

Contents

Formulae, Symbols and Abbreviations	III
List of Figures.....	V
List of Tables.....	VIII
Kurzfassung	IX
Abstract.....	X
1 Introduction.....	1
2 State of Research.....	3
2.1 Advanced High Strength Steels	3
2.1.1 Transformation-Induced Plasticity Steels	4
2.1.2 Twinning-Induced Plasticity Steels	4
2.1.3 Hot-Formed / Martensitic Steels	4
2.1.4 Dual Phase Steels.....	5
2.2 Surface Coatings	8
2.2.1 Hot Dip Galvanization / Galvannealing	8
2.2.2 Electrolytic Galvanization	9
2.3 Resistance Spot Welding.....	10
2.3.1 Process Characteristics.....	10
2.3.2 Process Parameters.....	12
2.4 Liquid Metal Embrittlement	13
2.4.1 Theoretical Models.....	13
2.4.2 Occurrence and Characteristics	14
2.4.3 LME during Resistance Spot Welding of AHSS.....	14
2.4.3.1 Enforcement Setups	15
2.4.3.2 Influencing Factors	16
2.5 Welding Simulation.....	20
2.5.1 Process and Material Simulation	21
2.5.2 Structure Simulation.....	21
3 Materials and Procedure.....	24
3.1 Materials.....	24
3.2 Resistance Spot Welding.....	27
3.2.1 Welding Current Range.....	28
3.2.2 Electrode Cap Wear	29
3.2.3 Thermal History Measurements	29
3.2.4 Contact Resistance Measurements.....	30
3.3 Welding under External Load	31
3.4 Testing Methods.....	34
3.5 Welding Simulation.....	36
3.5.1 Model.....	36
3.5.2 Simplifications and Assumptions	37

3.5.3	Type of Analysis.....	40
4	Results	42
4.1	Material Characterization and Testing	42
4.1.1	800 MPa Class.....	42
4.1.2	1000 MPa Class.....	46
4.2	Electrode Cap Wear Analysis	52
4.2.1	Uncoated	52
4.2.2	Hot-dip Galvanized.....	55
4.2.3	Electro-galvanized.....	57
4.2.4	Galvannealed.....	60
4.3	Welding under External Load	63
4.3.1	800 MPa Class.....	66
4.3.2	1000 MPa Class.....	69
4.4	Numerical Simulation.....	75
4.4.1	800 MPa Class.....	75
4.4.2	1000 MPa Class.....	81
5	Discussion.....	87
5.1	Material Characterization and Testing	87
5.1.1	800 MPa Class.....	87
5.1.2	1000 MPa class	89
5.1.3	Comparison of Strength Classes.....	91
5.2	Electrode Cap Wear Analysis	94
5.2.1	Uncoated	94
5.2.2	Hot-dip galvanized	95
5.2.3	Electro-galvanized.....	97
5.2.4	Galvannealed.....	98
5.2.5	Comparison of Coating Types	99
5.3	Welding under External Load	102
5.3.1	800 MPa Class.....	103
5.3.2	1000 MPa Class.....	104
5.3.3	Comparison of Coating Types	107
5.3.4	Comparison of Strength Classes.....	110
5.4	Numerical Simulation.....	113
5.4.1	Validation of the Simulation Model	113
5.4.2	800 MPa class	114
5.4.3	1000 MPa class	118
5.4.4	Comparison of Strength Classes.....	123
6	Conclusions.....	125
7	List of Literature.....	127