2022 Asia and Pacific Mathematical Contest in Modeling

Problem A

Feature Extraction of Sequence Images and Modeling Analysis of Mold Flux Melting and Crystallization

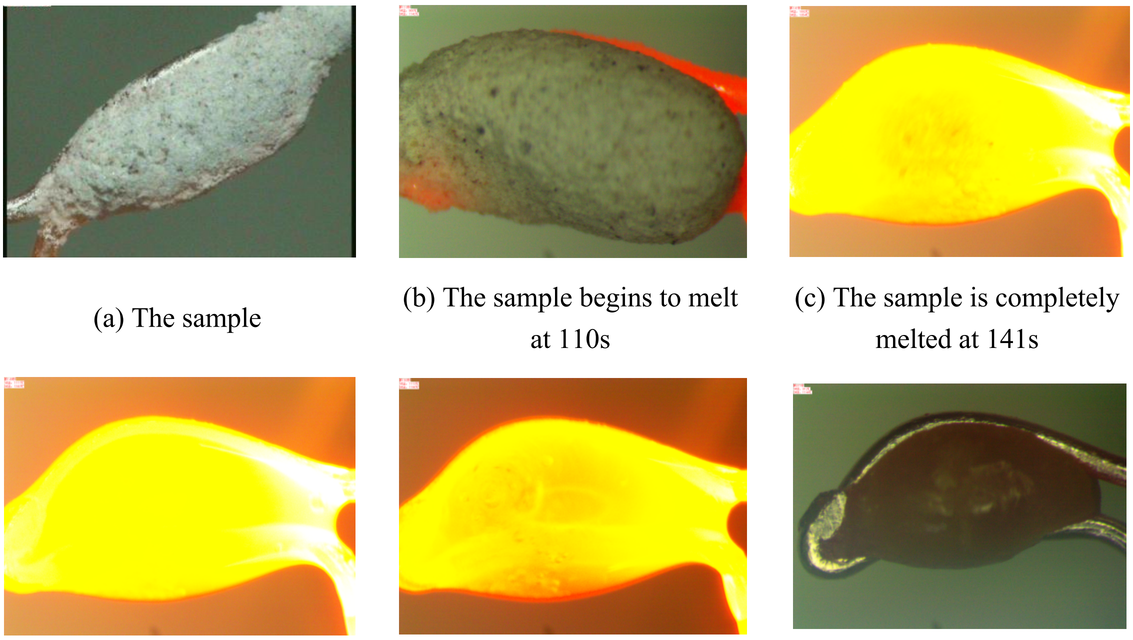
Mold fluxes in continuous casting process thermally insulate the molten steel meniscus, prevent reoxidation of liquid steel during continuous casting of liquid steels, control heat transfer, provide lubrication of strand, and absorb nonmetallic inclusions. Metallurgical functions of mold flux is mainly determined by its melting rate and crystallization rate under the temperature control curve. It is therefore important to study the phase distribution of mold fluxes in the gap between mold wall and strand shell.

Continuous casting mold fluxes are added to the top of liquid steel in the mold. These solid slags, accumulating on the surface of liquid steel as a powder layer, can prevent liquid steel level crusting due to excessive temperature drop of liquid steel. The temperature of mold fluxes then gradually rise to the melting point, and mold fluxes are melted to form a sintered layer. Raw materials of mold fluxes form low-melting-point substances and then liquid slag through chemical reactions, and the composition of mold fluxes will change to a certain extent. **It is melting process**.

As mold fluxes are completely fused, a liquid slag layer will be formed and covering on the surface of liquid steel. The slag film will be formed when the liquid slag infiltrates from the slag pool at the steel liquid surface into the gap between the shell and the copper mold wall. The slag against the strand still maintains liquid phase, because of the high temperature of the strand surface. However, as the temperature of liquid slag decreases with that of the strand surface in the longitudinal direction of the mold, the slag film, against the copper mold wall, is quenched and solidified to form a glassy solid slag film (solidification behavior of slag film), with mold's forced cooling, while slag film will crystallize at certain areas and form a crystalline layer (crystallization behavior of slag film) under suitable conditions, finally creating a typical three-layer slag film structure: glassy layer, crystalline layer and liquid slag layer. **This process is crystallization.**

Because of the high temperature, transient fluid flow, complex phase transitions and chemical reactions as well as the opacity of mold wall, it is difficult to observe the phase changes of mold fluxes directly. The SHTT II tester of melting and crystallization temperature is now widely applied to observe the crystallization behaviors of mold fluxes. After the experiment is finished, experimenters demonstrate the images one by one, record the information in the upper left corner of the images, and identify the key node images with naked eyes and experience (see Figure 1), so as to guide the design of mold fluxes to meet the solidification requirements of steel grades. This process wastes manpower and hinders the development of experimental process information. It is urgent to develop automatic feature extraction and mathematical modeling technology of sequence images.

Attachment 1 has 562 sequence images of mold fluxes' melting and crystallization. These sequence images are collected from the 110th to 671st seconds when the experiment starts. The file serial numbers follow the collection time sequence, and images are collected every 1s. The information is presented by digital images in Attachment 1 (see Figure 1). The upper left corner of each image is marked with the corresponding time of the image and the temperature values of No.1 thermocouple and No.2 thermocouple.



(a) The sample

(b) The sample begins to melt at 110s

(c) The sample is completely melted at 141s

(d) The sample sees steels melting at 149s

(e) Crystallization begins at 150s

(f) Crystallization ends at 671s

Fig. 1 Melting and crystallization of mold fluxes

To realize automatic feature extraction and mathematical modeling of sequence images of mold fluxes melting and crystallization, please answer the following three questions.

Question 1: With image segmentation and recognition or other technologies, please automatically extract temperatures of No.1 thermocouple and No.2 thermocouple in the upper left corner of each image and import them automatically into the corresponding table in

Attachment 2 (please write a step-by-step technical operation document), and please make a temperature-time curve diagram (1#wire temperature-2#wire temperature-time diagram; 1#wire average temperature-2#wire average temperature-time diagram). In addition, the test result of 1#wire or 2 #wire is inaccurate. Please point it out and explain.

Question 2: According to the six node images in Fig.1, please study and quantify the dynamic differences between adjacent sequence images in the process of mold fluxes melting and crystallization by applying digital image processing technology. On this basis, please make a time series modeling of the quantified different characteristics, and discuss the melting and crystallization process curve of mold fluxes based on the simulation results of mathematical model.

Question 3: Given the changes of temperature and time, as well as the research results of Question 2, please make a mathematical model to discuss the functional relationship between the changes of temperature and time as well as the melting and crystallization process of mold fluxes, and discuss the kinetics of melting and crystallization of mold fluxes (the relationship between temperature, melting rate and crystallizing rate) based on numerical simulation results.

Your PDF solution of no more than 25 total pages should include:

- One-page Summary Sheet.
- Table of Contents.
- Your complete solution.

Note: The APMCM Contest has a 25-page limit. All aspects of your submission count toward the 25-page limit (Summary Sheet, Table of Contents, your complete solution). However, the pages of Reference List and Appendices are not limited.

Attachment:

Attachment 1.zip, download on the website: https://share.weiyun.com/ubtXPGz0

Attachment 2.xlsx