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The Technology of The Manufacturing Thin Wire of TiNi-based Alloys by Using Infrared Radiation

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Abstract

The paper describes the technology of manufacturing a thin nickel-titanium wire through direct exposure to infrared radiation (IR). The effect of IR on the change in the structure of a thin wire made from the TiNi-based alloy was studied during its manufacturing. A comparative analysis of the Ti, Ni and O concentration in the TiNi wire was carried out. The analysis was performed for both a thin wire exposed to infrared radiation and that not exposed to infrared radiation. The wire samples were studied using a scanning electron microscope with the energy dispersive analysis. The infrared radiation effect on the structure of the wire is shown after thermal treatment in the local area of the material.

1 Introduction

TiNi(MoFe) alloys significantly differ from materials commonly used in medicine. These alloys exhibit such properties as super elasticity and shape memory. Similar to the tissues, these are characterized by hysteretic behavior and damping properties. The materials display high chemical stability when exposed to tension, temperature and deformation effects.

Manufacturing a thin TiNi(MoFe) wire is a complicated and cost-effective process. It includes hot rolling, multiple drawing combined with thermal annealing and preparation of a semi-finished product for the following deformation. The demand in a very thin TiNi wire (about 40 μm) in different areas of medicine is currently increasing (Fig. 1).

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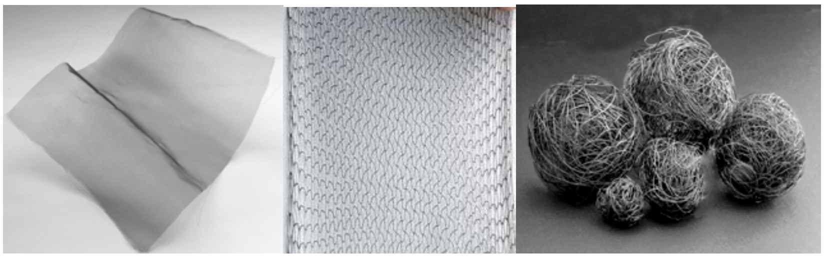


a) b) c)

Fig. 1. These materials made of the thin TiNi wire: a – the fabric material; b – the knitted mesh; c – the fabric material

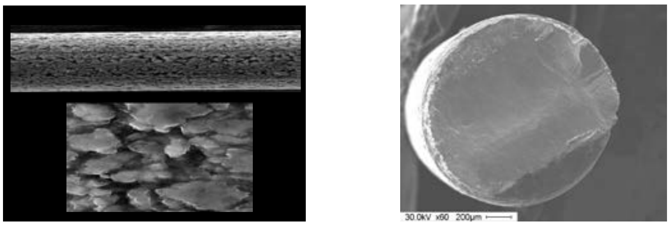
The quality of the wire depends not only on the original properties of the TiNi alloy but also on the dynamics of the changes in the diameter of the wire during its processing. The change of the geometric shape and size of the product significantly changes the structure and physical and mechanical properties of the processed TiNi-based alloy. The deformation compression of the alloy passing through the die leads to formation of a transition phase in complicated processes of plastic deformation and relaxation of the alloy. This results in a specific structure of the wire surface layer. With this, it is specifically related to heat generation, which can be observed in the TiNi-based alloys when a low-temperature phase is formed under tension [1-3].

The latent heat generated during phase transition in the TiNi alloy contributes to the drawing conditions. The effect of temperature and mechanical conditions should be taken into account. The compliance with the conditions optimizes the structure of the material, minimizes the defects and breakages during wire manufacturing. This increases the production rate and reduces the cost of the product.

2 Experimental

A thin wire made of the TiNi(MoFe)-based alloy features a multi component and composite characteristics of the material. It consists of a core – super elastic TiNi(MoFe) alloy, and a shell – titanium oxide Ti(O). The properties of these alloys are distinctly different.

The core of the wire matrix material (Fig. 2, a) exhibits a high level of strength and plastic properties. It is able to relax (reduce) high tension under deformation due to formation and movement of the interphase in martensitic phase transition. An oxide layer (Fig. 2, b) has quite the reverse characteristics, that is, low plasticity, increased fragility, and during drawing the wire surface causes formation of cracks, splinter and other defects.



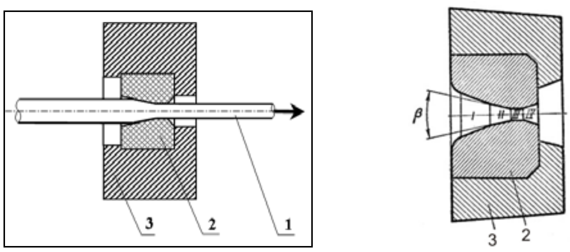
a) b)

Fig. 2. The structure of TiNi (MoFe) wire: a – the surface layer; b – the transverse section

The die is the main tool used in the drawing technology of the TiNi wire production (Fig. 3). The die hole has a transverse tapered section, which is gradually reduced. The wire being drawn through the die is plastically deformed. After the die, the wire changes its shape thus changing the sizes of the final section of the hole (Fig. 4).

a) b)

Fig. 3. The dies: a – the general view of the dies; b – the process of the broach



a) b)

Fig. 4. The structural view: a – the wire stretch through the die (1 - the wire, 2 - the die, 3 – the holder); b – the specific areas of the die (I - the input “lubricating” cone for introduction of the wire in the wire at the angle about 40 degrees, II - the working “deforming” cone

with the angle from 10 to 24 degrees, III - the calibrate part “cylindrical shape”, IV – the output cone with the angle from 45 to 60 degree

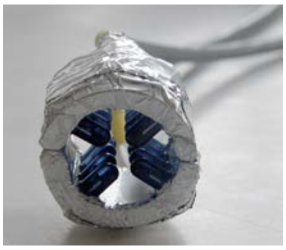
During drawing, most of the energy (about 85%) is consumed on drawing. Further, as a result of external friction and plastic deformation, the generated heat heats up the deformed alloy, lubrication and die. However, this heating is not sufficient for drawing the TiNi-based alloys (about 150 °C). A negative effect on drawing can be observed at higher temperature. When the wire has a small diameter, it breaks particularly often, that is why the drawing process is carried out under external heating at temperatures varying from 300 to 350 °C.

From a scientific and technical standpoint, the technology of manufacturing a thin wire (d ~ 30 μm) from the TiNi alloy is challenging. Infrared heating device can be used to improve the efficiency of drawing a thin TiNi wire and to reduce the number of defects. It allows circular IR exposure of the local surface of the wire before it enters the die.

The dynamics of the drawing process with preliminary heating implies heat generation due to infrared heating and heat absorption caused by phase transitions in the matrix. Heating is caused by the friction and pressure exerted on the die walls during drawing. An optimal thermomechanical mode and the range of its effect on the drawing process can be obtained through the control of a combination of dynamical processes such as heat waves, phase transition waves and external strain waves. The pressure during drawing should not exceed a specific limit and it should be distributed uniformly along the perimeter, because the resistance caused by drawing increases, and the wire can break. When drawing the TiNi wire at some angle, the pressure can insignificantly increase in a local area. In practice, these conditions limit the minimum diameter of the produced wire to the value of about 30 μm [2, 4, 5].

The functioning of the device used for additional local heating is based on circular emitted IR radiation. This radiation affects the surface structure of the wire when it enters the die.

The working section of the device comprises six blocks that are identical and parallel-connected (Fig. 5). Each of the blocks includes sixteen IR LEDs with 920 nm wavelength and 140 mW power located on the inner surface of the blocks. (Fig. 6).



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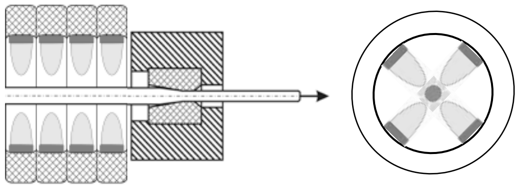


b)

Fig. 5. The device for creating the circular IR: a – 1 of the six the identical parallel connected components of the device; b – the layout of the block IR in the moment broaching of the wire

The functioning of the device implies the metered heating of the wire performed by IR LEDs during its drawing through the die. Vibrations cause circular motions in the plane that is perpendicular to the device axis. During forward motion of the wire, the contact area moves spirally along the wire surface. The bend of the wire and maximum mechanical effect on the wire surface can be observed in the contact area. The force level depends on the radial displacement of the wire relative to the die to provide significantly extended range of thermomechanical effects on the drawn wire.

Fig. 6. The general view of the device

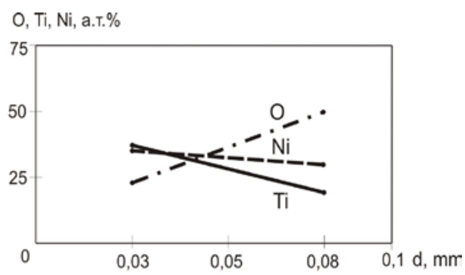
IR radiation provides local heating of the surface oxide layer and the near surface layer of the metal. This leads to the decreased yield point and increased plasticity of the drawn wire. Thus, IR radiation provides local excitation of atoms in the limited volume. Then, increase in the temperature of the material (local heating) results in the decreased yield point and increased plasticity of the alloy. In this case, the respond of different areas of the material to IR radiation is different. The TiNi matrix volume hardly responds to IR exposure. This does not lead to the wire heating since the martensitic phase transition from phase B19 to phase B2 can be observed in the case of local impact on the alloy. The process is accompanied by excess heat absorption, and thereby the temperature does not increase. High plasticity properties of the TiNi-based alloy and positive effect of IR radiation on the surface oxide layer of the wire significantly increase the efficiency of the drawing technology [2, 4].

As a result, the wire plasticity increases by 15–20% that improves the material quality and characteristics. The ultimate strength of the wire after drawing under IR radiation increases by 10–15%, and the number of the breakages reduces several times.

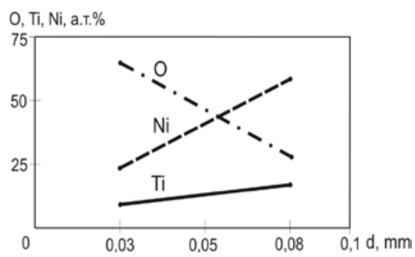
3 Results and discussion

The research results show that respond to IR exposure varies for different diameters of the wire. At the same time, IR radiation hardly affects the matrix core, but it has a significant impact on the structure of the near surface layer of the wire. The Ti and Ni concentration in the core remains practically unchanged. After additional exposure to IR, the changed ratio of the elements can be observed in the surface layer: change in the O concentration caused by local heating changes the Ti and Ni concentration.

The dependencies of the Ti, Ni and O concentration in the surface layer (oxide layer) of the TiNi wire of various diameters made by the traditional method that employs IR radiation are presented in Fig. 7. The reduced diameter of the wire manufactured by the traditional method leads to the decreased O concentration and increased Ti and Ni concentration. Apparently, the reduced diameter of the wire results in the decreased thickness of the oxide layer in which the O concentration depends on the heating time. The thinner the wire, the faster its cooling before passing through the die, and therefore the O concentration in thin wires is lower. Consequently, the Ti and Ni concentration increases.



a)



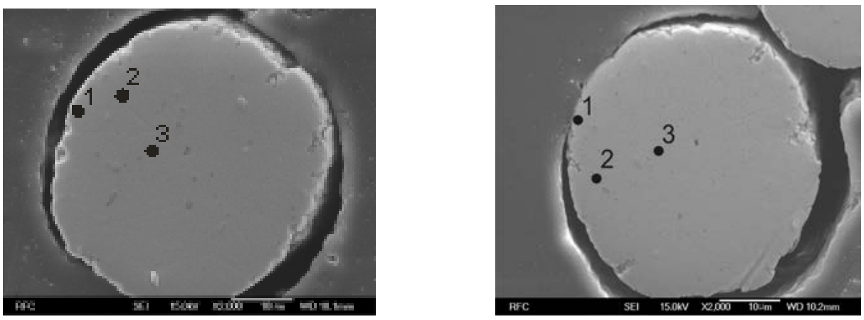
б)

Fig. 7. The concentration dependence of O, Ni and Ti in the surface layer (at the boundary of the oxide layer and matrix) TiNi alloy, obtained: a – the traditional process; b – with the use of IR

In the wires produced by the method that employs IR, the decreased wire diameter significantly increases the O concentration in the oxide layer and, as a consequence, decreases the Ti and Ni concentration. Additional heating of the wire under IR exposure, when the wire enters the die, increases the O concentration. At the same time, the Ni concentration in the surface layer falls dramatically compared to the initial concentration.

The results of the microstructure analysis of the O concentration in thin TiNi wires with a diameter of 30 μm were compared for the wires produced by the traditional method and those exposed to IR radiation.

The research includes evaluation of the IR radiation effect on the O concentration in the samples of a thin TiNi wire in the cross section (Fig. 8). The three areas in each sample were investigated. The areas were located at the same distance from the surface: 1 μm, 3.2 μm and 8.5 μm in depth. Then the O concentration was determined for each level of the wire samples. The dependencies of the O concentration for the surface and inner layers of the TiNi wire samples based on the data obtained are presented in Fig. 9.

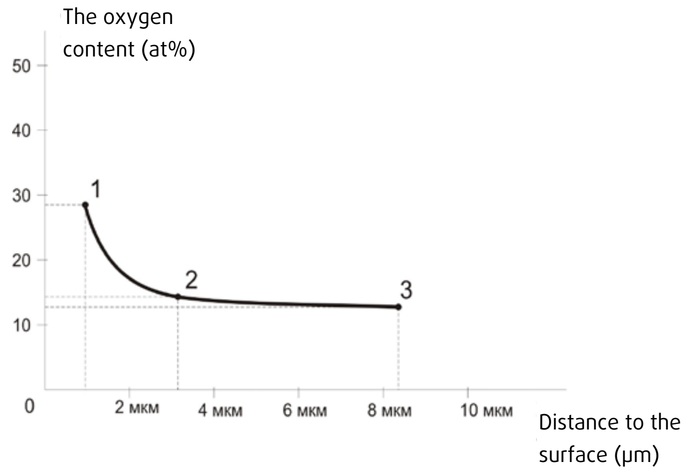


a) b)

Fig. 8. The research areas of the cross section TiNi wire with d – 30 mkm: the sample made without the using IR; b – the sample with using IR

The obtained data show that IR radiation hardly affects the core of the matrix, but it has a significant impact on the structure of the wire surface layer. The changed O concentration caused by heating can be observed in the surface layer after exposure to IR radiation. The additional heating of the wire due to IR exposure when the wire enters the die increases the O concentration. In addition, the Ni concentration in the surface layer sharply decreases compared to the initial concentration.

The drawing force under IR radiation decreases by about 15% compared to drawing which does not employ IR radiation. With this, the plasticity of the drawn wire increases by 15–20%. The ultimate strength of the TiNi wire under IR radiation increases by 10–15% after drawing. IR exposure reduces the number of wire breakages by about 70%. The structure of the TiNi wire changes under IR radiation and thus enhances the production efficiency. One of the important results achieved is the reduced cost of the thin TiNi wire production (Fig. 10).



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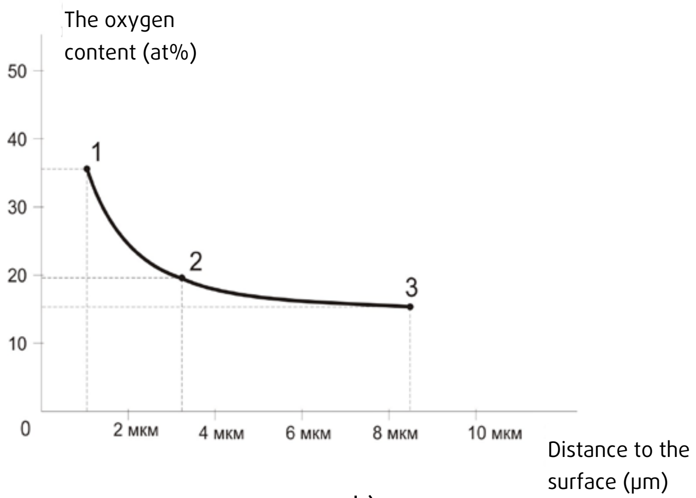

b)

Fig. 9. The graphical of the concentration of the oxygen in the layers of TiNi wire (30 mkm): a – without using IR; b – with using IR

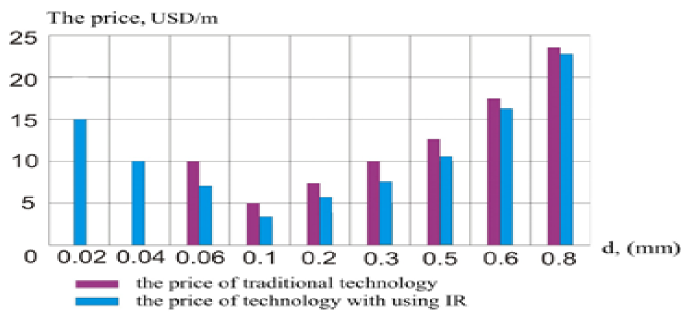

Fig. 10. The manufacturing cost TiNi wire made by drawing method: on traditional technology and with using of IR

4 Summary

Thin wires are widely applied in medicine. They are made of knitted, mesh, fabric and fiber materials, which are used to produce the suture material, fastening systems and orthodontic working elements, to reconstruct the ligament in traumatology and to fix the retina in ophthalmology.

The medical instruments and components made of the TiNi alloy have important properties such as: wear resistance, ability to change the shape, flexibility and elasticity. These materials can function in a body for a long time without destruction after multiple exposures. The materials and implants enable us to create new medical equipment based on highly effective medical technologies of surgical treatment in different areas of medicine.

The use of the technology for manufacturing thin wires from the TiNi-based alloys with IR radiation employed improves the efficiency and widens the range of implant production, and opens up new perspectives for medical technology.

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