Experience in the application of the non-destructive method of acoustic emission in the production of titanium billets and products of transport engineering

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Abstract. The article discusses the issue of using the non-destructive method of acoustic emission at the stage of blank production. So, due to the violation of the heat treatment modes, various defects are formed in the starting material, which affects the operational properties of the finished products. To eliminate this problem, the stages of production of titanium blanks and products of transport engineering were studied, such as: heat and mechanical treatment, ultrasonic quality control, determination of the level of mechanical properties and control of the structure. In the course of the research, a method of acoustic emission control was developed and tested. The experiment on setting the locations of defects was carried out on ingots of VT22 titanium alloy during cooling. The reliability of the developed method is confirmed by the existing method of ultrasonic flaw detection. It has been established that this method can be effectively used to control workpieces and machined workpieces for the manufacture of particularly critical mirrors for searching for inhomogeneous inclusions and increasing the efficiency of the technological process by eliminating machining of VT1-0 titanium surfaces with inhomogeneous inclusions. In addition, this method can be used to search for defects commensurate with the grain size of the ingot, as well as significantly smaller sizes.

1. Introduction

Violation of the heat treatment regimes can lead to the formation of various defects in the starting material, which affects the performance properties of the finished products. An analysis of the
application of the acoustic emission (AE) method for identifying external and internal defects in the material under static, dynamic and cyclic loading showed that the physical essence of the method allows it to be used to assess the quality of initial blanks, as well as to predict their mechanical and operational properties. Studies show that the radiation energy of an acoustic signal during loading presumably consists of two parts: the energy released during the course of plastic deformation and relaxation processes, and the energy released during the formation and development of a defect (crack) in a controlled object.

2. Application of titanium alloys in transport engineering
In 2005, the Titanium Corporation published the following estimate of titanium consumption in the world: about 7% of titanium is used in mechanical engineering in various fields, including transport (figure 1) [1].

Domestic manufacturers produce a wide range of stamped forgings of various configurations and purposes. These are structural products for aircraft (fuselage, landing gear, general purpose), rotary (disks, blades, shafts), etc. (figure 2).

![Airplane A380](image1)

Figure 1. Airplane A380.

At the production stage, the blanks are subjected to heat and mechanical treatment, ultrasonic quality control, determination of the level of mechanical properties and control of the structure. All these operations are necessary to ensure the high quality of the products sold, however, control methods are often laborious. The question of finding and choosing the optimal (universal) control method that allows it to be introduced into existing production processes remains open to this day [3].

![Titanium die forging](image2)

Figure 2. Titanium die forging.
3. Technique of experimental research

3.1. Inspection of original blanks

As part of the experimental work in the process of cooling ingots of titanium alloy VT22, AE sensors were installed and defects were located (figure 4). The experimental research was carried out using the equipment of the Center for Collective Use "Center for Materials Research" BSTU "VOENMEKH" named after D.F. Ustinov.

According to the results of the experimental study, the ingots were controlled by the existing method of ultrasonic flaw detection, which showed the reliability of the data obtained by the method of acoustic emission (figure 5) [2].

![Figure 3. Types of titanium billet inspection. a) visual, b) ultrasonic.](image)

![Figure 5. Illustration of acoustic emission sensors.](image)
Figure 4. Installation of acoustic emission sensors on an ingot of titanium alloy VT22 and data collection using a special software and hardware complex. a - interpretation of the detection of a defect (location) in the software and hardware complex; b - installation of acoustic emission sensors on an ingot made of titanium alloy VT22 and collection of acoustic emission data.

Figure 5. Detection of a defect in an ingot of titanium alloy VT22 after ultrasonic flaw detection and machining of the ingot. a - a scheme for searching for coordinates in a linear object by the acoustic emission method, b - a defect detected in an ingot of titanium alloy VT22.

The choice of the type of antenna is always based on the assessment of the geometry of the object as a whole and/or the geometry of its individual parts. Let us explain with examples: if you need to examine a pipe (and a cylindrical object with a length-to-diameter ratio of 10:1 or more can be considered a pipe), then you need to select the "For locating linear objects" type. With a linear type of antenna, the sensors are arranged in a chain, one after the other. The distance between two adjacent
sensors is limited by signal attenuation. Locations are calculated only for two adjacent sensors. The disadvantage of locating linear objects is that the program will only calculate the position of the section of the cylindrical object in which the sound source was located, but at what point of this section perpendicular to the pipe axis the desired sound source was located, there will be no answer.

You also need to take into account the additional measurement error arising from the fact that we simplify the surface of the cylinder to a one-dimensional linear object. To locate linear objects, it is necessary to install at least 2 sensors. For all other antennas, the minimum required is the presence of an arbitrary triangle of three sensors. Locating by triangles gives the coordinates of the point at which the sound wave was generated. If your object is a flat sheet of some material, then select the "For locating planar objects" type. With the planar type of antenna, the sensors are located on the plane in an arbitrary way. Locations are calculated for any triangle formed by sensors. If you need to find the coordinates of sound sources on a cylindrical surface, you can use two types of antennas: "For locating on a cylinder sweep" and "For locating on a cylinder surface". Flat Pattern is a 2D representation of the surface of a cylinder, and Surface is a 3D representation of the surface of a cylinder. The "Sweep" type differs from the planar one by the presence of calculation of locations "through the seam" of the sweep of the cylinder of the controlled object. If the controlled object is a flat round bottom, then select the "For locating on the bottom" type. With the "Bottom" type, the sensors are located on a plane along a circle, the locations are also calculated for any triangle formed by the sensors. If the name of the antenna type includes the words "on the surface ...", then this means the use of a three-dimensional model of the corresponding surface of the object. For 3D surface models, locating algorithms are used that take into account the curvature of the surface. To search for locations on spherical vessels, the type "For location on the surface of a sphere" is used - a three-dimensional representation of the sphere. To search for locations on the lids of cylindrical vessels, use the "For location on the surface of a sphere segment" type - a three-dimensional representation of a sphere segment. The "Data acquisition without locating" type is used in cases when it is only necessary to obtain data on the AE impulses without searching for locations. Thus, the antenna type specifies the type of locating algorithms that will be used to find the coordinates of locations and the type of object image that will be drawn on the screen for The most important engineering task in the manufacture of mirror blanks from titanium alloy VT1-0 is the detection at an early stage of inclusions in the material, which during final machining can lead to the impossibility of obtaining a surface for sintering (figure 6).

The AE method allows you to quickly determine the location of the defect in the workpiece and exclude the possibility of its further machining [4, 5].

4. Conclusions
As a result of the acoustic emission control under thermal loading of the ingot, the sources of acoustic emission in the ingot were identified, having the following coordinates along the length: along X - 0.79; on Y - 0.00; for Z - 0.50; at the end, at X - 0.00; on Y - 0.19; on Z - 0.00. When the ingot cools down, the acoustic emission method can be used to search for defects commensurate with the ingot grain size, as well as much smaller ones. In general, the technique will make it possible to assess the...
quality of the workpiece being manufactured. When applying the method of acoustic emission to control the ingot, it is possible to quickly determine the locations of locations, which, after cooling, can be checked by the existing method of ultrasonic flaw detection, thereby reducing the inspection time and automating the process, which will intensify the manufacturing technology. The AE method can be effectively used to control workpieces and machined workpieces for the manufacture of particularly critical mirrors to search for inhomogeneous inclusions and increase the efficiency of the technological process by eliminating machining of VT1-0 titanium surfaces with inhomogeneous inclusions.

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