Progressed Sinter Brazing Technology Enables the Production of Complex Shaped Parts

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Powder metallurgy is a processing method whereby green parts are compacted using dies and sintered .It offers equivalent strength as cast iron and superior design flexibility, and produces near-net shaped parts at lower costs as it reduces the need for machining process. For these reasons, powder metallurgy has expanded its market as a result of VA[*1] applied to cast iron parts. However, while compaction tooling offers design flexibility in two dimensions, it has difficulty in producing parts with height (in the Z-axis direction) due to ejection constraints. We have introduced bonding technology to compaction tooling using powder metallurgy and achieved design flexibility in three dimensions. This paper describes the characteristics of bonding parts and details assurance methods for bonding areas in our current production.

Keywords: powder metallurgy, sinter brazing, planetary carrier

1. Introduction

Sumitomo Electric Industries, Ltd. has many years of experience in powder metallurgy. In 1939, the company commenced trial manufacture of oilless bearings at its research division. Since then, the company has designed, manufactured, and sold sintered products for over 70 years and expanded their application range from air compressor parts for household electrical appliances to gears and other automotive parts. The heart of the sintered product market has recently shifted to automotive parts whose service lives are required to be 5 to 10 years and manufacturing lots ranging from several thousands to several tens of thousands of pieces. In response to such changes in the market, the company has promoted sales of sintered products with main the focus on gears, sprockets,[*2] and other products whose shapes are advantageous to die forming.

On the other hand, powder metallurgy has constraints regarding the design flexibility of sintered product height since the sintered products must be ejected from the dies after being formed.

Automotive parts are increasingly complex in shape as they become more functional, therefore, greater design flexibility in the vertical direction is required for highly functional products. To overcome the design constraints on product height, the company has added machining to some products. However, machining reduces the cost effectiveness of near-net-shape[*3] manufacturing using powder metallurgy. In the course of promoting manufacturing by effectively using powder metallurgy, we have introduced brazing technology to meet the users' needs for more complexly shaped products and have succeeded in opening up a new market for sintered products. This paper outlines the sinter brazing technology and details the products to which this technology is applied.

2. Manufacturing Process of Sintered Products and Their Features

The manufacturing process of sintered products and their features are described briefly in this section.

2-1 Manufacturing process

The manufacturing process of sintered products is shown in Fig. 1. To manufacture ferrous sintered products, copper powder with a grain size of several to several tens of μm, graphite powder, or other alloy raw material, and stearic acid or other chemical that will lubricate between the products and the forming die are added to iron powder with a grain size of several tens to a hundred and several tens of μm, and they are mixed under dry conditions. After they are fully mixed, a predetermined amount of the mixture is fed into a forming die and compacted by a forming press in the vertical direction. The compaction pressure ranges from 500 to 700 MPa and the density of the compact reaches approximately 6.7 to 7.1 g/cm^3 (85% to 90% of the true density). The compact is heated in a sintering furnace. In the heating process, diffusion and alloying of metal atoms bind the grains to one another and create a sintered body having a strength equivalent to cast iron. The sintering temperature and time are usually 1100°C

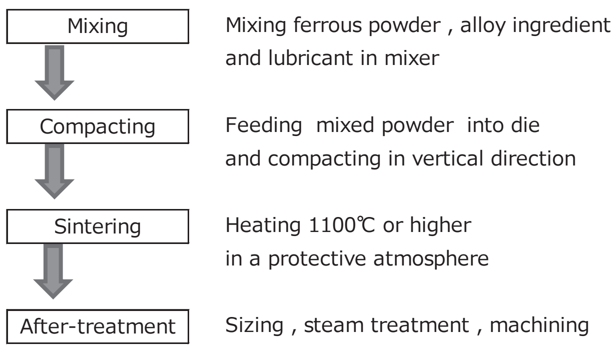


Fig. 1. Sintered Product Manufacturing Process

to 1150°C and 15 to 30 minutes, respectively. When particularly high strength and toughness are required of sintered products, the sintering temperature is raised to 1200°C to 1300°C and the sintering time is extended to 15 to 90 minutes. Sintering is usually performed in a converted gas or nitrogen gas atmosphere.

Sintered bodies go through various processes depending on their purpose of use. Major processes include 1) sizing in which each sintered body is compacted again in a forming die to enhance their dimensional accuracy, 2) machining with a lathe or other machine, 3) heat treatment, such as case hardening and induction hardening, 4) surface treatment, such as plating and steam treatment, and 5) finish treatment, such as barrel polishing and shot blasting. These processes are combined depending on the properties required of the sintered products.

2-2 Features of sintered products

The shapes of sintered products are constrained by the following factors characteristic of the sintering process:

1) Shapes that can be ejected from a forming die
2) Shapes that can receive the metal powders uniformly

To make it possible to manufacture more complexly shaped sintered products by eliminating the above constraints, we have continuously improved the conventional powder metallurgy process. In particular, we have been devoted to enhancing the quality of forming die surfaces, improving the metal powder feeding system, and developing a high-density forming technique. However, these improvements cannot alleviate the constraints in the three dimensional design flexibility of sintered products. Bonding technology is effective for manufacturing sintered products having more flexibly designed shapes.

3. Sintered Products Made by Bonding

3-1 Purpose of bonding

Bonging is usually used for the following two purposes:

1) To obtain a new functional part by combining components made of different materials
2) To obtain a part whose shape is too complex to form with an ordinary die or a part that is difficult to obtain as a single body

Parts of type 1) include a cutting tool made by bonding cemented carbide or ceramic to the edge of a steel member and a lightweight, wear-resistant rocker arm made by bonding a cemented carbide tip to an aluminum body. Parts of type 2) include sintered products and most of other parts having especially intricate shapes.

When it is impossible or too costly to finish a part into an intended shape as a single solid body, the part is usually divided into two or more components. These components are processed individually and bonded or joined together by brazing, welding, bolting, or other proper method. Unlike other manufacturing techniques, sintering allows only a limited number of product shapes. Some products are impossible to manufacture by sintering as solid bodies, even though they can be manufactured by different techniques.

3-2 Classification of bonding techniques

The principal bonding techniques that are currently used for sintered products are shown in Table 1.

Table 1. List of Bonding Techniques Used in Powder Metallurgical Process

Bonding process	Bonding method		Strength of bonded joint	Reliability of bonding	Flexibility of material selection	Flexibility of shape design	Cost
Bonding simultaneously with sintering	Shrink fitting diffusion	Combined sinter bonding	○	○	△	○	◎
	Liquid phase bonding	Sinter brazing	◎	◎	○	○	○
		Copper infiltration bonding	○	○	○	○	×
		Liquid phase bonding	○	○	×	○	△
Bonding in separate process after sintering	Mechanical bonding	Press fitting	△	△	○	○	◎
		Caulking	△	△	△	○	◎
		Bolting	○	○	○	△	○
	Fusion bonding	Welding	○	○	△	○	△
		Friction welding	△	△	○	○	△
	Others	Adhesion	△	△	○	○	○
		Insert casting	○	○	○	○	×

◎: excellent ○: good △: average ×: poor

Two techniques are mainly used to bond compacts. One is bonding simultaneously with sintering and the other is bonding in a separate process after sintering. The first technique, which is used exclusively for sintering, is economical and efficient since it bonds compacts together in the same sintering process. This technique can be further divided into the following three categories:

1) Bonding compacts together using the liquid phase that occurs inside the compacts when they are sintered.
2) Bonding compacts together by solid phase diffusion at a high sintering temperature.
3) Bonding compacts together by a sort of shrink fitting and partial diffusion in solid state. Shrink fitting uses the dimensional difference between the compacts that occurs when they are sintered because of the difference in material.

The technique for bonding compacts together in a separate process after they are sintered is widely used to join ordinary ingot materials. This technique ensures a stable manufacturing quality and is easy to use for general products. Though the concept of joining ingot materials can be also applied to sintered parts in principle, sintered parts require some points to be noted. These points are characteristic of sintered parts and are mainly attributed to the cavities in the parts.

Sumitomo Electric has extensive experience in the mass-production of sintered products by combined sinter bonding, sinter brazing, press-fitting, caulking, and friction welding. At present, the company mass-produces a wide variety of sintered automotive parts by mainly using sinter brazing technology that ensures the highest reliability of joints.

4. Features of Sinter Brazing Technology

Brazing is divided into two categories: Brazing in the atmosphere using a gas torch or induction heating and brazing in a protective atmosphere in a furnace. The latter is superior to the former in reliability and mass-production efficiency.

The mechanism of sinter brazing is shown in Fig. 2. After assembling two or more compacts to be bonded together, brazing filler metals are placed in the contact interfaces. The filler metals melt when the assembled compacts are sintered, and the molten filler metal penetrates dominantly into the contact interfaces and cavities in the compacts due to the capillary action. If a general purpose brazing filler metal is used, the melt will penetrate into cavities without being controlled properly and will prevent the supply of a suitable amount of the melt into the contact interfaces.

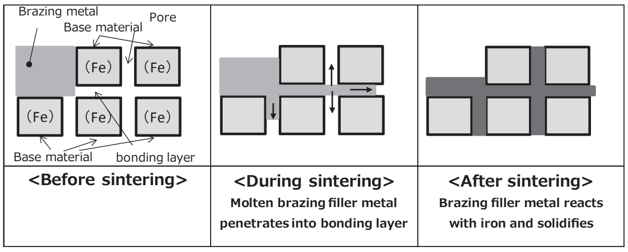


Fig. 2. Mechanism of Bonding by Sinter Brazing

To solve the above problem, we began to develop a brazing filler metal exclusive for sintered parts, and succeeded in developing a Cu-Ni-Mn alloy filler metal.[1] The new filler metal melts at approximately 900°C to 1000°C, which is lower than the sintering temperature of ferrous materials. The melt of the new brazing filler metal penetrates into the surface boundary between two compacts and the cavities in the base material. When the melt penetrates into the material, the melt reacts immediately with Fe in the base material and dissolves Fe. As a result, the solidus line temperature of the melt increases. When the Fe content of the melt reaches a certain level, the melt begins to solidify because of the increase in solidus line temperature and stops further penetration of the melt into the material. As a result, the melt is fed stably into the boundary between two compacts, ensuring secure bonding of compacts even if they have cavities inside.

Proper penetration of the brazing filler metal into a material creates an anchor effect that helps realize firmly bonded sintered parts.

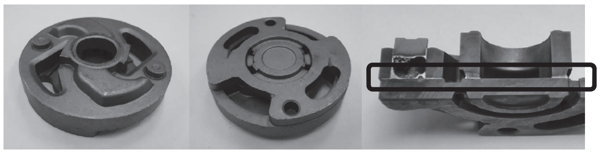
The brazing filler metal we have newly developed facilitates the bonding of two or more compacts together, thereby enhancing innovatively the flexibility of sintered product design from conventional two-dimensional shapes to three-dimensional shapes.

5. Examples of Sintered Products Made by Sinter Brazing

Using the new brazing filler metal that has been developed exclusively for sintering applications, we developed hollow parts that are impossible to obtain by conventional die forming methods. Since 1982 when Sumitomo Electric began to manufacture the first sintered product by using sinter brazing, the company has manufactured various types of sintered products. The following sections introduce some typical examples of these products.

5-1 Power steering pump part

This product is used to regulate the direction of oil flow in a power steering pump. Realization of a complexly configured product in which a hollow portion is formed as an oil path enabled the downsizing of the power steering pump. The external appearance and cross sectional view of the product are shown in Photo 1. Since powder metallurgy techniques are unable to form a hollow portion, the product is divided into two formable components, which are bonded together when sintered. Brazing filler metal completely seals the gaps between the two components and thereby prevents oil leakage when the pump is operated. This product won a 1984 New Product Award in the Design Category from the Japan Powder Metallurgy Association.[2]



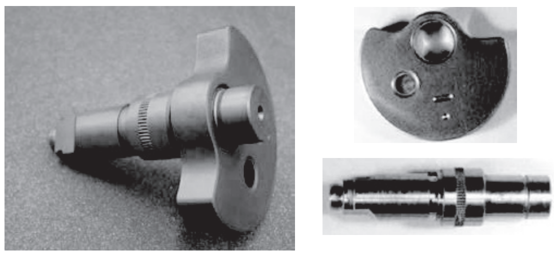
External appearance of product

Cross sectional view of product (bonded portion is boxed)

Photo 1. Power Steering Pump Part

5-2 Part for half-shut automobile door automatic locking mechanism

This product is used in a system for automatically locking a half-shut automobile door. The cam face of this product is required to be wear-resistant. This product is shown in Photo 2. Fabricating this product by welding a



External appearance of product

Die-formed cam (top) Steel shaft (bottom)

Photo 2. Door Automatic Locking Mechanism Part heat-treated cam and a shaft was difficult because blow holes*4 were formed in the welded joint because of cavities and other defects inside these components.

As an alternative method, the cam is formed with a die and bonded to the steel shaft by sinter brazing. The hardness of the sinter-brazed part is further increased by carburization.

5-3 Planetary carrier for transmission

A planetary carrier is a part of the planetary gear mechanism*5 installed in an automobile transmission. As illustrated schematically in Fig. 3, a planetary gear mechanism consists of four kinds of parts: planetary gears, a sun gear, an internal gear, and a planetary carrier.

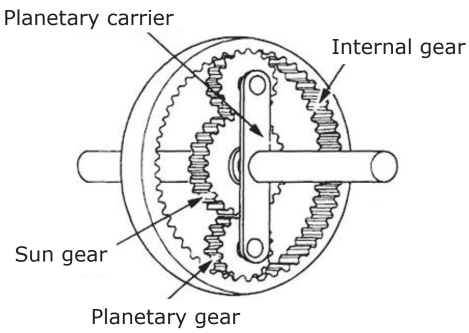


Fig. 3. Planetary Gear Mechanism

A planetary carrier contains hollow portions to carry planetary gears and transmits torque from an engine or motor to a drive shaft. The end face of the planetary carrier is required to have a complex shape because it needs to carry planetary gears and contains oil grooves/holes to enhance lubrication efficiency.

Planetary carriers can be manufactured by various techniques, such as 1) bending steel plates (metal working) and 2) machining cast iron or aluminum blocks. Meanwhile, planetary carriers for automotive applications are manufactured at a rate of several thousands to several tens of thousands pieces per month. Their shapes are complex because of hollow portions, complex end face shapes, and the necessity of retaining planetary gears. Considering the above, sinter brazing technology capable of near net shaping by die forming is appropriate to manufacture planetary carriers.

An example of a planetary carrier we developed is shown in Fig. 4. This planetary carrier retains the planetary gears used in the auxiliary transmission of a 4WD vehicle. This sophisticated product consists of an inner gear spline that works as a mechanical dog clutch and a pillar that works as a planetary carrier. In the past, this product was manufactured typically by combining forging, machining, and welding. However, the above manufacturing technique faced problems with shape accuracy, manufacturing man-hours and efficiency, and the strength of welded joints. We solved these problems by introducing sinter brazing and succeeded in developing a sintered planetary carrier for 4WD applications. Four key points to which we paid attention in the development are described below.

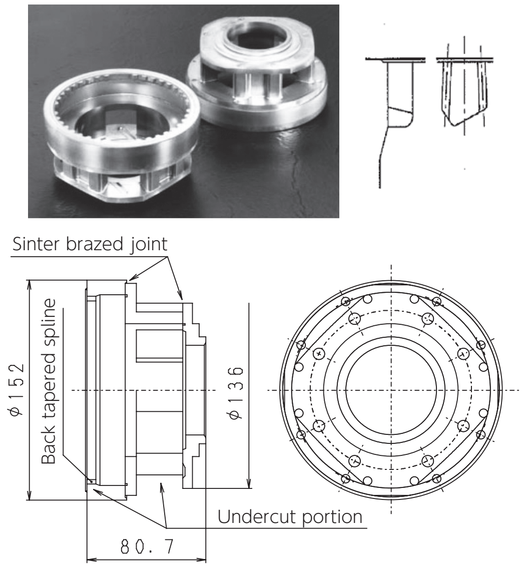


Fig. 4. Sinter Brazed Planetary Carrier for 4WD Vehicle's Auxiliary Transmission Mechanism
(Upper left: Planetary carrier Upper right: Asymmetric, backtapered spline Bottom: Cross sectional views)

1) The planetary carrier has been designed as a structure consisting of three sinter-brazed components in order to form four gear pockets that carry planetary gears and to provide two undercut portions in a high-accuracy, reverse-tapered spline that works as a dog clutch. To manufacture this product, three die-formed compacts are assembled accurately and unified into one body by bonding together with brazing filler metals located in 16 positions.
2) The asymmetrically chamfered inner gear spline (single-chamfered shape), which works as a dog clutch, is made by bonding a die-formed compact to the other compacts when sintered. After sintered, the internal gear spline is further subjected to specific shape correction with a sizing die. We devised this after-treatment process to obtain reverse-tapered splines without machining.
3) An oil groove is die-formed in each sliding surface of the four gear pockets that carry planetary gears. The pockets are then bonded to the other compacts to form an oil groove in a hollow portion that cannot be obtained by machining.
4) When the planetary carrier was designed, its strength was analyzed using the FEM stress analysis method. This analysis made it possible to thin the portions that did not affect the strength and thereby minimize the weight of the carrier without degrading the required characteristics.

This product won a 1996 New Product Award in the Design Category from the Japan Powder Metallurgy Association, a Sokeizai Center President's Award for Sokeizai Industry Technology Development. It also won a 1996 U.S. MPIF P/M Part-of-the-year grand prix.(3)

An example of a planetary carrier currently manufactured by Sumitomo Electric is shown in Photo 3. The portions requiring high accuracy are machined, the gears are die-formed, and the hollow portions are made by making full use of sinter brazing technology. Planetary carriers manufactured by using sinter brazing technology are used not only for AT vehicles and CVT vehicles, but for hybrid vehicles and electric 4WD vehicles. For hybrid vehicles in particular, planetary carriers are used in the power distribution system. Planetary carriers manufactured by using sinter brazing technology are Sumitomo Electric's main products, and the range of their application is expected to further expand in future.

Photo 3. Sinter-Brazed Planetary Carrier for CVT Application

6. Quality Assurance System for Products Manufactured by Sinter Brazing

Since it is impossible to visually inspect the bonded interfaces of sinter-brazed products, inspection of bonding conditions plays a very important role in production engineering and quality control. If an insufficiently brazed product is used in a vehicle, the product will break when the vehicle is driven and may raise a significant problem in the market. Three methods are used to assure the quality of sinter-brazed joints, as shown in Fig. 5.

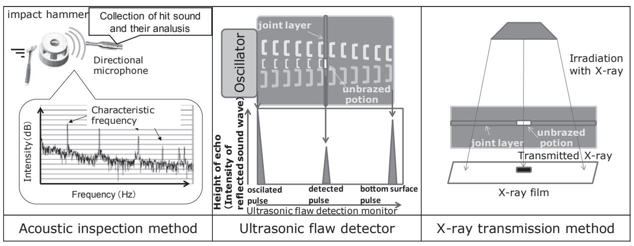


Fig. 5. Quality Assurance System for Products Manufactured by Sinter Brazing

In the acoustic inspection method, the product to be inspected is hit with a copper bar or other proper tool and the sound reflected from the product is analyzed to judge whether the product is acceptable or not. If the product has been completely sinter-brazed, sounds of a natural frequency and waveform will be detected. In contrast, if the product has been incompletely sinter-brazed, the reflected sounds will cancel each other out to create a sound whose frequency is different from the natural frequency. The frequency difference between the above reflected sounds is used to judge whether the product is acceptable or not.

In the ultrasonic flaw detection method, the product to be inspected is irradiated with an ultrasonic wave and the wave reflected from a defect inside the product is detected. When a sinter-brazed product is subjected to this inspection, the ultrasonic wave is focused on the brazed joint surface and the ultrasonic wave reflected from the bonded interface is detected. Whether the product is acceptable or not is judged based on the percent defective on the brazed joint surface.

In the X-ray transmission method, X-rays are transmitted through the sinter-brazed product to be inspected in order to detect defects.

Sumitomo Electric uses the acoustic inspection method and the ultrasonic flaw detection method. In particular, since acoustic inspection devices can be acquired at relatively low cost, the company has installed in-line acoustic inspection systems to assure the quality of sinter-brazed products by one hundred percent inspection.

In addition to the above nondestructive inspections, Sumitomo Electric samples actual products and actually breaks them to inspect the ruptured surfaces of the joints and check their strength. In this manner, the company assures the quality of sinter-brazed products.

7. Total System from Product Design to Evaluation

As shown in Fig. 6, Sumitomo Electric has computerized an in-house total control system that can repeat the cycle of strength analysis, i.e. (FEM analysis) → product design → prototyping → evaluation. When the company receives layout information, specifications (torque to be transmitted, thrust force,*6 etc.), and other necessary product information from a customer, the company can propose the shape of the product, manufacture it, and evaluate its performance. Through effective use of the above integrated development system, the company can manufacture products having complex shapes that cannot be obtained by conventional powder metallurgy techniques.

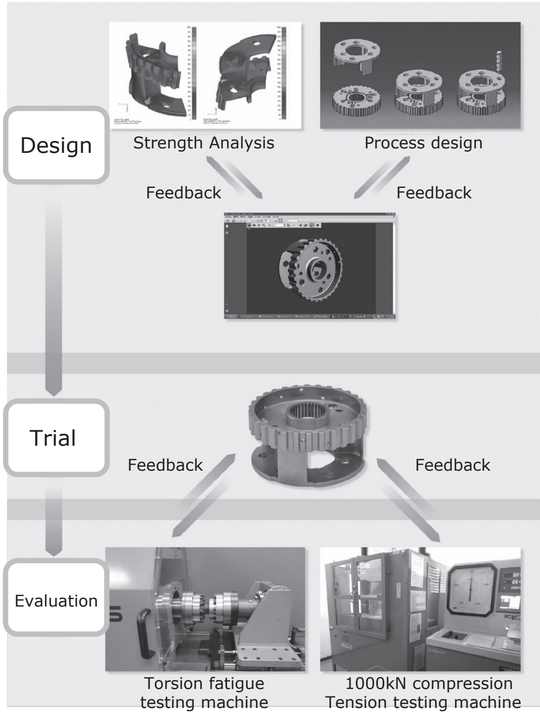


Fig. 6. Total System from Product Design to Evaluation

8. Conclusion

The introduction of sinter brazing technology into die-forming by powder metallurgy has expanded the flexibility of product shape design from two dimensions to three dimensions. Such enhanced design flexibility has made it possible to manufacture sintered products containing oil paths, gear pockets, and other complexly shaped hollow portions, as well as to obtain complexly shaped sintered products to which steel parts are bonded.

Technical Terms

∗1 Value analysis (VA): Analysis of products from the viewpoints of their mechanism and cost to reduce costs.
∗2 Sprocket: A toothed wheel that transmits revolution from a shaft to a roller chain or vice versa.
∗3 Near net shape: A powder-forming technique capable of finishing complexly shaped products without machining or other after processing.
∗4 Blowhole: A spherical cavity defect formed in a welded joint.
∗5 Planetary gear mechanism: A gear speed reduction mechanism in which two or more planetary gears rotate about shafts and at the same time revolve around a sun gear.
∗6 Thrust force: Force acting in the axial direction of a rotating body.

References

(1) Japanese Patent application Publication, No.2-15875
(2) 1984 JPMA Award
(3) 1997 JPMA Award

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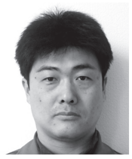

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