High-Productivity Green Machining for Variable Valve Timing Sprockets

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With the increasing performance of variable valve timing (VVT) systems, there is a growing demand for powder metallurgical parts with more complicated geometries. On the other hand, high productivity is also required in the manufacturing process to respond to the increasing demand for VVT parts. Accordingly, we have applied green machining, which achieves both high formability and productivity. This technology allows green compacts to be machined "before sintering," which makes it possible to process parts about nine times faster than conventional post-sintering machining and thus enables volume production.

Keywords: variable valve timing system, sintered parts, green machining

1. Introduction

Variable valve timing (VVT)*[1] is a mechanical system that improves fuel economy and reduces emissions by altering the timing of opening and closing of intake/exhaust valve in automotive engines. Depending on the drive system, VVT systems are divided into two types: hydraulic and electric. The current mainstream is inexpensive hydraulic VVT with a small number of components whose shapes are suitable for powder metallurgy, hence the production of these components has become one of the main fields of the sintering business.

A recent trend toward an even further reduction in the number of components of VVT for cost reduction has necessitated extra multi-functionality and geometrical complexity of VVT components, which are achieved by machining and entails issues about the increase of cycle time and costs for producing sintered parts. Accordingly, we explored the use of green machining*[2] for sprockets, which are components of hydraulic VVT systems (Photo 1), with the aim of achieving high productivity, and had success in enabling volume production.

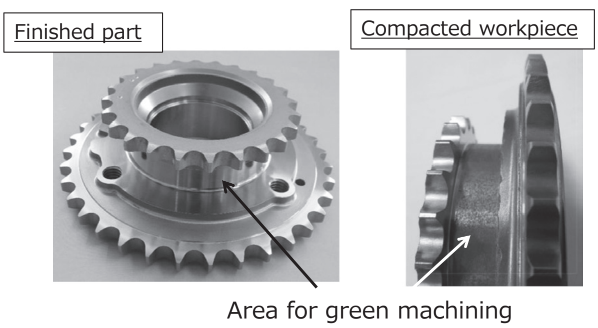

Photo 1. Product in question

The function of the sprocket is to transmit the drive of the chain to the crankshaft and camshaft and it has a large transverse groove near the center of the total length to provide a clearance for chains as a geometric feature. In the conventional powder metallurgy process, grooves are cut by the application of machining onto the sintered blank due to the incapability of forming transverse grooves at compacting with tools, which has increased the cycle time, resulting in declining production efficiency. Consequently, we aimed to achieve high productivity, considering the application of green machining for forming green compacts with the groove at the blank stage. This was achieved by obtaining the shape as close as possible to the finished products before sintering to reduce the machining allowance. Previously, this was not possible because the sprocket's geometry is not suitable for conventional powder metal compacting operation and was a factor that hindered high productivity.

2. Green Machining Development

Figure 1 shows a common manufacturing process of sintered parts. In the compacting process forming the shape of products, green compacts are produced by feeding raw metal powders containing iron as the main ingredient in the tools and pressurizing it at between 500 and 700 MPa in a compacting press. The shape of this green compact is simply made by compacting metal powders, and it is maintained solely by mechanical forces acting between particles entangled with each other instead of the particles being

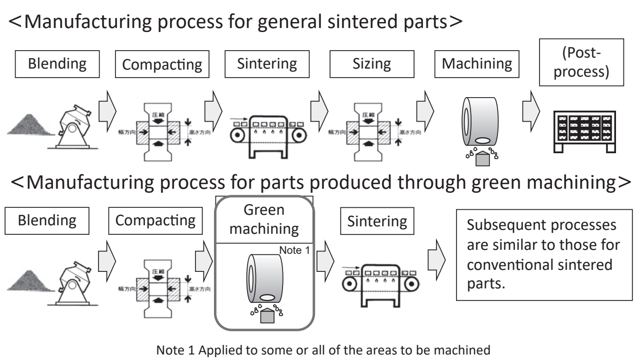

Fig. 1. Manufacturing processes of general sintered parts and parts produced through green machining

metal-bonded to each other. Subsequently, the green compact is heated at a temperature between 1,100°C and 1,200°C at the sintering process, and the powder particles are metal-bonded to each other to form a sintered body, or sintered part, which can be handled similarly to steel parts.

In contrast to conventional machining for sintered body, the green machining technique makes it possible to perform machining with less amount of shear stress because the shape is given by machining the green compact where the powders are not metal bonded (Fig. 2).

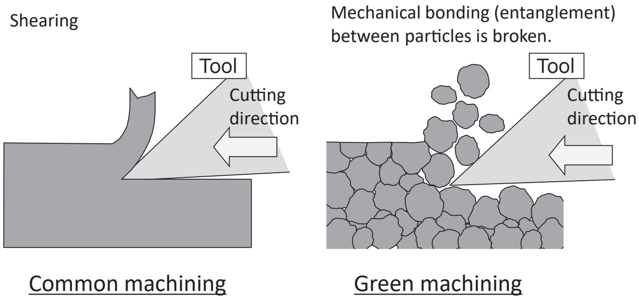

Fig. 2. Comparison between common machining and green machining

The principal features of green machining include: ① High productivity, ② Long tool life, ③ Compact machining equipment, and ④ Formation of no machining burrs due to the absence of plastic deformation of metal particles. In particular, taking advantage of the feature that no machining burrs are formed, green machining is applied in cases where the removal of burrs is difficult, as with cross holes.

However, the greatest challenge involved in green machining is that chipping easily occurs during machining due to the brittleness of the green compact to be processed.

To counter chipping of the compact, two effective measures are taken: ① Improvement of strength of green compacts, and ② Optimization of green machining conditions. The measure ① requires ingredient changes, which is subject to increasing material costs and other costs. Therefore, we aimed for the application of green machining, while optimizing machining conditions without altering the material.

2-1 Green machining tools

The first step in studying green machining conditions was the selection of the optimum tools. It is vital for selecting tools to place importance on the performance of tools that enables machining in a short cycle time for the purpose of volume production as well as minimizing workpiece chipping during machining. Generally, turning tips or end mills are used for machining grooves, however, another specialized tool was selected for the green-machining of the sprocket. This tool has the advantage of being able to machine grooves in less cycle time as it can machine at a higher speed than turning tips and machine wider areas than end mills.

However, there is another drawback for applying this specialized tool to actual workpieces that the number of workpiece chipping cannot be suppressed to a satisfactory level depending on the tool. To address this challenge, we identified suitable conditions for reducing the creation of shear stresses during machining, thereby suppressing chipping. This approach involved optimizing parameters such as tool material, dimensions, and shape, which allowed us to devise the ideal tool for green machining of the current workpieces.

Figure 3 illustrates a layout of the green machining tool. This green machining process removes approximately 15% of the weight of a green compact. The newly developed process had successfully shortened the cycle time for machining significantly about one-ninth that of the conventional style of machining after sintering.

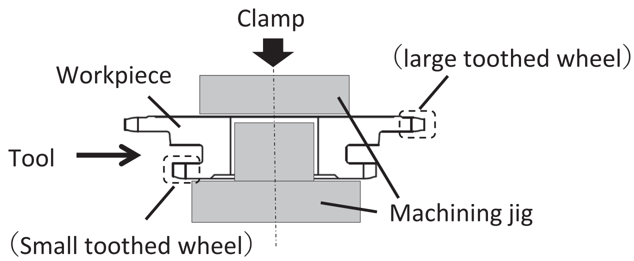

Fig. 3. Layout of green machining tool

2-2 Green machining jigs

Although chipping of the workpiece was reduced by suppressing shear stress due to the optimization of the tool, the problem of chipping still remained in actual machining. In some areas, the occurrence of excessive stress could not be avoided because of the angle at which the tool was applied to the teeth. Specifically, large chips were generated on the side where the machining tool comes out of the small toothed wheel located on the opposite side of the large toothed wheel across the groove. To further suppress chipping, an external force was applied to the workpiece in the direction opposite to the tool's moving direction as a fundamental measure, which cancels shear stresses created in the workpiece during machining.

To implement this measure for the small toothed wheel that exhibited large chipping, a jig was designed to hold the small toothed wheel firmly, which operated separately from the workpiece chuck used during machining. This purpose-designed jig comprised a stopper holding the workpiece and a base securing the stopper. The stopper was formed cylindrically to hold the workpiece, and protrusions provided on the inner side of the stopper backed up the teeth of the workpiece, which reduced shear stresses during machining while suppressing workpiece chipping. A substantial effect was achieved by setting the backup position on the particularly chipping-prone side where the tool was withdrawn. Furthermore, the stopper was engaged with another jig and pulled similarly to the working of a collet chuck, which allowed the protrusions on the stopper to come into contact with and entirely back up the small toothed wheel, thereby preventing chipping.

This system of entirely holding the small toothed wheel with a stopper faced a transfer-related problem that automated attachment and removal with a robot was not feasible due to the absence of a clearance between the workpiece and the stopper. In order to solve this problem, we designed a stopper to hold the workpiece only in areas prone to chipping during machining and to provide a clearance in other areas unrelated to chipping. This enabled automated transfer and volume production while preserving the effect of the cancellation of shear stresses by the stopper. The area of chipping was successfully reduced by about half compared to before implementing the measure by machining the workpiece using this jig (Photo 2 and Fig. 4).

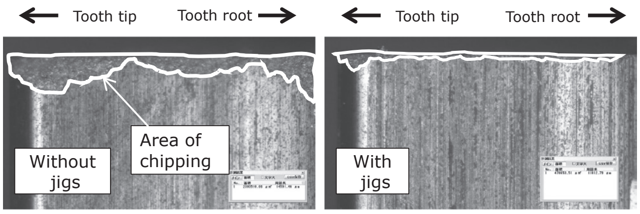

Photo 2. Workpiece chipping (tooth face, on the tool withdrawal side)

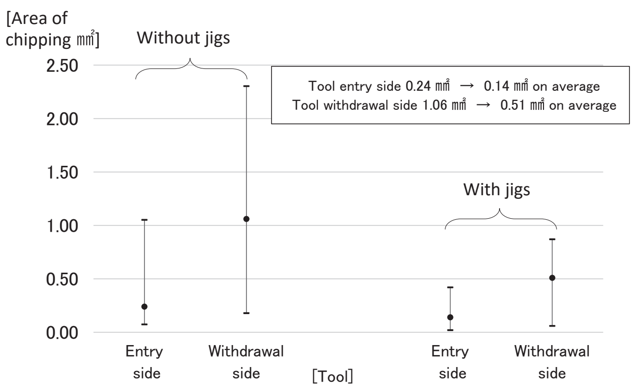

Fig. 4. Areas of chipping during green machining

2-3 Green machining parameters

Regarding green machining parameters, optimal green machining conditions were established through a process window evaluation, as shown in Fig. 5. Tool rotation speeds and feed rates were plotted along the x-axis and y-axis, respectively. A range of optimal green machining conditions was ascertained by checking the occurrence or absence of chipping under different sets of conditions. In actual volume production, the conditions are controlled within a narrower range than that of these optimal green machining conditions to achieve a sufficient safety margin.

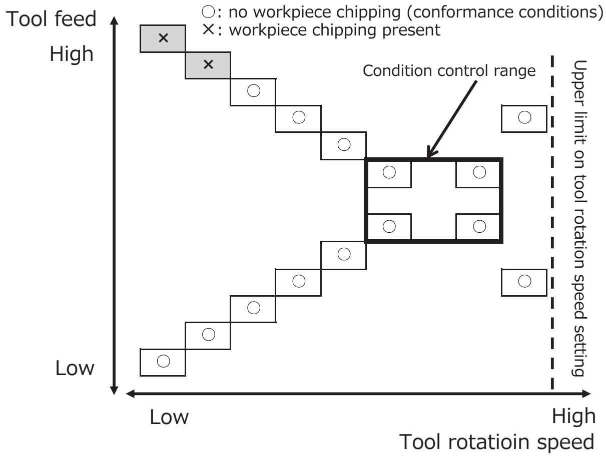

Fig. 5. Process window for green machining parameters

2-4 Reuse of cutting chips formed in the green machining process

Cutting chips produced by green machining can be reused as a raw metal powder because the particles are in a state before undergoing particle fusion by sintering. By making the most of cutting chips through reuse, green machining is a clean technology contributing to resource conservation.

3. Conclusion

Sales expansion of hydraulic VVT systems is expected to substantially spur demand for sprockets. We began volume production of sprockets incorporating high-productivity green machining and have ensured stable supply. We are confident that the expertise obtained through the current development will contribute to the broad dissemination of green machining technology in the future.

Technical Terms

∗1 Variable valve timing system: A system used in four-cycle reciprocal engines that varies the timing of opening and closing of intake/exhaust valve (valve timing) for multiple engine speeds, which was conventionally constant.

∗2 Green machining: A technique for machining green compacts made by compacting powders before undergoing solid-phase sintering, which is used in powder metallurgy.

References

(1) Japan Powder Metallurgy Association AWARD (2019)

(2) Naoto IGARASHI et al, "High-Quality High-Productivity Manufacturing of Variable Valve Timing Parts by Green Machining," SEI Technical Review, No. 85 (2017)

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