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Quality Prediction and Control of Continuously Cast Slabs

by

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Summary

Surface defects in the continuous casting process require treatment by grinding. This extra phase in the process causes lower throughput of final product and extra energy costs. The elimination of slab treatment after casting implies that slabs can be directly rolled or hot charged, resulting in higher throughput and lower energy costs. To increase the number of slabs that can be directly rolled or hot charged, defects have to be predicted before a slab has completed the casting process. This eliminates post-casting surface inspection, and allows the steel-making company to schedule slabs so that defect-free slabs can be direct rolled or hot charged. Slabs with defects are still sent for treatment. The control of continuous casting parameters can lead to the eradication of defects so that all slabs are defect-free, thus eliminating the grinding process altogether. Transversal and longitudinal cracking, casting powder entrapment and other inclusions, bleeders, deep and uneven oscillation marks, stopmarks and depressions are the defects which are considered for prediction and control and are the output variables of the predictor. Only the variables in the mould are considered as inputs to the predictor, and as manipulated variables to control the occurrence of defects. 1060, 1280, 1335 and 1575mm wide slabs are considered, and the prediction techniques are applied on a real stainless-steel producing plant in South Africa.

A literature overview on the causes of defects, goodness-of-fit tests, correlation, auto-regression with exogenous input and a linear quadratic tracker at steady-state is presented. Goodness-of-fit tests are used to determine which mould variables have an effect on the occurrence of defects, and correlation is used to find linear dependence among mould variables. A structure of two models is proposed. The first model describes the effect of mould level, water inlet temperature and casting speed (MV—manipulated variables) on 38 thermocouple temperatures (IV—intermediate variable). Casting speed is a manipulated variable while mould level and water inlet temperature are measured disturbances. This model is known as the MV to IV model, and is used to control the occurrence of defects. The second model describes the effect of the thermocouple temperatures on the defects at different positions and locations on the slabs (OV—output variables). This model is known as the IV to OV model and is the predictor of defects. The models are determined using time-series methods in the form of auto regression with exogenous input using data of approximately 500 slabs cast over a period of 6 months. The models are validated using new data at the same plant from 44 slabs gathered three years later, with good results. As an example, published results give a sensitivity and specificity of 61.5% and 75% respectively for longitudinal cracks on validation data, while the presented method gives 63.6% and 93.5% respectively. The IV to OV model is used in an inversion to determine the optimal thermocouple temperatures for each slab width. The MV to IV model is then used to design a controller to maintain the thermocouple temperature set-points. Three controllers were designed and compared in simulation. The system is inherently uncontrollable, because one manipulated variable exists to control 38 outputs. The linear quadratic tracker at steady-state gave the best results with an overall tracking improvement over the uncontrolled case of 30%, 40% and 1% for the 1060, 1280 and 1575mm wide slabs respectively; with single output control second with 23%, 39% and -2% improvement respectively and the worst case controller came in last with 13%, 31% and -6 % improvement respectively. An increase of the number of thermocouples embedded in the mould walls, as well as proper installation of the thermocouples can improve the predictor. An increase in the number of manipulated variables by using individually controlled water pockets in the mould can improve the control of defects.

Keywords

continuous casting, model, defect, predict, control, direct rolling, hot charging, goodness-of-fit, correlation, time-series, ARX, LQR, bump-less transfer (Afrikaans)

Opsomming

Oppervlakdefekte wat vorm in die stringgietmasjien benodig behandeling d.m.v slyping. Hierdie ekstra fase in die proses veroorsaak laer deurset van finale produk en ekstra energiekostes. Die uitskakeling van platblok behandeling na gieting beteken dat platblokke direk gewals of warm gelaai kan word, wat 'n hoër deurset en verlaagde energiekoste tot gevolg kan hê. Om die hoeveelheid platblokke wat direk gewals of warm gelaai kan word te verhoog, moet die defekte voorspel word voordat die platblok klaar gegiet is. Die voorspeller verwyder na-gieting inspeksies en laat die staalmaker toe om platblokke te skeduleer sodat defeklose platblokke direk gewals of warm gelaai kan word. Platblokke met defekte word steeds gestuur vir behandeling. Die beheer van stringgietmasjienparameters kan lei tot die uitskakeling van defekte sodat alle platblokke defekloos is en sodoende die slypingsfase algeheel uitskakel. Transversale en longitudinale krake, gietpoeier vasvanging en ander inklusies, bloeiers, diep on ongelyke ossillasiemerke, stopmerke en depressies is die defekte wat oorweeg is vir voorspelling en beheer en is die uitsetveranderlikes van die voorspeller. Slegs die veranderlikes in die gietvorm word oorweeg as insette tot die voorspeller; en as gemanipuleerde veranderlikes om die voorkoms van defekte te beheer. 1060, 1280, 1335 en 1575mm wye platblokke word beskou, en die voorspellingstegnieke word op die aanleg van 'n vlekvryestaal produseerder in Suid-Afrika getoets.

'n Literatuuroorsig aangaande die oorsake van defekte, passings-akkuraatheid toetse, korrelasie, outo-regressie met eksogene inset en 'n lineêre kwadratiese volger by gestadige toestande word weergegee. Passings-akkuraatheid toetse word gebruik om te bepaal watter gietvormveranderlikes 'n effek op die defekvoorkoms het, en korrelasie word gebruik om lineêre afhanklikheid tussen gietvormveranderlikes te vind. 'n Struktuur met twee modelle word voorgestel. Die eerste model beskryf die effek van gietvlak, water inlaattemperatuur en gietspoed (MV—gemanipuleerde veranderlikes) op 38 termokoppeltemperature (IV—intermediêr). Gietspoed is 'n gemanipuleerde veranderlike terwyl gietvlak en waterinlaattemperatuur is gemete versteurings. Hierdie model staan bekend as die MV na IV model, en word gebruik om die voorkoms van defekte te beheer. Die tweede model beskryf die effek van termokoppeltemperature op die defekte by verskillende posisies en liggings (OV—uiset veranderlikes). Hierdie model staan bekend as die IV na OV model en is die voorspeller van defekte. Die modelle word bepaal deur van tyd-reeks metodes gebruik te maak in die vorm van outo-regressie met eksogene inset en data van ongeveer 500 platblokke wat oor 'n tydperk van 6 maande gegiet was. Die modelle word bekragtig deur nuwe data van 44 platblokke wat drie jaar later ingesamel is, met goeie resultate. As voorbeelde gee gepubliseerde resultate 'n sensitiwiteit en spesifisiteit van 61.5% en 75% respektiewelik vir longitudinale krake op bekragtigingsdata, terwyl die voorgestelde tegniek 63.6% en 93.5% respektiewelik gee. Die IV na OV model word gebruik in 'n inversie om die optimale termokoppeltemperature vir elke platblokwydte te gee. Die MV na IV model word dan gebruik om 'n beheerder te ontwerp om die termokoppeltemperature se stelpunte te handhaaf. Drie beheerders word ontwerp en d.m.v. simulasie vergelyk. Die stelsel is inherent onbeheerbaar want slegs een gemanipuleerde veranderlike is beskikbaar om 38 uitsette te beheer. Die lineêre kwadratiese volger by gestadige toestande het die beste resultaat gelewer met 'n algemene volgfout verbetering teenoor die onbeheerde geval van 30%, 40% en 1% vir die 1060mm, 1280mm en 1575mm wye platblokke respektiewelik. Die enkeluitsetbeheerder was tweede met 23%, 39% en -2% verbetrings respektiewelik en die slegste geval beheerder was laaste met 13%, 31% en -6% verbeterings respektiewelik. 'n Verhoging in die hoeveelheid termokopples wat in die gietvorm se wand ingeplant word, asook die korrekte installering van die termokoppels kan tot gevolg hê dat die voorspeller verbeter. 'n Verhoging in die hoeveelheid gemanipuleerde veranderlikes d.m.v. waterholtes in die gietvorm wat individueel beheer kan word kan die beheer van defekte verbeter.

Sleutelwoorde

stringgiet masjien, model, defek, voorspel, beheer, direk wals, warm laai, passings-akkuraatheid, korrelasie, tyd-reeks, ORX, LKR, stamplose-oordrag

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Contents