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Investigation of coatings of austenitic steels produced by supersonic laser deposition

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ABSTRACT

The structure and properties of stainless austenitic steel coatings obtained by the supersonic laser deposition are studied in the paper. Implantation of the powder particles into the substrate surface and simultaneous plastic deformation at partial melting improved the mechanical properties of the coatings - tensile strength limit was 650 MPa and adhesion strength was 105 MPa.

It was shown that insufficient laser power leads to disruption of the deposition process stability and coating cracking. Surface temperature increase caused by laser heating above 1300 °C resulted in coating melting. The X-ray analysis showed that radiation intensifies the cold spray process and does not cause changes in the austenitic base structure.

1. Introduction

Nowadays austenitic stainless steels are widely used in nuclear, aerospace, chemical, food industries. Fe-Cr-Ni alloys containing a minimum of 10.5% chromium and up to 1.2% carbon are called stainless steels [1]. They are classified according to their microstructure and divided into five categories: austenitic, martensitic, ferritic, duplex, and precipitation hardening steel [2].

Alloy 316L is of greatest interest, it is often used due to its perfect mechanical properties, corrosion resistance, fatigue features and biocompatibility. These characteristics guarantee long service life of medical instruments [3,4]. In recent decades, the alloy has been used in surgery implants, in particular in spherical femoral head orthopedic field, as the skull plates, spinal implants, coronary heart stents, and dental implants [5–10]. The ductility, weldability and reasonable cost of this alloy is better in comparison with other metallic biomaterials [11].

Today, there is a large number of production methods, in particular powdered stainless steel implants [12]. Due to developing methods of additive manufacturing [13], direct laser deposition [14], selective laser melting [15] and thermal treatment of products, data collection period [16] and manufacturing of metal products take a few minutes or even seconds. Having the same material characteristics, the resulting additive techniques are not inferior to conventional methods and sometimes even more preferable due to ultrafine-grain structure formation, that is provided by heat input of laser radiation and high-speed cooling.

International experience in manufacturing of multi-layer coatings and products from metal powders by cold supersonic spraying [17–21], including stainless steels [22] has been gained, and is used now along with a conventional method of heat treatment [23].

Another modern method of additive manufacturing is supersonic laser deposition, the idea of the method is to obtain a powder metal multi-layer coating on a substrate with the help of simultaneous laser action [24,25].

The key part of the method is the usage of De Laval nozzle to accelerate powder particles to supersonic velocity. A particle leaving a nozzle is not solid, but partially melting due to fiber laser heating. This method can be applied to a wide range of deposited materials and processed items. As soon as the technology is new, the issues related to the formation of structure and properties of multilayer coatings, stainless steel, produced by supersonic laser surfacing, are studied quite poorly.

The objective of this study is to investigate the structure, micro-hardness, roughness, ultimate tensile strength and adhesion strength of the coatings produced by the supersonic laser deposition.

2. Experiment description

The scheme of supersonic laser deposition system is represented in Fig. 1. A nitrogen flow is divided into two streams at pressure from 10 to 30 bar, one is delivered to the nozzle directly and the other is directed to a powder feeder.

As a result, the two streams are mixed and fed to a supersonic

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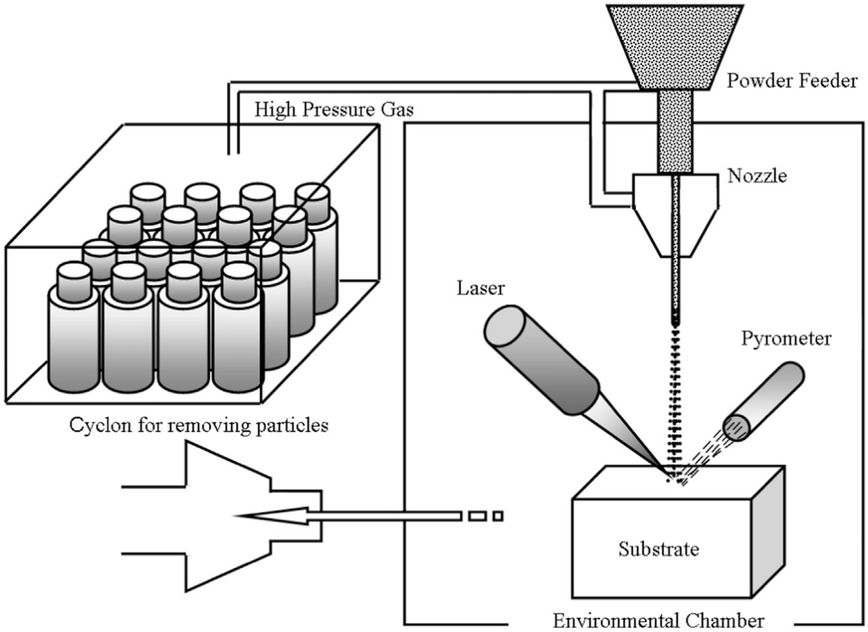

Fig. 1. The scheme of supersonic laser deposition system.

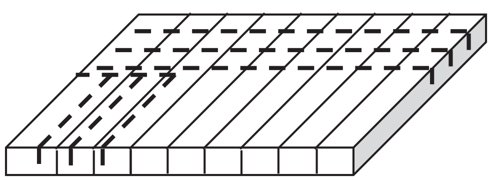

Fig. 2. Scheme of cutting of samples from the coating test on static stretching, transverse direction and longitudinal direction.

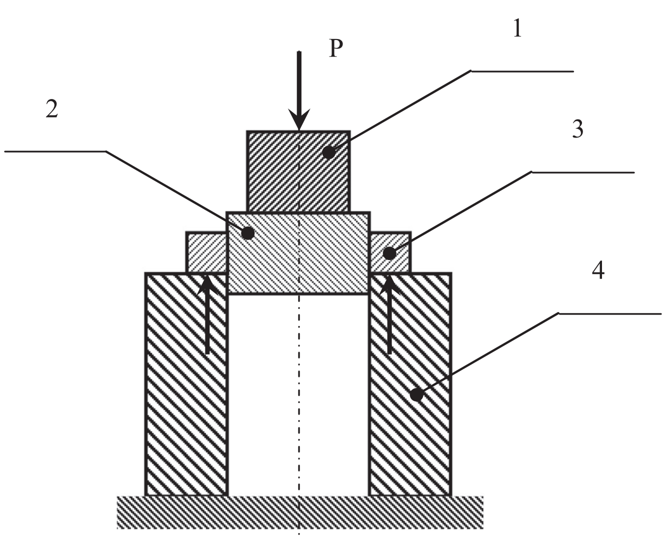

Fig. 3. Scheme of coating adhesion strength determining. 1 – punch, 2 cylindrical sample (substrate), 3 – coating, 4 – support ring, P – the load.

nozzle, where they are accelerated up to the supersonic speed. The jet of powder mixture leaves the nozzle and is directed towards the substrate. Powder particles hit the substrate surface with a simultaneous effect of the fiber laser beam at wavelength of 1070 nm and maximum power of 6 kW.

The deposition process is carried out at a constant temperature, controlled by a pyrometer, and the laser power is set periodically by automatic control system built into the software. A supersonic nozzle, a laser head and a fixed pyrometer are immobile during deposition and all the moving parts are robot-operated.

Spherical powder particles with a diameter of 10–50 µm are used for deposition. The chemical composition corresponds to 316L alloy brand [22]. The following preparations of samples were carried out to detect macro and microstructures: grinding, coarse and fine polishing, chemical etching of microsections by a special reagent. The reagent consists of copper sulfate (4 g), ethanol (100 ml), hydrochloric acid (50 ml). An automated Macro/Micro Durometer Tukon 2500 was used for micro-hardness measurements.

Measurements of surface roughness and surface profile of the samples was performed using the profiler Abris PM7. Static tensile test and determination of the adhesive strength of coatings were conducted using Electropuls E10000 model test systems. The samples were cut from the coating in the longitudinal and transverse directions with respect to the deposited metal layers (Fig. 2), they had rectangular shape and the aspect ratio of 5×20×2 mm.

A special device shown in the Fig. 3 was used to determine the adhesive strength of the coating.

Analysis of the metallographic sample surface structure is performed using universal inverted microscope Axio Observer Z1m. an Electron microscope image of the sample surface received at the workstation Auriga CrossBeam.

3. Results and discussion

Fig. 4 shows the steps of a supersonic laser deposition. The best mode for laser deposition corresponds to the image specified in Fig. 4 (c, g). The coating formation process at the supersonic laser deposition process is accompanied by simultaneous plastic deformation of the powder particles and the partial melting of the substrate surface. If the laser power is insufficient Fig. 4(a, e), then some detachment of powder particles is observed due to weak bounds in the coating.

Fig. 4(a, b) shows the bright elongated trail of loose powder material which extends from the laser spot on the surface of the deposited items. This happens due to lack of substrate heating.