

Development of feedback-speed-control system of fixed-abrasive tool for mat-surface fabrication

K. Yanagihara* and R. Kita

National Institute of Technology, Ariake College, Higashi Hagio-Cho 150,
Omuta-Shi, 836-8585, Japan

* Corresponding Author: Kiyoshi@ariake-nct.ac.jp

Abstract: This study deals with the new method to fabricate a mat-surface by using fixed-abrasive tool. Mat-surface is a surface with microscopic irregularities whose dimensions are close to the wavelengths of visible light (400-700 nanometers). In order to develop the new method to fabricate mat-surface without pre-masking and large scale back up facility, utilization of fixed-abrasive tool is discussed. The discussion clarifies that abrasives in shot blasting are given kinetic energy along to only plunge-direction while excluding traverse-direction. If the relative motion between tool and work in fixed-abrasive process can be realized as that in blasting, mat-surface will be accomplished with fixed-abrasive process. To realize the proposed idea, new surface-fabrication system to which is adopted feedback-speed-control of abrasive wheel has been designed. The system consists of micro-computer unit (MPU), work-speed sensor, fixed-abrasive wheel, and wheel driving unit. The system can control relative speed between work and wheel in optimum range to produce mat-surface. Finally experiment to verify the developed system is carried out. The results of experiments show that the developed system is effective and it can produce the surface from grinding to mat-surface seamlessly.

1. Introduction

Mat-surface is a surface with microscopic irregularities whose dimensions are close to the wavelengths of visible light (400-700 nano-meters) [1].

In common industrial techniques, mat-surface is produced by using chemical etching, electrical or laser abrasion, loose abrasive lapping, or shot blasting. These conventional processes, however, demand pre-masking of work-piece and relatively large scale back up facility.

Therefore, in order to develop the new method to fabricate mat-surface without pre-masking and large scale back up facility, new tool which is utilizing fixed-abrasive is developed in this study.



2. Fundamental idea for Tool design

2.1. Mechanism of mat-surface fabrication by means of abrasive process

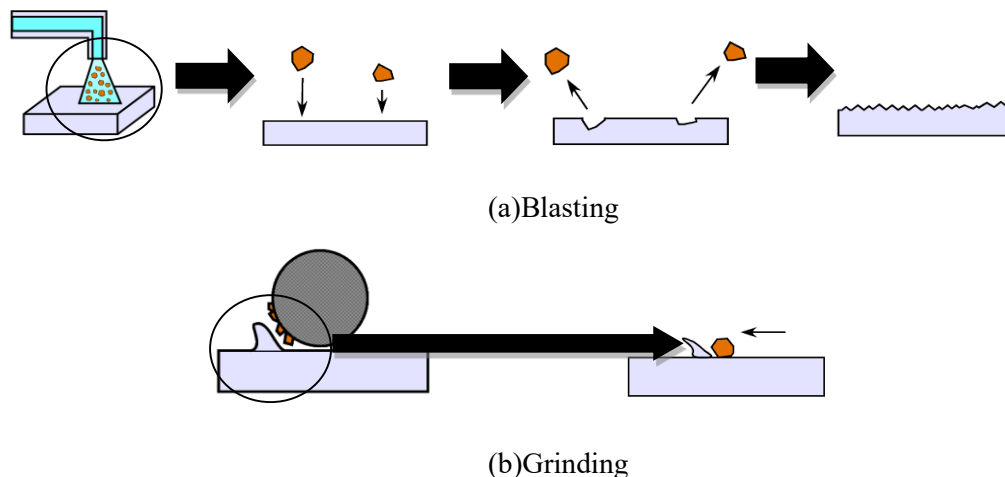


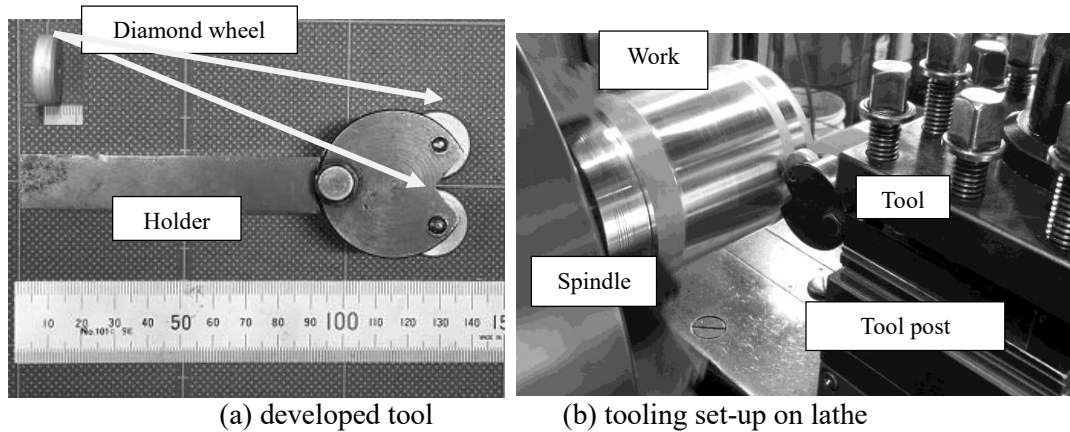
Figure 1. Comparison of surface-generate mechanism

One of the means to fabricate mat-surface is blasting. Figure 1(a) illustrates how blasting process surface of work-piece. In blasting process, hard abrasive-grains whose diameter is from μm to mm are given kinetic energy with compressed air. Then the abrasives with high kinetic energy smash work-piece, and can produce some small dimples on the surface of the work-piece as mat-surface. In this process, regarding each abrasive grain as a tool, the kinematics of tool has only movement of plunge-direction to work-piece without that of traverse-direction.

On the other hand, in grinding process with fixed-abrasive tool, abrasive grains on the tool-surface are given kinetic energy of traverse-direction against work-piece with rotational movement of spindle of grinding machine as shown in figure 1(b). When each abrasive grain touches work-piece surface tangentially, each grain work as a cutting edge. It must scratch and cut the surface of work-piece with a little volume.

Therefore, in designing new fixed-abrasive tool that can produce mat-surface, realization of the movement of abrasive grains which can be plunged into surface of work-piece is necessary without any grain movements of traverse-direction.

2.2. Driven type mat-surface fabrication tool



(a) developed tool (b) tooling set-up on lathe

Figure 2. Driven type of mat-surface-fabrication-tool

Table 1. Tool specifications and experimental conditions

	Abrasive grain	Diamond
	Mesh size	#400
Fixed-Abrasive Wheel	Particle size(μm)	44
	Tool width(mm)	20
	Work-piece	Less than
Processing conditions	speed(m/min)	497
	Feed	6.64
	rate(mm/min)	

Figure 2 (a) shows the designed fixed-abrasive tool for mat-surface fabrication. The tool has two diamond wheels whose specifications are shown in table 1. The two wheels are just contacted to work-piece as shown in figure 1 (b) when it is used. The wheels are driven by rotation of work-piece with relative-speed zero between each wheel and work-piece, while excluding traverse movement of abrasive grains against surface of work-piece to avoid that each abrasive on wheel does not work as a cutting edge.

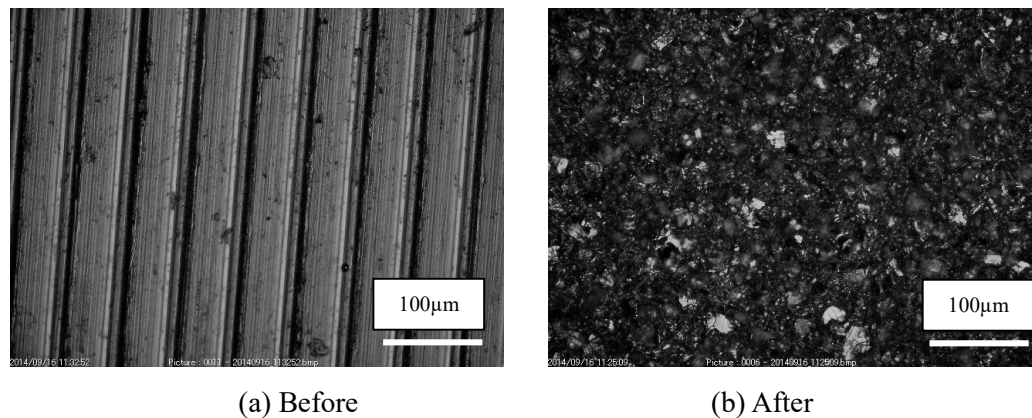


Figure 3. Surface of work-piece

3. Characteristics of Mat-surface fabrication with fixed-abrasive tool.

3.1. Proof experiment of tool-design concept

At the beginning, to confirm whether our discussed idea is right or not, the developed tool is examined with lathe, as shown in figure 2 (b). The experimental conditions are also shown in table 1. The material of work-piece is aluminum alloy in this experiment. Figure 3 shows the photo of surface of work-piece before and after experiments. In figure 3 (a): the work surface before experiment, some regular marks which are generated by cutter of lathe are observed. On the other hand, in figure 3 (b): after processed with the developed tool, the cutter marks are disappeared, and mat-surface is generated.

The topography of the obtained mat-surface is measured, as shown in figure 4. Random dimples are clearly observed over processed surface. This proves that the idea to produce mat-surface by applying fixed-abrasive is right, and that the developed tool is applicable.

Processing with fixed-abrasive tool has an advantage in the control of its processing area without any masking, and can be done by installing the tool on machine tool since machine tool provides axis feeding to the installed tools.

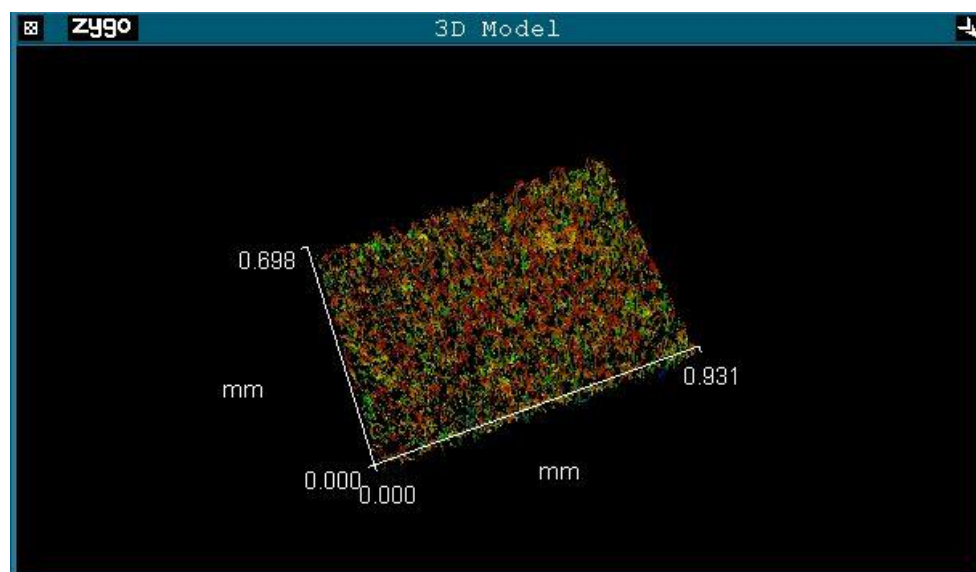


Figure 4. Topography of obtained surface

3.2. Control-ability of tool positioning

Figure 5 shows that some spots of mat-surface is selectively fabricated on the surface of work-piece with the developed tool which is installed on machine tool. It demonstrates that the tool can produce a mat-surface wherever a designer wants to fabricate it without any masking.

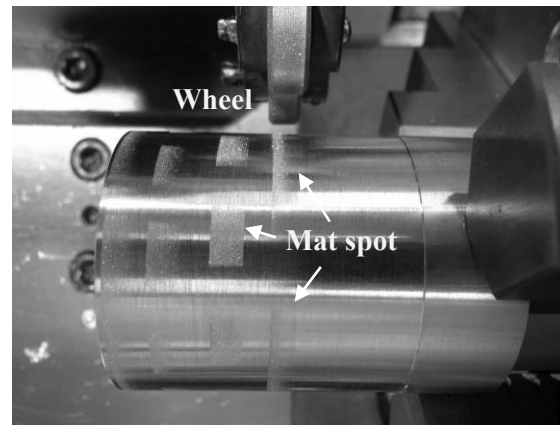


Figure 5. Spots of mat-surface

Table 2. Surface roughness Ra at several surface speeds

Work surface speed (m/min)	Ra(μm)
-	1.68 (pre-processed)
23	2.52
73	2.64
152	2.09
284	2.14
497	3.02

3.3. Speed of work-piece

In order to realize the processing condition that is “zero” of the relative speed between the work-piece and the abrasive wheel while traversing wheel of the whole tool-body, the two wheels of the tool are driven by the work-piece rotation. The drive force is generated by friction of the contact area between the tool-wheel and the surface of the work. If any efficiency of the process is considered, it is desired that the processing time is as short as possible. Table 2 shows surface-roughness of obtained mat-surface in different processing-speed; spindle speed is one of the conditions of lath-process. Roughness of the work-piece is 1.68 μm Ra before the experiment. From 23 to 284 m/min of processing speed, mat-surfaces of about 2 μm Ra are averagely obtained. In 497 m/min of processing speed, however, surface roughness is rougher than those in the other conditions since some scratches are seen on the processed work-surface. The driving force of the developed tool basically depends on friction force between work-piece speed and grits on wheel. Therefore this demonstrates the limitation of processing speed, and at least below 284 m/min is desirable for stable processing for the developed tool.

3.4 Normal force in processing

Figure 6 shows normal force of tool in processing mat-surface. In the figure, processing-forces of the developed tool are compared with those of a knurling tool since processing mechanism of the developed way is similar to that of knurling way. In the experiment, two kinds of materials of work-piece, S35C steel and aluminum alloy, are experimented. It results that normal force of the developed tool is 1 0times lower than that of knurling tool in processing of both the steel and aluminum. The reason of the result is the difference of size of cutting edge of each. The size of one of the edges on surface of knurling-tool is mm order. It is usually used with initial indentation of edges in mm range. Otherwise the size of it on surface of fixed-abrasive is μm order. Thus the initial indentation of edge of our proposed tool is μm range. Therefore, friction force of the developed tool between tool and work is apparently estimated less than that of knurling tool.

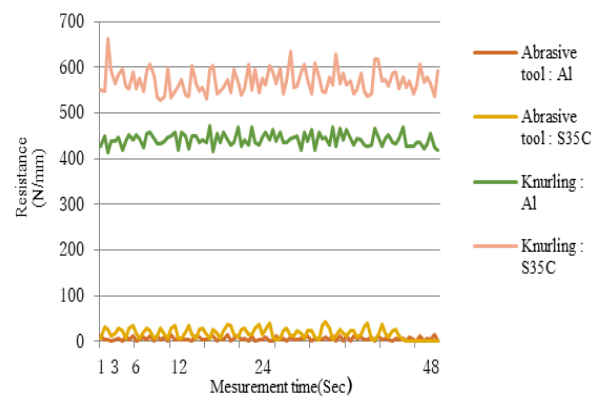


Figure 6 Comparison of normal forces

4. Development of feedback-speed-control system

4.1. System outline

In former chapter, the limit of driven-type mat-surface fabrication appeared in higher range of the work-speed since driving force of driven-type tool depends on the friction force between the tool and the work. To apply the developed mat-surface fabrication method by means of fixed-abrasive tool for wider situation with higher productivity, not passive but active control of the wheel driving is necessarily to track high speed rotation of work-piece.

Figure 7 shows active wheel-driving with feedback control system for mat-surface fabrication. The system consists of a stepping motor to drive an abrasive wheel, a rotary encoder to detect work-piece speed (revolution), and a 8-bit micro-computer to integrate the feedback system.

The rotary encoder is coupled to a contact wheel. The wheel is contacted to work-piece before processing is started. The rotary encoder is driven and produces pulses in proportion to the revolution of the spindle. The outputted pulse is input to the microcomputer. The microcomputer calculates optimum revolution of the abrasive wheel to provide relative speed of zero between the work-piece and the abrasive wheel. After the calculation, the microcomputer sends the calculated pulses which have the optimum frequency to realize the relative speed zero, to stepping-motor-driver-unit, as shown in figure 8.

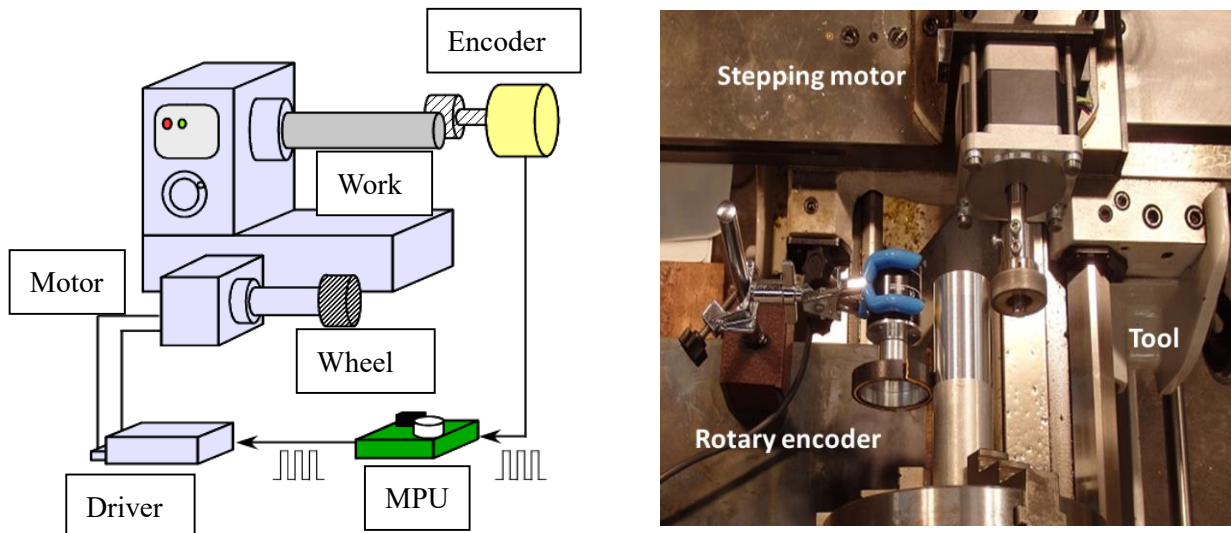


Figure 7. Work-speed feedback control for mat-surface fabrication

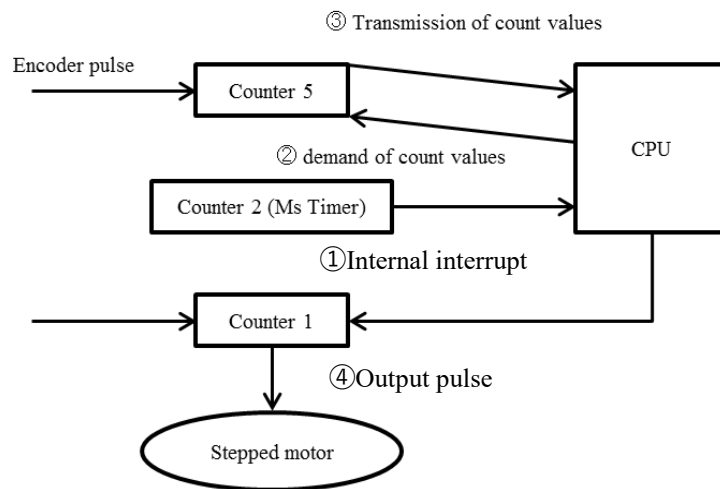


Figure 8. Control sequence among microcomputer and other devices

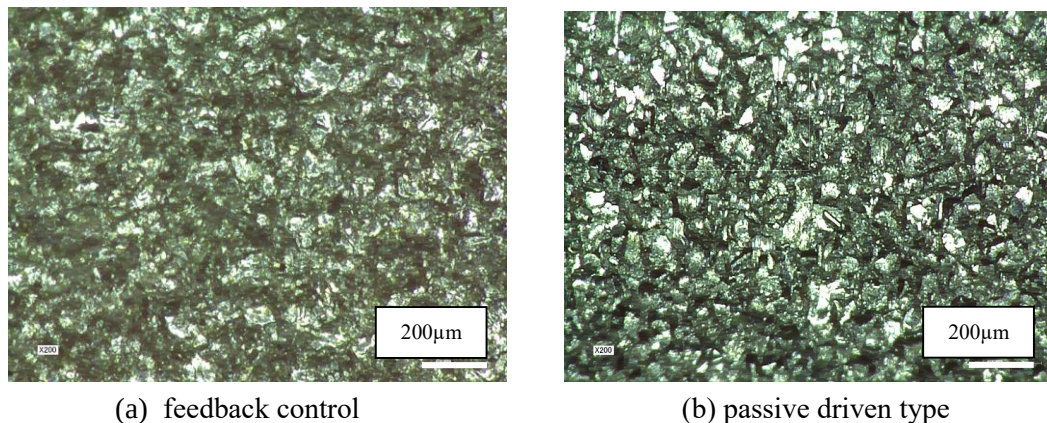


Figure 9. Comparison of microscope images of obtained surfaces

4.2. experiment to verify the developed system

The developed system is verified under the experimental conditions as shown in table 2. Figure 9 is micro-scope images of obtained surface. Figure 9 (a), (b) is the surface which is generated with the proposed feedback controlled, the passive driven-type controlled tool, respectively. Also, Figure 10 shows the roughness curves and the surface roughness R_a of each surface. They are almost the same surface. Therefore, it is verified whether the developed system realizes relative speed zero between work-piece and abrasive wheel, thus it can produce mat-surface as the driven-type tool which is passive controlled.

4.3. Constant relative-speed control finishing

The developed feedback control system can produce not only relative speed of zero but also keeping of constant relative speed. Figure 11 is the obtained surface when transition of relative speed between aluminum-work and tool are produced intendedly. At the beginning of the experiment, relative speed is existing to produce grinding state. Then, feed-back control is started to produce mat-surface in processing of grinding. The figure shows both grooved area that means grinding state and mat-surface that means state of relative speed zero.

The result demonstrates that the developed system can produce the surface from grinding to mat-surface seamlessly.

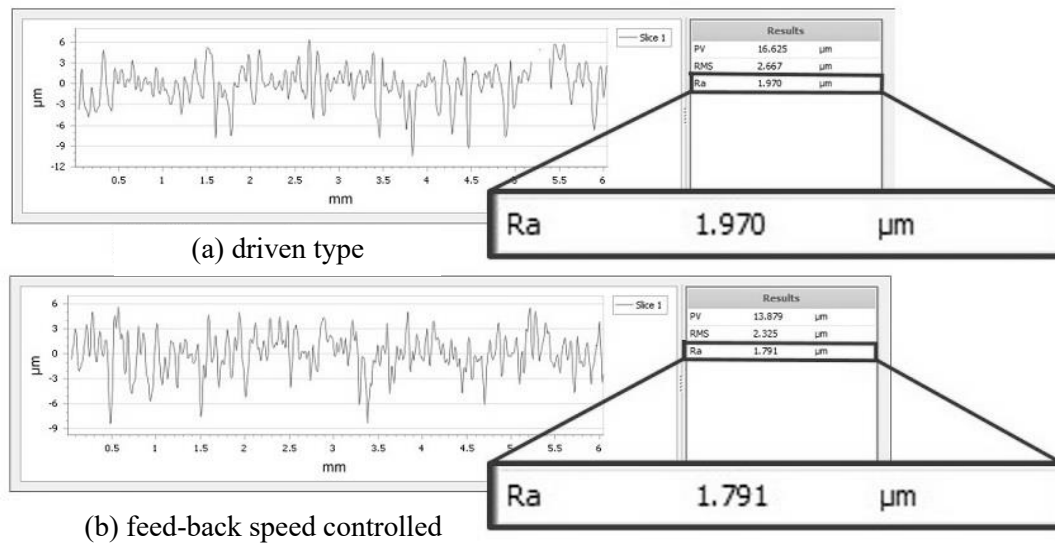


Figure 10. Comparison of roughness curves

Grinding zone | Mat-surface zone

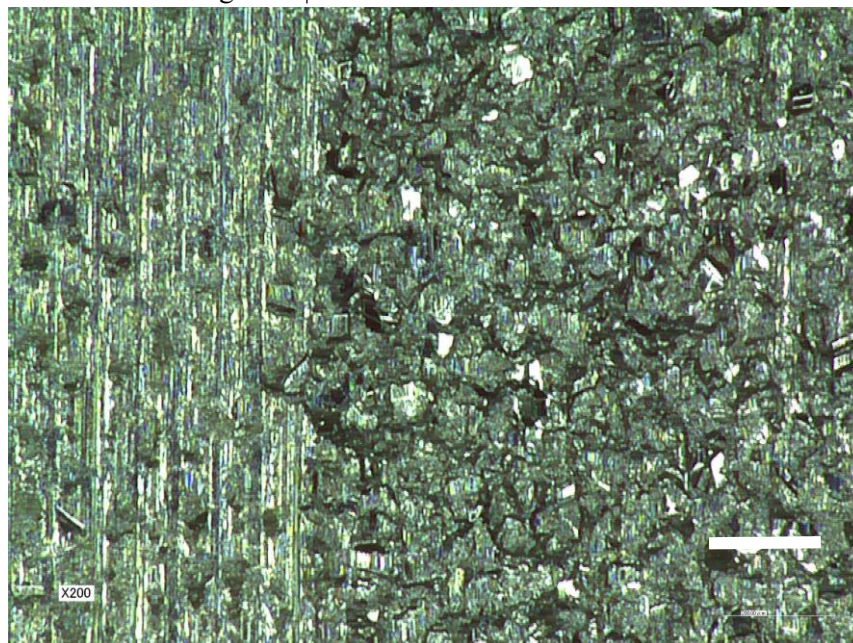


Figure 11. Surface when transition of relative speed between work and tool are occurred

5. Conclusion

In order to fabricate mat-surface without pre-masking and large-scale back-up facility, utilization of fixed-abrasive tool is discussed and new method to fabricate mat-surface with fixed-abrasive tool is proposed. The proposed method is experimented with new designed tool. The obtained results are following:

- (1) To fabricate mat-surface with fixed-abrasive tool, it is important that realization of the function as abrasive grains which can be plunged into surface of work-piece is necessary without any grain movements of traverse-direction against work-piece.
- (2) According to (1), new fixed-abrasive tool for mat-surface-fabrication is designed. The tool has two abrasive wheels, and the wheels are driven by movement of work-piece to prevent relative motion of traverse-direction.
- (3) normal force of the developed tool is 10times lower than that of knurling tool in processing of both the steel and aluminum.
- (4) Feed-back active-speed-control system is developed to produce mat-surface without any dependency of the friction force between surface condition on the tool and the work piece, and it is verified that the system is effective.
- (5) the developed system can produce the surface from grinding to mat-surface seamlessly in case of processing aluminum work-piece.

Acknowledgement

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