Experimental, Theoretical, and Simulation Comparative Study of Nano Surface Roughness Generated During Abrasive Flow Finishing Process

Abrasive flow finishing (AFF) is one of the advanced finishing processes used mainly for finishing of complex surface features. Nano finishing of aluminum alloys is difficult using conventional finishing processes because of its soft nature. So, in this work, aluminum alloys are finished using AFF process. Since the finishing is carried out using polymer rheological abrasive medium (medium), the finishing forces on aluminum alloy workpieces are too low compared to conventional finishing processes. Thus, this process generates nano surface roughness on aluminum alloy. By using the theoretical model, change in surface roughness ($\Delta R_a$) with respect to various AFF input parameters is studied. A new simulation model is proposed in this paper to predict the finishing forces and $\Delta R_a$ during AFF process. Modeling of finishing forces generated during the AFF process is carried out using ANSYS POLYFLOW. These forces are used as input in the simulation model to predict $\Delta R_a$. Medium rheology decides the magnitude of the generated finishing forces in AFF process. Therefore, to predict the forces accurately, rheological properties of the medium are measured experimentally and used as input during modeling. Further, to make the simulation more realistic, abrasive particle bluntness with respect to extrusion pressure and number of strokes is considered. Because of considering these realistic conditions, simulation and experimental results are in better agreement compared to theoretical results. [DOI: 10.1115/1.4035417]

Keywords: abrasive flow finishing, theoretical, simulation, bluntness, rheology

1 Introduction

Conventional finishing processes find great difficulty in achieving a high quality of surface roughness, especially on complex external and internal surface features. Surface roughness is one of the important factors which decide the component performance and life span. The role of surface roughness increases as the dimensions of the component become in the order of surface roughness. The basic principle behind the abrasive flow finishing (AFF) process is to use semisolid to liquid based abrasive medium to finish simple to complex features. Abrasive particle possesses random cutting edges, orientation, and geometry mixed with a medium. The medium takes the path of the component through which it flows that results in achieving surface roughness even in difficult to reach areas of the component. Rhodes presented a case study and concluded that soft material like aluminum to tough nickel alloys can be finished by AFF process [1]. He also reported that the depth of the indentation of abrasive particles depends upon AFF process parameters like extrusion pressure, size, relative hardness, and sharpness of abrasive particle. Loveless et al. investigated the effect of AFF on the surface produced by various traditional premachining processes and concluded that medium viscosity affects the final surface roughness more as compared to extrusion pressure [2]. William and Rajurkar did the AFM experiments and analyzed the generated surface with the help of stochastic modeling and analysis technique called data-dependent systems (DDS) [3]. Later, Williams to online monitor AFF process developed an acoustic emission (AE) based monitoring system [4]. Jain and Adsul studied the effect of various process parameters (abrasive mesh size, medium flow speed, abrasive concentration, and number of cycles) on surface roughness [5]. Raju et al. conducted AFF experiment on spheroidal graphite cast iron and evaluated the generated surface in terms of surface roughness, out of roundness, induced residual stresses, and bearing area friction [6]. Sankar et al. did rotational abrasive flow finishing (R-AFF) and reported that R-AFF is a more effective process compared to AFF [7]. Raju et al. carried out AFF experiments and studied the effect of surface roughness with respect to the number of passes. The above researchers have done experimental study to understand the effect of input process parameters on output responses during the AFF process [8]. To reduce the number of experiments, significant research has pursued in numerical as well as theoretical modeling of AFF process. Jain et al. used abrasion theory, theoretically evaluated the forces acting on a single abrasive particle, and concluded that the developed model predicts the radial stresses at the workpiece surface with reasonable accuracy [9]. Gorana et al. experimentally measured the axial and radial forces by using a dynamometer [10]. Later on, they developed a theoretical model of forces acting on a single abrasive particle and correlated with the experimentally measured forces. Numerical simulation is an alternate and effective means to replace the actual experimental work to get preknowledge about the effects of various input process parameters on surface roughness during the AFF process [11]. Jain and Jain simulated the active abrasive particle density and the final surface roughness profile [12,13]. Gorana et al. proposed an analytical model to simulate and predict the surface roughness for different finishing conditions of AFF process [14]. Jain and Jain proposed a finite-element model to simulate the flow of viscoelastic medium in AFF process and also predicted the final surface roughness