Vacuum 156 (2018) 39–47

Contents lists available at ScienceDirect

Vacuum

journal homepage: www.elsevier.com/locate/vacuum

Removal inclusions from nickel-based superalloy by induced directional solidification during electron beam smelting

Qifan You[a,b], Hua Yuan[c], Longhai Zhao[a,b], Jiayan Li[a,b], Xiaogang You[a,b], Shuang Shi[a,b], Yi Tan[a,b,*], Xiaofei Ding[d]

[a] School of Materials Science and Engineering, Dalian University of Technology, Dalian, 116023, China
[b] Laboratory for New Energy Material Energetic Beam Metallurgical Equipment Engineering of Liaoning Province, Dalian, 116024, China
[c] Science and Technology on Advanced High Temperature Structural Materials Laboratory, Beijing Institute of Aeronautical Materials, Beijing, 100095, China
[d] School of Mechanical and Power Engineering, Dalian Ocean University, Dalian, 116023, China

ARTICLE INFO

Keywords:
Purification
Nickel-based superalloy
Electron beam smelting
Induced directional solidification

ABSTRACT

The electron beam smelting (EBS) is employed in refining the nickel-based superalloy. Removal efficiency of impurities and inclusions in nickel-based superalloy during EBS has been investigated. The morphology, microstructure and the content of oxygen in nickel-based superalloy before and after the experiment were analyzed. The EBS process is divided into three stages: melting stage, refining stage and solidification stage. The results show that the oxygen has been removed during the EBS process. The optimal experiment parameters are smelting power of 9 kW and smelting time of 30 min, by which a minimal evaporation loss of the alloy and a highest removal efficiency of impurities can be acquired. The removal efficiency of oxygen reaches 60% with the optimized experiment parameters. The inclusions are consist of oxides of aluminum, silicon and calcium and their composite oxides. The inclusions enrich at the circular region of the ingot periphery during solidification. A new method for preparation of nickel-based superalloy with high purity is found in the laboratory, and the enrichment mechanism of inclusion is analyzed.

1. Introduction

Powder metallurgy (P/M) nickel-based superalloys are one kind of the most important materials for high-temperature structural applications in turbine discs [1–4]. Due to the good creep and tensile properties, and micro-structural stability at temperatures up to 650 °C for extended periods, the FGH96 superalloy is widely used in turbine discs [5,6]. The main kinds of defects in P/M superalloy are PPB (Prior particle boundary), TIP (Thermal induced pore) and nonmetallic inclusions [7,8]. Among them, the nonmetallic inclusions show the most detrimental effect [9]. The performance of nickel-based superalloys in critical engineering applications is frequently dependent upon both the number and the size of the inclusions presented in the matrix [10]. The cleanliness of nickel-base superalloys is important, because the fatigue and fracture mechanics properties of superalloys can be strongly affected by the ceramic and metal-reaction introduced inclusions during the primary melting process [11]. It is widely believed that the low cycle fatigue life of nickel-base superalloys is greatly increased as a consequence of inclusion reduction in the melting process.

When the chemical composition of the desired superalloy is determined, all kinds of raw materials for the desired composition are prepared into master alloy ingot through smelting process. In order to ensure the excellent quality of superalloys, the chemical composition must be strictly controlled, and the purity of the P/M superalloy needs to be improved from the source, namely the smelting of master alloys. Vacuum induction melting (VIM) is the most mature process for smelting P/M master alloy at home and abroad, but the master alloy could be contaminated by the crucible refractory during VIM. Consequently, the master alloy after VIM needs to be refined in order to improve the purity of P/M superalloy. Besides, the vacuum arc remelting (VAR) is used for the secondary refining on the basis of VIM in Russia. The United States carries out a secondary refining of electroslag remelting (ESR) on the basis of VIM, and finally carries out the third time refining with VAR. The electron beam button melting (EBBM) process has been widely used for assessing the content of inclusions in high strength alloys, notably of nickel-based superalloys [12,13]. Various investigations have been carried out regarding the melting and solidification process during EBBM [14–20]. Under a high temperature

* Corresponding author. School of Materials Science and Engineering, Dalian University of Technology, No.2 Linggong Road, Ganjingzi District, Dalian, 116023, China.
E-mail address: tanyi@dlut.edu.cn (Y. Tan).

https://doi.org/10.1016/j.vacuum.2018.07.014
Received 6 February 2018; Received in revised form 10 May 2018; Accepted 9 July 2018
Available online 10 July 2018

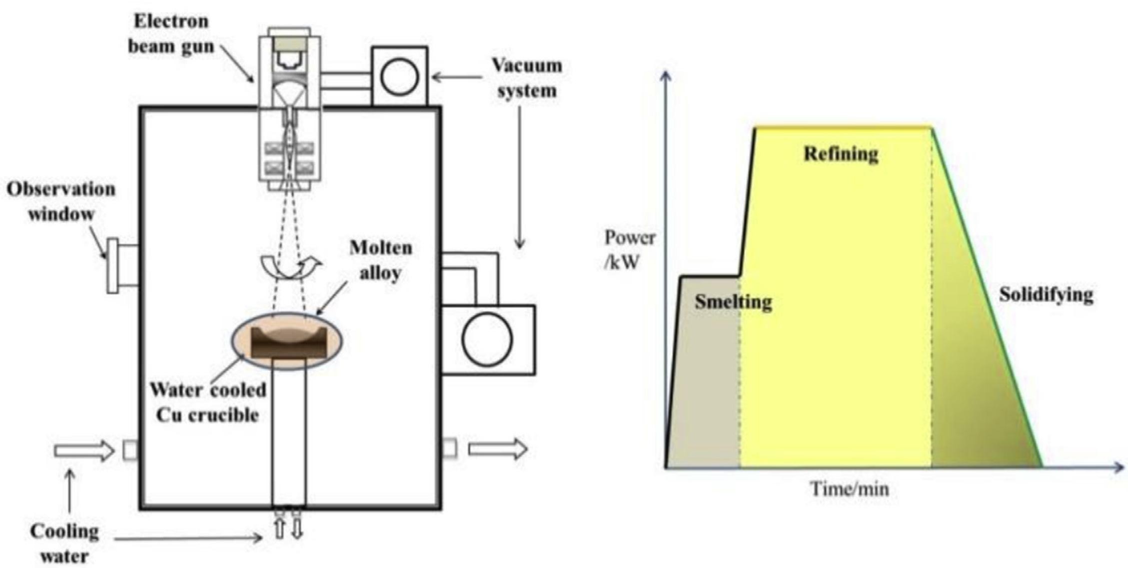

Fig. 1. The schematic diagram of EBS.

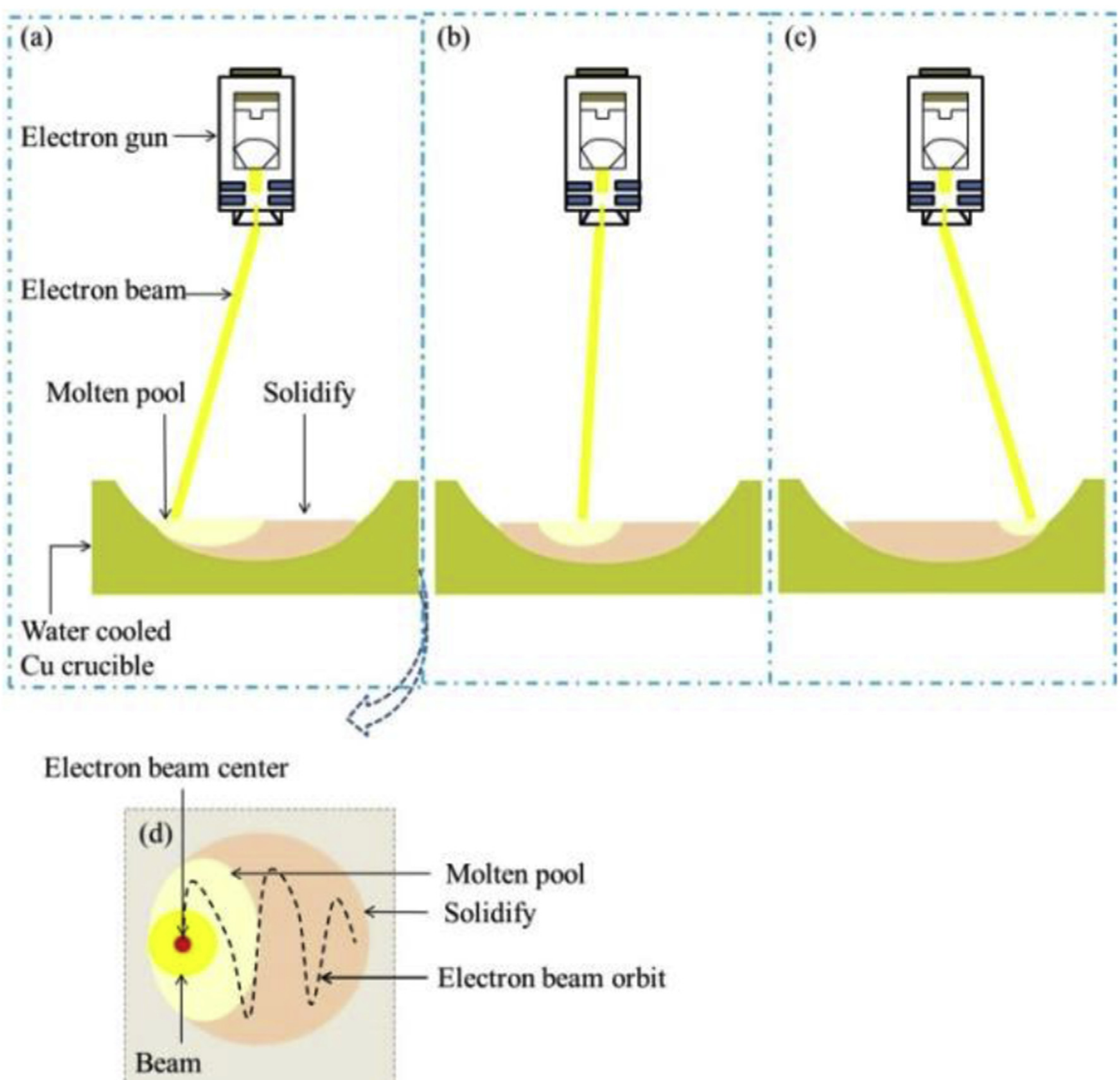

Fig. 2. The schematic diagram of the induced directional solidification during EBS process. (a) On the beginning of solidifying; (b) During solidifying process; (c) At the end of solidifying; (d) top view of (a).