

Technology and equipment of thermoplastic hardening

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Abstract. Strain hardening is one of the simplest and effective means of adding fatigue strength to an alloy. Widely known strain hardening methods deform alloys by solid elements. Such mechanism is poorly suited for alloys that are operated at high temperatures. In this case, the positive effect is weakened. The reason lies in the relaxation processes that return the alloy to its original state. The stronger the plastic deformation is, the faster this process proceeds. The paper presents the technology and equipment of thermoplastic hardening, which makes it possible to increase the fatigue strength without significant plastic deformation. The effect of thermoplastic hardening persists for a long time. Due to this, the method is well suited for the turbine blades.

1. Introduction

Aircraft engineering uses gas turbine engines widely. The most important part of the engine is the first stage blade. It operates at temperatures of 550...600° C under conditions of cyclic loads and erosion [1-4]. The blade is made of a heat resistant alloy and further strengthened. Traditional methods of work hardening increase the fatigue strength of the blades by 30 ... 40 %; the temper of the metal about 20...40 % [5, 6]. But the fatigue strength from high operating temperatures quickly returns to its original state [7, 8]. This circumstance makes traditional hardening methods ineffective in this case. The reason for the low efficiency is as follows. It is known that work hardening creates a dislocation stopper for other dislocations [9, 10]. The dislocations pile up against each other and can become intertwined. This dislocation entanglement prevents any further permanent deformation of that particular grain, without the use significantly greater energy. This greatly increases the strength of the material under any subsequent loading. However, the problem lies in the fact that high operating temperatures lead to high mobility of grains, destroying the dislocation stopper. This phenomenon is called relaxation of metal. And the higher the temper of the metal, the faster the relaxation process.

Thermoplastic hardening increases fatigue strength in a fundamentally different way. The dislocation barrier is created by residual compressive stresses. The temper of the metal is very low: about 0.5 %. This allows one to increase the fatigue strength to 80 % and, more importantly, to keep it in the period of operation [11, 12].

2. Hardening mechanism

The mechanism of thermoplastic hardening (TPH) is as follows [13]. The part is heated to a certain temperature, depending on the physical properties of the alloy (for nickel alloy blades about 75° C). Then it warms up to the full depth for a certain time, after which it is sharply cooled by water. Cooling should be sprayed under high pressure (about 0.5 MPa). This is necessary to remove the steam jacket



and more efficient heat dissipation. As a result of the sharp temperature difference between the surface and the base of the part, strains that stretch the surface layer arise. In this stretched state, the surface layer freezes. Then the base layer of the alloy begins to cool, squeezing, at the same time, the surface. Compressive residual stresses are created. These stresses create an obstacle for the exit of dislocations to the surface of the part. As a result, dislocations intertwine below the surface, as described above, and increase fatigue strength. The process of thermoplastic hardening differs from the quenching process in that neither the phase nor the structural state of the alloy changes as a result of heating. In addition, residual stresses, which are undesirable during quenching, play a basic role in TPH.

3. Equipment

A method of thermoplastic hardening can be implemented in a plant as shown in figure 1. The installation for thermoplastic work hardening works as follows [14].

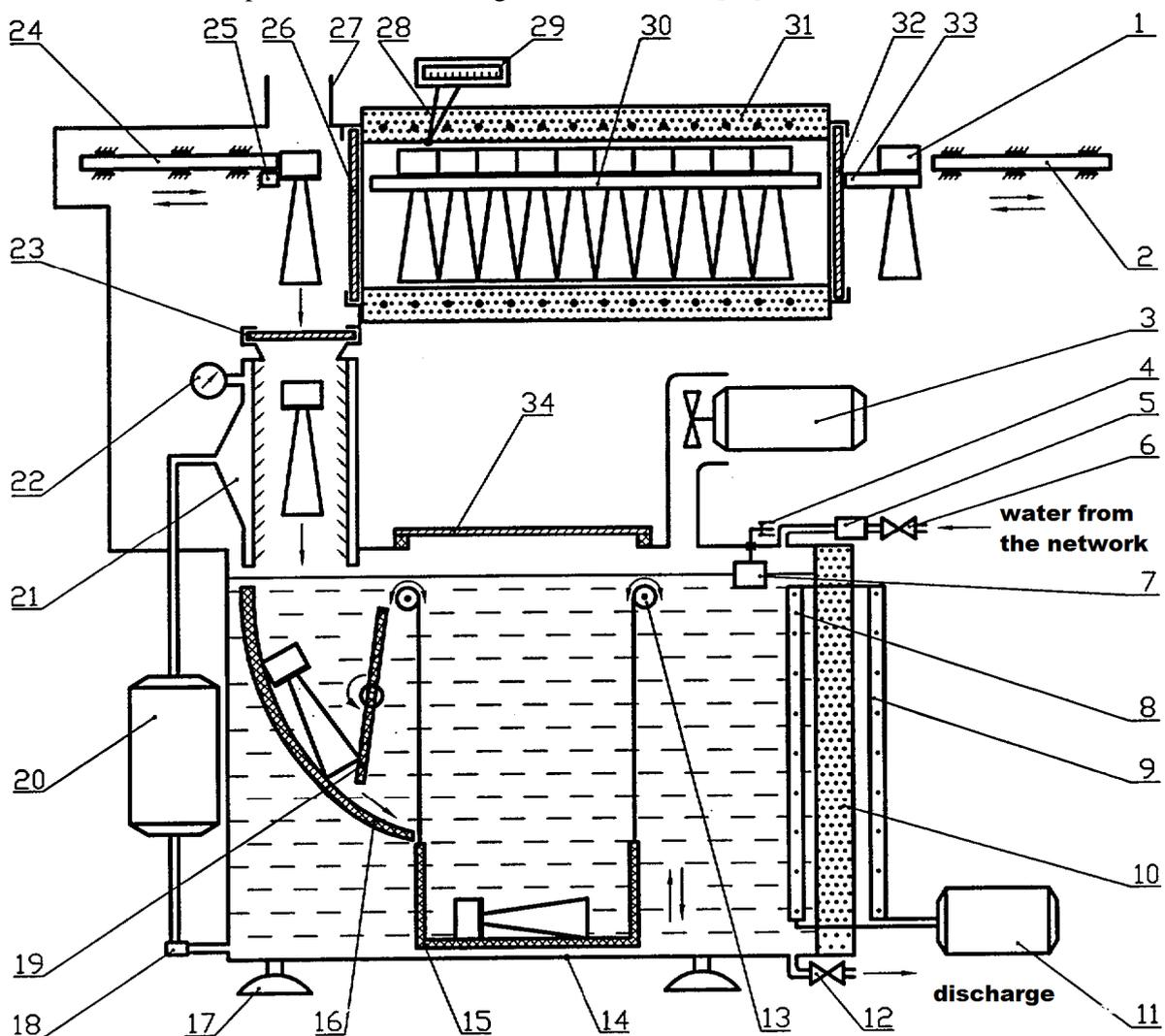


Figure 1. The design of the thermoplastic hardening plant: 1 – the part; 2 – the pusher; 3 – the fan; 4 – the limit switch; 5 – the filter; 6, 12 – the crane; 7 – the float; 8 – evaporator; 9 – condenser; 10 – thermal insulation; 11 – compressor; 13 – block; 14 – capacity; 15 – container; 16 – elastic slip; 17, 18 – a strainer; 19 – an elastic pusher; 20 – a high-pressure pump; 21 – an annular sprayer; 22 – a manometer; 23 – a gate valve; 24 – a grip; 25 – fixed stop; 26, 32 – gate valve; 27 – branch pipe; 28 – thermocouple; 29 – temperature relay; 30, 33 – guide; 31 – electric furnace; 34 – the hatch cover.

The part 1 slips from the receiver to the rails 33. The pusher 2, with the latch 32 open, moves the part on the guide 30 inside the furnace 31, after which the valve 32 closes. The electric furnace is equipped with a thermocouple 28 and a temperature relay 29. When the desired temperature is reached, the valve 26 automatically opens and the workpiece 24 moves to a fixed stop 25. The part is then released from the gripper 24 and falls freely under its own weight. This closes the valve 26 and opens the gate 23 at the entrance to the annular sprayer 21. The annular sprayer 21, during the free fall of the part, supplies coolant from the tank 14 through the filter 18 with a high-pressure pump 20. The coolant pressure is 0.8...0.1 MPa and is controlled automatically. The manometer 22 serves to visually monitor the pressure of the cooling liquid. To supply the coolant to the ring sprayer 21, a complex consisting of a compressor, a receiver, a pipeline and a shut-off valve and a control system can be used instead of a high-pressure pump 20.

The old sprayer design (figure 2a) was unregulated. The new sprayer design (figure 2b) is a hollow ring that allows evenly cooling all surfaces of the part. In the ring sprayer 21, the openings are arranged in such a way that the coolant jets retard the movement of the part and knock off the steam jacket. In order to prevent steam impact, in the ring sprayer, a discharge pipe is used 27. The angle of inclination of the jets in the ring sprayer is from 0 to 45° C and is determined in accordance with the size and configuration of the part by empirical testing. Hardening in the ring sprayer 21 with the free falling of the part allows to strengthen all the surfaces of the part more qualitatively and evenly due to the free access of coolant jets to all surfaces of the part and higher pressure. The process of thermoplastic hardening is very fast-moving and is no more than 0.03...0.05 sec. [11].

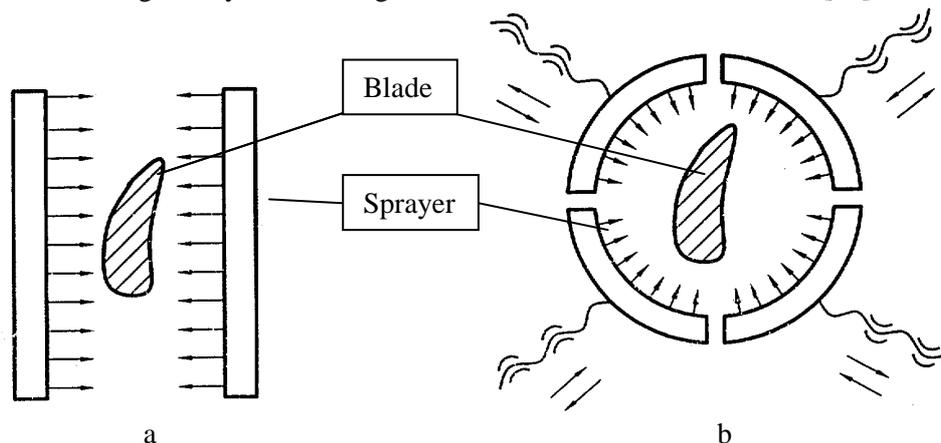


Figure 2. The design of the sprayers: a – old sprayer design.; b – new sprayer design.

The part after treatment during the free fall inside the annular sprayer 21 falls on the elastic slip 16, after which the elastic pusher 19 moves to the container 15. In this container, the final cooling of the part takes place. Then the part in the container with the help of blocks 13 automatically rises to the cover of the hatch 34. The hatch cover is also automatically opened. The part is evacuated by the operator, after which the container 15 is lowered down and the cover of the hatch 34 is closed. This completes the treatment cycle of the part. For the closed cycle of the process is a system for filtering, cooling and controlling the level of the cooling liquid. It consists of a tap 6 and a filter 5, a float 7 and limit switches 4, while automatically maintaining the required level of coolant. The filter 18 installed at the inlet of the high pressure pump 20 prevents contamination of the coolant when fed to the ring sprayer 21. To cool the liquid, is a fan 3 and a cryogenic unit consisting of a compressor 11, an evaporator 8 and a condenser 9 separated by a thermal insulation 10. However, the work of a single fan 3 may be sufficient.

After a certain number of treatment cycles, the spent coolant is drained through the tap 12 and updated from the network through the tap 6 and the filter 5. To prevent vibration of the installation, four vibra-supports 17 serve.

4. Conclusion

The authors of the article presented a method of thermoplastic hardening. The physical principle of it, which differs from other methods of hardening, is shown. The design of an installation for thermoplastic hardening of blades is demonstrated. It is characterized by high productivity and quality processing. The method of thermoplastic hardening is best suited for parts operating at high temperatures (turbine blades, discs, etc.), since it forms a more stable dislocation stopper. The dislocation stopper allows counteracting cyclic loads, thereby increasing the durability of the parts. For example, the durability of the first stage blades of gas turbine engines subjected to thermoplastic hardening is at least 12.000 hours of operation. This time is enough to achieve a planned repair. The viability of the blades can be prolonged by repeating of the treatment process.

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