ANALYSIS OF POSSIBILITIES TO IMPROVE THE SURFACE PHYSICAL MECHANICAL PROPERTIES OF SCREW TYPE PUMP ROTORS

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Abstract: More frequently rotor pumps and screw type compressors as kind of them are used as machines for production of compressed air. These compressors are operating with greater efficiency on high speeds of rotary rate, and operate in a wide range of pressures. The rotors of pump are inferior to influencing of variable forces and rotary moments which produce compressed gases. So, as the requirements for these rotors are comparing high, they should be made of quality materials, which provide excellent characteristics in statistical and dynamic pointers of mechanical resistance. In foundation of the article the main attention is paid to making of new or improved technologies, to perfect the properties of steels of lower quality, which will assure material, which always technological and mechanical dignities would characterize, adjusted for the production of rotors. The purpose of the work - to establish, that not always rotors should be made of regulated expensive materials, but it is possible to use cheaper materials. This work analyzes in more detail changes of steel technological, mechanical properties, using the mechanical strengthening, thermal and thermomechanical processing methods of strengthening, their advantages and failings. Knowing many elements, as for example, carbon, nitrogen and other elements which improve technological and mechanical properties of the overhead layer of material, in the work also the thermal influence is analized, and also the change of the properties of the surface using various coverages for rotors. At the end of the article the conclusion gives various advices for improvement of the surface of rotors.

Key words: rotor pumps, screw compressor, processing, surface, rotors, improve, quality.

Introduction

Nowadays developments of the technique and technologies have very important catch, not only in engineering, but also and in any industry of production of national economy in general, compressed air is applied. Many times not only in transport, but also in machines of agriculture for producing of compressed air rotors pumps are used. Always more frequently technologically most fashionable, economic and the safest machines of compressors – screw type compressors are used. The hasty growth of screw compressors and variety of their constructions enable these spaciously to use.

A screw type compressor is one of the simplest mechanisms that is used for production of compressed air. This construction is comparatively simple, a difference is only in the principle of air compressing, which takes place between two specially created revolved rotors. These pumps can operate with high efficiency at comparatively high speed of the rotary, at pressures of wide range. The rotors of screw type compressors are one of the most responsible parts of the compressor, on which their productivity of action depends.

Fig. 1. **Rotors of screw type compressor**

The rotors of the pump are inferior to influencing of variable forces, which the compressed gases create, and also to the forces of inertia and moments of rotation. In case of resonance external and internal tensions appear additionally.

The requirements for these rotors comparing high, they should be made of quality materials, that provide excellent characteristics in statistical and dynamic pointers of mechanical resistance. The criteria of screw compressors efficiency action and boldness depend on various features of exploitation, mutual placing of units and their commutability, as well as correct choosing of materials for parts.

Selection of materials

Product planning includes not only making of this construction, but also the choice of rational material. Primary in planning of a product its actions, functions, boldness, look also over the market requirements and demand for this product, standard of living and other factors are considered. The choice of rational material is a multifunctional motion. In planning of a product it is advisable to take into account recurrent connection after the primary choice of material.

Nowadays developing a technique and technology considerably enlarge the exposure of the applicable materials. New materials are created still with much better mechanical and technological properties. Today in engineering, also in building industries such construction materials that still recently are called as future materials are widely used. Noticing that the pumps of screw type rotors can operate in conditions of various environments, choosing the rotor materials of screw type compressors it is needed to consider, that they would provide excellent characteristics in statistical and dynamic pointers of mechanical resistance, longevity, and also they owe to be with excellent technological properties, warm resistance etc. For manufacturing of rotors it is possible to use different kinds of materials on both constructions of quality and alloy steels constructions. For rational use of materials for constructions, we need to know not only their properties, but also to understand the factors, witch provide these properties. Structures of materials affect mechanical and technological properties, which can change using different processing methods, for example, deformations of structure and thermal processing. Substantially material mechanical properties are influenced by alloying elements - chrome, nickel, molybdenum, vanadium etc. To protect rotors from unfriendly external environment influence various kinds of surface coverage are used.

Analyzing the above examined, we come to the conclusion, that for making of rotors it is necessary to use materials with high mechanical properties - large endurance R_m 850 N mm^{-2}, high elasticity R 650 N mm^{-2} and high plasticity A 12 %. To provide large wearproofness and life of work for rotors, it is necessary to choose material with its hardness in scopes HRC 25-32. Knowing the manufacturing technology of rotors it is necessary to pay attention to technological properties of the material. So as rotors work in comparatively severe circumstances of work, it is needed to pay attention also to properties of material surface. Properties of material surface provide us their alloying elements.

The leading producers of screw compressors are recommending constructions of quality steels (C22, C45), for larger compressors alloyed materials of constructions (15Cr3) are advised. Substantially mechanical properties of materials are influenced by alloying elements as chrome, nickel, molybdenum, vanadium etc. Alloying elements improve mechanical properties of the material. The dry type screw compressors operate at comparatively greater temperatures, therefore steels with more resistance of temperature (30CrMoV, 35CrNi5) are recommended. Increasing of working temperature diminishes mechanical stability of steels. Compressors which work in aggressive environments use resistant corrosion alloy steels (X10Cr13, X7Cr13). In the first table we can see the main mechanical properties of steel for rotors of rotor pumps.

Table 1

Mechanical properties of recommended steels

Steel	Re, (N mm^{-2})	Rm, (N mm^{-2})	A, (%)	HRC
C22	35	46	23	22
C45	36	61	16	24
15Cr	34	50	18	23
35CrNi5	50	65	14	26
30CrMoV	60	85	12	31
X10Cr13	42	60	20	24
X7Cr13	42	60	19	24

Not always it is possible to extract such materials with such mechanical, technological and surface properties, which are needed for the rotors of pumps. Often they are not accessible or are expensive. Sometimes it is acceptable to use materials the properties of which are lower, therefore rotors are with less endurance, lower wearproofness, lower elasticity etc. We need to notice these above mentioned requirements. Using modern nowadays technologies and knowledge, we can find many ways how to improve mechanical properties of rotor materials.

Improvement of properties

For many parts of machines, and also pumps of rotors it is needed to survive the protracted influence of the variable and cyclic loadings, impacts, frictions, influence of aggressive environment, and also various combinations of the mentioned factors. The overhead layer of these parts owes to be hard and wearproof, but the part of core owes to be with large viscosity, longevity and resistance. The aggregate of such properties can be attained, using the various receptions of surface strengthening of the parts.

1. Mechanical strengthening of material

Not looking on a spacious metal and its alloys, we can improve the mechanical properties of almost any material.

One of the varieties of improvement of mechanical properties is mechanical strengthening of the material. With the processing methods, we can improve only overhead layer properties of material (strengthen an overhead layer) – increasing hardness HB of the overhead layer, wearproofness and higher tensile strength R_m. Mechanical processing we can carry with, for example, processing the overhead layer of material with balls, with special billows etc. By mechanical strengthening of the overhead layer, plastic deformations are a result and influence of tangential tensions, there are deformations of shear change in material, as to increase hardness and resistance in the result. The depth of the overhead layer is identical with the deformed thickness of the layer. Energy of deformation partially accumulates in the metal, in such a way that it creates distortions of crystalline grate and new defects of grate.

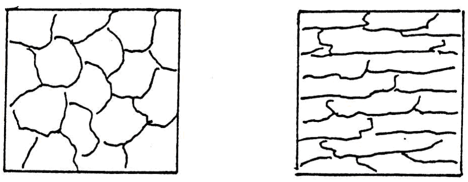

Fig. 2. **Structure of material before and after deformations**

Multiplying the stage of deformation, the border of flow increases more rapidly than the border of strength and in case of the stage certain deformation achieves it. In cold plastic deformation of mechanical strengthening the processing explains with multiplying the tightness of distributions, sectional cleaving of the structure, and also with deformation of crystalline grate and together with it formation of third index internal tensions.

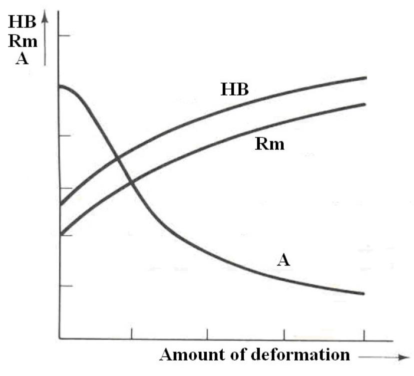

Fig. 3. **Influence of deformations on mechanical properties of materials**

Not always it is needed to use fashionable technologies for improving mechanical properties of contact surfaces of rotors. The surfaces of rotors can be strengthened using the influence of plastic deformation, processing these with the help of billows. In the above examined figure (Fig. 3) demonstratively the change of mechanical properties of rotors depending on the amount of deformation is shown.

2. Heat treatment

As everyone knows the changes of material structure have strong influence on mechanical and technological properties of the material. One of the improvement types of material mechanical properties, which also is widely used in engineering is heat treatment with its influence on the material. Heat treatment consists of a process, where the product warms T_{heat}, self-control in this temperature and cooling the task of which is noticing the certain regimes to change the structure of the material and properties. A thermal processing process is represented in Figure 4.

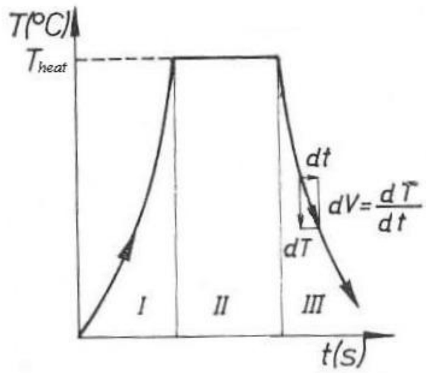

Fig. 4. **Thermal processing process**

In that way we can get considerable changes of properties without changing of the chemical composition. Nowadays the thermal processing method is based on metal physics, dislocation theory and changes of metal structure regularity. The kind of thermal processing stipulates to change the metal phases and structure. Heat treatment can be executed for moulding, forging, rolled metal, parts of press, welding connections, for more responsible parts of the machine and tools. Depending on the type of rotors manufactured we can use suitable thermal processing operations for improving of the properties. The main thermal kinds of processing are shown in Figure 5.

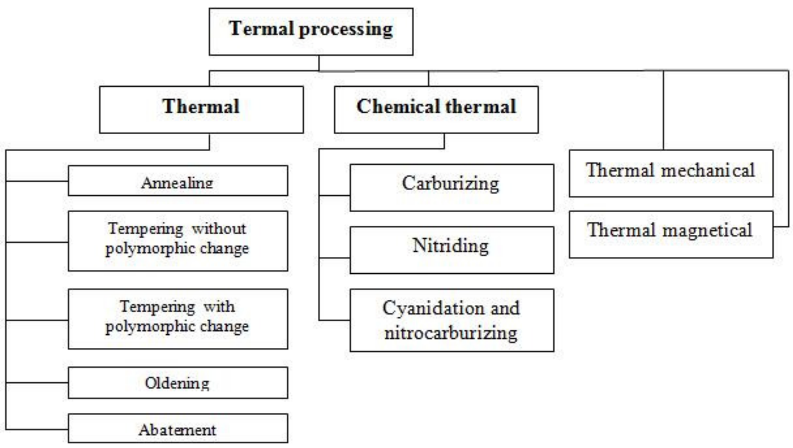

Fig. 5. **Thermal processing kinds**

Hardening is one of the kinds of thermal processing which we are using for promotion of strength, hardness HB and etc. mechanical properties of materials. Hardening more frequently is a way to extract a martensite structure which is the hardest structure. The influence on speed of the material cooling tries to save unstable structures and together with it to increase hardness HB and the strength of materials R_m.

The purpose of tempering is considerable to promote the force of the material and hardness. We can execute tempering mainly for more part of steels, in which C>0.25...0.30 %. Tempering leans on steel crystallization means heating above critical temperatures, sufficiently maintaining in this temperature and rapid cooling. In such kind austenite transformations in perlite are prevented. The speed of the austenite transformations and character depend on the stage of supercooling. During the time of warming and after cooling unstable structure of satiated hard solution or structure, that consists of various kinds of dispersion stage of hard solution transformation products is saved. Tempering steels have not balanced martensite, beinite, trostite or structure of sorbite.

So with hardening we can achieve equivalent properties of the material that are needed for the rotors of pumps. Depending on the speed of cooling we can achieve the various structures of the material. So if you have an aim to achieve a martensite structure, then environment of hardening must provide satisfactory speed of cooling in the temperature interval of the smallest austenite stability (650...550 °C). The ooling speed needs to be greater than the critical speed of cooling. Within the interval of transformations temperature of the martensite $M_s...M_b$ cooling is desirably less, to prevent deformation of the parts and cracking. The below examined figure (Fig. 6) allows hunting down austenite for duration of transformations.

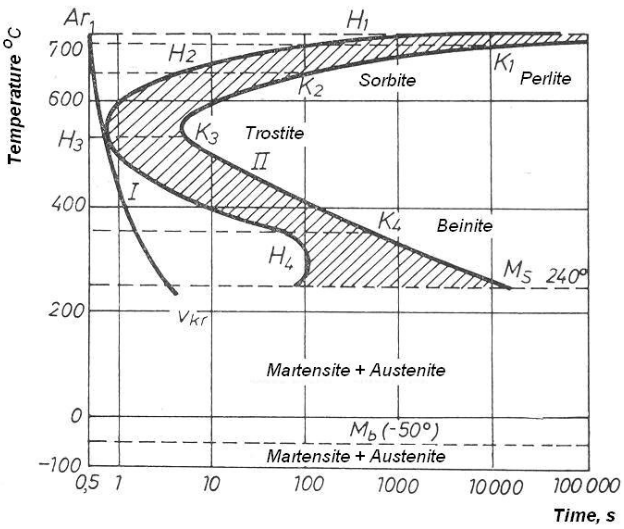

Fig. 6. **Curve of austenite isothermal transformation**

Changing the properties of the material with the help of hardening we obtain especially more strength R_m, hardness HB, but plasticity A of the material diminishes in same queue. The material becomes harder, more fragile and more wearproof. Manufacturing the rotors of pumps from ordinary steel of constructions C45, we subordinate this steel to hardening in 820 – 840 °C temperature, in the result we obtain steel with scopes of elasticity R_e=580 N mm^{-2}, maximal endurance scopes R_m=850 N mm^{-2}, plasticities A 13 % and hardnesses of the overhead layer of the material HRC 24-31. After hardening in materials internal tensions occur and the core of the part stands hard, what is not good in the circumstances of rotor exploitation.

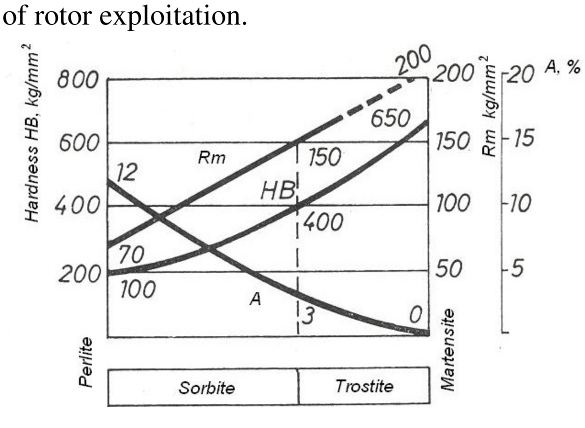

Fig. 7. **Change of properties**

Knowing that rotors work in heavy circumstances of work, it is inferior for the variable dynamic loading, together with it after hardening it is necessary to subordinate these rotors to abatement, which would liquidate internal tensions and give these rotors a little viscosity which would hold more dynamic loads. The changes of the properties depending on the temperature of creating the structure are represented in Figure 7.

Choosing the correct temperature of abatement after hardening, we obtain steel with excellent mechanical, technological properties. In Table 2 a possibility to examine the change of the steel C45 properties depending on temperature of abatement is given.

Table 2

Influence of abatement temperature on mechanical properties of steels

Abatement temperature, °C	Re, N mm^{-2}	Rm, N mm^{-2}	A, %	HRC
450	850	1000	10	31
500	750	850	12	28
550	650	800	16	26
600	600	750	25	24

To decrease intransient austenite amounts in hardening steel and to increase his hardness, therefore converts untransient austenite - martensite, using cold treatment of steel which characterize with cooling of hardening steel below than a zero. Martensite is the hardest and most fragile structure.

Hardening can be executed also only for the overhead layer of the part, hardening the surface of the part above the critical temperature, by heating a thin overhead layer only, but internal layers are not heated. After hardening the part has a hard overhead layer and sinewy core.

There are also failings of material hardening. The defects of hardening are cracks, warping and decarbonisation. Cracks appear because in separate places the volume changes are irregular and tensions occur which in these places exceed the tensile strength of metal. Crack and warping are the main reason of uneven change of the volume of the part warming, and also exceptionally quickly cooling. The surface of steel decarbonisation appears in the result of burning down of carbon, if the part is warmed for a long time in environment oxidizing in high temperature.

As often as not, that would hardened steel, it needs to be prepared, executing his normalization. In the result of normalization steel obtains a fine-grained and homogeneous structure.

As often after hardening of steel we would need to increase fatigue strength and to decrease fragility, and abatement it. Abatement softens the influence of tempering, diminishes or takes off untransient tensions, promotes fatigue strength, diminishes hardness of steel and fragility.

3. Chemical-thermal treatment

Not always we are ready to pay large money for good quality steel with large maintenance of carbon and mechanical and technological dignities. Most ordinary steels of construction are accessible to us with little maintenance of carbon C<2 % and lower mechanical properties. This in no value, that we cannot improve these steels. Not so popular kind of thermal processing is chemical-thermal treatment. That treatment consolidates thermal and chemical influence, what changes the chemical composition of the overhead layer and structure, together with improving of good mechanical, physical and chemical properties. By using of tempering we do not incompletely use the part of the material core. Chemical-thermal treatment allows us to manufacture the part from the cheapest and the simplest material, its overhead layer properly strengthening. Nowadays chemical heat treatment is often only united with ordinary heat treatment. The steel chemical heat treatment is satiation of the overhead layer in a diffusive type in high temperatures with various elements, for example, carbon, nitrogen, aluminium, silicon, chrome etc. The impregnation process consists of separation of active atoms from the molecules of the neighboring environment, their divisions or in the result of the chemical reaction, from pressing of active atoms in the overhead layer of the part, where these dissolve or form chemical compounds, and from moving of the absorbed atoms on the deepest layers.

In a carburizing process satiation of steel surface with carbon is executed. Carburizing is used for multiplying wearproofness elements of the machines. For providing large dynamic loading resistances, the part of the core is desirable to save plastery. Therefore, for making of the carburizing parts steel with maintenances of carbon 0.1...0.18 % is chosen. Diffusion of carbon in steel is possible only then, if carbon is in a specific state. Using carburizing we increase wearproofness of the overhead layer of the part certainly deep. The carburized layer thickness depends on the temperature, duration of self-control and carbonizing composition. As compared to chemical thermal, thermal treatment is a very labour intensive process. That the carburized details would extract final properties, they are subordinated to thermal treatment. After carburizing in hard carbonizing double hardening and low abatement are obtained. So, therefore rotors of the screw type pumps do not wear out too far, carburizing of steel is conformable for our requirements.

Satiation of the overhead layer of the material with nitrogen often is called as nitriding. This process is used for increasing wearproofness, longevities, hardness of the surface and for multiplying endurance of corrosion of the machine parts. Hardness of nitriding the overhead layer considerably exceeds hardness of the cemented and tempered overhead layer. Nitridind is done for the responsible parts of machines and mechanisms, for example, rotors of screw type pumps, which are inferior to the friction and which the variable loading of the size and direction operates on. For it steels, which are alloyed with chrome, manganese, vanadium, tungsten, molybdenum, titan, aluminum etc. are suitable. In the process of nitriding nitride appears, which is selected as a type of dispersion particles and promotes hardness of steels.

Often to improve the properties of the overhead layer of the part, cyanidation, nitrocarburizing processes are used in which simultaneous satiation of steel surface with carbon and nitrogen takes place. Thus the treated surface obtains both carburizing and nitriding properties: large hardness, wearproofness and resistance of corrosion in the atmospheric circumstances and longevity is promoted in case of variable loading. Cyanidation is more effective than carburizing. The cyanidation depth can be attained from 0.1 – 2 mm.

4. Thermomechanical treatment

The thermomechanical treatment is comparatively new processing type of steels, heat treatment and plastic deformation is incorporated in it. In the result of thermomechanical processing more mechanical dignities are obtained than in ordinary heat treatment - higher fracture and fatigue strength and force, more longevity, but plasticity and viscosity are saved or even increased.

The high mechanical properties of steel after thermomechanical treatment could be explained as closenesses of large distributions in martensite and shredding of grains in separate certain mutual oriented fragments. A strengthening phase (various carbides etc.) was evenly divided not only on the scopes of grains, but also on the volume of grains and sliding planes. The concentrations of distributions are hamper sliding processes and they stipulate large force of steel. The increase of plasticity is related to diminishing of internal tensions.

5. Various surface coverages

For improving the properties of the overhead layer of rotor material of screw type compressors, various coverages are offered. That will multiply hardness of the overhead layer of screw rotors, and also wearproofnes, and diminishes friction. The overhead layer of the material can be covered with various coverages, for example, TiN, Ti(CN), SiC, Mo_2N, TiAlN, teflon, and also other coverages. Coverages on the working surfaces of rotors are possible to cover with various methods. One of the coating methods is CVD. Chemical Vapor Deposition, or CVD, is a thin-film coating with a chemical and metallurgical bond that results from the reaction between various gaseous phases and the heated surface of the substrate. The final result is a hard, wear-resistant coating with an extremely strong bond to the substrate. CVD is sometimes referred to as a “hot coating” because the process approaches temperature around 1051°C. For this reason, special post-coating vacuum heat-treating processes have been developed for steel components as well as for screw type rotors. The second method of covering is PVD. Physical Vapor Deposition, or PVD. The most common of these PVD coating processes are hollow cathode reactive ion plating, cathodic arc deposition, and magnetron sputtering. All of these processes occur in vacuum at roughly 10-2 to 10-4 Torr. All of these deposition methods involve the generation of positively charged ions. These ions react with gases that are introduced into the vacuum chamber to create various coating compositions. The parts to be coated are given a negative bias in order to attract the positively charged ions. Finaly we get srew rotors with great hard, wear-resistant coating. For coverages of the material surface we can also use methods of sputtering or the method of electronforming. With the help of coverages we obtain an overhead layer with diminished porosity, balanced structure, promoted connection with the basic layer. The various coverages are used for improvement of rotor mechanical properties of the overhead layer of rotor pumps are widely used in manufacturing of screw type rotors. Using of coverages allows decreasing the manufacturing time.

These are some of the processing kinds, with the help of which we can multiply hardness and wearproofness of the surface of the screw rotor of screw type compressors.

Conclusions

1. From the issues examined above it can be concluded that the choice of materials nowadays is very spacious and they are very important in most of all industries. The requirements for these rotors comparing high, they should be made of quality materials, which provide excellent characteristics. Often rotors act under hard conditions, then we should choose a material with great mechanical properties. The mechanical properties of materials are pretty important in exploitation of the parts in time. We can easily change the properties with heat treatment. In our days the methods of production and facilities are so varied, that it is possible to obtain the same result with various technological processes. Heat treatments in a large measure stipulate a various detail, instrument and other quality of wares. With heat treatment we can assign for wares necessary mechanical properties and provides for them normal term of service, knowing development conditions of rotor materials.
2. Analyzing these special methods for force increasing a conclusion was drawn, that with thermal processing methods for material we can obtain much better mechanical, physical and technological properties than using simple methods. We can obtain them, using special methods of increase of the force of material, from plastic material far more hardy material which can not be achieved with ordinary methods.
3. Using chemical thermal treatment, we fully use the core parts of the part materials, what allows to make the part from the simplest, cheapest material, accordingly strengthening its overhead layer.
4. We can make more effective mechanical properties of the rotor contact surface by using of different coatings. By using of these different coating processes for rotors of rotor pumps we achieve good surface properties: with great hardness, wear-resistant coatings, heat resistance and a surface with reduced friction coefficient.

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