EAMT Japan Industrial Publishing
English article for Machine & Tool
No.3 2017

This sentence is reconstructed in English from the technical commentary on January 2016 issue of "Kikai to Kogu"; therefore, the nuance may be different. We appreciate your understanding.

Special issue

Creating High Value-added Technology: Cutting of Tomorrow

Current status and future prospect of environment-friendly processing technology

by

Hiroo SHIZUKA

Shizuoka University

1. The need for environment-friendly processing technology

Since the Industrial Revolution, the manufacturing industry has become more convenient and affluent than the lifestyle of people, which has also under gone rapid development. However, such development accompanied consumption of enormous amount of finite natural resources and environmental destruction. In the second half of the 20th century, environmental pollution and global warming were created at the expense of the industrial development. In this regard, conversion to permanently sustainable industrial structure has become necessary while considering the environment.

In the production and processing sector also, environment and ecology became an important issue, for instance in 90s, Dioxin became a hot potato in society and PRTR law (law that controls release of certain chemicals) was stipulated to protect the environment, leading to research and development of environment-friendly processing technologies. Japan and Germany are especially active in the research of these technologies and in Japan, a coinage 'eco-machining' was created and used generally.

In environmental processing technologies, there are many tasks, such as reduction of power consumption, waste of the machine tool, and efficiency of production activities. However, among these, oil solution is regarded to be the most pressing concern. For grinding or cutting, a large amount of the processing fluid is used rather than for the purpose of lubrication, cooling, or cutting waste discharge. Using too much processing fluid can create immense disposal waste. In Japan alone, one million tons of waste liquid are disposed. They pollute the environment as well as affecting human lives. In this regard, reducing usage of the processing fluid remains an important issue to be resolved, and numerous research institutes and universities have been working on this.

As a solution to reducing the processing fluid usage, there are two methods: dry processing and semi-dry processing. Herein, we discuss a cutting processing as the exemplary case study of research.

2. Semi-dry processing

The semi-dry processing is an efficient way to supply a small amount of processing fluid to the processing point. In general, it is called either MQL (Minimum Quantity Lubrication) or NDL (Near Dry Lubrication). The main method involves making processing fluid into mist to supply to the processing point. In Japan, MQL pass for such mist processing mostly.

Mist processing makes processing fluid into mist. This means that mist might not be supplied effectively to a processing point, also damaging the machine. Therefore, how to supply effectively has been the subject of research, and tools in Figure 1 are being sold in the market, supply mist in the vicinity of the cutting point.

Figure 1. Turning holder with oil hole (by Fuji BC Giken HP)

Also, when the particle size of supplied processing fluid is too small, it lead to a divergence of the course of the mist. If the particle size is too big, liquid dropping inside the tube may occur. For such problems, supplying the fluid from the outside or supplying via a machining canter's center-through function lead to optimization of particle size. For the type of processing fluid used in the mist processing, cutting fluid suitable for mist processing is commercially available now. Other fluids for drilling or light cutting are also under development.

In mist processing, it is important to reduce the amount of processing fluid used while obtaining equivalent effect of the conventional processing. There has been much research with respect to the amount of processing fluid being used. Initial study of mist processing showed that 30NL/h is the optimal amount. However, now there has been advancement in mist processing technology and from the author's point of view, 10NL/h is enough to obtain desired lubricating effect.

As explained above, in mist processing, despite minute supply of processing fluid, technology is advancing to the point of obtaining lubricating effect. However, since the amount of supply of processing fluid is much less compared to flood supply, mist processing has a constant problem of insufficient cooling.

The authors have focused on specific heat and the heat vaporization of water and researched oil - water complex mist that can add cooling effect from water. It is seen in Figure 2 that oil and water are being mixed from independent water and oil sprays by using compressed air. The picture on the left shows mist arranged coaxially with a double nozzle, and blowing the oil mist from the center of the nozzle to wrap around in the water mist. Here, lubrication on the cutting edge part is required to supply oil rich mist to obtain water-rich mist, which has cooling effect to the surrounding. Also, when using the conventional nozzle, it can also be premixed. In which case, by changing the water-oil mist composition depending on the work material and cutting conditions, it is possible to adjust the cooling effect and lubricating effect.

The mist processing method using the cooling effect of the water has been studied in many research groups. Especially, Prof. Nakamura and colleagues in Nagoya University developed oil film with a drop of water that produce a mist covering the surface of the water droplets in the oil (OoW: Oil on Water), which has already been commercialized.

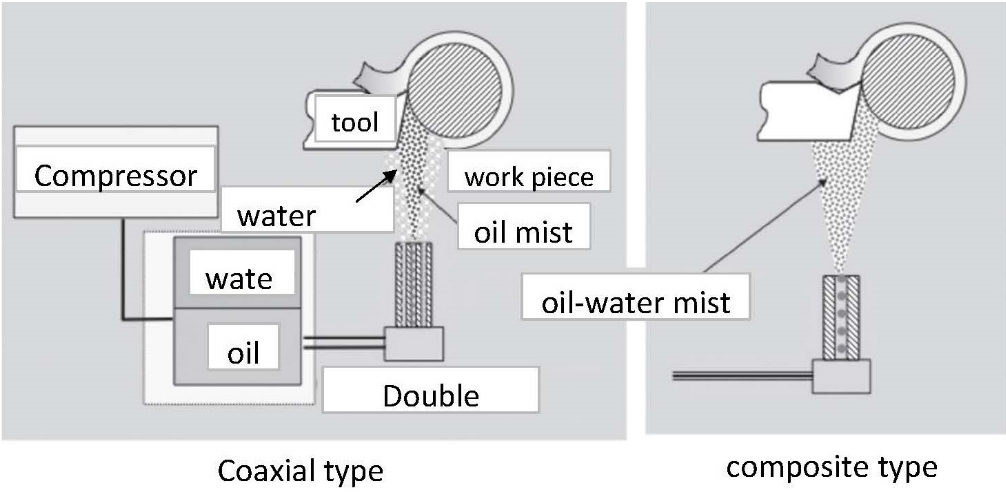

Figure 2. Oil - water composite mist cutting system

3. Other MQL processing method

Although the purpose of MQL processing is to supply minute amount of processing fluid to the processing point, in mist processing, due to loss of scattered mist, not all-processing fluid can reach the processing point. In respect to this fact, our laboratory introduces other methods of supplying small amount of processing fluid.

Figure 3 is an example of supplying minute amount of processing fluid by wall sticking. This method, equipping the tool inverted, reduces the rate of air for the mist production significantly. Since the air rate is low, processing fluid does not become mist, and drops from the double tube center, supplying oil to the cutting edge part by wettability of the tool. Because of this, the cutting edge part is always covered in oil, reducing the amount of processing fluid.

There are other methods, such as Pipette type trace lubricating oil-supplying method. Figure 4 shows a machine with a needle-like pipette at the tip of the tool and drops the processing fluid. Using the surface tension, small volume of air is blown so that least quantity of drop is supplied. Modified from this is Tubing type trace lubricating oil-supplying method that using a roller pump rather than a piston cylinder smaller amount processing fluid can be supplied to the processing point. This is known that only several NL/h of processing fluid can have the same effectiveness as the mist processing. As explained above, many methods regarding MQL method has been suggested. Mist processing is becoming generalized in terms of ease of integration into NC machine and versatility.

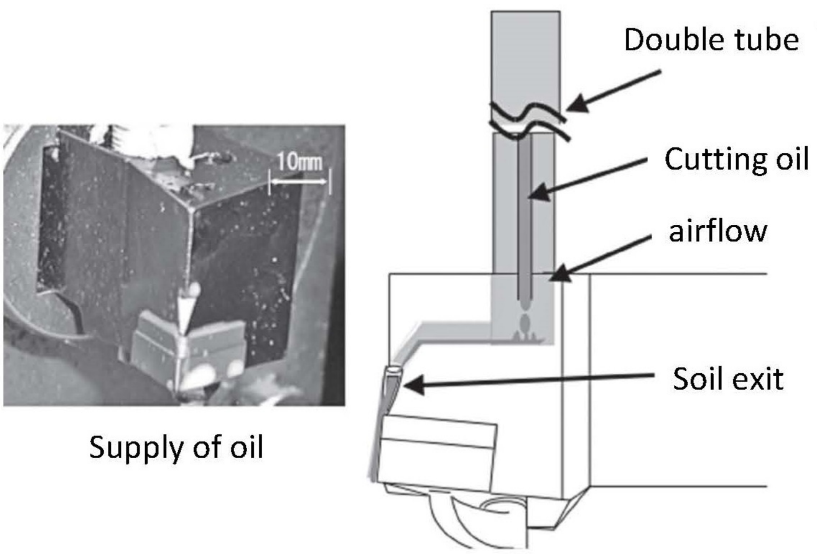

Figure 3. Wall-stick trace amounts of lubricating oil supply method

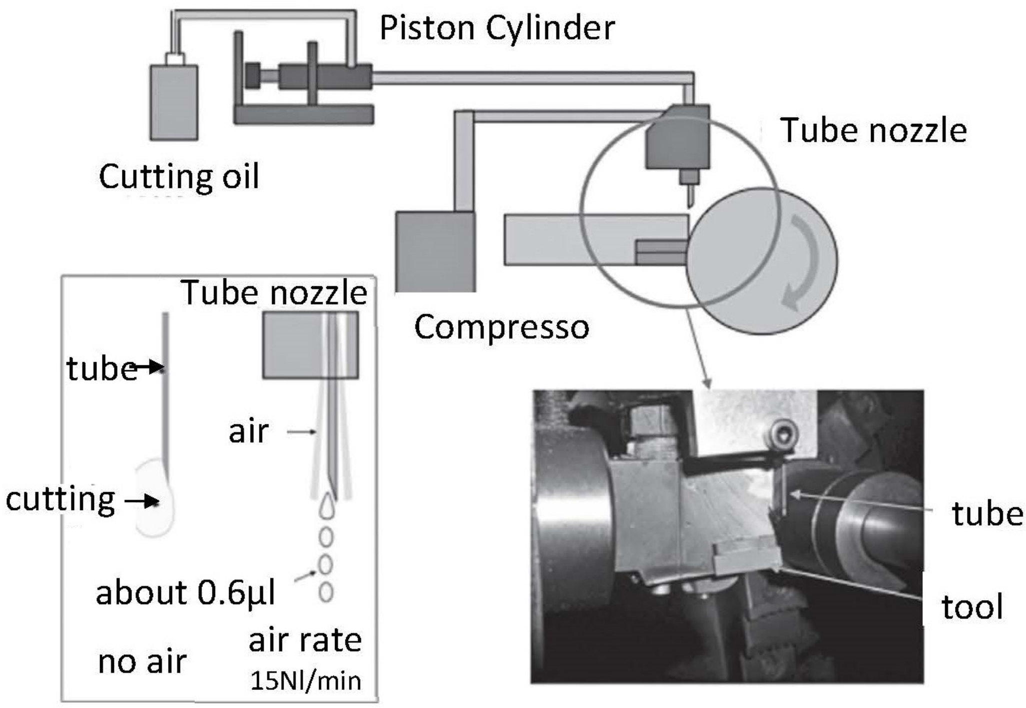

Figure 4. Tube type trace amounts of lubricating oil supply method

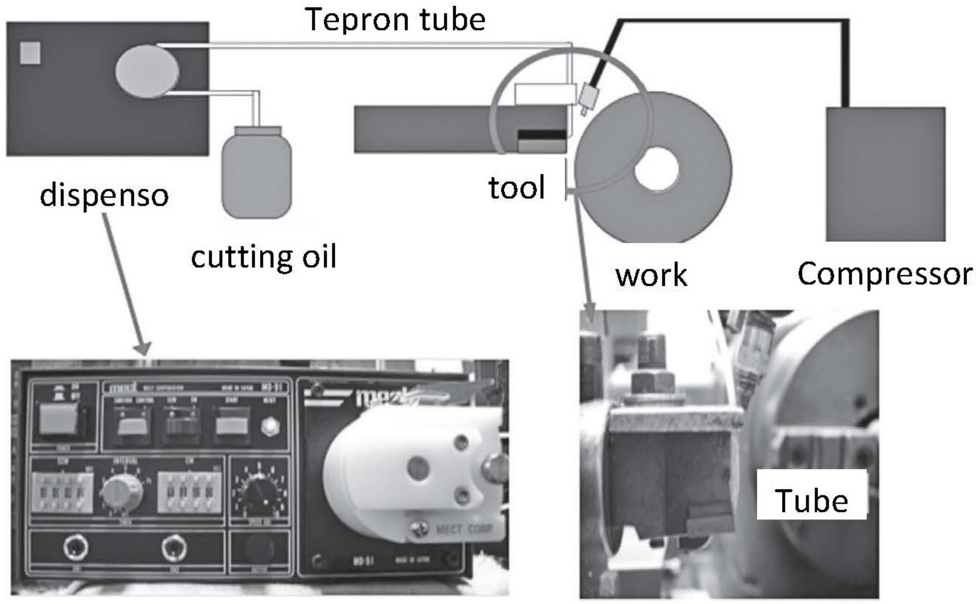

Figure 5. Tubing type trace amounts of lubricating oil supply method

4. Dry processing

In MQL processing, such as mist processing, reducing the amount of fluid processing is possible but it cannot get rid of it completely. As already mentioned, effect of cutting fluid is lubrication, cooling and chip disposal. In order to achieve dry processing, we need to acquire those effects without using processing fluid.

For example, known methods of cooling are cold processing, using heat-absorbing agents (endothermic tool), and etc. Cold air processing is cooling by blowing cold air with a temperature below -30 ℃. Its research history of since 1995 is the longest history as an eco-machining technology in Japan. In addition, endothermic tool is a method of circulating the cooling water inside the tool and absorbing heat into cutting tool.

For the lubricating effect improvement, oil immersion treatment tool that the authors proposed is renowned. This method immerses cutting tool in the oil and treats under high pressure and high temperature, so that the tool itself can possess lubricating effect. Also about the chip disposal improvement, studies such as chip recovery tool has been conducted and some of them are already put into practice. As a unique dry processing technology, we will talk about nitrogen atmosphere processing in the following.

4.1 Nitrogen atmosphere processing

Instead of adding coolants, this is a method of reducing the heat generation itself during cutting. The source of heat generated during cutting, as shown in Figure 6, is mainly from friction between work materials and the tool, causing shear deformation during the chip generation. Also, fresh surface created by cutting gets oxidized, generating heat. Improvement of the above two points is difficult, but the oxidation heat is thought to be reducible by utilizing anaerobic condition during the cutting. Therefore, nitrogen, CO_2, or argon atmosphere can be used as a method of reducing heat from oxidation.

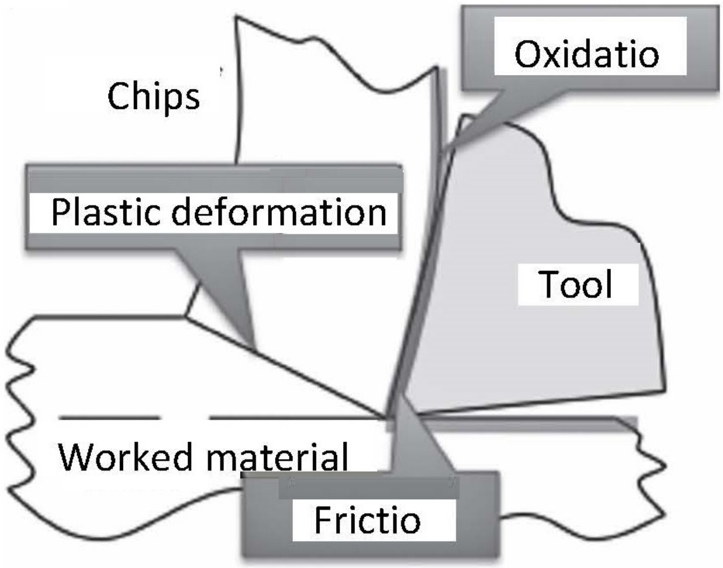

Figure 6. Heat source during cutting

Inert gas research has a long history. It started in 1950s. However, the most plausible reason that it could not be used in practical use is because of its severe adhesion to the tools. Figure 7 is an example in which carbon steel is processed in a nitrogen atmosphere. Severe adhesion is visible in the figure. Usually, any metal surface is covered by an oxide layer and it has low friction coefficients of 0.2~0.7, thus working as a lubricating layer. But when cutting is done in a nitrogen atmosphere, there is no oxide layer, so the surface leads to adhesion due to lack of lubrication. As a solution to this, various tests have been done and Improvement of adhesion was observed in the coating tools and cermet tool. Also, regarding cutting methods, the same adhesion improvement was observed from intermittent cutting and high-speed cutting. Therefore, cutting temperature reduction by suppression of oxidation heat became possible which was the original objective of using a nitrogen atmosphere, and this resulted in tool abrasion reduction as well.

Processing in a nitrogen atmosphere enables reduction of tool abrasion (Figure 8) and improves surface roughness (Figure 9). Such boundary wear (surface roughness) is also called ‘oxidation wear’. This is because it is greatly affected by oxidation. Processing in nitrogen shows reduction of the tool before flank boundary wear can be seen, but because flank is a direct contributing factor to the finished surface that it is

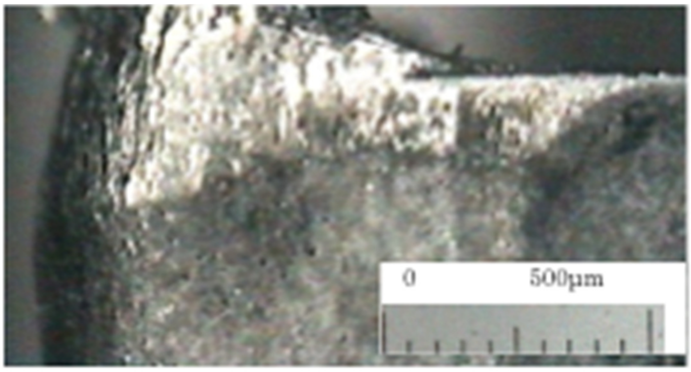

Figure 7. Adhesion in nitrogen atmosphere cutting (v 250m/min, f 0.2mm/rev, t 0.5mm)

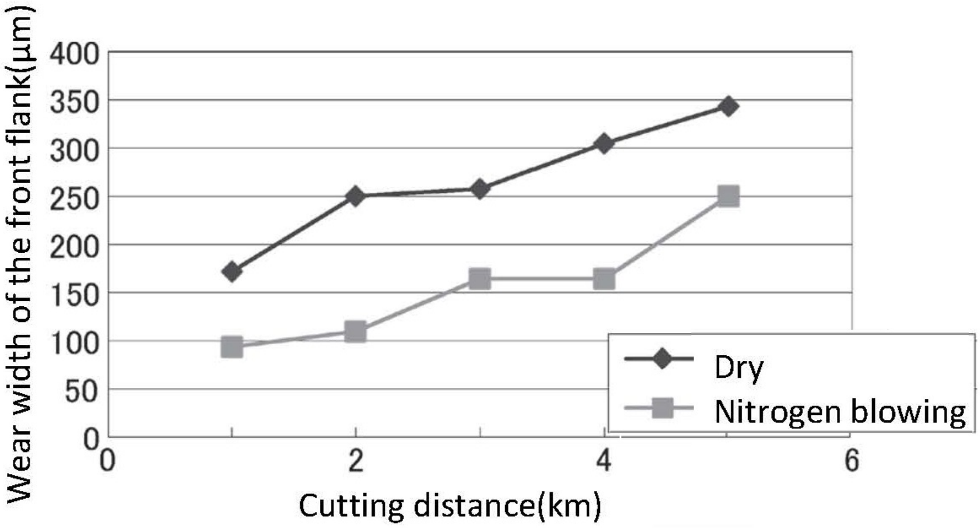

Figure 8. Nitrogen blow by boundary wear reduction

(v 150m / min, f 0.15, t0.5, cermet tool, S45C, intermittent)

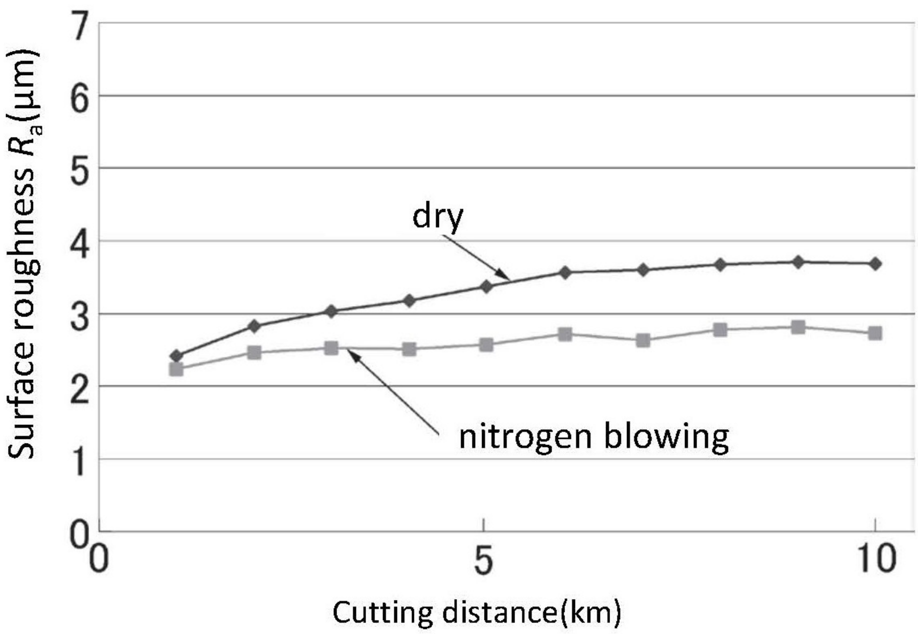

Figure 9. Surface roughness improved by nitrogen blow processing

possible to prevent a decrease in finished surface roughness if we finish this portion where wear reduction is apparent.

For cutting in a nitrogen condition, it is better if the cutting point is surrounded by nitrogen. While it is not necessary to have an airtight container like Figure 10, spraying by a nozzle, collet-through or center-through nitrogen supply are also as effective.

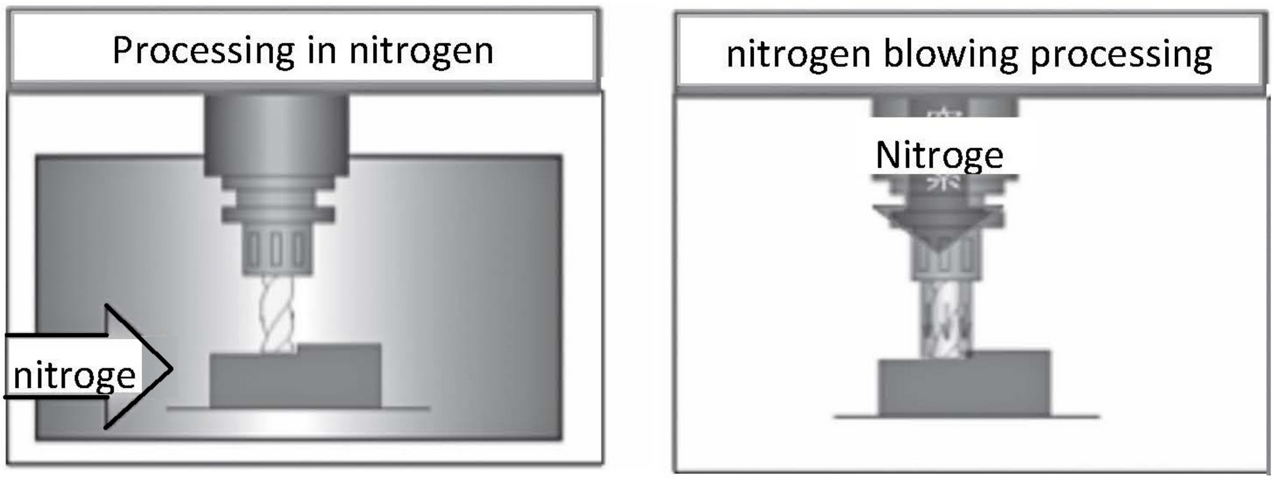

Figure 10. Nitrogen gas supply method

Figure 11 is an example of the high-speed and high-feed processing by blowing nitrogen gas from the collet of end mill. Because this experiment was conducted in a condition where, cutting speed was 3 times and the feed was 5-fold higher than values recommended by tool companies that in dry and air blow processing, red-hot sparks at the tools can be seen like in the picture. Tools within cutting distance of 20m were broken (Figure 12). In this regard, nitrogen blow processing showed no such sparks, reducing tool wear. Therefore, nitrogen atmosphere cutting can reduce tool wear in intermittent, high-speed, and high-feed processing.

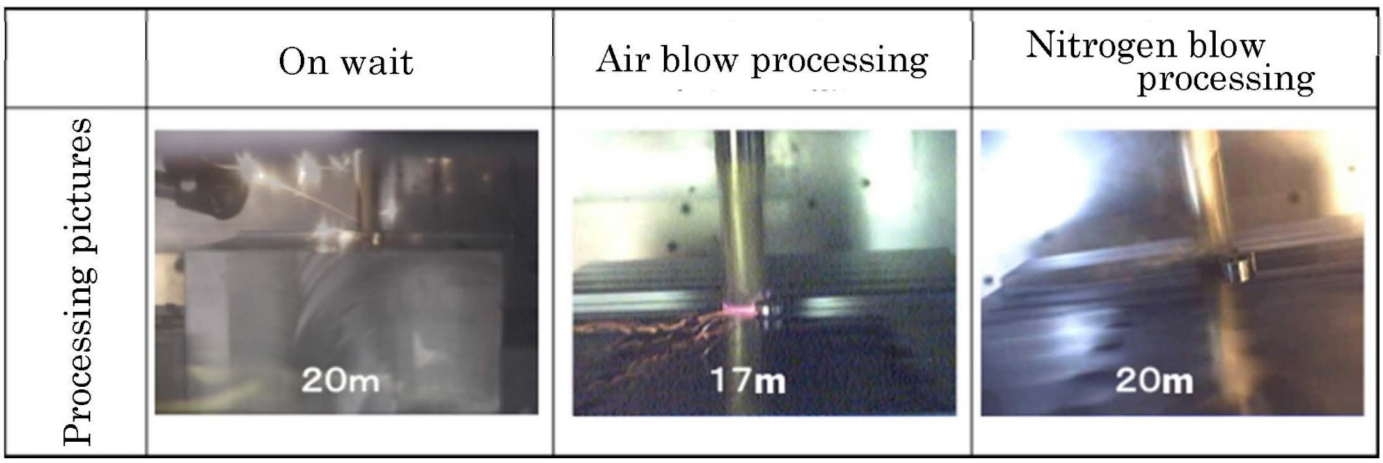

Figure 11. States during processing (v 314m / min, f 2,000mm / min, rd9mm, ad2mm)

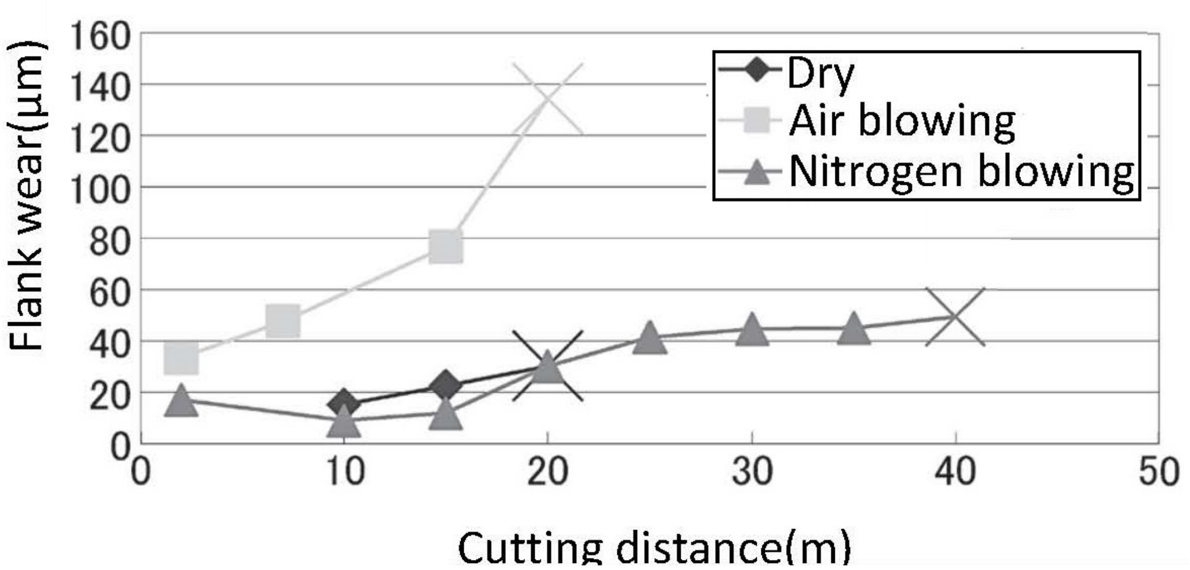

Figure 12. Tool wear reduction in nitrogen blow processing

The aim of the nitrogen atmosphere processing is exclusion of oxygen, reduction of heat from oxidation, and reduction of tool abrasion. However, for example, if titanium alloy is to be cutting processed under nitrogen, it has been found that the nitride is produced at the surface of a work piece. It has also been confirmed to suppress oxidation wear of the tool itself. Furthermore, when the atmosphere is changed to CO_2, the effect of non-oxidation heat suppression, such as ferrous carbonate exhibiting lubricity to the resurfacing of a work piece, has been discovered.

5. Future prospects of the environment-friendly processing technology

When the authors started research into eco-machining (the beginning of year 2000), many people said 'while being environment-friendly is laudable, it is absolutely pointless if it undermines production rate. It is simply not practical'. Also, environment-friendliness had a reduction-in-production ring to it. Even in places of conferences, power saving of MQL and machine tools, and waste reduction were only heard in eco-processing sessions.

However, since mist processing was used in commercially available machine tools as the standard, it is now commonly used in manufacturing sites. Also, in regard to power saving and efficiency of machine tools, and reduction of waste, general impression is that they are widely accepted. The reason that the perception of the eco-friendly technology has changed is that with the development of environment-friendly technology, aforementioned environmental concerns and productivity are leveled.

Upon promoting the environment-friendly technology to a commercialization, these technologies being tied to energy conservation and cost reduction is the most important thing. For example, about the processing fluid, not only its cost of purchase, management, and disposal, but also tremendous amount of energy cost is necessary to keep it running. This leads to huge management cost reduction of MQL processing and dry processing. Moreover, taking processing in nitrogen for example, not only cost innovation by reduction of tool abrasion, but improvement in production efficiency owing to high-speed, high-feed is also possible. Likewise, advancement in environment-friendly technologies is proceeding to a practical stage from a research stage. Here, not all environment-friendly technologies can meet our expectancy in all forms of processing, but by applying these technologies to the suitable processing, we can obtain both environmental friendliness and high productivity. Thus, we forward to seeing these environment-friendly technologies prosper in the coming future.