微米级裂纹对水冷无氧铜坩埚的影响 *

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摘 要:本文主要使用了电子束物理气相沉积、扫描电子显微术、X 射线衍射和有限元模拟等技术手段研究了微米级微裂纹对水冷无氧铜坩埚失效的影响。有限元模拟显示在使用过程中水冷铜坩埚的温度分布范围是 33 ℃ ~ 183 ℃,温度最高的区域对应于出水口附近的水道过盈配合处。在薄的坩埚内壁上侧截面温差大、热应力大。导致水冷无氧铜坩埚失效原因是在热应力作用下产生的宏观裂纹,而不是熔融金属铈腐蚀和杂质有害相的形成。宏观裂纹起源于在制备铜坩埚时水道过盈配合过程中引入的几十微米的微裂纹。在热应力的作用下,这些微米级裂纹会逐渐扩展,形成由延伸方向近似平行的裂纹组成的裂纹带,之后该裂纹带演化成贯穿内壁连通水道的宏观裂纹,最后导致水冷铜坩埚失效。坩埚内壁正面区域的裂纹扩展情况并不严重,在坩埚内壁外的其它区域几乎没有明显的变化。

关 键 词:微米级微裂纹;水冷无氧铜坩埚;电子束物理气相沉积;材料失效
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Effect of Crack in Micrometer Scale on the Water-cooled Oxygen-free Copper Crucible

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Abstract: Electron beam-physical vapor deposition, scanning electron microscopy, X-ray diffraction and finite element simulation were used to study the effect of crack in micrometer scale on the failure of water-cooled oxygen-free copper crucible. The temperature distribution of the water-cooled copper crucible ranged from 33 to 183 ℃, and the highest temperature region was referred to the interference fit at the water channel near the water outlet. The cross section of the upper part of the inner wall had a large temperature gradient, which induced large thermal stress. The reason of the failure of the water-cooled copper crucible was the macrocrack induced by the thermal stress, rather than the corrosion of molten metal cerium and the formation of harmful impurity phase. The macrocrack was rooted in the microcrack in tens of micron induced by the interference fit at the water channel during the manufacturing processes of copper crucible. Under the effect of thermal stress, the microcrack grew into the approximately straight crack band. The crack band was composed of cracks with approximately parallel extension direction. Then the growing crack penetrated through the inner wall of the water-cooled copper crucible, which made the copper crucible failure. The frontal area of the inner wall varied a little in the crack growth. No obvious change happened at the regions other than the inner wall of copper crucible.

Key words: microcrack in micrometer scale; water-cooled oxygen-free copper crucible; electron beam-physical vapor deposition; material failure

金属结构材料在服役过程中会出现断裂失效的现象,从而造成经济损失甚至人员伤亡[1,2]。温度梯度引起的热应力和机械应力是常见的疲劳断裂失效形式[3-5]。造成疲劳破坏的应力一般低

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