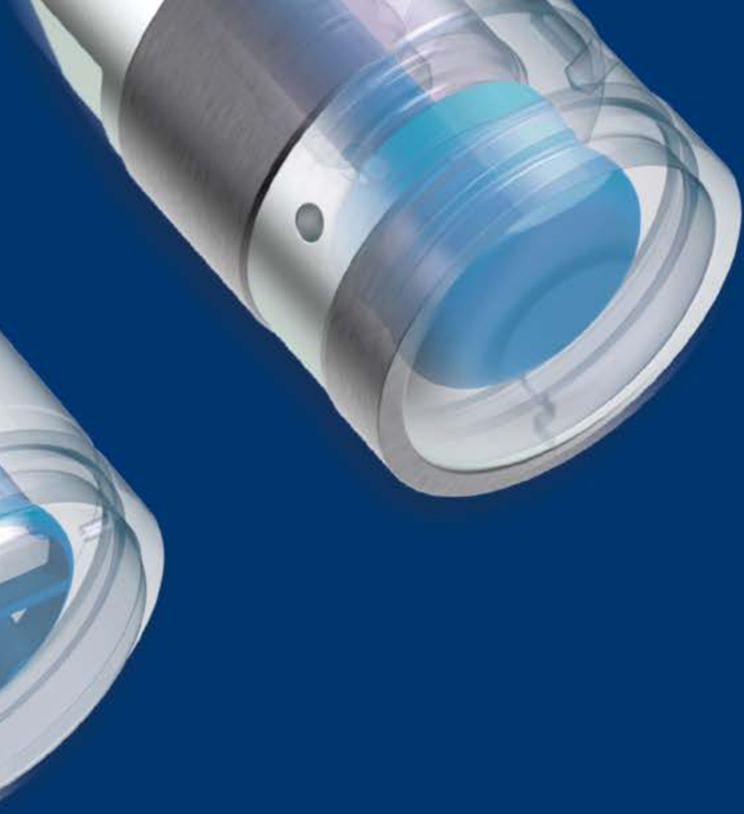
Key Considerations for Plunger Selection in HPDC

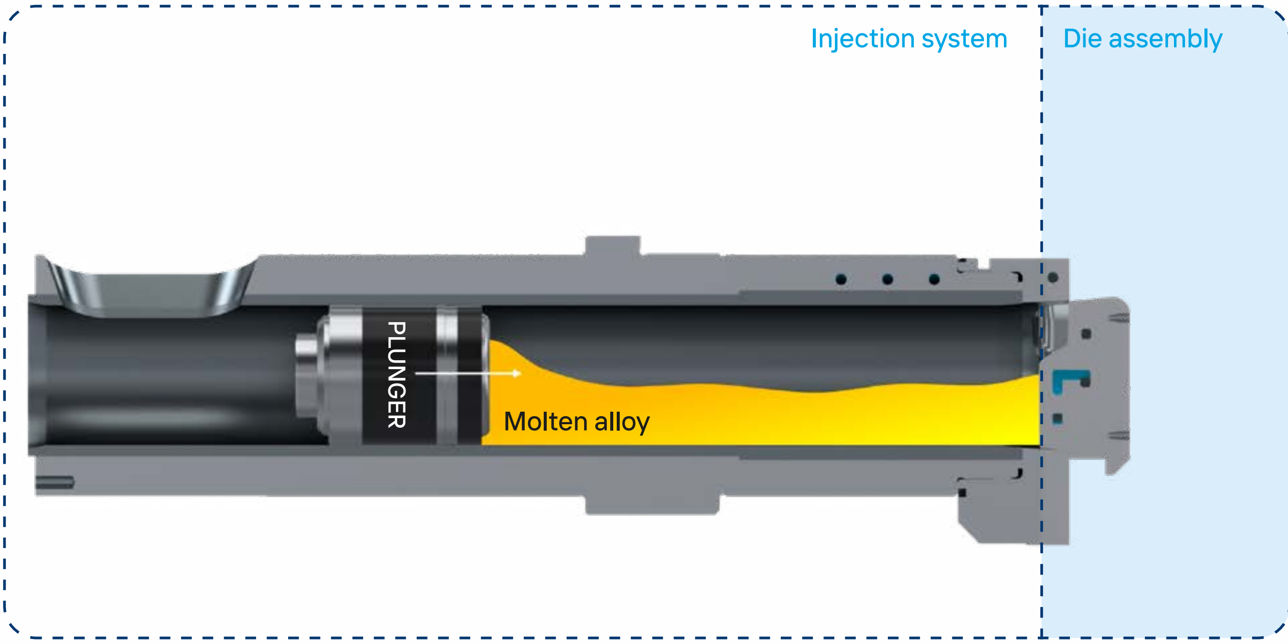


This white paper explores essential considerations in plunger selection for die casting systems, providing insights into the diverse types of plungers and their specific applications. We address common challenges stemming from improper plunger choices and offer practical strategies to overcome these issues.

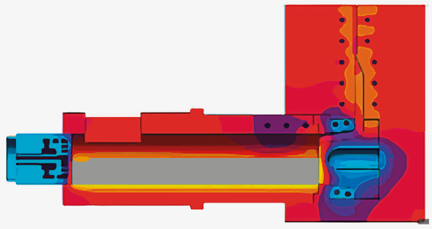
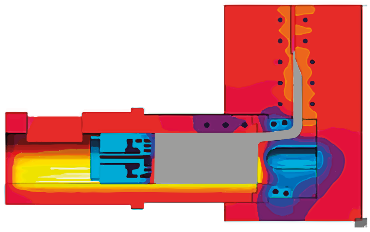
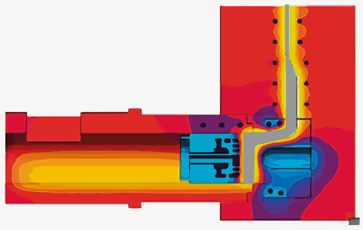
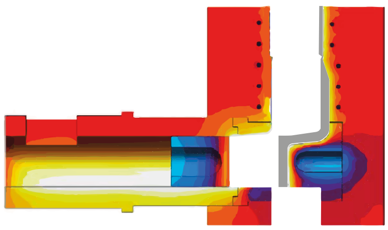
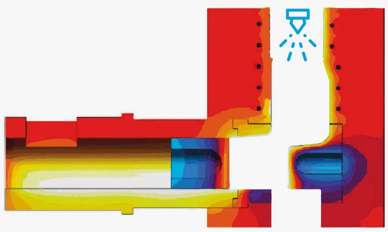
Whether you are navigating the complexities of sealing effectiveness or optimizing performance in high-volume production environments, this comprehensive guide equips you with the knowledge needed to make informed decisions.

1. The function of a casting plunger in die casting

In high pressure die casting (HPDC), the main function of the plunger is to inject molten alloy from the shot sleeve to fill the mold cavity under high pressure. This ensures that the alloy completely fills the cavity and accurately takes on its shape.



During the casting process, there are several steps that exert different functional requirements on the plunger

Steps of the casting process	Plunger role/function	
Step 1: **Fill in the alloy** - the plunger is in the rear position and does not move	• **Sealing the shot sleeve:** to prevent aluminum from leaking backward	
Step 2 - phase 1: **Pre-filling** – the plunger moves forward at a slow speed until the the plunger has passed the pour hole and the runner is filled up to the gate	• **Sealing the shot sleeve:** to prevent aluminum from leaking backward • **Ensuring smooth plunger movement at low speeds:** to avoid the stick-slip effect • **Allowing air to escape**	
Step 2 - phase 2: **Mold filling** – the plunger moves forward at a rapid speed until the cavity is fully filled	• **Sealing the shot sleeve:** to prevent aluminum from leaking backward • **Good sliding effect** of the plunger at high speeds: to reduce wear	
Step 2 - phase 3: **Holding pressure** - high static pressure, also known as solid-ification pressure, is applied to compress the trapped air and fill the shrinkage porosity/ holes.	• **Stability of the plunger** to withstand high pressures • **Cooling effect** to accelerate the solidification of the biscuit	
Step 3: **Mold opening with part removal** – plunger pushes the biscuit out of the sleeve as the mold opens	• **Cooling effect of the plunger:** to accelerate the solidification of the biscuit	
Step 4: **Spraying**	• **Sealing the shot sleeve:** to prevent the entry of spray medium (especially water)	
Step 5: **Plunger retraction**	• **Good sliding effect** of the plunger at low speeds	

Plunger functional requirements

1. SLEEVE SEALING: the plunger provides a seal in the shot sleeve and prevents molten alloy from flowing back into the shot sleeve during injection. This ensures that the alloy completely fills the cavity and accurately takes on its shape.

2. GOOD GLIDING EFFECT: in order to ensure optimal flow dynamics during mold filling, the speed and pressure of the plunger must be precisely maintained. This is necessary to minimize turbulence, pre-filling or air pockets and to reduce the likelihood of defects such as porosity or flaking. Stick-slip effects can negatively impact the plunger's performance.

3. ALLOWING AIR ESCAPE: in phase 1 (pre-filling), the goal is to push the air in the sleeve out without mixing it into the melt. Therefore, it is beneficial for the plunger to seal against the melt but allow the air (due to its significantly lower viscosity) to escape.

4. STABILITY OF THE PLUNGER: in phase 3 (holding pressure), a considerable force is applied to the plunger. This helps reduce porosity defects and ensures that the casting retains its desired shape and structural integrity.

5.COOLING EFFECT OF THE PLUNGER: the secondary task of a plunger is to cool and solidify the runner system as quickly as possible. In many cases (thin-walled components), this can shorten the cycle time. A well-functioning plunger then contributes to faster cycle times, improves productivity and thus reduces manufacturing costs.

2. The importance of using the right plunger

In die casting, the plunger is critical to the overall process efficiency, quality, and service life of other components. The selection of the right plunger helps in avoiding several problems and increases production efficiency.

2.1 Impact on shot sleeve

Poorly designed plungers with inadequate lubrication impact the lifespan of the shot sleeve and can lead to more frequent replacement and maintenance of components.

1. **EXCESSIVE WEAR AND DAMAGE:** if the plunger is poorly designed with poor plunger lubrication, the frictional forces between the plunger and the walls of the shot sleeve can lead to accelerated wear. This wear occurs predominantly at contact points where the plunger interacts with the shot sleeve or mold cavity walls.

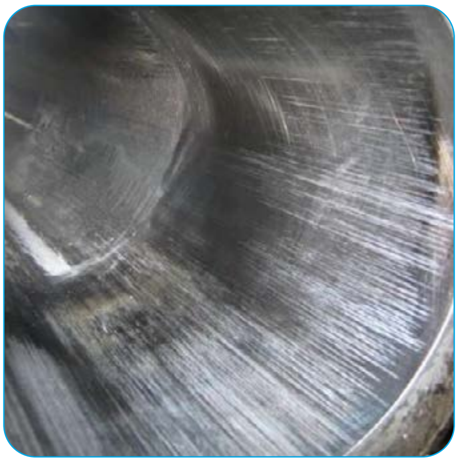
2. **ABRASIVE WEAR:** when the hardness or composition of the plunger material is not compatible with the shot sleeve material (such as steel or alloy), abrasive wear can occur. This abrasive wear results from repeated contact and sliding movements during the injection process, gradually eroding the surface integrity of both the plunger and the sleeve walls.

3. **THERMAL FATIGUE:** additionally, thermal fatigue is a concern for plungers that are not designed to withstand the thermal cycling inherent in die casting operations. Rapid heating and cooling cycles cause expansion and contraction of the plunger material. Over time, this can lead to micro-cracks, deformation, or even complete failure of the plunger, further contributing to increased wear on the shot sleeve.

Examples of sleeve issues with sub-optimal choice of plunger

DEFORMATION OF SLEEVE

Sleeve without thermoregulation



DEFORMATION OF SLEEVE

Plunger and sleeve not well aligned

STUCK PLUNGER

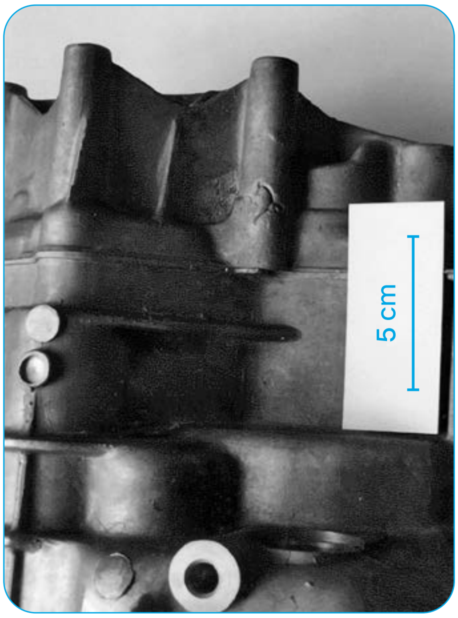
Sleeve overheating / Plunger cooling insufficient

2.2 Impact on cast part quality

Sub-optimal plunger design can lead to casting defects such as
porosity, cold flows (shuts) and/or flaking short fill.

These defects occur due to improper filling of the mold cavity, uneven plunger speed, or turbulence in the melt. During mold filling, the plunger is exposed to extreme heat, which, if not sufficiently cooled, can cause rapid expansion of the front of the plunger. This can result in the plunger getting stuck within the sleeve, reducing the transmission of plunger pressure to the molten alloy and causing issues with ejecting the casting.

POROSITIES IN HPDC PART



COLD FLOW AT HPDC PART

2.3 Impact on plunger-sleeve sealing

Poor plunger design can result in inadequate sealing between the plunger and the shot sleeve, leading to leaks of molten alloy. This not only wastes material but also poses safety risks. Insufficient lubrication can cause overheating, increased friction, and premature wear, leading to thermal fatigue, galling, and potential stucking of the plunger

Addressing these issues requires careful consideration of plunger material, geometry, thermal properties, and compatibility with the specific requirements of the die casting process and the materials used. Solutions involve optimizing plunger design to balance these factors effectively, ensuring a robust and efficient die casting operation.

2.4 Impact on cycle time

An inefficient plunger design can lead to longer cycle times due to **slower biscuit solidification,** reducing overall productivity and increasing production costs.

Material selection and cooling design are critical to efficiency. Poor thermal conductivity or insufficient heat dissipation can lead to slower cooling rates, delaying the solidification process and the start of the next cycle. The optimized cooling design with effective cooling channels ensures fast and uniform cooling, shortening cycle times and increasing productivity. Therefore, careful consideration of material and cooling design is essential for efficient die casting.

3. Types of plungers and their applications

3.1 Based on material choice

Depending on the process requirement, plungers can be made from different materials, such as hot-work tool steel and copper alloys with beryllium or nickel.

Material	Key advantages	Drawbacks
Copper alloys (beryllium/nickel)	High thermal conductivity	Low durability
Hot work tool steel	High durability	Limited thermal conductivity

COPPER PLUNGERS are typically made using forged beryllium-copper alloys, which offer a good combination of strength and thermal conductivity. Although beryllium and nickel improve mechanical properties, the lifespan of a copper-based casting plunger is still significantly shorter compared to one made from hot work tool steel.

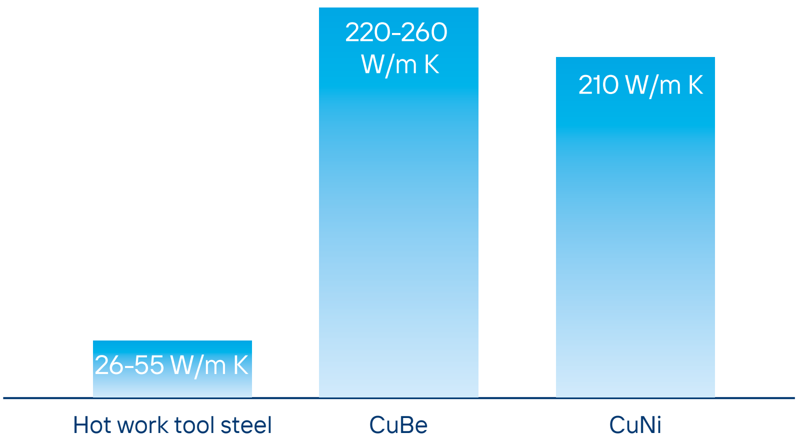
STEEL PLUNGERS, typically made from hot work tool steel, are much tougher than copper plungers and exhibit significantly better mechanical properties, particularly in terms of tensile strength and resistance to thermal fatigue. Additionally, hot work tool steel is designed to retain its hardness even after prolonged use, resulting in higher mechanical wear resistance compared to copper alloys. However, the thermal conductivity of steel is much lower than that of copper. To achieve optimal productivity and extend the lifespan of steel plungers, they must be designed accordingly. This often involves the use of thin walls and advanced cooling schemes to maximize efficiency. When properly implemented, steel plungers can be ideal for high-volume production environments where minimizing downtime is crucial.

Thermal conductivity of different materials

Materials with higher thermal conductivity can extend the life of plungers

Thermal conductivity plays a crucial role not only in performance, but also in the management of thermal stress. With better thermal conductivity, the heat transfer between the outer surface that comes into contact with the alloy and the cooling channel is more efficient. This improved heat transfer reduces temperature gradients and induced thermal stress, which has a positive effect on the longevity of the plunger. Consequently, materials with higher thermal conductivity can extend the life of plungers by mitigating the risks associated with thermal fatigue and stress, ensuring more reliable and consistent operation over time.

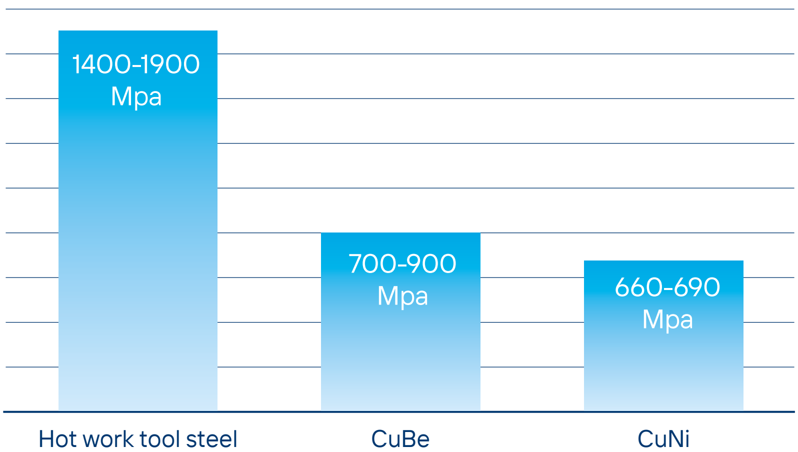
Depending on the alloy type, conductivity can vary within the range shown in the following graph.



Graph: Conductivity of different alloys

Mechanical properties

When looking at the mechanical properties, hot-work steel has a significantly higher tensile strength compared to copper alloys, which makes it much better able to withstand the mechanical stresses during operation. In addition, the coefficient of linear thermal expansion is an important factor; a lower coefficient is preferable because it indicates lower expansion and contraction with temperature changes, thereby reducing the risk of thermal stress and deformation. Hot-work steel typically has a lower coefficient of linear thermal expansion compared to copper-beryllium alloys, which contributes to its superior performance in high-stress, high-temperature environments.



Graph: Tensile strength of different alloys

3.2 Based on build complexity

Depending on the complexity, we distinguish between 2 types of plungers.
One-piece/solid and system plungers.

One-piece (solid) plungers

Solid plungers are typically used due to their lower manufacturing cost compared to multi-part plungers. They are usually replaced more frequently, leading to higher downtime costs. Their cooling geometry is generally simple and is achieved through a direct cooling method since all forces during the process must be absorbed by the plunger itself. Solid plungers are ideal for low-volume applications where low procurement costs are a priority.

System plungers

System plungers are a more complex and expensive alternative to solid plungers. They are designed to withstand a large number of cycles and feature improved cooling. They are typically equipped with 1 or 2 rings that provide better sealing and reduce wear.

Rings generally fail earlier and are thus designed to be easily and quickly replaceable. Due to the better fit, these plungers are often used in vacuum die-casting applications as they allow for better air sealing. The market offers many different variations of system plungers with various material pairings.

Endura Plunger by HTS

Conducta Plunger by HTS

Endura T-R Plunger by HTS

4. Plunger ring & spring bush

Function of the plunger ring

Sealing

The plunger ring seals between the plunger and the shot sleeve wall, preventing molten alloy from passing by the plunger during the injection process. This ensures that the molten alloy is properly directed into the mold cavity, which improves casting quality and consistency.

Reduction of friction

By providing a smooth surface bonded to the cylinder, the plunger ring reduces friction and wear between the plunger and the cylinder wall. This helps to extend the life of both the plunger and the shot sleeve.

Managing thermal expansion

The plunger ring helps to balance the thermal conditions between the shot sleeve and the plunger. It can provide a buffer that mitigates the thermal loads on the plunger, reducing the risk of thermal shock and other heat-related failures.

Enhancing maintenance efficiency

Plunger rings can be replaced relatively easily and inexpensively, compared to replacing the entire plunger, as is common with traditional solid plungers. This modularity allows for more efficient maintenance and cost savings, as worn or damaged rings can be quickly replaced without the need for a complete replacement of the plunger.

Function of the spring bush

Sealing

In vacuum-assisted die casting processes, maintaining a uniform and reliable seal is paramount to ensure proper evacuation of the air from the pressure cavity. The spring bush helps to create the best possible seal between the plunger and the shot sleeve and prevents air leakage during the vacuum phase of the casting cycle. This sealing effect is critical to achieving high-quality castings with minimal gas porosities, as even small leaks affect component quality and lead to porosity or other surface defects.

Alignment and support

A spring bush helps to properly align and support the plunger inside the shot sleeve. Furthermore, the spring bush improves the gliding effect with its surface.

5. Typical failure modes of casting plungers

5.1 Thermal shock, thermal fatigue and heat cracks

The casting process with its different steps induces various thermal loads on the casting plunger. From the transition from phase 3 to spraying, for example, the extremely hot plunger front surface is aggresively cooled (thermally shocked) by spraying.

Furthermore, repeated heating and cooling cycles lead to thermal expansion and contraction, leading to the formation of cracks and eventually failure of the material. Thermal fatigue failure is usually directly linked to thermal cracking, where rapid changes in temperature cause small surface cracks called thermal cracks. These small cracks can spread over time, weakening the plunger and leading to larger cracks and eventually failure.

Thermal cracks at plunger

Crack line water leaks

5.2 Mechanical wear

Continuous friction and contact with the melt wear down the surface of the plunger, causing it to lose dimensional accuracy and thus its sealing effect. Over time, this wear leads to the loss of the function of the plunger.

Wear caused by the friction of the plunger and the sleeve

Aluminium back penetration caused by worn sleeve.

6. Plunger comparison

The following is an overview of plungers categorized by material, fitting, components,and models, along with recommendations for their usage based on various production requirements. This guide aims to help in selecting the most suitable plunger for specific applications.

	MATERIAL	
	Copper	**Steel**
+	best cooling power	long lifetime
	more flexible: when not perfectly aligned with the chamber	cheap material
–	short lifetime	lower cooling power
	high price	
	long purchasing time	
Conclusion	for process with focus on cooling power	for process with focus on long lifetime
	for process which is not well aligned to ring plungers (sleeve, lubrication. etc.)	for process which is well aligned to ring plungers (sleeve, lubrication. etc.)

	RING	SPRING BUSH
	Ring	**Spring Bush**
+	easy to change	better sealing >> vacuum
	cheap	less friction
	longest lifetime of tips	
–	more parts (complex)	more parts (complex)
Conclusion	for all processes	for process with focus on sealing: vacuum
		for process with focus on friction: big diameters

FITTING	
Bayonet	**Thread**
easy change	simple design (possibility to remachine)
never blocks	it gets blocked
hardly any damage	It deforms
no remachining	higher setup time for change
for process with focus on frequent change of plungers	for process with focus on highrunner
	best to run one DCM with one Plunger

SPECIAL MODEL		
Bullet Nose	**Flexible**	**High Conductivity**
reduce thickness of biscuit: reduce solidification cycle	allow perfect work for old machines which need to be overhaulen	better cooling power than steel
has to be aligned to machine (risk differing dosing weights)	more parts (complex)	expensive
	higher price	
for process with focus on biscuit thickness: large diameters	for process which is not well aligned: casting press to sleeve and rod	to upgrade from steel when focus is on solidification

7. HTS Plungers

Overview

	PREVIOUS DESIGNATION	NEW DESIGNATION
	ARP Plunger	Plunger CONDUCTA CONDUCTA B CONDUCTA B-R CONDUCTA B-RS
	ABS Plunger	Plunger ENDURA ENDURA B-RS ENDURA T-RS
	ATS Plunger	Plunger ENDURA
	iTherm Plunger	Plunger PERFORMA PERFORMA T-R PERFORMA T-RS

T - Thread
B - Bayonet
R - Ring
S - Spring Bush

Pro tip

To implement the best possible plunger system,
HTS recommends using the entire HTS injection system:

- Plunger lubrication
- Rod
- iTherm® shot block
- iTherm® feed ring
- innoSleeve

The optimal design of the overall system achieves
the best possible performance with maximum service life.

Suggested Use

	CUNDUCTA B	CUNDUCTA B-R	CONDUCTA B-RS
+	easy to change	easy to change	easy to change
	good cooling power	good cooling power	good cooling power
		changeable ring	changeable ring
		big working range (diameter)	big working range (diameter)
–	short lifetime of tip (D90 < 10.000 shots)	longer lifetime of tip (D90 > 40.000 shots)	longer lifetime of tip (D90 > 40.000 shots)
			more parts (complex)
Conclusion	for tryouts or problems at production	for low lot sizes	for low lot sizes
	for low lot sizes	high performance cooling	for better sealing: vacuum
			high performance cooling

ENDURA T-RS	ENDURA B-RS	PERFORMA T-R	PERFORMA T-RS
	easy to change		
higher lifetime	higher lifetime	highest lifetime and good cooling power (conformal cooling)	highest lifetime and good cooling power (conformal cooling)
changeable ring	changeable ring	changeable ring	changeable ring
big working range (diameter)	big working range (diameter)	big working range (diameter)	big working range (diameter)
change not so easy	longer lifetime of tip (D90 > 60.000 shots)	change not so easy	change not so easy
less cooling power	more parts (complex)	less cooling power	less cooling power
	less cooling power		
	change from current CONDUCTA and use existing equipment	for highrunners	for highrunners
for better sealing: vacuum	not focus on solidification	best compromise of lifetime and cooling power	best compromise of lifetime and cooling power
			for better sealing: vacuum

Need more guidance?

Consider us an extension of your team.

DEDICATED EXPERT ONSITE SUPPORT

HTS acts as an integral part of your team, providing dedicated, expert onsite support and collaboration throughout the entire lifespan of your project. At HTS, we ensure you receive comprehensive support and guidance to maximize both the performance of our products and your production performance through each phase of the project, starting before your purchase to installation and setup of components and performance.

TRAINING PROGRAM

Our training program spans the entire die-casting process, encompassing everything from fundamental principles to the operation and maintenance of components, as well as specialized knowledge in casting processes and technologies.

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