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一種急跳度精微電解技術應用於

高溫耐蝕合金之微孔型結構製造研究

Study on a micro-ECM technology with jerk movement for machining micro holed-structures on high-temperature corrosion-resistant alloy steel.

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摘要

本研究旨在開發一種電極具急跳度運動模式的精微電解技術，應用於高溫耐蝕合金的微孔型結構之製造研究。直徑 Ø 150 μm 以下具倒錐、內擴及內縮等特殊微孔型結構，適用於高壓流體輸送的微噴嘴或微流道，以便提升其噴射壓力，這類的噴嘴材料傳統加工技術很難製作。本研究提出一種「急跳度精微電解」技術，藉由電解電極於微直孔內的急跳度位移運動，於電解間隙中創造出不同的電場強度，以改變孔壁的材料移除率，製造出特殊微孔型結構。實驗規劃首先以直徑 55 μm 微細實心的碳化鎢鑽針製作電解電極，透由真空鍍膜披覆一層膜厚 5 μm 的派瑞林(Parylene)絕緣層，然後將電極端面的絕緣層磨除以與孔壁產生電場。電極在微孔中心位置以旋轉方式，在不同的正負值急跳度運動模式下，由微孔下端緩升至上端，隨硝酸鈉電解液由下而上的沖流運動，孔壁材料會因電解間隙不同的電場強度而發生不同的金屬溶解率，進而創造出各式特殊的微孔造型。研究結果顯示，當急跳度 J= +0.00002 mm/s^3 及電流 I=13 mA 時，可製造出錐率 0.130 的倒錐微孔型結構；急跳度 J= ±0.00002 mm/s^3 及電流 I=16 mA 時，可得錐率 T 為 0.0470 及 - 0.0731 之沙漏型內縮微流通道；反之，急跳度 J= ∓0.00002 mm/s^3，錐率 T 為 - 0.1485 及 0.1510 之鼓脹型內擴微流通道。這些微孔型結構皆具高同軸精度與高對稱精度；比起放電加工技術，電解加工的微孔孔壁沒有凹凸不平的放電坑，故可大幅降低高壓流體的流動阻力，非常適於如柴油引擎的高壓噴嘴之燃油輸送與霧化，提高燃燒效率；或適用於生醫體液傳送，藉由重力使細胞沉澱於流道凹陷處，達血液細胞分離效果。研究證實，所提技術能為特殊微孔型結構的製造，提供另一種高效且無切削力與無熱應力的加工技術，深具商業化潛力。

關鍵詞: 精微電解、急跳度運動、微孔型結構、內擴、內縮

Abstract

The purpose of this study is to develop a micro electrochemical machining (micro-ECM) technology with an electrode jerk movement, so as to be applied to the manufacture of micro holed-structures on high-temperature corrosion-resistant alloy steel. The diameter below Ø150 μm has the special holed-structures such as inward upside-down taper, inward expansion or inward shrink, which is suitable for micro nozzles or micro channels for high-pressure fluid delivery whereby increase its injection pressure. The material of this type of nozzles is mostly made of high-temperature corrosion-resistant alloy, which is difficult to manufacture by traditional processing technology. A "micro-ECM technique with electrode jerk movement", which creates different electric field strengths in the electrolysis gap through the jerk movement of the electrode in the micro-straight hole is proposed in this study, thereby changing the material removal rate on the hole-wall to create special micro holed-structures. Electrode is made of micro solid tungsten carbide rod with 55 μm in diameter. Firstly, the surface of the electrode is coated with a Parylene insulating layer with a thickness of 5 μm by vacuum coating. The insulating layer on the end-face of the electrode is then ground off to create an electric field with the hole-wall. The electrode rotates at the center of the micro-hole, and slowly withdraws from the lower end to the upper end of the micro-hole under different positive and negative jerk movement modes. With the flushing of the sodium nitrate electrolyte ($NaNO_3$) from bottom to top, the material of the hole-wall will different metal dissolution rates occur due to different electric field strengths in the electrolytic gap, thereby creating various special micro holed-structures. The experimental results show that when the jerk J= +0.00002 mm/s^3 and the current I=13 mA, a micro hole with an inward upside-down taper of taper-rate T=0.130 can be produced; When the jerk J= ±0.00002 mm/s^3 and the current I=16 mA, the micro channel with a hourglass-shaped inward shrink with the taper-rate of T= 0.0470 and T=- 0.0731, respectively can be created; On the contrary, when the jerk degree is at J= ∓0.00002 mm/s^3, it can make the micro channel with a bulging-shaped inward expansion with the taper-rate of T= -0.1485 and T=0.1510, respectively. These micro-hole structures have excellent coaxial and symmetric precision; compared with the discharge machining technology, the micro-electrolytically machined hole-walls do not have uneven discharge craters. This reduces the flow resistance of high-pressure fluids, which is very suitable for high-pressure nozzles such as diesel engines for fuel delivery and atomization, improving their combustion efficiency. In addition, it is also employed in biomedical fluid transfer, where gravity causes the cells to precipitate in the concave part of the flow channel to achieve the effect of blood cell separation. The study confirms the commercialization potential of the proposed technology, which provides an alternative, highly efficient, non-cutting and non-thermal machining technique for the manufacturing of special micro holed-structures.

Keywords: micro-ECM, jerk movement, micro holed-structures, inward expansion, inward shrink