing with use of pulsed heating of carbon steel. Originally short-term pulsed heating of steel up to the temperature significantly above A_{C3} is made, but temperatures the solidus providing completion of formation of austenite and homogenization of carbon with the subsequent cooling under training are lower, as a result we will receive rather coarse-grained martensitic structure (a rack or needle martensite). In case after the first pulsed heating and receiving a martensite to make repeated high-speed heating to the same temperature, the structure of hereditary coarse-grained austenite is formed. The phase peening will lead to a partial refinement of grains. Therefore, it is necessary to make annealing for significant crushing of structure of steel. Generally annealing can be as oven, and with use of the same energy source, as for training. Application of this method significantly speeds up work, due to decrease in time of annealing to seconds or even a share of seconds, at the same time it is necessary to make heating. Temperature and temporary endurance when annealing is defined by an ultimate structure of steel – troostite, or troostite-martensite. Annealing, at the subsequent heating prevents formation hereditarily of coarse-grained structure of austenite. In situ initial austenitic grain a set of crystallization centers of a high-temperature phase at the subsequent heating are formed. For obtaining especially fine grained structure, including nanometric, it is necessary to execute follow-up several similar cycles training annealing, at the same time temperature of each subsequent pulsed heating under an austenization has to decrease for the above-named reason.

In the following cycle pulsed heating similar previous is made for a steel austenization. And, heating temperature needs to be reduced in comparison with temperature in the first cycle. Decrease in temperature is caused by obtaining more fine grained structure after the first cycle having heated annealing. Lower heating temperature leads to suppression of body height of austenitic grain. After cooling under training the second annealing is made. As at pulsed heating only heating of the surface layers is made, there is a need of a preliminary heat treatment of a metal product on traditional technology [7]. Having created at the same time the required structure of inner layers of a product. And use of thermal-cycle processing on the way described above will allow to receive on a surface highly dispersive structure up to nanometric, and respectively, high hardness and wear resistance [8]. Considering above told, application of pulsed heating allows to solve a problem of perfecting of thermal-cycle processing.

Estimates show that application of concentrated streams of energy, from the power point of view more efficiently, than application of oven heating what is caused by locality of heating of a metal product, significant reduction of scattering of thermal energy in space. Specifically the energy efficiency depends on technological process and an inventory. We can talk about at least ten times lower energy consumption.

As an example it is possible to consider use for annealing of an electron stream. In figure 1 the structure of steel 45 having initial martensitic structure, processed by an electron stream with a diameter about 2 mm and a step between passes of 2 mm in the isentropic mode, a specific energy release of 4.2 MJ/m^2 , energy of electrons a kidney of 1.5 MeV with overlapping of a zone of thermal influence is presented. When passing a bunch there is a heating of a surface to speed about 10^6 K/s , and cooling, due to heat removal inside with a speed of 10^5 K/s . In the surface layer there is training to formation of highly dispersive martensitic structure. At the subsequent passing of a bunch on a surface with the shift and partial imposing of zones of thermal influence annealing zones are formed. And, the zone of annealing is observed in a zone of thermal influence where heating was below A_{C3} [9].

The zone of annealing (figure 1) has structure from troostite-martensitic (light gray area) to highly dispersive structure (dark area). Thus, at pulse influence by concentrated streams of energy, due to

heating temperature change, for thousand shares of seconds it is possible to make annealing of steel from low to high. Use and currents of high frequency for a heat hardening and annealing is similarly possible, regulating the power of a source and time of influence.

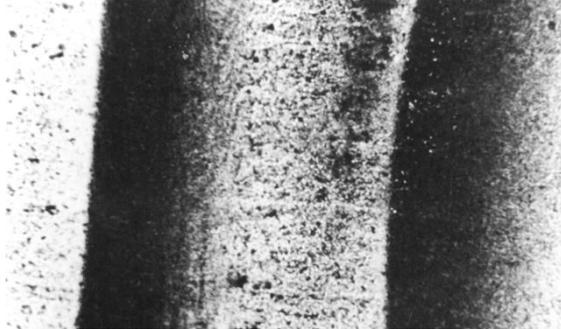


Figure 1. A general view of zones of thermal influence when scanning steel 45 with an electron stream when overlapping zones of processing (increase in X50).

Approbation of the principles of thermal-cycle processing explained above with use of currents of high frequency is made, considering availability and a wide spread occurrence of equipment for the face induction hardening. Let's consider the receptions described above on a concrete example of thermal-cycle processing.

3. Results

The experiment was made on exemplars from steel 65G, 70*100*6 mm in size, in a condition of delivery (GOST of the USSR 14959-79). Heating of an end face of an exemplar (70*6 mm) was made by currents of high frequency with use of the VChG-160/0.066 generator. Zone heating of 10-12 mm. Adjustment of the maximum temperature and heat rate was carried out by change of power of the generator and time of influence, at the same time heat rate of 75-100 K/sec was provided. Measurement of temperature was performed by a pyrometer (model CEM DT-8835). Cooling of exemplars happened after automatic shutdown of the generator, by heat removal in an exemplar and immersion of exemplars in I20A oil. As a result in steel the structure of training was formed. Annealing was made by pulsed heating and further cooling to environment temperature. The research of structure and properties of exemplars happened by a standard metallographic technique to use of a metallographic research microscope of METAM LV-34, and hardness was measured on Rockwell's device.

Each cycle of thermal-cycle processing consisted of two operations – training and annealing. Heat rate of exemplars made about 75-100 K/sec. At the first heating (figure 2, operation 1) the maximum temperature was about 1200 °C. The time spent there were higher than temperature of A_{C3} ~ 7-8 seconds. At the same time there is a formation of austenite and partial homogenization of alloying elements. After switching off of the generator, training by immersion of exemplars in oil was made. Hardness after the first heating was 63 HRC.

In figure 2 dependences of temperature on time are schematically shown. As a rule, these two cycles training annealing, in most cases is enough as the fine grained structure meeting the requirements of almost important tasks turns out. The last annealing, in this case gets out of a condition of necessary finishing mechanical characteristics (for example, structure and hardness).

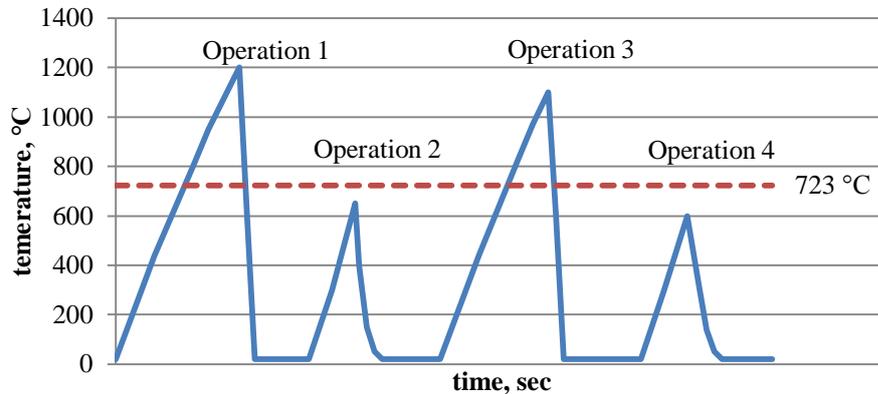


Figure 2. Schematic dependence of temperature on time at thermal-cycle processing.

Further annealing (figure 2, operation 2) on the same inventory was made. Time of annealing got out of a condition that temperature of annealing didn't reach A_{C3} . The maximum heating temperature when annealing made about 650 °C, cooling on air to environment temperature followed further. The structure of steel 65G received after the first cycle of thermal-cycle processing is given in figure 3a.

The second cycle was similar to the first. The difference consisted in decrease in the maximum temperature under training and when annealing. So the maximum temperature under training was, about 1100 °C (figure 2, operation 3), and the annealing temperature (figure 2, operation 4) was in the range of 550-600 °C.

As a result after the second annealing the structure a martensite of annealing (figure 3b) hardness – 62 HRC was received.



Figure 3a. Structure of steel 65G after the first cycle (increase in X500)

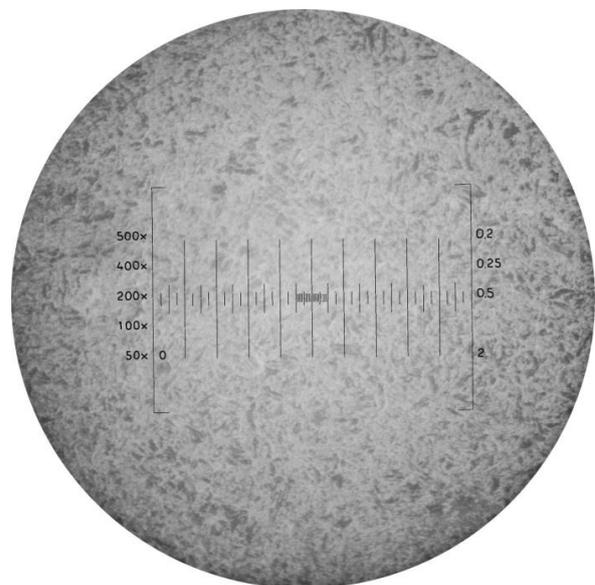


Figure 3b. Structure of steel 65G after the second cycle (increase in X500)

Further cycles can be carried out similar to the first two, the main thing to keep decrease of the maximum temperature in the subsequent cycles in comparison with previous. But the expediency of increase in quantity of cycles depends on the required final properties of steel.

The total time of the carrying out thermal-cycle processing consisting of 4 operations described above made about 30 minutes.

4. Conclusions:

Application of pulsed heating in technologies of thermal-cycle processing of metal products, with use of concentrated sources of energy allows:

1. To considerably reduce time.
2. To increase energy efficiency of technological process.
3. To create especially fine structure in the surface layers of products.

References

- [1] Gulyaev A.P. 1986 *Metal science*. The textbook for technical colleges. the 6th prod., revised. and additional (M.: Metallurgy) p. 544
- [2] Feduykin V.K., Smagorinsky M.E. 1989 *Thermal-cycle processing of metals and details of cars*. (Leningrad: Mechanical engineering) p 255
- [3] Konopleva E. V., Éntin R.I., and Bayazitov V.M., 1985 "The influence of thermal cycling treatment with accelerated heating on the structure, properties, and kinetics of phase transformations of constructional steels", in: *News in Investigations of Phase and Structural Transformations in Steels* [in Russian] (Mosk. Home Science Tekh. Inf.) P.58–63
- [4] Shmatov A. A. The nature of the hardening of tool steels during thermal cycle processing 2014 *Materials science*. No. **12**. 20
- [5] Pyndak V.I., Novikov A.E., Fomin S.D., Kalinichenko V.V. Increase in wear resistance and operational indicators of soil-cultivating actions 2014 *News of the Lower Volga agro university complex*. No. **2**. 89
- [6] Mordasov D. P., Zotov S.V. 2016 Thermal-cycle processing of stamps for work in the conditions of hot deformation from steel H12MF *The TGTU Bulletin*. **22** No. 3 481-490.
- [7] Komolikhov A.S., Kalinin. S.A., And., Kozyr' I.G., Kuzenkov S.E. 2017 The method of thermal-cycle processing of steel. *Patent of the Russian Federation for invention* No. 2646180.
- [8] Komolikhov A.S., Kozyr' I.G. 2015 The method of thermal-cycle processing of steel. *Patent of the Russian Federation for invention* No. 2594925.
- [9] Kozyr' I.G., Borodin R.V., Voropaev A.V., Potapov V.G. 1998 Structure and properties of the tool steel after electron beam treatment and following tempering. *Physics and chemistry of processing of materials*. No. 3. 30