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Multi-physical Numerical Modelling of Remelting Processes in a Double Layer Metal Composition

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Abstract

The application of induction technology has been investigated by multi-physical numerical modelling to realize a smart surface remelting process, which leads to a number of technical and economic advantages in a double layer metal composition. The self cooling gradient effect inside the workpiece can be advantageous used to get a desirable material structure after surface remelting followed by rapid solidification. In order to apply and optimize the induction remelting process two-dimensional transient multi-physical numerical models of the heating, melting and solidification process including turbulent melt flow in the liquid phase and dynamic free melt surface deformation caused by electromagnetic forces and intensive melt flow have been developed. The reliability of the presented modelling approaches has been validated in advance by measurements carried out from various experimental investigations. The results show how the remelting and solidification process depends on various process parameters, like inductor design, inductor current and frequency, as well as material properties of the surface metal layer.

Introduction

Induction heating and melting offers numerous possibilities in further improvement of existing industrial techniques and in development of new technological processes. Some of the major advantages of induction heating applications are the fast heating-up rate, the exact temperature control and the predictable spatial and time depending temperature distribution in the workpiece. Multi-layer materials are used, where several different materials in one unit satisfies the conflicting demands to the products. Steel plate covered by bronze, aluminium or white metal (Babbitt) alloys are typical examples of multi-layer product applications, e.g. for sliding bearings [1].

Sliding bearings, which are used e.g in big ship engines, are normally made from steel shells covered with a white metal layer, which is a tin based alloy. Today these bearings are made by casting separately molten liquid tin-alloy onto soundly heated steel followed by rapid quenching and cooling. To guarantee the product quality, the layer of the cast metal is made much thicker than the final product needs. It results to expensive mechanical treatment and high energy losses, because 80% of the casted material has to be recycled.

One innovative idea is to reduce significant the thickness of the casted layer and to guarantee the final product quality, this means the purity and homogeneous metallurgical structure of the layer as well as the optimal bonding between the white-metal layer and the steel shell by applying an induction surface remelting process.

During the induction surface remelting process for the double layer metal composition the white-metal alloy layer will be locally melted followed by a rapid solidification process due to the self-cooling effect caused by the steel shell. In order to design this complex induction remelting process a two-dimensional transient multi-physical numerical model of the heating, melting and solidification process including the dynamic free melt surface deformation caused by electromagnetic forces and by the intensive melt flow has been developed.

1. Numerical Modelling and Results

In this work a verified complex numerical modelling approach for simulation of induction melting processes has been applied. The computation of electromagnetic (EM) induced flow and free melt surface dynamics is ensured by means of external coupling between EM force recalculation in *ANSYS*, Volume of Fluid (VOF) Large Eddy Simulation (LES) of a two-phase turbulent flow in *FLUENT*, free surface shape reconstruction in *CFD-Post* and a self-written surface filtering procedure [2]. The temperature dependence of the material properties are taken into account.

The double layer ring consists of the inner white-metal layer and the outer steel shell, where the inner radius of the ring is 300 mm. The line inductor is placed in the inner side of the ring and magnetic flux concentrator is applied. Different width and number of turns of the inductor have been investigated. During the remelting process, the ring is rotating continuously with a rotation speed of 1 cm/s.

In the first step, a single inductor system has been investigated, where high frequency (50 kHz) current has been applied. The results show that a high inductor current of 2,600 A is necessary in order to realize a sufficient melting of the white-metal layer, but in this case the surface deformation of the melt pool caused by the magnetic pressure is too intensive and not acceptable. Therefore, a two inductor system has been investigated, where the first inductor will realize an intensive pre-heating up to the melting temperature and the second inductor realize the complete melting of the surface layer, where lower current and therefore lower magnetic pressure leads to reduced surface deformation.

The numerical parameter studies applying different inductor currents and frequencies show that it is possible to realize the surface remelting with acceptable surface deformation, followed by a fast solidification process, but a stable quasi-steady state working point is very difficult to reach. In particular in the case when the white-metal layer is completely melted the electromagnetic field is penetrating the ferromagnetic steel, which leads to a spontaneous increasing of the electromagnetic flux intensity and deforming of the molten white-metal layer, where in particular the influence of the surface tension and wedding angel plays a significant role as the transient numerical simulations have shown.

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