CONSTRUCTIONS, MATERIALS AND CONDITIONS OF THERMOMECANICAL LOADING OF ENERGY-MECHANICAL ENGINEERING OBJECTS AND APPARATUSES OF CHEMICAL PRODUCTIONS

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ABSTRACT

The work presents bimetallic materials for the manufacture of vessels and high-pressure apparatuses, should be chosen in accordance with the specifics of their designs, production and operation, as well as taking into account possible changes in the initial physical-mechanical components of materials under the corrosive effect of the treated environment under the conditions of this chemical-technological process.

Bimetallic materials representing axisymmetric structures (reactors, autoclaves, heat exchangers, distillation columns, pipelines, etc.) with wall thickness of clad parts are 8-300 mm, with a ratio of layer thicknesses of 0.05-0.25, the operating temperature is in the range of 255-700 K and the working pressure (for vessels) is 1.0 h - 5.0 MPa and more. The thickness of the plating layers is determined by the aggressiveness of the environment, the service life of the vessel and economic considerations.

Despite the variety of methods for producing various bimetals that have been used in industry for vessels and high-pressure apparatuses can be divided into the following groups: foundry cladding method, rolling cladding method, cladding by building-up followed by hot rolling and explosion welding metals.

The strength of bimetals under static loading is one of the most accessible ways to assess the properties of structural materials. When testing the effect of temperature, the calculated temperature is assumed to be equal to the maximum temperature of the medium in contact with the wall.

When assigning the basic design parameters of the structure and subsequent calculations of strength and resource, the initial defects are, first of all, the loading characteristics of the structure, including mechanical and thermal loads.

The most dangerous defect is surface or subsurface cracks with a length several times greater than the depth located near the inner surface of the housing wall and oriented perpendicular to the action of the greatest tensile stresses.

Key words: high-pressure apparatuses, bimetals, cladding methods, loading conditions, temperature effect.

INTRODUCTION

Types of devices, designs and materials. In the petrochemical, energy and chemical industries used a large number of cylindrical vessels, autoclaves, reactors and tanks operating under filling or intravenous overpressure. The dimensions of these vessels depend mainly on the required capacity of the working environment. High-pressure apparatuses include apparatus operating at pressures above 10 MPa. These are usually thick-walled vessels, they are manufactured of the smallest possible diameter, which makes it possible to obtain relatively little force from the internal pressure on the lid of the apparatus and thereby ensure the structural perfection of the sealing elements. The main unit of the vessel and the apparatus is the body, which determines its shape, size, volume, performance and cost. The case of a modern atomic reactor weighs about 550 tons, diameter 5 m, height 15 m, wall thickness up to 250 mm. 18 t of corrosion-resistant steels are consumed for building-up the surface.

Depending on the purpose and operating conditions of the structures, various levels of thermal and mechanical loads are set. For example, power reactors of the VVER type with a capacity from 200 to 1000 mW of pressure in the primary circuit are 10–16 MPa, and the vapor pressure in front of the turbine is 3–6 MPa; the temperature of the coolant at the outlet of the reactor is 270-330°C. At the same time, with test and non-stationary modes in VVER and BN reactors, as well as with the operation of emergency protection systems, maximum pressures can reach 19-20 MPa, and temperatures - 600-620°C.

During the deposition of such steels in a certain area of the heat-affected zone under the deposited anticorrosion layer after tempering at a temperature above 5700C, cracks are formed on the tips of the grains. The formation of cracks is explained by the fact that during the cladding of corrosion-resistant chromium-nickel steel, a certain amount of ferrite is contained in the weld metal, which reduces the tendency of steel to form crystallization cracks.

The nodes of the vessels working under pressure with a wall thickness of more than 30 mm are subjected to annealing to relieve tension. In this case, some of the ferrite in the annealing process turns into the σ - phase. As a result, the impact strength of the deposited metal decreases, and most sharply in the temperature range of 550-900 ° C. Impact strength decreases the more, the more ferrite is contained in the weld metal [1].

MATERIALS AND METHODS

Bodies of apparatus, depending on the method of their manufacture, are cast, forged, welded and multi-layered.

Cast - the most simple to manufacture, but their strength is much less than that of forged, so the wall thickness and weight of the device is significantly increased compared to forged; welded; welded - welded from stamped semi-quartz, they are cheaper than forged ones and are now widely used; multilayer enclosures are made twisted and rolled. Twisted shells consist of a central shell with a thickness of 18-20 mm of high-alloyed steel, on which sheets of low-alloyed steel with a thickness of 4–6 mm are screwed tightly, the use of coiled apparatuses significantly saves the metal and reduces the cost of their manufacture.

Materials for the manufacture of vessels and high-pressure apparatuses (thick-walled vessels and apparatus) should be chosen in accordance with the specifics of their designs, production and operation, as well as taking into account possible changes in the initial physical-mechanical properties of materials under the corrosive effect of the environment being processed this chemical process. So when processing hydrogen-containing substances, hydrogen corrosion has a special effect on the machine’s performance, and at operating temperatures above 350°C, steel creep.

In addition, it is always needed to strive for low cost equipment.

RESULTS AND DISCUSSION

It is known that carbon and low-alloy steels, bimetals, coatings on carbon steels are several times cheaper than high-alloyed (heat-resistant, heat-resistant and corrosion-resistant). The working pressure in a thick-walled vessel or apparatus is the maximum overpressure during the normal course of the process without taking into account the permissible short-term pressure increase during the operation of the safety device.

The design pressure P_d is assumed to be equal to the working pressure P. However, when the pressure increases during the operation of the safety valve by more than 10% compared to the operating pressure (P_{cr}), the device is calculated for pressures equal to $0.9P_{cr}$, but not less than the working one. The estimated wall temperature of the vessel or apparatus is taken as the maximum wall temperature determined on the basis of the results of the test or thermal calculations.

If it is impossible to carry out calculations or tests, the calculated temperature is assumed to be equal to the maximum temperature of the medium in contact with the wall. Standard allowable stress for all details of these apparatuses are determined $\sigma^* = \min\{\sigma_B / n_B; \quad \sigma_T / n_{pT} \}$

where $n_{B,} n_T$ - strength factors, respectively, for tensile strength and yield strength,

σ_B, σ_T - respectively, the tensile strength and yield strength of the material at the calculated temperature. Allowable stress is determined by the formula $[\sigma] = \xi\sigma^*$, where $\xi -$ correction factor taking into account the operating conditions of the device.

The development of modern industries is inextricably linked with the increasing requirements for structural materials in terms of ensuring the reliability and durability of the structure in experimental work conditions (under conditions of intense exposure, mechanical loading, aggressive working environments, etc.).

Considerable efficiency of using bimetals is due to:

First, the separate combination of different metals or alloys in a bimetal, it is possible to combine the necessary operational properties that are not possessed by individual metals. The use of bimetals allows you to create products that by their design characteristics are superior to similar products from monometallic and at the same time are more economical.

Secondly, the use of bimetals provides significant savings for expensive and scarce metals and alloys, while simultaneously increasing strength or reducing the mass of products and structures. The economic efficiency of bimetallic rolled products is determined by the fact that expensive scarce metals and complex alloyed alloys are used in bimetal as relatively thin cladding layers (10-15% of the total sheet thickness) in combination with a cheaper base metal.

Despite the variety of methods for producing various bimetals, which have found application in industry, they can be divided into the following groups, and each group is united according to the basic principles of bimetal production:

• the method of foundry cladding, which consists in combining the components in the interaction of the expanded component with a solid metal. The combination of components occurs in the process of crystallization of the base material on the substrate of another, followed by hot rolling;

• rolling cladding method based on the combination of components during their joint cold and hot rolling deformation;

• cladding using a building-up method followed by hot rolling required for the manufacture of a bimetallic sheet of the required thickness;

• explosion welding of metals resulting from the throwing of one metal against another by a blast wave;

In the first case, the technological process of bimetal production consists in the manufacture of two and multi-layer ingots and their subsequent rolling to the required thickness of the clad sheet.

Both small ingots weighing several kilograms and large ingots weighing up to 10-15 tons are obtained by the foundry method. The main advantage of the foundry cladding method is that it does not require significant capital expenditures, installations, special equipment, etc. The significant disadvantage of foundry cladding should include [2]:

- the possibility of producing bimetallic sheets from a relatively small number of combinations of metals of the base and cladding layers;
- formation of an oxide strip between the contacting surfaces, preventing the bonding of the layers during the subsequent rolling;
- damage to the surface of the cladding layer during rolling (risks, dents, scratches), which degrades the quality of the surface of the sheets, requires a large amount of work on stripping sheets;
- consumption of a larger amount of metal, as well as a large uneven thickness of the cladding layer;
- strong distortion of bimetallic sheets during cooling after rolling, which makes it difficult to carry out subsequent technological operations (cutting, heat treatment, straightening, etc.).

Methods based on the principle of joint plastic deformation are now widely used for the production of sheets, strips, tapes, shaped profiles, rods and wires. When batch rolling, the billet usually serves as a four-layer package consisting of two sheets of material of the cladding layer (between which there is a coating of inert refractory material) placed between the plates made of base material.

Sealing the package around the perimeter is usually carried out using electric arc welding. After that, the bag is heated and rolled, during which, at high temperature and high specific pressure, two pairs of surfaces of the base and the cladding layer are firmly joined to each other. The quality of the adhesion of the layers can be improved by using vacuumed packages or by rolling in vacuum or in an environment of neutral gases. The batch cladding method has the following advantages:

• assembly of packages does not interfere with the main technological process in metallurgical workshops;

• batch method does not require the presence of blooming at the plant, since in the vast majority of cases the package is rolled directly on a plate or sheet mill;

• surface quality of the cladding layer is much better than with the foundry cladding method, since the surface is not exposed to the atmosphere of the furnace, no scale is formed on it and it does not need to be etched;

• thickness of the cladding layer is more uniform compared to the foundry cladding method;

• due to the symmetrical arrangement of the layers relative to the product, the strip does not bend during rolling and warping the rolls during cooling.

The disadvantages of batch rolling include:

• high complexity of preparatory operations;

• need for a specialized workshop or compartment for assembling packages;

• restriction on thickness (no more than 80-100 mm) and weight of sheets during batch rolling;

• Increased thickness variation of rolled sheets due to uneven heating of packages and furnaces and some other factors.

Metal cladding using the building-up method (metal building-up) is an effective way of extending the service life of machine parts. Electric arc surfacing in its various modifications is distinguished by its versatility with respect to the shape of the guided surface, it allows to apply coatings of hard alloys that do not allow pressure treatment. The method of cladding with overlaying can be used to apply a cladding layer on finished products and structures, for example, on the inner surface of a tank, in the manufacture of rolled products for critical equipment, in particular, for nuclear energy [3].

The disadvantages of the building-up method are:

• high labor intensity and cost,

• significant deformations

• inaccurate adherence to surfacing thickness,

• insufficient surface of the surfacing,

• the need to apply several layers to suppress the effect of dilution of the metal of the cladding with
the base metal.

The method of electroslag building-up is productive, but has a significant drawback due to the significant penetration of the base metal, which is not constant over the surface being deposited. During the surfacing of the first layers, the steel of the cladding layer is mixed at a certain thickness and may contribute to the formation of brittle interlayers at the boundary of the layers.

Use for the production of bimetals explosion welding method based on the pulsed mechanical interaction of layers of intelligent metals. The main advantage of explosion welding is that this method can make the connection of metals of practically any combination [4].

The advantages of this method also include the possibility of obtaining large bimetallic sheets without subsequent rolling. By explosion welding, sheets of practically any thickness can be clad. Compared with the cladding, the required thickness of the cladding protective layer is drastically reduced due to its guaranteed value in explosion welding. A positive economic factor is the fact that sheet steel used for cladding is 2-3 times cheaper than more alloyed thin wire or tape used for surfacing. However, with this method of cladding, there are also disadvantages:

• specially equipped landfills are required, occupying a large area and very remote from the metallurgical plant;

• seasonality of the landfill, which complicates the timely execution of orders;

• a large amount of cladding material is consumed due to waste and breaking off at the explosion of the hanging parts of the plates being welded;

• during the subsequent rolling of a bimetallic billet obtained by explosion welding, as in the casting method, bending of the strip during rolling, warping during cooling, the need for etching.

Operational loading conditions. Bimetallic materials are used in products that are axisymmetric structures (reactors, autoclaves, heat exchangers, distillation columns, pipelines, etc.) although it is possible to use them in the manufacture of other structures (blades of hydroturbine impellers, tube plates, flanges, etc.). The wall thickness of clad parts is 8–300 mm with a layer thickness ratio of 0.05-0.25, the operating temperature is within 255-700 K and the working pressure (for vessels) is 1.0 h - 5.0 MPa and more. The thickness of the plating layers is determined by the aggressiveness of the environment, the service life of the vessel and economic considerations.

The high pressure vessels and pipelines operating on VVER are subjected to different types of fatigue-related loads, which are associated with voltage, start-up and shutdown conditions, power fluctuations, emergency shutdowns of a reactor or turbine, and hydraulic tests. Such cyclic loading can cause the growth of defects, which can accelerate even more if it gets into the growing defect of the reactor water [1].

It is also necessary to take into account that the deposited reactor vessel is loaded with static stresses from pressure, thermal stresses caused by stationary temperature differences, various thermal expansion coefficients, as well as with increased frequencies under the influence of hydrodynamic forces, mixing coolant flows of various temperatures, mechanical vibrations, etc. The metal is also exposed to residual stresses (welding and due to technological deformations in the manufacture and installation of local plastic deformations in areas of stress concentration from operational loads), determining the asymmetry of cyclic loading together with static stresses. If various low-frequency cycles are repeated dozens, hundreds of times during the operation of 30-40 years, then high-frequency loading is associated with hundreds of thousands and millions of cycles.

The process of fatigue damage consists of successive stages, the formation of fatigue cracks and its development. The resistance to destruction of materials under the combined action of cyclic loading and corrosive environment at each of these stages depends on a larger number of factors than in a neutral environment. These factors include the level of deformation, frequency and shape of cycles, temperature, surface condition, structure, residual stresses, etc.

The strength of bimetals under static loading. Determination of strength under static loading is one of the most accessible ways to assess the properties of structural materials. Despite limited information about their performance in difficult operating conditions, the determination of static characteristics is an indispensable requirement when choosing materials and designing engineering facilities. The behavior of the layer materials has certain specificity related to the difference in the properties of their components and the presence of inhomogeneous transition zones. At the same time, not only general levels of strength, but also features of the development of damage, a preferential tendency to failure, one or another indicators of plasticity, etc., become important.

Materials under static loading conditions, regardless of the method of preparation, can have high strength properties. Destruction in all cases occurs on the base metal, while no noticeable influence of residual and thermal stresses is observed due to their redistribution and partial relieving with the joint deformation of the components of bi-metals. As the treatment temperature increases, a decrease in the temporary resistance, yield strength, and tearing strength of the cladding layer with increasing ductility and toughness is observed.

Temperature influence. Temperature stresses are caused by the temperature difference within a certain structural element, the heterogeneity of linear expansion coefficients used in the practice of materials.

Resistance to thermal fatigue impacts is an essential characteristic of structural materials operating at elevated temperatures. This is especially important for materials with degenerate heterogeneity of properties in the joint zone, different heat conduction and temperature coefficients of linear expansion. Rapid heating and cooling lead to the emergence of sharp temperature gradients and high temporary and residual thermal stresses, and with repeated repetition - to the phenomena of thermal fatigue. Non-uniform stress - the deformed state in the connection zone of bimetallic materials can accelerate these processes [2].

The deformation of the samples as a result of the own sudden cooling of the metal in the temperature range of the test is the predominant factor. Therefore, the stresses additionally arising during heating and cooling of dissimilar materials, apparently, should not have a strong influence on the damage process, in particular, in the study of a bimetal with welding ∝=11.8·10-6, the thermal coefficient of linear expansion of which is even slightly lower than for pearlitic steels ∝=(16.7-17.3)·10-6 Additional thermal stresses are minimal here, while damage is greatest. The experiments described confirm the minor effect of residual stresses on the mechanical properties of bimetallic materials (at least in the field of plastic states). Apparently, the main reason for the activation of thermal fatigue damage is the heterogeneity of the structure of the compound, the presence of weak decarbonized zones in which cracks originate as a result of localization of deformation with a significant increase relative to the average level on the sample surface.

It is known from [2] that the resistance of bimetal to thermal fatigue substantially depends on the temperature range of its operation. The strength of the joint zone of austenitic and pearlitic steels at temperatures above 500-550 ° C is determined by the phenomena of creep, aging and diffusion.

CONCLUSION

The developed method of drying fruits allows to increase the yield of the finished product up to 30-32% or more, to improve the appearance of raisins, dried apricots and prunes by preserving the integrity of the berries, reducing the drying time of dried fruits to 96 hours instead of 10-30 days with the output of the finished product by 20- 25%.

The introduction of the developed drying technology based on the author's invention of the Republic of Kazakhstan No. 20923 "Method of drying grapes" will reduce the drying time by 2 times, increase the yield of the finished product to 30-32% with a residual moisture of 16-18%, improve the appearance of the finished product with preservation of taste inherent in the (natural product) fresh fruit.

Market prices today selling price of imported dried fruits: dried apricots 1600-3000 tg / kg; raisins from 1200-2000 tg / kg; The estimated selling price of domestic dried fruit is reduced: dried apricots to 600-800 tg / kg; raisins to 700-900 tg / kg. Domestic dried fruits will be 2-3 times cheaper than imported dried fruits and will be a branded product Made in Kazakhstan.

REFERENCES

1. Global Strategy on Diet, Physical Activity and Health. Resolution WHA.55.23 accepted session of World Health Assembly (WHA), World Health Organization, Geneva, 2013.

2. Dietary protein quality evaluation in human nutrition. Report of an FAO Expert Consultation. Food and agriculture organization of the United Nations Rome, 2013, Vol.9, pp. 52-57.
3. Ostrikov A.N., Skladchikova Yu.V., Sturova Ye.V. Resursosberegayushhaya texnologiya proizvodstva fruktovy'x chipsov [Resource-saving production technology of fruit chips]. *Materialy' II Mezhdunarodnoj nauchno-tekhnicheskoj konferencii "Novoe v texnologii i texnike pishhevy'x produktov*" [Materials of II International Scientific and Technical Conference "New in technology and food technology]. Voronezh, 2010, pp. 248-251.
4. Kamovnikov B.P., Malkov L.S. *Vakuum-sublimacionnaya sushka pishhevy'x produktov* [Vacuum freeze drying of food]. Moscow, Agropromizdat, 2010. 145 p.
5. Ushakova A. S. *Razrabotka kompleksnoj texnologii pererabotki sushenogo plodovo-yagodnogo syr'ya*: diss. ... kandidata texnicheskix nauk [Development of complex technology for processing dried fruit and berry raw materials: diss. ... Cand Tech. Sci., 2017, 154 p.
6. Mr Yang Hou Chen, Mr Peter Pschner Heat Transfer with the Speed of Light using Microwaves in Industrial Chemical Processes presented on AchemAsia, Beijing, China, 2013. 7 p.
7. Khazimov M.Zh., e.a. *Vliyanie texnologicheskix parametrov na process sushki i kachestvenny'e pokazateli produkta* [Influence of technological parameters on the drying process and quality indicators of the product] Trudy' *XIII Mezhdunarodnoj nauchno–prakticheskoj konferencii.* [Proc. XIII International Scientific and Practical Conference]. Novosibirsk, 2015, pp.48-51.
8. Ms Sabine Ambros, S.A.W. Bauer The Potential of the MicrowaveVacuum Technique in Drying of Probiotic and Starter Cultures / Ms Sabine Ambros, S.A.W. Bauer, Ulrich Kulozik, Petra Frst. Technische Universitt Mnchen, Xiamen, China, 2012. 13 p.
9. Roman Morschhuser, Matthias Krull Microwave-assisted continuous flow synthesis on industrial scale / Roman Morschhuser, Matthias Krull, Christoph Kayser, Cornelia Boberski, Ralf Bierbaum, Peter A. Pschner, Toma N. Glasnov, C. Oliver Kappe. Green Processing and Synthesis, V. 1, Issue 3, 2012, pp. 281–290.
10. Bennamoun L., Belhamri A. Numerical simulation of drying under variable external conditions: Application to solar drying of seedless grapes. Journal of Food Engineering, 2006, Vol. 76, pp. 179-187.
11. Tochanov M.T., e.a. *Sposob sushki vinograda* [Method for drying grapes]. Patent RK, no20923, 2009.
12. George Mateljan Foundation: The World's Healthiest Foods: Raisins. Available at: http://www.whfoods.com/genpage.php?tname=foodspice&dbid=33 (accessed Jan 2008).
13. Abzalova D., Myrzaliev D., Duissebaev Sh., Aktayeva U., Rivkina T. Study of Protective Properties of Coverings on the Basis of the Epoxy Novolak Xylitan Block Copolymer (ENBCx) Of The Cold Mode of Solidification. Industrial Technology and Engineering, 2018, No. 2(27), pp. 5-14.