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電化學鏡面拋光於AISI 304不鏽鋼之材料移除動力學與磨潤性質分析

Analysis of material removal dynamics and tribology properties in electrochemical mirror-like finishing of AISI 304 stainless steel

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摘要

本研究旨在探討電化學鏡面拋光AISI 304不鏽鋼之加工表面性質，藉由建立工作物與電極之平衡間隙(equilibrium gap)方程式，製造高親水拋光表面，獲得預期之磨潤性質。雖然如此，平衡間隙與電氣參數存在非線性耦合關係，造成材料移除與氧化膜生成之拉鋸作用，導致加工困難。本研究建立材料移除微分方程式，可修正過電位 (α_1)、過切投影面積 (α_2)與移除原生氧化膜($C_{initial}$)對應之間隙、投影面積與電量之非線性誤差。此外，函數式可準確界定極間電壓、電極工作間隙與電解液導電率於鈍化、過鈍化、溶解與鏡面拋光加工表面所對應之臨界值。在驗證實驗中，分析並證明平衡式參數對汲取電流密度與材料移除率產生之效應。結果顯示，依據平衡間隙與電氣參數於電流密度建立之反應曲面，可定義鈍化(Passivation)反應之電流密度區間為<60 A/cm^2，過鈍化(Trans-passivation)反應區間為60–80 A/cm^2，而鏡面拋光(Mirror-like finishing)區間則發生於>80 A/cm^2。經實驗證實，鈍化表面形成之氧化鉻膜(Cr_2O_3)膜具備微小浮凸微結構，貢獻疏水性質(contact angle~135.28°)。相較之下，選擇性腐蝕反應形成之加工表面為蜂巢狀結構(R_a~19.2 nm)，呈現親水性質(contact angle~78.95°)。此外，當不鏽鋼原生之氧化鉻膜(Cr_2O_3)轉化為氫氧化鉻膜($Cr(OH)_3$)時，形成之羥自由基(Hydroxyl radical)為一極性基體，使得加工表面呈現出極親水性質(contact angle~63.33°)。電化學鏡面拋光所形成之溶解機制原理、表面特徵、產生疏水與親水性質之微結構與機制，皆詳盡於內文。

關鍵字：電化學鏡面拋光、加工表面性質、高效率材料移除、親水性表面

Abstract

This study aims to investigate the surface properties in electrochemical polishing of AISI 304 stainless steel workpieces. Through establishing the equilibrium gap equation between the workpiece and the electrode, a highly hydrophilic polished surface can be obtained for the expected tribology properties. However, the coupled parametric terms exhibit non-linear relationships with boundary conditions, which produced contradict effects between material removal and oxide film formation, resulting in machining difficulties. In this study, a differential equation for material removal is established to correct the nonlinear errors of the gap, projected area, and charge corresponding to the overpotential (α_1), overcut projected area (α_2), and removal of the native oxide film ($C_{initial}$). In addition, the equilibrium equation can accurately define the critical values of the voltage, working gap, and electrolytical conductivity corresponding to the passivation, trans-passivation, and mirror polished surfaces. In the verification experiment, the effects of the equilibrium parameters on the drawn current density and material removal rate are analyzed and demonstrated. Based on the established current density plots, the current density ranges of the passivation, trans-passivation and the mirror-like finishing surfaces, can be defined as less than 60 A/cm^2, 60–80 A/cm^2, and greater than 80 A/cm^2. The experiment confirmed that passivation surfaces featured the chromium oxide (Cr_2O_3) film with micro-protruded fingers, which contributed the hydrophobic property (contact angle~135.28°). In contrast, the trans-passivated surfaces presenting hydrophilic properties (contact angle~78.95°) were exhibited with micro-honeycomb structures (R_a~19.2 nm) which were produced by selective corrosions. Moreover, when the chromium oxide film (Cr_2O_3) was converted into a chromium hydroxide film ($Cr(OH)_3$), the hydroxyl radical formed a polar matrix, making the machined surface extremely hydrophilic (contact angle~63.33°). The material removal mechanisms, surface characteristics, alterations of microstructures and activated mechanisms for hydrophobic and hydrophilic surfaces in electrochemical mirror-like polishing are all detailed.

Keywords: Electrochemical mirror-like finishing; Surface properties; High-efficiency material remove; Hydrophilic polished surface