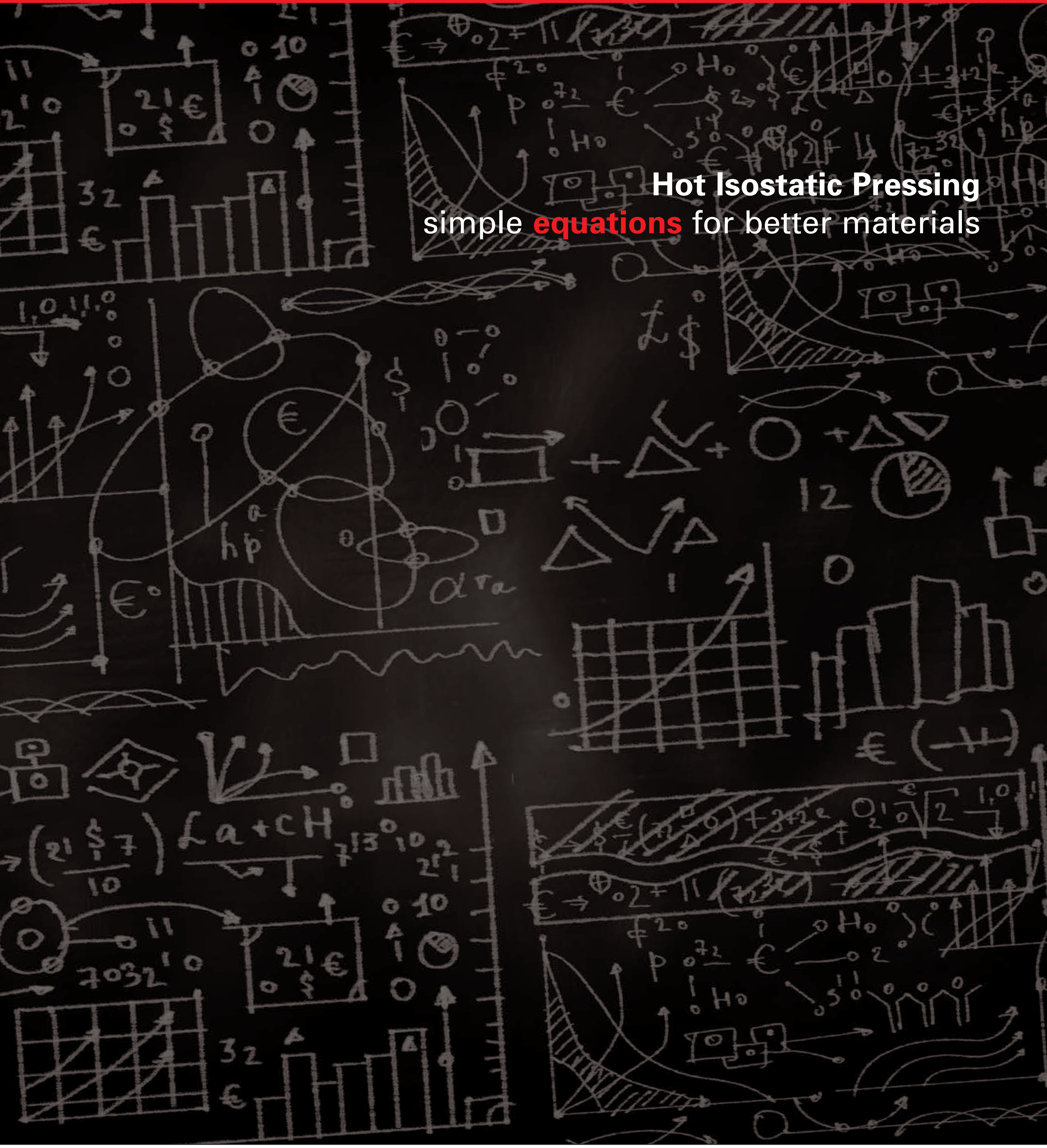
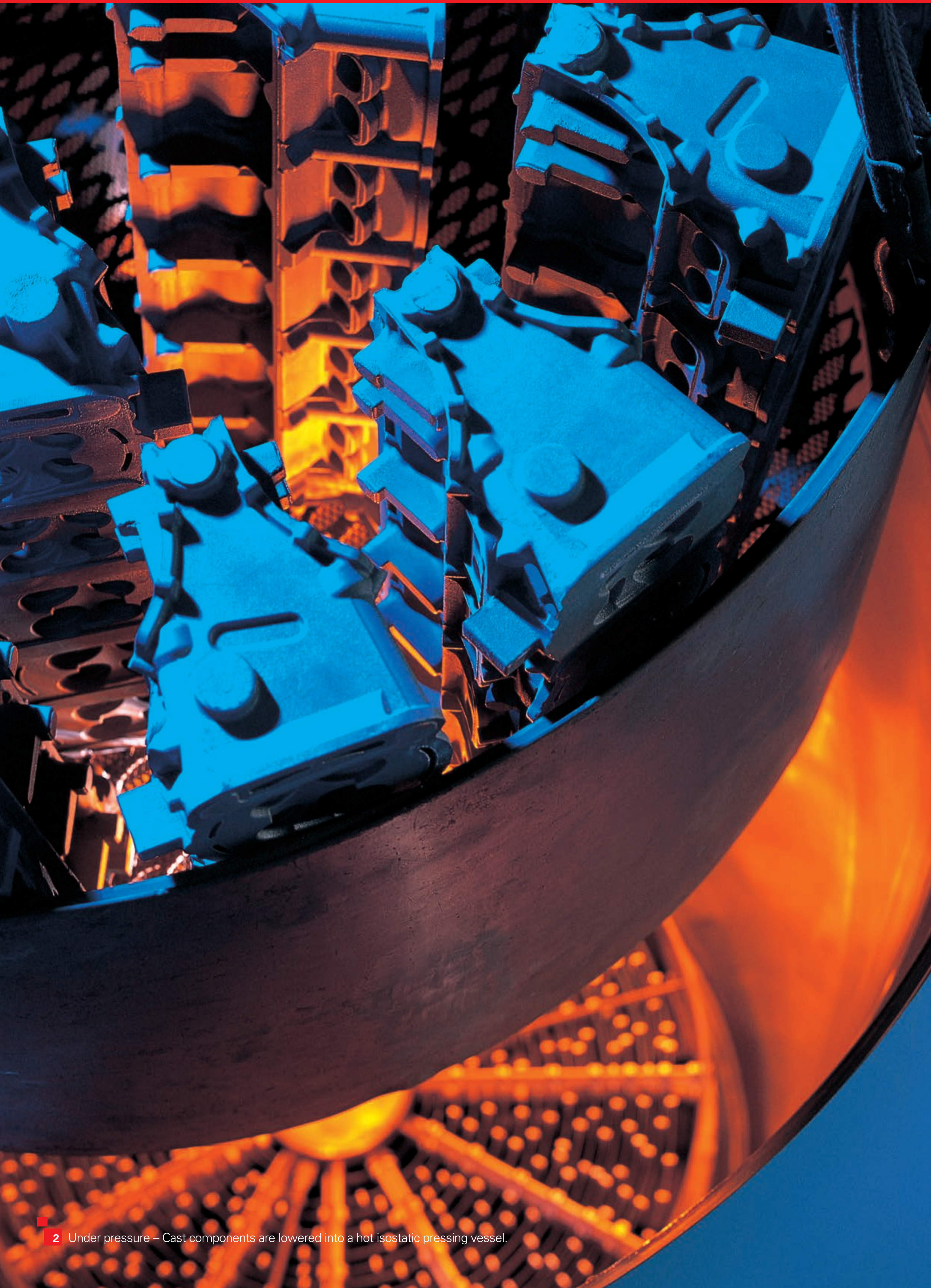


Hot Isostatic Pressing

simple **equations** for better materials

Bodycote



2 Under pressure – Cast components are lowered into a hot isostatic pressing vessel.

What is Hot Isostatic Pressing (HIP)?

HIP combines high temperatures (up to 2,000°C) with isostatically applied gas pressures (up to 45,000 psi) – comparable to the Mariana Trench 11,000m deep in the Pacific Ocean.

HIP is used to eliminate porosity in castings and consolidate powder metallurgy materials into fully dense components. Further, dissimilar materials can be bonded together to manufacture unique, cost-effective parts.

HIP technology allows the engineer to optimise component design and manufacture, whilst simultaneously improving microstructural homogeneity and material properties.

Temperature
+ pressure
+ expertise
=
The most versatile materials optimisation process

About Bodycote

Bodycote operates a global HIP business with the largest equipment network in the world and continues to invest in greater capacity in recognition of growing demand for HIP technology. Having established HIP expertise over decades, Bodycote has over 50 HIP vessels of varying sizes in multiple locations and is able to accommodate large volumes of small product as economically as large individual components.

Bodycote provides two major HIP routes for customers:

- HIP Product Fabrication, for the manufacture of components through powder metallurgy and diffusion bonding; and
- HIP Services, providing porosity removal through HIP densification.

Each week a typical Bodycote HIP plant will process many tons of materials such as titanium, aluminium, steel, cobalt and nickel-based superalloy castings, removing porosity and uprating the performance of parts such as turbine blades, medical implants and turbochargers.

Cast + HIP > forged

Casting is the premier near-net shape manufacturing process. The properties of cast components will, however, be limited by the unavoidable shrinkage of solidifying metal. Even the best castings may have a small amount of residual shrinkage or gas porosity; defects that are liable to impair their service performance and reliability. Impact resistance and fatigue properties, in particular, are extremely sensitive to small amounts of porosity.

One of the uncertainties regarding cast part performance and reproducibility has been associated with the distribution of porosity within a casting and the influence of such porosity upon mechanical properties.

The HIP process exposes the casting to the simultaneous application of heat and high pressure inert gas within a specially designed and controlled pressure vessel. This combination of heat and isostatic pressure eliminates internal porosity. During HIP processing, micro and macro porosity are removed by a complex combination of plastic yielding, creep and diffusion effects as material moves uniformly to fill voids from all directions. Diffusion bonding across the void surfaces during the final stage of densification ensures that defects are completely removed. A HIPed casting can challenge those properties expected from forged or wrought equivalents.

The removal of porosity from both powder and cast products by HIP is responsible for

- Improvement in the homogeneity of cast alloys
- Enhancement of fatigue strength, tensile ductility and fracture toughness
- Reduction in the scatter band of properties demonstrated by as-cast parts
- Significant reduction of casting rejection rate and inspection costs
- Elimination of internal voids in castings, metal injection molded parts and metallic components created by additive manufacturing methods

Glass + HIP = a clear advantage

A specialised HIP cycle maximizes optical or infra-red transparency for critical industrial or military applications.

Superalloy + HIP = cost-effective quality improvement

Superalloy castings are HIPed to obtain the ultimate high-temperature creep properties in high quality, high cost investment castings. For cast parts that are exposed to very high stresses and repeated thermal cycling, HIP can enhance low and high cycle fatigue and stress rupture properties.

Titanium + HIP = a pertinent partnership

HIP is recognised as an integral part of the production route for high-quality titanium castings owing to the difficulties in casting pore-free titanium.

High speed steel + HIP = no segregation

The cutting speed of conventional high speed steels is constrained due to their coarse segregated microstructure. HIP of gas atomised powder alloys permits faster speeds and feeds due to a more refined microstructure with evenly dispersed phases. Our process also eliminates any directionality of properties.

Ceramic + HIP = full theoretical density

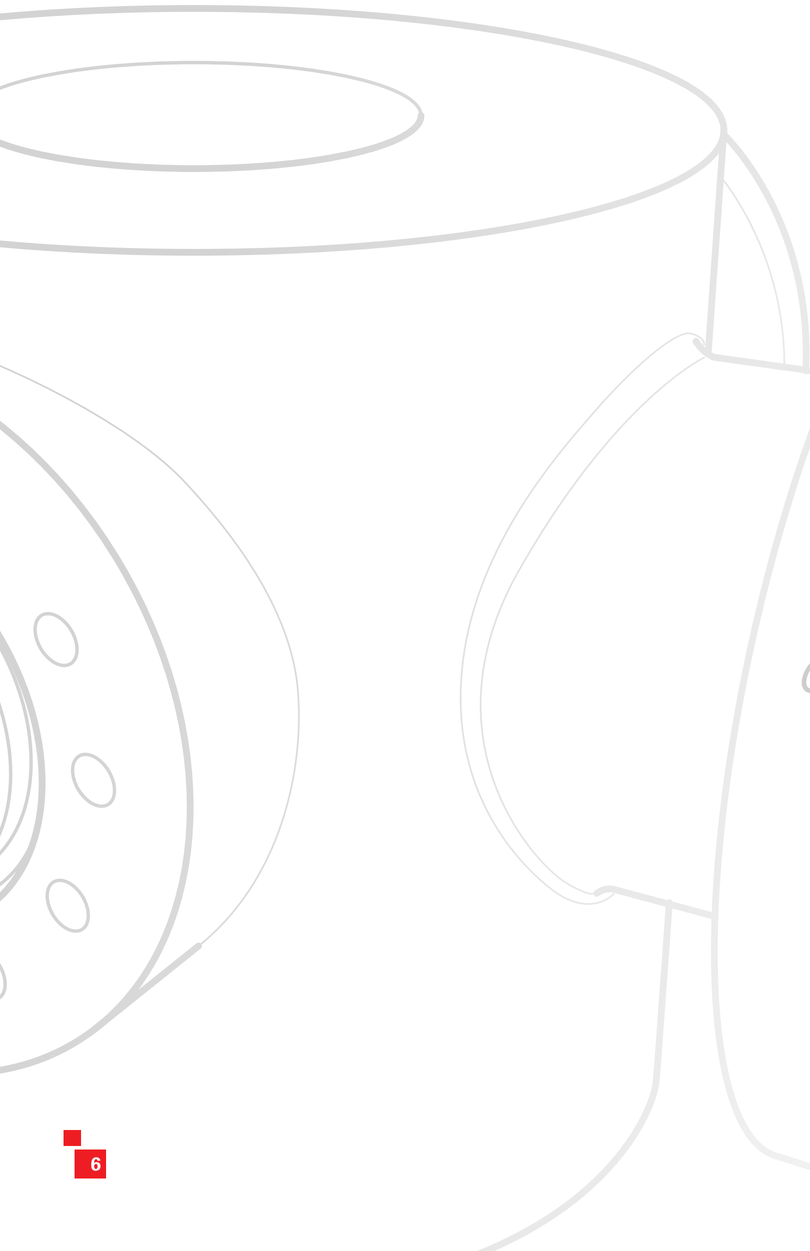
Advanced ceramics are very sensitive to minor amounts of porosity. The HIP process eliminates the porosity of pre-sintered material to improve mechanical properties.

Science + art =

Redefined component manufacturing

Imagine a component with no weaknesses, no cracks due to welding, optimised weight and material properties, and a superior lifetime – all achievable with a significant reduction in expensive machining and deliverable in weeks rather than months.

The process of producing a component from HIP Powder Metallurgy Near-Net Shape (PM NNS) offers a valuable alternative for engineers looking to produce components of both simple and complex geometries in a cost effective, timely way with reduced welding and machining and improved material properties and component lifetimes. Bodycote's Powdermet® process ensures complete elimination of all internal porosity combined with structural homogeneity – characteristics which are not possible to achieve with conventional manufacturing methods. Our design engineers can demonstrate solutions that you may not know are possible and can elevate your product design, economy and throughput to give you a real edge on the competition.



Powder + FEA + expertise =

No compromises

It is possible to consolidate metal powders to their maximum theoretical density using advanced capsule fabrication techniques and HIP. A leak-free capsule made of stainless steel or low carbon steel is designed and manufactured in order to encapsulate the powder material. Bodycote's HIP specialists have extensive knowledge and experience in the advanced field of PM NNS. When a component is isostatically pressed it shrinks uniformly. Our designers use finite element methods and 3D modeling to accurately calculate the dimensional change which will occur during the HIP process – even with complicated geometries – and incorporate this into capsule design, thereby producing a component which requires minimal post-manufacture finishing.

The PM NNS product fabrication process enables design engineers to realise complex external and internal geometries produced in one piece, for example, integral flanges can be accommodated into a capsule's design. Such components produced by casting or forging methods typically require extensive machining and welding during the manufacturing process. However, components produced by powder metallurgy can offer a cost-effective alternative, reducing machining and material wastage.

The flexibility inherent in the PM HIP design means that combinations of materials can be used to give desired properties, enabling the production of components from metallic compositions that are difficult or impossible to forge or cast.

Bodycote's Powdermet® process provides:

- Design flexibility
- Short delivery times
- Reduced welding and machining
- Isotropic mechanical properties
- Superior stress corrosion properties
- Ultrasonic inspectability
- Weight optimisation

Cold Isostatic Pressing (CIP)
CIP transmits pressure uniformly in all directions to compact metal, plastic, composite or ceramic powders enclosed in a flexible, sealed container and immersed in a pressure vessel filled with water at ambient temperature. CIP creates relatively simple shape preforms, or compacts, from powders that can then undergo further processing steps, such as encapsulation and HIP, to achieve full density. CIP also improves cleanliness by eliminating the need for binders and die wall lubricants.

Complex materials + HIP =

Novel results

Designers often require the ultimate combination of properties from a single material. HIP can combine normally incompatible materials to produce complex materials with special properties which cannot be manufactured by other means. A common example is a metal matrix composite (MMC), which is a consolidated mixture of powders or solids from different materials.

A particular kind of MMC is a mixture of diamonds in metallic matrices that are used under high stresses. The aim of HIP is to prevent the harder diamond phases from breaking off from the metallic matrix during machining. HIP improves the chemical and mechanical bonding of the diamond phase in the metal matrix, thus improving material properties and minimising diamond drag-out during use.

Dissimilar materials + diffusion =

HIP cladding

It is possible to bond different materials together to give an optimum combination of material properties and to save on the expense of manufacturing an entire component from premium material. HIP can produce multiple diffusion bonds in a single process cycle. Unlike other joining techniques there is minimal change in the properties of each material; for example, good corrosion resistance may be combined with high thermal conductivity. A diffusion bond is formed when two mating surfaces are processed under conditions of temperature and pressure that allow atomic diffusion to occur across the interface.

HIP cladding is commonly used to bond premium materials with superior properties, such as corrosion and wear resistance, onto more economical substrates, so that a part may be designed cost effectively. Bi-metallic compounds can be produced by bonding powder to powder, powder to solid, and solid to solid combinations. HIP cladding also eliminates the need for temperature-limiting adhesives.

Incompatible materials + interlayer =

Solid state HIP brazing

The joining of two dissimilar materials may not be possible via simple HIP diffusion bonding. It is necessary in this case to use an interlayer which is compatible to both materials. In cases where conventional brazing does not provide sufficient integrity, such an interlayer, used with encapsulation techniques and HIP, provides the solution. The manufacture of composites via diffusion bonding is limited if: the difference in thermal expansion coefficients of the materials is very high, there is no solubility in the solid state, unwanted high levels of diffusion occur, or deleterious compounds form. In all these cases an interlayer is necessary. Encapsulation and HIP enables a complete bonding of the interlayer material with no porosity.

versatility + dynamism =

A process for all industries

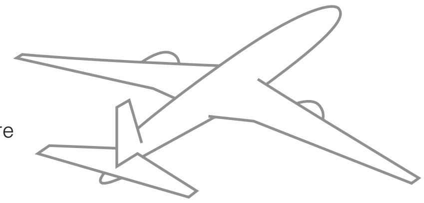
Aerospace & Defence
Closed porosity and voids in cast aerospace engine components are potential initiators of failure; for parts that are subjected to high in-service stresses, the removal of porosity is essential to maximise the properties and working life of the component. Turbine blades and vanes from the high-temperature section of jet engines are routinely HIPed to ensure freedom from residual microporosity. HIP is used to optimise the properties of the latest generations of single crystal and directionally solidified investment cast blades.

Working together with customers, Bodycote can provide cost-effective development of exotic and novel materials using HIP technology. New classes of raw materials, such as metal matrix composites (MMCs), were developed using the HIP process. For example, an aluminium alloy matrix with a high proportion of silicon carbide ceramic particles may be compacted to full density by the HIP process to give a very light and stiff material. Many precision airframe castings from alloys such as titanium, aluminium and steel are HIPed to ensure integrity, optimise mechanical properties and improve fatigue life.

The ability to diffusion bond dissimilar materials, each having specific properties, expands the manufacturing possibilities, enabling the protection of aerospace components to be addressed. For example, diffusion bonding and superplastic forming are used to make titanium airfoils in the fan section of large jet engines. Additionally, a thick cladding of wear and corrosion resistant material, such as the cobalt chrome alloys, may be applied by HIP to enhance the performance of actuators and other aircraft components.

Bodycote is working closely with aerospace OEMs to explore and develop opportunities for the wider use of HIP powder metallurgy in this sector.

Oil & Gas
Oil & gas operations require specialised equipment that must be reliable, cost effective and safe to the environment. The HIP powder metallurgy near-net shape process allows the designer flexibility to manufacture parts with complex geometries that require minimal machining compared to conventionally forged billets and preforms. Such design flexibility can significantly reduce expensive materials and, for example, eliminate up to 80% of the welds needed for subsea manifold systems.

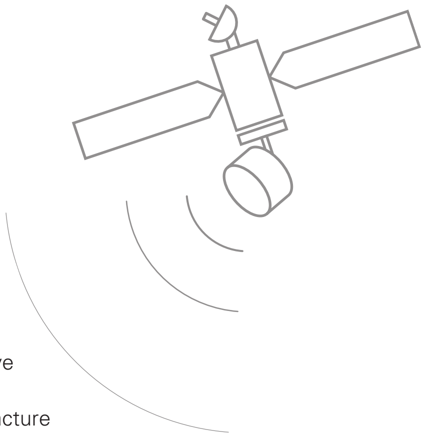


The homogeneous microstructure attained through PM and HIP can give components increased wear and corrosion resistance which meets the stringent demands of the offshore industry. Large scale parts such as petrochemical valve bodies may be formed directly to shape by the HIP of encapsulated stainless steel powders. Large and complex components such as valve bodies, pump housings, swivels, tees, hubs and manifolds can be produced in one piece by HIP Product Fabrication, providing a cost-effective manufacturing route.

Bodycote has world leading experience and capability in the production of near-net shape in this market sector, for example complex parts operating in subsea oilfield systems.

Medical
The stress on a hip or knee joint when a person jumps off a chair is equal to around 100 tonnes per square inch. Our bones, effectively composites, absorb such stresses regularly and effectively for much of our lifetime. When joints fail, they are often replaced with metal alloy implants. These implants must be incredibly strong, biocompatible, and able to last the lifetime of the patient. Many medical implants require a biomedical coating to promote bonding between the implant and body tissue, so the coated parts are hot isostatically pressed to eliminate porosity, improve fatigue life and enhance the bonding of the coating.

Automotive
Gas or shrinkage porosity in cast automotive engine components can lead to leakage of pistons, cylinder heads and other pressurised components. Further, if the pores are above the critical defect size they can lead to the failure of an engine causing significant damage to the entire engine and not just a single component. Bodycote provides a service for the densification of aluminium alloy castings, which reduces porosity in components such as turbochargers, cylinder heads and crankcases. As-cast components can benefit from a reduction in the scatterband of properties including proof strength, ultimate tensile and ductility as well as significantly improving the creep and fatigue properties of cast aluminium alloys.



These properties are highly beneficial for design engineers, particularly for high performance cars, as improved density can allow significant reductions in the wall thickness of components without loss of performance which enhances the overall weight saving of the car.

Aluminium powders and flake alloys can also be consolidated by HIP. Typical components machined from PM HIP blanks are turbochargers and pistons, and due to the inherent fine grain structure offered from PM and flake materials these components, at low operating conditions, are comparable to titanium alloys. Many high temperature nickel alloy turbochargers are also HIPed to increase the fatigue performance of these parts for heavy automotive and truck applications. HIP diffusion bonding is also used to bond a tungsten carbide disc to valve lifters used in diesel engines to increase their wear resistance and life which reduces downtime and maintenance costs.

Tooling, Mining & Machinery

Powder metallurgy can achieve higher quality products due to the absence of macro-segregation in the material and due to the extremely high purity and low oxygen content of the gas-atomised powder. Benefits include improved machinability, excellent toughness, high wear resistance, better corrosion resistance, and improved cutting performance, which all contribute to increased tool life. High speed steel and tool steel can be efficiently produced in almost any size and shape with short lead times. Rolling and forging billets can also be produced with good economy in modest tonnage. Bodycote is able to manufacture hollow bars, also available with more than one inner diameter, saving time and expensive drilling costs for the customer.

Electronics & telecommunications

HIP is used to manufacture sputtering targets for coating flat panel displays, semiconductors, data storage, architectural glass and solar panels. In sputtering it is key to have targets with a fine microstructure as well as full density. With HIP, powders can be densified to full density while maintaining a fine microstructure. Dissimilar materials can be blended as powders and HIPed to form new combinations for sputtering. HIP is also used to diffusion bond backing plates to sputtering targets to achieve better bond strength.

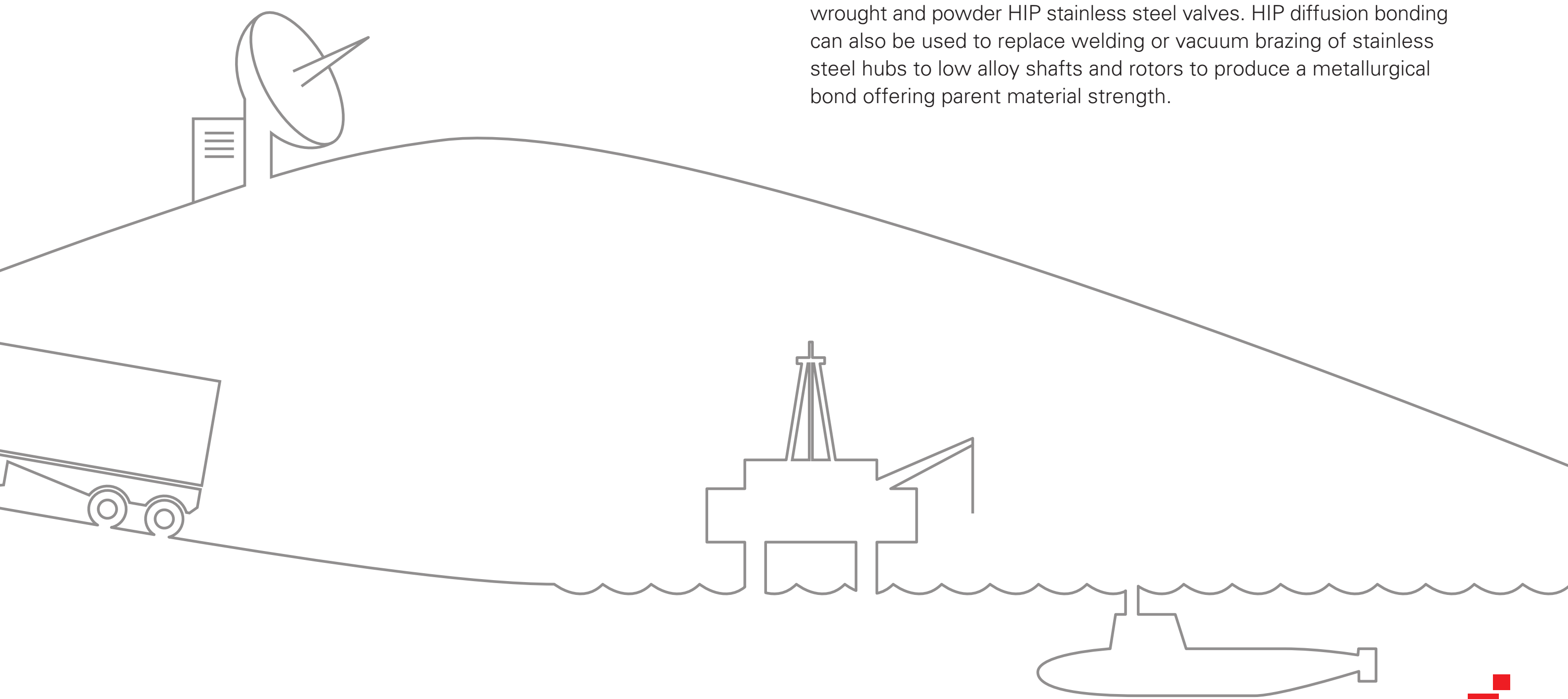
Power generation

The power generation industry is constantly working to improve the efficiency of turbines and looking at new ways to manufacture components. PM HIP provides a flexible manufacturing route with the ability to create very complex geometries. An example of this is a steam chest for steam turbines which has many complex internal cavities. Bodycote's powder metallurgy process makes it possible to optimise design to increase the efficiency of the turbine. Other examples of power generation applications include rotors, turbine discs, diaphragms, valve bodies and steam generator components.

Marine

Marine operations require specialist materials and equipment designed to meet the demanding environment in which they operate. Marine components must be of extremely high quality and reliability and be cost effective to manufacture. Valves and bonnets used in submarines operate at the sea bed for a service life of up to 20 years with limited maintenance. The powder (PM) HIP near-net shape process offers flexibility in design, as the component design is the key criteria. PM HIP parts require minimal machining so in comparison to conventional wrought components the design can be tailored around the actual requirements of the part instead of the limitations of subsequent machining operations. In many instances large complex components can be produced in one piece reducing the need for post-weld examination and offering a cost effective manufacturing route. Typical powder alloys used in marine applications include 316L and 316LN for valve, bonnet, shaft and rotor applications. The HIP consolidated powder alloys offers a homogenous microstructure, low inclusion content and isotropic mechanical properties.

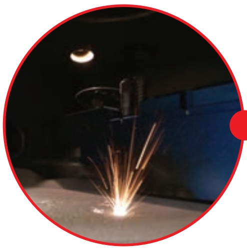
HIP diffusion bonding also allows the manufacture of bi-metallic components for marine applications, producing a tough substrate material to be HIP bonded or HIP clad with a specialised material to offer increased corrosion, wear and abrasion resistance in specific areas of a component. Over the last 20 years, weld overlay to produce hard facing seats in submarine valves and bonnets has largely been replaced by the diffusion bonding of powder HIP seats into both wrought and powder HIP stainless steel valves. HIP diffusion bonding can also be used to replace welding or vacuum brazing of stainless steel hubs to low alloy shafts and rotors to produce a metallurgical bond offering parent material strength.



A component journey

Adding Value - 3D printed metal part

Almost all metal parts built by the additive manufacturing process require secondary treatments to make them suitable for their intended use. Bodycote provides a complete post-manufacture service solution including hot isostatic pressing to remove micro-porosity and reduce the extent of segregation in the built structure, heat treatment to improve material properties, and associated quality assurance testing.



The metal part is 'built' onto a plate in a 3D printing machine by depositing metal powder in layers which are then consolidated, for example using lasers.

The part is stress relieved in a vacuum furnace to minimise any distortion.

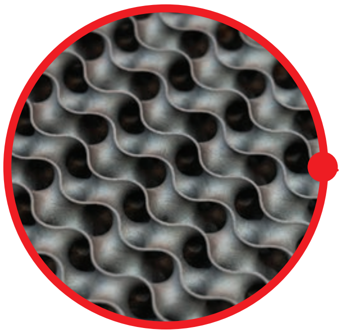
The component is then removed from its build plate by electrical discharge machining (EDM) to prepare for HIP and heat treatment.

Hot Isostatic Pressing (HIP) ensures that any porosity within the part is removed, thereby reducing the variation in mechanical properties when compared with the as-built part, and improving ductility and fatigue strength.

The part next undergoes heat treatment to achieve full material properties and improve the microstructural characteristics of the component if needed.

Various testing methods are used to check that the part meets specification – these may include radiography, tensile testing, and metallography.

The component will undergo any necessary finish machining and dimensional inspection.



End applicatiom

3D printing is creating components in a range of industries including aerospace, medical, and power generation.

Denotes the parts of the component journey undertaken by Bodycote

Expertise + state-of-the-art technology =

Assured quality

Our in-house metallurgical laboratories are equipped with state-of-the-art systems for powder characterisation, metallography and microscopy including measurement of density and argon content and SEM/EDS (scanning electron microscope/energy dispersive spectrometer) analysis. Some examples of laboratory services include:

- As-cast versus post-HIP microstructures to prove the benefits of HIP
- Documenting material behaviour at HIP-bonded interfaces
- Argon analysis as a valuable quality control tool to assure the integrity of encapsulated HIP PM
- Microscopic examination of HIPed parts to ensure the absence of internal porosity

Bodycote's near-net shape solutions are supported by our vast experience in designing complex and challenging products for the PM HIP process. Design engineers collaborate with the customer to cover all requirements and inputs and to maximise the benefits of this approach. We offer tailor-made solutions to create cost effective products, minimising material usage, machining and welding. The PM HIP route enables our designers to offer solutions not possible with conventional manufacturing methods.

Bodycote utilises state-of-the-art computer modeling and software for simulation and analysis created exclusively for the HIP process. CAD creates 3D models illustrating the desired geometry to be delivered. The main focus is to add value by exploiting the unique attributes of the PM HIP technique, and close collaboration with the customer is critical. The follow-on design stage consists of creating manufacturing models. Virtual iterative trials are performed using finite element analysis (FEA) software run in a high-performance computer cluster, utilising materials' properties input and historical data from the 'real life' PM HIP process. Manufacturing models and drawings are optimised to ensure product delivery as agreed to and in accordance with customer requirements.

In addition to standard quality and environmental accreditations, Bodycote's HIP facilities hold:

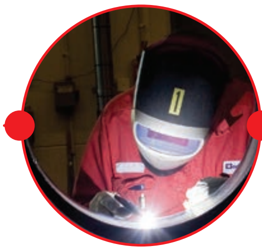
- ASTM A988/A988M and ASTM A989/A989M
  (standard specification for Hot Isostatically Pressed Stainless Steel Flanges, Fittings, Valves, and Parts for High Temperature Service)
- NORSOK M-630 - MDS: D44, D54, R14
  (developed by the Norwegian petroleum industry to ensure adequate safety, value-adding and cost-effectiveness for petroleum industry developments and operations)
- Nadcap
  (leading worldwide accreditation for special processes within the aerospace industry)

A component journey

A twist to resist – Bi-metallic extrusion screw

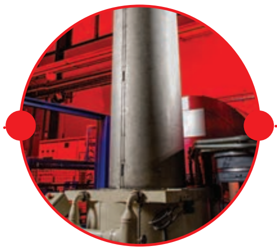
Plastic extrusion technology is used to create a huge number of everyday items for industries such as plastics, pharmaceuticals and food. The equipment used to compound the polymer feedstock, such as extrusion screws and barrels, must be highly resistant to brittleness, wear and abrasion. Parts produced from monolithic materials cannot be optimised to produce the desired specification, so the use of bi-metallic parts produced by hot isostatic pressing (HIP) and powder metallurgy overcomes this limitation by bonding a high wear and abrasion resistant powder alloy onto a tough substrate.

The extruder screw begins life as a forged steel bar.



An empty cylindrical steel capsule is manufactured. The steel bar is placed into the centre and the free volume is filled with metal powder.

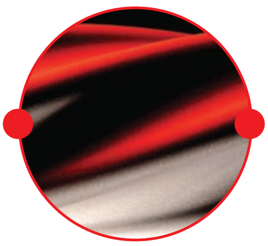
The bar requires cladding to add a layer of wear-resistant material. This material will be produced from high quality steel powder.



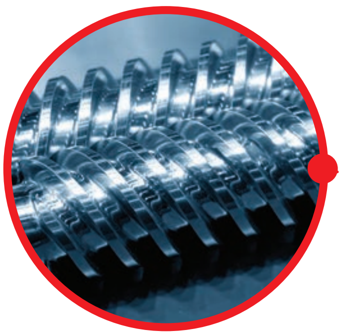
The capsule is HIPed to fully densify the powder metal and bond the steel bar creating a coating.

The outer profile is machined to the final shape and dimensional tolerances.

The finished screw is hardened and tempered using a thermal cycle engineered to allow the material to retain toughness whilst allowing optimum hardness characteristics in the (clad) surface.



K-Tech coating applied for increased wear resistance, corrosion protection, and anti-galling.



End applicatiom
plastic extrusion equipment

Denotes the parts of the component journey undertaken by Bodycote

Lots of information + exciting possibilities =

Frequently Asked Questions

What about distortion?
Distortion is always a concern during the processing of components downstream from the casting operation. If a casting contains internal porosity, volumetric shrinkage during HIP is inevitable; the percentage of shrinkage being equal to the volume percent porosity present in the casting prior to HIP. In castings where porosity is primarily from interdendritic shrinkage, the overall fraction of porosity within the material will be small and evenly dispersed; thus, volumetric shrinkage during HIP will be small, and no gross distortion of the part will occur.

In contrast, when pores are larger and located near the surface, it is common to see small dimples in the surface where metal from the near-surface region has flowed into the pore. If gross porosity is present within a casting and the pores are isolated from the surface, HIP can still produce a pore-free part; however, HIPing parts having large volume fraction of porosity will result in large volumetric shrinkage within the part. If the gross porosity is localised to a specific region within the casting, distortion can occur.

Can HIP eliminate surface-connected porosity?
No. When considering HIP as a means of achieving improved mechanical properties in castings, it must be realised that HIP only eliminates subsurface porosity from a casting. The presence of surface-connected porosity is the most common cause for dissatisfaction when a foundry or end user decides to employ HIP to solve a porosity problem. The simple fact is that there must be a gastight layer of material surrounding the pores for HIP to work. The best solution to a surface-connected porosity problem is to eliminate its occurrence in the casting operation through modification of the mold design, by incorporating chills into the mold, or by using any other technique that will help to ensure that a solid layer of metal is formed on all surfaces. A surface-sealing process, such as weld overlay, can also be used.

It sounds expensive?
With over 50 HIP vessels of varying sizes in multiple locations, Bodycote is able to accommodate large volumes of small product as economically as large individual components. Densification of castings by HIP can offer a significant reduction in foundry scrap as HIP allows recovery of castings that would otherwise be rejected based on x-ray inspection. For parts produced by HIP powder metallurgy, the reduction in welding, machining and material wastage during the fabrication process, versus traditional manufacturing methods, offers a cost-effective production route with additional value-adding benefits.

Is there a size limit?
Our processing capability can accommodate components with sizes up to 1.8m diameter by 3.3m high and ranging from 0.1kg to over 30,000kg in weight.


Danger

www.bodycote.com

Operating an international network of facilities and serving a wide range of industries, Bodycote is the world's largest and most trusted provider of thermal processing services – a vital link in the manufacturing supply chain.

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