DEVELOPMENT OF HIGH –EFFICIENCY TECHNOLOGIES AND DEVICES OF
CONTROLLED COOLING FOR THERMOHARDENING OF METAL

Heat treatment of metal products is the most economical and efficient way to provide the optimal combination of strength and plasticity of metals. This paper is devoted to development of the technology and facility of thermohardening.

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Introduction

Modern technologies of thermohardening based on application of the controlled cooling systems can provide considerable increase in the strength of articles, high fracture toughness particularly at low temperatures, at the same time maintaining sufficiently high level of plasticity. The operational characteristics of thermohardened products (durability, endurance, destructiveness etc.) are superior to those of non-thermohardened products. In addition the production price reduces considerably because the necessary level of the mechanical properties is provided without using expensive alloying admixtures to the metal or by minimizing their amount.

The Institute of Metallurgical Heat Engineering (VNIIMT) deals with the problems of internal and external heat exchange under the conditions of jet cooling, hydrodynamics of the coolant jet formation and their interaction with a heat-strengthened article, the patterns of structure formation and obtaining the required level of mechanical properties under the conditions of controlled cooling.

The great amount of research having done permits to develop the methodology of well-grounded choice of the parameters for controlled cooling systems, the technologies of heat-strengthening of articles of different branded and size assortment.

VNIIMT has developed the systems of controlled cooling for heat-strengthening of rolled products made of steel, titanium, aluminium alloys, fittings, pipes, rails, railroad wheels, chairs etc. and machine-building production. More than 20 various devices for the thermohardening of metal products of different brands and sizes for different industries have been built with our assistance or by our experts.

In this report the authors would like to submit for your consideration two directions of our work on the development of the technology and facility of thermohardening. In terms of providing the high level of the product mechanical properties these directions undoubtedly have...
great prospects. These are technologies of heat-strengthening based on the systems of water-and-air and high-intensity cooling of products.

**Water and air cooling systems**

In the field of machine building the hardening of products, as a rule, is performed by their submerging into a tank with a hardening agent (coolant). Oil, water, alkaline solutions and brines, polymer mixtures etc. are used as coolants. Such technology does not provide controlled process of cooling. Lack of control over the cooling rate in different temperature intervals does not allow providing the optimum combination of the strength and plasticity of products, minimization of stresses after heat-strengthening. The use of the metallurgical properties of a metal is not full and effective enough. When oil or saltpeter is used as a coolant the ecological compatibility decreases and the fire hazard increases.

At our institute controlled cooling devices have been developed, which use water-and-air mixtures as a coolant. Water-and-air cooling permits realization of both the “mild” (as in oil, saltpeter) and intensive (as in water, alkaline) variants. The possibility to control the rate of cooling allows reaching higher level of mechanical properties and operating characteristics unachievable for products hardened by submerging into a tank. In addition fire hazard, harm for the personnel health, the problems of aging and utilization of coolants are eliminated; the price of the products reduces considerably.

Some variants of water-and-air cooling devices have been developed on the basis of the research made. Cooling of products, when they are being hardened, is performed using water-and-air mixture (mist) produced in the generators of water-and-air mixture, and supplied to the product being cooled though collectors and nozzles. The design and operating parameters of the installations for water-and-air cooling allow changing the intensity of the heat transfer (the rate of cooling) up to 10 times (see Figure 1), even if the control system is simple enough. In these installations by changing the water-air ratio one can realize the cooling mode with higher intensity than that in the water tank and, if it is necessary, with lower intensity than that in oil. The algorithm and the system of cooling allow changing the rate of cooling both in average, when changing the assortment, and repeatedly in different temperature and time intervals during one cycle of hardening.
The application area for such installations is very wide. Using the pilot device the following types of heat treatment were tried:

- heat treatment of various articles of mass production (stop rings, ball-units, bolts etc.) in connecting lines with conveyor or shaker;
- heat treatment of different springs and spring parts, carriage springs;
- as well as articles of different chemical composition.

At almost all industrial enterprises straight-through units (Akhilen Ibsen, Izderbash, Russia) are widely used for thermal strengthening. Heating for hardening is performed in furnaces with protective atmosphere on conveyor or shaken bottom. After heating products are hardened in tanks filled with water or oil.

The device of water-and-air cooling has been developed at the institute; it allows realization of all the technological requirements for cooling rates of different media in one device. The device is compact, can be installed under the existing chute for products discharging into the tank and it can be inserted into the space over the conveyor of the tank existed.

The device for water- and air-cooling includes:

- system of water and air supply with locking, controlling, and measuring devices;
- hardening chamber with water-and-air collectors;
- system of removing of the mixture used together with a water separator;
- mechanism of product transportation from the furnace to the hardening chamber;
- automated system of control.

After heating in the protective atmosphere products enter the hardening chamber. Water-and-air mixture produced in a generator of specific design is supplied from two sides onto articles being hardened through the system of collectors with nozzles.

Depending on the technological requirements and the type of assortment the required intensity (rate) of cooling is provided by change of the water/air ratio in the water-air mixture. The water and air consumption is controlled and regulated.

The design and parameters of such a device for water-and-air cooling allow implementation of the treatment according to the standard hardening technique with tempering and the cooling rate as in existing hardening media (oil, water); it is also possible to realize new, highly effective technologies like the following:

- hardening on the modes of varied cooling provides the considerably higher level of the mechanical and operating characteristics;
- self-tempering hardening (the cooling of products is interrupted at a temperature of self-tempering). The technology excludes from the process flow the necessity to make enough tempering after cooling. It gives considerable cost saving maintaining the quality of products high.

In the pilot device different mass-produced parts and products of various brands from low-carbon to high-alloy steels were treated according to the technique of controlled water-and-air cooling. Bolts including those of high strength, nuts, washers, axles, ball-units, race rings, self-tapping screws etc. were treated. Parts serially produced by Avtonormal works, OJSC AVTOVAZ, KAMAZ, UralAZ the Bearing Plant in Vologda, the Machine-Building enterprises in Kurgan, as well as the parts brought from the special plant of thermal treatment located in Milan (Italy) underwent heat strengthening. Analysis of the results showed that the structure and the level of mechanical properties of all the products are in accordance with the standards and they are better than those produced according to the existing hardening techniques by submerging them in a tank with a coolant.

The techniques of controlled water-and-air cooling have the following advantages in comparison with the traditional hardening in a tank:

- **Engineering advantages:**
  - stable optimum structure of products of different assortment and chemical composition is achieved with minimum thermal stresses and lack of cracks, which allows increasing the level of mechanical and operational characteristics of products;
  - possibility to introduce new, effective, and economical technologies is realized;
- parts with light surface are provided after the heat strengthening.

• Ecological advantages:
  - coolant is pollution-free;
  - hardening process is fire-safe.

• Economical advantages:
  
  The analysis made showed that when the device is fitted into the line existing and when the line works according to the technology of hardening with tempering only due to exclusion of the hardening tank and washing machine from the processing flow the payback period will be less than 1 year thanks to saving energy, exclusion of the expenditures for acquisition, preparation of oil and washing mixtures as well as for regeneration of the oils used and washing solutions. When implementing the technique of heat strengthening with tempering the efficiency of such furnaces will be higher due to exclusion of tempering furnace from the production flow.

  When building new lines of heat treatment the reducing of capital expenditures (1.5±2 times less) will be reached because of exclusion from the production flow of the oil and washing tanks with the total weight about 10÷15 t, reduction of the production areas taken by the equipment.

Systems of high-intensive (gradient) cooling

  At OJSC VNIIMT highly effective technology and devices for heat strengthening of products of different configuration by controlled cooling with the intensity 3-7 times higher than during hardening in water tank have been developed. Under the conditions of highly effective cooling hardening provides the rates of cooling equal to 500÷1500°С/sec on the surface of the product. Such cooling is close to the ultimate one which is theoretically possible when the temperature of the surface becomes immediately equal to the environment temperature. As a result of the accelerated cooling of products on the base of such technology natural composite of alternating layers with different structural and phase composition is created. Structure formation in the surface layer at so high rates of cooling takes place on the atomic layer and related to significant distortion of the lattice. The multilayer structure shows itself in different dimensioned levels of the structure: the macrolevel (product as a whole), interlevel (state of the grain-subgrain ensemble), and the microlevel (state of the carbide subsystem). The high-intensity cooling provides obtaining of the highly dispersed structures thanks to fast passing the temperature interval of transformation, which significantly limits the conditions facilitating the growth of a grain and coagulation of carbides and carbonitrides before and after transformation.

  After heat treatment using such technology high-strength surface layer and viscous core form in the product, which provides fundamentally higher level of the mechanical properties and operational characteristics, than that obtained after treatment according to the standard technique.
The cooling of products was performed with water under pressure of 2-4 bar, supplied to product through collectors with nozzles. High intensity of cooling due to the design and arrangement of collectors with definite hydrodynamics of the outflow and in leakage of water jets from the nozzles.

To provide similar conditions of cooling, and, therefore, minimization of the warping and crack formation for different-mass elements of a product differentiation of water amount supplied for heat-strengthening was performed.

Under the conditions of stand test treatment of different parts from alloyed steel was performed – spring steels, drill rods, ball-units, strong stud axes, metal goods. The properties of strength obtained for all the products examined after hardening or ultimate ones for the given assortment or close to ultimate. At the same time good plasticity (within standard requirements) and high resistance to brittle failure remain. There were no cracks on the parts.

In the middle of 1990 at "EVRAZ NTMK" NSMZ plant VNIIMT experts developed and put into operation the pilot line for heat-strengthening of rail-chair for concrete crossties according to this technology of highly intensive cooling.

Treatment using the technique of hardening in a water tank provides the hardness equal to 180–190 HB along of all the section of a rail-chair. The strength is about 20 % higher in comparison with the hot-rolled state. After hardening in VNIIMT's device the hardness in the surface layer with depth of 3–5 mm from each surface reaches 350–420 HB, in the middle it is 130–150 HB less than on the surface.

Hardening of the industrial batches of rail-chairs using the technique of highly intensive cooling the hardness increased persistently 2÷2.5 times in comparison with tempering in a tank, strength increased almost 3 times. Comparative tests on a vibration stand and experimental ring showed that the operational resistance of the rail chairs treated with such techniques 3÷5 times less than those treated using the standard one (Fig.2).

Production butches of such chairs have been installed on 5 railroads. For three years of operation none chair has been broken.

Stand tests using the technology of highly intensive cooling showed good mechanical properties and structure of drilling and pump rods, high-strength screws for bridge building, high-strength studs for fitting for oil and gas piping. We should anticipate good wearing resistance of parts treated using the technique, and undergoing abrasion and alternating loads. Realization of the technology is considered to be perspective one as well as the technology of varied cooling (combining highly-intensive cooling in the area of high temperatures and mild water-and-air cooling in the low-temperature interval) for heat treatment of gears, motor-car shafts, agricultural machinery, defense industry, springs for railcars etc.
The preliminary analysis shows that when the optimum structure and thermostressed state form after treatment using our hardening technology together with chemical heat treatment the resistance of gears, toothed wheels for cars can be two or three times as much.

Fig.2 The results of fatigue (a) and ground (b) tests of rail chairs KB-65 using vibration stand and experimental ring of VNIIZHT.

1 – chairs of batch production 15.5 mm thick;
2 – chairs of 15.5 mm thick hardened by highly intensive surface-volumetric tempering;
3 – chairs of 13.5 mm thick hardened by highly intensive surface-volumetric tempering.
Contact us

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