List Of Figures

Figure	Title	Page
No	The	No
1.1	Flow diagram illustrating the research work	4
2.1	Schematic diagram of tensile test specimen a) before testing b) After testing. ΔL	12
2.1	is the total extension of the specimen during the tensile test.	15
2.2	Engineering stress=strain curve showing a) different stresses, b) 0.2% proof	1.5
2.2	stress	13
2.3	True stress - true strain curve (flow curve).	15
2.4	The stress-elongation curve. The elastic elongation is exaggerated for clarity.	16
25	The Charpy impact test sample and impact toughness versus test temperature	10
2.5	curve.	18
2.6	Schematic view of arc welding process.	21
2.7	Schematic view of manual metal arc welding (MMAW).	22
2.8	Different types of joint preparations.	23
2.9	Schematic view of the various zones in a single pass weld metal.	28
	a) Schematic diagram showing different constituents of the primary	
2 10	microstructure in the columnar austenite grains of a steel weld, b) scanning	20
2.10	electron micrograph of the primary microstructure of a steel weld. α -	29
	allotrimorphic ferrite α w- Widmanstatten ferrite and α a-acicular ferrite.	
2.11	Various regions in a multilayer welding.	30
0.10	Microstructural variations in heat affected zone The banded structure is a	31
2.12	characteristic feature of segregated steels which have been rolled	
	Schematic CCT diagram for steel weld metal, summanzmg the possible effect of	
2.13	microstructure and alloying on the transformation products for a given weld	32
	cooling time.	
2.14	Temperature dependence of the yield strength of iron (gettered with titanium) at a	22
	plastic strain of 0.002. The strain rate is 2.5x IO-4s-I.	33
2.15	Contributions to the solid solution strengthening of ferrite.	36

- 2.16 The effect of some substitutional solutes (3 at.%) on the yield strength of iron. The strain rate is $2.5 \times 10-4 \text{ s-1}$.
- 2.17 Carbide sequence in water quenched 2¹/₄Cr-1Mo steel, where 'M' represents 38 metallic elements.

The weld microstructure consists of allotriomorphic ferrite (α), Wimanstetten ferrite (α w) and acciular ferrite (α a). Nitrogen is assumed to be in solid solution

and any Strain ageing effects in the as-welded microstructure are assumed to be 41 negligible. The solid solution strengthening (σss) is expressed as the sum of the contributions from each solute:

A schematic diagram of a three-layer feed-forward network. The model's

2.19 complexity is controlled by the number of neurons in the second layer, known as 45 hidden units.

Under-and over-fitting. A set of noisy data points (hollow boxes) has been fitted

- 2.20 by (a) linear regression and (b) an overly complex function. In the first case the fit clearly does not represent the data, and in the second case the fit over lies the training data perfectly but generalizes poorly to new points (crosses).
- Comparison of error on training and testing sets as a function of network
 complexity, illustrating the problem of over complex models as in Figure 3.2.
 Schematic illustration of the uncertainty in defining a fitting function in regions
 where data are sparse (B) or noisy (A). The thinner lines represent error bounds
- 2.22 due to uncertainties in determining the weights. Note that, outside the range of 50 data, the extrapolation is increasingly uncertain(C). Are as of high uncertainty will provide the most informative new experiments.
- 2.23 A schematic representation of a simple neural network with the elements 51 2.24 Shows the functions in Neural Networks. 53 2.25 Activation function in Neural Network 54 2.26 The process of the genetic algorithm 60 2.27 Principle of the Uniform crossover 64 Database distribution used for yield strength model. "p.p.m.' corresponds to parts 3.1 71 per million by weight. 3.2 (a to f) Yield Strength (YS) model features. 76

х

3.3	The perceived significance value of best seven yield strength models in a	76
	committee for each of the input variables.	
3.4	(a to c) 2 Training data, validation data and test data of the Best GRNN model for	80
	Yield Strength.	
3.5	Database distribution used for Ultimate Tensile Strength model. "p.p.m .'	89
	corresponds to parts per million by weight.	
3.6	(a,b,c,d,e,f) 5.2 : Ultimate Tensile Strength (UTS) model features.	93
37	The perceived significance of best eightUltimate Tensile Strength	94
517	models for each of the inputs.	
38	Training data, validation data and test data of the Best GRNN model for Ultimate	98
5.0	Tensile Strength.	70
39	Database distribution used for Elongation model. "p.p.m .' corresponds to parts	107
5.7	per million by weight.	107
3.10	(a,b,c,d,e,f) Elongation (EL) model features.	112
2 1 1	The perceived significance σ wvalue of best two Elongation models for each of	112
5.11	the inputs.	115
3 1 2	Training data, validation data and test data of the Best GRNN model for	117
5.12	Elongation	11/
2 1 2	Database distribution used for Charpy Toughness model. "p.p.m .' corresponds to	126
5.15	parts per million by weight.	126
3.14	(a,b,c,d,e,f) : Charpy Toughness (CT) model features.	130
2 15	The perceived significance σ wvalue of best eight Charpy Toughness models for	121
5.15	each of the inputs.	151
2.16	(a to c) Training data, validation data and test data of the Best GRNN model for	125
5.10	Charpy Toughness.	155
4 1	(a to q) Response graphs (a to q) of Input variables and Yield Strength of Ferritic	142
4.1	Steel Welds using committee model of Bayesian Neural Network	143
4.2	(a to q) Response graphs of Input variables and Yield Strength of Ferritic Steel	150
	Welds (GRNN)	153
4.3.1	Predicted variations in Yield Strength (MPa) as a function of the Carbon and	155
	Manganese concentrations	130

xi

4.3.2	Predicted variations in Yield Strength (MPa) as a function of the Carbon and	157
	Nickel concentrations	157
4.3.3	Predicted variations in Yield Strength (MPa) as a function of the Carbon and	158
	Chromium concentrations	150
4.3.4	Predicted variations in Yield Strength (MPa) as a function of the Carbon and	159
	Molybdenum concentrations	157
125	Predicted variations in Yield Strength (MPa) as a function of the Carbon and	160
4.3.5	Vanadium concentrations	100
436	Predicted variations in Yield Strength (MPa) as a function of the Carbon and	161
ч.э.0	Silicon concentrations	101
437	Predicted variations in Yield Strength (MPa) as a function of the Carbon and	162
ч. <i>э</i> .т	Boron concentrations	102
438	Predicted variations in Yield Strength (MPa) as a function of the Carbon and	163
4.5.0	Titanium concentrations	105
439	Predicted variations in Yield Strength (MPa) as a function of the Carbon and	164
1.5.9	Niobium concentrations	101
4310	Predicted variations in Yield Strength (MPa) as a function of the Carbon	165
1.5.10	concentration and Heat input	105
4311	Predicted variations in Yield Strength (MPa) as a function of the Carbon	166
1.5.11	concentration and Interpass temperature	100
4.3.12	Predicted variations in Yield Strength (MPa) as a function of the Carbon	167
110112	concentration and Post-weld heat treatment time	107
43.13	Predicted variations in Yield Strength (MPa) as a function of the Nickel and	168
	Chromium concentrations	100
4.3.14	Predicted variations in Yield Strength (MPa) as a function of the Molybdenum	169
	and Vanadium concentrations	10)
4.3.15	Predicted variations in Yield Strength (MPa) as a function of the Boron and	170
	Niobium concentrations	170
4.3.16	Predicted variations in Yield Strength (MPa) as a function of the Heat input and	171
	Interpass temperature	1/1
4.3.17	Predicted variations in Yield Strength (MPa) as a function of the Post-weld heat	172

treatment temperature and Post-weld heat treatment time

4.3.18	Predicted variations in Yield Strength (MPa) as a function of the Carbon and	173
	Post-weld heat treatment temperature	175
4.4	Response graphs (a to r) of Input variables and Ultimate Tensile Strength of	101
	Ferritic Steel Welds using committee model of Bayesian Neural Network	171
4.5	(a to r) Response graphs of Input variables Ultimate Tensile Strength of Ferritic	201
	Steel Welds	201
161	Predicted variations in Ultimate Tensile Strength (MPa) as a function of the	204
4.0.1	Carbon and Silicon concentrations	204
162	Predicted variations in Ultimate Tensile Strength (MPa) as a function of the	205
4.0.2	Carbon and Manganese concentrations	203
162	Predicted variations in Ultimate Tensile Strength (MPa) as a function of the	206
4.0.3	Carbon and Nickel concentrations	200
1 6 1	Predicted variations in Ultimate Tensile Strength (MPa) as a function of the	207
4.0.4	Carbon and Chromium concentrations	207
165	Predicted variations in Ultimate Tensile Strength (MPa) as a function of the	200
4.0.3	Carbon and Molybdenum concentrations	208
100	Predicted variations in Ultimate Tensile Strength (MPa) as a function of the	200
4.6.6	Carbon and Vanadium concentrations	209
	Predicted variations in Ultimate Tensile Strength (MPa) as a function of the	010
4.6.7	Carbon and Titanium concentrations	210
1 6 0	Predicted variations in Ultimate Tensile Strength (MPa) as a function of the	011
4.6.8	Carbon and Boron concentrations	211
1.6.0	Predicted variations in Ultimate Tensile Strength (MPa) as a function of the	010
4.6.9	Carbon and Niobium concentrations	212
4.6.10	Predicted variations in Ultimate Tensile Strength (MPa) as a function of the	010
	Carbon concentration and Heat input	213
4.6.11	Predicted variations in Ultimate Tensile Strength (MPa) as a function of the	
	Carbon concentration and Interpass temperature	214
4.6.12	Predicted variations in Ultimate Tensile Strength (MPa) as a function of the	
	Carbon concentration and Post-weld heat treatment temperature	215

Predicted variations in Ultimate Tensile Strength (MPa) as a function of the	216
Carbon concentration and Post-weld heat treatment time	210
Predicted variations in Ultimate Tensile Strength (MPa) as a function of the	217
Nickel and Chromium concentrations	217
Predicted variations in Ultimate Tensile Strength (MPa) as a function of the	218
Molybdenum and Vanadium concentrations	210
Predicted variations in Ultimate Tensile Strength (MPa) as a function of the	210
Oxygen and Titanium concentrations	219
Predicted variations in Ultimate Tensile Strength (MPa) as a function of the	220
Boron and Niobium concentrations	220
Predicted variations in Ultimate Tensile Strength (MPa) as a function of the Heat	221
input and Interpass temperature	221
Predicted variations in Ultimate Tensile Strength (MPa) as a function of the Post-	222
weld heat treatment temperature and Post-weld heat treatment temperature time.	LLL
(a to r) Response graphsof Input variables and Elongation of Ferritic Steel Welds	240
using committee model of Bayesian Neural Network	240
(a to r) Response graphs (a to r) of Input variables Elongation of Ferritic Steel	251
Welds	231
Predicted variations in Elongation (%) as a function of the Carbon and	255
Manganese concentrations	233
Predicted variations in Elongation (%) as a function of the Carbon and Silicon	256
concentrations	230
Predicted variations in Elongation (%) as a function of the Silicon and Manganese	257
concentrations	237
Predicted variations in Elongation (%) as a function of the Nickel and Chromium	250
concentrations	238
Predicted variations in Elongation (%) as a function of the Molybdenum and	250
Vanadium concentrations	239
Predicted variations in Elongation (%) as a function of the Copper and Oxygen	260
concentrations	200
	 Predicted variations in Ultimate Tensile Strength (MPa) as a function of the Carbon concentration and Post-weld heat treatment time Predicted variations in Ultimate Tensile Strength (MPa) as a function of the Nickel and Chromium concentrations Predicted variations in Ultimate Tensile Strength (MPa) as a function of the Molybdenum and Vanadium concentrations Predicted variations in Ultimate Tensile Strength (MPa) as a function of the Oxygen and Titanium concentrations Predicted variations in Ultimate Tensile Strength (MPa) as a function of the Boron and Niobium concentrations Predicted variations in Ultimate Tensile Strength (MPa) as a function of the Heat input and Interpass temperature Predicted variations in Ultimate Tensile Strength (MPa) as a function of the Post-weld heat treatment temperature and Post-weld heat treatment temperature time. (a to r) Response graphsof Input variables and Elongation of Ferritic Steel Welds using committee model of Bayesian Neural Network (a to r) Response graphs (a to r) of Input variables Elongation of the Carbon and Manganese concentrations Predicted variations in Elongation (%) as a function of the Silicon and Manganese concentrations Predicted variations in Elongation (%) as a function of the Nickel and Chromium concentrations Predicted variations in Elongation (%) as a function of the Nickel and Chromium concentrations Predicted variations in Elongation (%) as a function of the Nickel and Chromium concentrations Predicted variations in Elongation (%) as a function of the Molybdenum and Vanadium concentrations Predicted variations in Elongation (%) as a function of the Copper and Oxygen concentrations Predicted variations in Elongation (%) as a function of the Copper and Oxygen concentrations

xiv

concentrations

4.9.8	Predicted variations in Elongation (%) as a function of the Boron and Oxygen	262
	concentrations	202
4.9.9	Predicted variations in Elongation (%) as a function of the Niobium concentration	263
	and Heat input	203
4.9.10	Predicted variations in Elongation (%) as a function of the Heat input and	264
	Interpass temperature	204
4011	Predicted variations in Elongation (%) as a function of the Post-weld Heat	265
4.9.11	treatment temperature and Post-weld Heat treatment time	203
4012	Predicted variations in Elongation (%) as a function of the Nickel concentration	266
4.9.12	and Heat input	266
4012	Predicted variations in Elongation (%) as a function of the Chromium	267
4.9.15	concentration and Heat input	267
4 10	(a to t) Response graphs (a to t) of Input variables and Charpy Toughness of	202
4.10	Ferritic Steel Welds using committee model of Bayesian Neural Network	283
4 1 1	(a to t) Response graphs of Input variables and Charpy Toughness of Ferritic	204
4.11	Steel Welds (GRNN)	294
4 10 1	Contour plot showing the variation in Predicted Charpy Toughness as a function	200
4.12.1	of the Carbon and Manganese concentrations.	298
4 10 0	Predicted variations in Charpy Toughness (J) as a function of the Manganese and	200
4.12.2	Nickel concentrations	299
4 10 2	Predicted variations in Charpy Toughness (J) as a function of the Manganese	200
4.12.3	concentration and Interpass temperature	300
4 10 4	Predicted variations in Charpy Toughness (J) as a function of the Nickel	201
4.12.4	concentration and Interpass temperature	301
4 10 5	Predicted variations in Charpy Toughness (J) as a function of the Chromium	202
4.12.5	concentration and Interpass temperature	302
4.12.6	Predicted variations in Charpy Toughness (J) as a function of the Heat Input(kJ	202
	mm-1) and Interpass temperature	303
4.12.7	Predicted variations in Charpy Toughness (J) as a function of the Carbon and	204
	Silicon concentrations	304

4.12.8	Predicted variations in Charpy Toughness (J) as a function of the Nickel and	305
	Chromium concentrations	
4.12.9	Predicted variations in Charpy Toughness (J) as a function of the Molybdenum	306
	and Vanadium concentrations	
4.12.10	Predicted variations in Charpy Toughness (J) as a function of the Copper and	307
	Qxygen concentrations	201
4.12.11	Predicted variations in Charpy Toughness (J) as a function of the Qxygen and	308
	Titanium concentrations	500
1 12 12	Predicted variations in Charpy Toughness (J) as a function of the Nitrogen and	300
4.12.12	Boron concentrations	309
1 12 12	Predicted variations in Charpy Toughness (J) as a function of the Niobium	210
4.12.13	concentration and Heat input(kJ mm-1)	510
1 10 11	Predicted variations in Charpy Toughness (J) as a function of the Post-weld Heat	211
4.12.14	treatment temperature and Post-weld Heat treatment time	311
4 10 15	Predicted variations in Charpy Toughness (J) as a function of the Interpass	210
4.12.15	temperature and Testing temperature for Charpy Toughness	512
4 10 10	Predicted variations in Charpy Toughness (J) as a function of the Nickel and	212
4.12.10	Testing temperature for Charpy Toughness	313
4 10 17	3D Contour Plot of Charpy Toughness, Nickel Manganese and Testing	220
4.12.17	Temperature for Charpy toughness $> 213K$ (-60C) (GRNN)	320
4 10 10	3D Contour Plot of Charpy Toughness, Nickel Manganese and Testing	221
4.12.18	Temperature for Charpy toughness > 233K (-40C) (GRNN)	321
	Ternary Categorial Graph of Chromium, Manganese, Nickel, Heat Input and	
4.13.1	Charpy Toughness shows 25 J line with Heat input <=2.1 (wt% Mn range from 0	323
	to 2.31, wt% Ni range from 0 to 10.8, wt% Cr range from 0 to 11.8)	
	Ternary Categorial Graph of Chromium, Manganese, Nickel, Heat Input and	
	Charpy Toughness shows 25 J to 275 J lines with Heat input in range 3.6 to 5.11	
4.13.2	(wt% Mn range from 0 to 2.31, wt% Ni range from 0 to 10.8, wt% Cr range from	325
	0 to 11.8)	
4.13.3	Ternary Categorial Graph of Chromium, Manganese, Nickel, Heat Input and	_
	Charpy Toughness shows 25 J to 300 J lines with Heat input > 5.1 1 (wt% Mn	326

xvi

range from 0 to 2.31, wt% Ni range from 0 to 10.8, wt% Cr range from 0 to 11.8) Ternary Categorized Graph of Chromium, Manganese, Nickel, Heat Input and

4.13.4 Charpy Toughness(Enlarged view of Figure.10 near the Chromium.) (wt% Mn 327 range from 0 to 2.31, wt% Ni range from 0 to 10.8, wt% Cr range from 0 to 11.8)