热循环条件下 NiCrAlYSi/YSZ 热障涂层层间损伤及元素扩散行为研究

戴建伟,牟仁德,何利民,杨文慧,刘德林,许振华

(北京航空材料研究院 航空材料先进腐蚀与防护航空科技重点实验室 北京 100095)

摘 要:采用真空电弧镀设备制备热障涂层(TBCs)中的 NiCrAlYSi 金属粘结层,采用电子束物理气相沉积工艺(EB-PVD)制备 YSZ 陶瓷层,利用带能谱仪的扫描电子显微镜对沉积态和热循环损伤后的热障涂层试样的形貌、组织结构以及元素成分进行分析,研究热障涂层从热循环初期到失效的过程中层间损伤及元素扩散行为。结果表明,随着热循环时间的延长,NiCrAlYSi/YSZ 涂层先后经历快速氧化和氧化速率很低的阶段,1100h 后由于陶瓷层脱落,粘结层继续氧化导致涂层增重突然增大。热循环初期,Zr、O 向内扩散,Ni、Cr、Al 向外扩散,TGO 层中的 Al 元素供应充足,主要发生 Al 的选择性氧化;1100h 后,TGO 层中 Al 元素供应不足,Cr、Ni 开始氧化, 生成 $Al_{1.92}Cr_{0.08}O_3$ 和镍铝氧化物。这种不均匀的氧化使局部涂层体积膨胀,裂纹萌生于 TGO 层,随着裂纹的增殖、生长,最终贯穿等轴晶区和 TGO 层,导致热障涂层失效。

关 键 词:热障涂层;热循环;层间损伤;元素扩散

中图分类号:TG146 **文献标识码**:A **文章编号**:1002-0322(2021)03-0023-07

doi:10.13385/j.cnki.vacuum.2021.03.05

Behavior of Interlayer Damage and Elements Diffusion of NiCrAlYSi/YSZ Thermal Barrier Coatings under Thermal Cyclic

DAI Jian-wei, MU Ren-de, HE Li-min, YANG Wen-hui, LIU De-lin, XU Zhen-hua

(*Aviation Key Laboratory of Science and Technology on Advanced Corrosion and Protection for Aviation Material, Beijing Institute of Aeronautical Materials, Beijing 100095, China*)

Abstract: The NiCrAlYSi bonding layer was prepared by vacuum arc plating. The YSZ ceramic layer was prepared by electron beam physical vapor deposition (EB-PVD). Microstructure, crack morphology and elemental composition of the as-deposited coatings and TBCs after thermal cyclic were analyzed by using SEM with energy dispersive spectrometer. The behavior of interlayer damage and elements diffusion of TBCs from early stage of thermal cycling to failure process were investigated.The results show that, with the increase of the thermal cycling time, NiCrAlYSi/YSZ TBCs experienced rapid oxidation and low oxidation rate stages. After 1100h, the ceramic layer fell off and the bond coat continued to oxidize, resulting in a sudden increase in coatings weight. At the beginning of the thermal cyclic, Al, Ni, and Cr in bond coat diffused outwards, while O and Zr diffused inwards from the ceramic layer. Al in the TGO layer is sufficient and the selective oxidation of Al mainly occurred. After 1100h, Al in the TGO layer was insufficient, Cr and Ni began to oxidize, forming $Al_{1.92}Cr_{0.08}O_3$ and nickel aluminum oxide. The uneven oxidation resulted in the local volume expansion in the coatings and the cracks initiated in the TGO layer. With the proliferation and growth of cracks, the cracks eventually penetrated the equiaxed crystal region and TGO layer, leading to the failure of TBCs.

Key words: TBCs; thermal cyclic; interlayer damage; elements diffusion

为了满足航空发动机涡轮叶片等热端部件材料苛刻的服役环境要求,热障涂层技术受到了越来越多的关注和重视。热障涂层是由低热导率陶瓷面层和金属粘结层组成的隔热系统,金属粘结层有降低基体与陶瓷层热物理性能不匹配和提供氧化膜形成所需元素等作用,陶瓷面层在热

收稿日期:2020-12-29

作者简介:戴建伟(1988-),男,河北省唐山市人,博士,工程师。 **通讯作者**:许振华,研究员。

* **基金项目**:关键技术攻关项目(KH9A200503)和创新基金项目(KJSJ180513)。