

High-Rate Pulsed Galvanostatic Anodic Dissolution of Chromium–Nickel Steels in Electrolytes for Electrochemical Machining: The Role of Surface Temperature

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Abstract—A pulsed galvanostatic anodic dissolution of chromium–nickel steels (types Kh18N10 (Cr18Ni10) and KhN35VT (CrNi35WT)) under the conditions of electrochemical machining is studied in chloride, nitrate, and mixed chloride–nitrate electrolytes at current densities up to 100 A/cm². In all the considered solutions (except for the dissolution of CrNi35WT in chloride solutions), for relative pulse durations $s \geq 2$ (duty cycle $D \leq 50\%$), the faradaic rate of dissolution reaches a limiting value of ~ 0.18 mg/C, irrespective of pulse duration (from 20 μ s to 2 ms), which translates into the current efficiencies of alloy dissolution of 50 and 68% for the Cr18Ni10 and CrNi35WT alloys, respectively. Using direct current for processing (i.e., $s < 2$) boosts the current efficiency, and the rise in surface temperature is crucial to this effect.

Keywords: electrochemical machining, high-rate anodic dissolution, chromium–nickel alloys, pulsed processing, ECM electrolytes

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INTRODUCTION

Electrochemical machining (ECM) is a modern method for materials processing based on high-rate anodic dissolution of metals and alloys in concentrated salt solutions [1–3]. The method has found a widespread use in machining of parts of aircraft engines, including turbine engine blades. The method is evolving and being perfected along the line of pulse machining. With pulsed current, anodic dissolution can be made more confined, and precision in transfer of the tool shape can be improved [2–9]. In addition, it seems to be nearly impossible to use ECM for processing large surfaces while not using pulsed machining. Typically, ECM is applied to chromium–nickel steels and, in particular, high-temperature alloys [2, 3, 10]; therefore, electrolytes often used in these processes are concentrated solutions of chlorides, nitrates, or their mixtures [1–3]. The Faraday law underlies calculation methods for processing rates, as well as their control and distribution across the surface to be processed; however, there are specific features to application of this law under ECM conditions. The applicability of this law depends on current efficiency η , a quantity that markedly depends not only on the electrolytes used and processing parameters but it may also change on passing from direct current (dc) to

pulsed current. In particular, when applying ultra-short pulses (typically, in the nanosecond range), a fraction of passed charge may not necessarily be related to Faradaic processes but to capacitive current due to the double layer at the interface. Double-layer effects underlie micro-ECM (or μ ECM), a special variant of ECM [11–13].

With ECM being an electrochemical process carried out under conditions far away from thermodynamic equilibrium, i.e., at high current densities and high potentials, thermokinetic effects based on the interplay between the rate of an electrochemical process and the surface temperature play an important part in controlling this process [14–16]. Studies [7, 17] showed the feasibility to control not only processing rates of chromium–nickel steels and alloys under ECM conditions but also their distribution along the surface being processed (with the purpose to improve processing confinement) using pulsed current with pulse duration in the microsecond range.

However, the nature of observed effects is still a subject of discussions. In particular, the role of thermokinetic effects was not addressed because the surface temperature was not measured. In the present paper, we investigate the anodic dissolution rates of chromium–nickel steels under the conditions of