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CHANGE OF METAL TEMPERATURE AT HEAT TREATMENT WITH WATER-AIR SPRAY COOLING

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У статті сформульовано основні технологічні та конструктивні параметри водно–повітряного струменевого охолодження, які впливають на зміну температури металу при термообробці. Ці закономірності будуть корисними для дослідження частини інтегрованих процесів виробництва, включаючи обробку металу тиском та наступну термообробку з метою досягнення певної (заданої) структури металу та властивостей виробу.

Ключові слова: *водо-повітряне охолодження, інтегровані металургійні технології.*

Main technological and design parameters of water-air spray cooling, which affect change of metal temperature at heat treatment have been formulated in this article. These regularities will be useful to research of a part of integrated manufacturing processes, including metal forming and subsequent heat treatment, with the pur-pose of achieving defined metal structure and properties of the product.

Key words: *water-air spray cooling, integrated metallurgical technologies.*

Statement of the problem. Reduction of the weight of metal products used in most of the economy, stipulated by requests of metal`s economy and resources, as at the stage of production so in exploitation process, requiring compensation quantity of used materials transformed into quality. Some of the most important parameters of quality metal products are mechanical and performance properties. Form and precision of geometric dimensions of the product have to be compatible with the required properties of metal it`s made. There are some criteria requiring by properties of strength and plasticity. In most cases, they eliminate each other. However, modern innovative materials allow combining high rates of both of these criteria, thanks to their precise alloying [1]. This combination can be achieved by a chemical composition, and with the help provided by the chemical composition of opportunities to control the properties of metal in the process of deformation and heat treatment. Factors, setting the properties of the metal during deformation process, are: stain, strain rate, strain-stress state in the deformation zone, and temperature treatment. The temperature and duration of treatment are such factors for heat treatment. Thus, the actual task is analysis of the change temperature of metal in the integrated treatment process as facilities of managing end-point properties.

Analysis of previous results. Integrated processes of metal treatment include deformation in the temperature range of recrystallization or, for example, for austenitic steel and immediately following heat treatment, which basically lies in the cooling the product at a specific speed. Such processes are well known [2]. The feature of these processes is the ability to achieve high strains at metal forming, which is associated with good plastic properties of metal in the specified temperature range and low strain resistance. As for the following heat treatment, so an important thing is using the heat, remaining in the metal after its coming out from the deformation zone – "rolling heat". The control of cooling rate of the metal, coming out from the deformation zone "with rolling heat" to room temperature for alloys, containing appropriate alloying additions [3, 4], allows to change the properties of deformed products. This modification happens because of the formation of different structures in the metal. Most of all, because at high cooling rate stand phases, making distortion and (or) additional tension in the crystal lattice. It results in increasing strength of the metal and risk of product failure [5]. Normally, these tensions, besides the changes in the mechanical properties of metal, appears themselves as follows: provide a significant level of residual tensions at measurements by X-ray method, lead to self-deformation of product, reduce long-term, and (or) the fatigue strength. Reducing the cooling rate makes decreasing internal tensions, but also reduces the strength of the product.

The combination in integrated process high and low cooling rate allows to realize scheme "hardening - tempering ", which provides a high strength and low residual stresses [6, 7]. To provide this combination of cooling rates allows - with water-air spray cooling. Water-air spray cooling has some advantages that allow us to speak about the prospects of its use in the integrated processes. In addition to opportunities controlling the cooling rate, which will be described later, this spray has advantages by ecological compatibility and low energy and resource capacity, also simplicity of its installation in the process.

During for 2000-2011 period SFB 489 the project "Prozesskette zur herstellung präzisionsgeschmiedeter hochleistungsbauteile" [8] was working up at the Institute of Materials Science of the University of Hanover (Germany). It directed at creating an effective technology for machine details based on the integration of precision forging and spray cooling. During for execution parts of this project related to spray cooling authors faced with insufficient of analytical dependences describes the behavior of products with different geometrical characteristics in spray cooling condition. This disadvantage has led to the getting empirical dependences with narrow range of functionality.

Also it was found that the rate of temperature decreasing as at cooled surface so in the deep layers of the metal have a combined effect of such factors as: the size and shape of the part, the unit consumption of water and air, and design characteristics of the equipment.

The purpose of the task. The purpose of this work is the formulation of the main directions of research on the influence of parameters of water-air spray cooling on the character temperature change of the metal and on the parameters of properties of the metal. By these research we are going to receive the dependences allowing to predict changes in the properties of the metal, and also to realize the cooling modes, which provide the required properties of the metal and their distribution over cross the section of the product.

Basic material. In general, the influence of the parameters of spray cooling to change the properties of the metal in the integrated treatment process can be graphically presented in the form of a diagram (Figure 1). This scheme does not consider influence chemical composition of the metal, and also previous deformation and can be used in the research of products made of the same metal, get under similar temperature and deformation conditions. In this work, using the radial spray cooling experience [9, 10] is shown description of each of the influencing factors to the change of metal temperature.

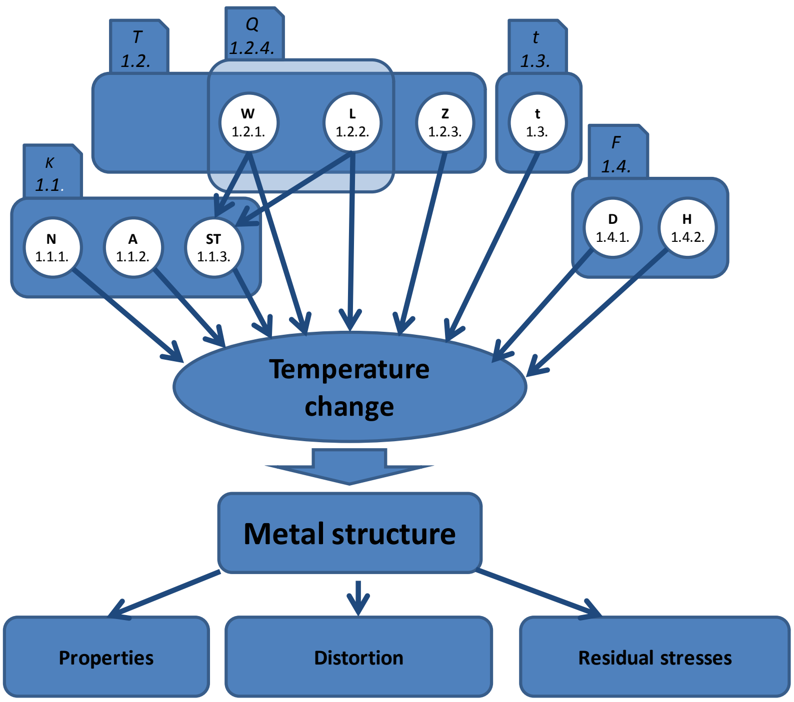


Figure 1. Scheme of influence of parameters spray cooling to change of the metal temperature (the notation are shown in Table 1):

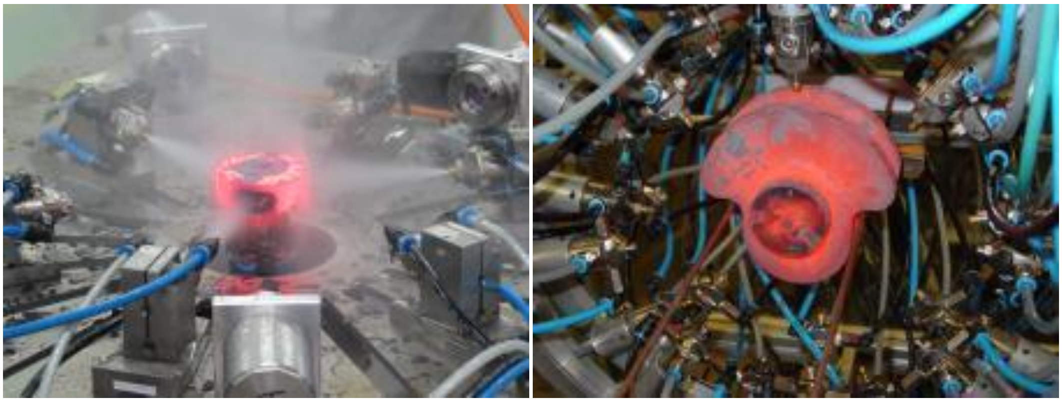
Table 1. Parameters specified in Figure 1

Number of parameter / link	*Name of parameter*	*Parameter/ link*
1.1	*K*	*Design parameters of device*
1.1.1	*N*	*Number of nozzles*
1.1.2	*A*	*The distance between the nozzle and the cooled surface*
1.1.3	*ST*	*Shape of the spray*
1.2	*T*	*Technological parameters of the cooling process*
1.2.1	*W*	*Specific water consumption (per unit time)*
1.2.2	*L*	*Specific air consumption (per unit time)*
1.2.3	*Z*	*Treatment time*
1.2.4	*Q*	*The total consumption of water / air (for the time of treatment)*
1.3	*t*	*Temperature of the product before cooling*
1.4	*F*	*Shape of the product is shown, for example, cylindrical*

The analysis of Figure 1 should us pay attention to the fact that the change of temperature, the metal structure provide as static so dynamic effects on the properties, the distortion of sizes and shapes, and also the residual tensions. The dynamics is connected to the rate and location of temperature change and the structure of the metal.

Let`s consider more detail the factors that have influence to the change of temperature and properties of the metal in water-air spray cooling.

1.1. The design parameters. For radial cooling of rotary bodies, in particular, cylindrical parts, normally used the devices where nozzles are arranged radially and oriented to the center of the circle. If there are no requirements on the special distribution of the properties of the, target point of intersection of the axes nozzles must coincide with the center of gravity of the cross section of cooled product. To provide a more uniform cooling of the surface, especially if the surface has a relief, it is appropriate to provide rotational movement relative to the injectors products subject to constant communication point of intersection of the axes nozzles with the center of gravity injector section. Structurally, it may be provided as a rotation / swing nozzles around the product, and on the contrary. Also cooled product can be moved with a certain speed in the axial direction perpendicular to the field of the placement nozzles. For convenience, by default it will be a radial unit, called sprayfield. Variants of this sprayfield, situated in the Institute of Materials Science of the University of Hanover, are shown in Figure 2.



a *b*

Figure 2. Variants of the laboratory radial sprayfield of the Institute of Material Science Hanover University: a – horizontal spray with motionless nozzles and rotating / swing sample; b – vertical spray with rotation / swing nozzles and ability moving the sample

By the images shown in Figure 2 we can note next important design parameters of sprayfield.

1.1.1. The number of nozzles. This parameter depends on the design of the device and size of cooled product. According to our observations more quantity of small nozzles give better results for cooling of the surface, than less quantity of large ones. However, we should keep in mind that small nozzles are more sensitive to the purity of water and air.

1.1.2. The distance from the nozzle to the cooling surface. This option is also associated with the design of the device and the sizes of the cooled product. The most important conditions for its determination are: providing the desired rate of droplets on the surface of the metal, what must be to overcome the "Leidenfrost effect", the homogeneous spray at the contact with the metal surface, and the resistance of the nozzles and reinforcements in a thermal radiation from the cooled detail. The speed and sizes of droplets at a distance A (Figure 3) from the nozzle are measured by dint of phase Doppler anemometry. This data can then be used in determining the heat transfer index.

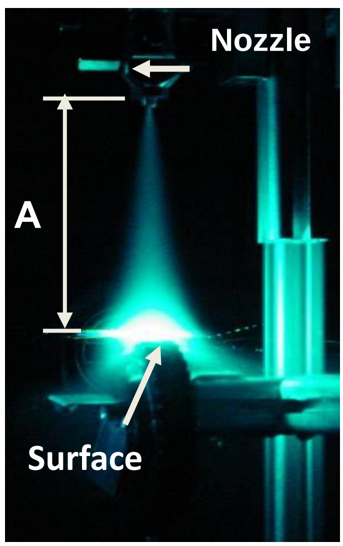


Figure 3. The shape of the spray and the distance to the cooling surface

1.1.3. The shape of the spray. In the main the shape of the water-air mixture spray is determined by design of the nozzle. However, the regulation of pressure of air and water also changes the shape of the spray. In general, the effect of the shape of the spray on the temperature reduction is determined by compromise between the cooling area surface and the amount of water supplied to this surface per unit time. We should pay attention to the fact that on the entire contact area of the spray and cooling surface must be guaranteed a constant cooling intensivity, which affects the dynamics of the temperature falling. During the experiments it was found that at a certain ratio of water and air pressure for current type of nozzle may appear wave density of water-air flow along the spray. Thus, the variable in time cooling speed, typical for an unstable spray leads to waves in the distribution of properties, particulary hardness in the radial direction (Figure 4).

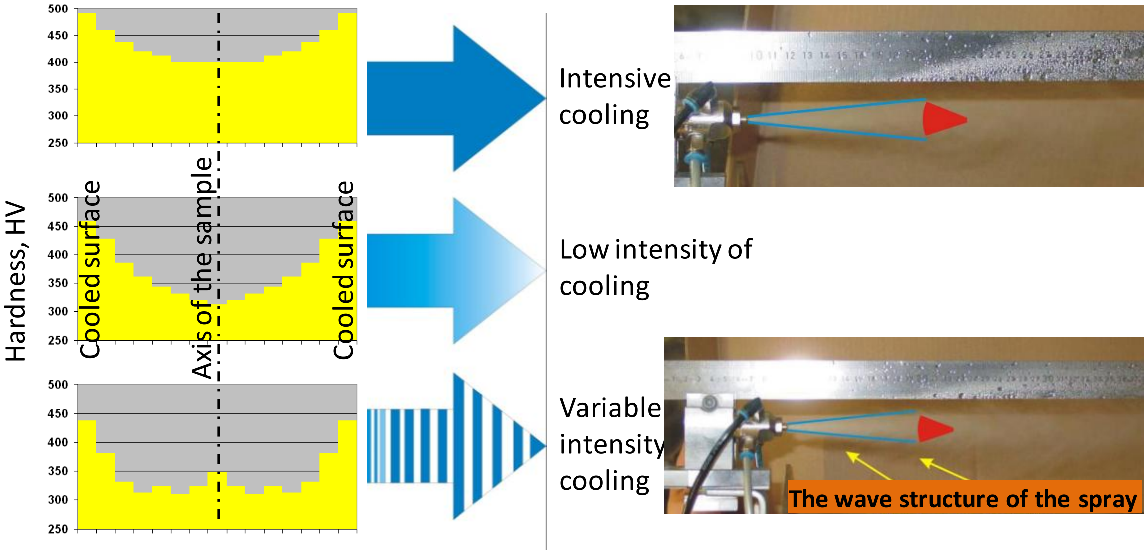


Figure 4. Scheme on the influence of the spray stability on distribution of hardness in a cylindrical sample of steel 42CrMo4 with radial spray cooling

1.2. Technological parameters of the cooling process. As for sprayfield usage, technological parameters are most important to provide the required cooling rate. These parameters include the specific consumption of water and air, and the effective cooling time.

1.2.1. Specific water consumption. Usually, the specific consumption of water is determined by the pressure in the system and it`s an important factor provides the heat sink from the cooling surface. During the experiments it was proved that the water consumption has the main influence on the temperature difference between the surface and the axial part of the sample, that increases the gradient of mechanical properties, hardness of the cross-section of the product. Range of influence of the specific water consumption on decrease temperature speed is limited on the one hand of physical properties of water in spray cooling, on the other hand - sizes of the cooled product. As the size of the sample bigger the influence of the specific water consumption is less. Besides, specific water consumption, has an influence on the shape of the spray. And also, the higher pressure, the narrower spray.

1.2.2. Specific air consumption. This parameter in water-air spray cooling plays three roles: actually cools the surface due to the heat transfer, supports the rate of water droplets and forms a conditional (effective) width of the spray. Besides, it`s noted that in some designs of nozzles increases the air consumption results to reduction the water. This is due to back pressure in the mixing chamber of the nozzle.

1.2.3. Treatment time. Spray exposure time on cooling product determines the depth of the hardenability in layer in case of hardening, and value tempering temperature on the scheme "hardening - tempering". Fig. 5 has the experimental temperature-time curves for cooling of cylindrical sample OD 180 mm in the radial sprayfield with specific water consumption of 90 gr./s.

1.2.4. The total consumption of water and air. This parameter is a substitute for the time scale for the comparison cases of the different modes of treatment. It is especially effective to compare cooling modes with different specific consumption of water and air.

1.3. Temperature of the product before cooling. The influence of the absolute temperature values is determined by the values of the heat transfer index and also the difference temperature between the surface and the cooling environment. Important aspect of the integrated processes is almost uniform distribution of the primary temperature of the cross-section of the product. The temperature difference between the surface and the center before cooling is usually less than 5%.

1.4. The shape of the product. Cooling surface area to product volume ratio – main index to estimation of the shape of product. This is due to the fact that, the heat capacity is proportional to the volume of the product, and the heat transfer – to the area of the cooling surface.

Changing of the metal temperature. Spray cooling, according to the shape and size of the product and the specific consumption of water and air can provide the cooling rate in the range of 10...300 K / s (Figure 5). Such a difference of speeds according to the thermo-kinetic diagrams for each material let manage the structure and properties of the metal. So, for example, it`s possible to produce hardening with given cooling speed, and make processes "hardening-tempering" and "hardening-aging" with required end cooling temperature.at the end of the regulated cooling temperature. Achieving of this temperature is possible by controlled parameters of the process.

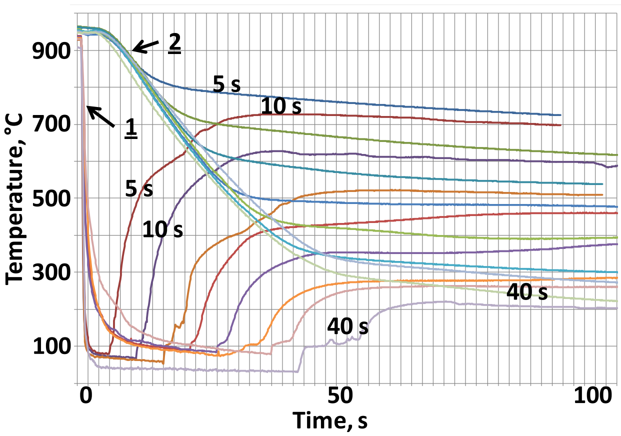


Figure 5. Time – temperature curves (by thermocouples): 1 – 1 mm from the cooled surface; 2 – the center of the sample. Sprayfield exposure time – 5, 10, 15, 20, 25, 30, 35 and 40 seconds

CONCLUSIONS

Further research of the water-air spray cooling process in integrated processes must be developed in the following areas:

- temperature fields in the cooling products with different geometrical characteristics and properties of the metal;
- the effect of design parameters and cooling technology on change these fields;
- methods of calculating the heat transfer index for spray cooling.

The dependences of structure, properties, residual stresses and shape distortion of the products according to parameters of the integrated process.

This study was finished in 2012 year.

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