

*Commission V*

*Handbook  
on the  
Ultrasonic Examination  
of  
Austenitic and Dissimilar Welds*

*IIW Handbook*

## TABLE OF CONTENTS

|   |           |
|---|-----------|
| <b>1. INTRODUCTION</b>  | <b>13</b> |
| 1.1 Scope and objectives of handbook                              | 13        |
| 1.2 Structural characteristics of austenitic weld materials       | 13        |
| 1.3 Inspection of austenitic welds                                | 14        |
| <b>2. PARENT MATERIAL AND WELD STRUCTURE</b>                      | <b>15</b> |
| 2.1 Parent Material Properties                                    | 15        |
| 2.1.1 Wrought Materials   | 15        |
| 2.1.2 Cast Materials  | 16        |
| 2.2 Welding Process   | 16        |
| 2.2.1 Grain Angle Distribution                                    | 17        |
| 2.2.2 Welding Types   | 18        |
| 2.2.3 Welding Position  | 21        |
| 2.2.4 Weld Repairs  | 23        |
| 2.2.5 Dissimilar Metal Welds                                      | 24        |
| 2.3 Welds in Duplex Stainless Steels                              | 25        |
| <b>3. DEFECTS</b>   | <b>26</b> |
| 3.1 Manufacturing defects   | 26        |
| 3.2 Service Induced Defects and Degradation                       | 28        |
| 3.2.1 Mechanical fatigue cracks (Figure 13)                       | 30        |
| 3.2.2 Thermal Fatigue Cracks (Figure 14, Figure 15)               | 30        |
| 3.2.3 Intergranular Stress Corrosion Cracking (IGSCC) (Figure 16) | 30        |
| 3.2.4 Transgranular Stress Corrosion Cracking (TGSCC) (Figure 17) | 30        |
| 3.2.5 Intergranular Attack (IGA)                                  | 30        |
| 3.2.6 Corrosion   | 30        |
| 3.2.7 Erosion   | 30        |
| <b>4. PROPAGATION OF ULTRASOUND THROUGH AUSTENITIC WELDS</b>      | <b>31</b> |
| 4.1 Introductory Remarks  | 31        |
| 4.2 Physics of Wave Propagation in Austenitic Weld Material       | 32        |
| 4.2.1 Wave Mode and Polarization                                  | 32        |

|   |           |
|---|-----------|
| 4.2.2 Velocity of Ultrasonic Waves in Austenitic Materials    | 33        |
| 4.2.3 Beam Deviation Effects and Focusing/Defocusing Effects. | 37        |
| 4.2.4 Snell's Law and Slowness Surface                        | 38        |
| 4.2.5 Simulation  | 38        |
| 4.2.6 Grain Boundary Scattering                               | 39        |
| <b>5. FACTORS AFFECTING INSPECTION CAPABILITY</b>             | <b>40</b> |
| 5.1 Introduction  | 40        |
| 5.2 Access  | 40        |
| 5.3 Parent Material   | 40        |
| 5.4 Welding   | 41        |
| 5.4.1 Weld Volume   | 41        |
| 5.4.2 Welding Position  | 41        |
| 5.4.3 Weld Interfaces   | 42        |
| 5.4.4 Weld Repairs  | 44        |
| 5.4.5 Dissimilar Metal Welds                                  | 44        |
| <b>6. ULTRASONIC TECHNIQUES</b>                               | <b>45</b> |
| 6.1 Overview of techniques for detection                      | 45        |
| 6.2 Equipment   | 49        |
| 6.3 Probes  | 49        |
| 6.3.1 Shear Wave Probes                                       | 49        |
| 6.3.2 Compression Wave Probes                                 | 49        |
| 6.3.2.1 Single crystal compression probes                     | 51        |
| 6.3.2.2 Twin crystal compression probes                       | 51        |
| 6.3.3 Special Probes  | 53        |
| 6.3.3.1 Creeping wave probes                                  | 53        |
| 6.3.3.2 Mode conversion probes (LLT)                          | 54        |
| 6.3.3.3 Focused probes  | 56        |
| 6.3.3.4 Phased array probes                                   | 57        |
| 6.3.3.5 EMAT probes   | 58        |
| 6.3.3.6 TOFD Probes   | 58        |
| 6.3.4 Couplant  | 58        |

|   |           |
|---|-----------|
| <b>7. GUIDELINES FOR THE INSPECTION PROCEDURE</b>       | <b>59</b> |
| 7.1 Introduction  | 59        |
| 7.2 Evaluation of Parent Material                       | 60        |
| 7.2.1 General   | 60        |
| 7.2.2 Techniques for the Examination of Parent Material | 60        |
| 7.2.3 Techniques for Measuring Attenuation              | 61        |
| 7.3 Time base calibration                               | 61        |
| 7.4 Sensitivity setting                                 | 61        |
| 7.5 Probe characterization                              | 62        |
| 7.5.1 Introduction                                      | 62        |
| 7.5.2 Probe index of angled longitudinal wave probes    | 64        |
| 7.5.3 Distance amplitude curve                          | 64        |
| 7.5.4 Beam angle  | 65        |
| 7.5.5 Beam width  | 66        |
| 7.5.6 Amplitude behaviour for different reflectors      | 66        |
| 7.5.7 Estimation of dominant frequency and bandwidth    | 67        |
| 7.5.8 Dead zone and near field                          | 68        |
| 7.5.9 Nominal signal to noise ratio                     | 68        |
| 7.6 Evaluation level                                    | 68        |
| 7.6.1 Characterization of Indications                   | 68        |
| 7.6.2 Defect Sizing and Location                        | 70        |
| 7.7 Procedure   | 72        |
| 7.7.1 Scope   | 72        |
| 7.7.2 References  | 72        |
| 7.7.3 Personnel   | 72        |
| 7.7.4 Description of the object                         | 72        |
| 7.7.5 Equipment   | 72        |
| 7.7.5.1 Manipulator                                     | 72        |
| 7.7.5.2 Data acquisition system                         | 72        |
| 7.7.5.3 Evaluation system                               | 73        |
| 7.7.6 Probes  | 73        |

|  |            |
|--|------------|
| 7.7.7 Couplant   | 73         |
| 7.7.8 Cables   | 73         |
| 7.7.9 Calibration  | 73         |
| 7.7.9.1 Probe measurements   | 73         |
| 7.7.9.2 Sensitivity setting  | 73         |
| 7.7.9.3 Calibration control  | 73         |
| 7.7.10 Inspection/Data Acquisition                                   | 74         |
| 7.7.11 Evaluation  | 74         |
| 7.7.12 Reporting   | 75         |
| <b>8. INSPECTION QUALIFICATION / PERFORMANCE DEMONSTRATION</b>       | <b>75</b>  |
| <b>9. GENERAL RECOMMENDATIONS AND CONCLUSIONS</b>                    | <b>76</b>  |
| <b>APPENDIX A1 - REFLECTION AND REFRACTION</b>                       | <b>78</b>  |
| A1.1 Effects of boundaries on wave propagation                       | 78         |
| A1.2 Snell's Law   | 79         |
| A1.3 Critical angles   | 82         |
| A1.4 Energy reflection and refraction coefficients                   | 83         |
| A1.4.1 The weld-fine grain interface                                 | 83         |
| A1.4.2 The ultrasonic probe's coupling layer                         | 89         |
| <b>APPENDIX A2 - EFFECTS OF THE MICROSTRUCTURE ON THE ULTRASOUND</b> | <b>91</b>  |
| A2.1 Features of columnar grained weld metal                         | 91         |
| A2.2 The velocity surfaces   | 93         |
| A2.3 Polarization  | 95         |
| A2.4 Beam Skewing  | 98         |
| <b>APPENDIX A3 - SLOWNESS SURFACES</b>                               | <b>100</b> |
| A3.1 Introduction  | 100        |
| A3.2 Definitions   | 100        |
| A3.3 Examples of slowness surfaces                                   | 101        |
| A3.3.1 Isotropic case  | 101        |
| A3.3.2 Anisotropic case  | 102        |

|  |            |
|--|------------|
| <b>APPENDIX A4 - PHASED ARRAY TECHNIQUE</b>  | <b>104</b> |
| A4.1 Beam angle control  | 104        |
| A4.2 Beam focusing   | 105        |
| A4.3 Electronic scanning   | 106        |
| <b>APPENDIX A5 - ELECTROMAGNETIC ACOUSTIC TRANSDUCERS FOR SHEAR-HORIZONTAL WAVES</b> | <b>107</b> |
| A5.1 Introduction  | 107        |
| A5.2 Physical Principles   | 107        |
| A5.3 General properties of EMATs for the angle incidence                             | 108        |
| A5.4 Probe configurations  | 111        |
| A5.4.1 Electromagnet probes  | 111        |
| A5.4.2 Permanent magnet probes   | 112        |
| A5.5 Practical Points About EMAT probes  | 113        |
| <b>APPENDIX A6 - TYPICAL TECHNIQUES FOR MEASURING ATTENUATION</b>                    | <b>114</b> |
| A6.1 Compression Wave Measurements   | 114        |
| A6.1.1 Probe   | 114        |
| A6.1.2 Technique 1   | 114        |
| A6.1.2.1 Results   | 114        |
| A6.1.3 Technique 2   | 114        |
| A6.1.3.1 Results   | 115        |
| A6.2 Shear Wave Measurements   | 115        |
| A6.2.1 Probes  | 115        |
| A6.2.2 Technique   | 115        |
| A6.2.2.1 Results   | 116        |
| A6.3 Grain Size  | 116        |