

ENGINEER'S GUIDE TO SINTERING

for Refined Component Performance



Do you find forging or machining limiting?

For hundreds of years, sintering has guided powder metallurgy toward better properties while maintaining what makes powder metal special.

Whether you haven't considered powder metallurgy (PM) as a solution, or you need to take your current PM part to a new level, **this guide will give you several great takeaways:**

- The basics of sintering, and how it differs from melting
- The benefits of conventional sintering and sinter hardening
- How high-temperature sintering takes part properties even further
- How ultra-high-temperature sintering surpasses them all
- Where advanced sintering can replace traditional manufacturing processes
- Special techniques to improve your assembly

By the end of this e-book, you'll have a reinvented idea of what sintering can do. With more freedom than ever in material use, you can **create parts that perform better than you ever imagined possible with PM.**





What is Sintering?

When you start investigating [how powdered metal parts are made](#), learning about sintered metal is essential. Many of the things we love most about powder metallurgy can be **traced back to the sintering process**.

[What is sintered metal?](#) Fortunately, while the fine details are quite complex, the basics are easy to understand. To make small metal parts, you've got to poke them, prod them, and (usually) put some heat to them. Metal is stubborn, and sintering helps **make sure the powder behaves after your part is formed**.

The sintering process, exclusive to powder metallurgy, involves heating a compacted powder to fuse the particles. This forces the part to become **harder and stronger**. While the compaction process does a lot of that work, the physical pressure produced in the press isn't enough to create a final, work-ready component. Sintering is the final major step to produce a component you can rely on.

Sintering can accomplish a lot when done right, including:

- Reducing pores
- Increasing strength
- Partially or fully diffusing other elements in the mix, such as nickel, copper, and graphite
- Improving thermal conductivity
- Improving electrical conductivity

Before & During The Sintering Process

To get a clearer idea of how sintering fits into powder metallurgy, let's start at the beginning of the powder metal process:

1. Choosing a Powder Composition: After talking with you about your performance requirements, your manufacturer will pick a composition of iron, nickel, etc. that will yield the desired properties. It will also include lubricants to improve the flow of the powder into the die and facilitate ejection of the part after compaction. In a single-furnace setup, lubricants are [removed by evaporation](#) and heat before sintering.

2. Compaction: After the powder is poured into the die, it's pressed with controlled high-pressure forces to interlock the powder. This new formation won't exactly crumble in your hands, but it still needs to be finished by sintering to achieve optimal strength and hardness.

3. Sintering: Your components head through a furnace set to just below the melting point of your parts' primary metal. This causes the metal particles to bond.



Sintering vs. Melting

It's easy to assume that sintering is just like melting, the core process in casting operations. Actually, there are distinct [differences between sintering and melting](#).

The melting process actually **changes the metal from solid to liquid**. Sintering is different because the heating process is highly controlled. You get the enhanced properties you need without quite reaching the point of melting. One of the great things about sintering is that you can easily make parts out of metals with high melting points.

We'll talk more about the advantage of sintering compared to other manufacturing methods later in [this](#) e-book.

Good: Benefits of Conventional Sintering & Sinter Hardening

A discussion about the efficiency and performance possibilities of modern metal manufacturing is incomplete without sintering.

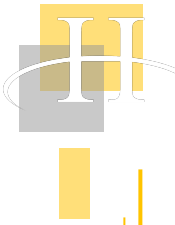
Sintering fuses the loosely bonded particles that comprise metal powder, providing a boost in strength and hardness. After sintering the part is often **reheated to allow quenching, then tempered to further increase hardness and strength**.

Sintering of iron-based PM parts is usually done at around 2020-2100°F.

Sintering is a process of diffusion bonding. Below a material's melting point, adjacent grains of metal begin to share molecules. This forms "necks" between the grains that lock them into a rigid structure.

Time for an example: Often you need to diffuse and homogenize an additive to the powder. Most commonly, die-pressed ferrous powders are produced with almost no combined carbon because alloyed carbon reduces compressibility, **and in turn density**. But a carbon-free part will lack the strength required for many applications. So, graphite is added to the powder mix -- it diffuses completely into the iron powder during sintering, making steel.

Copper is another elemental alloy used in many PM parts, for much of the same reason. Once initial diffusion happens, the subsequent diffusion of the copper into the iron slows down. Thus, the copper is not completely homogenized in the part. Other elemental elements (such as nickel) will only partially diffuse because they have a higher melting point. Yes, you can pre-alloy these elements but there are **certain trade-offs** to consider, including the inability to achieve high density and somewhat limited alloy selection.



The Case for Sinter Hardening

Whereas sintering can make a metal component ready for service, [sinter hardening](#) does that **and hardens the component in the same process cycle**. Sinter hardening minimizes secondary processing steps and grants greater dimensional precision.

For the metallurgically savvy: Conventional heat treatment (reheating and quenching) forms martensite within the part that **has high hardness but breaks like peanut brittle**. Tempering lowers the hardness slightly but dramatically increases the strength. This has been the tried-and-true method for hardening in both PM and conventional parts manufacturing.

However, using special sintering furnaces coupled with engineered powder materials lets your manufacturer eliminate the reheating step and merge it into the sintering step. You get the same transformation along with the benefits of strength and hardness.

Let's go deeper into what makes sintering stand out from other heat treatment services and competing manufacturing processes

Conventional Sintering



Greater flexibility in material selection, need to secondary hardening operation (if required), potential for larger distortion due to heat treatment, ideal for DC magnetic properties.

Sinter Hardening



Greater flexibility in material selection, need to secondary hardening operation (if required), potential for larger distortion due to heat treatment, ideal for DC magnetic properties.

Sinter hardening allows for an accelerated process that conserves production and labor costs. But don't forget about the planet – sintering is also an environmentally friendly process.



More on Sinter Hardening vs. Other Heat Treatment Processes

Imagine all the energy that goes into sintering a part. Then you have to re-establish all that energy to (conventionally) heat treat the part. In the era of energy efficiency, **sinter hardening can save 60% of the energy cost** required to heat treat a powder metal part. This is a great way to advance the idea of powder metal parts being “green.” Energy use by the manufacturer **affects your own production costs**, so the comparison below may interest you.

Think of the numbers as a ratio of time and effort it takes to complete each process:

CONVENTIONAL SINTERING, ENERGY CONSUMPTION

Conventional Sintering : **1.0**

Heat Treatment : **0.6** *(could be higher depending on the operation)*

Tempering : **0.1**

Total : 1.7

SINTER HARDENING, ENERGY CONSUMPTION

Conventional Sintering : **1.0**

Heat Reheating : **0**

Tempering : **0.1**

Total : 1.1

Sintering Cost vs. Other Heat Treatment Processes

Powder metal is literally a crucial component of low-cost manufacturing for the automotive industry (and others). The many advantages of powder metal eliminate the need for higher-cost forming technologies associated with other means of fabrication.

Sintered metal products have great net-shaping capability and eliminate or reduce the need to include costly metal removal processes into the production line. This also leads to a great reduction in waste and scrap byproduct, which improves profitability and meets the standards of eco-conscious companies (and states and nations!).

OK, But What About Performance?

Sinter hardened parts offer excellent performance for a variety of industries. Their durability and adaptability have made them proven successes in gearing, automotive, firearms, lawn & garden, and much more.

But what about those projects that require a little extra “something” to outperform competitors?



Great: High Temperature Sintering

When furnace temperatures soar beyond 2020-2100°, sintering becomes high-temperature sintering. **Even a seemingly small change in temperature can have fascinating implications** for component properties and operating costs. Anyone designing or sourcing sintered parts should understand the implications of high temperatures on both price and performance.

High Temperature Sintering vs. Conventional Sintering

OEM customers come to powder metallurgy manufacturers with all sorts of definitions for “high-temperature sintering.” In a way, the definition depends on your perspective. For example, in terms of stainless we’ve heard 2100° called “high-temp.” Technically, that’s (barely) correct because conventional sintering is performed at 2050°.

High-temperature sintering furnace typically runs 100-250° hotter than one used for regular sintering. **We prefer to think of “high-temperature”** for structural powder metal parts as 2100°. For stainless steel PM parts, we consider 2350° an accurate description.

If you’re sintering these materials instead, here’s what we consider high-temperature:

- Aluminum: 1350°
- Copper: 1900°
- Iron: 2150°
- Tungsten: 3200°

So, the definition very much depends on the material you use.

More than 90% of all powder metal parts are sintered at 2050 F°. Raising the sintering temperatures above the conventional range accelerates the diffusion of atoms across the iron particle interfaces. This results in greater sinter neck formation and more pore rounding. Additionally, the homogenization of the elemental alloy additions is enhanced.

Want to hear that again in English? Both of these concepts imply **greater mechanical or DC magnetic properties**, which means a stronger or simply better PM part. High-temperature sintering also allows for the use of more innovative powder metal materials that can give:

- Better hardness
- Potentially lower raw material cost
- ... at the same (or even higher) level of mechanical properties!

In one study, researchers were able to increase a component’s:

- Tensile strength by 30%
- Bending fatigue strength by 15%
- Impact energy (a measure of toughness) by 50%
- Modulus of elasticity up to 10% higher
- All for parts produced at the same density!



Drawbacks vs. Conventional Sintering

Improvements in sintered metal part strength come at a cost. (Isn't there always a caveat?)

The components themselves actually shrink in size by the time they're ready for shipping. Your parts manufacturer can address this during design of the compaction tools. Sometimes manufacturers limit maximum temperature to better control the part size.

Perhaps of greater relevance to buyers and end users, high-temperature sintering is more costly than its conventional cousin. **That doesn't necessarily mean parts produced through this process will be more expensive.**

A paper presented at the International Conference on Powder Metallurgy & Particulate Materials (PM²TEC) [addressed this apparent contradiction](#). Furnaces for high-temperature sintering are far more expensive than those for regular temperature work. In addition, productivity tends to be lower. On top of that, as you get above the 2150° range, [sintering belt life](#) goes down dramatically. Thus, many high temperature furnaces use a pusher design with ceramic trays that carry the parts through the furnace.

Fortunately, a few smart-thinking parts manufacturers have devised setups that avoid some belt-life issues. (The details shall remain a secret.)

Still, the supplier's high production and equipment costs inevitably limits your own costs-effectiveness. That is, unless you take this opportunity to improve your part's properties.

Since high-temperature sintered metal makes for stronger parts, **it's possible to switch to less expensive powder** materials. In some very application-specific cases, this can actually result in high-temp sintered parts that are more cost-effective than those made at conventional temperatures. Another way you can leverage these improved properties is to design smaller parts that require less material – and therefore less investment.

Applications for Metal Parts Sintered at High Temperatures

The best candidates for high-temp sintering are **projects where the component in question is subject to high tensile, and possibly fatigue, loads**. These include components in appliances and [firearms](#), but [especially those in the automotive sector](#). With weight reduction an overarching concern in modern vehicles, any opportunity to reduce part size is a potential contribution toward fuel economy goals.

Improved properties open up new applications for sintered metal, too. More specifically, increased impact strength means sintered metal can be considered where wrought iron and steel are currently king.



Best: Ultra-High-Temperature Sintering

We've discussed how high-temperature sintering can **take your component's properties to a level conventional sintering can't match**. But through unique, recent advances in powder metallurgy, you can take your component yet another step further -- through a process we like to call [ultra-high-temp sintering](#) (UHTS).

Strength Improvements

Sintering has always come with a tradeoff of lower ductility. But with ultra-high-temperature sintering, we can mitigate that.

Look at the [MPIF Standard 35](#) most engineers use as a baseline guide for specifying PM materials. At the same tensile strength, without ultra-high-temp sintering, your part will crumble in your hands due to little or no ductility. With UHTS you can **achieve that same level of strength**, but without the built-in brittleness.

Who doesn't want more confidence in the integrity of their design?

Time for an example: Current connecting rod materials are dubious from a properties standpoint -- 100,000-120,000 in tensile strength. What if you could have **2x the strength while taking weight out of the assembly**? That's UHTS. With higher part stiffness, you can **make a 7.1 g/cc density part look and feel more like a 7.3 g/cc part**.

That's the opportunity sintering is creating for structural applications. There's also a whole branch on the PM material family tree that's dedicated to marrying strength with magnetic performance.

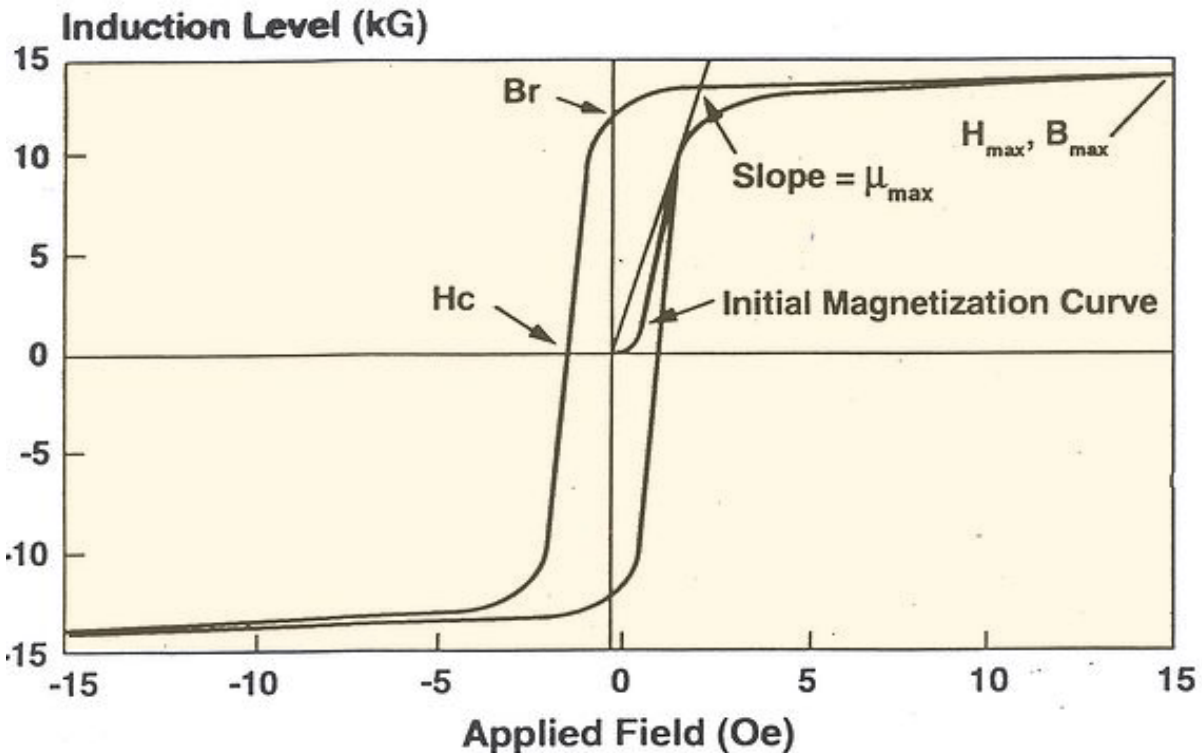
Magnetic Performance

Welcome to the world of [sintered soft magnetic materials](#).

The definition of soft magnetic materials starts with this: **A soft magnet is not permanent**. You can easily magnetize and demagnetize a soft magnet.

The magnet you attach to your kids' homework on the fridge is a hard, or permanent magnet. A soft magnet wouldn't work there because it doesn't consistently maintain magnetism.

So why bother using a soft magnetic powder? We primarily use them to [enhance or channel the flux](#) that an electric current produces.



The [BH curve](#) above provides some key information -- if you know how to interpret it. In the right hands, it can translate to high-performing soft magnetic materials. This seemingly simple chart teaches a lot about magnetic performance, including:

- **Permeability** – a measure of how easily you can magnetize a material. High permeability implies that to achieve a certain level of magnetic induction, you need less applied field or current. This can represent an **energy savings** with the right soft magnetic material.
- **Coercive force** – a measure of how easy it is to demagnetize the material, coercivity is the opposite of permeability. Lower coercive force means less current is required to get back to zero induction.
- **Induction max** – a measure of how much induction your component achieves at a given level of applied field. Knowing the maximum is important if you need a specific level of induction or force. The threshold for induction depends on material type, permeability, sintering methods and environment, residual carbon and oxygen, and any cold work done to the part.

Applications of Soft Magnetic Materials

All of this material and process wizardry isn't just for show. Like powder metallurgy as a whole, the properties of soft magnetic materials allow for several niche applications.

Sintered soft magnetic materials' uses include:

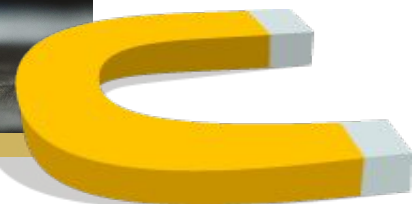
- Solenoids
- DC rotors and stators
- Rotors for brushless DC motors

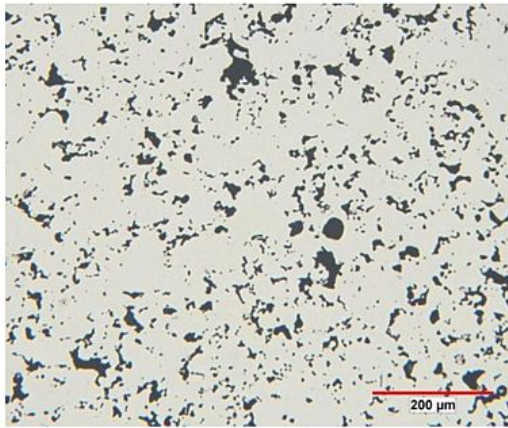
In the case of brushless DC motors, sintered soft magnetic powders lend excellent strength coupled with high magnetic performance.

UHTS expands the variety of metal powders you can use -- even ones not normally associated with conventional ferrous PM. Industry leaders are taking this opportunity to **achieve even greater magnetic properties**. Do we have data to show the improvement of magnetic properties with UHTS

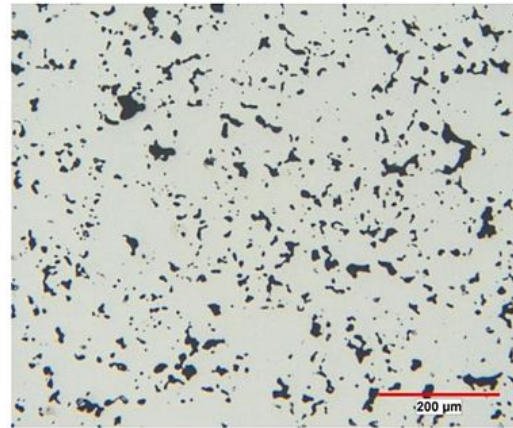
Recently, Horizon Technology collaboratively developed the ability to sinter iron powder parts at temperatures well beyond traditional sintering temperatures. Not only can you now have a combo of prealloyed materials with elemental additions, you can also get significantly enhanced atomic diffusion and homogenization. With greater pore rounding, this technology promises greater **static and dynamic properties**, such as:

- Tensile strength
- Fatigue resistance
- Impact strength





Alloy sintered at 2300° F



Alloy sintered at 2500° F

Let's take a look at the pore-rounding effect of UHTS. Above are unetched photomicrographs of a proprietary alloy developed by Horizon, sintered at 2300° F (left) and 2500° F (right). The sintered densities of both samples were approximately the same (7.1 g/cm^3).

However, on the left you see a large number of fine pores more or less outlining the prior particle boundaries. On the right, the "outlining" is reduced. The appearance of the porosity is more rounded, and the number of fine pores is lower.

Material	Density, g/cm^3	Transverse Rupture Strength, psi	Yield Strength, psi	Tensile Strength, psi	Elongation	Modulus/Stiffness, psi
FC-0208 (iron-copper)	7.2	155,000	65,000	75,000	<1%	22.5 million
FC-0208 Heat Treated (iron-copper)	7.2	150,000	No Defined Yield Point	105,000	<1%	22.5 million
FN-0205 (iron-nickel sintered at 2050° F)	7.1	185,000	130,000	145,000	<1%	21.5 million
FN-0205 (iron-nickel sintered at 2300° F)	7.1	305,000	125,000	162,000	<1.5%	22.5 million (estimated)
Horizon Alloy (sintered at 2500° F)	7.1	350,000	105,000	215,000	<1.7%	23.5 million (estimated)
Powder Forged Connecting Rod Material	7.82 min.	45,000 - 80,000	80,000 - 90,000	140,000 - 160,000	5-7%	30 million
Wrought Steel/ AISI 8620	7.85	N/A	160,000	200,000	5-6%	30 million

Moving from 2300° to 2500° caused the ultimate tensile strength to shoot up from 162,000 psi to ~215,000 psi. Equally important is the improved elongation characteristics in the UHTS samples. Elongation is a good measure of **damage tolerance**. Modulus is a measure of material stiffness; recent research suggests that the pore rounding associated with high sintering temperatures increases the modulus.

If we refer to the [MPIF Standard 35](#) for powder material standards, this combination of properties is **not available in any of the listed materials** at a sintered density of 7.1 g/cm³.

Yes, a 4% nickel steel with 0.5% graphite and 0.85% molybdenum will give higher strength. But this material was also sintered at 2300° and evaluated at a minimum density of 7.3 g/cm³. It showed elongation of 1% or less. The damage tolerance of this material will be less than the UHTS material.

Now that you see the “how,” it’s time to learn the “why.”

UHTS vs. Casting

Engineers who need high performance from their materials should look not just at the materials themselves, but also the processes used to perfect them. Ultra-high-temperature sintering is poised to outperform competing processes in many demanding applications. high performance from material systems.

In the right situation, UHTS is a candidate to replace **cast, machined, and forged parts**.

Related Resource: [More on the advantages of powder metallurgy vs. die casting](#)

UHTS vs. Forging

While modern forging still has great situational uses, it comes with several limitations compared with advanced sintering:

- Lack of control over microstructure
- Higher need for secondary machining, adding costs and lead time
- Cannot produce porous bearings, sintered carbides, or parts with a mix of multiple metals

With ultra-high-temperature sintering, a high level of control is easily achievable. This allows **fine tuning of electrical and magnetic properties, density, damping, toughness, and hardness**.

Related Resource: [An expanded look at powder metallurgy vs. forging](#)



UHTS vs. Machining

Sintered powder metal parts can compete with, and even replace, many machined parts due to far superior material efficiency.

Time for an example: The making of modern transmission carriers is pictured in the dictionary under “wasteful.” Your manufacturer has to throw away a massive percentage of material to achieve the final shape.

You can instead conserve tons of material with a precise powder metal process like sinter brazing. (More on that next.)

Need a big gear on top and a small gear on the bottom? Powder metallurgy can handle that in a single process thanks to its shape-combining ability. Multipiece assemblies can be made as a single part without the need to weld, braze, or stake the additional parts.

Transmission carriers and many other products can be streamlined with sinter bonded or brazed components

Other Ways to Apply Sintering & Powder Metal?

As long as we’re talking about sintering, we might as well share a few bonus secrets.

There are other shape-making options you can explore as you’re learning to incorporate sintering into your processes. These include **sinter bonding** and **sinter brazing**.

Both are great techniques with unique qualities for optimizing your powder metal part. (You may even be able to replace tried-and-true processes like welding!)





Sinter Bonding

In [sinter bonding](#), the manufacturer **bonds two pieces together during sintering**.

Sinter bonding allows you to:

1. Reduce the number of components in your assembly
2. Reduce costs from assembly of multiple components
3. Create complex shapes not typically produced with conventional processes
4. Creates the opportunity to isolate a material in a specific location of a part

What's amazing about sinter bonding is being able to bring two parts together directly, just like welding. This **creates a single sintered assembly**.

Say you need one component to accomplish one goal, but another part to do something else. High-wear applications and magnetic parts are great examples. What if it's essential that only part of your assembly is magnetic? The only way to accomplish this besides sinter bonding is a very expensive process like laser welding.

Sintered bonding can combine any two assemblies, as long as those assemblies have the right properties.

Time for an example: You can use a nickel-iron outside and a copper-steel inside to build one assembly with multiple sets of properties. During sintering, the copper will expand and the nickel will shrink. The differences between the two materials result in intimate contact, and the parts sinter together.

Why Sinter Bonding?

- **Unique shape-making capability:** Some shapes can't be molded, but they can be created through sinter bonding.
- **Eliminates secondary machining & scrap:** With proper planning and execution, you'll reduce material and production costs.
- **Higher strength:** Create a final part that's as strong as either of the original parts.
- **No additional elements necessary:** Simply rely on the unique qualities of the two parts, plus the skill of your manufacturer.



Sinter Brazing

In [sinter brazing](#), you introduce a third, filler material to the mix. This filler melts into the pores of the two parts to create what basically becomes a third component.

The filler material must be in place before the parts go into the furnace. As the parts go through the furnace, the filler material will connect them for life.

Applications for Sinter Brazing

We already know sinter bonding is great -- why not just always use that and save the cost of a third material? While sinter bonding is the most economical way to bond two parts, it's not feasible in all applications:

1. The way each part reacts to heat may make sinter bonding impossible.
2. The material might not be conducive to welding.
3. You may need to limit material properties to a certain part of the assembly.

In the case of point #1, The answer in these cases is **not to resort to welding**, but to use sinter brazing.

Time for an example: Say you want to bond a stainless steel component to an iron part. Stainless [shrinks dramatically](#) post-sintering, but it also grows tremendously when it's in the furnace. As it heats it will grow away from the other part, making sinter bonding impossible.

Yes, welding is an option. But, powder metal parts can contain contaminants -- sometimes due to the material's porosity and sometimes due to other factors. **This can make welding these parts more difficult**, and requires much more technical expertise. Plus there is the **additional cost penalty of welding** -- a penalty that sinter brazing avoids.

For additional ideas of when to use sinter bonding and when to use sinter brazing, [check out this article](#). Now let's address point #3 from above.

Time for an example: If you only want one section of an assembly to be magnetic, you can use sinter brazing to separate the magnetic portion from the nonmagnetic portion. The third material will act as the diplomatic peacekeeper. Sinter brazing serves as a neat workaround when you'd lose functionality by making the whole part magnetic (or another characteristic).

To see a real-world application of sinter brazing, [check out this engine mount system](#) for a world-famous luxury sports car.

A Collaborative Future

As part performance needs to evolve further, advanced powder metallurgy companies continue to tweak the PM formula:

- Advanced compaction technology
- New alloy compositions
- Sintering process improvements

These breakthroughs are **improving density and mechanical properties as we speak**. While these developments are ongoing, there's much we can accomplish in the here and now.

You may not realize it, but **your specs may be a few hundred degrees short** of where you should be performance-wise. It's important you understand what treatment your design needs to get the performance you desire.

That's where your PM parts maker should come in. Parts manufacturers with top-end capabilities may seem pricier, but they'll also give you higher sintering temperatures for optimal performance. They'll also know how to balance your strength and magnetic needs with your price point.

If you need more application-specific advice, submit a question to one of our engineers below:

