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Preparation of ultra-high aspect ratio micro holes by casting

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ABSTRACT

It was introduced that a very novel technique to prepare micro holes by direct casting method. And the micro hole (in diameter of 0.22 mm) with very large aspect ratio (as large as 1800) was successfully prepared. And anticipate to produce new functional material.

1. Introduction

Ultra-high aspect ratio (U-HAR) micro holes has a wide range of applications in industry, such as include inkjet printer nozzles, spinnerets holes, turbine blades cooling channels, diesel fuel injection nozzles, drug delivery orifices, etc. (Diver et al., 2004). Besides, ultra-high aspect ratio (U-HAR) micro holes are applied as a pre-machining step for wire electrical discharge machining (wire EDM) operations, it was reported by Ferraris et al. (2013). In consequence, manufacturing of long micro holes with diameter less than 1 mm is a field of great interest both in research and industrial application. In recent years, different manufacturing methods of ultra-high aspect ratio (U-HAR) micro holes were introduced by scholars (Sánchez et al., 2013; Masuzawa, 2000).

It is difficult to fabricate ultra-high aspect ratio micro holes by traditional casting process, Wang et al. (2006) reported that regular porous magnesium was fabricated with radial porse distribution by 2D Gasar process, the effect of gas pressures on the mean pore size, the porosity and the pore size distribution of lotus-type porous magnesium fabricated with Gasar process were also investigated (Yuan et al., 2005, 2006), it is a very novel technique to prepare holes, however it is difficult to fabricate a micro hole with ultra-high aspect ratio. Therefore most of the micro holes are generally fabricated by mechanical machining methods at present. Masuzawa (2000) reported that drilling can be used to manufacture holes of 70 μm in diameter, laser has the ability of preparing holes of 40 μm in diameter, but both of them are very difficult to prepare ultra-high aspect ratio (U-HAR) micro holes. Micro EDM drilling is also a well-known process for deep micro holes, but as everyone knows, the common problem in EDM drilling is the electrode wear, the discharge gap usually is several microns, it is very difficult to remove gaseous bubbles and debris from such a small gap. The debris concentration results in abnormal discharges (arcs and/or short circuits), which leading to unstable machining and excessive electrode wear, it was reported by Koch et al. (2001) and Masuzawa et al. (1992). In addition, when the debris concentration at the bottom of the gap between the electrode and workpiece reaches a certain critical value, it will not only deform the machined geometry (Ekmekci and Sayar, 2013), but also lower the surface integrity of the workpiece by forming microcracks and thickened heat affected zones (Yeo and Tan, 1999). For improving flushing capability in micro EDM drilling, vibration assisted methods have been extensively investigated in the recent years. Sheu et al. (1997) report that micro holes of an aspect ratio of 15 have been achieved using deionized water as dielectric liquid and vibrating workpiece, but the rapid movement of the workpiece may cause the vibration of electrode, which results workpiece is poor in precision. Hung et al. (2006) combined ultrasonic vibration of the workpiece with helical micro tools, fabricated directly on board by wire electrical discharge grinding (WEDG), to enhance flushing renewal and debris evacuation. Yu et al. (2002) apply a planetary movement on the tool, also combined with ultrasonic vibration (Yu et al., 2009), to provide an unevenly distributed gap for debris and bubbles to escape from the discharge zone easily. Wansheng et al. (2002) employ longitudinal single-side notched electrodes to provide extra space for debris removal and flushing supply. Those methods show overall

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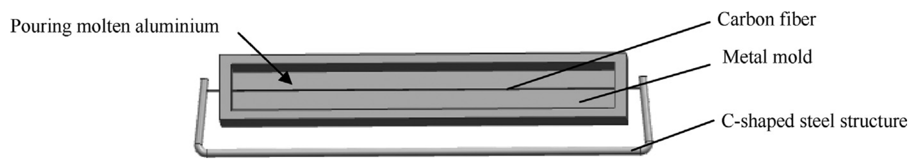

Fig. 1. A gravity pouring pattern.

improved performance, in terms of shape quality, machining time and surface roughness of the drilled holes. The results, however, are still not satisfactory as ultra-high aspect ratio micro holes, e.g. AR > 30, are required (Ferraris et al., 2013).

For overcoming above problems, a very novel technique to prepare micro holes by direct casting method is described in this paper. Carbon fiber is selected as the core of the hole for its high strength and poor wettability with liquid metal, and pulled out after the metal liquid solidifies, a micro hole (in diameter of 0.22 mm) with very large aspect ratio (as large as 1800) was successfully prepared, it is a micro hole with maximum aspect ratio based on literatures have been reported. Obviously, this result is different from those to prepare the holes by mechanical machining methods, and anticipate to produce new functional material. The hole wall roughness (Ra) is 6.3 μm, it was analyzed by XRD, the analysis result shows that all the main diffraction peaks are aluminum peaks, Carbon is not founded. It proves that the reaction hardly happened between Carbon fiber and aluminum, so the structure of carbon fiber is almost not destroyed. Its tensile strength is still very big, which provide a guarantee for removing carbon fiber after the metal liquid solidifies. In addition, a fibers tacking model was established to estimate the diameter of the micro hole, According 2D trigonometry, a mathematical formula is deduced to predict the diameter of the micro hole, which made theoretical value in good agreement with experimental results, the relative error was 2%.

2. Materials and methods

2.1. Materials

A bunch of carbon fiber was adopted as the core of the micro hole, which contains 1000 monofilaments. Monofilament was 5–8 μm in diameter and 3.7 Gpa in tensile strength. Tensile modulus was 210 Gpa. Carbon content was 94% or higher; the linear density was 66.7 mg/m; made in China Anhui Xin Fang carbon fiber co. Ltd. The metallic matrix was 99.5% pure aluminum. Argon gas was selected as protective gas. c-shaped steel structure was selected as the pre-tightening device of carbon fiber.

2.2. Methods

The length of carbon fiber increased gradually with heating temperature, under the action of buoyancy from the metal liquid. Carbon fiber is easy to bend upwards, which cause the loss of a micro hole straightness. Therefore, a pre-tightening device was utilized, which made carbon fiber was pulled tightly.

Firstly, the carbon fiber was attached on the pre-tightening device so that it would be strained, it is shown in Fig. 1. It is a c-shaped steel structure which has certain elasticity, and the carbon fibers were attached on both ends of the c-shaped steel structure, then a definite pre-tightening force was exerted on the carbon fibers. When the carbon fiber increased in length, which caused by heated in casting process, it could be tightened timely so that overcome the influence (elongation) of the buoyancy from the metal liquid in order to maintain its straightness.

Then a pre-tightening device and carbon fibers were put into metal mold. Fig. 1 shows the metal mold was a long and thin groove structure. Molten aluminum was heated to about 800 °C. It gets poured around carbon fibers under argon gas protection state. All of the carbon fiber monofilaments are held together under the effect of liquid metal pressure, without gaps. The core of the hole was pulled out after the liquid metal solidifies, a micro hole could be fabricated by this way.

In the end, the length of the hole and the diameter were measured repeatedly by measurement software for the optical microscope, and then the aspect ratio was calculated. The roughness (Ra) of the hole wall in different parts was measured to describe the hole.

3. Results and discussion

3.1. Results

A micro hole was prepared. As shown in Fig. 2, the sample was 400 mm in length. For obtaining the average value of its diameter, their diameter was measured repeatedly in different parts of the micro hole. As shown in Table 1, it was 0.22 mm, and then the aspect ratio was 1800.

Roughness was one of the critical parameters of a micro hole quality, therefore, it was measured in different parts of the micro hole wall to describe the hole. Roughness of the hole (Ra) is about 6.3 μm, it has already reached the parameter that common mechanical processing can attain.

3.2. Discussion

The amount of reaction between Carbon fiber and aluminum, it is an important role to that the carbon fiber can be pulled out.

a. Sample b. The cross section of the hole

Fig. 2. Micro hole sample.