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University of Strathclyde Engineering

Fatigue Life Comparison of High Strength Steels and Conventional Steels

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WEIR

NMIS National Manufacturing Institute Scotland

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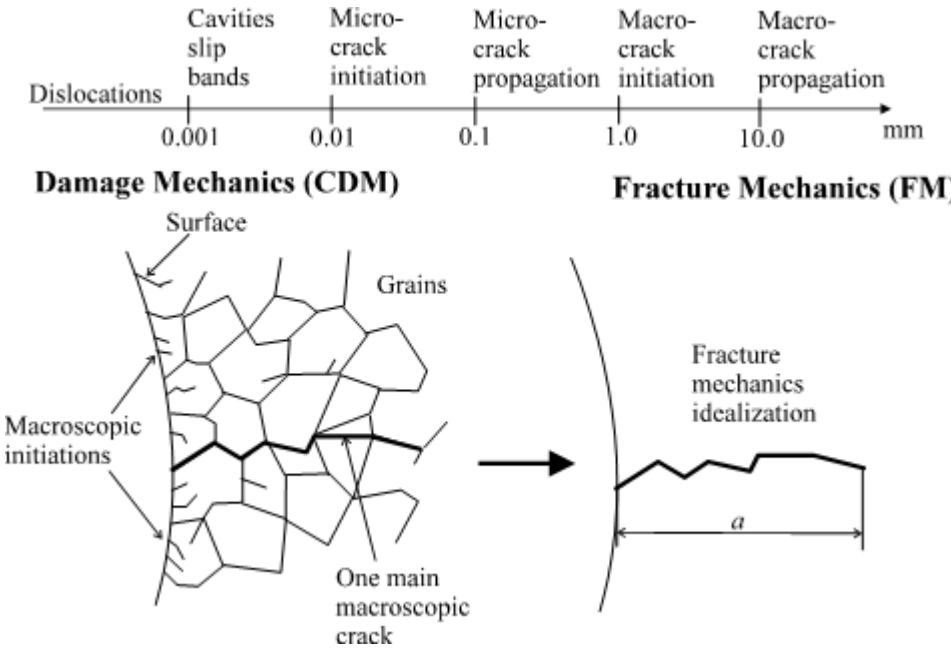
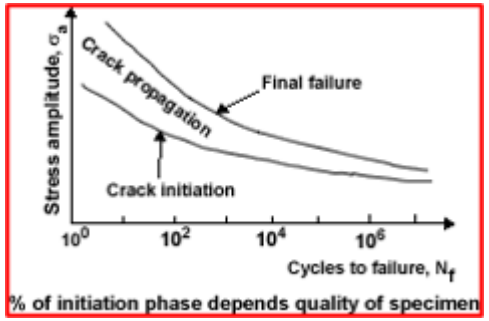
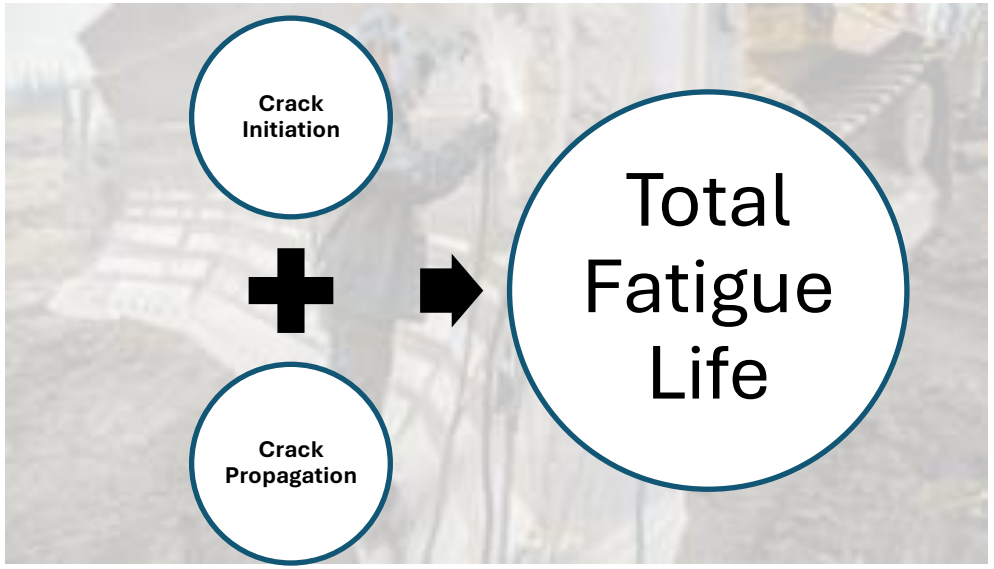
Background



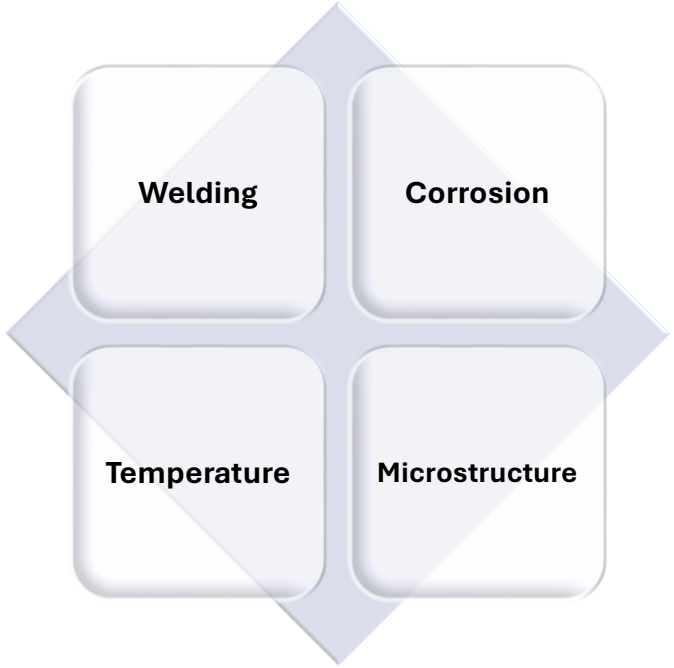
Size of defects[1]





Assumption: **Higher yield strength improves fatigue crack initiation resistance & higher ductility improves fatigue crack propagation resistance**

Question: **Which grade is better in total fatigue life, also considering environmental effect?**



[1] Chaboche, J.L. (1988) "CDM: Part I—General Concepts." ASME. J. Appl. Mech., 55(1): 59–64.

Methodology

Fig 1: UFT samples in the corrosion tank

Fig 2: Vickers Hardness Test

Material Selection & Sample Preparation

Material Characterisation

Fatigue Crack Initiation

Zwick HA250

Shimadzu USF-2000A

Low Cycle Fatigue (Strain Controlled)

Ultrasonic Fatigue Test (Stress Based) – [WES 112 (2017)]

Fatigue Crack Propagation

Instron 8801

Influence of environmental factors (temperature & corrosion)

Fracture Mechanics: Compact Tension (CT) [ASTME647]

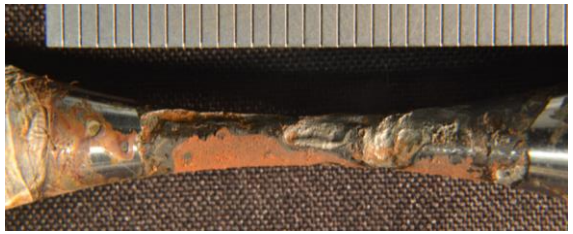


Fig 3: 4-week Pre-corroded UFT sample

Fractography

FEA Simulation

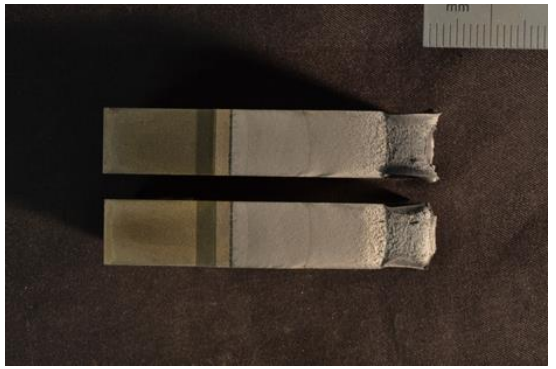


Fig 4: Fractured surface of CT sample after testing

Material Properties

Steel Grade	C (%)	Si (%)	Mn (%)	S (%)	P (%)	Cu (%)	Ni (%)	Cr (%)	Mo (%)	Nb (%)
Grade 1	**0.13**	0.28	1.17	0.003	0.007	0.01	0.07	0.24	0.14	0.02
Grade 2	**0.32**	0.27	0.48	0.006	<0.003	0.25	0.11	1.01	0.19	0.01
Grade 3 (Q355B)	**0.17**	0.34	1.40	0.012	0.016	-	-	-	-	-

Grade	Yield Strength (MPa)	Vickers Hardness	Microstructure
Garde 1	**844**	**314**	**Martensite**
Garde 2	**572**	**219.25**	**Ferrite + Overtempered Martensite**
Garde 3 (Q355B)	**355**	**174**	**Ferrite Pearlite**

- Comparison of tested Grades of Steel.

Ultrasonic Fatigue Testing (UFT)

- Piezoelectric actuator vibrates at resonance frequency
- Produces fatigue data at 20,000Hz – up to 1000x faster than traditional methods
- Allows cost effective testing in the very-high cycle regime (>10^6 cycles)
- However, still has many challenges to overcome – **frequency effect (strain rate sensitivity), size effect, heating effect**

Test Method	1 million cycles	1 billion cycles	10 billion cycles
Traditional (20Hz)	14 hours	580 days	Years..
Ultrasonic (20kHz)	50 seconds	14 hours	6 days

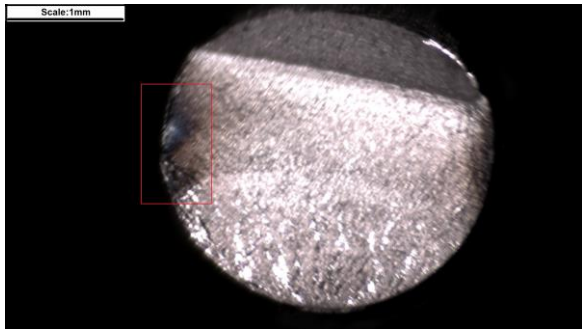


Fig 5: Discolouration on the facture surface due over heating

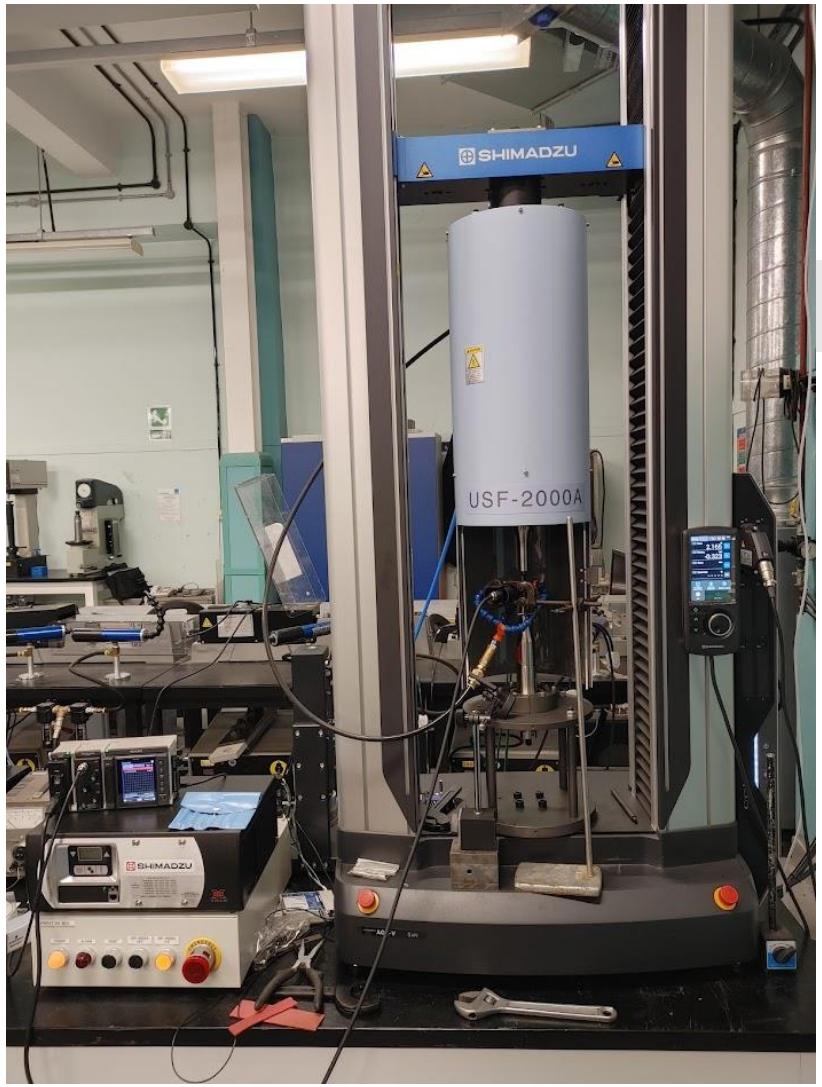


Fig 6: UFT test setup at the lab

Grade 1 UFT results

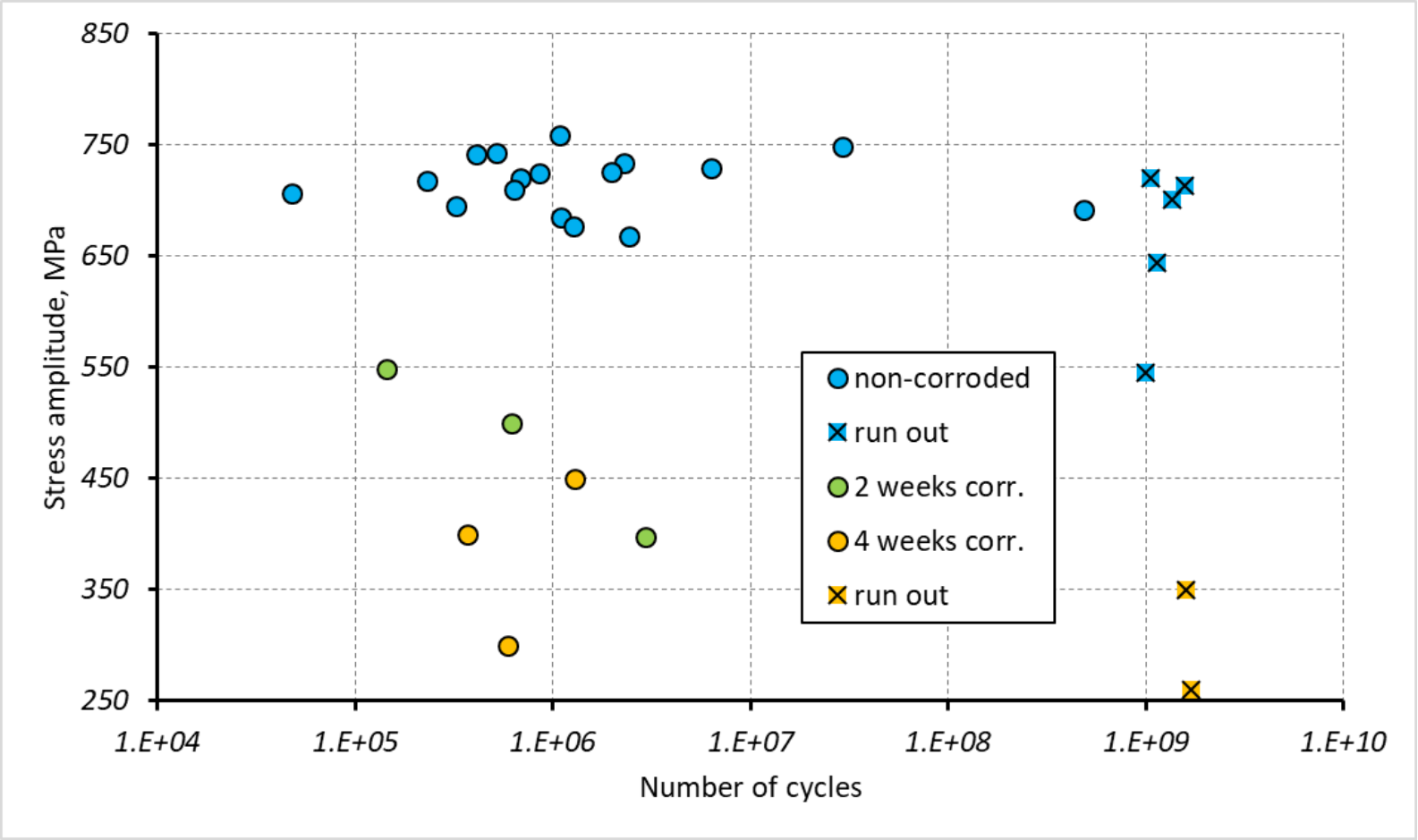


Fig 7: Data points on the S-N curve for Garde 1 samples

- Cycles to failure data is scattered.
- More samples need to be tested to better understand the material fatigue behaviour.

Fig 8: 4-week pre-corroded UFT samples Grade 1

Grade 2 & 3 UFT Results

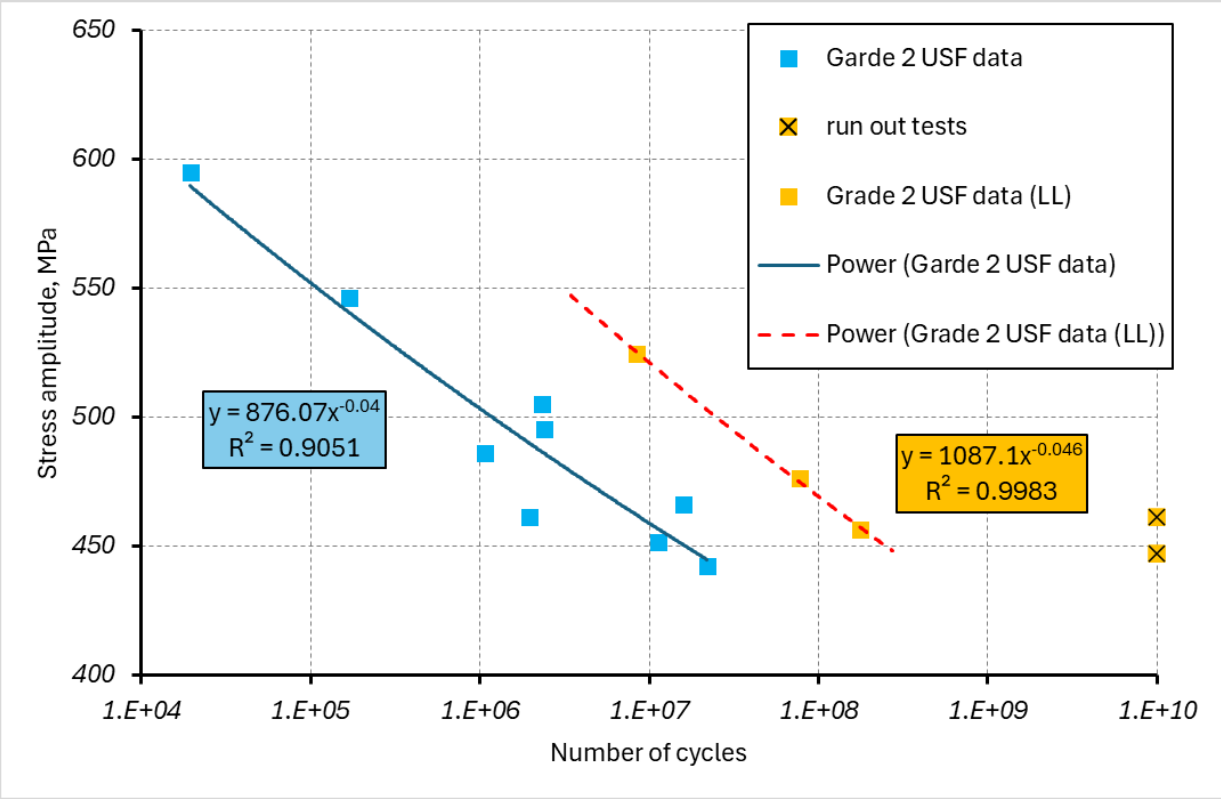


Fig 9: SN curve at 20kHz for Grade 2

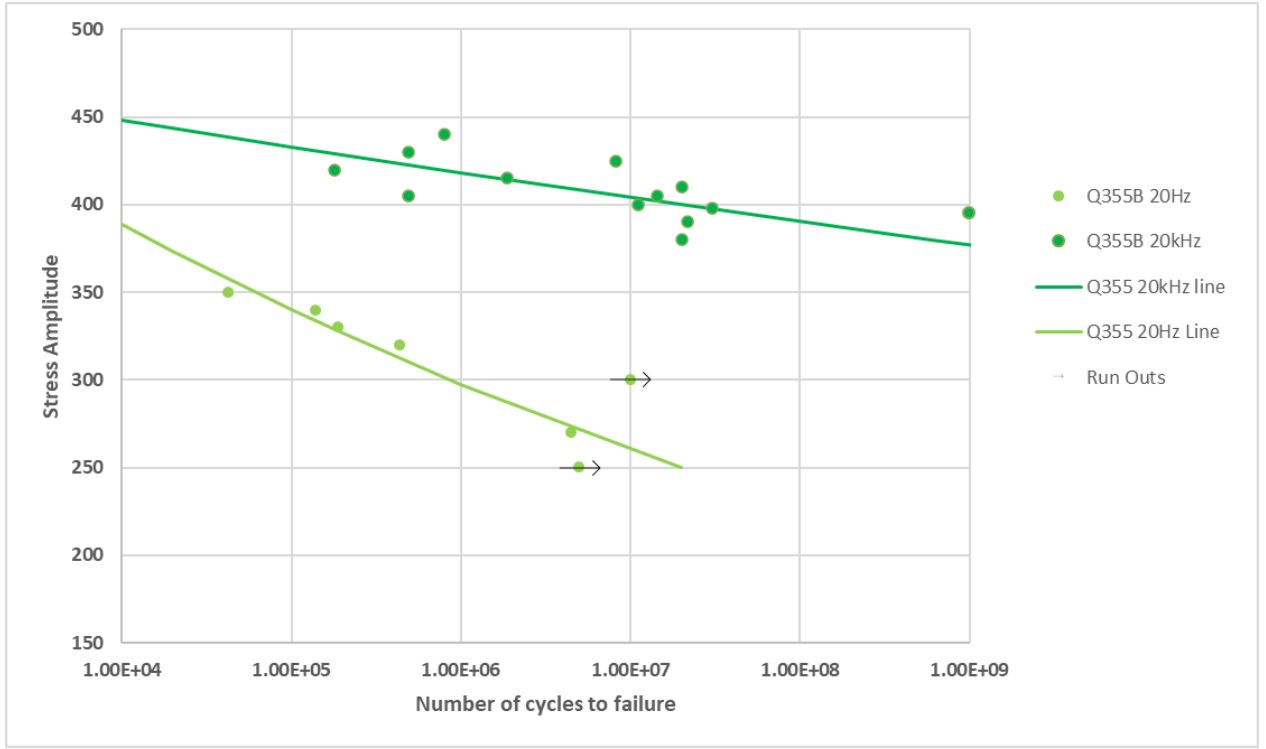


Fig 10: SN curve at 20 Hz and 20kHz for Grade 3 [2]

- Some amount of scatter is expected due to inherent probabilistic nature of fatigue.
- No massive heating issue when compared to Grade 3 steels.
- Need to investigate the Long Life (LL) transition in Grade 2

- No clear fatigue limit is observed
- Significant heating issue observed even at maximum cooling pause 5 sec.
- For ferritic steels intensive localized heating will occur once the crack is found.

[2] Milne, L., et al(2022). Frequency Effects in Ultrasonic Fatigue Testing (UFT) of Q355B Structural Steel. Procedia Structural Integrity, 42, 623–630. https://doi.org/https://doi.org/10.1016/j.prostr.2022.12.079

Crack Growth Test Conditions

Fracture Mechanics Testing

- Instron 8801, 100kN frame, Mode I fracture mechanics, ASTM E647 standard.
- Room Temperature
- Stress Ratio **R =0, R=0.1**
- Constant amplitude sinusoidal cyclic waveform at **5Hz & 10Hz** frequency
- Maximum applied load $\mathbf{P_{max} = 10kN}$
- CMOD gauge with gauge length of **10mm** on the front face
- Back Face Strain Gauge (BFS) with 120Ω resistance with Quarter Bridge configuration is attached.

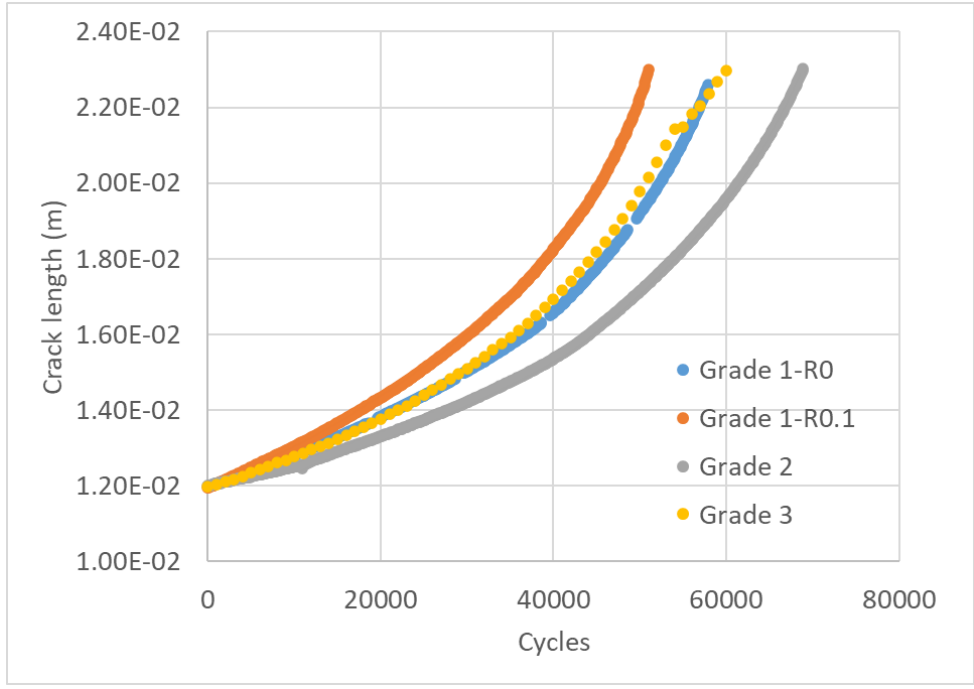


Fig 11: Plot comparing the Crack length vs Cycles for 3 grades

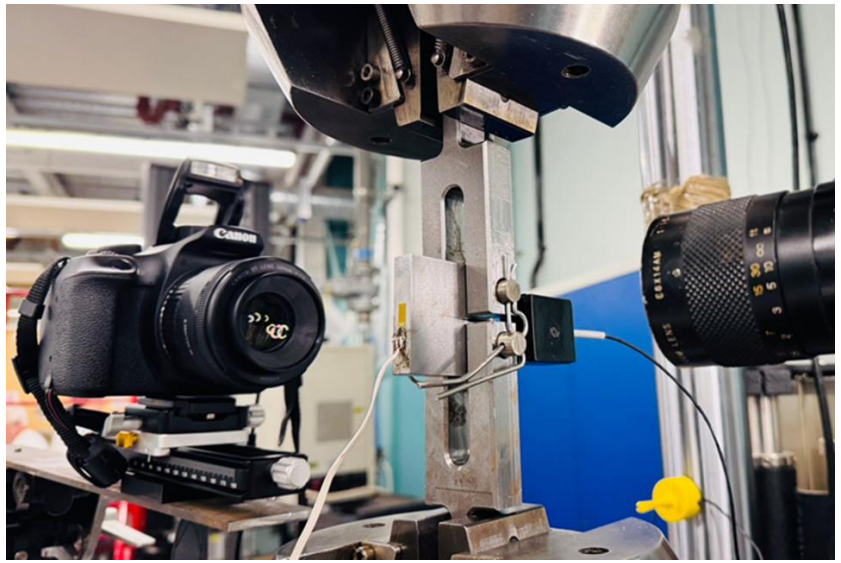


Fig 12: Visual crack monitoring technique

Crack Growth Results

Garde	Stress Ratio (R)	m	C
Grade 1	0	2.864	5.53E-13
	0.1	2.72	1.345E-12
Garde 2	0.1	2.4135	3.49E-12
Garde 3	0	3.0486	4.0644E-12

- Experimental crack mouth opening displacement (CMOD) & BFS data results are post processed to obtain **crack length vs cycles**.
- da/dN vs ΔK and the Paris law constants **m & C are** estimated with a logarithmic regression analysis

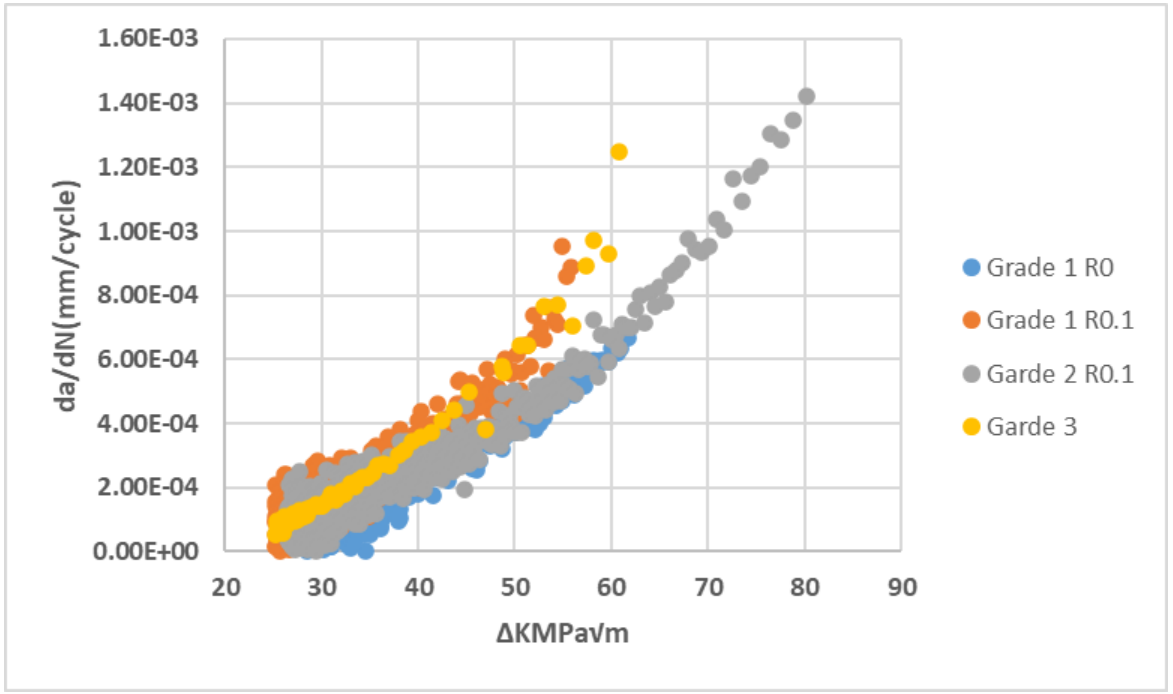


Fig 13: Visual crack monitoring technique

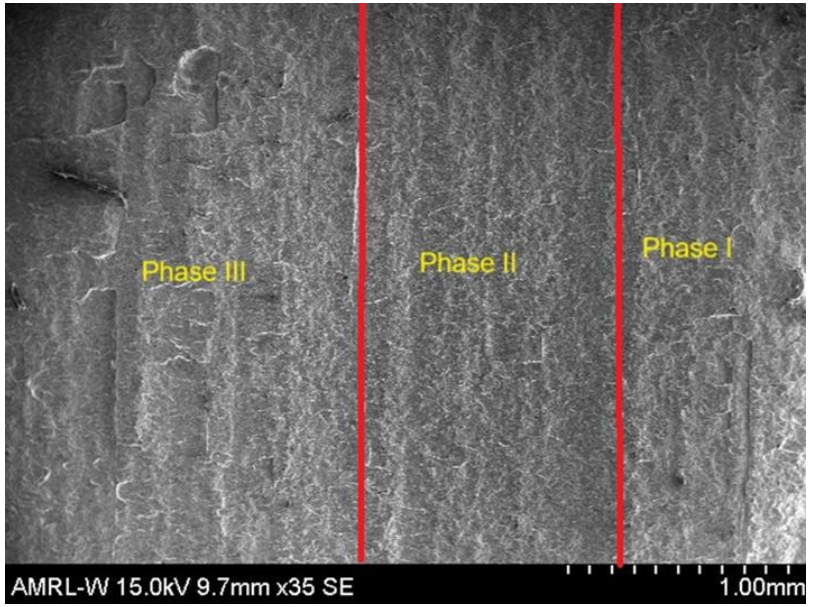


Fig 14: SEM images of the fractured CT samples

Preliminary Conclusions

Microstructure as an influence on the fatigue life. Crack Initiation : Grade 1> Grade 2> Grade 3

- **Grade 1** offers better fatigue crack initiation resistance followed by Grade 2 and Grade 3 when tested using UFT machine.

Crack Propagation: Grade 2 > Grade 1, Grade 3

- **Grade 2** the crack propagation is slower when compared to the other Garde 1 & Grade 3.
- **Frequency** does not influence the crack growth rate in air. However, need to check for the range of Stress Ratios (R).

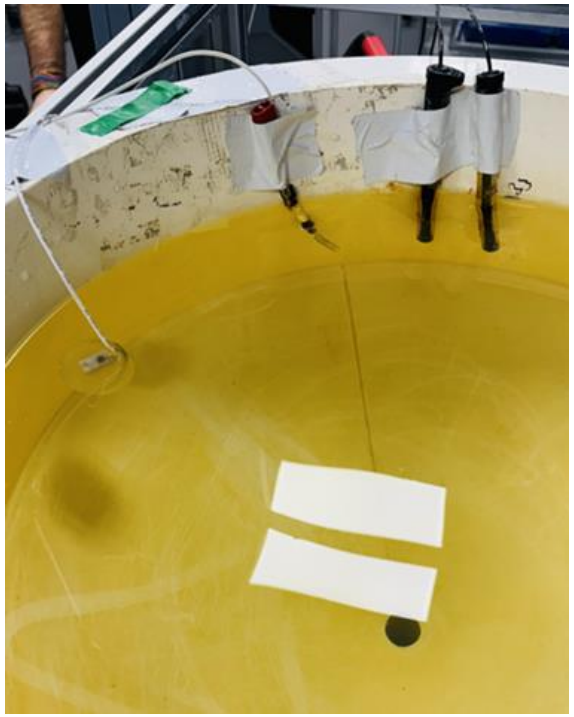


Fig 15: Test setup to static polarization

Future Work

- Compare the crack propagation rates for different environments (subzero, corrosion)
- Study the influence of microstructures on the crack propagation rate.
- Apply the experimental results on finite element numerical models of components & optimize application.

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