

Local Heat Transfer and Stress Analysis of Direct Chill Casting Process

Dissertation

Zur Erlangung des akademischen Grades

Doktoringenieur

(Dr.-Ing.)

Vorgelegt von

M.Sc. Gaurav Abhay Kulkarni

Geb.am 05.10.1989

In Aurangabad, India

Genehmigt durch die

Der Fakultät für Verfahrens- und Systemtechnik
der Otto-von-Guericke-Universität Magdeburg

Gutachter:

Prof. Dr.-Ing. Eckehard Specht

Institut für Strömungstechnik und Thermodynamik, Universität Magdeburg

Jun.-Prof.Dr.-Ing. Daniel Juhre

Institut für Mechanik, Universität Magdeburg

Prof. Dr.-Ing. Udo Fritsching

Institut für Werkstofftechnik, Universität Bremen

Contents

Preface	iii
Acknowledgement	v
Abstract	vii
Zusammenfassung	ix
1 Introduction	1
1.1 Overview and Motivation	1
1.2 Description of DC casting process for Aluminium Alloys	2
1.3 Quality Issues in DC casting	3
1.3.1 Hot Tearing	3
1.3.2 Cold Cracking	6
1.3.3 Ingot Distortion	7
1.3.4 Macrosegregation	7
1.3.5 Other Defects	9
1.4 Purpose	10
1.5 Overview	11
2 Literature Review	13
2.1 Secondary Cooling	13
2.2 Boiling Water Heat Transfer	14
2.3 Experimental Analysis	16
2.4 Inverse code: Obtaining Boiling Curve	17
2.5 Thermo-Mechanical Aspect of DC casting	18

3 Eulerian Steady State Solution of Boiling Curve for Impinging Water Jet on Moving and Stationary Hot Metal Plate	21
3.1 Introduction	21
3.2 Experimental Method	21
3.2.1 Setup	21
3.2.2 Experimental Sample	22
3.2.3 Experimental Results	23
3.3 Analysis Method	23
3.3.1 Advection	24
3.3.2 Eulerian Steady State	25
3.4 Heat flux as a function of position	28
3.5 Heat flux as a function of temperature	30
3.6 Results and discussion	30
3.6.1 Boiling Curve	30
3.6.2 Comparison with Inverse Model	33
3.6.3 Front Width	34
4 Heat Transfer Analysis of Moving Metal Sheet with an Array of Jets	35
4.1 Introduction	35
4.1.1 Mechanism of Heat Transfer	35
4.2 Results and Discussion	37
4.2.1 Influence of Water Quality	39
4.2.2 Temperature of Water	41
4.2.3 Jet Velocity	43
4.2.4 Jet Impingement Angle	45
4.2.5 Thickness of Metal Sheet	46
4.2.6 Casting Speed	49
4.2.7 Initial Temperature of Metal Sheet	51
4.2.8 Kinds of Metal	52

5 Heat Transfer Analysis of Stationary Metal Sheet with an Array of Jets	57
5.1 Introduction	57
5.1.1 Mechanism of Heat Transfer	58
5.2 Results and Discussion	60
5.2.1 Influence of Water Quality	62
5.2.2 Temperature of Water	63
5.2.3 Jet Velocity	66
5.2.4 Jet Impingement Angle	68
5.2.5 Thickness of Metal Sheet	70
5.2.6 Initial Temperature of Metal Sheet	72
5.2.7 Kind of Metal	74
6 Water Ejection - Phenomenon and Physical Understanding	77
6.1 Introduction	77
6.2 Boiling Curve	80
6.3 Width of Impingement Zone	82
6.4 Mechanism of Heat Transfer	83
6.5 Simulation of Water Ejection	84
6.6 Results and Discussion	85
6.6.1 Temperature of Water	86
6.6.2 Thickness of Metal Sheet	87
6.6.3 Casting Speed	87
6.6.4 Jet Velocity	88
6.6.5 Jet Impingement Angle	88
6.6.6 Initial Temperature of Metal Sheet	89
6.6.7 Quality of Water	89
6.7 Critical Casting Speed	90
7 Implementing Laboratory Results to Industrial DC Casting Process Simulation	93
7.1 Extending Laboratory Results for DC Casting	93
7.2 Mathematical Modeling of DC Casting Process	95
7.2.1 Thermal Modeling	95

7.2.2 Solidification Model	96
7.2.3 Mechanical Modeling	98
7.3 Thermal and Mechanical Boundary Condition	101
7.4 Casting Parameters	102
7.4.1 Material Properties	102
7.4.2 Casting Speed	105
7.4.3 Water Flow Rate	106
7.5 Analysing Experimental Results from DC Casting	106
7.6 Thermal Boundary Condition during Secondary Cooling	109
7.6.1 Boiling Curve	110
7.7 Simulation of DC Casting	113
7.7.1 Computational Domain	113
7.8 Results	114
7.8.1 Thermal Results	114
7.8.2 Mechanical Results	119
7.9 Critical Casting Speed	127
7.10 Formation of Meniscus	128
8 Conclusion	131
Bibliography	135
I Appendix	141
List of Publications	147
List of Thesis Supervised	149
Curriculum Vitae	151