Investigating the Benefit of Soft Magnetic Composite Inserts on Energy Efficiency in Cold Wall Billet Casters Using Computer Simulation

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Abstract—Cold wall induction (CWI) applications are widely used for melting or processing metals, oxides, glasses, and other reactive or high purity materials. Multiple studies have been made for their optimization, but their energy efficiency is still low compared to other processes. The rise of additive manufacturing (AM) has resulted in renewed interest in the use of CWI applications for powder manufacturing and recycling. The emerging AM techniques require highly consistent powders with a small range of size, shape and chemical composition. Current powder production techniques, such as electrode induction gas atomization (EIGA) and drip melting, tend to have relatively low acceptable yield for AM. Recycling processes which use CWI to convert the out of specification powder back into raw billets for reprocessing are receiving renewed interest.

This paper will look at the use and optimization of soft magnetic composites (SMC) for inserts or other components to increase energy efficiency of cold wall induction billet casters used for powder recycling. Modelling will be used to predict electrical parameters for comparison. Also, some discussion will be had on potential to further improve energy efficiency due to the improved thermal efficiency of the system.

Keywords—cold wall induction, soft magnetic composites, magnetic inserts, computer simulation, energy efficiency, powder metal recycling

I. INTRODUCTION

Cold wall induction (CWI) is a technology used for melting high purity metals, oxides, or reactive metals. Melting occurs within a segmented, water-cooled copper crucible or open bottom mold. These latter devices are used for recycling out of specification powder from other processes into billets. Atomization processes require high purity incoming billets, making CWI technology a viable candidate for powder recycling. However, CWI is a low efficiency technology, making it a costly process.

Previous work has been done on using soft magnetic composite (SMC) inserts which demonstrated the ability to control the magnetic flux to significantly increase electrical efficiency [1]. Subsequent studies on 55 mm OD ingots and 129 kW input power, experimental results showed a 31% increase in casting rate. Additionally, simulation results showed the use of the SMC inserts increase the electrical efficiency from 29.6% to 34.2% [2].. The goal of this study is to model 70 mm diameter billet and determine whether an efficiency increase can be obtained using SMC inserts.

II. COMPUTER SIMULATION STRATEGY

A. Geometry Description

The geometry of the billet caster was chosen based on commonly used dimensions. The cold wall induction mold was designed for a 70 mm diameter billet with a total height of 295 mm. A mold design with 12 segments was used, with 0.51 mm slit width, and segment height of 250 mm. Two SMC inserts were added between each segment near the top and bottom of the coil. The size and location of the inserts was varied for the purposes of this study. The inductor used was a multi-turn coil with rectangular copper tubing. The coil had SMC shunts and an upper and bottom SMC rings attached to it in some of the cases. A schematic of the geometry is shown in Fig. 1.

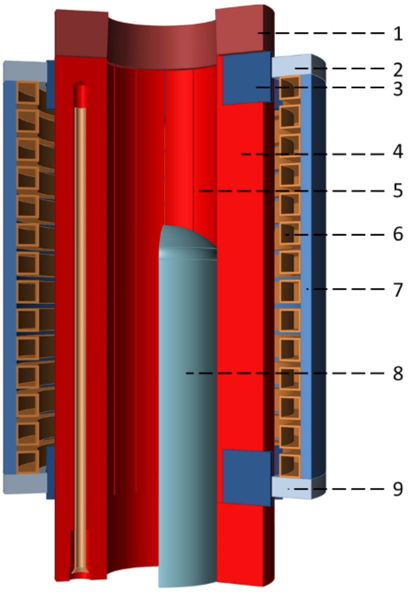

Fig. 1. Schematic of the geometry of the billet caster.

Fig. 1 shows the geometry used. Where 1 is the top copper ring, 2 is the top SMC ring, 3 is the SMC insert, 4 are the water-cooled copper mold segments, 5 is the slit between segments, 6 is the coil copper, 7 is the SMC shunt, 8 is the load, and 9 is the coil's bottom SMC ring.

B. Simulation Description and Strategy

3D electromagnetic simulations were run using Flux 3D software [3]. The simulations used rotational symmetry planes to reduce the simulation size. As a result, 1/24th of the system was modelled. Fluxtrol 100 B(H) curve magnetic properties and loss equations and data were used for the SMC material for the inserts, shunts, and rings [4]. Fig. 2

shows the geometry used in the simulation, where (a) is reduced geometry and (b) is the superimposed geometry.

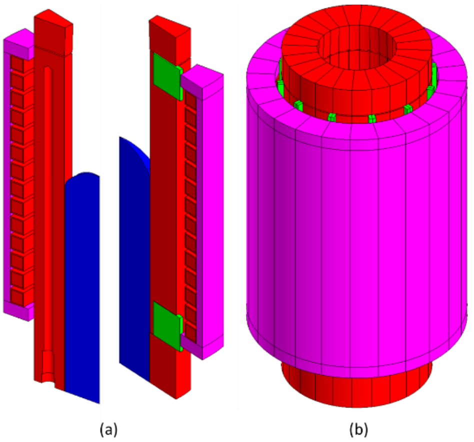

Fig. 2. Geometry example used in the simulation with reduced geoemtry (a) due to the symmetry and full geometry (b).

The goal of the simulation is to compare the electrical efficiency of the coil head without the use of SMC's and with the SMC's. The efficiency is described by equations (1) and (2).

$$\eta = P_{Load} / P_{Total} \tag{1}$$

$$P_{Total} = P_{Load} + P_{Coil} + P_{Mold} + P_{SMC} \tag{2}$$

Where η is the electrical efficiency, P_{Load} is the power induced in the load through joule heating, and P_{Total} is the total power in the coil head. P_{Total} includes the losses in the coil, load, mold, and SMC's. Other losses, such as coil leads, chamber, and other are not considered in this investigation.

The simulations will also study the changes in electrical parameters as a result of using the different SMC's. Additionally, the distribution of the induced power density is compared between the different models.

C. *Simulation Parameters*

The simulations will start with an original case, with no SMC's for inserts, shunts or rings. Other cases will include inserts, shunts, and/or top and bottom rings. The inserts' dimensions are 5.4mm thickness x 30mm depth x 30mm height. The coil shunts' dimensions are 85.2 mm ID x 91.55 mm OD x 219 mm height. The coil rings' dimensions are 68 mm ID x 91.55 mm OD x 10.9 mm height.

All simulations use 5 kHz frequency and a constant current source of 1000 A_{rms}. The load used is a titanium bar at a uniform electrical resistivity, ρ, of 1.7 μΩm. The coil has 14 turns with 12.7 mm square copper tubing and 1.02 mm wall thickness. The coil has an ID is 72.5 mm and height of 219mm.

III. RESULTS

A. *Electrical Results*

The results for voltage, current, power, and coil head efficiency for the different modelled cases will be tabulated similar to that shown in Table 1.

TABLE I. SIMULATION ELECTRICAL PARAMETER RRESULTS

Case	U	P_{Load}	P_{Coil}	P_{Mold}	P_{SMC}	η
Bare	7.9	368	280	612	0	29.2%
In	9.1	634	268	647	4	40.8%
Ri+In	9.8	714	279	733	7.7	41.2%
Ri+Sh	9.4	435	316	771	29	28.0%
Ri+Sh+In	11.1	824	328	872	47	39.8%

Where case Bare case is a coil with no SMC, In indicates the use of inserts, Ri indicates the use of rings, and Sh indicates the use of shunts. The results in the table are for 1/24th of the system.

B. *Current Density Results in the load*

The addition of SMC's to the coil and caster changes the current density distribution on the load and segments. Figure 3 shows the current density distribution in the load for the different cases.

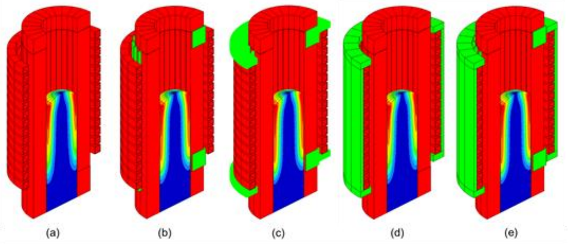

Fig. 3. Current density distribution in the load for the different cases. (a) no SMC, (b) inserts, (c) rings and inserts, (d) rings and shunts, and (e) rings, shunts, and inserts.

IV. SUMMARY

The use of SMC's on power recycling casters was shown to improve coil head efficiency. The use of inserts was shown to improve coil head electrical efficiency of ~10%, while shunts and rings do not provide any substantial benefit to the electrical efficiency. However, the use of magnetic shunts and rings is known to reduce the required current and chamber heating, thus providing potential reductions in overall electrical efficiency and reactive power. Furthermore, the use of inserts may allow for the mold length to be shortened and the design improved for additional improvements, though mold and coil redesigns were not investigated in this work.

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