Fundusze Europejskie Wiedza Edukacja Rozwój
Rzeczpospolita Polska
UNIWERSYTET TECHNOLOGICZNO-HUMANISTYCZNY im. Kazimierza Pułaskiego w Radomiu
Unia Europejska Europejski Fundusz Społeczny

Projekt pt.: **„Zintegrowany Program UTHRad.”,** POWR.03.05.00-00-Z105/17
współfinansowany ze środków Unii Europejskiej w ramach Europejskiego Funduszu Społecznego

Course title: Materials Engineering and Application

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LECTURE №5

Hot and cold isostatic pressing

The hot isostatic pressing is a progressive method combining molding and sintering processes. This method uses gas thermostats, it is universal and widely known in the practice of powder metallurgy. In modern facility, pressures up to 300 MPa and temperatures up to 2000 °C are achievable. The metallic welding capsules for powder are made from carbon or corrosion-resistant steel. For simple products, only steel capsules are used, while for complex shapes a separate metal-ceramic molds technology is applied. The quality of final products is affected not only by the technological parameters of hot isostatic pressing, but also by the quality of the capsules and the filling them with powder. Often, when capsules are filled with powder with vibrational compaction, the powder degassing and thorough sealing of the capsules are carried out. In the case of nanopowders, due to their large specific surface area and a tendency toward gas saturation, process of degassing is particularly important. As a result of fhe fundamental research in the field of condensed matter physics, the high-pressure and high-temperature technique has worked out the equipment with compressed gas as a working medium, which performs barothermic processing of large enough objects at significant exposure times. This technique is currently known as a hot isostatic pressing (HIP). However, the barothermal process is possible without the application of elevated temperatures. Thus, the cold isostatic pressing (CIP) was developed with application of a liquid medium.

The isostatic pressing requires high pressure vessels (HPV), where the pressured inert gas or liquid is applied either directly to the object being processed or to the

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surfaces of the capsule filled with powder. The problems of safety were solved by creating installations in which radial forces are taken by an all-forged steel cylinder pre-stressed by winding of a kilometer long, strong steel wire, and axial forces are transmitted by two movable covers to an external frame, which is also in a restressed state generated by wound wire. Negative compression stresses in the HPV produced by the wound wire are designed properly, so that the most critical components of the presses (HPV and the frame) are in a somewhat compressed state even when maximal pressure is inside the vessel.

Thanks to such a technical solution, the modern presses have a decreased weight and high fracture resistance characteristics under cyclic loads, and therefore they are very safe. Examples are shown in Figures 4.1 and 4.2.

Three parameters of barothermal treatment, namely, pressure, temperature and time, are selected so that the object would acquire its full density. Depending on the expected results of the process, the pressure and temperature in modern HIP equipment can reach 200 MPa and 2000 °C. The equipment has been developed for special applications that allows to obtain temperatures up to 3000 °C and pressures up to 300 MPa in the working volume.

Fig.4.1. Hot isostatic presses (HIP thermostats)

Fig. 4.2. Examples of old isostatic presses (hydrostats, CIP)

The hot isostatic pressing application scope

One of the important features of HIP technology is 10–15% decreased temperature necessary for sintering, as a consequence of the applied pressure. This circumstance is of considerable interest from the point of view of the technology of metals and ceramics, since in these materials, after barothermal treatment appears fine-grained crystalline structure, which largely determines their mechanical properties.

High thermal conductivity coefficient of the gas, which at high pressure has a density close to the density of water, is a major factor in the cooling process. This leads to two advantages: firstly, a noticeable decrease in the cooling process time, which determins the total cycle time, and secondly, the possibility to perform hardening at the end of the cycle in some cases (for example, when processing turbine blades and medical endoprostheses). The metal powders consolidation is the most common application of HIP. The reasons for this are that traditional casting techniques, such as ingot casting and continuous casting in particular, include rather long stages of ingot cooling, during which the atoms of the elements of the alloy diffuse from the outer layers of the ingots to the core. As a result, inhomogeneities of both the chemical composition and the microstructure of the ingots are formed, which complicates the further processing of the metal and

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decreases the physical and mechanical properties of the products. Powder metallurgy can solve this problem by converting molten metal into microscopic drops when it is dispersed.
In this case, the chain of technological operations for obtaining material from the powder includes four stages. First, a powder is formed by atomization of the melt in an inert medium. Then the powder is loaded into the capsule on a vibrating table to obtain the maximum loading density, after which the air from the capsule is removed and sealed. Next, cold isostatic pressing is carried out to increase the thermal conductivity of the powder, which occurs when the contact areas between the particles of the powder mass increase. In the last stage, the capsule is heated to a compacting temperature before being placed in the HIP.
The hot capsule minimizes loading on the HIP installation, where preliminary compaction is performed at a temperature of about 1150 °C and a pressure of 100 MPa. Since the metal further undergoes stamping and rolling, there is no need to achieve full density at this stage. Thus, a barothermal treatment requires rather short time. In the HIP technology, it is possible to obtain products of complex shape with numerous internal cavities and channels, as well as products with overall dimensions of the order of meters out of powdered steels. Notably, the obtained shape and dimensions are only slightly different from the desired finished ones. This way, the metal consumption of the workpieces is drastically decreased and the number of subsequent mechanical operations processing are eliminated. In large-sized products, the HIP technique allows to reduce the weight of the fabricated workpieces by up to 60%. The role of the HIP in removal of defects in cast metal billets is also noticeable.

The powder consolidation is one of the most promising areas of HIP applications. Another is the improvement of the metal castings. The latter is associated with the removal of internal defects, such as porosity, internal shrinkage, and inter-dendritic cracks that appeared during the solidification of the metal. The HIP eliminates these defects first by closing the void walls by creep and plastic deformation mechanisms, and then by diffusive welding of the pore surfaces brought into contact. Thus, the casting acquires a homogeneous, completely dense structure. In general, the properties of metal casting after HIP treatment become very similar to the properties of the objects obtained from plastic forming.
It is obvious, that barothermal treatment does not remove defects of the surface layer. Removal of this type of defect requires a capsule, which serves as a barrier to the compressed gas. It should also be noted that diffusion welding of the contacting walls of the former voids is impossible if the metal-metal contact is

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interrupted, for example, by an oxide film on the pore walls or residual gas in the pores, which cannot diffuse into the bulk of the material.

The HIP defects removal is currently used on an industrial scale for materials such as stainless steel, titanium and aluminum alloys, as well as nickel and cobalt superalloys. Moreover, the HIP treatment guarantees improved mechanical properties for less exotic materials products obtained by deformation. Aluminum casting after barothermic treatment also increases ductility and resistance to cyclic and thermal fracture.

The porosity removal in the near-surface layer of castings significantly improves the quality of the machined surface, provides better wear resistance and reduces friction, improves resistance to gas pressure at the weld points and reduces the number of centers that initiate corrosion. A significant number of critical components of racing car engines for Formula 1 (cylinders, cylinder blocks, cylinder heads) are necessarily subjected to hot isostatic pressing.

The HIP technique is very effective in restoring rotating turbine blades, which are the most loaded parts of a gas turbine due to high temperatures of the working medium and mechanical stresses. The HIP operations for restoring resource-bladed blades include welding, heat treatment, and coating. The purpose of these measures is to remove voids and cracks and to restore the mechanical characteristics of the blades to their original state. It should be noted that in this case, the HIP treatment also removes microcracks that appeared during reconditioning welding.

The HIP method allows also to obtain products from ceramic refractory materials such as Si_3N_4, SiC, TiB_2, B_4C, BN, and AlN.

Among the available technologies, the HIP most fully satisfies the conditions for the production of ceramic materials and products with close to theoretical density, minimal or complete absence of sintering additives, and at product formation temperatures noticeably lower compared to conventional methods.

In existing technological schemes, the HIP is applied for the production of ceramic parts during the formation of preforms. After removal of the plastic binder, the preforms are coated with glass powder and placed in a HIP unit. As the temperature rises, the glass softens, and forms a continuous coating on the surface of the ceramic billet, preventing the penetration of compressed gas into the ceramic body. Compaction is carried out at high gas pressure up to 200 MPa, and sintering temperatures are in the range of 1300 ÷ 1900 °C, depending on the material. During the cooling process, the glass capsule is destroyed, and its residues are removed by sandblasting.

For example, the practical implementation of the technological process with HIPs

include the manufacture of ceramic yarn feeders and knives for the textile industry, desulfurization nozzles, sandblasting devices and gas blasting, corrosion-resistant components for the chemical industry, medical prostheses, cutting tools, balls for hybrid bearings, pump parts, gas turbines, as well as diesel and gasoline internal combustion engines.
The HIPs are also used for sintering diamond tools with significantly higher resulting chemical and structural homogeneity, which determines the superiority of mechanical characteristics.
The decreased dispersion in the structure, improved mechanical properties of material after the HIP, and almost no limitation in the shape of parts, it all makes possible both to optimize components obtained using conventional technologies and to fabricate parts that cannot be manufactured by other, traditional methods. Due to these advantages, the range of applications of hot isostatic pressing is growing rapidly, and it is expected that within several years the volume of barothermal treatment will increase by 15 ÷ 20% annually in various areas.

In the Fig. 5.3 a-h, some examples of the application of hot isostatic pressing technology to obtain high-tech products are presented.

a

b

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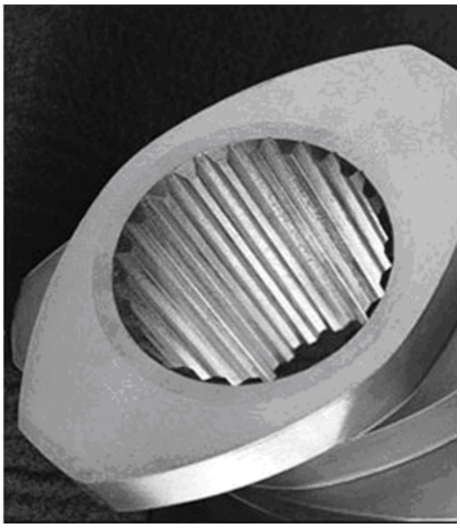

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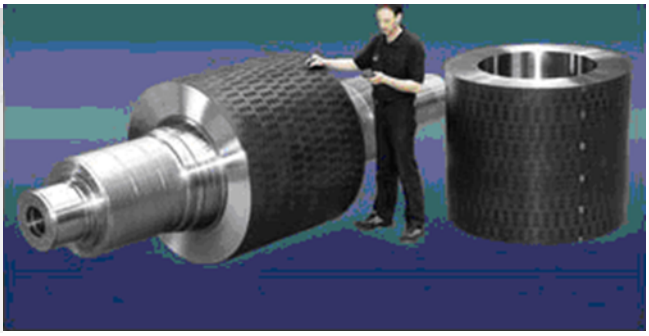

e f


g h

Fig. 5.4. Examples of the application of hot isostatic pressing technology to obtain high-tech products

a - sintering of powder parts and compaction of castings from titanium, heat-resistant alloys, aluminum and steel; b - HIP-soldering of parts; c - manufacturing of medical implants; d - diffusion connection of parts from various materials; e - sintering of parts from high-tech ceramics; f - cladding parts; g - manufacturing of processing tools; and h - manufacture of parts from heavy-duty ceramics.

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HIP is widely applied for production of heat-resistant materials, as follows:

- production of preformed graphite blanks;
- heavy metal processing;
- preliminary compaction of ceramics;
- production of fine ceramic elements;
- manufacture of metal filters;
- preliminary compaction of metal powders;
- production of preformed beryllium blanks;
- production of elements from rare earth metals;
- production of preformed graphite blanks;
- production of polytetrafluoroethylene compounds and teflon.

Summary of hot isostatic pressing principle

Hot isostatic pressing is a process in which the pressing is exposed to inert gas under high pressure at high temperature. Equal pressure in all directions leads to isotropic properties of bulk material. The application of high pressure ensures the final density of the material even at temperatures lower than those required by conventional sintering. The HIP makes it possible to form the microstructure of the material more accurately, and allows obtaining parts with unrivaled characteristics. The HIP is used for pressing sintered parts, for healing defects in castings, for diffusion welding of metals, and for the production of composite materials.
In the Fig. 5.5, there are examples of the use of HIP for pressing sintered parts: a - parts of complex shape with final density and isotropic properties are made of powders using HIP; b - conventionally sintered ceramic cutting inserts, ferrite rings of magnetic recording heads, etc.; c - parts from alloys on a titanium and nickel basis.

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a b

c

Fig. 5.5. The HIP sintered parts

Characterization of cold isostatic pressing

The Cold Isostatic Pressing (CIP) is a compacting process that can give additional strength and durability to a wide range of powder metals, ceramics, and plastic. The powder located in the container is placed inside the chamber with a liquid medium and is exposed to high pressure directly from all sides.
The cold isostatic pressing using for compacting powders, high quality and hardness of materials are achieved. The density and strength of the green material makes it possible to process it in a raw state. Compression of a homogeneous material during sintering reduces the cost of further processing.

The process of cold isostatic pressing is characterized by the possibility of manufacturing a wide range of parts of various fields of application; large parts with a large diameter and height; parts of complex shape, such as nozzle, pipe, filter, insulator, as shown in Fig. 5.6 and 5.7. The final products have a wide range of applications due to isotropic properties.

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Fig. 5.6. Ceramic products made by cold isostatic pressing technology: a - ceramic insulators; b - ceramic products for the metallurgical industry

Fig. 5.7. Examples of parts obtained by cold isostatic pressing

The isostatic presses are developed taking into account the need to meet individual customer requirements, in particular, to improve the process of compaction of powder materials, an elevated temperature pressure medium can be used. Auxiliary systems are selected from the conditions of compliance with specific parameters of the process.

The CIP methods are used to compact substances that for various reasons cannot be subjected to direct gas-conditioning at high temperature. In particular, this process is necessary for products made from powder materials, which are subsequently sintered under uniaxial compression, obtaining a distinguished direction in the volume of the material, achieving controlled anisotropy of properties.