Development of Nanofiber Abrasive Buffing Pad Produced with Modified Melt Blowing Method

Wei Wu[1, a], Eiichi Aoyama[2, b], Toshiki Hirogaki[2, c],
Kenichi Urabe[3, d], and Hiroyoshi Sota[3, e]

[1] Organization for Research Initiatives and Development, Doshisha University
1-3 Miyakodani, Tatara, Kyotanabe-shi, Kyoto, 610-0321, Japan

[2] Faculty of Science and Engineering, Doshisha University
1-3 Miyakodani, Tatara, Kyotanabe-shi, Kyoto, 610-0321, Japan

[3] M-TEchX.Inc. 3-25-11, Higashi, Shibuya-ku, Tokyo, 150-0011, Japan

[a]weiwu@mail.doshisha.co.jp, [b]eaoyama@mail.doshisha.ac.jp,
[c]thirogak@mail.doshisha.co.jp, [d]urabe@mtechx.co.jp, [e]sota@mtechx.co.jp

Keywords: melt-blowing method, nanofiber, oil adsorption, nonwoven polypropylene nanofiber, buffing, buffing pad

Abstract. Nanofibers can be used in fields/applications such as medical care, environment protection, apparel, and agriculture. It can also be believed that these fields will experience rapid growth in the next few years. This study focuses on one of the applications: abrasive buffing. We proposed the oil adsorption physical model of abrasive buffing and compared it with experimental results to develop a nanofiber buffing pad. It can also be used to calculate the mass ratio of oil to abrasive grain and the abrasive size in abrasive machining when the fiber mass and bulk density are constant. Further, for realizing the free-form nano surface, such as molding die surface, we conducted a base experiment with different diameter fibers and different size grains and investigated its base polishing characteristics compared with commercial felt buff. From the experimental results, we considered the buffing mechanism of fiber and grain contact the workpiece surface to polish. As a result, the effect of combination of mesh size and grain size on polished surface roughness of the workpiece was demonstrated, and controlling the polished surface roughness using this low-cost new abrasive material in abrasive machining was realized.

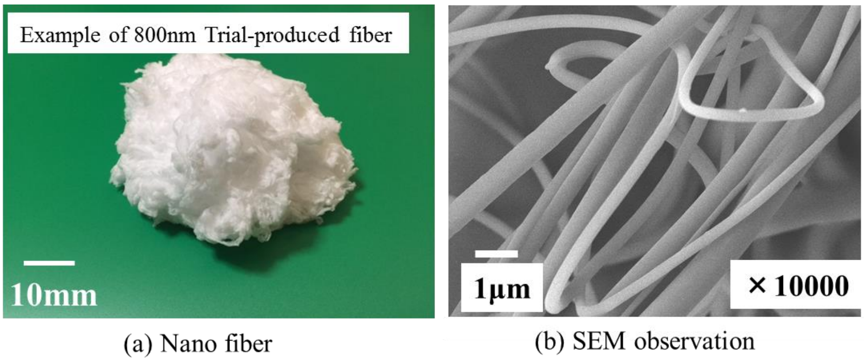
Introduction

Until recently, majority of the makers have used the centrifugal force method [1] and electro spray deposition (ESD) method [2] to produce nanofibers. However, these two methods possess a risk of explosion. Moreover, these methods are expensive and possess low efficiency. Therefore, industrial applications are limited. Further, the American Naval Research Laboratory developed the melt blowing method in the 1950s as one of the nonwoven fabric microfiber manufacturing methods of organic quality. Subsequently, elucidation of the phenomenon and the elucidation of the multiphase flow [3] have advanced; therefore, we were able to observe its possibility [4] as one of the nanofiber manufacturing processes. This time, a trial manufacturing of nanofiber was conducted using the modified melt blowing method, which adjusted the venturi nozzle and the negative pressure condition. We estimated that its properties seem to be sufficient for applications such as medical care, protection of the environment, apparel, agriculture and semiconductor abrasive pads.

Therefore, in this study, abrasive machining was focused as one of the applications. Polypropylene (PP) possesses water repellency and oil adsorption characteristics; the oil adsorption performance of PP with respect to nanofiber nonwoven fabric for dozens of times its own weight was proved [5]. This time, we proposed its oil adsorption physical model and compared it with experimental results to develop a nanofiber buffing pad. It can also be used to calculate the mass ratio of oil to abrasive grain and the abrasive size in abrasive machining when the fiber mass and bulk density are constant. Further, for realizing the free-form nano surface, such as molding die surface, the base experiment with different diameter fibers and different size grains was conducted and its base polishing characteristics compared with commercial felt buff were investigated. From the experimental results, the buffing mechanism of fiber and grain contact with respect to the workpiece surface to be polished were investigated. As a result, the effect of combination of mesh size and grain size on polished surface roughness of the workpiece was demonstrated, and the controlling of the polished surface roughness using this low cost new abrasive material in abrasive machining was realized.

Trial produced nanofiber using modified melt blowing method

Using the general melt blowing method, to achieve the diameter thinning of fiber, it is necessary to accelerate the injection of air or decrease the polymer melt micro quantity from the nozzle. However, using the air acceleration method, the fiber may become short. Further, the polymer melt micro quantity method will affect the production quantity. In either case, it is difficult to obtain high-quality nanofiber. Therefore, to solve these problems, the location of the polymer melt nozzle at the potential core boundary zone of the high-speed free jet air was corrected, control the flow velocity distribution and temperature distribution of the high temperature air jet to space, and we control the temperature to control the viscosity of the polymer. The polymer jet quantity from the nozzle to the proposed modified melt blowing method can also be controlled, which can produce high-quality nanofiber (minimum is approximately 300 nm–500 nm) and achieve high volume production (output efficiency is above 30 Kg/h). Fig. 1 (a), (b) show an example of the trial-produced nanofiber using the proposed method. We trial-produce the nanofiber with polypropylene (measured density is ρ = 0.895 g/cm^3. The contact angle with respect to oil is 29°–35° [6]). Generally, it is difficult to define the diameter of the chemical fiber, but approximately 10–50 μm diameter is standard. This time, the mass production by the proposed method, for which the fiber diameter is less than 1/10 was achieved.



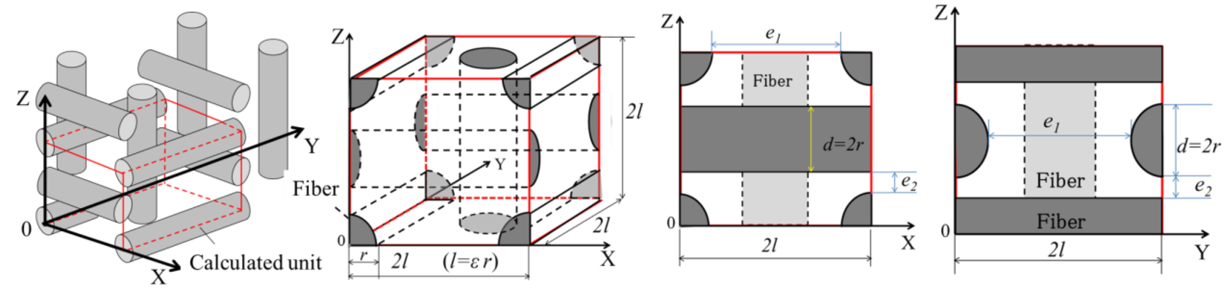
(a) Nano fiber (b) SEM observation

Fig. 1 Trial-produced nanofiber

Three-direction oil adsorption physical model

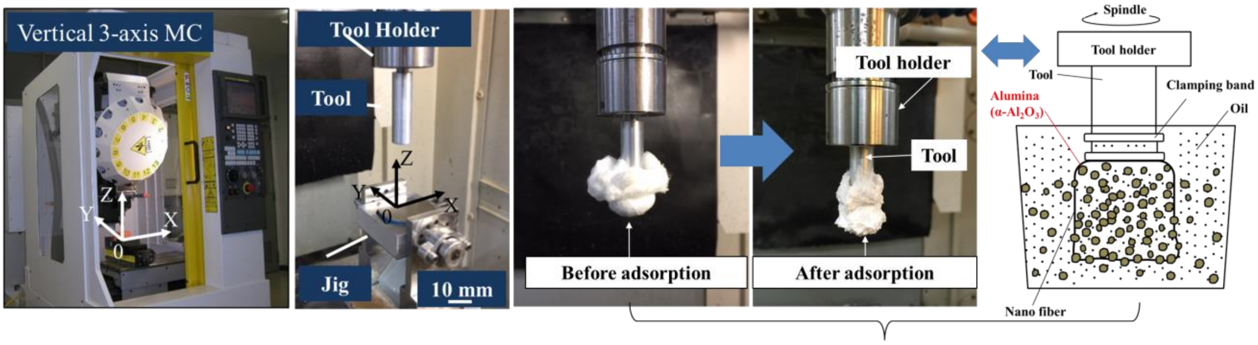
To explain the application performance of nanofiber, we proposed a three-direction physical model of fiber as shown in Fig. 2 (a), (b), (c), and (d). **<u>On the other hand, its effectiveness and the relationship between this model, grain diameter and pressure were also discussed in preceding study</u>** [5] [7]. Fig. 2 (a), (b) show the image of the three-direction fiber model and the minimum calculating unit in fiber aggregate. From this model, the equation 1 can be got. Here, the free volume is η, fiber diameter is d, the fiber gap is e_1 and the center distance of the fibers is $2l$.

$$e_1 = 2l - 2r = d\left(\sqrt{\frac{3\pi}{4(1-\eta)}} - 1\right) \tag{1}$$



(a) 3-direction model of fiber aggregate (b) Minimum calculated unit (c) X−Z plane model (d) Y−Z plane model

Fig. 2 Three-direction fiber aggregate model



(a) Vertical 3-axis MC (b) Processing tool (c)Fitted polishing fiber cloth

Fig. 3 Processing equipment and tool fixing method

Experimental method of abrasive machining

The processing equipment used in this experiment is vertical three-axis machining center ROBODRILL α-T14 Dse is shown in Fig. 3 (a). Fig. 3 (b) shows the processing tool Φ6-Φ10, which we manufactured, and the fiber will attach on it when we conduct the experiment. The abrasive consists of abrasive particle (alumina, grain size #220, #600, #2000, #3000) and high-viscosity multi-purpose oil SUPER LUBE (ISOVG145). Further, the felt buff used for comparison was S-1370 manufactured by Yoita Tool Industry Co., Ltd. In this study, regarding the materials of the processing workpiece, we used SKD11 (Cold die steel, Rockwell hardness [HRC] is 60), a disk with 30-mm diameter and 5-mm thickness. When we conducted the polishing process experiment, we attached the fiber to the processing tool with a clamping band to maintain the oil and abrasive as shown in Fig. 3 (c). Fig. 4 shows the polishing tool path. In addition, the force sensor used in this experiment is a dynamometer (9347C KISTLER, three-axis force). The experimental conditions are shown in Table 1. We desired to inspect the effectiveness of the basic abrasive property of the nanofiber; thus, the evaluation system of the machining used to remove the quantity M_p and the arithmetical average roughness R_a are considered as the parameters to evaluate the surface property. The surface roughness meter used is a contact-style roughness meter manufactured by Tokyo Seimitsu E-35B. We measured the removed quantity unit time with a high-precision electronic balance manufactured by As One Co., Ltd.

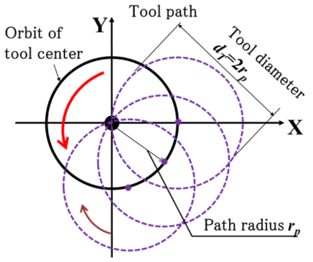


Fig. 4 Processing path

Table1 Processing condition

Rotation number N	750min^{-1}
Pressing force F	20N (0.25MPa)
Feed forward velocity f_{xy}	10mm/min
Path radius r_p	3mm, 5mm, 8mm

Experimental results and discussion

Buffing mechanism of fiber. The PP nanofiber non-woven fabric possesses exceptional oil adsorption and maintains the capacity, and it can be considered that the fiber supplies sufficient oil and small run off from the buffing surface in the process. Therefore, the slurry adsorbed fiber aggregate can also be considered to possess small run off in the process. However, in reality the inconsistency in the nonwoven fabric mesh size and the change owing to pressing force during processing are also considered. Therefore, to elucidate the mesh size, Fig. 2 was considered, and it is investigated as a parameter in three dimensions under the uniform distribution assumption [5] [7]. From equation 1, the results of effect of free volume on the gap between the fibers can be calculated as shown in Fig. 5. Based on this result, the fact that when the fiber diameter is relatively thick, the fiber gap will be large under the conditions of constant fiber diameter and fiber aggregate bulk density constant can be comprehended. These relationships are shown in Fig. 6. From Fig. 6 (a), it can be observed that when the fiber diameter is relatively thin, the gap e_1 is small and it can maintain the massive small size grain, sufficiently contact the workpiece, and the buffing efficiency will be high. Conversely, in Fig. 6 (b), the buffing efficiency could be considered to be low. Otherwise, based on Fig. 6 (a), it can be considered that when the grain diameter d_g is larger than the fiber gap e_1, it can sufficiently contact the workpiece to polish and the buffing efficiency will be high. Conversely, Fig. 6 (b) shows that the grain almost penetrates into the fiber aggregate and only few of them could contact the workpiece; thus, the buffing efficiency was considered to be low. Furthermore, the pressing force transmitted through the fiber reaches the workpiece but only a part of it can reach the grains. As a result, it is extremely important to determine the combination of the fiber diameter, bulk density, and grain size depending on the workpiece material and propose can be understood.

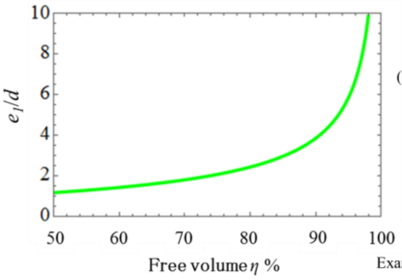
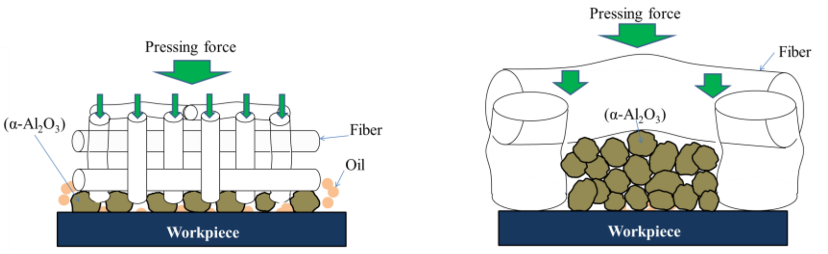


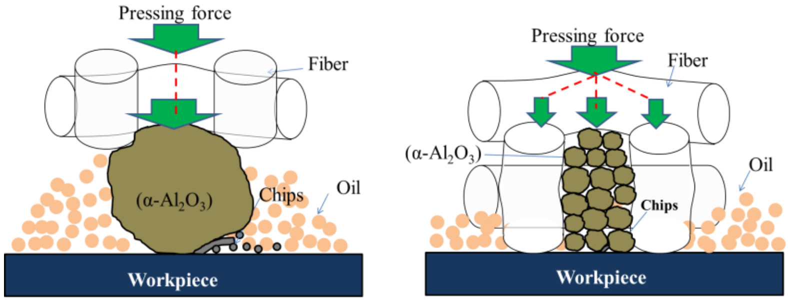
Fig. 5 Effect of free volume on e_1/d_g



(a) **Bulk density=Constant, Thinner diameter**
(Example of ρ_b=0.1g/cm^3, Gap size, e_1 ≒ 12μm)
Example of combination of 3μm **fiber and** #800(Ave≒20μm) **grain**

(b) **Bulk density=Constant, Thicker diameter**
(Example of ρ_b=0.1g/cm^3, Gap size e_1 ≒ 160μm)
Example of combination of 40μm **fiber and** #800(Ave≒20μm) **grain**

Fig. 6 Relationship between fiber diameter and buffing efficiency under constant fiber bulk density



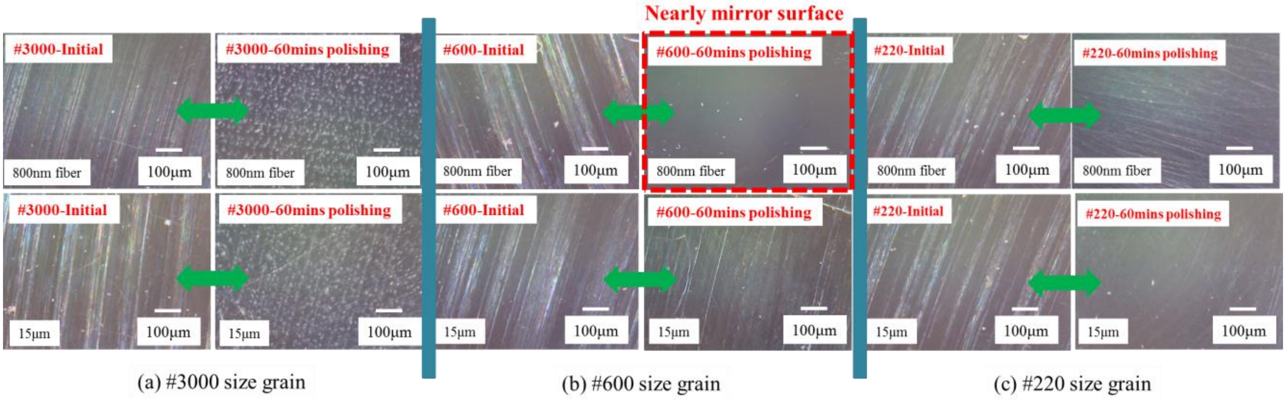
(a) **Grain size＞Gap size**

(b) **Grain size ＜Gap size**

Fig. 7 Effect of gap and grain diameter on buffing processing

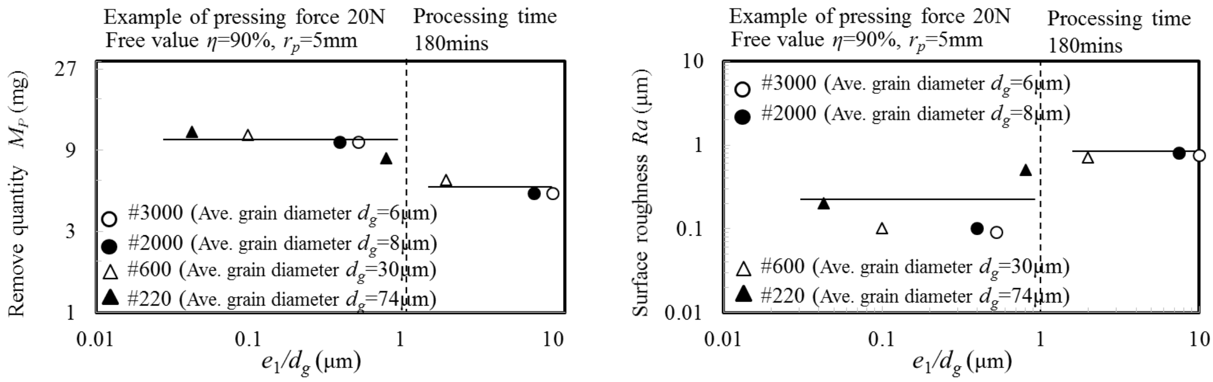
Comparison among different fiber diameter base polishing ability. In this study, we used the oil adsorption and high maintenance performance of alumina abrasive grain of PP nanofiber cloth to polish hard steel material. Therefore, the ratio of oil to abrasive grain when the fiber mass is constant requires elucidation. Fig. 2 (d) shows two gaps from fiber to fiber e_1, e_2, this time, whether the grain mixed with oil can penetrate into the fiber mesh was considered; thus, only the maximum mesh entryway gap e_1 was considered. Here, we assume the volume of grain cannot exceed the total volume V_{total}. Using the value of V_{total}, the grain mass m_g can be approximately determined under the condition of constant fiber mass and bulk density, and this time, the grain concentration in the experiment was approximately 23% [5] [7].

To utilize this performance, we consider its polishing property while maintaining the lube oil and alumina abrasive in the polishing process. The experiment using high-viscosity oil (ISOVG 145) and two fiber diameters, 800 nm and 15μm, under the conditions illustrated in Fig. 4 and Table 1 was also conducted. Here, the commercial buff fiber diameter is approximately 20μm. In addition, we set the processing time in 30-min units, with a maximum of 180 min. In the experiment, we removed the workpiece from the jig every 30 min and measured the removed quantity and surface roughness. Fig. 8 shows the electronic microscope observation before and after processing with abrasive grains of different sizes.



(a) #3000 size grain (b) #600 size grain (c) #220 size grain

Fig. 8 Comparison of before and after polishing



(a) Remove quantity (b) Surface roughness

Fig. 9 Influence of ratio of grain and gap size (e_1/d_g) on buffing efficiency

The quantitatively arranged remove quantity and surface roughness before and after processing are shown in Fig. 9. Here, the grain diameter is assumed as d_g. Based on Fig. 9, when the grain diameter d_g is smaller than the fiber gap $\{(e_1/d_g) > 1\}$, it exhibits a high remove quantity and surface roughness value; conversely $\{(e_1/d_g) < 1\}$, it also exhibits high polishing efficiency, and its low surface roughness value can be confirmed. Here, when the value of (e_1/d_g) is below 0.1, it exhibits larger remove quantity and exceptional surface roughness. Therefore, when the gap size is significantly smaller than the grain size (below 1/10), it almost near the best suitable parameter was considered.

Therefore, abrasive in the buffing process, if the abrasive grain size is smaller than the mesh size, a majority of the grains cannot contact the workpiece, and the buffing efficiency will be low. When the abrasive grain size exceeds the mesh size, the grain makes sufficient contact with the workpiece to polish it in the process because it cannot penetrate the gap between the fibers, and the polishing efficiency is also satisfactory.

Summary

In this study, the polishing features and ability of the developed new nanofiber abrasive buffing pad were demonstrated. The results are summarized as follows:

1) In this study, we proposed a three-direction physical model of fiber aggregate. Using this model, the abrasive grain size and mass ratio of oil to abrasive grain in abrasive machining can be approximately determined when the fiber mass is constant.
2) For realizing the free-form nano surface, such as molding die surface, the evaluated experiment with different diameter fibers and different size grains was conducted and its base polishing characteristics were investigated. As a result, abrasive in the buffing process, if the abrasive grain size is smaller than the mesh size $\{(e_1/\ d_g) > 1\}$, a majority of the grain cannot contact the workpiece, and the buffing efficiency will be low. When the abrasive grain size exceeds the mesh size $\{(e_1/\ d_g) < 1\}$, the grain makes sufficient contact with the workpiece to polish it in the process because it cannot penetrate the gap between the fibers, and the polishing efficiency is satisfactory. Otherwise, when the gap size is significantly smaller than the grain size (below 1/10), it can be considered as nearly the best suitable parameter, and it can also be confirmed that our proposed model and method are useful.
3) The nanofiber abrasive pad can sufficiently be used in abrasive machining with oil slurry as a next generation abrasive material.

References

[1] Xiangwu Zhang， et al., Centrifugal Spinning: An Alternative Approach to Fabricate Nanofibers at High Speed and Low Cost， Journal of Polymer Reviews, 54 (2014). pp.677.

[2] Eduard Zhmayev, et al., Nanofibers from gas-assisted polymer melt electrospinning， Journal of Polymer, 51 (2010), pp.4140.

[3] Yingying Hu, et al., Numerical study on two-phase flow patterns in coaxial electrospinning, Journal of Applied Physics, 101 (2007), pp.084307–1.

[4] Masaharu Matsubara, et al., Fiberization of Ceramics Using Melt-Blowing Method， Journal of JSME, 74 (2008), pp.74.

[5] Wei Wu, et al., STUDY ON ADSORPTION AND POLISHING CHARACTERISTICS BY NOVEL NANO FIBER PAD FOR ULTRA-PRECISION ABRASIVE MACHINING, Proceedings of the ASME 2017 International Manufacturing Science and Engineering Conference, MSEC2017-2678, pp.1.

[6] Phaechamud, T. et al., Contact Angle and Surface Tension of Some Solvents Used in Pharmaceuticals, Research Journal of Pharmaceutical, Biological and Chemical Sciences, ISSN: 0975-8585, Vol.3, Issue.4 (2012), pp.513.

[7] Wei, Wu, et al., Polishing characteristics of buff machining using non-woven nanofiber fabric, Journal of the Japan Society for Abrasive Technology, Vol.61, No.11 (2017), pp.34. (in Japanese)