High Temperature Sintering – a Cost Effective Way to Future High Performance Materials

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ABSTRACT

The development of high performance materials and more efficient production methods makes a changeover from traditional manufacturing methods both possible and profitable. High temperature sintering is one potentially effective processing technique to capture future applications demanding high performance of the material system. In this paper, an analysis comparing conventional belt furnace sintering at 2050°F to high temperature sintering at 2280°F is presented. The study covers a comparison of sintering costs for a P/M gear made of two different low alloyed steels. Static and dynamic properties of these materials achieved at these temperatures are discussed.

INTRODUCTION

This paper will explore the manufacturing costs associated with sintering at 1120°C (2050°F) using a belt furnace to sintering at 1250°C (2280°F) using a pusher furnace. The cost per hour and cost per pound will be examined. Also examined will be the increased properties achievable with high temperature sintering and the opportunities these enhanced properties provide.

HIGH TEMPERATURE SINTERING VS. CONVENTIONAL SINTERING

In general, high temperature sintering is considered to be from 1175°C (2150°F) to 1425°C (2600°F)[1]. The main advantage of high temperature sintering is the increase in material properties achievable. Increased properties can be attributed to improved diffusion of alloying elements, improved sinter necks, and rounder pores[1]. These microstructural enhancements are the result of increased sintering activity at higher temperatures and lead to improved static and dynamic properties. As properties increase, P/M is able to compete with wrought materials in more and more high performance applications. Increased properties also provide the potential for lower cost high temperature sintered materials to replace more highly alloyed conventionally sintered materials, or to replace more complex processes, such as double press/double sinter or secondary heat treatment.

The disadvantages of high temperature sintering are generally considered to be higher cost, lower productivity, and increased complexity. The initial capital cost of a high temperature sintering furnace can be 50 to 100% greater than the cost of a similar mesh belt furnace. Productivity in high temperature furnaces is also typically lower due to size, cycle time, etc. The operating costs, mainly related to sintering furniture and maintenance of items such as the pusher mechanism, are also generally higher than for mesh belt sintering.

Conventional sintering in a mesh belt furnace also has many advantages and disadvantages. Mesh belt furnaces generally have lower capital, higher throughput, and lower operating costs compared to high temperature furnaces. Mesh belt furnaces are also well understood from an operation and maintenance standpoint, since the installed base is rather high. Conventional mesh belt furnaces are also versatile, allowing such options as rapid cooling. The main disadvantage of mesh belt furnaces is inability to constantly operate at temperatures about 2150, mainly due to the limitations of currently available belt material.

HIGH TEMPERATURE SINTERING VS. CONVENTIONAL SINTERING: CAPITAL AND OPERATING COSTS

The following study compares the cost per hour and cost per kilogram (pound) of operating a high temperature sintering furnace compared to a conventional sintering furnace. For the purpose of this comparison, a 24" mesh belt sintering furnace (capacity = 200 kg (450 lb)/hr) is compared to 12" pusher furnace (capacity = 90 kg (200 lb)/hr) were selected. Table I compares the capital and depreciation costs for the two furnaces.

Table I: Depreciation Cost/hour for High Temperature Sintering vs. Conventional Sintering

	Conventional Sintering	**High Temperature Sintering**
Furnace Type	24" Mesh Belt	12" Pusher
Initial Cost ($)	225,000	400,000
Utilization (%)	85	75
Hours/year[1]	5,100	4,500
Hours/life[2]	35,700	31,500
Depreciation ($/hr)[3]	**6.30**	**12.70**

1. 24 hrs/day * 5 days/week * 50 weeks/year * Utilization
2. Hours/year * 7 year accounting life
3. Initial cost/life (in hours)

As shown in Table I, the total calculated depreciation cost per hour is twice the amount for the high temperature sintering furnace as the conventional furnace. The primary reasons for the increase are the larger initial capital investment and the lower utilization rate. Higher initial capital cost is related to the increased complexity of the furnace. The lower utilization rate is due to the longer anticipated maintenance cycles required due to the increased complexity of the high temperature sintering furnace.

Table II compares the average cost per hour for electricity and atmosphere. The costs and consumptions are based on industry estimates. These cost numbers may be considered as relative for areas where the costs are higher or lower. The consumption values are based on the manufacturer's recommendations for the furnaces in the comparison.

Table II: Electricity and Atmosphere Cost/hour for High Temperature Sintering vs. Conventional Sintering

	Conventional Sintering	**High Temperature Sintering**
Furnace Type	24" Mesh Belt	12" Pusher
Electrical Consumption (kw-hr)	145.2	95.0
Electricity ($/hr)[1]	8.71	5.70
Atmosphere Flow (cfh)	2,400	1,450
Atmosphere ($/hr)[2]	7.56	4.57
Total Electricity/Atmosphere ($/hr)	**16.27**	**10.27**

1. Based on $0.06/kw-hr
2. $90^{v}/_{o} N_2/10^{v}/_{o} H_2$; N_2 @ $0.25/cfh; H_2 @ $0.90/cfh

The overall utility cost is lower for the high temperature sintering furnace. The cost of electricity per hour for high temperature sintering is only 65% of the amount for the mesh belt furnace. This is mainly due to the high temperature furnace's smaller size, the well insulated high heat zone, and lower throughput. The atmosphere cost for high temperature sintering is reduced by almost 40% for essentially the same reasons.

Table III describes the cost associated with maintenance, consumables, and labor for daily operation of the furnace. These costs are based on manufacturer's estimated costs as well as averaged values from costs supplied by several component manufacturers. Sintering furniture in this example is assumed to be ceramic and belt materials are stainless steel.

Table III: Labor, Maintenance, and Consumable Cost/hour for High Temperature Sintering vs. Conventional Sintering

	Conventional Sintering	**High Temperature Sintering**
Furnace Type	24" Mesh Belt	12" Pusher
Labor ($/hr)[1]	5.00	10.00
Consumables ($/hr)[2]	3.15	7.30
Maintenance ($/hr)	5.00	6.90
Total Labor/Maintenance/Consumables ($/hr)	**13.15**	**24.20**

1. Labor @ $15.00/hr; 3 mesh belt furnaces/operator; 1.5 pusher furnaces/operator
2. Consumables include sintering furniture, replacement belts, etc.

The costs associated with maintenance, consumables, and labor is almost 80% greater for the high temperature sintering furnace. Maintenance cost is increased due of the increased complexity of the high temperature furnace, including the pusher mechanism. The consumables for the high temperature sintering furnace consist mainly of the trays used to sinter the components. These trays are generally expensive, fragile, and have a limited service life. Finally, due to the added complexity of loading, unloading, and handling of sintering furniture, the labor for high temperature sintering is generally higher.

Table IV is a summary of the total cost per hour and cost per pound based on the example furnaces and costs described in Tables I – III. The purpose of this summary is to demonstrate the total cost for sintering components based on weight. Weight was chosen as a relative measure of the cost for operating the different types of furnaces.

Table IV: Sintering Cost in \$/kg (\$/lb) for High Temperature Sintering vs. Conventional Sintering

	Conventional Sintering	**High Temperature Sintering**
Furnace Type	24” Mesh Belt	12” Pusher
Operating Cost (\$/hr)[1]	35.72	47.17
Capacity (kg/hr (lb/hr))	200 (450)	90 (200)
Operating Cost (\$/kg (\$/lb))	0.17 (0.08)	0.52 (0.24)

1. Labor @ \$15.00/hr; 3 mesh belt furnaces/operator; 1.5 pusher furnaces/operator
2. Consumables include sintering furniture, replacement belts, etc.

The overall cost per hour for high temperature sintering is approximately 30% higher than conventional sintering based on this example. However, when the cost is considered on a per weight basis, using the example furnaces, the cost for high temperature sintering is three times that of conventional sintering.

ADVANTAGES OF HIGH TEMPERATURE SINTERING: IMPROVED MATERIAL PROPERTIES

With such a high cost penalty for high temperature sintering, it is important to realize significant advantages in properties. Table V shows the potential property increases achievable with a common material, Astaloy CrM®:

Table V: Property Improvements Achieved with Astaloy CrM® + 0.4% C when High Temperature Sintered (density = 7.0 g/cm^3)[1]

Property	**Sintered at 1120°C (2050°F)**	**Sintered at 1120°C (2050°F)**	**Improvement**
Tensile Strength MPa (10^3 psi)	800 (115)	1100 (158)	**30%**
Bending Fatigue Strength MPa (10^3 psi)	290 (42)	330 (48)	**15%**
Impact Energy J (ft-lb)	22 (16)	33 (24)	**50%**

These types of increases in properties will provide the opportunity for P/M to compete with wrought materials in high performance applications. The increase is particularly significant for impact energy, a property where P/M is unable to achieve the values of wrought steels. These increases are due to the microstructural enhancements at high temperature sintering discussed earlier.

ADVANTAGES OF HIGH TEMPERATURE SINTERING: LOWER OVERAL PROCESSING COST

Higher material properties achieved with high temperature sintering also provide the opportunity to either replace more highly alloyed materials sintered at conventional temperatures or to replace more expensive operations, such as secondary heat treatment or double press/double sinter. Table VI describes a case where high temperature sintered Astaloy CrM® + 0.4% C is able to achieve tensile properties similar to a traditional FLN2-4405 sintered conventionally and then heat-treated.

Table VI: High Temperature Sintered Astaloy CrM® + 0.4% C compared to FLN2-4405HT (density = 7.0 g/cm^3)[1][2]

Material	Process Route	Tensile Strength MPa (10^3 psi)	Process Cost $/kg ($/lb)[1]
Astaloy CrM®	Compact + High Temp. Sinter[2]	1100 (158)	0.52 (0.24)
FLN2-4405HT	Compact + Conventional Sinter[3] + Heat Treat & Draw	1125 (162)[4]	0.79 (0.36)

1. Based on estimated heat treating cost of $0.62/kg ($0.28/lb)
2. 1250°C (2280°F), 30 minutes, $90^v/_oN_2/10^v/_oH_2$
3. 1120°C (2050°F), 30 minutes, $90^v/_oN_2/10^v/_oH_2$
4. Properties based on MPIF Standard 35

In this comparison, high temperature sintered Astaloy CrM® is able to match the strength of conventionally sintered FLN2-4405HT with a process cost savings of $0.27/kg ($0.12/lb). This example demonstrates the advantages that can be obtained when high temperature sintering is viewed as an alternative to traditional processing techniques. Another advantage not discussed in this case is the fact that the material cost is also lower for the Astaloy CrM®, increasing the total cost advantage.

CONCLUSIONS

Based on the comparison of high temperature and conventional sintering, the following conclusions can be drawn:

- High temperature sintering is more expensive than conventional sintering for the furnaces in the study. The higher costs are related to capital, maintenance, and consumables.
- High temperature sintering provides the opportunity for significant increases in static and dynamic properties. For Astaloy CrM® + 0.4% C, the tensile strength can be increased 30% and the impact energy 50%.
- Increased material strength allows Astaloy CrM® to achieve similar tensile strength to FLN2-4405HT with a 33% cost savings.
- High temperature sintering's positive affects on properties provides the potential for high temperature sintered materials to replace more expensive materials that require additional processing.

REFERENCES

1. Hu, Bo, Klekovkin, Alex, Milligan, David, Engström, North America Höganäs, Maroli, Barbara, Berg, Sigurd, Höganäs AB "Properties of High Density Cr-Mo Pre-alloyed Materials", *Advances in Powder Metallurgy and Particulate Materials 2004*, compiled by W. Brian James and Russell Chernenkoff, Metal Powders Industries Federation, Princeton, NJ, 2004.

2. MPIF Standard 35: Material Standards for P/M Structural Parts 2003 Edition, Metal Powder Industries Federation, Princeton, NJ, 2003.