euspen's 17th International Conference &
Exhibition, Hannover, DE, May 2017
www.euspen.eu

A novel vibration-assisted magnetic abrasive polishing method for complex internal surface finishing

Jiang GUO[1], Ka Hing AU[1], Kui LIU[1], Seow Tong NG[1] & Kah Chuan Sean SHAW[1]

[1]*Singapore Institute of Manufacturing Technology, 73 Nanyang Drive, Singapore 637662, Singapore*

guojiang3302@hotmail.com

Abstract

Components with complex internal surfaces are increasingly important for air or fluid flow applications in aerospace and automotive industries. Recently, as an emerging manufacturing technology, three dimensional (3D) additive manufacturing (AM) technology enables a one-step fabrication of these complex internal surfaces. Although 3D AM technology eliminates the need for complex assembly process, due to the rough surface finish and poor surface and sub-surface integrity, achieving a favourable surface condition is quite challenging. Therefore, a post-polishing process is essential for these 3D AM complex internal surfaces. This paper presents a novel vibration-assisted magnetic abrasive polishing (VAMAP) method to finish a kind of complex internal surface which has a double-layered tube structure fabricated by selective laser melt (SLM) Inconel 718. The set-up consists of a pair of magnets located externally to the workpiece as well as a diametrically magnetised cylindrical magnet located at the centre of the workpiece, along the axial direction. Owing to the magnetic field, the magnetic abrasives are attracted to the internal surface of the outer tube and external surface of the inner tube. Moreover, a relative movement is generated by a rotary motion or linear vibration between the workpiece and magnetic abrasives. Therefore, the surfaces between the inner and outer tubes were polished. The results show that the surface roughness was reduced from about 7 µm Ra to 0.5 µm Ra, and a uniform material removal was obtained on both of the polished surfaces.

Polishing; Additive manufacturing (AM); Internal surface; Vibration; Magnetic field; Material removal; Surface roughness

1. Introduction

Components with complex internal surfaces are increasingly important for air or fluid flow applications in aerospace and automotive industries. Recently, as an emerging manufacturing technology, three dimensional (3D) additive manufacturing (AM) technology enables a one-step fabrication of these complex internal surfaces [1]. Although 3D AM technology eliminates the need for complex assembly process, due to the rough surface finish and poor surface and sub-surface integrity, achieving a favourable surface condition is quite challenging. Therefore, a post-polishing process is essential for these 3D AM complex internal surfaces.

To date, researches are mainly focused on internal finishing of one-layer tube structure using magnetic abrasive polishing method [2-4]. However, there is still no solution for internal finishing of double-layered tube structure. To solve the problem, in this paper, a new vibration-assisted magnetic abrasive polishing (VAMAP) method is proposed to finish a kind of complex internal surface which has a double-layered tube structure fabricated by selective laser melt (SLM) Inconel 718. The paper explains the principle and feasibility study of the VAMAP method which addresses the necessary issues including experimental setup and conditions, magnetic field analysis, and results.

2. Principle of the VAMAP method

Fig. 1 shows the schematic illustration of the VAMAP method for internal finishing of double-layered tube structure. The set-up consists of a pair of magnets located externally to the workpiece as well as a diametrically magnetised cylindrical magnet located at the centre of the workpiece, along the axial direction. From the cross-sectional views, owing to the magnetic field, the magnetic abrasives are attracted towards to the internal surface of the outer tube and external surface of the inner tube and therefore the surfaces between the inner and outer tubes could be polished. The source of magnetic field can be a permanent magnet or electromagnet, and the size grade of the magnets can be adjusted to fit the dimension of workpiece. A relative movement is generated by a rotary motion or linear vibration between the workpiece and magnetic abrasives, causing material to be removed by magnetic abrasives.

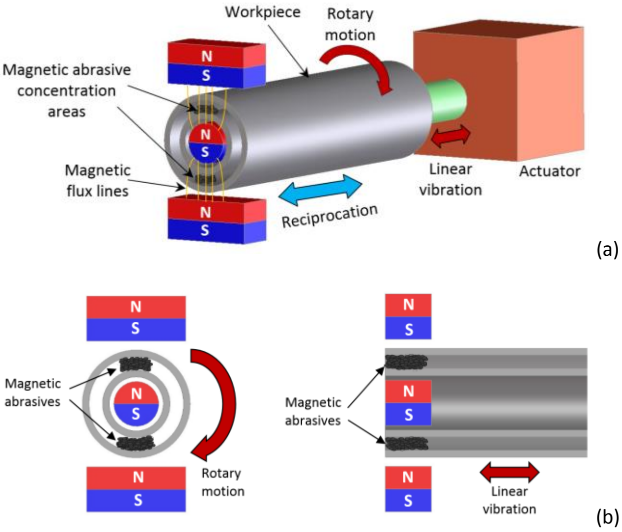

Figure 1. Schematic illustration of the VMAP method. (a) whole view and (b) cross-sectional views.

3. Experimental

To verify the feasibility of this method, experiments were conducted. As shown in Fig. 2, the setup was built in a lathe. As the source of magnetic field, both of the external magnets and cylindrical magnet were made of permanent magnets. The magnets were fixed in a fixture which was mounted on a pneumatic piston vibrator. The workpiece was fabricated by SLM Inconel 718 and it was fixed in the spindle of the lathe. The gap between the external magnets and workpiece can be adjusted. The magnetic abrasives were composed of iron powder (0.3 mm mean diameter) and SiC powder (40 μm mean diameter) with a weight ratio of 9:1. For polishing experiments, the relative movement was generated by rotation of workpiece and vibration and reciprocation of magnetics.

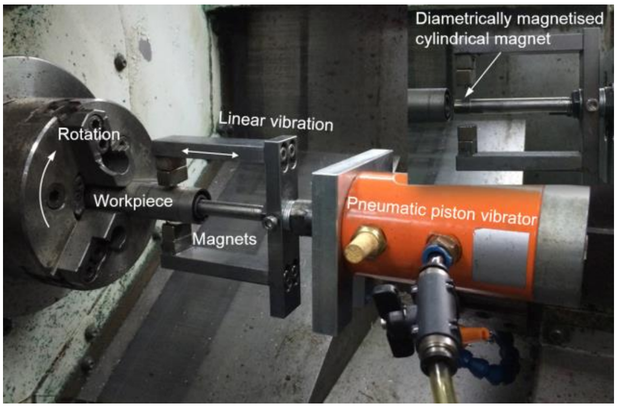

Figure 2. Experimental setup for feasibility study of the VAMAP method.

4. Magnetic field distribution analysis

The magnetic field distribution in cross-sectional view of the setup was analyzed based on the above-mentioned experimental setup using finite element method (FEM). As shown in Fig. 3, the simulation results indicated that through adjusting the size and grade of external and cylindrical magnets, the gap between the external magnets and workpiece, an almost uniform magnetic flux density on the internal surface of the outer tube and external surface of the inner tube was obtained. The magnetic abrasives will distribute following the magnetic flux density.

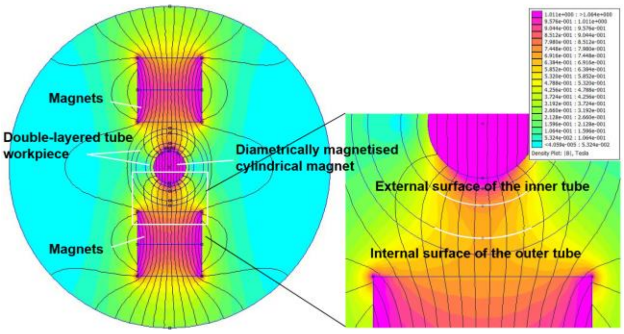

Figure 3. Simulation results of magnetic field distribution for double-layered tube structure.

5. Results

A preliminary experiment was conducted using the experimental setup shown in Fig. 2. Fig. 4(a) and 4(b) shows the picture of 3D AM double-layered tube workpiece and part of workpiece after polishing, respectively. The workpiece was fabricated by SLM Inconel 718 with an outer tube diameter of 24 mm and inner tube diameter of 15 mm. The length of workpiece was 50 mm and the thickness of tubes was 3 mm. For this experiment, only rotary motion was adopted. The reciprocating distance was 15 mm. The polishing time was about 3 hours. After polishing, the workpiece was cut by Wire-EDM, and the surface roughness and material removal were evaluated using a high-resolution aspheric measurement system (Form Talysurf PGI 2540, Taylor Hobson Ltd). As shown in Fig. 5(a) and 5(b), although some groove lines caused by rotation were observed, both of the surface roughnesses of the internal surface of the outer tube and external surface of the inner tube were improved from initial roughness of 7 μm Ra to about 0.5 μm Ra, reduced by over 90%. Fig. 6 shows material removal on inner and outer tubes. It is found that a uniform material removal of 70 μm was obtained on both of the surfaces.

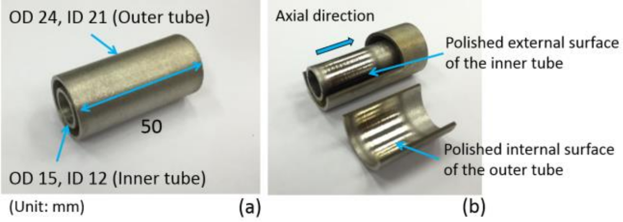

Figure 4. Results of (a) 3D AM double-layered tube workpiece and (b) workpiece after polishing.

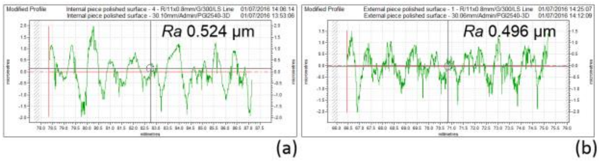

Figure 5. Surface roughness graphs of (a) the inner and (b) outer tubes in axial direction.

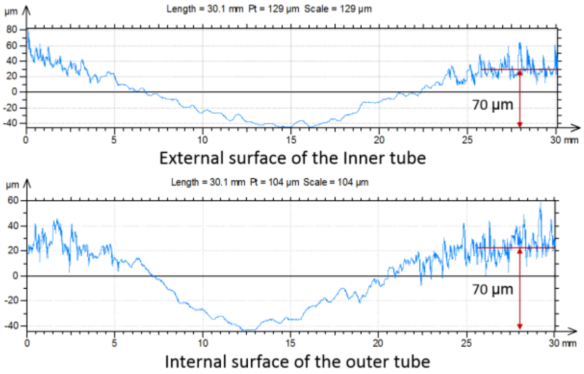

Figure 6. Material removal graphs of the inner and outer tubes.

6. Conclusions

As a summary, this paper presented a new VAMAP method for complex internal surface finishing. The principle was illustrated and the feasibility was verified by experiments. The surface roughness was reduced from about 7 μm Ra to 0.5 μm Ra and a uniform material removal was obtained on both of the polished surfaces. Further investigations will be focused on the material removal mechanism under the condition of combining vibration and rotation motions and optimization of process parameters regarding vibration, rotation, magnetic abrasives and etc.

References

[1] Gibson I, Rosen D W, Stucker B, 2010, Additive manufacturing technologies. Springer, New York **238**
[2] Shinmura T, Yamaguchi H, 1995, JSME Int J C: Mech Sy **38** 798–804
[3] Yamaguchi H, Shinmura T, 2000, *Precision Engineering* **24** 237–244
[4] Yamaguchi H, Kang J, Hashimoto F, 2011, *Annals of CIRP* **60** 339–342