

Content

1	INTRODUCTION	1
2	STATE OF THE ART	2
2.1	Industrial processing of dual phase steels	4
2.1.1	Hot rolling process	4
2.1.2	Runout table and coiling treatment	5
2.1.3	Cold rolling process	6
2.1.4	Final annealing process	7
2.2	Metallurgical aspects during the processing of cold rolled dual phase steels	9
2.2.1	Austenite conditioning during slab reheating	9
2.2.2	Hot working of austenite	10
2.2.3	Austenite decomposition and metallurgical effects during cooling	12
2.2.4	Metallurgical phenomena during cold rolling	13
2.2.5	Recovery and recrystallization during annealing	14
2.2.6	Austenite formation during intercritical annealing	15
2.2.7	Austenite decomposition after intercritical annealing	16
2.2.8	(Auto-)tempering of dual phase steels	17
2.3	Strengthening mechanisms of dual phase steels	17
2.3.1	Role of alloying elements	18
2.3.2	Role of dislocation density	19
2.3.3	Role of martensite volume fraction	19
2.3.4	Role of ferrite grain size	21
2.3.5	Role of precipitations	22
3	EXPERIMENTAL PROCEDURE	23
3.1	Investigated steels	24
3.2	Hot rolling experiments	24
3.2.1	Determination of T_{NR}	25
3.2.2	Thermomechanical treatment experiments	26
3.2.3	Hot rolling on a demonstrator mill	27
3.3	Cold rolling on a demonstrator mill	28
3.4	Intercritical annealing experiments	29
3.4.1	Recrystallization investigations after cold rolling	29
3.4.2	Phase transformation experiments during intercritical annealing	29
3.4.3	Conventional annealing approaches to determine mechanical properties	31
3.4.4	Alternative intercritical annealing treatments	32
3.5	Determination of mechanical properties	33
3.5.1	Hardness testing	33
3.5.2	Quasi-static tensile testing	34

3.5.3	Hole expansion testing	35
3.5.4	Three-point bending testing	36
3.6	Microstructural investigations	37
3.6.1	Light optical (LOM) and scanning electron microscopy (SEM).....	37
3.6.2	Transmission electron microscopy (TEM).....	37
3.6.3	Automated quantitative image analysis.....	37
4	HOT ROLLING PROCESS	39
4.1	Results of hot rolling investigations	39
4.1.1	Thermodynamic calculations	39
4.1.2	Determination of near-equilibrium temperatures	41
4.1.3	Determination of no-recrystallization temperatures (T_{NR})	42
4.1.4	Influence of the thermomechanical treatment on the hot rolled state	43
4.1.5	Influence of the hot rolled intermediate product on mechanical properties of the cold rolled and annealed dual phase steel	49
4.1.6	Hot rolled intermediate product after experiments on demonstrator mills.....	51
4.1.7	Precipitations after hot rolling of 15MnSiAlMo-M	52
4.2	Discussion of hot rolling experiments	55
4.2.1	Processing window for thermomechanical treatment	55
4.2.2	Austenite decomposition during hot rolling.....	57
4.2.3	Effect of hot rolling treatment on mechanical properties of cold rolled and annealed dual phase steels.....	58
4.3	Conclusions of hot rolling experiments	60
5	INTERCRITICAL ANNEALING OF COLD ROLLED DUAL PHASE STEELS	61
5.1	Experimental results.....	61
5.1.1	Recrystallization behaviour of cold rolled materials.....	61
5.1.2	Austenite formation.....	63
5.1.3	Isothermal austenite transformation	64
5.1.4	Austenite decomposition	66
5.1.5	Tempering behaviour of dual phase steels	71
5.2	Discussion of intercritical annealing experiments	75
5.2.1	Interaction of austenite formation and recrystallization	75
5.2.2	Austenite decomposition from intercritical annealing temperature	78
5.2.3	Tempering treatment of dual phase steels	79
5.3	Conclusions of intercritical annealing experiments	85
6	ALTERNATIVE ANNEALING TREATMENTS FOR DUAL PHASE STEELS	86
6.1.1	Air-quenched multiphase steels	86
6.1.2	Effect of intercritical annealing temperature on the mechanical properties.....	87
6.1.3	Tempering response of air-quenched dual phase steel	88
6.1.4	Austenite stabilization of 15MnSiAlMo-M	88

6.1.5 Nano-carbides precipitation evolution during intercritical annealing.....	90
6.2 Discussion of alternative annealing approaches.....	92
6.2.1 Austenite decomposition after intercritical annealing.....	92
6.2.2 Mechanical properties of air-quenched steels.....	94
6.3 Conclusions of air-quenching dual phase steel investigations	95
7 FORMABILITY OF HIGH STRENGTH DUAL PHASE STEELS WITH SELECTED HEAT TREATMENTS	96
7.1 Experimental results of selected heat treatments.....	96
7.1.1 Microstructures after intercritical annealing	96
7.1.2 Tensile testing of selected heat treatments.....	98
7.1.3 Bending testing of selected heat treatments.....	100
7.1.4 Hole expansion testing of selected heat treatments.....	101
7.2 Discussion on the formability of high strength dual phase steels	102
7.2.1 Stretch-flangeability of dual phase steels.....	102
7.2.2 Bendability of dual phase steels.....	105
7.3 Conclusions of formability investigations.....	106
8 GENERAL CONCLUSIONS AND PROSPECTS	107
9 BIBLIOGRAPHY	109