

TABLE OF CONTENTS

ACKNOWLEDGEMENTS.....	vii
TABLE OF CONTENTS.....	ix
LIST OF TABLES.....	xiii
LIST OF FIGURES.....	xv
ABBREVIATIONS.....	xxiii
NOTATION.....	xxv
PREFACE.....	xxviii
CHAPTER 1. Introduction and Literature Review.....	1-38
1.1 Introduction.....	1
1.1.1 Basic study of aluminium alloy.....	1
1.1.2 7075 Al alloy.....	3
1.2 Cold rolling of 7075 Al alloy.....	5
1.3 Precipitation strengthening of 7075 Al alloy.....	9
1.4 Fatigue crack growth study of 7075 Al alloy.....	16
1.5 Corrosion study of 7075 Al alloy.....	24
1.6 Current challenges and literature gap.....	38
1.7 Objectives of the thesis.....	38
CHAPTER 2. Experimental methods and Characterization.....	39-56
2.1 Alloy development.....	39
2.1.1 Density measurement.....	41
2.1.2 Heat treatment.....	43
2.1.3 Thermomechanical processing.....	44
2.2 Metallography investigation.....	46
2.2.1 XRD.....	46
2.2.2 Optical- microscopy.....	47
2.2.3 Scanning electron microscopy.....	58
2.2.4 Electron Backscatter Diffraction.....	49
2.2.5 Transmission electron microscopy.....	50
2.3 Corrosion testing.....	51
2.3.1 Immersion testing.....	51
2.3.2 Electrochemical testing.....	52
2.4 Mechanical testing.....	53
2.4.1 Vickers Hardness test.....	52
2.4.2 Tensile test.....	53
2.4.3 Fracture test.....	55

Chapter 3. Effect of thermomechanical processing on mechanical properties and microstructural evolution of Al-Mg-Zn alloy.....	57-71
3.1 Introduction.....	57
3.2 Materials characterization.....	58
3.2.1 X-ray diffraction.....	59
3.2.2 Microstructure investigation.....	59
3.2.3 Transmission Electron Microscopy.....	60
3.3 Mechanical Characterization.....	63
3.3.1 Hardness test.....	63
3.3.2 tensile test.....	63
3.3.2 Elastic plastic (J_{1c}) fracture toughness test.....	64
3.4 Fractography.....	67
3.5 Discussion.....	69
3.5.1 Microstructural and Mechanical properties correlation.....	69
3.5.2 Mechanism behind achieving 90% cold rolling.....	70
Chapter 4. Fatigue Crack Growth Rate Investigation of Cold rolled and aged Al-Mg-Zn alloy	72-100
4.1 Introduction.....	72
4.2 Metallographic investigation.....	73
4.2.1 XRD.....	73
4.2.2 Optical-microscopy.....	74
4.2.3 TEM.....	76
4.2.4 EBSD.....	77
4.3 Mechanical testing.....	81
4.3.1 Vickers Hardness test.....	81
4.3.2 Tensile test.....	82
4.3.3 Fatigue crack growth rate (FCGR) test.....	83
4.3.4 Conditional Elastic-Plastic (JQ) fracture test.....	85
4.4 Fractography.....	86
4.4.1 Fatigue crack growth rate test.....	87
4.4.2 Conditional Elastic-Plastic (JQ) fracture test.....	92
4.5 Discussion.....	107
4.5.1 Mechanical and Microstructural correlation.....	94
4.5.2 Fatigue crack growth rate.....	96
4.5.3 Conditional Elastic-Plastic (JQ) fracture test.....	99
Chapter 5. Influence of NaCl Environment on Elastic-Plastic Fracture behavior of Al-Mg-Zn Alloy	101-119
5.1 Introduction.....	101

5.2	Microstructural investigation.....	102
5.2.1	SEM.....	102
5.2.2	TEM.....	103
5.3	Corrosion testing.....	107
5.3.1	Open circuit potential (OCP) test.....	107
5.3.2	Nyquist plot.....	107
5.3.3	Tafel plot.....	108
5.3.4	Cyclic polarization curve.....	108
5.4	Mechanical testing.....	108
5.4.1	Hardness test.....	108
5.4.2	Tensile test.....	109
5.4.3	Elastic plastic J1c fracture test.....	110
5.5	Fractography.....	112
5.6	Discussion.....	115
5.6.1	Microstructural correlation with corrosion behaviour.....	116
5.6.2	Mechanical property in 3.5% NaCl solution.....	116
5.6.3	Influence of precipitation on corrosion behaviour.....	117
Chapter 6. Fatigue crack growth rate behavior of Al-Mg-Zn alloy under 3.5 % NaCl environment.....		120-131
6.1	Introduction.....	120
6.2	Fatigue crack growth rate behaviour.....	120
6.3	Fractography.....	122
6.3.1	Fractography of fatigue pre crack region for SHT sample in normal and 3.5% NaCl.....	122
6.3.2	Fractography of fatigue pre crack region for SHT+PA sample in normal and 3.5% NaCl.....	123
6.3.3	Fractography of fatigue pre crack region for SHT+45% CR sample in normal and 3.5% NaCl.....	124
6.3.4	Fractography of fatigue pre crack region for SHT+60% WR sample in normal and 3.5% NaCl.....	126
6.3.5	Fractography of fatigue pre crack region for SHT+PA+90% CR sample in normal and 3.5% NaCl.....	127
6.4	Discussion.....	128
6.4.1	Effect of 3.5% NaCl solution of all three regions of Paris curve.....	128
6.4.2	Effect of 3.5% NaCl solution on persisting slip bands (PSBs) formation....	130
6.4.3	Effect of 3.5% NaCl solution on striation length.....	130
Chapter 7. Conclusions and future work.....		132-139
References.....		140-164
List of publications.....		165

Conferences.....	165
Workshops and short -term courses.....	166

LIST OF TABLES

Table 1.1 Literature review of 7075 Al alloy for fatigue crack growth rate test.....	17
Table 1.2 Literature review on corrosion study of 7075 Al alloy.....	26
Table 1.3 Literature review on effect of corrosive environment on mechanical property of 7075 Al alloy	30
Table 1.4 Electrochemical corrosion behavior parameters.....	38
Table 2.1 Composition of 7075 Al alloy determined by PMI method.....	40
Table 4.1 micro strain and dislocation density of SHT+45% CR, SHT+60% WR and SHT+ PA+ 90 % CR samples	74
Table 4.2 tensile test result for as received, SHT, SHT+ PA, SHT+ 45% CR, SHT+ 60% WR, SHT+SHT+PA+90% CR respectively	82
Table 4.3 No. of cycles for all five conditions with as received condition.....	85
Table 5.1 Ecorr., Icorr. and corrosion rate values for all five conditions samples...	108
Table 5.2 The value of yield point, Ultimate tensile strength (UTS) and % elongation for all five conditions samples in 3.5 % NaCl solution.....	109
Table 5.3 The value of conditional fracture toughness (J _Q) for all five conditions samples in normal condition and 3.5 % NaCl solution condition.....	109
Table 6.1 Threshold value for SHT+ peak aged (PA), SHT+45% cold rolled (CR), SHT+60% warm rolled (WR) and SHT+PA+90% CR samples in normal and 3.5% NaCl solution.....	122
Table 6.2 No. of cycles for all five conditions in 3.5 % NaCl solution with as received condition.....	122

LIST OF FIGURES

Fig. 1.1. A comprehensive classification of Al alloys.....	3
Fig. 1.2 Application of 7075 al alloy in aviation.....	4
Fig. 1.3 (a) and (b) show images of 7075 and I-7075 aluminum alloy sheets during the cold rolling process, respectively. (c) illustrates the cold rolling performance of the alloy sheets.....	6
Fig. 1.4 A schematic representation of the decomposition and interaction between ZnO nanoparticles and molten aluminum.....	7
Fig. 1.5 Schematic illustration of the mechanism by which WLABs contribute to the reduction of dislocation cell size during plastic deformation.....	8
Fig.1.6 Thermo-mechanical treatment (TMT) processes parameters.....	11
Fig.1.7 XRD analysis of 7075 aluminum alloy under various heat treatment conditions.....	11
Fig. 1.8 TEM microstructures of 7075 Al alloy. (a) After solution treatment, (b–d) UA state (150 °C 2h), PA state (150 °C 8h) and OA state (150 °C 204h).....	13
Fig. 1.9 The matrix precipitates of 7075 at different aging times. (a) 8 h; (b) 24 h; (c) 48 h; (d) average size and number density of precipitated phases at different aging states.....	14
Fig. 1.10 TEM images of the 7075 Al alloy: (a) after solution treatment followed by cyclic loading; (b) in the T6 condition; (c) high-resolution TEM (HRTEM) image along the $\langle 110 \rangle_{Al}$ zone axis; (d) selected area electron diffraction (SAED) pattern along the $\langle 112 \rangle_{Al}$ zone axis.....	15
Fig. 1.11 Fatigue fracture surface of Specimen 05 tested under constant amplitude (CA) loading with a stress ratio $R = 0$ and maximum stress $S = 75$ MPa, including factor 2.0 overloads applied at crack lengths of 30 mm and 50 mm (tip-to-tip). (a) Top-down view of the fatigue fracture surface. (b) 3D view highlighting overload-induced markings and the transition zones from flat (plane strain) to slant (plane stress) fracture morphology.....	20
Fig. 1.12 Comparison of crack opening measurements with experimental results under constant amplitude loading at $R = 0$. (a) Crack opening measurements. (b) Front face of the specimen illustrating crack path deviation due to shear lip formation and the increase in crack opening load in the range of $c/w = 0.4$ to 0.6 . (c) Fracture surface on one side of the	

s p e c i m e n	2 2
Fig. 1.13 A crack initiation zone (marked by the solid rectangle) in AA2024C-T3 'LT' is located at the interface between the aluminum matrix and the clad layer, adjacent to the fastener bore hole, as indicated by the presence of striation ridges (outlined by dashed lines) and fretting debris	2 3
Fig. 1.14 Representative fatigue fracture zones (FFZs) displaying striation markings oriented perpendicular to the crack propagation direction in AA2024C-T3 'L' (left) and AA2198-T8 'L' (right)	2 3
Fig. 1.15 Surface morphologies of the samples of 7075 at different aging states observed by SEM. (a) and (b) UA; (c) and (d) OA	3 2
Fig. 1.16 Surface corrosion morphology of 7075 Al alloy after immersion testing:(a) Coarse-Grained (CG); (b) 3-pass Deformed-Grain with Uniaxial rolling (3-passes-DG-U); (c) 3-pass Deformed-Grain (3-passes-DG); (d) Enlarged view of (c); (e) 7-pass Nanograined with Uniaxial rolling (7-passes-NG-U); (f) 7-pass Nanograined (7-passes-NG).....	33
Fig. 1.17 presents the electrochemical corrosion results.....	35
Fig. 1.18 Electrochemical corrosion analysis of the 7075 alloy, 7075–3.5TiB ₂ composite, and 7075–7TiB ₂ composite:(a) Open Circuit Potential (OCP) curves, (b) Potentiodynamic polarization curves, (c) Nyquist plots, (d) Bode plots showing impedance and phase versus frequency, (e) Equivalent circuit models used to fit the Nyquist data.....	36
Fig. 2.1 Vacuum stir casting processing flow chart to develop 7075 Al alloy.....	41
Fig.2.2 7075 Al alloy developed through vacuum stir casting.....	41
Fig.2.3 (a) Casting set up (b) Al, Mg, Zn metals, (c) Vacuum stir casting(lab), (d) Slag removal, (e) pouring of molten metal.....	43
Fig. 2.4(a) As received sample (b, c) Muffle furnace, (d) quenched sample.....	43
Fig.2.5 (a) Samples for aging at 140°C, (b) Sample for aging at 220°C.....	45
Fig. 2.6(a) Rolling process (b) as received sample (c) 35% deformed sample(d) deformed sample with rolling defect of center crack	4 5
Fig. 2.7(a) cold rolling after SHT, (b) warm rolling after SHT at 200°C.....	46
Fig.2.8 (a) PA sample, (b) 90% CR sample, (c) rolling graph for 90% CR sample.....	46
Fig. 2.9 (a) Cold rolling after SHT with 45 % deformation, (b) Warm rolling after SHT at 200°C with 60 % deformation, (c) Alligator defect of SHT sample after 30 % deformation in cold rolling, (d) 80 % deformed sample after 21 h aging at 140°C, (e) 90 % deformed sample after 21 h aging	

Fig 3.3 (a, b) IPF image of 45% cold rolled sample after SHT and (c, d) IPF image of 90% cold rolled sample (SHT+PA+90% CR) after peak aged.....	61
Fig. 3.4 (a), (b) and (c) is the TEM image of peak aged sample, (d) is zoomed image of η " precipitate, (e) is the SAED pattern of η " particle highlighted in image (d), (f) is dummy image of SAED pattern in which satellite pattern with long range ordering can be seen very clearly.....	62
Fig. 3.5 (a) Hardness graph of SHT+140°C aging (red color graph) and SHT+220°C (blue color graph), (b) hardness graph of (1) SHT at 470°C 8 h, (2) (PA) Peak aging at 140°C 21 h, (3) (OA) Over aging at 140°C 24 h 24 h (4) Peak Aged at 140°C 21 h and 90% cold rolled (PAR).....	63
Fig. 3.6 Tensile test graph for as received (AR), SHT, peak aged (SHT+PA) and 90% cold rolled (SHT+PA+90% CR) sample.....	64
Fig. 3.7: Load vs displacement diagram of (a) SHT, (b) Peak aged, (c) Peak aged and 90% cold rolled samples (SHT+PA+90% CR).....	67
Fig. 3.8 Fractography image of SHT (a, b), peak aged (c, d), 90% cold rolled samples (SHT+PA+90% CR) (e, f) after tensile test.....	68
Fig. 3.9 Fractography of CT sample in SHT, peak aged (140°C 21H) and 90% cold rolled (SHT+PA+90% CR) condition.....	69
Fig. 4.1 XRD peaks of SHT+ 45% cold rolled, SHT+ 60% warm rolled and SHT+PA+ 90% cold rolled cold rolled sample.....	74
Fig. 4.2 optical image of (a) SHT sample, (b) SHT+ SHT+PA sample at lower magnification, (c) SHT+ SHT+PA sample at lower magnification, (d) IQ image of SHT+ 45% CR sample, (e) IQ (image quality) image of SHT+ 60% WR sample, (f) IQ image of SHT+ PA+ 90% CR sample, (g, h, i) grain size bar chart for SHT+ 45% CR, SHT+ 60% WR, SHT+ PA+ 90% CR.....	76
Fig. 4.3 (a) SHT+ PA sample TEM picture at lower magnification, (b) higher magnification TEM image of SHT+ PA sample and (c) is SAED pattern of image (b).....	77
Fig.4.4 (a, b, c) IPF image of SHT+45% CR, SHT+60% WR and SHT+PA+90% CR samples, (d, e, f) higher magnification image of a, b, c respectively.....	78
Fig.4.5 (a, b, c) Kernel Average Misorientation (KAM) image of SHT+45% CR, SHT+60% WR and SHT+PA+90% CR samples.....	78
Fig. 4.6 Image quality (IQ) map of (a) SHT+45% CR, (b) SHT+60% WR and (c) SHT+PA+90% CR samples.....	79

Fig. 4.7 Using the criteria $GOS < 1^\circ$ and limit misorientation $> 15^\circ$, the IPF-image was partitioned to determine the recrystallized-grains of (a)SHT+ 45% CR, (b) SHT+60% WR, and (c) SHT+ PA+ 90% CR. (d, e, f) higher magnification image of a, b, c respectively.....79

Fig. 4.8 To determine the sub-grains, the IPF-image is partitioned using the criteria $GOS > 2^\circ$ and $2^\circ < \text{limit misorientation} < 15^\circ$ (a) SHT+45% CR, (b) SHT+60% WR, and (c) SHT+ PA+ 90% C R 8 0

Fig. 4.9 The ϕ_2 at 0° , 45° , and 65° sections of the orientation distribution function (ODF) illustrate the standard components that are typically observed in face-centered cubic (FCC) metals and a l l o y s 8 0

Fig. 4.10 Texture image of (a) SHT+45% CR, (b) SHT+60% WR and (c) SHT+PA+90% CR s a m p l e s 8 1

Fig 4.11 Hardness test of SHT, SHT+ PA, SHT+45% CR, SHT+60% WR, SHT+PA+90%CR.....82

Fig. 4.12 Tensile test result of as received, SHT, SHT+ PA, SHT+45% CR, SHT+60% WR and S H T + P A + 9 0 % C R s a m p l e s 8 3

Fig. 4.13 (a, b, c, d, e) Paris law for SHT, SHT+ PA, SHT+45% CR, SHT+60% WR and SHT+PA+90% CR samples..... 84

Fig 4.14 Load vs displacement graph for SHT, PA, SHT+45% CR, SHT+60% WR, SHT+PA+ 9 0 % C R 8 5

Fig 4.15 Pre-crack and final fracture for SHT, SHT+PA, SHT+45% CR, SHT+60% WR and SHT+PA+90% CR samples.....86

Fig. 4.16 (a) SHT sample globular view of pre crack area with all three regions of (b) crack initiation, (c) crack propagation, (d) unstable crack growth region.....88

Fig. 4.17 (a) SHT+PA sample globular view of pre crack area with all three regions of (b) crack initiation, (c) crack propagation, (d) unstable crack growth region.....89

Fig. 4.18 (a)SHT+ 45% CR sample globular view of pre crack area with all three regions of (b) crack initiation, (c) crack propagation, (d) unstable crack growth region.....89

Fig. 4.19 (a) SHT+ 60% WR sample globular view of pre crack area with all three regions of (b) crack initiation, (c) crack propagation, (d) unstable crack growth region.....90

Fig. 4.20 (a) SHT+ PA+ 90% CR sample globular view of pre crack area with all three regions of

(b) crack initiation, (c) crack propagation, (d) unstable crack growth region.....	90
Fig. 4.21 stable crack growth region for (a)SHT, (b) SHT+PA, (c)SHT+45% CR, (d)SHT+60% WR and (e) SHT+PA+90% CR samples.....	91
Fig. 4.22 Unstable crack growth region for (a)SHT, (b) SHT+PA, (c)SHT+45% CR, (d)SHT+60% WR and (e) SHT+PA+90% CR samples.....	91
Fig. 4.23 Fractography image of final fracture zone of CT samples before P _{max} of (a)SHT, (b) SHT+PA, (c)SHT+45% CR, (d)SHT+60% WR and (e) SHT+PA+90% CR samples respectively.....	92
Fig. 4.24 Fractography image of final fracture zone of CT samples after P _{max} of (a)SHT, (b) SHT+PA, (c)SHT+45% CR, (d)SHT+60% WR and (e) SHT+PA+90% CR samples respectively.....	93
Fig.5.1 FE SEM image of SHT, SHT+PA, SHT+45% CR, SHT+60% WR, and SHT+PA+90% CR samples in normal condition.....	102
Fig.5.2 SEM images of SHT, SHT+PA, SHT+45% CR, SHT+60% WR, and SHT+PA+90% CR in 3.5% NaCl solution.....	103
Fig.5.3 (a) Bright field image of SHT sample, (b) SAED pattern of SHT sample.....	104
Fig.5.4 (a) Bright field image of SHT+PA sample, (b) dark field image of SHT+PA sample, (c) SAED pattern of SHT+PA sample.....	104
Fig.5.5 (a) Bright field image of SHT +60% WR sample, (b) SAED pattern of SHT+60% WR sample, (c) Bright field image of SHT +60% WR sample, (d) SAED pattern of SHT+60% WR sample, (e) dark field image of SHT+60% WR sample.....	105
Fig.5.6 (a)Bright field image of SHT +45% CR sample, (b) SAED pattern of SHT+45% CR sample.....	105
Fig.5.7 (a) Bright field image of SHT+PA+90% CR sample, (b) SAED pattern of SHT+PA+90% CR sample, (c) Bright field image of SHT+PA+90% CR sample, (d) SAED pattern of SHT+PA+90% CR sample, (e) dark field image of SHT+PA+90% CR sample.....	106
Fig.5.8 (a) OCP plot, (b) Nyquist plot, (c) Tafel plot, (d) Cyclic polarization plot of SHT, SHT+PA, SHT+45% CR, SHT+60% WR, and SHT+PA+90% CR.....	109

Fig.5.9 Hardness graph of all five samples (SHT, SHT+PA, SHT+45% CR, SHT+60% WR, and SHT+PA+90% CR) in 3.5% NaCl and solution and normal condition.....	110
Fig.5.10 Tensile test graph of all five samples (SHT, SHT+PA, SHT+45% CR, SHT+60% WR, and SHT+PA+90% CR) in (a) normal condition. (b) 3.5% NaCl and solution condition.....	111
Fig.5.11 Load vs crack opening displacement Conditional five samples (SHT, SHT+PA, SHT+45% CR, SHT+60% WR, and SHT+PA+90% CR) in 3.5% NaCl solution and normal condition.....	112
Fig. 5.12 Fractography image of fractured tensile sample of (a) SHT sample in normal condition, (b) SHT+PA sample in normal condition, (c) SHT+ 45% CR sample in normal condition, (d) SHT+60% WR sample in normal condition, (e) SHT+PA+90% CR sample in normal condition.....	113
Fig. 5.13 Fractography image of fractured tensile sample of (a) SHT sample in 3.5% NaCl solution condition (b) SHT+PA sample in 3.5% NaCl solution condition (c) SHT+ 45% CR sample in 3.5% NaCl solution condition (d) SHT+60% WR sample in 3.5% NaCl solution condition (e) SHT+PA+90% CR sample in 3.5% NaCl solution condition.....	114
Fig. 5.14 Fractography image of CT sample of (a) SHT sample in normal condition, (b) SHT+PA sample in normal condition, (c) SHT+ 60% WR sample in normal condition, (d) SHT+45% CR sample in normal condition, (e) SHT+PA+90% CR sample in normal condition.....	114
Fig. 5.15 Fractography image of CT sample of (a) SHT sample in 3.5% NaCl solution condition (b) SHT+PA sample in 3.5% NaCl solution condition (c) SHT+ 60% WR sample in 3.5% NaCl solution condition (d) SHT+45% CR sample in 3.5% NaCl solution condition (e) SHT+PA+90% CR sample in 3.5% NaCl solution condition.....	114
Fig.5.16 Schematic diagram illustrating the morphology of pit formation in SHT, SHT+PA, SHT+45% CR, SHT+60% WR, and SHT+PA+90% CR.....	119
Fig. 6.1 Paris law curve for all five conditions sample (SHT+ peak aged (PA), SHT+45% cold rolled (CR), SHT+60% warm rolled (WR) and SHT+PA+90% CR).....	121
Fig. 6.2 Fractography image of fatigue pre crack region for SHT sample(a) normal condition, (b)	

3.5% NaCl solution, (c, d) fractography image of stable crack growth region of SHT sample in normal and 3.5% NaCl solution 123

Fig. 6.3 Fractography image of fatigue pre crack region for SHT+PA sample(a) normal condition, (b) 3.5% NaCl solution, (c, d) fractography image of stable crack growth region of SHT+PA sample in normal and 3.5% NaCl solution... .. 124

Fig. 6.4 Fractography image of fatigue pre crack region for SHT+45% CR sample(a) normal condition, (b) 3.5% NaCl solution, (c, d) fractography image of stable crack growth region of SHT+45% CR sample in normal and 3.5% NaCl solution... .. 125

Fig. 6.5 Fractography image of fatigue pre crack region for SHT+60% WR sample(a) normal condition, (b) 3.5% NaCl solution, (c, d) fractography image of stable crack growth region of SHT+60% WR sample in normal and 3.5% NaCl solution... .. 127

Fig. 6.6 Fractography image of fatigue pre crack region for SHT+PA+90% sample(a) normal condition, (b) 3.5% NaCl solution, (c, d) fractography image of stable crack growth region of SHT+PA+90% sample in normal and 3.5% NaCl solution..... 128

ABBREVIATIONS

SHT	Solution heat treated
PA	Peak aging
CR	Cold rolling
WR	Warm rolling
SEM	Scanning electron microscopy
TEM	Transmission electron microscopy
OM	Optical microscope
XRD	X-ray diffraction
FCGR	Fatigue crack growth rate
PSBs	Persisting slip bands
EBSD	Electron backscattered diffraction

SAED	Selected area electron diffraction
EDX	Energy dispersive X-ray
H	Hour
E _{corr}	Corrosion voltage
I _{corr}	Corrosion current
OCP	Open circuit potential
GOS	Grain orientation spread
IPF	Inverse pole figure
IQ	Image quality
ODF	Orientation distribution function
mmpy	mm per year
LPD	Load point displacement
COD	Crack opening displacement

NOTATION

η''	Eta double prime
η'	Eta prime
η	Eta
J	Elastic plastic fracture toughness
J_{Ic}	Critical value of J integral in mode I
a	Crack length
b	Uncrack ligament
W	Width of the sample
K	Stress intensity factor
B	Sample thickness
J_{pl}	Plastic component of J integral
A_{pl}	Region under the COD vs Load curve from the origin to the maximum load
TN	Sample thickness
ν	Poisson ratio
E	Young modulus of elasticity
n_{pl}	Plastic correction factor
ρ	Dislocation density
σ	Stress
ϵ	Micro strain
D	Coherent domain size
Ω	Electrical resistance
χ	Chi
b	Burger vector
Hz	Hertz

