Nanofinishing of Microslots on Surgical Stainless Steel by Abrasive Flow Finishing Process: Experimentation and Modeling

Miniaturization of components is one of the major demands of today’s technological advancement. Microslots are one of the widely used microfeature found in various industries such as automobile, aerospace, fuel cells and medical. Surface roughness of the microslots plays critical role in high precision applications such as medical field (e.g., drug eluting stent and microfilters). In this paper, abrasive flow finishing (AFF) process is used for finishing of the microslots (width 450 μm) on surgical stainless steel workpiece that are fabricated by electrical discharge micromachining (EDM). AFF medium is developed in-house and used for performing microslots finishing experiments. Developed medium not only helps in the removal of hard recast layer from the workpiece surfaces but also provides nano surface roughness. Parametric study of microslots finishing by AFF process is carried out with the help of central composite rotatable design (CCRD) method. The initial surface roughness on the microslots wall is in the range of 3.50 ± 0.10 μm. After AFF, the surface roughness is reduced to 192 nm with a 94.56% improvement in the surface roughness. To understand physics of the AFF process, three-dimensional (3D) finite element (FE) viscoelastic model of the AFF process is developed. Later, a surface roughness simulation model is also proposed to predict the final surface roughness after the AFF process. Simulated results are in good agreement with the experimental results. [DOI: 10.1115/1.4039295]

Keywords: nanofinishing, rheology, surface roughness, finite element method, microslots

1 Introduction

Today’s technological advancement demands the miniaturization of the components without compromising its efficiency. The size variation in modern manufacturing industries is shifted from the macro- and millilevel to microlevel and further to nano- and subatomic level. However, machining and finishing of such components is the biggest challenge of manufacturing industries. Finishing accounts for 15% of the total manufacturing cost of the component. Traditional finishing processes, i.e., grinding, honing, lapping are limited to finishing of workpieces with simple geometries and particularly external surfaces. These processes can be upgraded for finishing complex features made of difficult to finish material [1] but proves quite uneconomical. Advanced finishing processes are developed over time to achieve the desired surface finish on complex featured workpieces. Few of them are abrasive flow finishing (AFF) process, magnetic field-assisted finishing process [2], etc. These processes can be used effectively for finishing components ranging from macro- to micro-features. In this paper, AFF process is used to finish microslots in surgical stainless steel. Nitiinol, surgical stainless steel, and such materials are used in metallic stent applications, where in microslots are fabricated using thermal-based micromachining processes (i.e., laser micromachining, electronic discharge micro-machining, EDM). As a result, the surface of these microslots is metallurgically deteriorated/changed having resolidified molten layer with loosely bonded metal debris attached to its surface. Microslots with such metallurgically changed layers used in stents applications can easily cause contamination of medicine while delivering through it. In some cases, addition of the loosely bonded resolidified metal debris contamination is harmful to the patient health. To avoid such issues, Berestovskiy et al. [3] proposed micromilling of microfeatures (microchannel) on the medical devices with ball-end tools.

Authors primarily aim in this paper is to check the feasibility of the AFF process to finish the microslot fabricated on the surgical stainless steel. Therefore, before finishing the costly stent, authors in this paper finished the microslot that are machined by EDM process on surgical stainless steel (SS 316L) workpieces. Finishing of the microslot by AFF process is studied in detail by carrying out the experiments. Also, finite element (FE) modeling of the AFF process and surface roughness simulation model is proposed. Figure 1 shows the medium containing abrasive particles extruded across the microslots passageway in the workpiece during the AFF process. This helps in the shearing of the surface roughness peaks on the microslot surface resulting in fine end surface roughness after the completion of the AFF process.

Perry [4] developed the AFF setup and tooling for finishing of orifices. Later, Walch et al. [5] developed a high precision AFF setup which can finish orifices using high to low viscosity medium. Abrasive flow polishing machine for finishing of microholes is designed by Yin et al. [6]. Authors studied the effect of number of slurry passes through workpiece on the output responses of the process. Effect of AFF input parameters on output responses during finishing of microfeatures using AFF process is reported by researchers [7,8]. Performance of the direct injection diesel engine is increased by Jung et al. [9] by finishing them with AFF process. The finished nozzle provides a more controlled fuel flow rate which helps in enhancing the engine performance. Liu et al. [10] developed AFF setup for finishing of common rail

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