电磁悬浮真空熔铸技术进展

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摘 要:介绍了电磁线圈悬浮 ELM,冷坩埚悬浮 CCLM,冷坩埚半悬浮熔炼 semi-CCLM——即感应凝壳熔炼 ISM,三类真空熔铸技术的发展和现状。对该类技术在精密铸造、材料提纯、锭材及合金制备、气雾化制粉四个领域的应用进行实例论述。指明悬浮熔炼技术在材料种类、设备容量、熔体过热度及运行工艺几个方面的发展趋势。随着水冷铜坩埚技术的发展,半悬浮熔炼技术得到较快发展,并演化出多种形式,促进新型材料研制。激光和等离子加热技术的融合,为新工艺的实施奠定了基础。

关 键 词:电磁悬浮;悬浮熔炼;冷坩埚悬浮熔炼;感应凝壳炉;钛合金精密铸造
中图分类号:TF13;TG249;TG456 **文献标识码**:A **文章编号**:1002-0322(2019)06-0043-06
doi:10.13385/j.cnki.vacuum.2019.06.08

Development of Electromagnetic Levitation Vacuum Melting Casting Technology

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Abstract: This paper introduces the development and current situation of electromagnetic coils levitation melting ELM, cold crucible levitation melting CCLM, cold crucible semi-levitation melting semi- CCLM which is induction skull melting ISM, three types of vacuum melting casting technology. The application of this kind of technology in precision casting, material purification, ingot material and alloy preparation, gas atomization powder were discussed. The development trend of levitation melting technology in material type, equipment capacity, superheat of melt and operation process is indicated. With the development of water-cooled copper crucible technology, semi-levitation melting technology developed rapidly and evolved into various forms, which promoted the development of new materials. The fusion of laser and plasma heating technology has laid a foundation for the implementation of the new technology.

Key words: electromagnetic levitation; levitation melting; CCLM; ISM; titanium alloy investment casting

1 概念及现状

随着高端材料需求日趋旺盛及技术装备水平的不断提高,近五年,国内的冷坩埚悬浮真空熔炼技术发展迅速,各应用领域的论文和会议报告数量显著增加[1]。在不同应用领域,悬浮炉和冷坩埚悬浮炉所表达的含义有所不同。电磁线圈悬浮熔炼(ELM)技术始于上世纪 20 年代的德国,由单频率(或多频率)线圈组实现悬浮熔炼,对于一些材料来说,悬浮也可由直流磁场获得。 由于熔体在坩埚内可进行较多的工艺步骤,上世纪 50 年代,美国推出了冷坩埚悬浮熔炼(CCLM)技术。小容量冷坩埚悬浮熔炼,由单频率多匝电磁线圈实现;大容量的冷坩埚悬浮熔炼,依靠多频率电磁线圈组完成,若采用单频率多匝线圈,在典型的电源功率下,由于熔体重量较大,电磁悬浮力只能将熔体推离坩埚壁, 熔体底部与冷坩埚接触,凝固成壳,即感应凝壳熔炼(ISM、ISR),也称

收稿日期:2019-05-12
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* **基金项目**:沈阳市双百工程项目(Z17-5-048)。