Application of ultrasonic testing methods for quality assessment of workpieces and products manufactured by selective laser melting of nickel alloys

Bychenok V¹, Berkutov I², Fedorov A³, Prohorovich V², Tkacheva N¹, Logacheva A³, Logachev I³
1 Engineering-Design Center of Space-Systems Support (Scientific Institution), Russia, bychenok-vladimir@mail.ru
2 ITMO University, Russia, afedor62@yandex.ru
3 OAO Compozit, Russia, info@compozit-mv.ru

Abstract

The article presents the results of experimental studies of ultrasonic wave propagation parameters in workpieces and products manufactured by selective laser melting (SLM). Measured parameters were analyzed to evaluate the correlation with the characteristics of imperfections in the product structure. On the basis of the obtained data, an experimental facility and a draft quality control procedure was developed and tested. The specific requirements for and potential of ultrasonic testing methods are also considered. Reference blocks with artificial defects were developed accordingly to the obtained results.

1. Introduction

Selective laser melting is an additive manufacturing technique developed to create items by fusing and melting metallic powders together. SLM allows producing details of complex geometrical shapes from such materials like steels, aluminum-, nickel- and titanium-based alloys. The microstructure of samples mostly depends on characteristics of initial powder and modes of processing (1,2). Disturbances of process conditions during the manufacturing of workpieces and products by the SLM can lead to the formation of pores. Compared to welding process, thermal impact of laser additive manufacturing is more intense and prolonged. This factor causes the rise of residual stress level and induces formation of cracks(4). The presence of such defects leads to failures of vital parts of construction during the operational process.

2. Experiment

Samples of multicomponent nickel-based alloys manufactured by SLM®280 2.0 (“SLM Solutions”) were examined in order to verify the suitability of NDT methods and techniques for quality assessment of geometrically complex liquid-propellant rocket engine SLM-manufactured components.

The first type of samples is ring-shaped, manufactured by the laser engineered net shaping system from Inconel 718 alloy powder with particle size of 40 to 100 µm. This type of samples has such defects as stress cracks. The second type of samples was
obtained from Inconel 718 alloy powder with a particle size of 40 to 100 µm with special operating modes which provided various porous structure of a material (Fig.1).

Fig.1 SLM-manufactured samples: a) “ring” sample; b) “cube” sample

Ultrasonic wave propagation characteristics were investigated using the equipment consisting of longitudinal ultrasonic wave generation and acquisition unit; acoustical signals processing and display unit; set of dual and single beam contact through transmission configuration transducers with operating frequency 2.5, 5, 10 MHz. Also measurements were performed by the laser ultrasonic defectoscope UDL-2M with optoacoustic transducers. Laser ultrasonic equipment is used for precision measurements of acoustic pulse travel time at different frequencies (3). Ultrasonic wave propagation velocity and signal spectrum were recorded and analyzed. The Figure 2 shows the results of laser ultrasonic testing of the “cube” sample obtained with the use of dual probe with operating frequency 5 MHz.

Fig.2 results of laser ultrasonic testing of the “cube” sample obtained with the use of dual probe with operating frequency 5 MHz: a) A-scan; b) signal spectrum

3. Results

Acoustical representation of the “cube” sample demonstrates the presence of high-amplitude background noises. Scan analysis makes it possible to distinguish and locate the largest reflectors. The internal defects were detected in the “ring” samples and its occurrence depth was determined. The obtained results show a persistent dependence between the features of the internal structure of a SLM-manufactured products and the signal spectrum of the transmitted ultrasound.

The metallographic examination was conducted in order to confirm the obtained data on the internal structure of the samples (Fig.3). Reference blocks (RB) with artificial defects were developed accordingly to the acoustical characteristics anisotropy of the products manufactured by the SLM (Fig.4). These reference blocks allow detecting internal defects with an opening of 2 µm and a size of 0.8 mm.
The conducted researches provided the basis for developing the methodology of laser ultrasonic evaluation of SLM products. The developed laser ultrasonic testing technique showed high efficiency and productivity compared to other NDT methods. Also during the quality assessment of SLM products the attention should be paid on the differences of ultrasonic wave propagation velocity in different scanning directions. The analysis of the amplitude, velocity and spectrum of the signal makes it possible to evaluate the anisotropy of the properties, internal stresses (4) and defectiveness of the products manufactured by SLM.

Such SLM products characteristics and features as acceptable porosity level, flaws, required strength level and others should be specified for each monitored item.

The advantages of ultrasonic testing methods are:

- high-precision measurements of ultrasonic wave propagation velocity could be used for integral estimate of the monitored item properties and for compliance verification of operational mode and post-processing;
- the ability to detect defects with an opening of 2 μm;
- internal defects are detected in items with thickness up to 150 mm (;
- ease of use: low requirements for personnel qualification and the environmental conditions of the equipment location;
- cheap price and high productivity (compared to the tomography testing: the cost of an industrial X-ray tomography is $1 000 000; the cost of the laser ultrasonic defectoscope is $40 000).
References