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Influence of Tool Feed Conditions on Surface Integrity in Roller Burnishing with Rolling and Sliding Effects

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Abstract. The influence of tool feed conditions on the burnished-surface integrity obtained by roller burnishing, which can generate the sliding effect, adding to the rolling effect at burnishing point, is addressed. A JIS SCM420 steel round bar was used as the workpiece. The surface integrity was improved by feeding the roller in the same direction with the sliding effect and by decreasing the tool feed rate. A better surface was achieved when the roller was fed in the opposite direction to the feed direction of the turning tool in a preceding process of the burnishing.

Introduction

Roller burnishing can achieve a smooth surface by compression of the fine irregular profiles on the target surface by using a roller. The surface layer, which has high abrasion resistance and high fatigue strength, can be obtained with a smooth surface by the combination of work hardening and compressive residual stress [1]. The processing efficiency of the roller burnishing is similar to that of the turning, and it is high compared with the grinding process for surface finishing. Moreover, roller burnishing can be conducted using a common machine tool for machining, and it does not require a dedicated machine [2].

Many theoretical and experimental studies of roller burnishing have been reported. Balland et al. proposed a three-dimensional finite element method model of roller burnishing and verified its applicability [3, 4]. Saldaña-Robles et al. [5] experimentally investigated the influence of the roller burnishing conditions on the burnished-surface roughness, hardness, and corrosion resistance of carbon steel AISI 1045. In the case of conventional roller burnishing, fine irregularities on the target surface are smoothed by only the compressive force generated by the rolling effect. However, when the target material hardness is high or high pressing force cannot be applied, the fine irregularities are easily retained, even after roller burnishing.

Zhao et al. [6] developed ultrasonic roller burnishing for titanium alloy material and demonstrated that the flow stress of the material deformation can be decreased by applying ultrasonic roller burnishing. Tian et al. developed a laser-assisted burnishing method, which can soften the surface layer of the target material to obtain appropriate deformation even for hard materials [7]. However, these burnishing methods require the dedicated devices and the equipment for processing are complicated.

Okada et al. [2] developed inclined-roller burnishing, and the advantages of the developed method were clarified. In the inclined-roller burnishing, the sliding effect can be generated at the burnishing point with a rolling effect only by inclining the rotation axis of the roller with respect to the rotation axis of the target round bar. A special device is not required, and only changing the roller set angle is required. In the inclined-roller burnishing, the generating sliding effect is directional with respect to the direction of the rotation axis of the target round bar. Moreover, the target surface of the round bar is, generally, finished by turning, so it shows a fine helical profile with directionally. However, the influence of the feed conditions, which are the roller feed direction with respect to the direction of the sliding effect and the fine helical profile and roller feed rate, on the burnished surface roughness and profile have not been evaluated. In this investigation, the influence of the roller feed direction and feed rate on the burnished-surface integrity were experimentally evaluated.

Experimental Method

Experimental Setup. Figure 1 shows the experimental setup. Roller burnishing tests were carried out using a bench lathe. The roller burnishing tool was fixed to the tool holder of the bench lathe at an inclination angle of α. The round workpiece bar was rotated using the main spindle of the bench lathe. The pressing force between the roller and workpiece was determined using a compression spring that spring constant was calibrated previously. A burnished surface was obtained by feeding the burnishing tool toward the axial direction of the workpiece. The tool feed was conducted by a servo motor to obtain feed speed control with high accuracy. Figure 2 shows the external view and shape profile of the burnishing roller. The burnishing roller was coated with the diamond-like-carbon (DLC) coating on the cemented tungsten carbide as a base material, and the authors have already evaluated that the DLC coating can achieve sufficient performance for burnishing with the sliding effect [8].

Definition of Tool Feed Conditions. Figures 3 (a) and (b) show the definition of tool feed conditions. In the case of inclined-roller burnishing, the sliding effect, which has a direction component in the rotation axis of the workpiece, was generated by inclining the roller, as shown in Fig. 3. Thus, the direction of the sliding effect was determined by the inclining direction of the roller. In this paper, the case of the burnishing tool fed to the direction of the sliding effect was called "forward sliding," and the case of the opposite was called "backward sliding."

The workpiece finished by turning, which was a preliminary surface for the burnishing, had a fine helical surface profile. It had a directional owing to the feed direction of the turning tool as a cutter mark, as shown in Fig. 3. Thus, the case of the burnishing tool fed to the feed direction of the turning tool was called "forward tool feed," and the case of the opposite was called "backward tool feed."

As a results, four types of feed conditions were defined, as shown in Fig. 3; for example, the tool feed condition of the forward sliding and the backward tool feed was called "F/B" in this study.

Experimental Conditions. The burnishing conditions are summarized in Table 1. The chrome molybdenum steel JIS SCM420 was used as a workpiece material. In the roller burnishing, the preliminary surface roughness strongly influencing the burnished surface has been reported [9]. Therefore, the surface roughness of the preliminary surface finished by turning, which is conducted under same conditions, was set in range of Ra = 2.10-2.26 μm. The inclination angle of the roller α, circumferential speed of workpiece v_w, and pressing force F were set at 30º, 72.3 m/min, and 90 N,

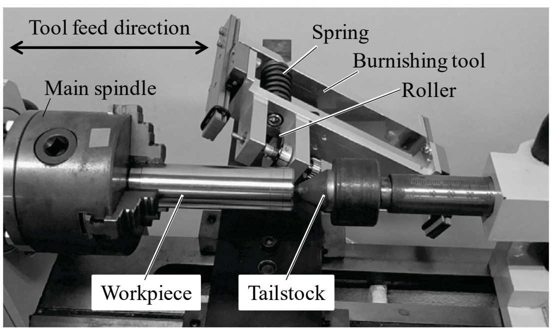


Fig. 1 Experimental setup.

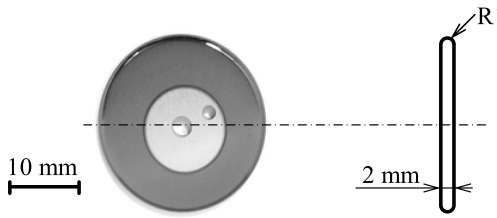
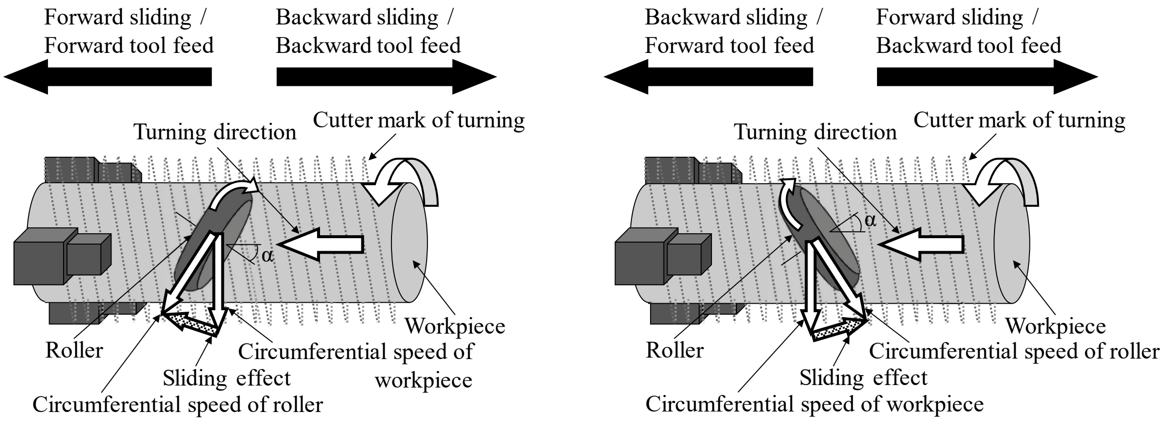


Fig. 2 External view and shape profile of diamond coated carbide roller.



(a) Definition of F/F and B/B. (b) Definition of B/F and F/B.

Fig. 3 Definition of tool feed conditions.

Table 1 Experimental conditions.

Burnishing tool (Roller)	Base material : Cemented tungstain carbide Coating material : DLC Diameter : D_r = 25 mm Circumferential profile : R = 1.0 mm
Workpiece	Material : JIS SCM420 Diameter : D_w = 23 mm Preliminary surface roughness: Ra = 2.10-2.26 μm
Inclination angle : α = 30° Circumferential speed of workpiece : V_w = 72.3 m/min Pressing force : F = 90 N Feed rate : f = 2-30 μm/rev Lubrication : BP-3000, Star Cut Industrial Company	

respectively. These conditions were determined as appropriate conditions, which can be obtained better burnishing results including the roller life. The feed rate was varied in the range of f = 2-30 μm/rev. The lubricant for plastic processing was coated on the preliminary surface. The roughness and profile of the preliminary and burnished surface were measured by a stylus-type roughness meter (SURFCOM NEX SD-12, TOKYO SEIMITSU CO., LTD.).

Experimental Results and Discussion

Influence of Feed Direction and Feed Rate on Surface Roughness. Figure 4 shows the relationship between the feed rate of the burnishing tool and arithmetic mean roughness of the burnished surface when the feed conditions were F/F and F/B. The burnished-surface roughness was measured in the axial direction of the workpiece. In the case of the B/F, the burnished-surface roughness improved with the decrease of the tool feed rate in the range of f = 20-30 μm/tooth. However, it deteriorated with the decrease of the tool feed rate in the range of f = 2-20 μm/rev. As a results, the burnished-surface roughness deteriorated to more than Ra = 0.7 μm at f = 2 μm/rev, although it was Ra = 0.4 μm at f = 20 μm/rev. However, in the case of F/F, the burnished surface roughness improved with the decrease of the tool feed rate under either feed rate. Moreover, the burnished-surface roughness in the F/F was lower than that in B/F at all tool feed rates, and it reached less than Ra = 0.2 μm at f = 2 μm/rev. From these results, the tool feed direction with respect to the sliding direction strongly influenced on burnished-surface roughness. The authors clarified that the surface roughness improved by increasing the sliding distance between the roller and workpiece by conducting the inclined-roller burnishing on the same part multiple times [10]. However, the results, as shown in Fig. 4, showed that this tendency depended on the tool feed direction and feed rate.

Influence of Feed Direction and Feed Rate on Surface Profile. Figures 5 (a)-(d) and Figs. 6 (a) and (b) show the three-dimensional profile of the preliminary and burnished surfaces obtained in B/F and F/F, respectively. The preliminary surface in the F/F was the same as that in the B/F, as shown in Fig. 5 (a). From these profiles of the burnished surface, the regular cutting marks generated by turning on the preliminary surface were suppressed, and a smooth surface could be obtained. However, in the case of f = 2 μm/rev in B/F, as shown in Fig. 5 (b), the regular convex and concave profiles on the preliminary surface clearly remained. Moreover, for the other profiles in B/F, as shown in Figs. 5 (c) and (d), they also slightly remained. However, in the case of F/F, as shown in Fig. 6, the convex and concave profiles almost disappeared, and the superior smooth surface was achieved.

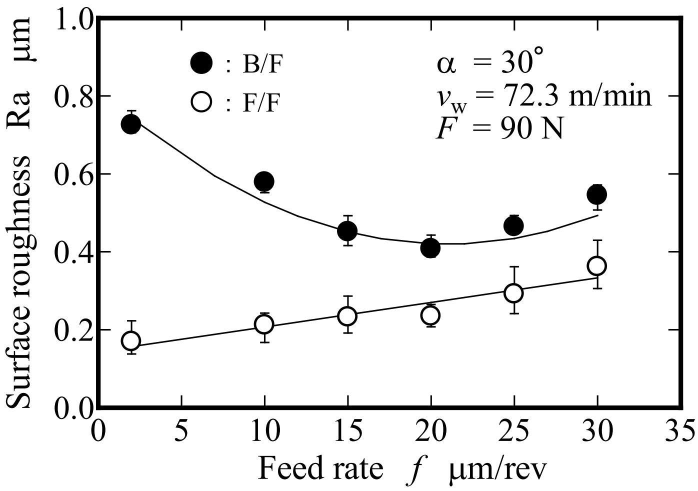
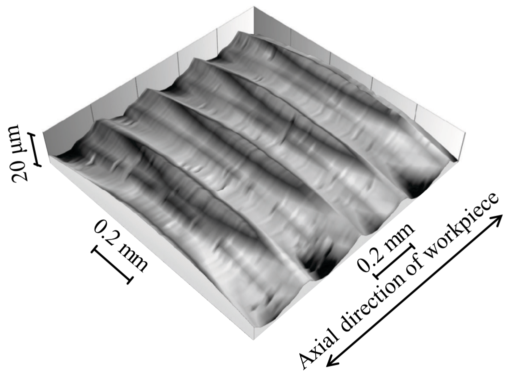
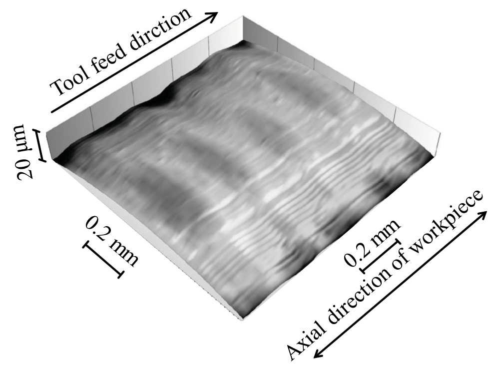


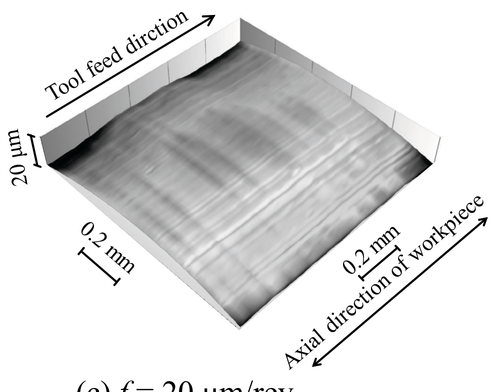
Fig. 4 Influence of feed direction and feed rate on burnished-surface roughness.



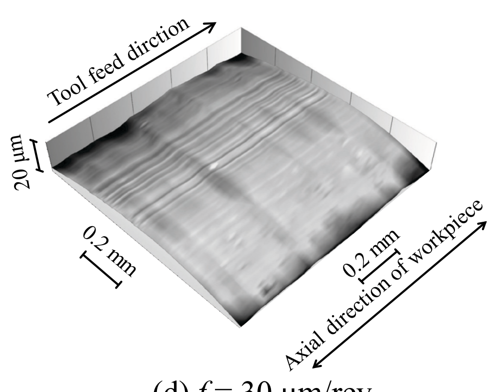
(a) Preliminary surface.



(b) f = 2 μm/rev.

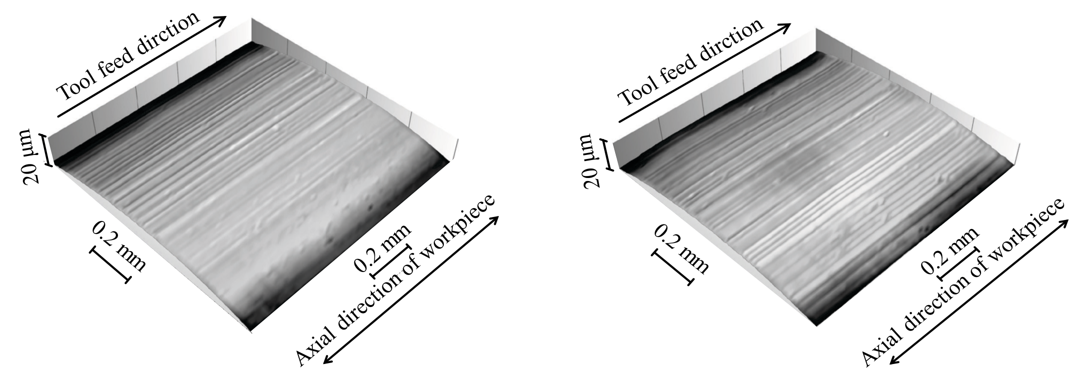


(c) f = 20 μm/rev.



(d) f = 30 μm/rev.

Fig. 5 Three-dimensional profiles of burnished surface in tool feed conditions of B/F.



(a) f = 2 µm/rev. (b) f = 20 µm/rev.

Fig. 6 Three-dimensional profiles of burnished surface in tool feed conditions of F/F.

Influence of Sliding Direction on Material Flow of Surface Layer. Figure 7 shows the sectional profile of the contact region between the roller and workpiece. It was obtained without the tool feed and was obtained by pressing the roller against the preliminary workpiece for approximately 10 s. The direction of the sliding effect acted from right to left, as shown in Fig. 7. The convex profile was observed on the left side of the contact area, and the material flow of the preliminary surface layer was selectively directed to the sliding direction by the inclined-roller burnishing. From these results, the burnished surface was effectively smoothed by actively flowing the material of the surface layer in the tool feed direction by the sliding effect. It seems that the effect can be obtained because of the smoothing of the surface irregularities by minute plastic deformation in the burnishing process. Moreover, the results shown in Fig. 4, where the burnished-surface roughness deteriorates at small feed rates in B/F, were caused by remaining of convex profile owing to material flow of the surface layer. In tool feed conditions of B/F, the tool was fed in the opposite direction to the material flow direction. Therefore, the surface roughness was deteriorated by generating a convex profile due to excessive material flow on the finished surface with decreasing the tool feed rate.

Influence of Preliminary Surface Profile on Burnished-Surface Roughness. Figure 8 shows the influence of tool feed direction with respect to the preliminary surface profile on the burnished surface. For simplicity of evaluation, conventional roller burnishing, which is not generated the sliding effect ($\alpha = 0$º), was also tested. The forward sliding, which can obtain better surface integrity, was applied in the test of inclined-roller burnishing. The burnished-surface roughness in the backward tool feed was better than that in the forward tool feed in both burnishing methods. From these results, the direction of the helical profile obtained by the turning influenced the burnished-surface profile, and better surface roughness could be achieved when the roller is fed in the opposite direction to the feeding of the turning tool.

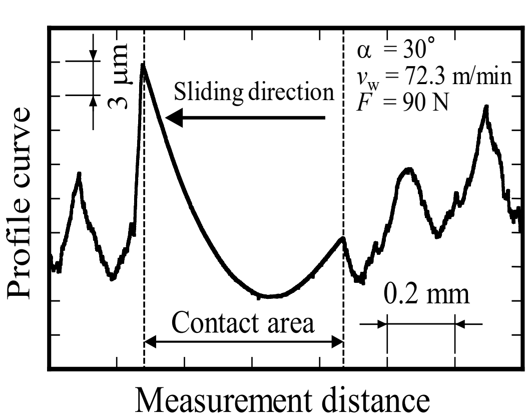


Fig. 7 Sectional profile around burnishing mark without tool feed.

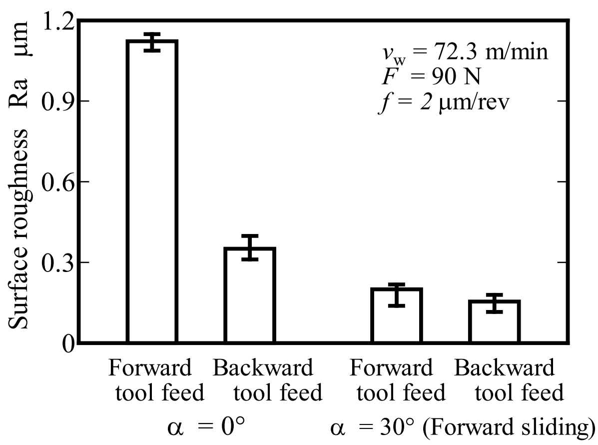


Fig. 8 Influence of tool feed direction with respect to preliminary surface profile on surface roughness.

Conclusions

The influence of tool feed conditions on the surface integrity in inclined-roller burnishing, which was developed by the authors and can generate the sliding effect, adding to the rolling effect, was evaluated. The surface roughness was improved, and the surface profile was smoothed when the roller was fed in the same direction as the sliding direction, which is defined as backward sliding. Moreover, in the backward-sliding condition, a superior surface can be achieved by decreasing the tool feed rate. The material of the surface layer was selectively flowed to the sliding direction. A better surface can be obtained when the roller is fed in the opposite direction to the feeding of the turning tool, which is used to finish the preliminary surface, in the conventional and developed inclined-roller burnishing.

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