



Araz Ardehali Barani (Autor)

**Optimization of the Critical Content of Tramp Elements in Ultra-High Strength Silicon Chromium Spring Steels through Thermomechanical Treatment**

Araz Ardehali Barani

---

**Optimization of the Critical Content of Tramp Elements in Ultra-High Strength Silicon Chromium Spring Steels through Thermomechanical Treatment**

---

 Cuvillier Verlag Göttingen

<https://cuvillier.de/de/shop/publications/1492>

Copyright:

Cuvillier Verlag, Inhaberin Annette Jentzsch-Cuvillier, Nonnenstieg 8, 37075 Göttingen, Germany

Telefon: +49 (0)551 54724-0, E-Mail: [info@cuvillier.de](mailto:info@cuvillier.de), Website: <https://cuvillier.de>

---

## TABLE OF CONTENTS

<b>1 Scope of thesis</b> .....	1
<b>2 Theoretical background</b> .....	5
2.1 Ferrous martensite .....	5
2.1.1 Martensite transformation.....	6
2.1.1.1 Nucleation .....	9
2.1.1.2 Growth .....	9
2.1.1.3 Crystallography of martensitic transformation .....	10
2.1.2 Martensite morphologies .....	12
2.1.3 Strength of martensite .....	14
2.1.4 Embrittlement of martensite .....	16
2.1.4.1 Fundamentals of grain boundary segregation .....	17
2.1.4.2 Carbide precipitation.....	21
2.2 Processing martensitic high strength steels .....	23
2.2.1 Austenitization .....	23
2.2.2 Austenite conditioning .....	25
2.2.3 Tempering.....	28
2.3 Strategy for optimization of mechanical properties .....	30
<b>3 Experimental approach and methods</b> .....	35
3.1 Approach .....	35
3.2 Materials .....	35
3.3 Sample processing .....	38
3.4 Mechanical testing.....	39
3.5 Microstructure characterization.....	41

---

<b>4 Results and discussion</b> .....	43
4.1 Definition of parameter windows .....	43
4.1.1 Austenitization .....	43
4.1.1.1 Experiments .....	43
4.1.1.2 Results .....	44
4.1.1.3 Discussion .....	44
4.1.2 Time-Temperature-Transformation .....	49
4.1.2.1 Experiments .....	49
4.1.2.2 Results .....	50
4.1.2.3 Discussion .....	50
4.1.3 Recrystallization behaviour .....	53
4.1.3.1 Experiments .....	54
4.1.3.2 Results .....	55
4.1.3.3 Discussion .....	58
4.1.4 Conclusion .....	59
4.2 Conventional Heat Treatment.....	60
4.2.1 Objective .....	60
4.2.2 Experimental .....	60
4.2.3 Results.....	61
4.2.3.1 Tempering temperature .....	61
4.2.3.2 Microalloying with vanadium .....	68
4.2.3.3 Effect of phosphorous on tensile properties.....	72
4.2.3.4 Effect of copper and tin.....	75
4.2.4 Discussion.....	79
4.2.4.1 Tempering temperature .....	79
4.2.4.2 Microalloying with vanadium .....	80
4.2.4.3 Effect of phosphorous .....	81
4.2.4.4 Effect of copper and tin.....	83
4.3 Thermomechanical Treatment.....	86
4.3.1 Objective.....	86
4.3.2 Definition of deformation temperature .....	86
4.3.2.1 Experimental .....	86

---

4.3.2.2 Results .....	87
4.3.2.3 Discussion .....	100
4.3.3 Austenitization temperature and strategy for thermomechanical treatment .....	104
4.3.3.1 Experimental .....	104
4.3.3.2 Results .....	105
4.3.3.3 Discussion .....	108
4.3.3 Tensile property after austenite conditioning .....	110
4.3.3.1 Experimental .....	110
4.3.3.2 Results .....	111
4.3.3.3 Discussion .....	117
4.3.4 Fatigue Results.....	121
4.3.4.1 Experimental .....	121
4.3.4.2 Results .....	121
4.3.4.3 Discussion .....	124
4.3.5 Microalloying and thermomechanical treatment .....	127
4.3.5.1 Results .....	127
4.3.5.2 Discussion .....	130
<b>5 Final discussion.....</b>	<b>135</b>
5.1 Process and impurity element effect.....	136
5.2 Morphology of grain boundary carbides .....	140
5.3 Refinement of martensite microstructure .....	142
<b>6 Summary and conclusion.....</b>	<b>149</b>
<b>7 References .....</b>	<b>152</b>
<b>Zusammenfassung (abstract in German) .....</b>	<b>159</b>
<b>Lebenslauf (Curriculum Vitae) .....</b>	<b>163</b>