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玻璃金属封接中冷却诱发应力的起源及演变

摘要

玻璃-金属（GTM）密封中的残余应力是决定其机械性能的关键因素。本研究主要关注冷却诱导应力的形成和演化。K 型热电偶和光纤布拉格光栅（FBG）传感器用于获取 GTM 密封在冷却过程中的原位温度和应力数据。同时，还建立了该过程的热力耦合有限元分析（FEA）模型。研究发现，玻璃的内部温度分布呈“水煮蛋”形状。这是由于导热系数低，导致中心出现延时效应。分析其应力形成曲线，当温度降至 200℃ 以下时，观察到应力反弹，这在有限元分析中已被证实是由热膨胀系数（CTE）的差异决定的。冷却速率直接决定了应力形成速率。本研究加深了对 GTM 密封件冷却过程中应力形成和演变的理解，并强调了不同冷却速率对应力形成的影响。它为优化工艺和定制应力分布提供了理论指导。

关键词

玻璃-金属封接；应力分布；有限元分析

Abstract

The residual stress in the Glass-to-Metal (GTM) seal is a key factor determining its mechanical performance. This study focuses on the cooling-induced stress formation and evolution. K-type thermocouples and fiber Bragg grating (FBG) sensors were used to obtain the in situ temperature and stress data of the GTM seal during the cooling process. At the same time, a thermo-mechanical coupling finite element analysis (FEA) model for this process has also been established. It was found that the internal temperature distribution of the glass exhibits a “soft-boiled egg” shape. This is due to the low thermal conductivity, which causes a time-delay effect at the center. Analyzing its stress formation curve, stress rebound was observed when the temperature dropped below 200℃, which has been confirmed in the FEA to be determined by the difference in thermal expansion coefficients (CTE)s. The cooling rate directly determines the rate of stress formation. This study enhances the understanding of the stress formation and evolution during the cooling process of GTM seals and emphasizes the impact of different cooling rates on stress formation. It provides theoretical guidance for optimizing the process and tailoring stress distribution.

Keywords

Glass-to-metal seal; stress distribution; finite element analysis

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