Reducing the porosity of AISI 6150 steel by hot isostatic pressing

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Abstract. The article presents the results of experimental studies obtained by hot isostatic pressing of AISI 6150 steel. The aim of the work was to reduce the number of pores formed in the material. The influence of the HIP process on structure of AISI 6150 steel samples is investigated by means of X-ray computed tomography. The results of the experiments show that the majority of pores can be successfully densified by means of HIP. The experiments presented in this work were carried out on the basis of a HIP system located at Vladimir State University.

1. Introduction
Hot isostatic pressing (HIP) is a promising method of processing materials, which allows to improve the quality of critical parts through combined comprehensive impact on the workpiece of high pressures and temperatures [1].

Wide technological capabilities have determined the rapid spread of gas-static treatment, despite the relatively high cost and low productivity of gas thermostats. Experiments to study the possibility of healing macrodefects (both natural and artificially created) have convincingly confirmed the assumption that gas-static treatment under correctly selected conditions completely eliminates closed pores even of very large sizes (of the order of tens of millimeters) [2-4]. Thus, it was shown that the process of gas-static treatment opens up the possibility of a fairly effective impact on materials and thereby on their performance characteristics.

High-temperature gas-static treatment is an effective way of processing structural materials and their welded joints. As a result, the structure is homogenized in steel welded constructions, defects such as discontinuities are welded [5]. The ductility, toughness, fracture toughness increases, characteristics values dispersion decreases. In addition, dendrites turn into equiaxed austenic grains, the size and number of point inclusions, as well as the content of delta ferrite, decrease. The paper considers the possibility of using the technology of hot isostatic pressing to reduce the porosity of steels using the example of AISI 6150.

2. Hot isostatic pressing of steel
The process flow diagram includes the following steps. Samples are loaded into the working vessel of gas thermostat, the vessel is closed, after which a cyclic process begins, consisting in pumping out air and then purging the vessel with argon. After cleaning, argon is pumped into the vessel, a preliminary pressure rise occurs. Upon reaching the required pressure, the furnace is turned on and a controlled rise in temperature begins with simultaneous pumping of argon. Calculated values of temperature and
pressure are maintained by the system at a constant level throughout the entire exposure time. After exposure, samples are cooled at a given speed with a gradual decrease in pressure. The number and dimensions of parts processed in one cycle are limited only by the volume of useful space in vessel. The main technological parameters of the HIP installation used for the experiments are presented in table 1.

### Table 1. HIP technological parameters.

| Parameter                  | Value               |
|----------------------------|---------------------|
| Useful diameter            | 250 mm              |
| Useful height              | 350 mm              |
| Maximum filling mass       | up to 30kg          |
| Camera type                | cylindrical         |
| Working pressure           | up to 2500 bar      |
| Working temperature        | up to 2000 °C       |
| Temperature gradient       | less than 3 °C      |
| Heating / cooling speed    | controlled          |
| Pressure medium            | argon               |
| Furnace type               | graphite            |
| Work mode                  | manual,automatic    |

As samples for investigating the effectiveness of hot isostatic pressing operation, was used a blank of a hydraulic equipment part operating at a pressure of up to 50 MPa. Sample material - AISI 6150 steel (after welding operation). Parts containing the maximum number of defects were used as samples. The aim of this approach was to study the effectiveness of eliminating various types of defects by hot isostatic pressing. In accordance with the literature, the application of HIP processing effectively eliminates pores, internal cracks in material, which do not have an exit to surface, increase material isotropy, which is widely used for processing parts obtained by SLM method [6-8]. The elimination of pores and cracks emerging on surface is possible when the part is encapsulated in a shell that prevents pores from filling with the medium (argon) used to increase pressure in vessel, however, this operation was not considered in this work.

The HIP process took place with the following parameters: working temperature – 1000 °C, working pressure 1500 bar, rate of rise and decrease in temperature – 6 °C/min, holding time – 7 hours. The graph of HIP processing is shown in figure 1.
Figure 1. Graph of HIP processing cycle.

Figure 2 shows the surface of the processed sample formed by a section of plane of the sleeve welded joint. The image was obtained by x-ray tomography. The same area was considered before and after HIP, orientation of the part is saved. The image shows many pores in the weld area. These defects could be formed as a result of the escape of gas pores from the volume of material into the volume of weld pool, which did not reach the surface during hydrodynamic flows.

Defects of two types are observed in samples according to ISO 6520-1-2007 [9] classification – pores and imperfections, pores in obtained sample, in turn, can be divided into three subtypes. The first is randomly spherical gas pores corresponding to code 2013. These defects are located in central region of the weld and are found at the surface, the minimum diameter of these pores recorded by X-ray tomography is 0.35 mm, and the maximum diameter is up to 2 mm (up to 1.5 mm in orthogonal plane). The second subtype is tubular pores, fistulas corresponding to the code 2016. Defects of this type are located along the entire plane of the cross section of the welded joint area, the highest
concentration is found at the base of the seam. The characteristic dimensions of these defects are 0.37 mm wide and 1.7 mm long. These defects have an axisymmetric structure; in the orthogonal plane, the width corresponds to the width in figure plane. Pores emerging on the surface correspond to the code 2017, are less common, the characteristic diameter of the inscribed circle is about 1 mm. The last type of defect is lack of fusion. The location is characteristic at the root of the weld, correspond to code 403, 4013.

3. Conclusion
As a result of HIP treatment, a significant improvement in the structure of material is observed. The pore content drops significantly, 5.39% before treatment and 0.21% after HIP. The total percentage of pores after the hot isostatic pressing operation in the weld area is comparable to the porosity of the base material. The pore content in the initial sample outside the weld pool before and after treatment in HIP is shown in figure 2. The nature of pores distribution in weld is different from the porosity of base material. Round pores with a diameter of up to 2 mm are recorded, which were probably formed as a result of the union of gas cavities. The presence of lack of fusion, uneven penetration corresponding to codes 403, 4013 was not detected. In literature [10], this feature is described as porosity caused by a high content of dissolved hydrogen in metal, which prevents the final collapse of pores under the action of pressure in vessel. The porosity of this origin can be eliminated by a longer HIP cycle. When atmospheric gases are contained in pores, the pores cannot be eliminated during the HIP treatment. Pores with an exit to surface cannot be eliminated, as is observed in figure 2 (a pore with an exit to the surface remains unchanged).

References
[1] Bocanegra-Bernal M H 2004 Hot isostatic pressing (HIP) technology and its applications to metals and ceramics J. Mater. Sci.
[2] Tammas-Williams S, Withers P J, Todd I and Prangnell P B 2016 Porosity regrowth during heat treatment of hot isostatically pressed additively manufactured titanium components Scr. Mater.
[3] Kumar A, Bai Y, Eklund A and Williams C B 2017 Effects of Hot Isostatic Pressing on Copper Parts Fabricated via Binder Jetting Procedia Manuf.
[4] Essa K, Jamshidi P, Zou J, Attallah M M and Hassanin H 2018 Porosity control in 316L stainless steel using cold and hot isostatic pressing Mater. Des.
[5] Hsu K-T, Wang H-S, Chen H-G and Chen P-C 2016 Effects of the Hot Isostatic Pressing Process on Crack Healing of the Laser Repair-Welded CM247LC Superalloy Metals (Basel).
[6] Finfrock C B, Exil A, Carroll J D and Deibler L 2018 Effect of Hot Isostatic Pressing and Powder Feedstock on Porosity, Microstructure, and Mechanical Properties of Selective Laser Melted AISi10Mg Metallogr. Microstruct. Anal.
[7] Tillmann W, Schaak C, Nellesen J, Schaper M, Aydinöz M E and Hoyer K P 2017 Hot isostatic pressing of IN718 components manufactured by selective laser melting Addit. Manuf.
[8] Voznesenskaya A A, Kochuev D A, Chkalov R V, Kireev A V and Morozov V V 2020 Research of post-processing approaches for parts obtained by the method of selective laser melting Journal of Physics: Conference Series
[9] Ryabtsev I A, Rozert R, Turyk E and Ryabtsev I I 2017 Classification and characteristic of defects of deposited layers according to the international standard ISO 6520-1:2007 The Paton Welding Journal 9 44-49
[10] Kruk S I, Sagalevich V M, Gorokhov V Y and Lukin V I 1991 Application of gas-static treatment for improvement of the welded joints quality Welding International 11 8-11