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Development and burnishing characteristics of roller burnishing method with rolling and sliding effects

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ABSTRACT

This paper proposes a novel roller burnishing method that achieves simultaneously rolling and sliding effects on the burnishing point to accomplish a finish with superior surface integrity using a commercially available roller burnishing tool. The circumferential surface of the workpiece, which is rotated by the main spindle of the lathe, was targeted. The sliding effect was obtained by changing the rotational axis of the burnishing roller with respect to the workpiece. The principle of this method was examined theoretically, and the generation of rolling and sliding effects was confirmed experimentally. The processing characteristics of the method with an aluminum-based alloy workpiece were evaluated to compare with the conventional method. The influence of the burnishing conditions, such as the burnishing speed, thrust force, and feed rate, was also investigated. The thrust force and feed rate had a large influence on the burnished surface integrity, whereas the influence of the burnishing speed was minimal. The applicability of the proposed method for burnishing a carbon steel workpiece material was also examined.

1. Introduction

Roller burnishing is a micro-plastic forming method that generates smooth surfaces and work-hardened layers by alleviating the micro-concavities and micro-convexities on a target surface using a roller. Roller burnishing has a high processing efficiency compared to other processes like grinding, and does not require dedicated machines because it can be accomplished with common machine tools for cutting processes. Therefore, various experimental and theoretical investigations related to improving roller burnishing have been performed. Balland et al. proposed a three-dimensional (3D) finite element method (FEM) model of roller burnishing and verified its applicability [1,2]. Yen et al. also constructed an FEM model of roller burnishing and analyzed the residual stress on the burnished surface [3]. Li et al. reported an analytical prediction of surface roughness during roller burnishing with experimental verification [4]. El-Tayeb et al. investigated the influence of the contact condition between the roller and workpiece on the burnished surface quality as well as the tribological behavior in roller burnishing of an aluminum alloy [5]. Sagbas applied an optimization method for surface roughness in ball burnishing [6]. Rodriguez et al. investigated the influence of the burnishing conditions on the characteristics of the burnished surface, such as roughness, hardness, and residual stress, and analyzed the residual stresses during burnishing using an FEM model [7]. Shiou et al. proposed a ball burnishing and polishing method for a plastic injection mold with a freeform surface using the machining center [8–10]. For roller burnishing, small concavities and convexities on the workpiece surface are smoothed by the vertical compressive force generated by the rolling. However, when the workpiece hardness is high, some micro-roughness remains. Tian et al. developed a laser-assisted burnishing method, which can soften the surface layer of the workpiece temporarily and locally to obtain appropriate deformation even for hard materials, and investigated its processing characteristics experimentally [11]. However, this method requires a special device in addition to the burnishing tool and the processing method is complex.

Additionally, tip burnishing uses a diamond tip and can obtain a smoothed surface using a sliding effect. Many investigations relating to tip burnishing have been reported. Luo et al. theoretically and experimentally analyzed a mechanism of tip burnishing using cylindrical polycrystalline diamond tools [12]. Korzynski theoretically analyzed the relationship between the burnishing force and

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Nomenclature

D_r	maximum diameter of main roller (mm)
F_t	thrust force (N)
f_r	feed rate (mm/rev)
Ra	arithmetic mean surface roughness (μm)
V_a	velocity component of V_r in axial direction of workpiece (m/min)
V_f	feeding speed of burnishing tool (m/min)
V_r	circumferential speed of main roller (m/min)
V_{sa}	sliding speed in axial direction of workpiece rotation (m/min)
V_{st}	sliding speed in tangential direction of workpiece rotation (m/min)
V_t	velocity component of V_r in tangential direction of workpiece rotation (m/min)
V_w	circumferential speed of workpiece (m/min)
α	inclination angle of main roller (deg.)
ς	taper angle of main roller (deg.)

surface roughness and experimentally validated its applicability [13].

For tip burnishing, the workpiece surface is subjected to a horizontal frictional force in addition to a vertical compressive force. However, tip burnishing requires a hard material for the tip, such as a diamond, which is expensive. Additionally, tip burnishing cannot be used for soft materials because of the risk of gouging and flaking [14]. Therefore, a processing method that can burnish a target surface with simultaneous rolling and sliding effects is required.

In this paper, a new roller burnishing method featuring a sliding effect in addition to a rolling effect is proposed. In conventional roller burnishing for the circumferential surface of a round bar workpiece, the rotational axis of the roller is parallel to that of the workpiece. Thus, the workpiece, which is rotated by the machine tool, rotates the roller at same circumferential speed as the workpiece. However, in the proposed method, the rotational axis of the roller is inclined relative to the workpiece. A sliding effect in the rotational and axial directions at the contact point of the roller and the workpiece evolves from the rolling effect because the roller is rotated at an inclined position against the workpiece. This method can be easily realized using an existing commercial roller burnishing tool. The method can also control the balance between the sliding and rolling effects simply by adjusting the inclination angle of the roller. The burnishing method proposed in this paper is novel, and similar methods are not available in the literature. In this paper, the theoretical processing principle of the proposed roller burnishing method is described. The superiority of the proposed method in comparison with the conventional method was verified considering the differences between the surface roughness, appearance, and profile. The influence of the burnishing conditions of the burnishing method on the surface integrity was also investigated.

2. Roller burnishing tool

2.1. Basic principle of conventional roller burnishing

Fig. 1 shows the conventional roller burnishing tool (SR5AL-S25, Sugino Machine Limited) used in this experiment. The tool burnishes the circumference of a round bar, and the shank of the tool is held by a chuck on the turret of a lathe in the same way as the turning tool. The schematic illustration of the side view of a part during conventional roller burnishing is shown in Fig. 2. The workpiece, which is rotated by the main spindle of the lathe, is subjected to a compressive force in the radial direction by the main roller, which rotates freely. The thrust force of the main roller is derived from the support roller, which also rotates freely and is in contact with the main roller. The support roller is linked to a spring in the main body. Therefore, the thrust force can be adjusted as it is proportional to the indentation distance. Fig. 3 shows an external view of the main roller. The main roller is tapered, and the maximum diameter is approximately 5.0 mm. Therefore, the contact region between the main roller and the workpiece can be assumed to be a point. The workpiece surface is burnished by feeding the burnishing tool along the axial direction of the workpiece.

2.2. Proposed roller burnishing method

In this experiment, the main roller was inclined from the rotational axis of the workpiece to generate simultaneous rolling and sliding effects on the point of contact. The schematic illustration of the processing principle of the proposed method is shown in Fig. 4. The main roller is inclined at an angle α and is rotated about the inclined axis at a circumferential speed V_r by friction with the workpiece, which rotates at a circumferential speed of V_w. V_r and its velocity component in the tangential direction of the workpiece

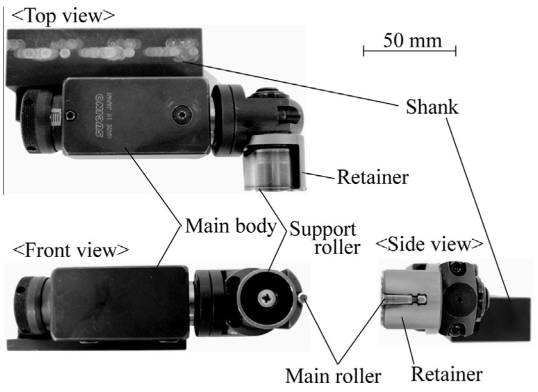

Fig. 1. External view of conventional roller burnishing tool.

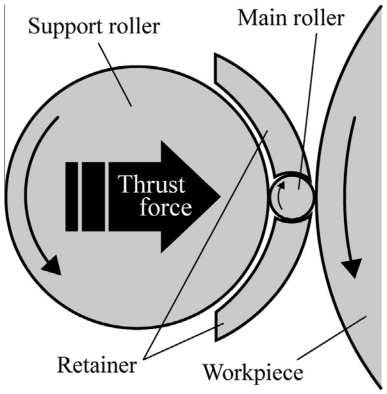

Fig. 2. Details of burnishing process.