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EDITORIAL

Editorial for the special issue on *Nanofinishing science and technology*

V. K. Jain [1]

Nanofinishing of a component is normally a functional requirement rather than only aesthetic need. It is an expensive and time-consuming operation. To overcome the limitations of the traditional finishing processes, advanced finishing processes (AFPs) have evolved over the years [1]. AFPs are also known as nanofinishing processes. These AFPs are comparatively faster, and they can easily finish 3-D components, complex-shaped components, and free-form surfaces. All this is possible because of the use of the flexible finishing tool which adapts itself according to the shape and size of the components being finished. Further, their extent of flexibility can be controlled on-line in some cases and off-line in other cases. On the other hand, this feature is not available in case of traditional finishing processes because they use the non-flexible cutting tool (in general, bonded abrasive particles work as finishing tools.). The AFPs are mainly divided in three classes that are non-magnetic/polymer-based, magnetic field–assisted, and hybrid finishing processes. All these processes can be investigated in two ways: experimentally and theoretically. Theoretical study can be modeling (mathematical, empirical, and numerical) and analysis, and simulation in general and molecular dynamics simulation at macro and micro/nano level in particular [2, 3]. Papers in this special issue have been categorized based on this classification.

Micro-/nano-manufacturing is the result of miniaturization in different walks of life including aerospace, nuclear power plants, automobiles, laptops, and computers. Micro-/nano-manufacturing can be studied in two classes: the first one deals with the creation of micro/nano level features and the second one deals with the creation of micro/nano level surface irregularities (or nanofinishing) [4, 5]. The first one is called *micro/nano-manufacturing* (here, we are restricting our discussion to micromachining only; however, micromanufacturing includes microwelding, microforming, and microcasting), while the second one is known as micro/nanofinishing. However, in both these classes, material removal is taking place at micro, nano, or sub-nano levels. Hence, in some sense, nanofinishing can be considered as a sub-set of micro/nano or sub-nano machining. This special issue mainly contains research papers related to *Nanofinishing science and technology* but a set of micromachining papers is also included.

Advanced nanofinishing processes have been classified into two classes, namely magnetic field–assisted advanced nanofinishing processes and general advanced nanofinishing processes. For the purpose of this special issue, the first one has been further categorized as magnetorheological finishing (MRF) and allied nanofinishing processes, and magnetic abrasive finishing (MAF) processes. The earlier one uses magnetorheological fluid under the influence of magnetic field as a flexible finishing tool while the second one uses a mixture of solid ferromagnetic particles and abrasive particles with some additives, as a flexible finishing tool whose shape, size, and strength are controlled by the magnetic field strength. The flexibility of the MRF tool is higher as compared to the MAF tool due to their composition.

The first paper in the first category deals with "Nanofinishing of 3-D surfaces by automated five-axes CNC ball end magnetorheological finishing machine using customized controller" by Alam et al. This paper claims that the proposed machine configuration gives more uniform surface finish, higher percent reduction in surface roughness, and on-line control of forces by varying current to the electromagnet according to the variation in the workpiece shape and size. It also simply means that one can extend this configuration to achieve differential finishing on the components requiring different surface finish in different areas. Although it seems to be more time-consuming but it gives better control over the finishing rate in general and complex-shaped components in particular. This ball end magnetorheological finishing (BEMRF) technique should be quite successful especially in case of nanofinishing of very small features, say, a millimeter or a fraction of a millimeter in size. Another interesting paper on nanofinishing is

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✉ V. K. Jain
vkjain@iitk.ac.in

[1] Mechanical Engineering Department, M.A.N.I.T., Bhopal, MP, India

"Preliminary investigations into nano-finishing of freeform surface (femoral) using inverse replica fixture" by Leeladhar et al. Some of the limitations of the BEMRF process are overcome in this rotary magnetorheological abrasive flow finishing (R-MRAFF) process by incorporating the inverse replica as a fixture. It results in nanofinishing of the whole component (all surfaces) at a time which substantially reduces the total time required for finishing a complex-shaped component having even the free-form surfaces. However, it is not easy to accurately finish miniature features as done by the BEMRF technique unless the MR polishing fluid has very low viscosity. However, at very low viscosity, how much effective it will be is a question mark to be investigated. Preliminary results of the R-MRAFF process are encouraging however it needs intensive work to be done in fixture design to get uniform MR polishing fluid velocity and uniform magnetic field on the workpiece surface accounting for the changing curvature of the workpiece at different locations. In the R-MRAFF process, percentage change in Ra (% ΔRa) in both the *X*-direction and the *Y*-direction is found to increase but for still better results there is a need for optimization of the process parameters. For making this process implementable on the shop floor, there is a need of applying finite element analysis and computational fluid dynamics (CFD) together for designing the inverse replica fixture for getting uniform nanofinish in minimum possible time in case of complex-shaped 3-D and free-form surfaces. The third paper of this class is on "Experimental investigations into nanofinishing of Ti6Al4V flat disc using magnetorheological finishing process" by Parameswari et al. In this case, a tapered *disc of titanium alloy (*Ti6Al4V) was finished to reasonably uniform surface roughness value. To achieve uniform surface roughness on the entire disc, a negative (inverse) replica was used as a fixture. Here, also as in the preceding paper, no scientific methodology has been reported as long as design of the fixture (inverse replica) is concerned. However, parametric analysis has been given.

The following paper by Ghosh et al. on "Parametric study on influence function in magnetorheological finishing of single crystal silicon" deals with the evaluation of the effect of certain process parameters on the influence function which is calculated in terms of the spot profile. It is analyzed to find out the volume of material removed and depth of the deepest penetration (ddp) using 3-D noncontact profilometer. The material removal characteristic of a polishing tool is described as influence function. The authors have used ring-type magnet and the flat workpiece made of single crystal silicon. It forms magnetically stiffened magnetorheological (MR) fluid ribbon as a flexible finishing tool which moves through the converging gap against the workpiece. It has been concluded that the working gap and wheel speed have significant effect on the volume of material removal and depth of the deepest penetration of the influence function. However, the shape and size of the magnet are likely to substantially affect the influence function which can be further studied. The fifth paper of this special issue is by Bedi and Singh on "An initial new approach for magnetorheological finishing of ferromagnetic internal cylindrical surfaces." In this paper, a tool has been designed such that it moves inside the cavity of the cylindrical part to be finished. Since the electromagnet axis and cylindrical workpiece axis coincide hence the maximum flux density is at the surface of the magnet rather than the internal surface of the hollow workpiece. As a result, the authors are able to finish both the magnetic and non-magnetic materials with the least probability of sticking of the MR fluid on the inner surface of the workpiece being finished. They also claim that they are able to eliminate the surface defects generated during grinding. The next paper is by Grover and Singh on "Improved design of magnetorheological honing tool based on finite element analysis and experimental examination of its performance." Here, two different designs of the magnetorheological honing tool have been analyzed using the finite element (FE) method. However, to have the acceptability of such simulation results on the shop floor, one should compare simulation results with the experimental results. The last paper of this sub-classification is by Khan and Jha on "Selection of optimum polishing fluid composition for ball end magnetorheological finishing (BEMRF) of copper." In this paper, it has been concluded that the electrolytic iron powder-based fluid exerts higher normal force during finishing as compared to the carbonyl iron powder. Further, the optimum fluid composition has also been suggested for ball end MR finishing of copper under the specified conditions. However, the process performance can be still better if it is further hybridized by adding appropriate chemical(s) in the MR polishing fluid to react with the workpiece material and to produce passive film which can be easily removed by the finishing tool/medium [3, 6]. Under this situation, the abrasive particles softer than the parent workpiece material can be used.

The second class of the magnetic field–assisted advanced nanofinishing processes is *magnetic abrasive finishing* which has three papers in this special issue. The first paper in this category is from Kajal et al. on "Experimental and theoretical investigations into internal magnetic abrasive finishing of a revolver barrel." In the present research work, 0.32-in. barrel of a revolver was finished using a well-established MAF process for magnetic and non-magnetic materials. Authors claim that they could achieve more than 80% improvement in surface finish of a rifled barrel. The second paper of this category is by Barman and Das on "Tool path generation and finishing of bio-titanium alloy using novel polishing tool in MFAF process." Authors have concluded from the experimental study that the proposed parallel tool path gives the best surface finish (as good as 10 nm) and surface topography, as well as surface texture. The last paper under this sub-category is by Jain et al. on the "Force analysis of magnetic abrasive nanofinishing of magnetic and non-magnetic materials." In this paper, an attempt has been made to apply the MAF process for both magnetic as well as non-magnetic materials. Effect of different process parameters on the different types of forces acting on these two types of workpiece materials has been studied, and some empirical models based on the experimental results have been proposed. However, theoretical models need to be developed for better understanding of the process applications for magnetic and non-magnetic materials.

The next class of nanofinishing processes deals with *general advanced nanofinishing processes.* The first paper in this class is on "Medium rheological characterization and performance study during rotational abrasive flow finishing (R-AFF) of Al alloy and Al alloy/SiC MMCs" by Ravi Sankar et al. In this paper, different types of nanofinishing media are prepared by varying composition of the silicon-based polymer, rheological additives, and abrasive particles. Later, rheological characterization (static and dynamic) of the medium is carried out to understand the flow and deformation properties. Experiments have been designed using the design of experiments (DoE) technique. The next paper in this class is by Singh et al. on "Viscoelastic medium modeling and surface roughness simulation of microholes finished by abrasive flow finishing process." An effort is made to understand the physics of the surface roughness improvement during the AFF process. Using the 3-D finite element method, finishing forces are calculated. The authors have also proposed a simulation model to predict surface roughness of the microhole walls' surface for various AFF input parameters. The simulated percent change in surface roughness (94%) and the experimental results (91%) have been compared and they are found to be in good agreement.

Traditional nanofinishing encompasses four papers in this special issue. The first one is by Baghel et al. on "Parametric optimization and surface analysis of diamond grinding-assisted EDM of TiN-Al_2O_3 ceramic composite." It is a hybrid finishing process more commonly known as electric discharge diamond grinding (EDDG) in the literature [7, 8]. The authors have proposed an empirical model to evaluate material removal rate (MRR) based on the experimental results while machining super alloys, namely titanium nitride–aluminum oxide (TiN-Al_2O_3) ceramic composite. The next paper in this sub-class is by Anandita et al. on "Surface generation via scallop overlap analysis during grinding." It is an interesting paper analyzing the effect of randomness of grit protrusion height and inter-grit spacing of a grinding wheel, on the ground surface profile. The trajectory of travel of each active abrasive particle is evaluated to compute the generated surface topography. The third paper of this class is on "Investigations into the effect of process parameters on surface roughness and burr formation during micro end milling of Ti-6Al-4V" by Vipindas et al. As is evident from the title, this paper is more of a parametric study about the effect of input process parameters on the surface roughness and top burr formation during micro milling of Ti-6Al-4V with two different carbide tools having diameter of 0.5 and 1 mm. Statistical models have been developed to predict the responses in terms of cutting parameters. They have proposed a strategy to minimize the top burr height in the micro end milling of a slot. The last but one paper in this sub-class is by Ghosh et al. on "Modeling and optimization of surface roughness in keyway milling using ANN, GA, and particle swarm optimization." In this paper, the artificial neural network model is coupled with GA. Further, the RS model is interfaced with the GA and particle swarm optimization to optimize the cutting conditions. The simulated results lead to the minimum surface roughness value. The last paper in this sub-class is on "Effect of free abrasive on subsurface damage in rolling friction contact of optical lens" by Chen. This is an interesting paper which proposes the rolling friction contact model between the abrasive particles and optical lens. In this model, surface morphology of the abrasive particles and workpiece surface are taken into consideration. The rolling contact analysis uses the finite element method. The effects of process parameters and abrasive particles' shape irregularity on sub-surface damage are analyzed and compared with the experimental results.

There are six papers related to micromanufacturing in this special issue. The first paper in this class is by Abhilasha et al. on "Single step laser surface texturing for enhancing contact angle and tribological properties." Here, an attempt has been made to produce micro-textures on polymeric and metallic surfaces using CO_2 laser and solid-state pulsed ytterbium fiber laser, respectively. In this work, an attempt has been made to understand how contact angle and coefficient of friction depend on substrate's surface topography and areal density of the texture. Fabrication of micro-channel array in two perpendicular directions using a laser beam has been used to generate micro-pillars' arrays. The second paper of this class is by Patel et al. on micro-texturing entitled as "Electrochemical micro texturing on flat and curved surfaces: simulation and experiments." For a large area micro-texturing on flat and curved surfaces, an economical single-step process has been proposed using electrochemical micro sinking without the masking technique with low voltage and short pulses. Analysis of current density and prediction of width and depth of micro dimples on a flat stainless steel surface are studied through 2-D numerical simulation carried out on COMSOL 4.3a. Authors have also pointed out the areas where research potential lies before it can be implemented on the shop floor, namely tool and fixture design, 3-D numerical modeling, and CFD analysis of the fluid flow in the micro-cavities/micro-channels. Contact angle of the textured surface can be enhanced by producing nano-pillars over these micro-pillars using a well-designed nanofinishing process as mentioned above. The next paper is by Zeng et al. on "A new processing technique for fabrication of ultra-thin wafer." In this work, authors have reported a new technique to fabricate an ultra-thin wafer with high quality by combining ultrasonic wet etching, temporary bonding, and chemical and mechanical polishing (CMP). Authors claim that they are able to fabricate ultra-thin wafer with an average thickness of 76 ± 2 μm, an average surface roughness of 0.32 nm, and a compressive stress of 101.4 MPa. The next paper is by Samanta et al. on "Influence of different control strategies in wire electrical discharge machining of varying height job." Authors have made an attempt to understand the nature of variation of responses (cutting speed, surface finish, and kerf width for any given height job) while varying different input parameters during wire EDM. The next paper in this category is by Patel et al. on "Investigations into insertion force of electrochemically micro-textured hypodermic needles." It reports about the experimental study of the tribological behavior of medical hypodermic needles having micro-textures on its outer surface. It is an interesting work from medical science point of view as well. The authors claim that the micro-textured needle decreased the insertion force and changed the behavior of fracturing of the hydrogel as compared to the needle without micro-textured surface. This can also be interpreted that when a micro-textured hypodermic needle is inserted in the patient's body, it will be less painful as compared to the non-textured hypodermic needle. The last paper of this special issue is on "Comparison in the performance of EDM and NPMEDM using Al_2O_3 nanopowder as an impurity in DI water dielectric" by Kumar et al. This paper compares the EDM performance with and without nanoparticles mixed in dielectric. Useful outcomes have been reported.

I hope this special issue will help in giving new directions to the researchers working in the area of micromanufacturing and nanofinishing. Last but not the least, I would like to thank Prof. A. Y. C. Knee, to permit me to bring out this special issue on *Nanofinishing science and technology.* I would also like to thank for the continuous support extended by the editorial office of *Journal of Advanced Manufacturing Technology.*

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