

## **Development of Lightweight Al-alloyed Austenitic Stainless Steels**

*Reza Rahimi*

## Table of Contents

|   |          |
|---|----------|
| <b>Chapter 1 – Introduction.....</b>                      | <b>1</b> |
| <b>Chapter 2 – Literature Review.....</b>                 | <b>3</b> |
| 2.1. Deformation of austenitic steels.....                | 3        |
| 2.1.1. Introduction.....                                  | 3        |
| 2.1.2. Stacking fault energy.....                         | 3        |
| 2.1.3. Transformation-induced plasticity (TRIP) .....     | 4        |
| Stress- vs. strain-induced martensite.....                | 5        |
| 2.1.4. Twinning-induced plasticity (TWIP) .....           | 6        |
| Critical stress for twinning .....                        | 7        |
| 2.1.5. Dislocation glide .....                            | 8        |
| Planar glide.....   | 8        |
| Wavy glide.....   | 9        |
| 2.2. Factors influencing the deformation mechanisms ..... | 10       |
| 2.2.1. Stacking fault energy .....                        | 10       |
| Temperature.....  | 10       |
| Chemical composition.....                                 | 11       |
| Stress state during deformation .....                     | 12       |
| 2.2.2. Crystallographic orientation.....                  | 12       |
| 2.3. Al-alloyed steels.....                               | 15       |
| 2.3.1. Alloying concept.....                              | 15       |
| 2.3.2. Phase constituents.....                            | 15       |
| Kappa carbide.....  | 16       |
| $\alpha$ Mn.....  | 17       |
| $\beta$ -Mn.....  | 18       |
| Aluminide intermetallics .....                            | 18       |
| 2.3.3. Oxidation and corrosion resistance .....           | 20       |
| 2.3.4. Hydrogen embrittlement.....                        | 20       |
| 2.3.5. Mechanical properties.....                         | 21       |
| Work hardening .....                                      | 21       |
| Low temperature mechanical properties .....               | 22       |
| Tensile properties.....                                   | 22       |
| 2.3.6. Deformation mechanisms .....                       | 24       |

|   |           |
|---|-----------|
| <b>Chapter 3 – Experimental Procedures.....</b>                             | <b>27</b> |
| 3.1. Melting and casting operations .....                                   | 27        |
| 3.2. Chemical composition of alloys.....                                    | 27        |
| 3.3. Heat treatment furnaces .....  | 28        |
| 3.4. Optical microscopy (OM).....   | 28        |
| 3.5. X-ray diffraction .....  | 28        |
| 3.6. Scanning electron microscopy (SEM).....                                | 28        |
| 3.7. Transmission electron microscopy.....                                  | 28        |
| 3.8. Dilatometry .....  | 29        |
| 3.9. Differential scanning calorimetry (DSC) .....                          | 29        |
| 3.10. Tensile test .....  | 29        |
| <b>Chapter 4 – Results and Discussion.....</b>                              | <b>31</b> |
| 4.1. Initial microstructure .....   | 31        |
| 4.1.1. Austenitic alloys: 9Ni0Al and 9Ni4Al .....                           | 33        |
| Dendrite arm bending during solidification.....                             | 35        |
| Phase transformation during cooling.....                                    | 36        |
| 4.1.2. Duplex alloy: 3Ni4Al .....   | 38        |
| 4.1.3. Ferritic alloy: 9Ni7Al .....   | 40        |
| 4.2. Dilatometry .....  | 43        |
| 4.3. Mechanical behavior of alloys.....                                     | 49        |
| 4.3.1. Austenitic steels .....  | 49        |
| Work hardening behavior.....  | 49        |
| Correlation between deformed microstructures and work hardening rates.....  | 52        |
| Temperature dependence of tensile properties .....                          | 61        |
| Role of Al in austenitic stainless and high Mn steels .....                 | 63        |
| 4.3.2. Duplex steel .....   | 64        |
| Temperature dependence of mechanical properties.....                        | 64        |
| Deformation characteristics of phase constituents at room temperature ..... | 70        |
| Influence of annealing on microstructure and mechanical properties .....    | 74        |
| <b>Chapter 5 – Conclusions.....</b>   | <b>83</b> |
| References.....   | 87        |
| Acknowledgments.....  | 95        |
| List of abbreviations.....  | 96        |
| List of Tables.....   | 97        |
| List of Figures.....  | 98        |
| Appendix 1.....   | 103       |