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Surface roughness modelling for Double Disk Magnetic Abrasive Finishing process

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ABSTRACT

Magnetic Abrasive Finishing (MAF) is a super finishing process having capability to produce surface finish in nano-meter level. The value of surface roughness obtained using MAF process depends upon the material properties of work piece and process factors. In the present work, a mathematical model has been proposed for Double Disk Magnetic Abrasive Finishing (DDMAF) process. DDMAF process is a process that can effectively finish even the flat paramagnetic work piece, which were considered ineffective to be finished by conventional MAF. In the present work, the surface roughness has been modelled as a function of workpiece material properties and process factors namely working gap, abrasive mesh number, percentage weight of abrasive, rotational speed and feed rate. The process model utilizes Lorentz force and Amperes law to estimate the finishing force experienced by an iron particle. The force so obtained has been used to calculate the finishing force transferred to the abrasive particle by using force equilibrium between iron and abrasive particle. The effect of normal distribution of abrasive particle size and the effect of frictional force on finishing forces have also been considered in this work. A MatLab code has been developed to include all the above aspects to determine the change in surface roughness. The model so obtained has been validated using experimental findings and thereafter used to study the effect of various process parameters.

1. Introduction

Magnetic Abrasive Finishing (MAF) process is a super finishing process and is in its early stage of development. The MAF process employs a resilient multipoint cutting tool that applies force of very small magnitude [1], thus overcoming the defects like micro-cracks, geometrical errors and distortions which are present with the conventional super finishing process. The finishing forces in MAF are primarily controlled by magnetic flux density in the working gap. The secondary means for controlling the finishing forces are percentage weight of abrasive, abrasive mesh size and rotational speed. The two main forces that are responsible for the finishing action are the normal and tangential cutting forces [2]. The magnetic flux density in the working gap is responsible for normal force which causes micro-indentation by Magnetic Abrasive Particle (MAP) on work piece surface. While a relative motion between work piece and MAPs are responsible for generating tangential cutting force. This force shears off the peaks present on work piece. Thus, the finishing forces generated during MAF dictate the type of surface finish obtained on workpiece.

Initially the research in the area of MAF has been focused on external [3,4] and internal [5,6] finishing of cylindrical work pieces and studying the effect of process factors on response variables. Magnetic flux density and working gap [3,4] were identified as the most influential process parameters affecting surface finish. Attempts [7–9] have also been there to study the effect of types and size of abrasive on surface finish. However, some researchers [10,11] have developed MAF to finish flat and free form surfaces. Even surface generated by Electric Discharge Machining [EDM] have also been successfully finished using MAF process [12]. Researchers have also attempted to improve conventional MAF by providing additional vibrations to work piece in two [13] and three mutually perpendicular directions [14]. In order to enhance the efficacy of MAF process, new variants of MAF have also been developed like designing new four pole electromagnet [15], integrating MAF with electro chemical turning [16], grinding [17], subjecting workpiece to ultrasonic vibrations [18,19]. Research has also been

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Nomenclatures

A_p	Area of cross reaction of the iron particle
A_{pole}	Area under single pole
$A_{sheared}$	Sheared area
B	Magnetic flux density with magnetic abrasive particle in working gap
B'	Magnetic flux density without magnetic abrasive particle in working gap
$B_{\max}$	Maximum magnetic flux density available
b_0	Width of the base of the triangular asperity
b_i	Width of the land of the asperity after i^{th} pass
D_{iron}	Diameter of iron particle
$D_{abrasive}$	Diameter of abrasive particle
$FMAB$	Flexible magnetic abrasive brush
f_n	Normal force acting on iron particle
f_{n_avg}	Average normal force excreted by the FMAB
$f_n{}'$	Normal force acting on abrasive particle
f_{net}	Net force acting on the iron particle
f_t	Tangential force acting on iron particle
f_{t_avg}	Average tangential force excreted by the FMAB
$f_t{}'$	Tangential force acting on abrasive particle
$f_{t1}{}'$	Actual force available for shearing
$F_{magnetic}$	Magnetic force acting on iron particle
$feed$	Feed rate in mm/min
G	Working gap
h	Indentation depth
h_i	Height of the peak sheared in the i^{th} stroke
H_m	Hardness of workpiece material
J	Current density
M	Weight of powder mixture
N_{active}	Number of abrasive actively participating in finishing
N_{rot}	Number of cycles
N_{total}	Total number of iron particle in the volume under single pole
P_B	Magnetic pressure
R_a	Average surface roughness
R_{ab}	Radius of abrasive particle
R_i	Radius of iron particle
R_{net}	Resultant force acting on abrasive particle
rps	Rotational speed in revolutions per second
ρ_{iron}	Density if iron
T	Magnetic tension
T_B	Magnetic tension per unit area
T_C	Total number of collisions
T_{N_ab}	Total number of active abrasives under four poles
$\tau_{available}$	Shear stress available for shearing of peak
$\tau_{material}$	Maximum shear stress of workpiece material
$\mathrm{V}_{\mathrm{gap}}$	Volume of working gap under a single pole
$\mathrm{V}_{\mathrm{ironparticle}}$	Volume of single iron particle
V_{i}	Volumetric fraction of the iron powder
W	Width of the indentation
$\mathrm{w}_{\mathrm{track}}$	Distance between two adjacent FMAB chains
θ	Angle of inclination of FMAB chain
θ_{avg}	Average angle of inclination of FMAB chains
Γ	Semi angle of asperity
μ_0	Magnetic permeability of air
μ_{cof}	Coefficient of friction between abrasive particle and work piece surface
μ_f	Magnetic permeability of iron particle
μ_m	Magnetic permeability of the iron and abrasive particle mixture
$\nabla \mathrm{B}$	Magnetic field gradient
$\%\Delta R_a$	Percentage change in surface roughness
$\%wt$	Percentage weight of abrasive

focussed on studying the effect of polishing trajectories on the surface integrity and surface homogeneity [20].

The above attempts have been focused on increasing the application of MAF and its modified/integrated forms. However, the modern industries look for manufacturing process that can be automated. In order to automate MAF for future industries a precise process control needs to be developed. The control over MAF output can be achieved if the output variables can be related to input variables.

Statistical based models have been developed to predict the response variables like surface finish [15,21,22] and finishing forces [10,23]. However, the developed statistical models have limitations that the θs developed are restricted to specific tool design, work material and process factors range. Attempts [24–26] have been made to develop process physics or analytical based models which can be modified according to the physical setup. In this regard, Kim and Choi [24] used an analytical approach to calculate the polishing pressure during MAF process. The model was validated with the experimental data and they reported the polishing pressure to vary between 0 and 50 kn/m^2. Assuming a triangular profile of the surface asperity, they evaluated the change in surface roughness assuming a constant stock removal rate. They observed the simulation results to be quite close to experimental results at low magnetic flux density. Jain et al. [25] developed a mathematical model to estimate the surface roughness as a function of process factors like magnetic flux density, working gap, rotational speed, volume fraction and magnetic abrasive particle size. They considered normally distributed surface roughness values. The simulation results yielded surface roughness less than the experimental values, which were explained due to the use of unbonded type of abrasives, while the mathematical model assumed the bonded type of abrasives.

Jayswal et al. [26] developed a finite element model to evaluate the distribution of magnetic force on workpiece surface. A theoretical model based on the approach proposed by Jain et al. [25] was used to simulate the surface roughness profile. Mori [27] explained that the magnetic abrasive brush was formed such that the summation of the three energies namely magnetisation, repulsion and tension was minimum. They calculated the normal force and tangential force acting on the edges of magnetic abrasive brush considering the summation of energy concept.

However, the above developed process physics or analytical model are not able to produce very good results. The reason for this could be that the assumptions made in these models are not able to account for some of the important mechanics that may significantly affect the response. Further the developed models have been based on workpiece with high magnetic permeability. Moreover, no attempt has been reported considering workpiece with low magnetic permeability.

It may therefore be concluded from the literature survey that the available models are not very accurate and more practical aspects are required to be incorporated that can improve the model accuracy. Moreover, the physics applied to these models should provide easy application to the new developed setups. The present works aims at developing process physics based model that incorporates some important physical aspects, which have not been modelled yet, like unbonded abrasive having normal size distribution, frictional force experienced by abrasive particle, incorporating the physical effect of rotational speed for a paramagnetic flat