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Nano-finishing Studies using Elastically Dominant Polymers Blend Abrasive Flow Finishing Medium

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Abstract

Abrasive flow finishing (AFF) process is one of the advanced finishing processes that uses polymer rheological abrasive medium to finish simple to complex surface features. AFF process comprises of machine set-up, tooling and medium. Among these three AFF process components, medium plays an important role. Depending on medium constituents and its quantity, the rheological property as well as its finishing abilities varies. In the current research work, soft styrene polymer and silicone polymers are blended along with additives and silicon carbide abrasive particles to make medium. The viscous and elastic properties of base polymers blend are varied using softeners (stearate), plasticizers (hydrocarbon oils) and abrasive particles. Finishing experiments are conducted on Al alloy/SiC (10%) metal matrix composites using central composite rotatable design as well as the responses are modeled using response surface methodology. The best surface finish achieved with optimally blended abrasive medium on Al alloy/SiC (10%) metal matrix composite (MMC) is 110 nm.

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*Keywords:*Abrasive flow finishing; Polymer blended medium; Rheology; Nano finishing

1. Introduction

Finishing is one of the backbone of today's manufacturing industry. With an increase in demand of manufacturing intricate and complex components for various industrial uses, the need for nano finishing is of utmost importance. Surface roughness plays a vital role as it influences the components life and appearance. The finishing cost of micro and macro feature components accounts for a significant portion of the total manufacturing cost. In order to achieve finishing of complex geometries, AFF process is used. AFF process consists of experimental setup, abrasive medium and tooling to hold the workpiece. The mechanical properties of polymer depend on local chain motions and intermolecular interactions between chains [1]. In AFF medium consisting of styrene base polymer, additives and plasticizers was used [2]. A styrene polymer based medium has been reported in [3]. Mechanical and rheological characterization was done to determine the properties using a rheometer and thermogravimetric analyzer. Rheological characterization showed the impact of strain, shear rate, cyclic loading and temperature on the developed media. The developed media helped in obtaining 88% improvement in surface finish. Tzeng, et al. [4] prepared a self-modulating abrasive medium and studied its properties for finishing of micro holes. Authors concluded that higher concentration of coarse abrasive particles at higher extrusion pressure generates better surface finish. The abrasive flow polishing of micro bores having diameter 260~500µm were generated and studied for the surface roughness as well as surface topography [5]. Finishing experiments on cylindrical workpiece (aluminum) using a rheological abrasive medium consisting of silicone polymer,

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abrasive particles and plasticizers were performed [6]. To study the finishing mechanism, authors determined the forces using a pressure transducer and performed a comparison between the developed and proposed model. Finishing of internal passageway of titanium alloy, using a developed abrasive medium was performed leading to 80% reduction in surface roughness values [7].

A compound media made up of silicone polymer mixed with SiC abrasive particles forming a viscoelastic medium was used and thereby reported the variation in process parameters on the surface of the workpiece [8,9]. Later, the wear performance of mild steel component was determined by performing the wear tests before and after AFF process. AFF experiments on aluminum cylindrical workpiece with an abrasive medium composed of silica gel, abrasive particles (SiC, #220, 60% wt. concentration) and some amount of plasticizer (silicone oil) were conducted [10]. The forces (axial and radial forces) were experimentally calculated with the help of pressure transducers to know the finishing mechanism properly and to correlate the proposed theoretical model. AFF process has been reported for achieving nano level surface finish [11]. A relationship is also established between R_a with the extrusion pressure and number of cycles. AFF experiments were conducted on non-ferrous orifice (nozzle of a plasma cutting machines) with an abrasive medium [12]. The authors prepared five combinations of abrasive medium consists of modeling clay mixed with definite proportions of abrasive particles and varnish oil respectively.

Aluminum alloy/SiC MMCs have a wide range of applications in automobile, aerospace and electrical industry because of better electrical as well as mechanical properties. Finishing of homogeneous materials is easy irrespective of their hardness by using harder abrasive particles in the medium. But in case of Al alloy/SiC MMCs, the mechanical properties of reinforcements and the matrix material is not same. SiC particles having high yield strength and elastic modulus are most suited as reinforcements in the aluminum alloy. Hence, the matrix material undergoes ductile fracture whereas the reinforcements undergo either plastic fracture or get pulled out of the MMC because of the formation of agglomerates. This is due to the formation of weak bonds in reinforcement's agglomerated region as compared to bond formation between matrix and reinforcements.

Based on the literature survey, it was observed that there is hardly any evidence related to the fabrication and characterization of polymer blended medium. Most of the researchers have used different types of polymers like silicon polymer, nitrile polymer and styrene polymer for medium development. In the present work, a new type of in-house medium capable of achieving nano level surface finish is developed. Soft silicone polymer and soft styrene polymer are blended together to form a base medium along with additives and abrasive particles. Soft styrene polymer possesses dominating elastic properties which impart a radial force to abrasive particles. The radial force enables the abrasive particles to perform shearing operation. Finishing experiments are carried out using in-house designed and fabricated AFF setup.

2. Experimentation

Abrasive flow finishing (AFF) process consists of three main components namely, experimental setup, workpiece and abrasive medium

2.1 Workpiece materials

Experiments are carried out on Al alloy/SiC (10%) metal matrix composites (MMCs) to achieve desired surface roughness. Advanced stir casting process is used for making MMCs with the silicon carbide (SiC) reinforcement particle size of around (6.0±0.5) µm. To maintain accuracy during measurement of workpiece hardness, Rockwell hardness tester was used to evaluate the hardness at 10 different locations. Then the average value (55±3 HRA) is determined as the final hardness value.

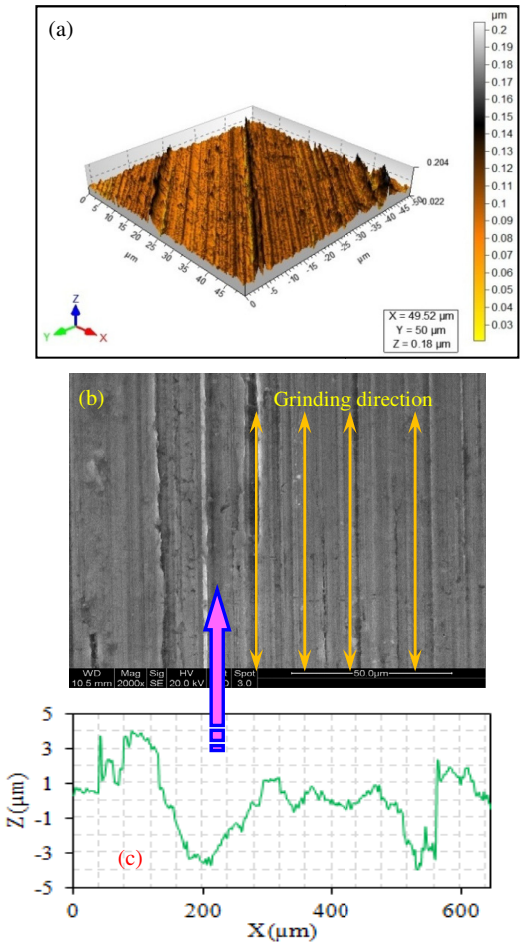

Fig. 1 : (a) 3D surface profile of initial surface, (b) FESEM image of surface morphology, (c) 2D surface roughness profile of the workpiece surface

Then the average value is determined as the final hardness value. Workpiece is prepared by grinding process leading to the formation of uniform level of surface roughness. Non-contact type profilometer (made: Taylor Hobson) is used to measure surface roughness before and after AFF experiment.