Experience and references of Powder Metallurgy parts produced by HIP (Hot Isostatic Pressing) in offshore applications for O&G industry.

Experiências e referências de produtos fabricados por HIP (Prensagem isostática a quente) em aplicações na indústria Offshore de Óleo e Gás.

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Abstract

The hot isostatic pressing (HIP) of gas-atomized powders is today a fabrication method for steel components of simple and complex shapes. There are applications from steam turbines and boilers up to flanges, valve bodies and manifolds, in the offshore industry.

During the last couple of years, manifolds, very important equipments in the Offshore Oil & Gas Industry, have been produced by HIP-process and it has been a remarkable application of this method. The most recognized companies at this sector, from north Europe, USA, Latin America and recently Brazil, already see Powder Metallurgy (PM) parts as an alternative.

The advantages of this manufacturing method comparing to conventional techniques are, among others, refined microstructure, cleanliness, very low slag inclusion level, homogeneous material leading to isotropic properties, ease to perform ultrasonic inspection, near net or net shape design flexibility, low tooling costs and short series economy and delivery time. Those features allow optimizing mechanical properties and corrosion resistance of the selected alloy. Within the most used alloys, super duplex stainless steels and nickel alloys can be highlighted.

Hot Isostatic Pressed (HIPed) parts are made of metallic powder compressed under high pressure (approximately 1000 bar) and high temperature (between 1000 and 1200ºC). The manufacturing of components using powder as raw material allows very good control of the grain size and phase balance in the microstructure. This is possible due to the fast cooling of the small metal particles of powder, which avoids segregation, and also due to the isostatic pressing that assures the isotropic and non-directional microstructure.

Resumo

A prensagem isostatica a quente de pós metalicos atomizados a gas, representa hoje um eficiente método de fabricação para componentes em aço com formas simples ou complexas. As áreas de aplicação compreendem desde turbinas a vapor e caldeiras até componentes como flanges, corpos de válvula e manifolds na indústria Offshore.

Os manifolds, equipamentos muito importantes na indústria de Óleo e Gas, produzidos pelo processo HIP, se tornaram recentemente uma aplicação notável neste mercado. Grandes empresas deste setor do norte da Europa, dos Estados Unidos, da América Latina e recentemente também o Brasil, enxergam a metalurgia do pó como uma boa e confiável alternativa.

As vantagens deste método de fabricação, em relação aos métodos convencionais, são bom acabamento, baixo teor de inclusões, microestrutura homogênea e isotrópica, fácil inspeção por ultrassom, flexibilidade de design e produção Near-Net Shape, economia em tempo de entrega, etapas de acabamento e custo/benefício elevado para pequenas quantidades. Estas características

otimizam as propriedades mecânicas e a resistência a corrosão da liga selecionada. Dentre as ligas mais utilizadas, os aços inoxidáveis super duplex e as ligas de níquel são as mais relevantes.

As peças HIPadas são feitas a partir da compressão de um pó metálico da liga desejada em altas temperatura (entre 1000 e 1200ºC) e pressão (aproximadamente 1000 bar). A fabricação de componentes usando pós metálicos de alta qualidade permite um bom controle do tamanho de grão e da distribuição de fases na estrutura final. Isto é possível através do resfriamento rápido das particulas de metal que resultam no pó metálico, e também pela pressão isostática aplicada na peça.

Introduction

The HIP process has been used for the last fifty years as a successful alternative for common metallurgical fabrication methods, such as forging and casting, using high performance materials such as duplex and superduplex steels. Combining high purity metal powder with both high temperature and pressure, the result of HIPing process is a product with mechanical properties and corrosion resistance over many other available fabrication methods. (WESTERLUND, 2000) Therefore, demanding environments became interested on those products and all the advantages they can provide.

Turbines, boilers, centrifugal separators and many other parts represent the freedom of design of this PM technique. And when it comes to Oil & Gas industry, where high pressure and corrosive media are frequent, HIP products can be much more efficient, cost effective and reliable.

This paper presents information about the process, starting from the metal powder, until the final Near-net shaped product, a production concept that may save joining processes and machining steps. Usual defects and failures within corrosive environments are briefly presented as well, since they are frequent in oil exploration process and avoidable with HIP method.

In addition, an overview of the Oil & Gas market helps to identify the applications that need better quality products, and thus, have a growing demand for PM pieces, such as flanges, fittings, tees, valve bodies, manifolds, piping and pump components. References are presented as successful cases of PM-HIP technology within the O&G industry, especially for subsea and topside applications, together with tonnage, part description and production field, building the HIP products manufacturing history. Limitations of the manufacturing PM method will be described as well, allowing new customers to adapt their projects to the HIP technology.

HIP production

The HIP method requires metallic powder as raw material. The metal is melt in an electric furnace, and then refined in different steps like AOD converter, slag removal and ladle furnace. The difference starts at the solidification point. Through an orifice at the bottom of the ladle, the molten metal flows and, as soon as it gets out, the flux is exposed to a high gas flow, producing small spherical particles within a diameter range from 0-500µm. After particle size controlling, blending, homogenizing, inspection and approval of cleanliness the powder is stored in containers.

The produced powder is then put into a 3D CAD projected capsule, which is equivalent to a mould, built with TIG welded mild steel plate. (HEBEISEN, 2005) This capsule, also named “can”, is made of 2-3 mm thick metal sheet and about 10% larger than the final shape to compensate the shrinkage of HIP process, and has controlled chemical composition so there is no contamination of the main part. (HJORTH, 2007)

The capsule is filled with powder under vacuum, sealed and put into a chamber, where the high pressure and temperature will be applied. The chamber is closed; the air is removed and then filled with the pressure gas, which normally is argon.

HIPing a part stands for forming and compacting the powder in a high-temperature (approximately 1100ºC) and high-pressure (approximately 1000 bar) vessel. This situation provides isostatic pressing and compaction, due to diffusion bonding of the powder particles, which will imply in important differences in properties, comparing to the production by other methods.

The component is then heat treated and afterwards pickled, also removing the capsule. Normally the Near-Net-Shape component is ready to inspection; however an eventual machining step might be required. Non-destructive tests are applied before the final check to customer specifications. The figure 1 shows the steps of the HIP process.

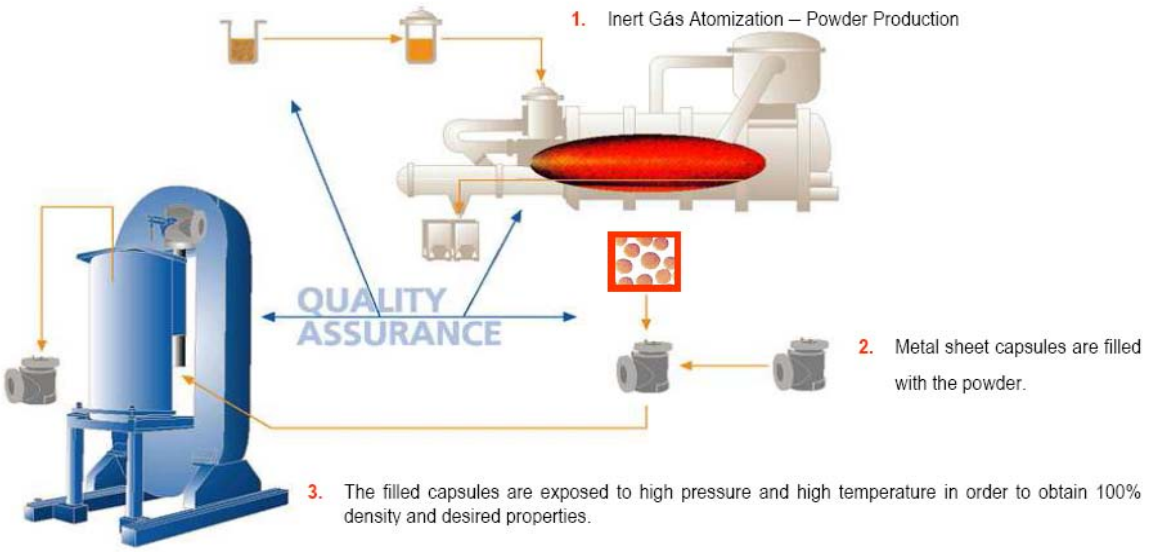


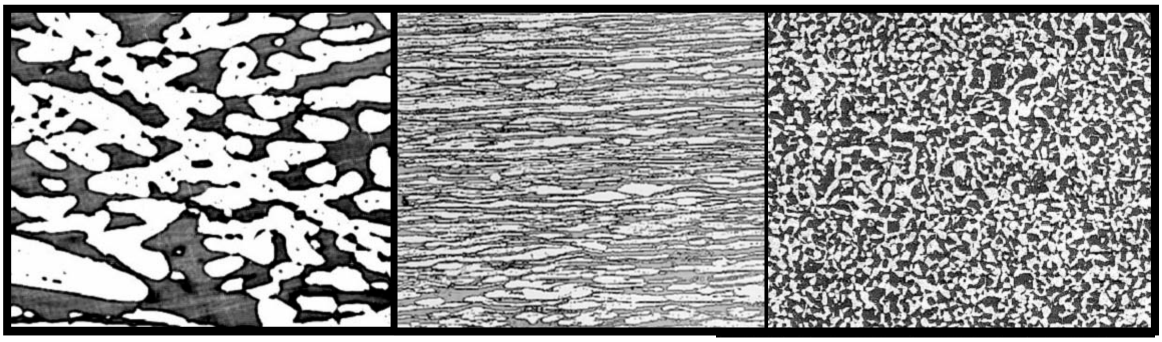
Figure 1 - Scheme of the steps of the HIP process performed by Sandvik Powdermet.

HIP features and properties

The PM technology enters the O&G industry as an alternative to others fabrication methods, such as casting and forging. Starting with the microstructure, which results from the basic characteristics of the process, HIP material shows fine grain size and homogeneous phase distribution. For example, in a duplex stainless steel, the austenitic grain size reaches with the HIP process approx. 20µm, which characterizes a refined structure, allied to the 15µm average Austenitic spacing size. (HJORTH, 2007) The figure 2 shows the microstructure for three fabrication methods, comparing phase distribution and grain size. The HIPed material has much more refined microstructure and grains are non-directionally oriented, in spite of what occurs in the other microstructures.

Since there is no melting of the metal during the process, the compressing of the spherical powder takes place through the whole component in all directions at the same time. Together with the isostatic pressure, the compaction is homogeneous and so is the resulting microstructure. Therefore, the mechanical properties are the same in all regions and directions of the component, even for complex designs with edges and small channels.

Controlled phase balance and absence of segregation characterizes the HIPed microstructure as well. Unlike the casting process, where the solidification starts from the mold walls, the HIP compaction deforms the powder plastically (ASM, 1998) and there is no relevant movement of the particles, thus the phases formed have no preferred orientation.



a **b**. **c**

Figure 2 - Typical Microstructures for Casted (a), Hot rolled (b) and HIPed (c) Duplex material with same magnification.

For any application, delivery time is often an important criteria, and HIPed material, through Near Net Shape concept, may offer advantages. Many components and modules fabricated for the Oil & Gas industry are combination of separated items and they are joined mostly through welding processes. Those joints are commonly regarded as weak points, especially in corrosive environments. The HIP method allows the manufacturing of large components with a reduced number of welds. For example, in subsea modules such as manifolds, the necessary welding is reduced in up to 70-80% (HEBEISEN, 2005). And it is important to mark that each weld or machining step adds production and inspection time, enlarging delivery time and so the costs.

The design freedom of HIP method allows, by constructing special high pressure capsules, to manufacture pieces with internal holes in more than one direction. Internal elbows and holes are possible to produce with HIP method, what would not be possible to produce from forged pieces or special casting methods, even with subsequent machining steps, which constrains project possibilities. Figure 3 shows an example of product project.

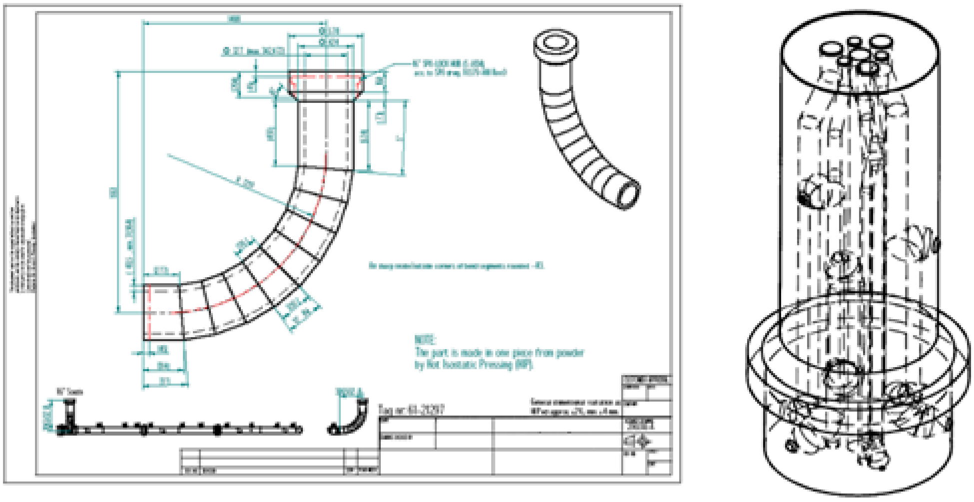


Figure 3 – Left: a HIP project drawing example, right: a swivel drawing showing internal elbows and holes.

O & G – Overall

The Oil & Gas Offshore industry is an important consumer of austenitic, duplex and super duplex stainless steels, for the use in top sides, subsea and downhole applications.

The subsea segment comprehend all the modules and equipments used in the oil exploration and production layed on the sea bottom, under water layers up to 2000m, for example in the Pre-Salt fields in Brazil. Manifolds, X-Trees, Well-heads and many other components are responsible to create the connection between the well (downhole) and the platform (Topside), controlling the production and the oil and gas flow.

According to the design codes for pressure vessels, there are reinforcement areas required at the nozzle area of a header (common subsea component in a X-mas Tree or wellhead). With the HIP technology is it possible to reinforce the outlet by making the wall thickness of the outlet on the manifold section thicker than the run pipe. To produce an outlet by the wrought conventional extrusion technique a thicker run pipe is always required. As a result the HIP technique will require less material and a lighter construction in comparison to wrought conventional extrusion. It is also possible to adjust the branch height and to integrate the flange without any critical welding needed and thus reducing the necessary testing and control of welds.

HISC

Hydrogen induced stress cracking, or generally known as hydrogen embrittlement, is a common failure mechanism in stainless steels subsea equipments exposed to cathodic protection. The DNV Recommended Practice DNV-RP-F112 (DNV, 2008) – Design of Duplex Stainless Steel Subsea Equipment Exposed to Cathodic Protection – discusses the issue of the Hydrogen embrittlement in subsea equipments, both design and material wise.

When dealing with HISC in DSS and SDSS, the cracks usually propagate through the ferrite, and the austenite acts like a barrier for this process (CASSAGNE, 2005). The main orientation is that an austenite spacing good enough to avoid the Hydrogen embrittlement should be less than 30 micrometers. If this value is higher and combined with directional microstructure, i.e. there’s no isotropy in the material, caused by unequal mechanical work (like forging, rolling, extrusion), the HISC potential is higher. Therefore, dealing with an isotropic material and refined grain size and small austenite spacing, provided by HIP method, there will be no problem regarding the direction of the stress applied in the part, and the design and project of the system will be much easier, when concerning to efforts and stresses.

Welding

Sometimes there are size limitations on the fabrication process of equipment, and even if the parts were produced by HIP method, a welding process is needed to join big parts, for example manifold parts. However, despite of having a different microstructure, HIPed parts can be welded with conventional welding methods and materials and the results have exceeded the acceptance criteria. Welding tests and comparison reports have been written in order to verify and guarantee good quality welds. (LARSSON, 2009)

Powdermet Experiences

Since 1998, more than 4000 ton of HIPed pieces for offshore industry were produced by Sandvik Powdermet. The most used grades are Duplex 22%Cr and 25% Cr (super duplex), Inconel 625 and 6Mo superaustenitic. From this total production, more than 90% were tested through NDE, such as Dye Penetrant and Ultrasonic and there was no defects at all.

Hubs

On the North Sea, there are subsea hubs produced by PM running on the fields Kristin, Dalia and Fram East on duplex and super duplex alloys. Features of HIPed material such as ease of UT inspectability, reduced delivery time and HISC avoidance were criteria when choosing PM technology for those exploration fields.

For applications involving a high number of connections, welded joints are largely used, and that increases the potential failure leaks. Since it is possible to save weldings using Near Net-shape products, PM technology is recognized as a good option for applications where joints are not desirable.

Manifolds

Manifolds are produced to net shape on the surfaces indicated. The only machining will be to prepare weld bevels for circumferential welds of header OD and sealing areas of connecting flanges. Manifolds sections are produced to an average length of 2,5 m and welded together to for a complete Manifold of required length. Typically, the PM HIPed part weight would range from 200 to 15 thousand kg. A hydro test is used as end user qualification testing to verify integrity of the whole manifold assembly. The figure 4.a) shows a Manifold part fabricated by HIP.

HIPed products offer isotropic material properties, lower weight potential, reduced amount of critical welding, shorter delivery time, design freedom, 10-20 % cost saving, which specially for high alloyed stainless steels, as duplex, super duplex or 6 Mo austenitic is very important. Also, because of the clean and fine microstructure, some parts are almost 100% ultrasonic inspected.

For the same reason, HIP technology is very welcome for Manifolds production. These subsea modules are responsible for controlling other modules and therefore the number of connections is high. As explained before, the more welded joints, the more failure potential, that is why HIPed pieces have been produced for this application. For example, in the fabrication of a part of a 14” Manifold for water injection in the Heidrun field, it was possible to reduce 85% the number of welds, producing the Manifold part in 4 different HIPed pieces.

It started in the North Sea’s Jade Field, year 2000, when a manifold system of 12” received 5 tons of HIPed material. Since then, manifold sections have been produced for offshore fields around the world, with diameter going from 8” up to 30”. The Shah Deniz Field, the largest gas field in Azerbaijan, received more than 70 tons of HIPed pieces in 2003 and more 12,5 tons in 2004.

Bended parts are also possible to manufacture via HIP process. There is the possibility of producing large or small radius bends with thick walls and accurate internal diameter, with the reliable properties and inspectability mentioned above, avoiding induction bending parts. Such design freedom for heavy pieces in special alloys is not achievable with other production methods (forging or casting) (ASM, 1998). Pieces like those ones were provided for Ekofisk oil field, in Norway, and for Rhum gas Field, in Scotland, together sum more than 70 tons of SDSS material.

Another example is the BP Rhum Gas Project, where manifolds, flanges, bulkheads and valve bodies were delivered, and some of those were tested at high pressures (1480 bar) and at different temperatures -50 / +120 ºC. Because of the sour environment of the application, super duplex grades were specified.

Figure 4 – a) A manifold part fabricated by HIP. b) A swivel fabricated by HIP.

Swivels

The HIP process also allows the manufacturing of large and complex components for subsea developments, such as multi-phase swivels used for FPSO (Floating Production Storage Offloading) weighing 5 to 16 tons in duplex stainless steel with intriguing inner cavities arrangement. These swivel components were designed, produced and delivered within 10 weeks. Since 2005, more than 40 swivels have been delivered. The powder is available from stock and the delivery time for most components are relatively short, comparing to the forged with machining steps alternative. The material properties are excellent and equal or better than a corresponding forged product thanks to the homogeneity of the material and its isotropy. Also, these components can be ultrasonically tested when produced from powder and HIP, while conventionally solidified material has a too coarse microstructure. Figure 4.b) shows a swivel fabricated by HIP.

It is possible to find HIPed swivels on fields on North Sea (Glitne, Geadon), Timor Sea (Bayu-undan), Brazil (Bijupira), Korea (Su Tu Den), Norway (Aasgard), Australia (Mutineer), Côte d'Ivoire (Baobab), Mauritania (Chinguetti) and many other places around the world, which make almost 240 tons of HIPed special material.

Other products

Barrel Casings and Hubs are other important parts produced by PM, For example, the project P 55 in Brazilian seas received almost 30 tons of material as Barrel Casings and on the Dalia field, in Angola, more than 40tons of Hubs.

Optimizing materials to produce components that are almost definitively shaped represent a consistent saving in weight and mechanical machining. A good example of this point is the Y-piece produced for the East Spar project, the first offshore gas field in Australia. If made with conventional methods of casting or forging this part, which has to work at 25 MPa, would have a weight of 3.5 tones with the necessary oversizing. Made with powders, the finished part weighs only 2 tones.

Complex designs, like wye-pieces represent an interesting opportunity for PM technology. It has already done on the fields Lobito and Tomboco (Angola) and Ormen Langen (Norway), providing almost 22 tons of SDSS alloyed pieces. The need of final machining in those cases was relatively low, as well as most of the HIPed parts. The images X and Y represent the complexity of internal design of a wye-piece and its final shape (piece used on Pazflor field).

Experience in Brazil

The powder metallurgy technique applied to Oil & Gas industry as HIPed pieces is also running in Brazil. Since 2001, over 63 tons of material were delivered from Powdermet, aiming not only the standard projects, but also the Pre-Salt one. Because of the extremely aggressive environment found in these deep-water fields, new technologies, together with special alloys such as duplex and super duplex stainless steels, are considered and HIPed material contributes to provide enhanced materials properties and reliability. For example, parts in super duplex stainless steel, used for subsea modules, were recently delivered for the P-55 project in Brazil.

Conclusions

The Oil & Gas industry is growing and new technologies for exploration and production are being developed. Subsea environment characteristics, such as corrosive media, high pressure and temperature, requires reliable materials such as duplex, super duplex stainless steels and nickel alloys.

Ensuring good properties of those materials is critical. Hot isostatic pressing appears as a cost effective and reliable solution, for special alloys and optimized properties. Homogeneous phase balance, refined grain and isotropic microstructure and low slag inclusion level, resulted from HIP process, are features that optimize alloy's properties. Freedom of design and reduced subsequent weld and machining steps provide Near-Net Shape products and therefore reduced costs and delivery time.

Many Oil & Gas companies have already proved HIP technology and over four thousand tons of HIPed material are installed in equipments for O&G production and exploration. Key applications include barrels, swivels, manifolds, hubs, flanges and complex shape pieces, in operation in North Sea, Gulf of Mexico and Brazil.

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