The problem of capsule manufacturing for hot isostatic pressing

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Abstract. The article deals with new materials, problems of manufacturing capsules for gas-sealing, the use of various types of welding to improve productivity and improve the quality of welds.

Hot isostatic pressing (HIP) of metal powders is a complex technological process that includes the following main operations: obtaining powder of various grades and fractions; designing and manufacturing of capsules; filling powder into capsules; sealing capsules by welding; isostatic pressing of powders in capsules at high temperatures and pressures; removal of capsule residues; finishing operations (mechanical processing, heat treatment, etc.). for HIP, sprayed spherical powders from various metal alloys are most often used.

In the manufacture of gas-sealing capsules, various materials and welding methods can be used, including welding with wire under flux, in a protective gas environment with a melting and non-melting electrode, plasma, laser, etc.

General patterns of application of various types of welding are revealed. Methods for calculating welding modes for capsules of various thicknesses made of various materials have been developed.

Comparisons of various welding methods by performance and quality are made (Figure 1).

Studies of the influence of various types of welding on the shape and size of welds Figure 2-5.

Figure 1. Diagram of specific energy costs for various methods of single-pass welding of steel; $\xi_{\text{total}}$ – total specific energy; $\xi_{\text{blank}}$ – specific energy introduced into the workpiece.
The powder material is formed using special hermetic plastic shells-capsules that serve as the initial form for filling the powder and transmit high-temperature force influence of the medium to it. Capsules are thin-walled shells, similar in shape to pressed products [1]. Usually capsules are made of well-welded sheet steel, various grades or alloys.

The capsule, therefore, is not just a container for filling powder material, but is a forming tool of complex configuration, which requires tightness, vacuum density at high temperatures (up to 1250°C) and pressures (up to 200 MPa).

This circumstance essentially distinguishes the processes of isostatic pressing from the entire range of processes for metal processing by pressure.

The use of a plastically deformable capsule leads to the appearance of an inhomogeneous stress state in the powder material and its complex shape change in the conditions of HIP. Therefore, when improving existing and creating new technologies, it should be taken into account that the capsule should help to stabilize the deformation process, especially at the initial stage, when the density of the powder is still small, and loss of stability is possible ("collapse") capsules. This condition also prevents the use of too thin-walled capsules.

In General, the solution to the problem of designing and manufacturing capsules for isostatic pressing is the need to:

- accounting for variable parameters that establish the relationship between the rheological characteristics of the material of capsules and granules, the geometric parameters of capsules, technological allowances and conditions for preparing the material for pressing;
- research and rational choice of capsule material and wall thickness;
- development of special regimes of thermal and force effects on capsules with a granular material to ensure that they are regulated by the deformation;
- regulated redistribution of the rigidity of capsule elements to ensure their stage-directed deformation, which is especially important for obtaining products of complex shape and products made of powders with a reduced bulk density;
- development of rational technology for manufacturing capsules using not only optimal physical and mechanical properties of selected materials, but also new high-tech methods of welding capsule elements, for example, high-energy laser methods.

When manufacturing parts in sheet capsules with a constant wall thickness, various deviations from the original shape are possible in the form of ellipsis, warping, meniscus and loss of stability. It is possible to exclude the appearance of these deviations when using the so-called "directed deformation capsules", which have increased rigidity in a given direction, which can be achieved by increasing the thickness of the capsule elements or by introducing a non-deformable embedded element.

The optimal and defining feature of "directed deformation" capsules is that they provide selective deformation of the granulated material under HIP conditions with minimal movements of the capsule walls [2, 3].

At the same time, on the one hand, the materials and structures used in the capsules must ensure a stable shape change during the pressing process, on the other - have a fairly low deformation resistance and ensure that 100% of the density of the pressed material is reached.

Thus, the use of "directed deformation" capsules allows you to actively manage the process of forming complex products from granules, eliminate irregular geometry distortions, reduce allowances for machining and, as a result, reduce the consumption of scarce materials while reducing the volume of subsequent machining of the resulting products.

At present, it can be considered established that the character of forming capsules in the pressing process is influenced not only by the configuration and geometric parameters of capsules, but also by the metal materials used for their manufacture and the methods of Assembly (welding) technologies used.

The most technologically advanced materials for the manufacture of capsules and their working conditions as the deforming tool with HIP can be stainless steel with low carbon content, microalloying with aluminum and thermally stable microstructure, enhanced isotropy of the mechanical properties of
the material as the initial stages of deformation and welding fabrication of the hull of the capsule and subsequent steps of heating at HIP [4]. Promising materials for use in the manufacture of HIP capsules are a group of high-quality sheet steels of domestic production, non-deficit, widely used in various industries table 1.

Table 1. Mechanical properties of sheet steels

| Steel grade | Condition  | Mechanical property | Mechanical property |
|-------------|------------|---------------------|---------------------|
|             |            | Tensile strength, $\sigma$, MPa | Elongation, $\delta$, % |
| 08JUA       | hot-rolled | 270-410             | 25.0-28.0            |
|             | cold-rolled | 270-410             | 24.0-26.0            |
|             | normalized | 255-320             | 40.0-42.0            |
| 09G2S       | hot-rolled | 480-490             | 16.0-18.0            |
|             | cold-rolled | 295-410             | 24.0-25.0            |
| 20          | normalized | 390-490             | 26.0-28.0            |
| H18N9       | tempered   | 530-540             | 38.0-40.0            |
| H18N10T     | tempered   | 530-540             | 37.0-38.0            |

Pre-eutectoid low-carbon steels in their initial state have a ferrite structure with a small amount of cementite inclusions. In the process of their production at the domestic enterprises of special metallurgy, when rolling on multicellular mills, ferritic grains change shape and the steel gradually hardens. The development of steel hardening occurs with an increase in the degree of deformation, in which the generation of dislocations and their sliding is observed in ferritic grains. Due to the interaction of dislocations in intersecting sliding planes and blocking of sliding by obstacles (grain boundaries, inclusions, intersecting sliding planes) at this stage, the steel is strengthened.

Therefore, usually used thin-sheet cold-rolled pre-eutectoid steels have a very heterogeneous microstructure with a pronounced anisotropy of mechanical properties and an increased level of internal stress. Taking into account that during the manufacture of the capsule, its individual elements must still be subjected to sufficiently deep plastic deformation and fitting of the edges for welding, these structural defects in the material must either be removed or the possibility of their adverse effect reduced.

This is achieved by applying heat treatment operations-normalization, which is advisable after cutting the sheet into separate blanks for specific parts of the capsule body. The heat treatment operation-normalization, provides complete phase recrystallization of the steel structure with the formation of equiaxially softened ferrite grains (Figure 2).

**Figure 2.** Microstructure of pre-eutectoid steel 09G2C in various states: a-cold rolled, b-hot rolled, c-normalization, $\times200$. 
To manufacture sealed capsule bodies from sheet and deformed billets, it is necessary to weld them. Currently, numerous welding methods have been developed, which use external sources of heating of the products being welded.

Due to the deep elaboration of theoretical and technological issues of welding processes, the developed welding methods are widely used in industry. In connection with the active development of new technological installations with the possibility of creating highly concentrated energy flows, new welding methods based on the use of highly concentrated high-power laser radiation flows are also being widely used.

Laser welding belongs to the thermal class of welding processes, for which the production of an all-in-one joint is achieved by local melting of materials followed by crystallization of the melt. When the melt solidifies, strong chemical bonds are established between the atoms of the materials, corresponding to the nature of the materials being joined and the type of their crystal lattice.

The source of thermal energy for activating the surface of processed solid materials that cause deep structural recrystallization is the energy of laser radiation absorbed by the materials in the zone of laser beam impact [5].

Currently, laser welding is divided into three types: micro-welding (joining elements with a thickness or depth of penetration less than 100 microns), mini-welding (depth of penetration 0.1 -1.0 mm) and macro-welding (depth of penetration more than 1.0 mm). For the first two types of welding, which are most widely used in the industry, mainly pulsed lasers are used with an extremely successful combination of radiation properties necessary for local welding.

A certain amount of energy is required to obtain the cast zone required to form a weld with the specified dimensions. The higher the power density of the laser beam in the heating zone, the less time it takes to enter this energy and melt the required volume of metal, and the smaller the size of the zone of thermal influence. The combination of short pulses of radiation with a high concentration of energy in a small spot of irradiation is a great advantage of laser pulse welding.

The mechanism of formation of a weld under the influence of powerful continuous radiation (macroswark) is similar in many respects to the mechanism of formation during electron-beam welding and is characterized mainly by gas-dynamic phenomena in the melt zone. When welding with a powerful CO₂ laser, a deep vapor-gas channel is formed in the head of the bath, which allows welding various materials of large thickness with a narrow penetration zone (Figure 3-5).

![Figure 3. Macrostructure of welded joints of sheet steel 08YUA: a-laser welding, b-arc welding (×20)](image-url)

![Figure 4. Laser welding of 08X18N10T steel: cross section (×10)](image-url)
The formation of a vapor-gas channel causes a high efficiency of using the laser beam, which is repeatedly absorbed on the walls of the channel due to numerous re-reflections. Laser welding is the most common method for obtaining angular, overlapping and butt joints of thin-walled parts [6]. Good quality of connections is provided by laser beam welding of both thin parts with each other, and thin parts with massive ones. In this case, if the parts to be welded differ significantly in thickness, during the welding process, the laser beam is shifted to a massive part, which equalizes the temperature field and achieves uniform penetration of both parts. To reduce the difference in the conditions of heating and melting of such parts, the thickness of the massive part at the junction is reduced by making it a Burt, technological flanging or cutting.

In laser welding, the heating and melting of the metal occur so quickly that the deformation of the thin edge does not have time to occur before the metal solidifies. This allows you to weld a thin part with a massive lap. To do this, when melting a thin edge and in the area of a massive part under it, a common welding bath is formed. This can be done by welding along the edge of the hole in a thin part or along its perimeter.

When analyzing microstructures in the welding zone, numerous experiments have shown that, due to the high speed of the thermal cycle: "heating-melting-cooling" both directly in the zone of the weld metal melt and in the transition zone of thermal influence, a fine-grained highly dispersed structure is formed (Figure 6).

At the same time, the zone of thermal influence has a small size, it is formed without breaks and without high internal stresses [7], which ensures minimal deformation and obtaining, in General, a more equal-strength welded joint with the main material (Figure 7).
Figure 7. Microstructure of 12H18N10T steel welded joint: a-weld, b-transition zone, c-base metal, ×100.

Laser welding has a number of undeniable advantages, but, like all welding technologies, it has its drawbacks.

**Main advantages of laser welding:** possibility of welding a variety of materials; high accuracy and stability of the heating spot trajectory; the smallest weld size among all welding technologies; no heating of the near-seam zone, which results in minimal deformation of the welded parts; the absence of products of combustion and x-ray radiation; chemical purity of the welding process (additives, fluxes, electrodes are not used); possibility of welding in hard-to-reach places and at a great distance from the laser location; possibility of welding parts located behind transparent materials; quick changeover when switching to the production of a new product; high quality of welded joints.

**Main (at this time) disadvantages of laser welding:** unique characteristics of the laser beam as a processing tool and the insufficient knowledge of the physico-chemical regularities of influence of laser radiation on the kinetics of formation of the complex physico-mechanical properties of materials and their behavior in different operating conditions; fairly high cost of equipment, spare parts and components; lack of training of engineering and scientific specialists in the development of laser technologies and their practical use in industry.

However, the expansion of the range of scientific and technical problems to be solved, the practical use of effective high-energy laser technologies, the conduct of in-depth research on laser technologies and the training of highly qualified laser specialists will help to eliminate the existing shortcomings.

**Conclusions**

Thus, the theoretical and practical significance of the research is that the main conclusions and provisions can be applied in the practical implementation of the integral concept of the introduction of methods for selecting the capsule material, types of welding and methods for calculating welding modes to increase productivity and improve the quality of production of capsules for gas-testing.

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