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Design of freeform surface finish using burnishing assistance following electrochemical finishing

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Abstract

This study discusses the performance assessment of the continuous burnishing processes following electrochemical finishing using a design, which incorporates a finish-tool that includes an electrode and a nonconductive burnishing-tool. One can expect to make an effective evaluation on the processing features and set up the complete data for processing parameters. In the future, it is also expected to spread a freeform surface finish instead of the conventional hand or machine polishing. In the experiment, a model toy missile is taken as a workpiece. The electrode is used with the continuous and pulsed direct current application. The burnishing-tool uses ceramic material and is connected with the electrode and axial feed. It was found that the finished effect of the finish-tool with convex features is better than that of the concave features. Pulsing direct current can slightly improve the effect of electrochemical finishing. High rotational speeds produce a better finish for workpieces. This presents an effective and low-cost finishing process that includes the design of a finish-tool, which uses burnishing assistance, and follows electrochemical finishing after traditional machining makes the freeform surface of a workpiece smooth and bright.

Keywords: Burnishing assistance; Freeform surface; Toy missile; Tool design; Electrochemical finishing

1. Introduction

Burnishing is a cold working process, which produces a fine surface finish by the rotation of hardened rollers over a bored or turned metal surface. Since all machined surfaces consist of a series of peaks and valleys of irregular height and spacing, the plastic deformation created by roller burnishing is a displacement of the material in the peaks that moves under pressure into the valleys. The result is a mirror-like finish with a tough, work hardened, wear and corrosion resistant surface. Lapping and honing are eliminated [1]. Simple ball-burnishing and roller-burnishing tools were used for the experimental work of the study. These tools are quite similar to their design principles. The performance of the tools and the effects of the burnishing force and number of burnishing tool passes on the surface roughness and surface hardness of commercially available aluminum and brass, were studied [2]. Burnishing is a super-finishing, and it is a plastic deformation process, which is becoming more popular as a finishing process. The lubricant, force, speed, and feed have significant effects on surface roughness and surface hardness. A set of rollers is used to roll on the component surface with adequate pressure. As a result all the pre-machined peaks get compressed into valleys, thus giving a mirror like surface finish. A pre-machined surface roughness of 0.63-0.75 μm (by turning) can be improved up to 0.11 μm (by burnishing) and a superior micro hardness is obtained [3].

Electrochemical machining (ECM) is suitable for high-strength and high-melting point alloy. Many

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industrial applications were realized throughout the decades, such as electrochemical drilling, electrochemical grinding, electrochemical deburring, and electropolishing [4]. The experimental results of Mileham et al. showed that the quality of the machined surface would be influenced by the current density, electrolyte flow rate, and gap width [5]. Bannard correlates the current efficiency with current density and electrolyte flow rate. The maximum efficiency varies with the type of electrolyte [6]. Shen used $NaNO_3$ as the electrolyte for the electropolishing on a die's surface. The result showed that the surface roughness of workpieces decreases with the increase of current density, flow rate and concentration of electrolytes. Moreover, polishing with pulsed direct current was found to be better than continuous direct current [7]. Electropolishing is a surface finish process using PO4-3-P as the electrolyte on brass alloys and zinc alloys. The polishing current increases with increasing zinc content in the alloy and with increasing temperature [8].

The gap width between the electrode and workpiece directly influences the electrical current condition and the dreg discharge [9]. Rajurkar et al. obtained the minimum gap width based on Ohm's law, Faraday's law, and the equation for the conservation of energy, beyond which the electrolyte will be boiled in electrochemical machining. An on-line monitoring system was proposed in [10]. Schuster et al showed that the machining resolution can be limited to a few micrometers by applying ultra short pulses of nanosecond duration, and thus, microstructures can be machined by ECM [11]. The conventional polishing is done by hand or machine. However, polishing by hand is heavily dependent on the experience of the staff, and either hand or machine polishing will result in nonuniform residual stress due to the contact between the tool and workpiece. Surface cracks and micro voids are often induced and deteriorate the service life of the die and mold. The electropolishing (EP) can efficiently produce workpieces that are free of the above-mentioned shortcomings [12].

Electropolishing is a very effective technique for approaching mirror-like surfaces on many metals. For many applications, a smooth and bright surface is essential, and electropolishing is the best technique for achieving this. Additionally, it is recognized that the highly polished surfaces are easier to maintain in a high state of cleanliness [13]. The electrochemical machining process is still being under-utilized because of a lack of understanding for the mechanism of metal removal and inefficient tool design methodology being used. Even for simple cases, it is not possible to accurately predict work profiles[14]. Various shapes of electrode were developed for the electropolishing of cylindrical surfaces including the disc, ring, turning tool, and screw-form [15-18]. Good surface quality of the workpieces was obtained through the arrangement of the experimental conditions. In ECM, when the machining depth increases, the structures have taper. A disc-type electrode is introduced to reduce the taper [19]. The improvement of the surface finish for an enlarged hole wall surface beyond a traditional rough boring by electrochemical smoothing using different types of feeding electrodes was developed and overcame the above-mentioned shortcoming of the taper [20].

However, the major difficulty of electrochemical finishing is the cost and the compensation design of the finish-tool. The design potential for the finish-tool is yet to be explored. Thus, the design of the finish-tool plays a major role [18]. The application of the continuous burnishing processes following electrochemical finishing and the design of the finish-tool are crucial for the finishing processes. In the current study, the most effective finish design and the advantages of low cost equipment with continuous processes is investigated.

2. Design of continuous processes and experimental set-up

The development of an effective design for the continuous burnishing processes following electrochemical finishing and the design of the finish-tool is illustrated in Fig. 1. It is based on a scientific method of design processes with an analysis that includes design considerations, design development, detail design, and experimental analysis to construct the final design results [21].

The system schematics and configuration of the finish-tool and workpiece for the experiment set-up are illustrated in Fig. 2. The configuration of the finish-tool and workpiece are shown in Fig. 3, and the geometry of the design for the finish-tool is shown in Fig. 4.

In the experiment, a toy missile is taken for an example. The workpiece is formed by the processes of die casting and by the continuous burnishing processes following electrochemical finishing as a finish operation instead of the conventional hand or

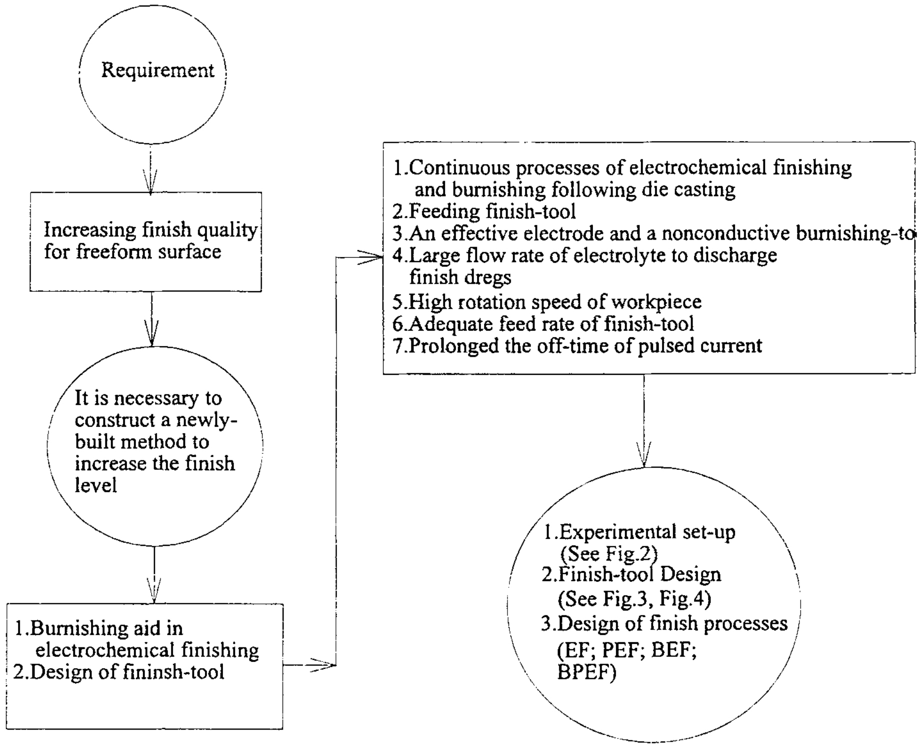


Fig. 1. Design and development of continuous processes.

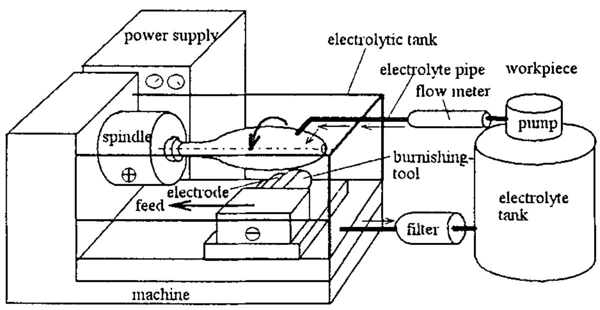
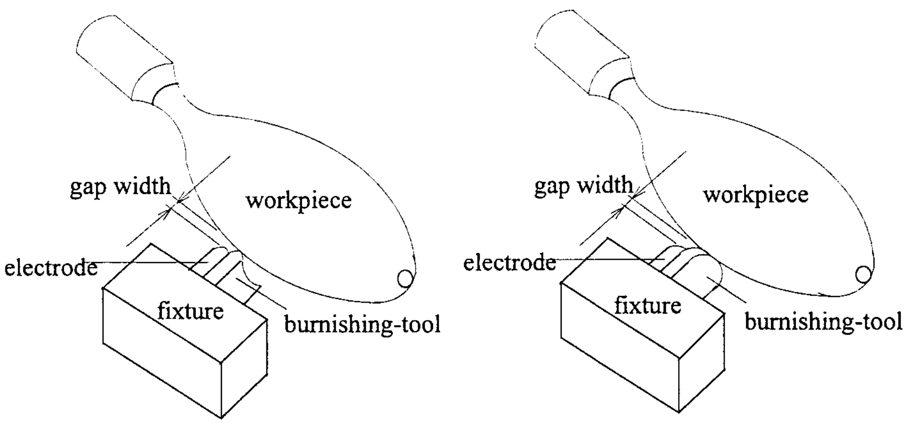


Fig. 2. Experimental Set-Up.

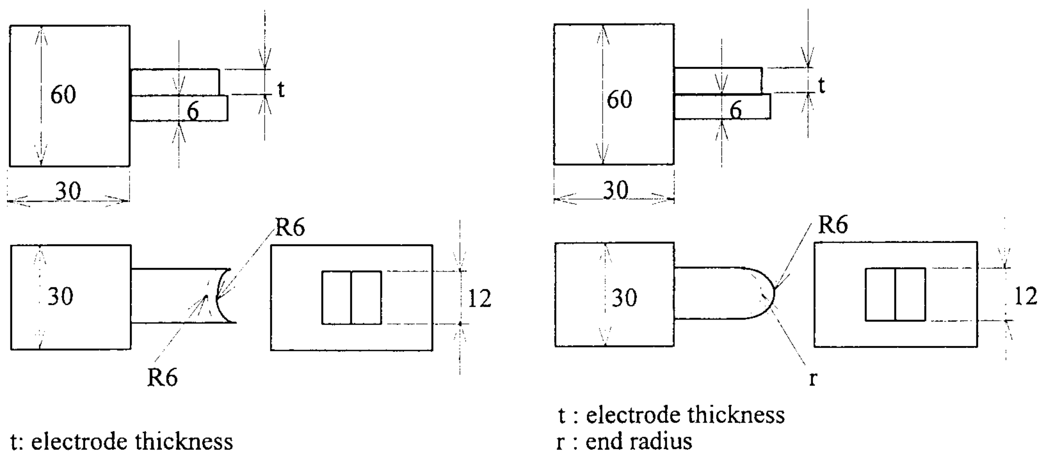
machine polishing. The amount of reduction in workpiece surface after electrochemical finishing and burnishing is 0.04 mm, which is designed in the processes for the dimensional control of parts. Brass castings (ASTM B584) are used for the experimental workpiece. The chemical compositions are shown in Table 1.

The electrolyte is $NaNO_3$ of 25%wt and PO4-3-P 10%wt. The flow rate of the electrolyte is 10 L/min. The temperature of the machining is maintained at 40±5℃. The gap width between the electrode and workpiece is 1.0, 2.0, 3.0, 4.0 and 5.0 mm. The rotational speed of the workpiece is 600, 800, 1000, and 1200 rpm. The current rating is 15, 20, 25, 30, 35, and 40 A. The feed rate of the finish-tool ranges from 20 to 120 mm min^{-1}. The pulsed period (on/off time) is 100 ms/100 ms, 100 ms/200 ms, 100 ms/300 ms, 100 ms/400 ms, and 100 ms/500 ms. The experiment relates to the design of the finish-tool imposed with electrochemical finishing (EF), pulsed electrochemical finishing (PEF), continuous burnishing processes following electrochemical finishing (BEF), and continuous burnishing processes following pulsed electrochemical finishing (BPEF). After electro-



(a) Type A finish-tool with concave features (b) Type B finish-tool with convex features

Fig. 3. Confizuration of finish-tool and workpiece.



(a) Type A finish-tool with concave features (b) Type B finish-tool with convex features

Fig. 4. Geometry of design finish-tool.

Table 1. Chemical composition of workpiece.

weight %	Cu	Zn	Al	Ni	Pb	Sn	Fe	Si
ASTM B584	68.37	29.42	0.26	0.82	2.14	1.12	0.48	0.04

chemical smoothing, all workpieces are measured by the surface roughness measurement (Hommel T500, the accuracy is within ±5 % after standard correction). The surface roughness is characterized by Ra, where the length of cut-off is 0.8 mm, and the measuring direction is perpendicular to the tooth mark. The measuring data is chosen from at least two different locations.

3. Results and discussion

Fig. 5 shows that an adequate gap width between the electrode and workpiece produces a better finish. A small gap width takes less time for the same amount of material removal, but it is difficult to discharge electrolytic depositions from the gap, and the finish effect is reduced. A large gap width takes a longer time since the electrochemical finishing effect is limited. As far as the stable operation for electrolytic depositions discharge of electrochemical finishing and grinding is concerned, a gap width of 2 mm is more effective in the current experiment and is suggested for the next-stage test. Fig. 6 shows that a good finish is achieved through an adequate combination of current rating and feed rate of the finish-tool for BEF. At a constant current rating, the finish-tool has an optimal feed for the best surface finish. A fast feed reduces the power delivered to a unit area of the workpiece surface, and a slow feed increases it. The former could not supply sufficient electrochemical power, while the latter could cause the problem of a dreg discharge. In order to reach the same removal amount of 0.02 mm for ASTM B584 from the continuous processes of electrochemical finishing and burnishing, the following combination of parameter values is suggested: 15 A and 20 mm/min, 20 A and 40 mm/min, 25 A and 60 mm/min, 30 A and 80 mm/min, 35 A and 100 mm/min, and 40 A and 120 mm/min for the finish process.

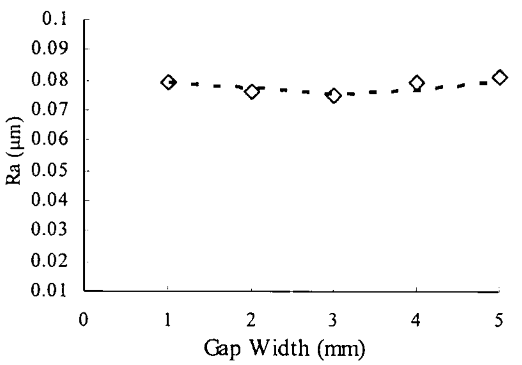


Fig. 5. Gap width between electrod and work piece (ASTM B584, 10 L/min, 40 A, 120 mm/min).

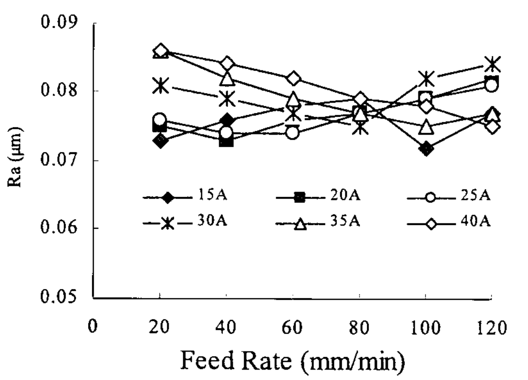


Fig. 6. Different feed rate of finish-tool through different current rating (ASTM B584, 10 L/min, 40 A, 120 mm/min).

The rotation effect of the workpiece is shown in Fig. 7. A range between 1000 and 1200 rpm is suggested. Over 1000 rpm, the rotation effect contributes much to the effective flushing, while high-speed rotation produces a strong centrifugal force will be helpful to discharge electrolytic depositions and improve the finish effect for the electrochemical finishing and the burnishing. Fig. 8 shows the effects of the pulsed direct current. A longer off-time is slightly more advantageous because the discharge of electrochemical finishing dregs during the off-time is more complete. However, the machining time is longer and the cost is increased.

Fig. 9 shows the sequence of electrochemical finishing (EF), pulsed electrochemical finishing (PEF), continuous processes of electrochemical finishing and burnishing (BEF), and continuous processes of pulsed electrochemical finishing and burnishing (BPEF) performance among different finish-tools (Types A and B). Type B gives the best surface finish. The design change of the finish-tool from the concave features (type A) to the convex

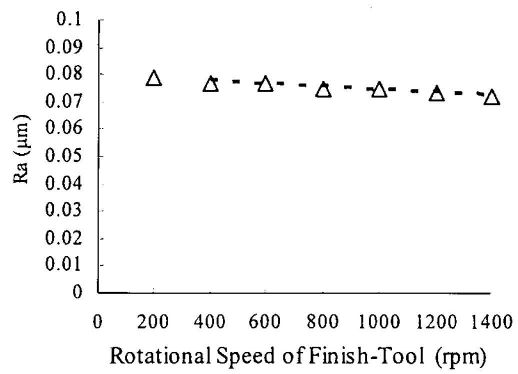


Fig. 7. Different rotational speed of finish-tool (ASTM B584, 10 L/min, 40 A, 120 mm/min).

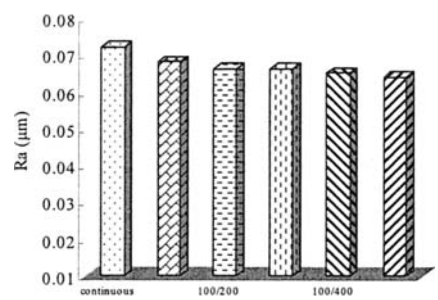


Fig. 8. Comparison of continuous and pulsed direct current (ASTM B584, 10 L/min, 40 A, 120 mm/min).

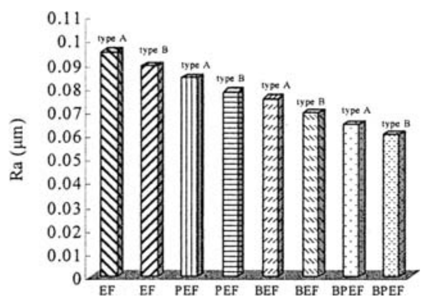


Fig. 9. Effects of different process (ASTM B584, 10 L/min, 40 A, 120 mm/min, 100ms/500ms).

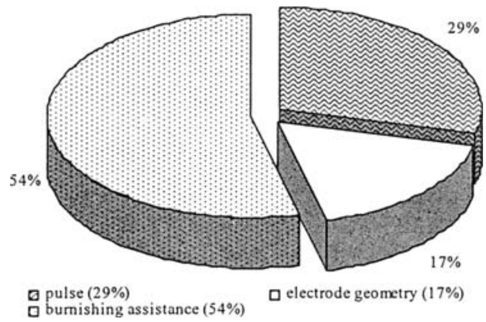


Fig. 10. The contribution pie of surface finish improvement (Type B, ASTM B584, 10 L/min, 40 A, 120 mm/min, 100ms/500 ms).

features (type B) provides more open space for dreg discharge, causes the electrolytic products and heat to be brought away more rapidly, and performs the best finish. The results show that the sequence of the finish effect of EF, PEF, BEF, and BPEF performance among different finish-tools remains the same. The surface roughness is obviously further reduced in this sequence than without the assistance of burnishing. Electrochemical finishing (EF) using burnishing is obviously superior to the use of pulsed direct current. Fig. 10 shows the average contribution of a compound processes for pulsed electrochemical finishing and burnishing (BPEF) to surface finish improvement through the use of pulsed current (29%), burnishing assistance (54%), and electrode geometry (17%).

In summary, the design of the continuous processes through burnishing produces the most influential parameter in this study. The continuous processes of electrochemical finishing and burnishing (BEF) without pulsed current are also recommended, while the use of pulsed current by itself is of limited advantage. This is particularly true when the increased finish time and cost of pulsed-power supply

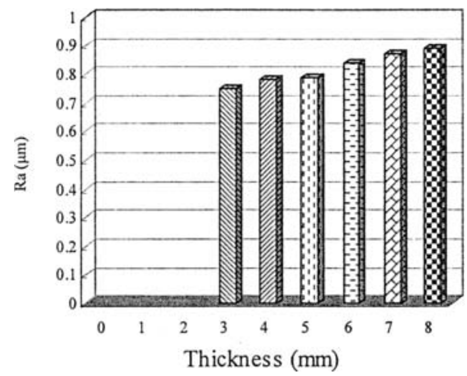


Fig. 11. Comparing of different electrode thickness (Type A, ASTM B584, 10 L/min, 40 A, 120 mm/min).

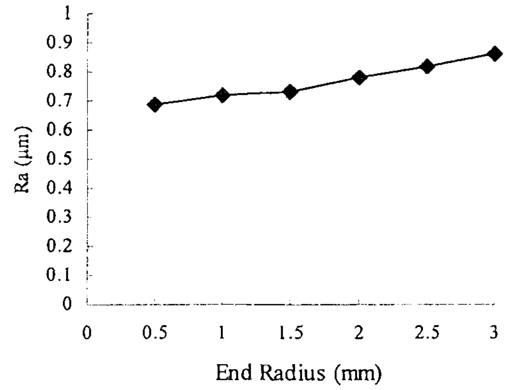


Fig. 12. Effects of end radius (Type B, ASTM B584, 10 L/min, 40 A, 120 mm/min).

equipment is considered. Fig. 11 illustrates the effects of the electrode's (type B) plate thickness. A thin plate provides more open space of dregs discharge and produces a better finish effect in the current study. Fig. 12 shows that Type B with a small end radius on the plate end of the electrode can actually operate at a higher current density, reduces the resistance of dregs discharge, and provides more open space of dregs discharge. The electrolytic products and heat can therefore be brought away more rapidly, which is advantageous for the surface finish. Thus, the smaller the end radius is, the more effective is the finish.

4. Conclusions

The continuous processes of electrochemical finishing and burnishing have been developed as a finish operation by a designed finish-tool that requires a shorter time to make the freeform surface smooth and bright. The effective finish-tool design with an effective electrode and a nonconductive burnishing-tool has an optimal value for the performance of the electrochemical finishing and the burnishing. A high rotational speed of a workpiece produces a better finish for the workpiece. The finish effect is better with a longer off-time because it becomes easier to discharge finish dregs. The design change for the finish-tool from the concave features to the convex features causes the electrolytic products and heat to be brought away more rapidly and performs the best finishing. The burnishing process following the electrochemical finishing can obviously improve the finished effect and take advantage of the low cost for equipment and the finish processes for the freeform surface.

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