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Study On The Electrical Fatigue Deterioration Mechanism And Reliability Of Stainless Steel Wire Under Current Conditions

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Abstract : Traditional fine springs, typically with a diameter of approximately 50 µm, are commonly fabricated from alloy steel and often gold-plated to enhance corrosion and wear resistance. However, with the ongoing growth in precision spring demands, high-frequency, long-term consistency is necessary for fine springs, unveiling the shortcomings of traditional alloy steel as a spring material. Semi-austenitic stainless steel has come up as an expectant choice in the precision spring field due to its outstanding mechanical properties, corrosion resistance, and high-temperature stability. The experimental results demonstrated exceptional mechanical performance, with the 50 µm-diameter wires achieving an ultimate tensile strength (UTS) exceeding 3000 MPa and a hardness of 508 HV. This remarkable strength and hardness are attributed to the combined effects of strain-induced martensite formation and grain refinement during severe cold working (About 99.56% deformation). To simulate the spring working under an electrical environment. The electrical and mechanical behavior of 50 µm stainless steel wires subjected to high-current electrical fatigue cycles and their characteristics' temporal variations are investigated for application in fine spring systems. This research also offers comprehensive recommendations for minimizing the deterioration of these wires in demanding environments Different current densities may contribute to non-identical degrading behavior on the stainless steel wires, including forming oxide scales and microcracks. The wires can withstand up to 15,000 electrical fatigue cycles at 0.30 A and retain good conductivity. At 0.35 A, the current reduces the residual stress, allows grain growth by the current-induced annealing effect, and forms a thin oxide layer of about 1.4 µm. This relatively thin layer has minimal impact on the mechanical and electrical performance. Nevertheless, at 0.37 A, the oxide layer becomes significantly thicker, measuring approximately 3.8 µm, and contains Fe_2O_3. Increasing thickness notably augments electrical resistance; furthermore, the thick oxide layer also becomes a point of stress concentration, decreasing the wires' strength and ductility. This study identifies a critical current that helps prevent degradation in fine stainless steel wires. Even under high frequencies and harsh environments over extended periods, stainless steel wire sustains excellent reliability. Owing to their durability, this research emphasizes that stainless steel fine wire has proved suitable for fine spring applications.

Keywords : electrical fatigue, fine spring, semi-austenitic stainless steel, stainless steel fine wire, electrothermal fracture mechanism

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