APPARATUS AND METHOD FOR MONITORING CASTING PROCESS

FIELD OF THE INVENTION

The present invention relates generally to an apparatus and method for monitoring the casting or thermal treatment of materials, and more particularly, for monitoring the liquid amorphous/solid crystalline interface in a material being cast so as to permit process control parameters to be established and/or controlled in response thereto.

BACKGROUND OF THE INVENTION

Advancements in materials processing technology have caused an increasing demand for parts made from superalloys. Many high performance aircraft, for example, now employ turbine blades that are single crystals of nickel-based superalloys. The desirability of superalloys results from their high strength at high operating temperatures.

Superalloy parts are typically produced as single-crystal or directionally-solidified castings. Elaborate casting and inspection methods are employed to ensure that each part is a single-crystal or directionally-solidified crystal with a desired orientation. Even minor defects in the crystalline structure may be unacceptable as they can result in mechanical failure.

To reduce the likelihood of defects in the crystalline structure, the casting process for such parts has become a labor and time intensive process. The molten alloy is poured into a mold located in a furnace. One end of the mold is cooled to initiate crystallization. The mold is then slowly withdrawn from the furnace. The withdrawal rate is extremely slow to ensure an acceptable crystallization rate and crystal of the correct orientation. A slow crystallization rate promotes flawless crystal growth in the direction of solidification. If the rate of crystallization is too rapid, the metal will form unacceptable polycrystals and the part must be discarded. The possibility of forming parts with defects in the crystal structure with a lack of a reliable technique to otherwise monitor the rate of crystal growth during casting has to date caused engineers to select extremely conservative (i.e., slow) crystallization rates.

Further, despite the noted precautions taken during casting, defects can still occur which result in discarded parts and wasted production time. The scrapped material cannot simply be remelted and reused but must rather be retreated by an expensive refinement process before further use.

SUMMARY OF THE INVENTION

It is an objective of the present invention to provide an apparatus and method for real time monitoring of the interface between the solid crystalline and liquid amorphous phases of a material being cast in a mold during casting, thereby allowing for an increase in throughput and decrease in production costs. It is a related objective to provide a monitoring apparatus and method to permit casting process control parameters to be established and/or controlled in response thereto, wherein the process provides optimal conditions for the desired crystal formation.

It is a further specific objective to increase throughput and decrease the production costs of single-crystal and directionally-solidified castings by decreasing the time required to form such castings and minimizing the occurrence of defects and flaws in the castings. As will be appreciated, the present invention is particularly useful for monitoring the

interface between molten (i.e., liquified) and solidified states of materials, such as alloys of iron, titanium, nickel, and aluminum, ceramics, semiconductors, such as silicon, germanium, gallium arsenide, cadmium telluride, cadmium sulfide, and indium phosphide.

By way of initial summary, the present invention includes: (i) directing source radiation through a casting mold and into an interface between a portion of the crystalline phase and amorphous phase of a material being cast to provide diffracted radiation having a first component associated with the crystalline phase and a second component associated with the amorphous phase; (ii) receiving at least a portion of at least one and preferably both of the first component and second component of the diffracted radiation outside of tile casting mold and providing an output signal in response thereto; and (iii) using the output signal to monitor the interface between the crystalline and amorphous phases.

Preferably, x-ray radiation is employed and, as will be further discussed, the energy and intensity of the source radiation should be sufficient to penetrate the mold/cast material and to otherwise provide the diffracted components at an intensity sufficient for associated detection by a radiation-sensitive receiver means such as one or more x-ray imager(s) or energy detector(s). The casting mold can be composed of either amorphous or crystalline materials provided that the container is penetrable by the source radiation and stable at the melting point of the cast material. Suitable container materials include, for example, sand, alumina, zirconia, quartz, graphite, ceramics, and more particularly, aluminum oxide, zirconium oxide, and other metal oxides. Additional intervening structures, such as the walls of a furnace, can be present between the radiation source and diffracted radiation receiver, provided that such structures do not block or otherwise unduly attenuate the source and/or diffracted radiation.

The first and second components of the diffracted radiation result from the differing manners in which the amorphous phase and crystalline phase of the cast material diffract the source radiation. Briefly, the crystalline phase produces a radiation diffraction pattern comprising concentrated radiation areas, or high-intensity spots, while the amorphous phase produces a more diffuse and lower intensity ring pattern. Consequently, the radiation-sensitive receiver means should be positioned so as to receive at least a portion of one and preferably both of said concentrated radiation and diffuse radiation associated with the crystalline and amorphous phases, respectively.

In this manner, e.g., the output signal of the radiation-sensitive receiver means will reflect, on a real-time basis, an increase over time in the received diffracted radiation associated with an increasing crystalline phase. More preferably, e.g., by receiving a portion of both the diffracted radiation associated with an increasing crystalline phase and the diffracted radiation associated with the decreasing amorphous phase, the output signal can reflect the increase of the diffracted radiation received from the crystalline phase relative to that received from the amorphous phase. In this regard, the output signal may include a first output signal component corresponding with the first diffracted radiation component that is received and a second output signal component corresponding with the second diffracted radiation component that is received.

As will be appreciated then, use of the output signal to monitor the crystalline phase/amorphous phase interface generally entails (i) generating for successive time intervals corresponding successive values corresponding with at least