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Behavior, cutting property and environmental load of machine tool in mist of strong alkaline water

机床在强碱性水雾中的行为，切割性能与环境负荷

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Abstract - ***In the 21st century, as it is important to produce products with care for protecting the earth, a producer must be careful to conserve energy, save resources and reduce waste which pollutes environment. Further, in case of a machine tool, much lubricating oil was used for smooth drive, electrical energy of forced cooling was used for high accuracy and much cutting oil was also used for lubrication and cooling. This is a large problem for protecting the earth. Therefore, the behavior of a machine tool in the mist of strong alkaline water was investigated and evaluated. Properties of strong alkaline water were firstly investigated for alkali-proof, corrosion and safety of health. Then the bench lathe was remodeled in the vessel with the mist of strong alkaline water (pH12.5), thermal deformation between the spindle and the tool post was measured for evaluation of accuracy. And cutting using CNC milling machine in the vessel with the mist of strong alkaline water was performed for investigating the effect of water evaporation in the strong alkaline water. It is concluded from the results that; (1) Alkali-proof regarding several elements of a machine tool and safety of health were cleared in the experiment, (2) The forced cooling using mist of strong alkaline water had a very strong influence. Thus, it could be said that the thermal deformation of structure can be effectively cooled by using a mist of strong alkaline water, (3) Thermal deformation of the bench lathe was very small despite no-forced cooling, (4) Accuracy of the machine tool was very good and the tool life was very long despite no-cutting oil, (5) Mist of strong alkaline was eco-friendly.***

Keywords - **forced cooling, machine tool, high accuracy, strong alkaline water, cutting, eco-Friendly**

I. INTRODUCTION

Since the beginning of the 21st century, the importance to manufacture products in an environmentally-conscious [1] way has been highlighted. In this regard, manufacturers not only need to conserve energy, but they also need to scrutinize in order to save resources and reduce environmentally-harmful pollutants. Nowadays, there are many researches related to the environmental impact of men [2], as well as countermeasures to reduce it [3]; however, these are still insufficient. Particularly, in the field of manufacturing, most machine tools highly depend on cutting and cooling oils to achieve the high accuracy. This represents a large environmental problem, since in most cases the cutting and cooling oils are misused, introduced into the environment and generate undesired pollution [4]. Consequently, the importance of developing new manufacturing ideas that consider parameters such as high accuracy, high quality and a low environmental impact had been underlined. Hence, manufacturers will be in the need of daring plans, unique ideas and new technologies [5].

Therefore, even though the cutting concept of this research is *ecology*, it also included other concepts related to the industrial sector. Among these are: suitable cost of a machine tool, low running and maintenance cost with high precision machining. Thus, this study is to achieve the application of the *ecology* and multiple industrial sector-related concepts, in conjunction with the advances of production engineering technology. For instance, regarding machine tool technology, while restraint of the thermal deformation on a machine tool was attempted to achieve high accuracy and quality, it was at the expense of using costly equipment and a large quantity of electrical energy. Even then, those countermeasures taken were not enough to satisfy these parameters [6].

Therefore, behavior of a machine tool in mist of strong alkaline water were investigated and evaluated. Properties of strong alkaline water were firstly investigated for alkali-proof, corrosion and safety of health. Then the bench lathe was remodeled in the vessel with mist of strong alkaline water (pH12.5), thermal deformation between the spindle and the tool post was measured for evaluation of accuracy. And cutting using CNC milling machine in the vessel with mist of strong alkaline water was performed for investigating the effect of water evaporation in the strong alkaline water.

II. The Corrosion Resistance of Materials in Strong Alkaline Water

The strong alkali water with pH value above 12.5 has high interfacial permeability, dissolving, emulsification, and separation properties. For these properties, it is well using for washing, sterilization, corruption prevention. Moreover, when strong alkaline water is kept long time in the air, it lost alkali property and become normal water of pH 7.0. This fact also regarded as very excellent for using it as cleaning agent with improved environmental protection.

In this section, the reactions of the various materials in strong alkaline water are tested. The specification of the device for making alkaline water is shown in Table 1. It is small and compact for making alkaline water of pH12.5. Fig. 1 shows the measurement results of pH values for keeping 10 L of strong alkaline water (pH12.5) in three containers (diameter ϕ25 mm, height 230 mm) and kept exposed to air for 2 months, in three different environment conditions. These conditions are different temperatures of 20°C, 40°C and 12°C with humidity 60% respectively. It is confirmed that the change in pH value even for the most decreasing condition with 40°C is just drop from pH 12.5 to pH12.0 during two months experiment. In the practical application of this method, there exist natural evaporation and evaporation due to generated cutting heat and it is necessary to fill up alkaline water to keep maintain the amount and pH value of water. However, from this experiment, it can be considered that this decreasing rate of pH value is quite enough to endure for the practical application of proposed method.

In the corrosion engineering, logarithmic value of metal ion concentration lesser than (-6) could not be corroded at equilibrium state. Here, according to the corrosion characteristic [7] of strong alkaline water, steel could not corrode in the alkaline water above pH10. Similarly, Nickel in the Nickel based alloys shows no chemical reaction in the range of pH8.5~pH13.0. Moreover, titanium alloys also shows no effect under pH13.0 range. From these facts, it can be considered that it is possible to operate underwater metal cutting processing of Titanium and Nickel alloy materials for compulsory water evaporative cooling with using the optimum range of pH values between pH10.0~pH13.0. The corrosion characteristics of these materials are also confirmed by experiment.

In the experiment, the tested materials are steel, titanium alloy, nickel alloy and those being used well in industries such as, copper, aluminum, brass and carbide (tool material) as shown in Table 3.

These materials are put in the test tubes containing water with three pH values, pH7.0, pH10.0, pH12.5 and keep in a room with constant temperature of 20±1 °C and 60% moisture for two months (see Table 2). The pH value is made to kept constant by changing alkaline water once per week.

The result of the experiment regarding to alkali resistance of the materials are shown in Table 3. The results shown there was no corrosion exhibit for the tested materials placing inside strong alkaline water for two months except aluminum. From this result, it was confirmed that the underwater cutting process for titanium alloys and nickel alloys can be applicable for compulsory tool cooling effect with the exception of aluminum. For cutting aluminum, it is necessary to take precaution and improvement as it is corroded in strong alkaline water. For the case of copper and brass, there occurred change in color.

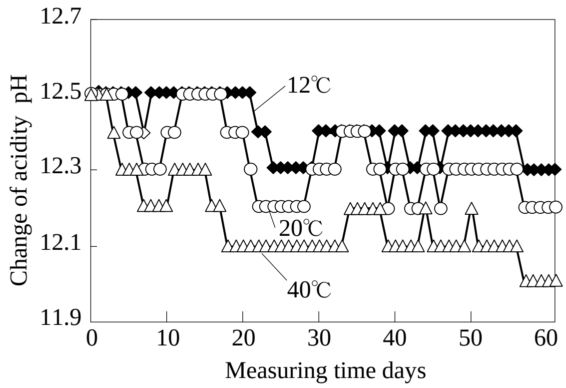


Fig. 1 Variation of pH values in different temperatures

Table 1 Specification of the system for making strong alkaline water and safty of health for strong alkaline water

Method of generation	Closed generation type	Assistant material		Potassium carbonate
Value of pH	pH 12.5	Safety of health	Smell	○ Odourless
Quantity of generation	10 ℓ/h		Touch	△ Wear gloves & glasses
Voltage & Power	100 V & 300W		Breath	△ Wear mask
Size	495W×430D×1100H		Drink	×

○ : No problem △ : Avoid × : Prohibition

Table 2 Materials and conditions used in corrosion test

Medium in the vessel	Strong alkaline water (pH 12.5)
Ambient conditions	Room temp.: 20±1℃, Humidity: 60%
Period	Two months

Table 3 Results of the proof test for two month in alkaline water with pH12.5

Machine tool structure	S45C	○	Changeless condition	Machine element	Rubber bushing	○	Changeless condition
	SUS304	○	Changeless condition		Exhaust cleaner	×	Corrode and discoloration
	Cast iron	○	Changeless condition		Thinned cylinder	△	Only screw corroded
Work piece	Ti	○	Changeless condition		Air chack	○	Changeless condition Same function
	Ti6Al4V	○	Changeless condition		Check valve	△	Only screw corroded
	Inconel 718	○	Changeless condition		Lubricator	○	Changeless condition Same function
	S45C	○	Changeless condition		Regulator	△	Only screw corroded
	Copper	△	Only discoloration	Electrical element	Push-button switch	△	Terminal corroded Screw corroded
	Brass	△	Only discoloration		Command switch	△	Terminal corroded Screw corroded
	Aluminum	×	Corrode		Optoelectronic switch amplifier	△	Terminal corroded Screw corroded
Tool	HSS	○	Changeless condition		Servomotor	△	Only screw corroded
	Carbide	○	Changeless condition		Box terminal	○	Changeless condition
	Cermet	○	Changeless condition		Electromagnetic contactor	×	Electromagnet corroded
	Diamond	○	Changeless condition		Solenoid valve	△	Only discoloration
	CBN	○	Changeless condition		Solenoid valve base	△	Only discoloration
	Ceramic	○	Changeless condition		Flat cable	○	Changeless condition
Coating material of tool	DLC	○	Changeless condition		Cable connector	○	Changeless condition
	Ti AlN	×	Discoloration		Direct acting two port solenoid valve	△	Only screw corroded and discoloration
	TiAlCr	×	Discoloration	Basic material	Acrylic acid resin	○	Changeless condition
Machine element	V-belt	×	Small crack		Vinyl chloride	○	Changeless condition
	Drive belt	○	Changeless condition Same function		Nylon	○	Changeless condition
	Timing belt	○	Changeless condition Same function		Polyurethane	○	Changeless condition
	O-ring	○	Changeless condition Same function		Polycarbonate	○	Changeless condition
	Bearing	○	Changeless condition		Nitrile rubber	○	Changeless condition
	Linear guide	○	Changeless condition Same function		Polyurethane rubber	○	Changeless condition
	Ball screw	○	Changeless condition Same function		Fluoro rubber	○	Changeless condition
	Oil seal	△	Spring corroded		Chloroprene rubber	○	Changeless condition
	Oil pump	×	Terminal corroded No work		Chlorosulfonated Polyethylene rubber,	○	Changeless condition
	Wire hose	○	Changeless condition		Oilproof vinyl mixture	○	Changeless condition
	Excel hose	○	Changeless condition		Urethane elastomer	○	Changeless condition
	Cap connector	△	Only screw corroded	Paint	Lacquer paint	○	Changeless condition
	Tube fitting	○	Changeless condition		Urethane resin paint	○	Changeless condition
	Oil level gauge	○	Changeless condition		Epoxy resin paint	○	Changeless condition

○ : Enable   △ : Only discoloration or only screw corroded   × : Disable

III. Cooling Property for Mist with Strong Alkaline Water

New nozzle was manufactured for making mist of strong alkaline water such as Fig. 2. The nozzle consists of an air tube (1x7 mm) and a tube (7x7 mm) of strong alkaline water. Then cooling property for mist with strong alkaline water was measured in experiment. Experimental set-up is shown in Fig. 3. A sensor for measuring heat transfer coefficient and a manufactured nozzle were set in the center of the vessel (556×386×310 mm). Sensor for measuring heat transfer coefficient is self consists of a ceramic heater (5x5x1.75 mm), two steel plates (5x5x0.06 mm) and 4 thermo-couples. The ceramic heater got caught between both two steel plates and is inputted electric power E (7.8 W). At this time, temperature on the steel plate becomes about 100 ℃ in the air. Two thermo-couples are measured temperatures T_{w1} and T_{w2} on the center of the each steel plate respectively. Other two thermo-couples are measured temperatures T_{M1} and T_{M2} of mist with strong alkaline water on the 5 mm distance from the each steel plate respectively. Heat transfer coefficient α is calculated by equation (1).

$$\alpha = \left(\frac{E\ /2}{A\,(T_{w1} - T_{M1})} + \frac{E\ /2}{A\,(T_{w2} - T_{M2})} \right) /\ 2 \qquad (1)$$

where A (5x5 mm) is area of steel plate. Average of heat transfer coefficient on twice steel plates is calculated. Because influence of radiation is also included in this heat transfer coefficient, this value is appearance heat transfer coefficient. However we thought that this is used for evaluation of cooling property because of similar condition to several manufacturing or machining fields.

Furthermore, the existing relationship between the heat transfer coefficient and the mixture ratio of air and strong alkaline water is shown in Fig. 4. In this case, the length L from output nozzle to measuring point was 225 mm. Moreover, the parameter considered here is the total flow rate of strong alkaline water. There are two plots in this figure; one is the mist condition (fine strong alkaline water) which has very

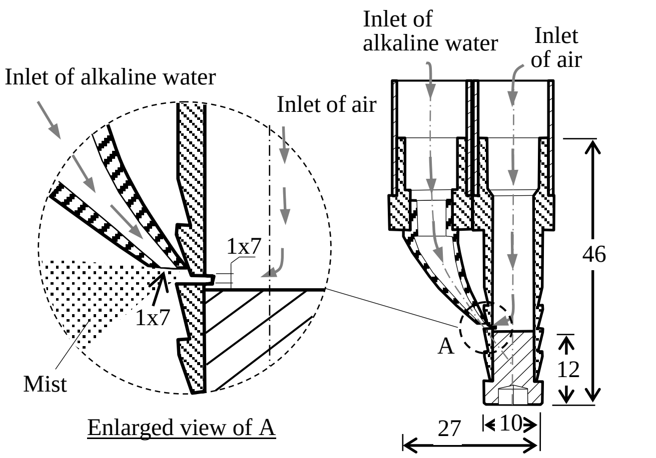


Fig. 2 Schematic view of nozzle for mist of strong alkaline water

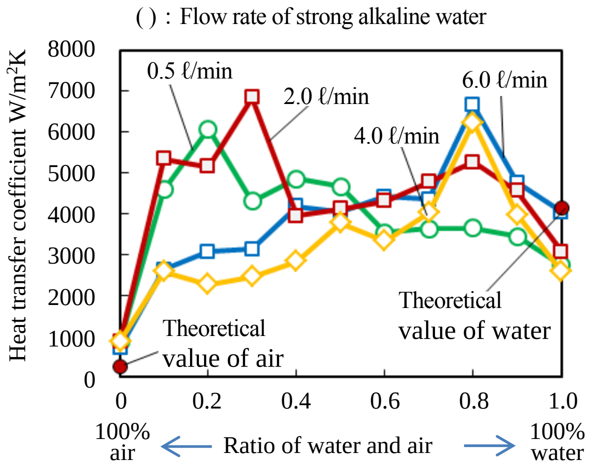


Fig. 4 Relationship between the heat transfer coefficient and the mixture ratio of air and strong alkaline water

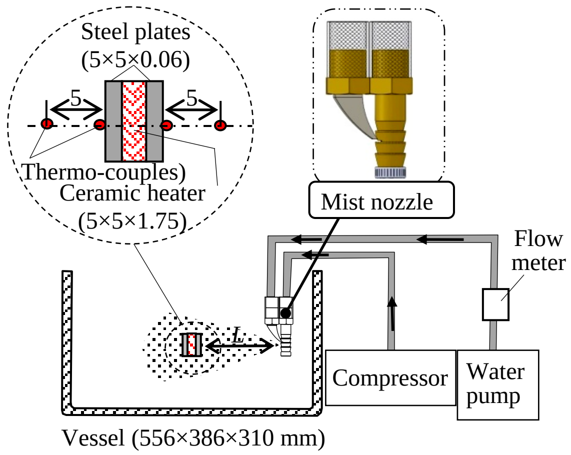


Fig.3 Experimental set-up for measuring heat transfer coefficient regarding mist of strong alkaline water

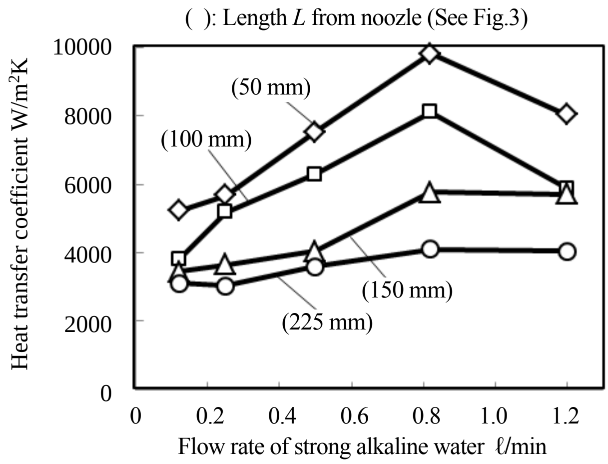


Fig.5 Relationship between the heat transfer coefficient and the optimum amount of air and strong alkaline water

large forced cooling effect because of the heat of vaporization, and the other one is the fluid condition (fine air pockets) which has a very large heat transfer coefficient because it presents a high speed.

The relationship between the heat transfer coefficient and the optimum amount of air and strong alkaline water is shown in Fig. 5. The parameter considered here is length *L* mm from output nozzle to measuring point. When the distance (*L*) becomes smaller, the heat transfer coefficient becomes larger. In this figure, there is a peak in each plot near 0.8 ℓ/min of total flow rate of strong alkaline water, and when amount of air is 113.3 ℓ /min, the total flow rate of strong alkaline water is 0.82 ℓ /min. At this point, the distance *L* mm from output nozzle to measuring point is 50 mm, and the heat transfer coefficient is about 10000 W/m^2K. These results clearly show that the forced cooling using mist of strong alkaline water has a very strong influence. Thus, it can be said that the thermal deformation of structure can be effectively cooled by using a mist of strong alkaline water.

IV. EVALUATION OF MANUFACTURING IN MIST OF STRONG ALKALINE WATER

The cutting fluids [8] or MQL (minimum quantity lubrication) [9] are commonly used for forced cooling during multiple processes. However, most cutting fluids pollute the environment and most MQL agents cooling performance is inferior to other cooling alternatives. In this research, a forced cooling method using a mist of strong alkaline water for restraining thermal deformation on a machine tool was developed and evaluated for only cooling effect. Additionally, among the reasons to choose strong alkaline water are that it shows a pH value above 12.5, has high interfacial permeability, dissolving, emulsification, and separation properties. Furthermore, after multiple corrosion tests of different machine tool components and materials for up to 2 months, it was observed that most components did not corrode under the influence of strong alkaline water. In contrast, it had a very large cooling effect because vaporization of the mist occurred due to the heat involved. Thus, mist of strong alkaline water was supplied around the structure of the machine tool and the machining area, in order to restrain the thermal deformation and alleviate the heat generation during machining. Accordingly, a bench lathe and a CNC milling machine were used for the experimentation. In the first instance, thermal deformation of the bench lathe was measured to evaluate the forced cooling effect that the mist of strong alkaline water possesses. Subsequently, the effects of mist of strong alkaline water were also evaluated with respect to the tool temperature during cutting, surface roughness and the tool life parameters on a CNC milling machine [10]. In this regard, the entirety of the experimental data and further explanation about it can be consulted in a parallel research [10].

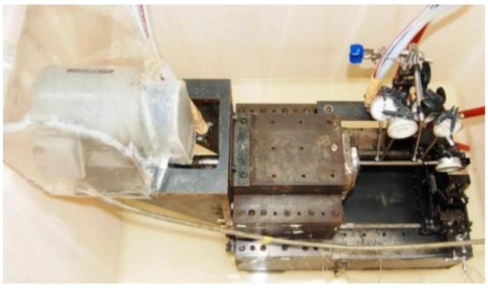
4.1. THERMAL DEFORMATION OF BENCH LATHE IN MIST OF STRONG ALKALINE WATER

Thermal deformation cause by heat from the friction of bearing unit can affect the machining accuracy of final cutting result. Here, the thermal deformation of bench lathe in the mist of strong alkaline water was measured.

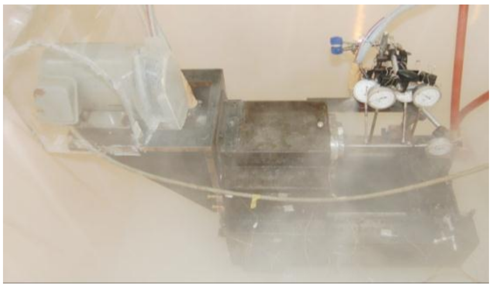
The same setup of bench lathe machine showed in Table 4 and Fig. 6 was used. There are 2 photographs before and after supplying mist of strong alkaline water in Fig. 6. The bench lathe is installed in vessel which sizes are L 1190×W 980×H 790 mm. The detail setup for this experiment is shown in Fig.7. Test bar was inserted into lathe chuck and the 4 dial gauges were used to measure the displacement of the test bar in horizontal and vertical direction during experiment. The experiment data was taken by compare between dry condition and using mist of strong alkaline water. The bench lathe was operated at spindle speeds 3600 min^{-1}. Red circles are positions of thermo-couples for measuring temperatures on the machine structure. The developed nozzles were set up on near centers of front and rear surfaces of the head stock. The mixed air (113.3 ℓ /min) and strong alkaline water (0.82 ℓ /min) is supplied by each nozzle. Distance between the nozzle and the machine structure is 50 mm.

Table 4 Specification of the bench lathe in the experiment

Head stock	Height of center from bed	177 mm
	Height of center from floor	337 mm
	Spindle speed	Max. 3600 min^{-1}
Bed	Size (W×L×H)	600×360×660
Tool	Stroke of Y axis	30 mm
Table	Stroke of Z axis	200 mm
Motor	Power	0.75 kW
Mass		200 kg



(a) Without mist of strong alkali water



(b) With mist of strong alkali water

Fig. 6 Photograph of the experimental setup

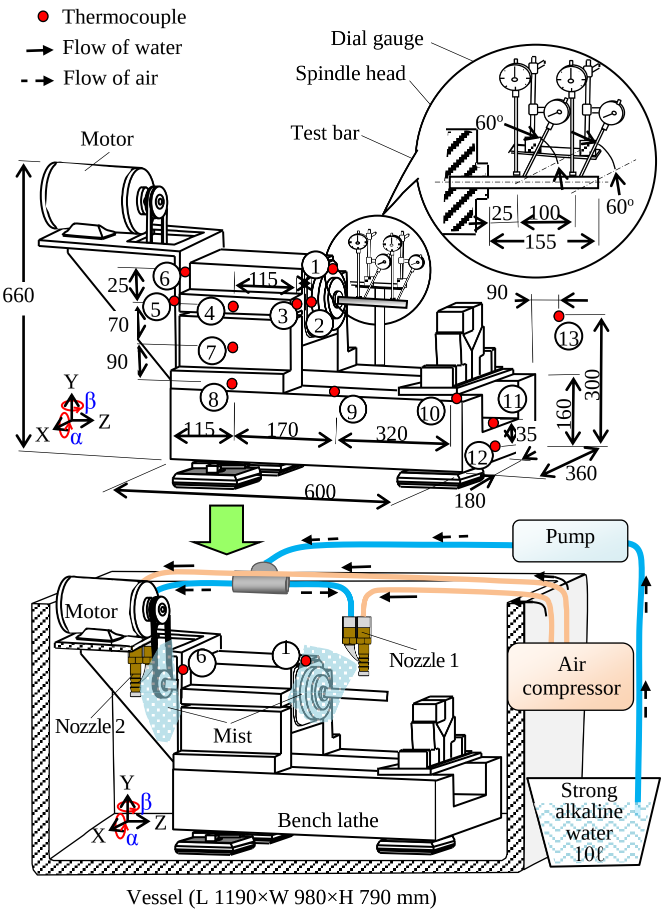


Fig. 7 Schematic view of the experiment using the bench lathe in strong alkali water mist

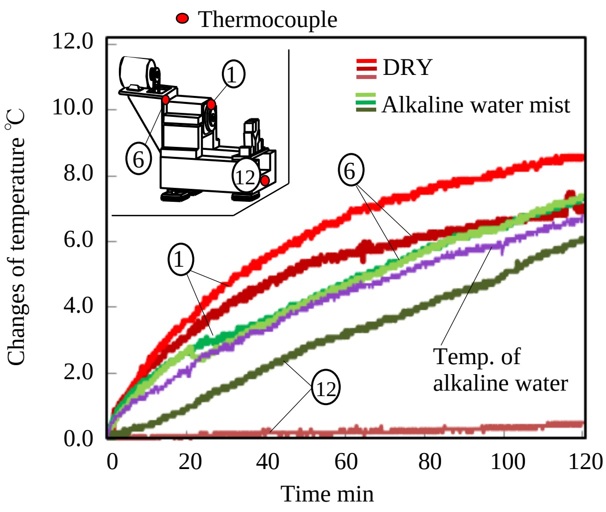


Fig. 8 Temperature change of the bench lathe using strong alkaline water mist operated in 3600 min^{-1}

Fig. 8 shows the experimental result of the temperature on the bench lathe at spindle tip surface ①, ⑥ and end of bed ⑫. At spindle speed 3600 min^{-1}, the rise in temperature (the maximum values at steady state condition) at the spindle tip surface ① which is the most influencing part of the machining accuracy were 8.3ºC at dry cutting, 6.4ºC for mist of strong alkaline. Temperature rising for mist of strong alkaline occurred because the heat generated by microbubble device caused the pump become warm during continuously operation in two hours. At that time, if the forced cooling is used, temperature rising is restrained. However the forced cooling is never used in this research, because this research is performed for earth-friendly. In case of dry cutting, as temperature distribution on the machine structure is very large, thermal deformation will also become very large. On the other hand, in case of mist of strong alkaline water, as temperature distribution is very small, thermal deformation will also become very small.

The relative displacement (X and Y directions) and angular displacement (α and β directions) of the tip of test bar measured at operation a speed 3600 min^{-1} are shown in Fig. 9. In the same way, the data between 20 min to 120 min were divided into 6 intervals and the average values and standard deviations of each of the six intervals are plotted. The results show that, in dry cutting, relative displacements are large with ΔX=6.0μm, ΔY=24.0 μm and angular displacements were α=55 μm/m and β = 200 μm/m, in mist of strong alkaline water, the relative displacements are ΔX=0.6 μm, ΔY=0.9

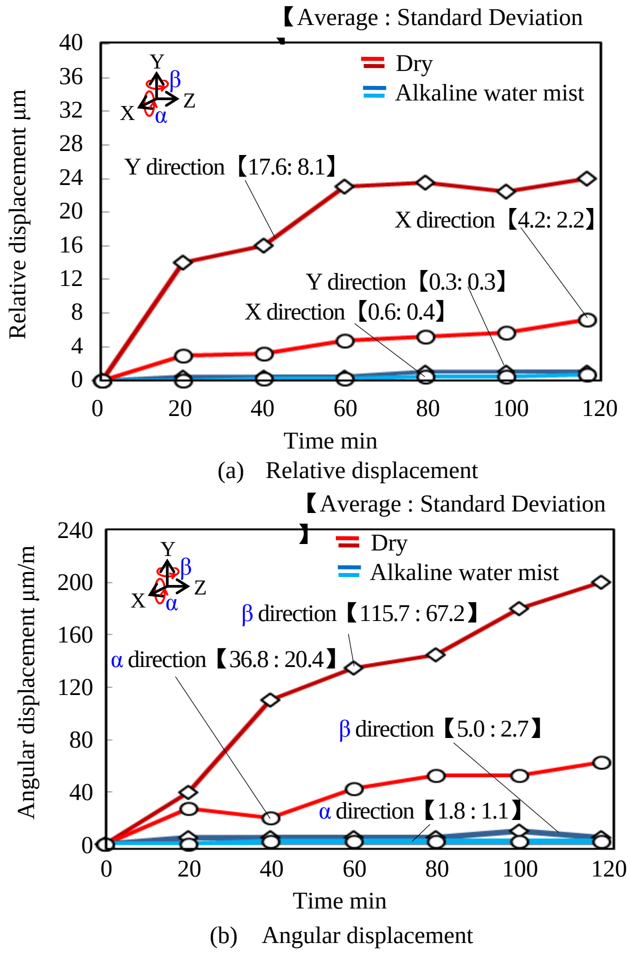


Fig. 9. Thermal deformation of the bench lathe in strong alkaline water mist at 3600min^{-1}

μm and angular displacements are α=3.6 μm/m and β=9.0 μm/m. This means that, when operated under a mist of strong alkaline water, the thermal deformations due to operation speeds reduced significantly. However, since standard deviations are very small in this case, temperature changes are also very small and therefore thermal behavior highly stable.

These results clearly show that relative displacement and angular displacement were restrained by using mist of strong alkaline water and showed a very strong influence. Therefore, it can be said that by using mist of strong alkaline water in bench lathe, the thermal deformation of machine structure can be effectively suppressed and resulting in a high machining accuracy.

4.2. Cutting Property of CNC Milling Machine in Strong Alkaline Water

Cutting area on the CNC milling machine was filled by mist of strong alkaline water, and two tool temperatures were measured for evaluation of cooling property. Cutting conditions for tool temperature measurement are shown in Table 5. This is middle cutting. Experimental set-up is shown in Fig. 10. Amount of air is 113.3 ℓ /min, total flow rate of strong alkaline water is 0.82 ℓ /min and *L* mm from output nozzle to measuring point is 50 mm. Workpiece was fixed to the spindle and tool was set to the vise on the table, because it is that the tool temperatures were measured without a hitch by thermo-couples. Then temperature on the top of the tool was estimated by the measured temperatures and FEM analysis. Here the tool model is firstly made, and tool temperatures with transient state are calculated by FEM analysis.

Table 5 Cutting conditions for tool temperature measurement

Cutting conditions		
Cutting speed 80 m/min	Feed speed 0.25 mm/rev	Depth of cut 0.4 mm
Work piece		
Material： S50C		
Tool (Bite)		
Rake angle: 5°	Coated carbide	

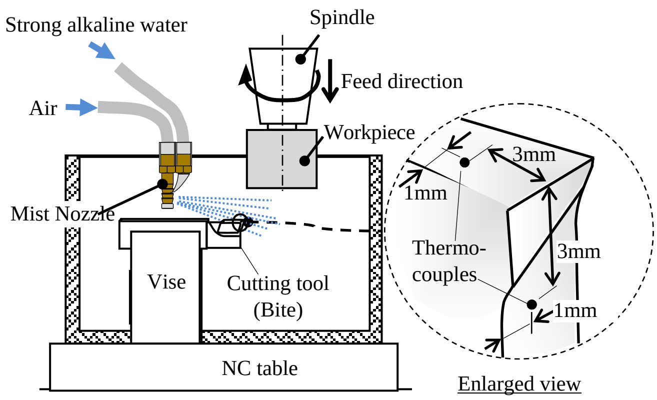


Fig. 10 Experimental setup for measurement of tool temperature

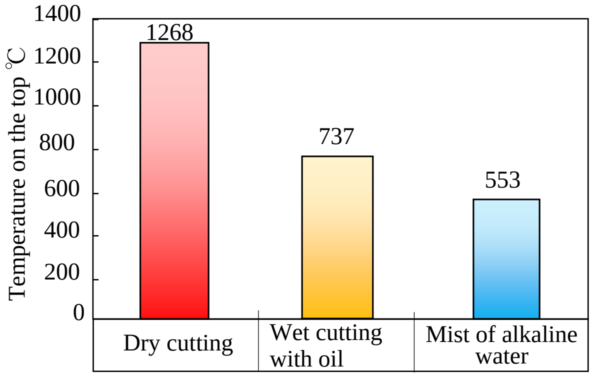


Fig. 11 Experimental results for temperature on the top

At that time, heat transfer coefficient and heat generation on the top of the tool for input data are changed one by one. When the result of the FEM analysis became same to the result of the two measured temperature, the calculated temperature on the top of the tool is adopted for its temperature.

Temperatures on the top of the tool were shown in Fig. 11. Dry cutting and wet cutting with oil were also shown for reference. Material of the used tool is coated carbide and its optimum temperature for cutting is about 800 ℃. Temperature on the top of the tool using mist of strong alkaline water was 44% of one of dry cutting and 75% of one of wet cutting with oil respectively. Mist of strong alkaline water is effective method for cooling tool.

Tool life for evaluation of cutting using mist of strong alkaline water was performed. Cutting conditions for tool life test are shown in Table 6. This is middle cutting. Experimental set- up is shown in Fig. 12. Amount of air is 113.3 ℓ /min, total flow rate of strong alkaline water is 0.82 ℓ /min and *L* mm from output nozzle to measuring point is 50 mm. Dry cutting and wet cutting with oil were also performed for reference. End-mill with 2 throw away tips was used for milling machining, because it is easy and certain for judgment of limit of tool life.

Table 6 Cutting conditions for tool life measurement

Cutting conditions			
Cutting speed 100 m/min	Feed/ tooth 0.15 mm/tooth	Width of cut 3 mm	Depth of cut 2 mm
Work piece			
Material： S50C			
Tool (Endmill with 2 throw away tips)			
Rake angle: 5°	Coated carbide		

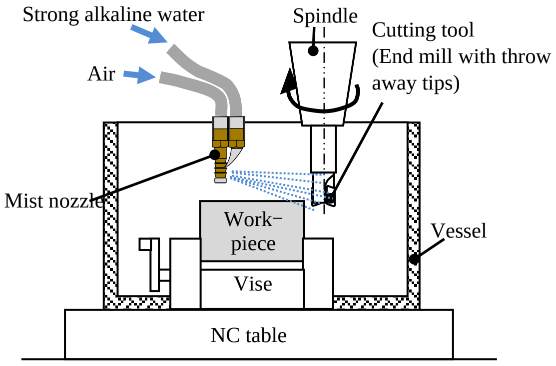


Fig. 12 Experimental set-up for measurement of tool life and surface roughness

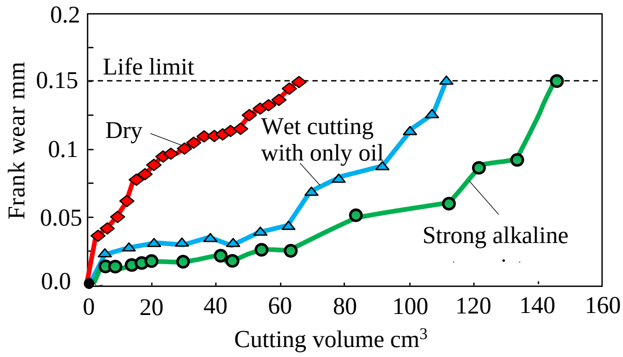


Fig. 13 Results of tool life test

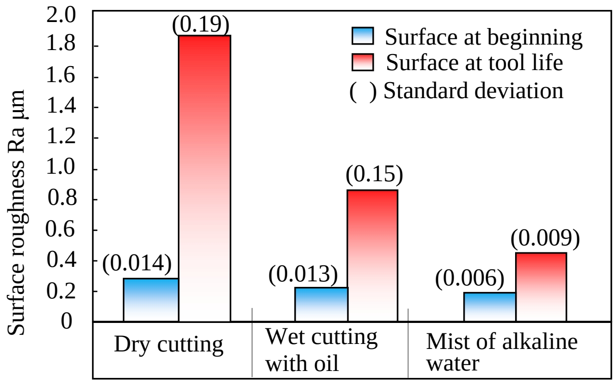


Fig. 14 Results of surface roughness

Similarly, the results of the tool life test were shown in Fig. 13 and dry cutting and oil wet cutting were also shown for reference. It was observed that that the tool life of the tool using mist of strong alkaline water was 2.5 times of one of dry cutting and 1.4 times of one of wet cutting with only oil respectively. Hence, it is thought that a mist of strong alkaline water is an effective method for extending the tool life during machining. To support this, in the case of the cutting using mist of strong alkaline water, defects were not observable in the microscope.

In addition, surface roughness test results are shown in Fig. 14 and dry cutting and wet cutting with only oil were also shown for reference. After machining, surface roughness on the workpiece using mist of strong alkaline at limit of tool life water was 22 % of one of dry cutting and 50 % times of one of wet cutting with only oil respectively. Surface roughness on the workpiece using mist of strong alkaline at start of the test is similar to that of dry cutting and wet cutting with only oil. However, a mist of strong alkaline water is thought to be an effective method for the improvement of surface roughness on the workpiece. Thus, it can be said that by using practice CNC milling machine with mist of strong alkaline water, the heat generation for cutting can be effectively removed; resulting in a low tool temperature, long tool life and fine surface roughness.

Lastly, nevertheless, a deep understanding of the thermodynamics field was also necessary to evaluate the water evaporation effect. Similarly, the alkaline water mist employed in this research also made use of the chemical engineering field. In the end, this makes the technology an environmentally-friendly and affordable one by reducing parameters that involve higher costs.

V. Evaluation and Consideration for Manufacturing in Mist of Strong Alkaline Water

Since the developed technology was created to support the intensity of production at a low-environmental impact level with the highest cost-effectiveness, in this section both the environmental and economic aspects of this technology will be assessed. In the first instance, the proposed model evaluates the degree of how "environmentally-friendly" a technology is through the CO_2 emissions involved. On the other hand, the economic aspect of the presented technologies will be based on a general overview of the technical requirements involved in this research.

Firstly, the environmental impact of this technology will be assessed based on a comparison of the amount of exhaust CO_2 using the proposed and conventional cooling. This was calculated through the relationship between the electricity consumption per hour and the CO_2 emissions. For this, it was considered that the electricity used by the coolant pump on the milling machine during conventional wet cutting was 1.2kW per hour and a working year being composed of 250 days and 8-hours per day. Furthermore, the amount of CO_2 emissions, CL_{CO2}, is calculated by using the equation (2).

$$CL_{CO2} = 0.468 \times W_E \qquad (2)$$

Where, W_E is the amount of used electricity (kWh) used in coolant pump and 0.468 the conversion value for kg-CO_2/kWh.

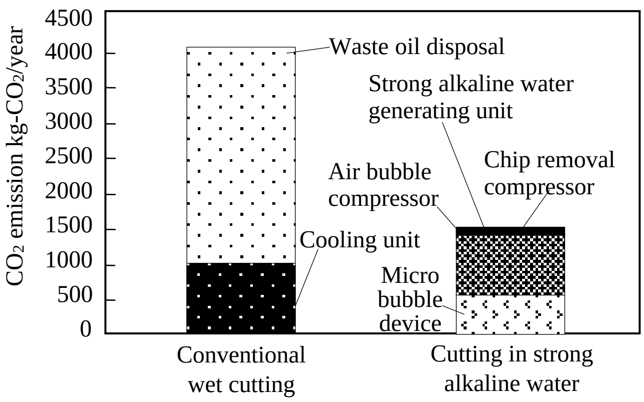


Fig. 15 Comparison of CO_2 emissions (Environment)

Table 7 General overview of proposed cooling and the conventional cooling expenses (Cost-profit)

Cooling method	Proposed cooling	Conventional cooling
Cooling capacity	Very large ◎	Average △
Initial cost	Alkaline water ○ Pump ○	Refrigerator ×
Running cost	Oil supply × Electricity ×	Oil supply × Electricity ×
Maintenance	Little ◎	Need ×
Remarks	Low-environmental impact and profitable	High-environmental impact

◎ : Excellent, ○: Good, ×:Weak

The corresponding calculated amount of CO_2 emissions for the coolant pump is 1123.2 kg-CO_2. Subsequently, the amount of CO_2 emissions due to the oil disposal was calculated. In this case, the amount of oil is assumed to be 340 L and disposal times to be 2 times/year a year. However, milling machines require a monthly oil fill-up which is assumed to be 30 ℓ a month (30 ℓ×12 month=360 ℓ). Hence, the total amount of disposed oil was assumed to be 1040 ℓ and the CO_2 emissions were calculated based on this value and using the equation (3) [11].

$$CO_2\ emission\ (\text{kg-CO}_2) = Disposed\ oil\ \text{k}\ell \times Emitted\ heat\ energy\ \text{GJ/k}\ell \times Carbon\ emission\ \text{t-C/TJ} \times (44 \div 12) \quad (3)$$

Where, the emitted heat energy is 40.2 GJ / kℓ and the amount of carbon emission is 19.22 t-C / TJ, and by using equation (2), the amount of CO_2 emission due to disposed oil was calculated and a value of 2946.3 kg-CO_2 was obtained. Therefore, the total amount of CO_2 emitted from both cases was 4069.5 kg-CO_2. Furthermore, the comparison between the conventional wet cutting method and the proposed method is shown in Fig. 15.

In contrast, the amount of CO_2 emissions of cutting in strong alkaline water mist can be reduced to 2634.9 kg-CO_2, (64.7 % reduced) in a year. This is due to the less power consumption for the cooling of the tool; as well as, the lower emissions that represent not using cutting oil in the proposed method. Thus, it can be considered that this method is not only effective in cooling the machine tool but also capable of reducing the impact to the environment.

Ultimately, a comparison between the expenses involved in the proposed cooling and the conventional cooling during machining is shown in Table 7. It can be noted that the proposal is more affordable, given that the initial costs would be considerably less because of the low market price of alkaline water. Thus, the proposed system goal of simultaneously reaching a "highly cost-effective" and "environmentally-friendly" technology is achieved.

Ⅵ. Conclusion

From this research, the following was possible to conclude;
(1) Alkali-proof regarding several elements of a machine tool were cleared in the experiment.
(2) Thermal deformation of the bench lathe for bathing was very small in spite of no-forced cooling.
(3) Accuracy of the machine tool was very good and the tool life was very long in spite of no-cutting oil
(4) The application into real production engineering problems and technology is proposed and presented "Forced cooling using mist of strong alkaline water" researches.
(5) It was concluded from the experimental results of this technology, that improvements in the environmental pollution, mechanical properties and cost parameters were achieved through the proposed research.

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