



## **Materials and Data Review**

# **A Review of Low Alloy Ferritic Steels for Elevated Temperature Service**

(Acronym: **Materials & Data Review**)

## **Final Report**

**ETD Report No: 1089-gsp-74**

*Principal Author:* **J Orr**

*Report Checked by:* **Dr D G Robertson**

December 2008



ETD Consulting, Fountain House, Cleeve Road, Leatherhead, Surrey, KT22 7LX, UK  
**Tel:** + 44 (0)1372 363 111 **Fax:** + 44 (0)1372 363 222 [enquiries@etd-consulting.com](mailto:enquiries@etd-consulting.com)  
[www.etd-consulting.com](http://www.etd-consulting.com) **BS EN ISO 9001: 2008 Certified** **VAT No: 733600853**

ETD Consulting is a trading name of European Technology Development Ltd, Registered in England No: 3553836

**ETD Report No: 1089-gsp-74**

**European Technology Development Limited**

Leatherhead, Surrey

United Kingdom

[enquiries@etd-consulting.com](mailto:enquiries@etd-consulting.com)

[www.etd-consulting.com](http://www.etd-consulting.com)

**Disclaimer:** European Technology Development Ltd. (ETD Consulting) has taken utmost care in the compiling and analysis of data and in the interpretation of the information supplied by the client. Whilst every effort has been made to ensure that the data provided in this report are correct and the advice or the guidelines given are of the highest standard and accuracy, neither ETD nor anyone acting on behalf of ETD makes any warranty, expressed or implied in any way, or accept any liabilities with respect to the use of any information, advice or methodology disclosed in this report.

**Copyright:** This Report has been produced by European Technology Development Limited (ETD) for the project sponsors, or any other body authorized in writing by ETD, only for use within their own organisation or on their clients' plant. No parts of this document may be photocopied or otherwise reproduced for distribution, sale, publication or use outside the sponsor's organisation without prior permission, in writing, from ETD.

# CONTENTS

|  | <b>Page No.</b> |
|--|-----------------|
| <b>Executive Summary</b>   | <b>3</b>        |
| <b>INTRODUCTION - METHODOLOGY USED</b>                           | <b>7</b>        |
| <b>SECTION 1: THE METALLURGY OF LOW ALLOY STEELS</b>             | <b>8</b>        |
| 1.1: STEEL GRADES USED FOR TUBES AND PIPES                       | 8               |
| 1.1.1: GENERAL MICROSTRUCTURAL CONSIDERATIONS                    | 8               |
| 1.1.2: ROLE OF MAJOR ALLOYING ELEMENTS                           | 8               |
| 1.1.3: ROLE OF NON-SPECIFIED / MINOR ELEMENTS                    | 12              |
| 1.1.4: RECENT LOW ALLOY STEEL DEVELOPMENTS                       | 14              |
| 1.2: LOW ALLOY STEELS USED FOR OTHER COMPONENTS                  | 18              |
| 1.2.1: LOW ALLOY STEEL GRADES IN PLATE AND FORGINGS STANDARDS    | 18              |
| 1.2.2: LOW ALLOY STEEL GRADES USED FOR TURBINE ROTORS            | 18              |
| 1.2.3: LOW ALLOY STEEL GRADES USED FOR BOLTING/FASTENERS         | 20              |
| <b>SECTION 2: THE USE OF LOW ALLOY STEELS</b>                    | <b>23</b>       |
| 2.1: A BRIEF HISTORY OF THE DEVELOPMENT OF LOW ALLOY STEELS      | 23              |
| 2.2: THE OXIDATION RESISTANCE OF LOW ALLOY STEELS                | 25              |
| 2.3: THE PHYSICAL PROPERTIES OF LOW ALLOY STEELS                 | 26              |
| <b>SECTION 3: SPECIFIED PROPERTIES OF LOW ALLOY STEELS</b>       | <b>28</b>       |
| 3.1: SPECIFIED CHEMICAL COMPOSITIONS                             | 28              |
| 3.1.1: 0.3 AND 0.5% Mo STEEL GRADES                              | 32              |
| 3.1.2: 1% CrMo STEEL GRADES                                      | 33              |
| 3.1.3: 2.25% CrMo AND T/P23 + T/P24 STEEL GRADES                 | 35              |
| 3.1.4: OTHER LOW ALLOY STEEL GRADES                              | 37              |
| 3.1.5: LOW ALLOY STEELS IN METI CODE                             | 38              |
| 3.2: HEAT TREATMENT DETAILS                                      | 40              |
| 3.2.1: 0.3 AND 0.5% Mo STEEL GRADES                              | 40              |
| 3.2.2: 1% CrMo STEEL GRADES                                      | 41              |
| 3.2.3: 2.25-3% CrMo AND T/P23 + T/P24 STEEL GRADES               | 42              |
| 3.2.4: OTHER LOW ALLOY STEEL GRADES                              | 43              |
| 3.2.5: LOW ALLOY STEELS IN METI CODE                             | 44              |
| 3.3: SPECIFIED ROOM TEMPERATURE PROPERTIES                       | 45              |
| 3.3.1: 0.3 AND 0.5% Mo STEEL GRADES                              | 45              |
| 3.3.2: 1% CrMo STEEL GRADES                                      | 46              |
| 3.3.3: 2.25-3% CrMo AND T/P23 + T/P24 STEEL GRADES               | 47              |
| 3.3.4: OTHER LOW ALLOY STEEL GRADES                              | 48              |
| 3.3.5: LOW ALLOY STEELS IN METI CODE                             | 49              |
| 3.4: SPECIFIED ELEVATED TEMPERATURE 0.2% PROOF / YIELD STRENGTHS | 50              |
| 3.4.1: 0.3 AND 0.5% Mo STEEL GRADES                              | 51              |
| 3.4.2: 1% CrMo STEEL GRADES                                      | 54              |
| 3.4.3: 2.25-3% CrMo AND T/P23 + T/P24 STEEL GRADES               | 58              |
| 3.4.4: OTHER LOW ALLOY STEEL GRADES                              | 62              |
| 3.5: STRESS RUPTURE AND CREEP STRENGTHS                          | 64              |
| 3.5.1: AVERAGE STRESS RUPTURE STRENGTH VALUES                    | 65              |
| 3.5.1.1: 0.3 AND 0.5% Mo STEEL GRADES                            | 65              |

|  |                  |
|--|------------------|
| 3.5.1.2: 1%CrMo STEEL GRADES   | 67               |
| 3.5.1.3: 2.25-3%CrMo STEEL GRADES  | 70               |
| 3.5.1.4: T/P23 AND T/P24 STEEL GRADES  | 73               |
| 3.5.1.5: OTHER LOW ALLOY STEEL GRADES  | 76               |
| 3.5.2: CREEP STRAIN STRENGTH VALUES  | 79               |
| <b>SECTION 4: DESIGN STRESS VALUES</b>   | <b>82</b>        |
| <b>SECTION 5: WELDING AND WELD PERFORMANCE</b>   | <b>92</b>        |
| 5.1 GENERAL CONSIDERATIONS   | 92               |
| 5.2 THE WELDING PROCESS  | 95               |
| 5.2.1 WELDING CONSUMABLES  | 95               |
| 5.2.2 PRE AND POST WELD HEAT TREATMENTS FOR RESISTANCE<br>TO CRACKING  | 102              |
| 5.2.3 WELD ASSESSMENT TECHNIQUES   | 108              |
| 5.2.4. DISSIMILAR METAL WELDMENTS (DMW)  | 122              |
| 5.2.5 WELD REPAIRS   | 123              |
| <b>SECTION 6: SERVICE AND LIFETIME PROPERTIES</b>  | <b>130</b>       |
| 6.1 AGEING OF PARENT MATERIALS   | 130              |
| 6.2 WELD PERFORMANCE DURING SERVICE  | 137              |
| <b>SECTION 7: CREEP AND FATIGUE INTERACTIONS</b>   | <b>143</b>       |
| <b>SECTION 8: FABRICATION ISSUES</b>   | <b>149</b>       |
| <b>CONCLUSIONS</b>   | <b>154</b>       |
| <b>REFERENCES</b>  | <b>157</b>       |
| <b><i>APPENDIX 1 - SPECIFIED COMPOSITIONS and PROPERTY VALUES<br/>FOR LOW ALLOY STEELS FOR BOLTING/FASTENERS</i></b> | <b>164</b>       |
| <b><i>APPENDIX 2 - CLEAN AND SUPER CLEAN STEELS</i></b>  | <b>170</b>       |
| <b><i>APPENDIX 3 - PHYSICAL PROPERTIES</i></b>   | <b>175</b>       |
| <b><i>APPENDIX 4 - DATA SHEETS FOR INDIVIDUAL MATERIALS</i></b>  | <b>184 - 232</b> |