Initiatives for Power-Saving Hole Making

Yusuke MAKIUCHI*, Yoichi TAKAHASHI, and Kazumasa KURIZUKA

In recent years, various industries, including the automotive sector, have been advancing their initiatives toward achieving green transformation (GX) by reducing CO_2 emissions in cutting processes. Decreasing CO_2 emissions involves cutting machine power consumption, leading to a rising demand for high-efficiency machining tools that reduce machine cycle time. To meet these requirements, we have developed the MULTIDRILL MDA Series for aluminum drilling and the MULTIDRILL MDH Series for steel and cast iron drilling. The MDA series enables high-precision, high-efficiency aluminum machining, while the MDH series delivers high-efficiency machining with reduced cutting force and power consumption for steel and cast iron processing. These tools contribute to power-saving in hole making processes.

Keywords: green transformation (GX), high-efficiency machining, drilling, PVD coating, stable long tool life

1. Introduction

Solid carbide drills, composed entirely of cemented carbide,*[1] are widely used across various industries, including automobiles. The high rigidity allows for precise drilling, and the excellent wear resistance results in a long tool life. These industries have been advancing their initiatives toward achieving green transformation (GX) to reduce CO_2 emissions in the cutting process. Machine tools, equipped with cutting tools, consume a lot of power during operation, which emits CO_2 when the power is generated. Therefore, reducing machine power consumption is essential for decreasing overall CO_2 emissions. The power consumption of machine tools can be calculated by multiplying the operational power with cycle time. Since the power consumed by the oil pump accounts for a large portion of overall power,[(1)] the reduction in power consumption resulting from improved cutting performance has little effect on the overall power consumption of machine tools. In contrast, reducing cycle time through higher machining efficiency has a substantial impact on power consumption. Therefore, there is an increasing demand from customers for tools specialized for high-efficiency machining. However, the trend toward downsizing and thinning workpieces introduces challenges. These modifications aim to reduce weight in workpieces, but they can lead to deformation and distortion as well. These effects complicate high-efficiency machining with a heavier cutting load. Furthermore, precision is critical in most hole-making processes, particularly concerning hole diameter and position. This accuracy is essential for applications such as through-holes for bolts and pre-holes for taps because of assembly accuracy. As a result, solid carbide drills are required to achieve power-saving through high-efficiency and high-accuracy machining even under more difficult cutting conditions.

To meet these demands, Sumitomo Electric Industries, Ltd. has developed the MULTIDRILL MDA Series for aluminum drilling and the MULTIDRILL MDH Series for steel and cast iron drilling. This paper describes their features, cutting performance, and power-saving effects.

2. Features of MULTIDRILL MDA Series

2-1 High-efficiency machining while improving hole position accuracy

Aluminum alloys are increasingly replacing steel in automotive components and other applications due to their high specific strength. Although aluminum alloys have good machinability, they pose a challenge due to the excessively small chips, which can lead to chip jamming. In order to improve chip evacuation, many drills for aluminum incorporate an overlap thinning*[2] geometry. This thinning broadens the space surrounding the center point. Conversely, this geometry features a wide flat area known as a chisel at the drill center. This chisel makes linear contact with the workpiece during the initial stage of drilling. This contact applies a horizontal force to either the tool or the workpiece and the force results in a loss of hole positioning accuracy. While sharpening the point angle around the center improves centering*[3] accuracy, it negatively impacts chip evacuation due to limited surrounding space. Therefore, it is essential to balance chip evacuation and centering capabilities.

Sumitomo Electric has developed RD thinning by integrating cutting edges of various sizes and by optimizing their arrangement. This RD thinning has achieved a sharper point angle around the center, as shown in Fig. 1, while maintaining a wide chip evacuation pocket. Furthermore, the body design adapts a wide double margin (Fig. 2). The margin serves to contact with the hole surface, stabilizing the drilling behavior. Additionally, the wide sub-margin improves guiding performance and hole accuracy. Through the development of these two geometric features, the MULTIDRILL MDA series has achieved a remarkable improvement in hole accuracy and enabled high feed rates of approximately twice that of conventional products.

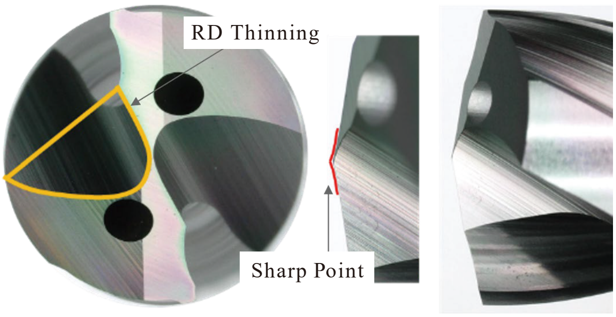


Fig. 1. RD thinning

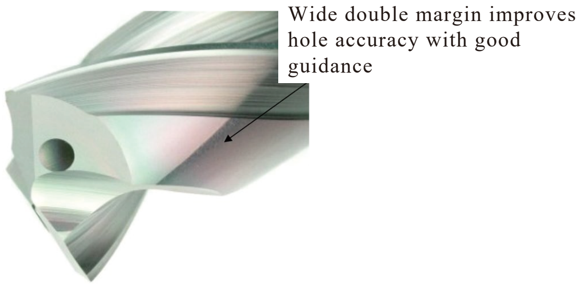


Fig. 2. Wide double margin

2-2 Support for pre-cast drilling

In drilling aluminum alloy components, it is necessary to perform both flat surface drilling and drilling into "cast holes". "cast holes" are commonly found in cast aluminum components (Fig. 3) and are pre-formed during the casting process to reduce machining steps and material waste. Subsequent processes such as threading for mounting bolts and high precision reaming follow after expanding the diameter and the depth with a drill. However, a challenge during pre-cast drilling is that the center of the cast holes may be misaligned with the machining center. If the cast hole is misaligned, any attempts to drill at the target position will result in a bent hole because the machining process follows the center of the cast hole. Higher machining efficiency is increased cutting resistance (horizontal force), and the resistance leads to substantially misalignment. As a result, this ultimately suppresses machining efficiency.

To improve this pre-cast hole drilling, Sumitomo Electric applies two design elements to the MULTIDRILL MDA Series. The first is an enhancement of drill rigidity.

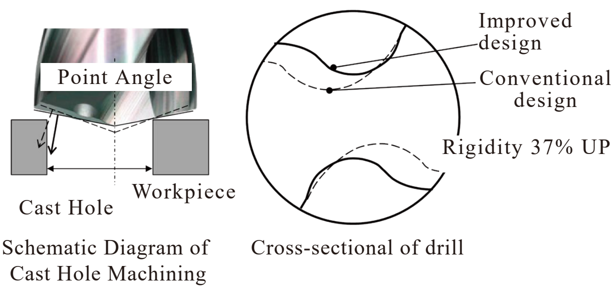


Fig. 3. Pre-cast drilling and MDA flute design

Drills have flutes to evacuate chips, and the flute geometry, which occupies most of the drill body, remarkably impacts on rigidity. While reducing the flutes size can improve rigidity, it exacerbates chip evacuation as well. To address this issue, Sumitomo Electric redesigned the flute configuration, increasing the volume of carbide substrate to enhance overall drill rigidity while maintaining chip evacuation performance. The second improvement is changing the point angle at 150°, making it more obtuse angle than previous designs. Sharp point angle tends to guide the drill into the cast holes easily and can lead to bending. Therefore, obtuse point angle improves the performance against cast holes. The combination of high rigidity and the 150°-point angle substantially improved the hole position accuracy for Pre-cast drilling.

However, while the obtuse point angle is effective for pre-cast drilling, it may negatively affect flat surface drilling. In order to address this issue, RD thinning, described in 2-1, and the obtuse point angle has been incorporated. They compensate for each demerit about centering performance. This approach effectively addresses the drilling into both cast holes and flat surfaces. As a result, MULTIDRILL MDA Series achieves effective drilling into both flat surfaces and cast holes with a single tool under unprecedented high-efficiency machining (Fig. 4).

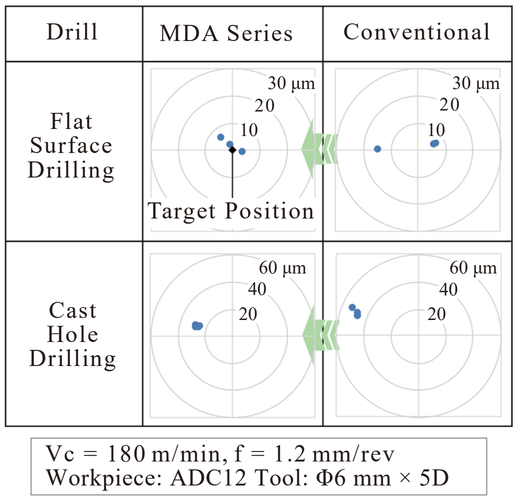


Fig. 4. Hole position comparison

2-3 Improvement of adhesion resistance

Another typical problem in aluminum cutting is tool damage caused by workpiece adhesion. Cemented carbide has a high affinity with aluminum alloys, resulting in excessive adhesion. To address this problem, Sumitomo Electric has applied DLC*4 coating on our conventional drills for aluminum alloys machining. For further performance improvement, the MULTIDRILL MDA Series is equipped with a newly developed DLC coating "Aurora Coat X." "Aurora Coat X" dramatically improves surface smoothness compared with conventional DLC coating (Fig. 5). The high smoothness dramatically enhances adhesion resistance and is expected to reduce tool damage, thereby extending tool life (Fig. 6). In addition, it leads to good chip evacuation and remarkably reduces cutting force during drilling, especially the thrust force (Fig. 7). The low thrust force also reduces the load of the machine tool and workpieces, then enables the unconventional high-efficiency machining high productivity.

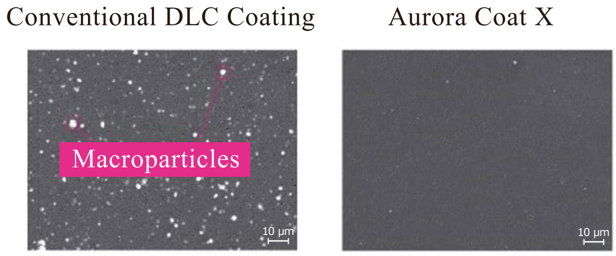


Fig. 5. Coated surface comparison

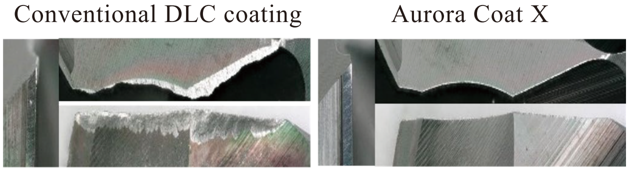


Fig. 6. Cutting performance of Aurora Coat X

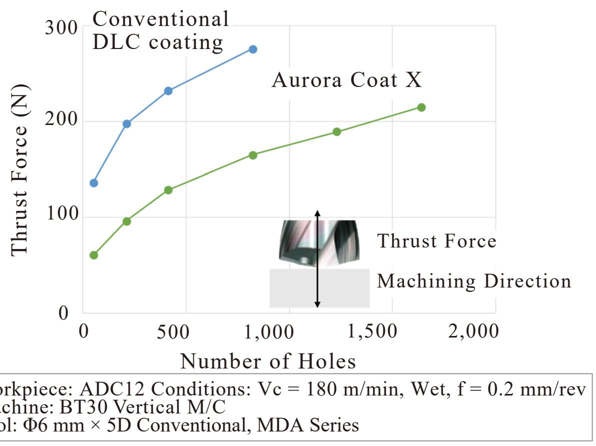


Fig. 7. Thrust force comparison

3. Features of MULTIDRILL MDH Series

3-1 Realization of high-efficiency machining by reducing cutting resistance

Steel and cast iron are widely used for components such as gears and shaft due to their strength and rigidity. However, their higher hardness and strength compared to non-ferrous metals, increase cutting resistance, particularly thrust force. This thrust force dramatically increases the load on the machine tool spindle, potentially leading to stoppages of the machining process. It is widely known that this thrust force is concentrated in the center of the drill and the thinning geometry has a substantial impact. Since the drill operates as a rotating cutting tool, the cutting speed at its center is effectively zero, causing this center point to merely compress the workpiece.

Sumitomo Electric has developed RP thinning, which can substantially reduce thrust force (Fig. 8). This RP thinning enlarges the pockets around the center of rotation to discharge compressed chips rapidly, while simultaneously thickening the chisel width to resist high-efficiency machining of steel and cast iron. This approach has resulted in a substantial reduction in thrust force (Fig. 9). In particular, when the feed rate, which corresponds to the amount of material cut per rotation, is doubled, thrust force decreases by approximately 35% compared to conventional product. This result confirms the effectiveness of this design in high-efficiency machining, which requires a large volume of chip evacuation. Consequently, this design enables the MULTIDRILL MDH Series to achieve twice higher feed rates machining than conventional product.

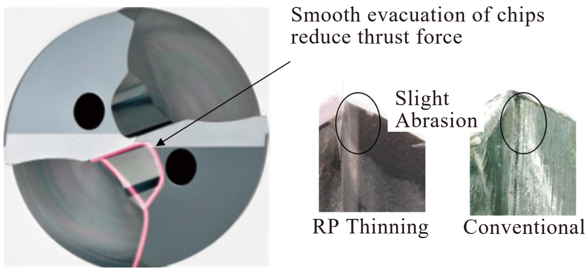


Fig. 8. RP thinning

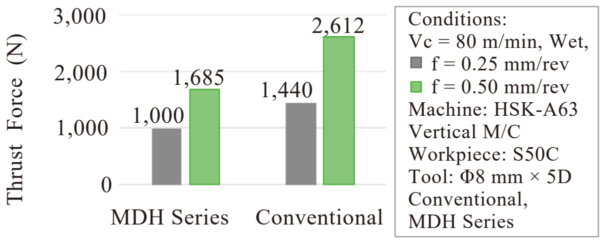


Fig. 9. Thrust force comparison

3-2 Coating and cutting edges to resist high stress

Another challenge in high-efficiency machining of steel is chipping of the cutting edge. In general, cutting tools wear out due to abrasion against the hard components of the workpiece, eventually reaching the limit of their tool life. However, early chipping occurs shortening tool life under high-efficiency machining. Examination of the tool condition just before chipping revealed that the coating applied to the cutting edge preparation*5 was chipping and peeling away, with material adhering to that area. Typically, cutting tool coatings composed of hard ceramic films resist damage from wear. However, chipping is observed much sooner than expected due to the high loads and impacts experienced around the cutting edge during high-efficiency machining.

To address this issue, the MDH Series utilized FEM analysis*6 to optimize the cutting edge geometry and edge preparation, thereby minimizing stress. By constructing the entire cutting edge as a smooth curve, stress concentration is suppressed (Fig. 10), which effectively reduces tool damage.

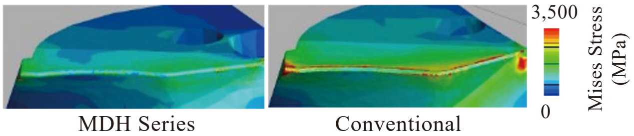


Fig. 10. Simulation of cutting edge stress during cutting

In addition, Sumitomo Electric developed a new PVD*7 coating, "HF Coat," to enhance the chipping resistance of the coating itself. Generally, high chipping resistance coating is thin, low hardness and not good wear resistance.

The new coating consists of two layers: a thick TiAlCrSiN-based super multi-layer that provides high wear resistance and a tough TiAlBN that provides high toughness and high chipping resistance (Fig. 11). This combination achieved stable long tool life even under high-efficiency machining.

Figure 12 compares the tool life of the MDH Series with that of a conventional drill under high-efficiency machining. Tool life was defined as the depth of cutting until the chipping at the cutting edge made continuous use impossible. The conventional tool experienced chipping in the early stages and broke after approximately 44 meters of cutting. In contrast, the MDH Series showed only minor wear and maintained usability for 111 meters of machining, which is 2.5 times longer than that of the conventional tool.

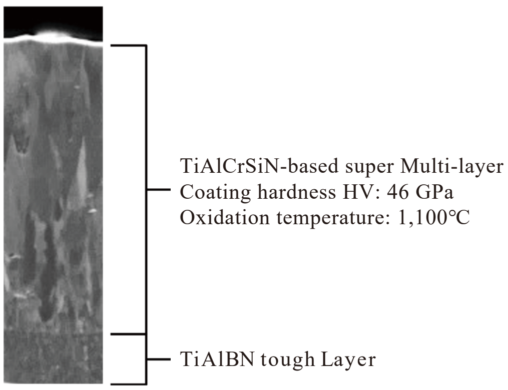


Fig. 11. Cross-sectional of HF Coat

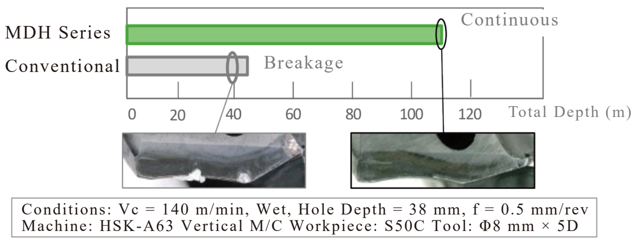


Fig. 12. Tool life comparison

4. Reduction in Power Consumption and Application Examples

Figures 13 and 14 show the results of power consumption measurements during high-efficiency machining using the MDA and MDH Series.

Figure 13 compares power consumption during 10-hole machining in an aluminum alloy using a conventional product and power consumption during high-efficiency machining with the MDA Series, which is four times more efficient than conventional condition. The power consumption represented by the areas labeled as "standby power" and "spindle rotation + cutting power" in the figure. The power consumed during cutting is indicated by the area circled in black, which is enough smaller compared to the standby power and the power related to spindle operation. On the other hand, the cycle time was reduced by 20% from 30 seconds with conventional products to 24 seconds with the MDA Series. In actual machining, the overall reduction in cycle time relative to the increase in machining efficiency is minor due to the time spent to return the drill after drilling. However, the reduction in power consumption is nearly proportional to the reduced cycle time. Assuming that 3,000 holes are machined using this method, this results in an approximate reduction of 1.6 kg of CO_2 emissions. This value was calculated by multiplying power consumption by the national average factor published by the Ministry of Economy, Trade and Industry.

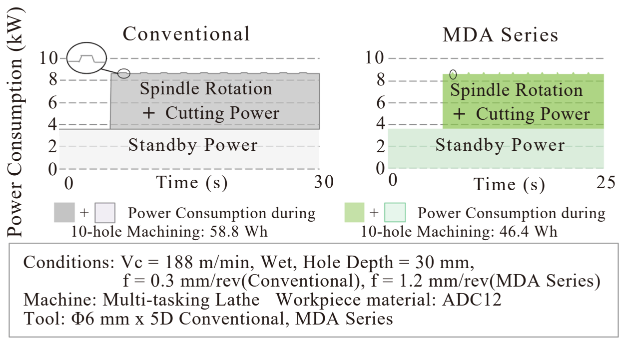


Fig. 13. Comparison of power consumption during machining between MDA Series and the conventional product

Figure 14 compares power consumption during machining under conventional conditions with the MDH Series and conventional products, as well as during high-efficiency machining with the MDH Series, which is the twice efficiency of the conventional methods. The result shows that even under the same machining conditions, the MDH Series consumes less power than the conventional product. This indicates that the lower thrust force by MDH Series than by conventional product reduces the power required to run machine tool. Although the momentary power consumption increases under high-efficiency machining conditions with the MDH Series, the cycle time has decreased from 39 to 22 seconds, resulting in an approximately 36% reduction in power consumption. When machining 3,000 holes, the estimated CO_2 emissions are approximately 1.26 kg, and Sumitomo Electric is confident that this will contribute to our customers' achievement of Green Transformation (GX).

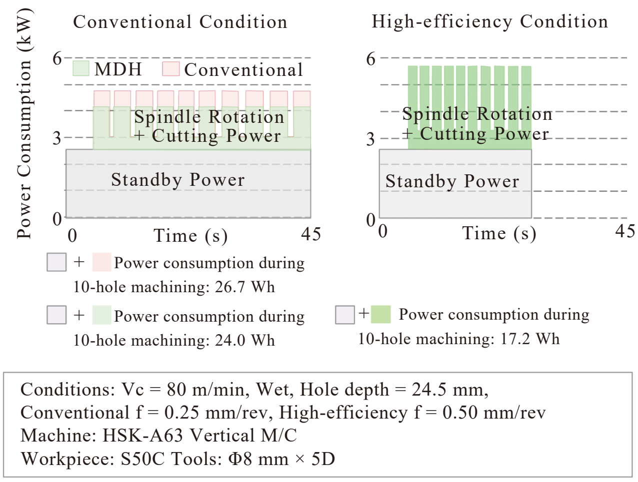


Fig. 14. Comparison of power consumption during machining between MDH Series and the conventional product

Figures 15 and 16 show actual machining examples using the MDA and MDH Series.

Figure 15 shows a case study of increased efficiency and tool integration in machining aluminum cases with the MULTIDRILL MDA Series. Conventionally, a twist drill was used for flat surface, while a burnishing drill*8 was used for cast holes. In contrast, the MDA Series can be used for both drilling applications due to its centering performance, allowing machining with a single tool. Since this integration reduces the time spent on tool changes, the cycle time has been reduced, leading to lower power consumption. Furthermore, the MDA Series achieves twice higher machining efficiency than conventional products, and as well as contributes to further improvement of productivity and power saving.

Figure 16 shows a case study of cylinder parts machined with the MDH Series at approximately three times the efficiency of conventional methods. The conventional product had chipping on the corner edge at the 498-holes drilling, but the MDH Series was good without any chipping even after 1,488-holes drilling under the high-efficiency condition. Although minor wear of the coating film within the edge preparation was observed, it was minimal. This result confirms that by reducing coating chipping, the MDH Series can achieve stable long tool life even under high-efficiency machining conditions.

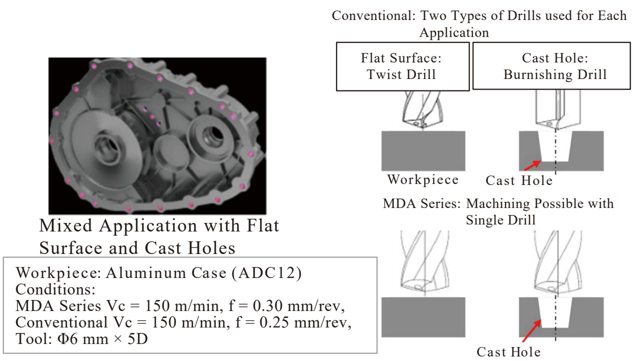


Fig. 15. Example of ADC12 machining by MDA Series

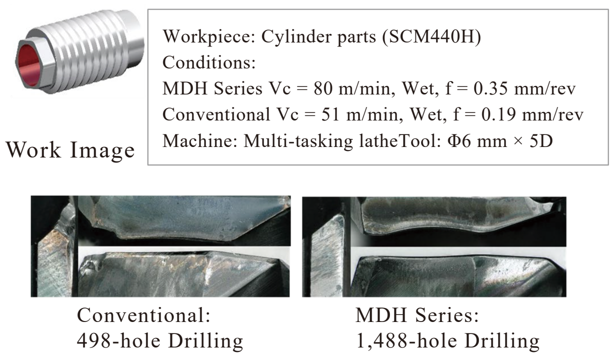


Fig. 16. Example of SCM440H machining by MDH Series

5. Conclusion

As described above, Sumitomo Electric has successfully developed various technologies to enable high-efficiency machining, and as well as have succeeded in developing "the MULTIDRILL MDA" Series for aluminum drilling and "the MULTIDRILL MDH" Series for steel and cast iron drilling. Sumitomo Electric is confident that these tools can substantially increase machining efficiency compared to conventional products and contribute to improved user productivity, as well as reduced power consumption of machine tools.

Technical Terms

*1 Cemented carbide: An alloy consisting mainly of tungsten carbide (WC) as the hard phase and cobalt (Co) as the binding phase. It is obtained by sintering WC and Co powders. This material has high hardness and is widely used for cutting tools that require high wear resistance.

*2 Thinning: A cutting edge formed at the center of a drill tip with flutes.

*3 Centering: The ability of a drill to make a hole at the center of the targeted position while machining.

*4 DLC: An abbreviation for Diamond-like Carbon. It is an amorphous carbon film with high hardness and wear resistance, as well as low friction.

*5 Edge preparation: A slight chamfer applied to the cutting edge of tools to retain its cutting edge strength.

*6 FEM analysis: Numerical analysis using the Finite Element Method (FEM). It is mainly used for strength analysis, eigenvalue analysis, and vibration analysis of structures.

*7 PVD: An abbreviation for Physical Vapor Deposition is a physical technique used to deposit thin films on the surface of materials in the gas phase.

*8 Burnishing drill: A tool that simultaneously performs drilling and burnishing (polishing the machined surface). It is characterized by high rigidity and resistance to horizontal force, but it is difficult to increase machining efficiency.

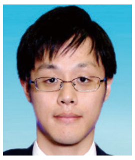
Reference

(1) M. Fujishima, Y. Oda, M. Mori. "Energy Consumption Reduction of Machine Tools," Journal of the Japan Society of Precision Engineering, vol.78, No.9, pp.752-756 (June 2012)

Contributors

The lead author is indicated by an asterisk (*).

Y. MAKIUCHI*
• Sumitomo Electric Hardmetal Corp.



Y. TAKAHASHI
• Sumitomo Electric Hardmetal Corp.

K. KURIZUKA
• Group Manager, Sumitomo Electric Hardmetal Corp.