Development of magnetic field-assisted finishing (MFAF) for exotic materials using abrasive slurry circulation system effects of media properties on the finishing characteristics

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Abstract

This paper is a progress update to the process development of Rapid-MRF, which has been reported by the authors previously as a new MFAF technology for Ti-6Al-4V components. A new embodiment with an abrasive slurry reservoir to address the problem of media scattering is presented and the effects of media properties on the finishing characteristics are studied. Firstly, certain carbonyl iron-abrasive (CI-abrasive) size ratio is found to generate pits on the polished surface. The ratio is estimated by considering the size of interstitial sites in the CI structure. Secondly, a slurry pH of 11.5 is found to retard CI oxidation and surface roughness (*Ra*) reduction. Lastly, an increase in slurry viscosity caused a drop in material removal rate (*MRR*) that may be explained with lubrication theory.

1. Introduction

Magnetic field-assisted finishing (MFAF) is a category of smart manufacturing processes for the fabrication of fine surfaces. Among the many MFAF processes is Rapid-MRF, which was developed by the authors for the surface finishing of Ti-6Al-4V aerospace components [1]. In the previous report, it was noted that non-magnetic abrasive particles and carrier fluid scattered during polishing due to centrifugal force and therefore compromised the process stability. In this paper, a new Rapid-MRF embodiment is presented to address that problem. Experiments are then conducted to study the effects of Ci-abrasive size ratio, slurry pH and slurry viscosity on the finishing characteristics.

2. Principles of Rapid-MRF with abrasive slurry circulation system

Principles of the previous Rapid-MRF embodiment had been explained elsewhere [1]. Figure 1 shows the schematic diagram the new Rapid-MRF embodiment. It consists of the same Rapid-MRF device and a new tank to contain a slurry reservoir consisting of abrasive particles suspended in a water-based carrier fluid. The slurry reservoir ensures that abrasive particles and carrier fluid, which scattered previously, are always present in the finishing zone. Long-term stability of process is thus improved.

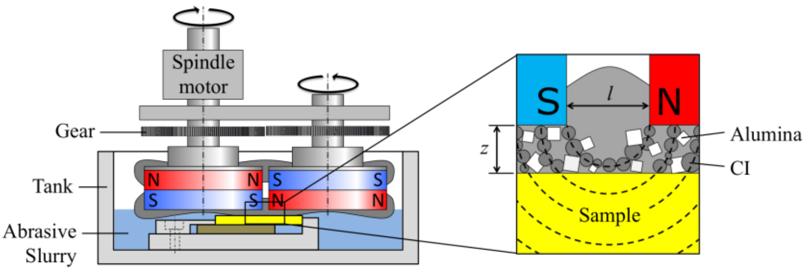


Figure 1: Schematic diagram of Rapid-MRF with abrasive slurry circulation system.

3. Methodology

Rapid-MRF polishing experiments using different combinations of CI and abrasive (aluminum oxide, Al_2O_3) particle sizes were conducted to study the effect of CI-abrasive size ratio. Experimental parameters are listed in table 1. To study the effect of pH, a 1% sodium carbonate solution was used to obtain a slurry pH of 11.5. For viscosity study, conventional polishing experiments were conducted on a Struers TegraPol machine. Slurry viscosity was increased by addition of emulsifying oil (Ecocool 700 NBF, Fuchs Lubricants). SUS316 flat plates were used as workpieces for all experiments. *MRR* and *Ra* were both measured by stylus profilometers.

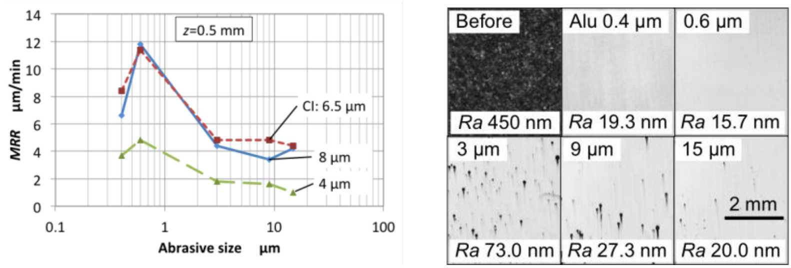
Table 1: Experimental conditions.

l/mm	*z*/mm	Tool revolutions/min^{-1}	Median particle size/µm	
			CI	Al_2O_3
1	0.5, 1	500	4, 6.5, 8	0.4, 0.6, 3, 9, 12, 15

4. Experimental results and discussions

4.1 CI-abrasive size ratio

Maximum *MRR* was achieved with Al_2O_3 particles of 0.6 µm in size, as shown in figure 2(a). In figure 2(b), it is interesting to note that small (0.4 µm, 0.6 µm) and large (15 µm) Al_2O_3 particles gave final *Ra* below 20 nm, but medium-sized (3 µm, 9 µm) Al_2O_3 did not. The pits on surface of workpieces finished by 3 µm and 9 µm Al_2O_3 indicated that the Al_2O_3 particles were not strongly gripped and therefore rolled on the surface. The authors hypothesized that Al_2O_3 particles may be more securely gripped when they fit into the interstitial sites of the CI structures. According to calculations based on simplifying assumptions of uniform spherical particles and face-centred cubic (FCC) packing, the required CI-abrasive ratio is 2.5. That did not correspond to the observed maximum *MRR*, although pits were observed on the surface when the CI-abrasive ratio was 2.67 and 0.89.



(a) *MRR* against abrasive size for different CI sizes

(b) *Ra* and microscope images of surface finished by different Al_2O_3 sizes (CI 8 µm)

Figure 2: Effect of CI-abrasive size ratio on *MRR* and *Ra*.

4.2 Slurry pH

Figure 3 shows that *Ra* reduction was retarded when slurry pH was increased to 11.5, although the same *Ra* was eventually achieved. The increase in pH also retarded the oxidation of the CI particles, which was observed when the slurry consists of Al_2O_3

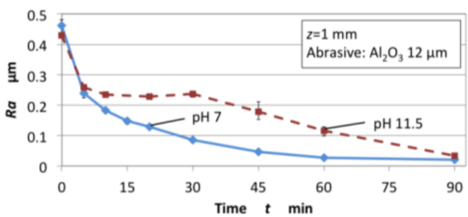


Figure 3: Effect of slurry pH on *Ra*.

particles of 3 μm and larger suspended in water. The role of pH in retarding oxidation is consistent with prior literature [3], although the difference in *Ra* reduction has not been reported previously.

4.3 Slurry viscosity

Figure 4 shows that the *MRR* decreased with increasing slurry viscosity. The abrasion may have occurred in the mixed lubrication regime in the Stribeck curve, where an increasing viscosity lowers the coefficient of friction, which in corollary reduced the *MRR*. When *MRR* decreased from 0.5 μm/min to 0.2 μm/min, *Ra* after 30 min improved due to gentler material removal. However, *Ra* after 30 min deteriorated upon further decrease of *MRR* from 0.2 μm/min because the total material removed may be insufficient for significant *Ra* reduction in that time frame.

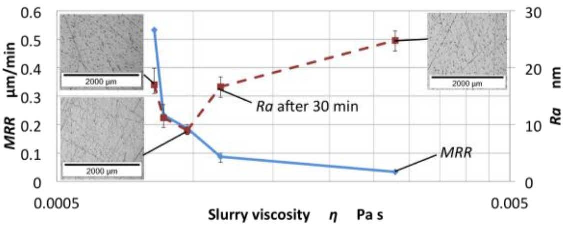


Figure 4: Effect of slurry viscosity on material removal and *Ra*.

5. Conclusion

Rapid-MRF in abrasive slurry circulation system presented in this paper is a precursor to future works in improving long-term process stability. For CI-abrasive size ratio, improved theoretical models that consider particle size distribution may be required to build upon the knowledge described in this paper. Similar analyses will also be carried out in the future for exotic materials such as Ti-6Al-4V, nickel alloys, tungsten carbides and silicon carbides.

References:

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