Review

Technology Advances for the Growth of Powder Metal in Automotive Applications

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SYNOPSIS

Powder metallurgy has made significant advances in the conversion of wrought steel and castings in automotive applications. North America leads in the total powder metal usage in general and in particular in automotive applications. Technological advances such as advanced binder-lubrication systems, higher density processes, new material systems, improved compaction and sintering technologies contributed to this growth. In this presentation challenges facing the powder metal industry is discussed as well.

KEY WORDS

High density, Cr containing alloys, sinterhardening, transmission market

1 Introduction

The success of powder metal usage depends on a systems approach. Close collaboration among end users, parts makers and powder producers is necessary to optimize a material system for the intended application. Powder Metallurgy (PM) is well recognized as a cost effective alternate to castings, stampings, forgings and screw machining. Listed below are the advantages of PM:

- 97% material utilization
- Net shape production, eliminates or minimize machining
- Cost and energy efficient
- Can be joined with other mating surfaces
- Accepted quality, reproducibility and consistency

The markets for the powder metallurgical parts are varied. Automotive applications have so far dominated the industry growth. However, non-automotive applications are becoming increasingly important. The latter applications mainly include hand tools, household and lawn appliances and industrial motor controls and hydraulics. The market breakdown is shown in Fig. 1. Although most discussions of PM technology and applications focus on automotive, it will be evident that the non-automotive segment is appreciable and similarly worthy of consideration.

Automotive powder metal usage in Asia is shown in Fig. 2. While it is anticipated that the total growth across the world will continue to increase. Auto-builts in North America have tapered off. However, the penetration of PM...
parts as a lower cost alternate nevertheless continues to increase and the expectation is that this trend will continue for the next several years. In addition, it is anticipated that auto-builds in China and Asia are likely to increase over the next several years. In North America, PM parts are consumed on the average of 20 kg (44 lbs) per car, whereas in Europe and Japan, it is estimated to be about 8 – 10 kg (22 lbs) per car. The difference in consumption is attributed to the use of automatic transmissions in North America. The growth of PM is dependent on the ability of technological advancements to deliver products with higher performance than that is currently available (2).

We discuss below some of the new developments in technology.

2 Ancorsteel® 4300

A newly developed alloy – Ancorsteel 4300 – counteracts the common oxygen-related problems associated with chromium through proprietary fabrication techniques (3). This alloy contains nominally 1.0 wt.% Cr, 0.85 wt.% Mo, and 0.6 wt.% Si, and is commercially available as a binder-treated product with nickel and graphite levels that can be tailored for specific application. The advanced processing methods allow for this alloy to be sintered at temperatures between 1120 and 1150 °C.

By combining chromium and silicon within one system, the alloy provides excellent strength, hardenability, fatigue, ductility, and toughness characteristics. An additional advantage of the newly developed material is that parts can be processed in conventional belt furnaces using operating temperatures that do not reduce belt lifespan. Fig. 3 illustrates the compressibility of a new alloy in comparison with diffusion-alloyed material (FD0405) and a hybrid alloy FLN4-4405, which is prealloyed 0.85% Mo with 4% nickel and 0.6% graphite admixed.

Fig. 4 shows the yield strength as a function of density after sintering at 1120 °C for 30–minutes in 90% Nitrogen and 10% Hydrogen atmosphere. Table 1 shows the mechanical properties with two different levels of graphite. The new alloy far exceeds the mechanical properties of a diffusion alloyed material inspite of the fact it has lower alloying elements. The dimensional stability is also superior as shown in Fig. 5. Figs. 6 and 7 show the benefits of accelerated cooling after sintering. At faster cooling rates more martensite is formed which reflects in higher strength and hardness.

![Yield Strength](image)

**Compressibility**

![Compressibility Graph](image)

Fig.3 Compressibility of Ancorsteel 4300, compared with diffusion alloyed material (FD0405) and hybrid alloy (FLN2-4405).

$\text{Table 1} \quad \text{Mechanical properties of Ancorsteel 4300 compared to diffusion alloyed material and hybrid alloy. Sintered at 1120°C in 90N$_2$–10H}_2\text{O atmosphere and furnace cooled (0.7°C per second) and tempered at 200°C for 1 hour.}$

<table>
<thead>
<tr>
<th>ID</th>
<th>YS MPa (10^5 psi)</th>
<th>UTS MPa (10^5 psi)</th>
<th>Elong %</th>
<th>Impact J (ft.lbf)</th>
<th>App. Hard</th>
<th>HRC</th>
</tr>
</thead>
<tbody>
<tr>
<td>4300+0.6gr</td>
<td>760 (110)</td>
<td>1060 (155)</td>
<td>1.9</td>
<td>20 (15)</td>
<td>33</td>
<td></td>
</tr>
<tr>
<td>4300+0.4gr</td>
<td>655 (95)</td>
<td>900 (130)</td>
<td>2.7</td>
<td>22 (16)</td>
<td>21</td>
<td></td>
</tr>
<tr>
<td>FLN4-4405</td>
<td>540 (80)</td>
<td>860 (125)</td>
<td>2.4</td>
<td>23 (17)</td>
<td>21</td>
<td></td>
</tr>
<tr>
<td>FD-0405</td>
<td>480 (70)</td>
<td>850 (120)</td>
<td>3.2</td>
<td>31 (20)</td>
<td>95 HRB</td>
<td></td>
</tr>
</tbody>
</table>

2050 °F, conventional cooling (1.3 °F/sec), tempered 400 °F for 1 h.
Technology Advances for the Growth of Powder Metal in Automotive Applications

![Dimensional Stability](image1)

Fig. 5 Dimensional stability, as shown by the dimensional change as a function of graphite content. Dimensional change from die was measured after sintering at 1120 °C and tempering at 200 °C for 1 hour.

![Effect of Cooling Rate](image2)

Fig. 6 Microstructure of 4300 grade after conventional cooling after sintering and tempering at 200 °C 1 hour. Mixture of Martensite and pearlite and Bainite.

In Table 2, a comparison is shown of the new alloy grade with wrought steel grades. At 7.0 g/cm³ the properties are equivalent to AISI 8620 quenched and tempered. With higher densities achievable with new alloy grade the performance is likely to exceed the wrought steel grades.

This new alloy is a significant advancement in the use of Cr in powder metal parts. Such continuous advancements allow powder metal technology to be preferred as a lower cost alternate to other metal working technologies.

As powder metallurgy is being accepted as a lower cost alternate to other metal working technologies further advancements were necessary to reduce the cost of processing and also improve material performance. Two developments are noteworthy of mentioning. Heat treatment adds additional cost, as parts after sintering have to be heated to austenitizing temperature and quenched to generate the martensitic microstructure. Often, heat treatment process produces significant distortions leading to material wastage. In order to avoid heat treatment a process called sinterhardening (4) became popular. As the furnace manufacturers were able to add rapid cooling system to the end of the sintering furnace, this allowed sintered parts exiting the furnace to be cooled directly from the austenite phase to predominantly to martensitic microstructure.

Table 3 lists the standard sinterhardening grades. Also Hoegaenae recently developed a sinterhardening grade called Ancorsteel 737SH that allows parts producers to achieve hardness equivalent to heat treated parts in large sections.

### 3 Ancorsteel 737SH Capabilities
A mix of 737SH, 2% Cu, and 0.9% graphite (coded...
Table 3  Typical sinter hardening grades before the development of Ancorsteel 737SH and Ancorsteel 4300.

**Standard Sinterhardening Materials**

**Sample Chemistries: MPIF 35 designations**

<table>
<thead>
<tr>
<th>Alloy</th>
<th>Mo (%)</th>
<th>Cu</th>
<th>Ni (%)</th>
<th>C (%)</th>
<th>Alloy Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>FLN2-4408</td>
<td>0.85</td>
<td>-</td>
<td>2.0</td>
<td>0.8</td>
<td>Hybrid</td>
</tr>
<tr>
<td>FLN4-4408</td>
<td>0.85</td>
<td>0</td>
<td>4.0</td>
<td>0.8</td>
<td>Hybrid</td>
</tr>
<tr>
<td>FLN6-4408</td>
<td>0.85</td>
<td>-</td>
<td>6.0</td>
<td>0.8</td>
<td>Hybrid</td>
</tr>
<tr>
<td>FLN-4608</td>
<td>0.50</td>
<td>-</td>
<td>4.0</td>
<td>0.8</td>
<td>Hybrid</td>
</tr>
<tr>
<td>FLC-4608</td>
<td>0.50</td>
<td>2.0</td>
<td>2.0</td>
<td>0.8</td>
<td>Hybrid</td>
</tr>
<tr>
<td>FLC-4908</td>
<td>1.50</td>
<td>2.0</td>
<td>-</td>
<td>0.8</td>
<td>Hybrid</td>
</tr>
<tr>
<td>FLNC-4408</td>
<td>0.85</td>
<td>2.0</td>
<td>2.0</td>
<td>0.8</td>
<td>Hybrid</td>
</tr>
<tr>
<td>FD-0208</td>
<td>0.5</td>
<td>1.5</td>
<td>1.7</td>
<td>0.8</td>
<td>Diff. Bonded</td>
</tr>
<tr>
<td>FD-0408</td>
<td>0.5</td>
<td>1.5</td>
<td>4.0</td>
<td>0.8</td>
<td>Diff. Bonded</td>
</tr>
</tbody>
</table>

Table 4  Nominal alloy compositions (%).

<table>
<thead>
<tr>
<th>ID</th>
<th>Fe</th>
<th>Mo</th>
<th>Ni</th>
<th>Mn</th>
<th>Cu</th>
<th>Gr</th>
</tr>
</thead>
<tbody>
<tr>
<td>FLNC-4408</td>
<td>Bal.</td>
<td>0.8</td>
<td>2.0</td>
<td>0.1</td>
<td>2.0</td>
<td>0.9</td>
</tr>
<tr>
<td>FLC-4608</td>
<td>Bal.</td>
<td>0.5</td>
<td>1.8</td>
<td>0.1</td>
<td>2.0</td>
<td>0.9</td>
</tr>
<tr>
<td>737SH+2Cu+0.9Gr</td>
<td>Bal.</td>
<td>1.3</td>
<td>1.4</td>
<td>0.4</td>
<td>2.0</td>
<td>0.9</td>
</tr>
</tbody>
</table>

1.4Ni-1.25Mo-0.4Mn-2Cu-0.8C (FLC24808) was compared to two common sinter-hardening grades used in North America, denoted by MPIF material codes FLNC-4408 and FLC-4608 as shown in Table 4. Fig. 8 shows comparative microstructures of the alloys. FLC24808 is clearly more hardenable than the other two alloys, with a 100% martensitic microstructure under these processing conditions.

These microstructural differences lead to significant changes in mechanical properties. The tensile strength of the FLC24808 mix has a far superior strength level compared to FLNC-4408 at the same or slightly lower densities, as shown in Fig. 9. This is a direct result of the complete transformation of the microstructure to martensite. The same trend is observed with FLC-4608. Apparent hardness increases through complete transformation of the microstructure to martensite and by higher sintered densities. Fig. 10 shows how the superior compressibility and hardenability of the FLC24808 mix results in higher apparent hardness values. A much higher cooling rate would be required to raise the hardness of the other materials to the same level.

4 Higher Density

The continuous quest in the PM industry for higher performance requires higher density. Higher density can be achieved by using higher compaction pressures and higher compaction temperatures. However there exists a natural limit to reaching higher densities, the pore-free density. Pore free density is the density of a green compact if all the porosity could be removed. Pore-free density is
5 ANCORDENSE® Process (Warm Compaction)

ANCORDENSE process was introduced several years ago (5). It includes heating both the tooling and the iron powder mix to about 130 – 150 °C (265 – 310°F). This process increased the compressibility of a regular premix by 0.10 – 0.15 g/cm³ at compaction pressures at least up to 700 MPa. Fig. 12 shows a comparison of a regular premix and a warm compaction processed FLN2-4405 premix.

6 AncorMax D® Process (Warm Die Compaction)

In a more recent development (6) a few years ago AncorMax D binder/lubricant system was introduced. It enables the user to reach 0.05 – 0.15 g/cm³ higher green densities than conventional premixes without the need to heat the iron powder mix. It only requires a die temperature in the range of 55 °C to 65 °C. This die temperature is frequently reached during regular compaction processes or it can be reached by preheating the die. Fig. 13 shows the compressibility of a regular premix and an FLN2-4405 premix processed via warm die compaction. This technology limits the part height to 20 mm. Sintered densities of 7.45 g/cm³ is achieved by this process on FLN2-4405.

7 AncorMax 200 Process

This newer technology (7) reduces the lubricant further to 0.4% form 0.55% used for AncorMax D. Allows
complex shapes can be produced. This requires tools to be heated to 83°C and requires no powder heating. Parts as high as 40mm can be produced. Densities achieved are close to 7.5 g/cm³ after sintering at 1120°C.

All these advances allow powder metallurgy to be competitive and meet growing demands from the end users.

PM parts manufactured today utilize several of the material systems described above. Any specific application is dependent on design and material performance to meet the design needs. For the same application, there could be more than one material system and process to match the performance characteristics. The exact material selection is made by discussions with the powder producers, parts producers, and the end user.

Number of changes are taking place in the automotive scene and these may affect the growth of PM. Newer engines, newer transmissions, hybrid power trains all impact differently the growth of powder metal.

8 5 or 6-speed Transmission

The driver for 5, 6 and 7 speed transmissions is the anticipated fuel mileage increase and driving experience (8). The higher the number the closer is the transmission simulating continuous variable ratio gearbox. The outcome could be close to 25% fuel savings. A number of auto companies offer 5 or 6-speed transmissions. Ford and GM collaborated together to develop 5 and 6-speed transmissions. This is applicable to front wheel drives and all wheel drive vehicles and GM plans on producing 3 million of these transmissions by 2010. Ford plans on production as well. Although jointly developed each company will use their own controls to suit their models.

GM 6T70 uses heat-treated gears that are honed to improve noise, vibration, harshness (NVH). A number of opportunities exist for PM in clutches, gearboxes and solenoids. Several variants of the 6-speed transmission are planned in the next 10 years.

AISIN reported a new 6-speed transmission that weighs 15 kg less than the current 4-speed transmission. This uses a Ravigneaux planetary unit and a simple planetary unit, ZF Friedrichshafen AG introduced a new 6-speed automatic transmission with an electronic clutch, which allows significant fuel savings.

9 Dual Clutch Transmission (DCT)

DCT allows a smoother transmission shift. Odd and even number gears are operated by two separate clutches. Borg Warner developed DualTronic™ wet clutch targeted towards manual transmission. It is anticipated that 20% of European transmissions will be converted to DCT. This is currently available in Volkswagen and Audi vehicles. Clutches are controlled electronically or mechanically.

10 Continuously Variable Transmission (CVT)

Instead of depending on gear ratios and living with their limitation, continuously variable transmission is of interest to design engineers since as far back as 1886. It has been revised over a period of years and due to cost considerations was set aside. More recently in the last 10 years or so CVT is making inroads. Three major types of CVT are considered today by the automotive engineers, Van Doorne, Torroidal variator, and hydrostatic transmission.

Van Doorne CVT consist of conical shaped driving pulleys, separation between the pulleys can be adjusted. CVT’s have three main components:
- Metal belt or rubber
- Driving pulley with variable input
- Driven pulley output

The distance between the drive and driven pulley can be varied. The drive pulley is connected to the crankshaft of the engine and driven pulley transfers energy to the drive shaft. If the pitch radius is small in the drive pulley and large on the driven pulley transmission runs slower. If the pitch radius on the drive pulley is large and the driven pulley is small than the transmission runs faster. The belt rides on the grooved pulley, and the distance between the pulley is adjusted by hydraulic pressure, centrifugal force or spring tension. The belt material consists of 9 or 12 bands of thin steel holding together bowtie shaped pieces of metal.

In Torroidal CVT, the belts are replaced with discs and power rollers.

CVT essentially eliminates gearbox and thus the number of powder metal parts.

11 Hybrid Powertrain

Hybrid powertrains are making inroads and they use conventional engine with a permanent magnet synchronous motor-generator and electric inverter. Three types are popular: 1) A series type in which both engine and electric motor driving the wheel in series. 2) Engine charges the battery and the battery drives the electric motor. 3) A parallel type in which engine and motor generator drive the wheels independent of each other. At any time one or the other drives the wheels. In a power split type engine power is divided between driving the wheels and charging the battery pack, which drives the electric motor and the wheel concurrently. Toyota-Prius utilizes power split
configuration. Additionally regenerative braking system captures 30% of the energy that is lost in deceleration in charging the battery. Sophisticated electronic controls are required to manage the whole system of vehicle speed, battery charge, engine, motor-generator, battery, etc. Hybrids use smaller engine and transmission and pose a threat to powder metal usage in automotive.

12 Impact on Powder Metal Industry

New transmissions increase the powder metal usage, as they require more planetary carriers and clutches. Table 5 shows the transmission builds worldwide. NAFTA projected to show a strong growth in 6-speed transmission and moderate growth in 5-speed transmission, Europe a strong growth in 6-speed transmission as well. Asian market also is projected to grow the 6-speed transmissions. CVT make inroads into NAFTA market, but has a strong presence in Asia. Insipite of these manual transmissions in Europe and Asia, automatic transmission in North America continues to show strong growth.

13 Conclusion

Growth of powder metal parts is fueled by technological advancements. Newer chromium containing grades offer easier processing and offer opportunities for replacing number of wrought steel grades such as AISI 8620 (JIS SNCM 220H). Sinterhardening grades offer a lower cost option to replace heat-treated parts. Higher density compaction technologies offer lower cost to replace double press double sinter operations and achieve densities approaching 7.5 g/cm³. Newer transmissions increase powder metal usage whereas hybrids and CVT reduces the powder metal components usage.

References

2) Source—Automotive Magazines—Data compiled by Eric Boreczky (Private Communication).