Gigacycle fatigue performance of steel welds

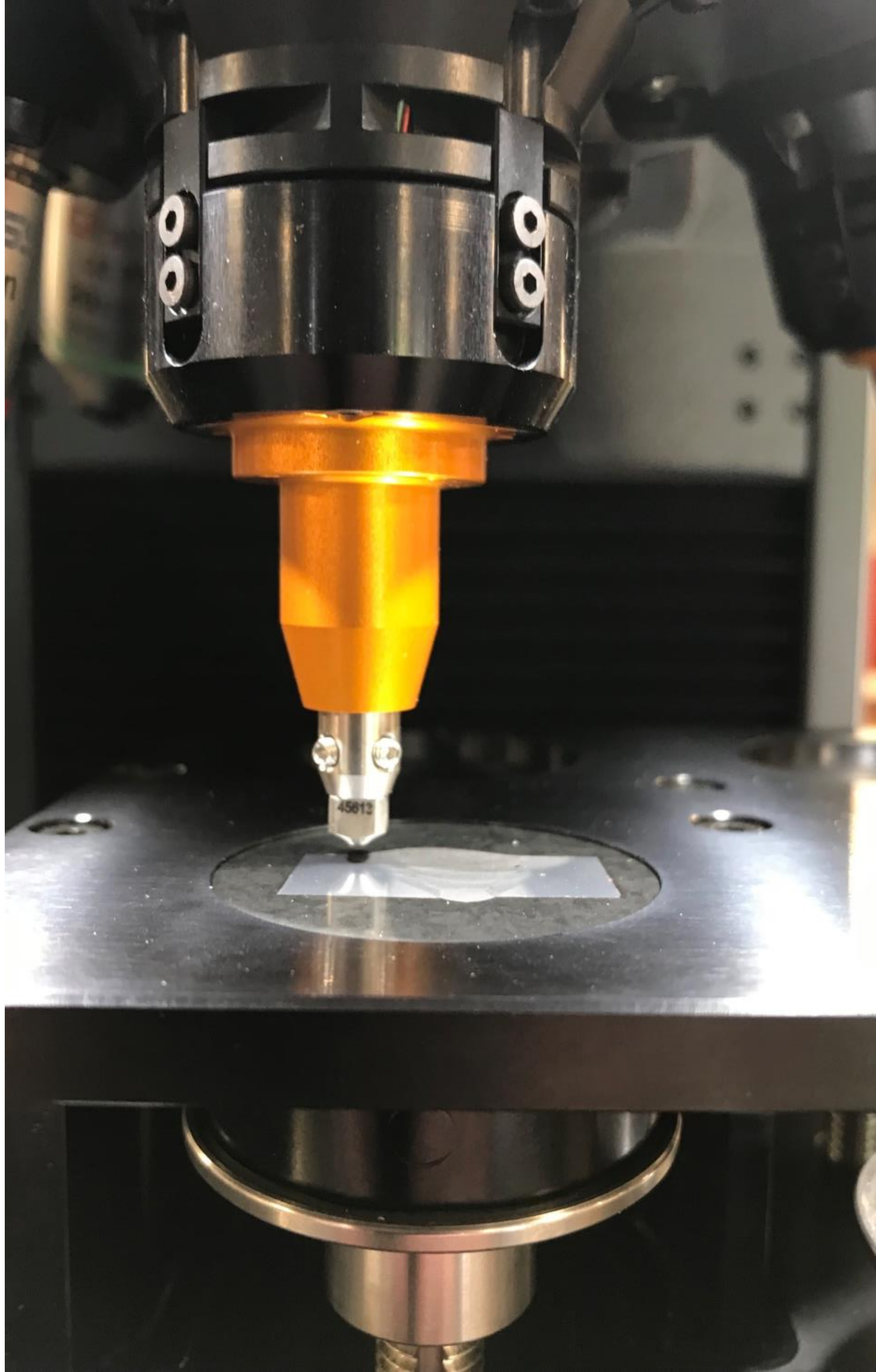
Andrew England, Athanasios Toumpis, Yevgen Gorash

Department of Mechanical and Aerospace Engineering, University of Strathclyde, Glasgow

28/02/23

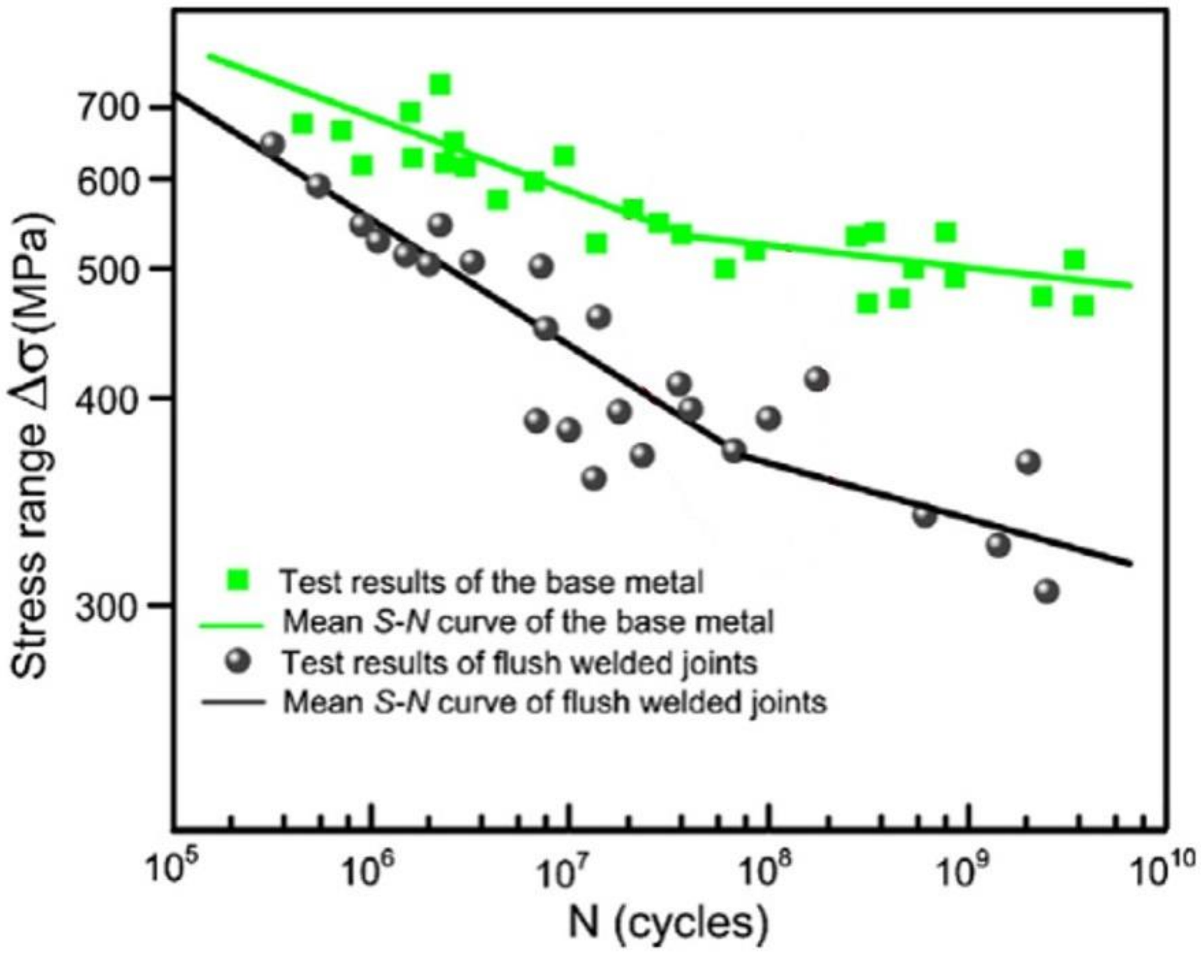
X THE PLACE OF USEFUL LEARNING

Contents



Background

- The design life of welded components and structures is often in the gigacycle regime
- Assumption that ferrous metals and their weldments have a fatigue limit has been proven invalid



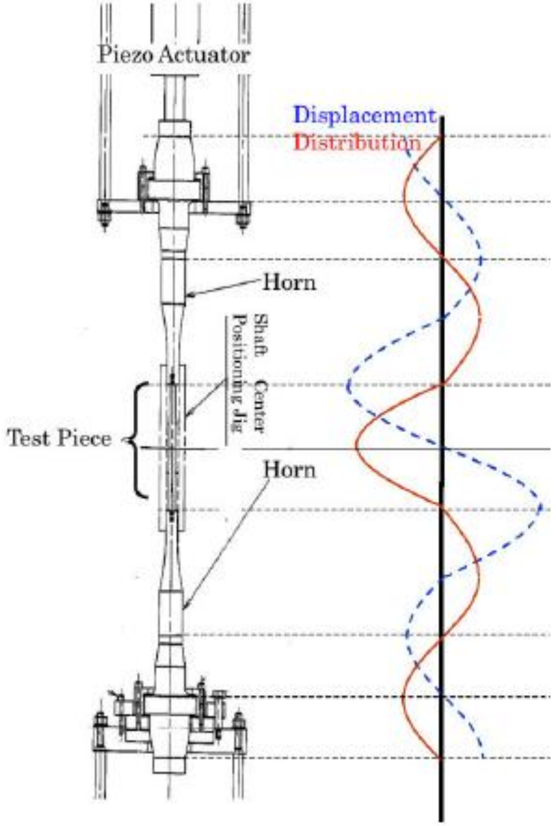
Gigacycle fatigue data for EH36 steel and welded joint [1]

[1] Zhao et al., *Int J Fatigue 36* (2012) 1-8

Background

Testing to the gigacycle regime requires ultrasonic fatigue testing (UFT)

- Specimen longitudinally vibrated at a natural frequency of 20 kHz
- Up to 1000x faster testing than servo-hydraulic machines
- Cooling of specimens is required
- Significant strain-rate effect on material properties for low-carbon steels



Ultrasonic fatigue testing schematic [2]

Fatigue test loading method	Test duration to 1 billion cycles
Conventional – 20 Hz	578 days
Ultrasonic – 20 kHz	14 hours

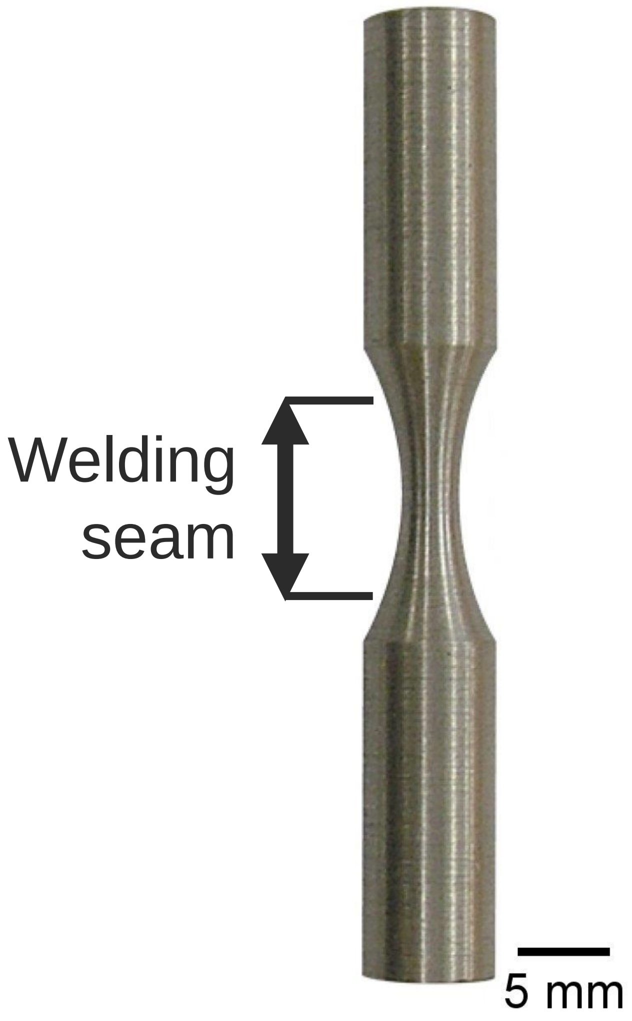
[2] USF2000A Manual, Shimadzu, Japan

Specimen design

Hourglass specimens are typically used for ultrasonic fatigue testing

<u>Aims</u>

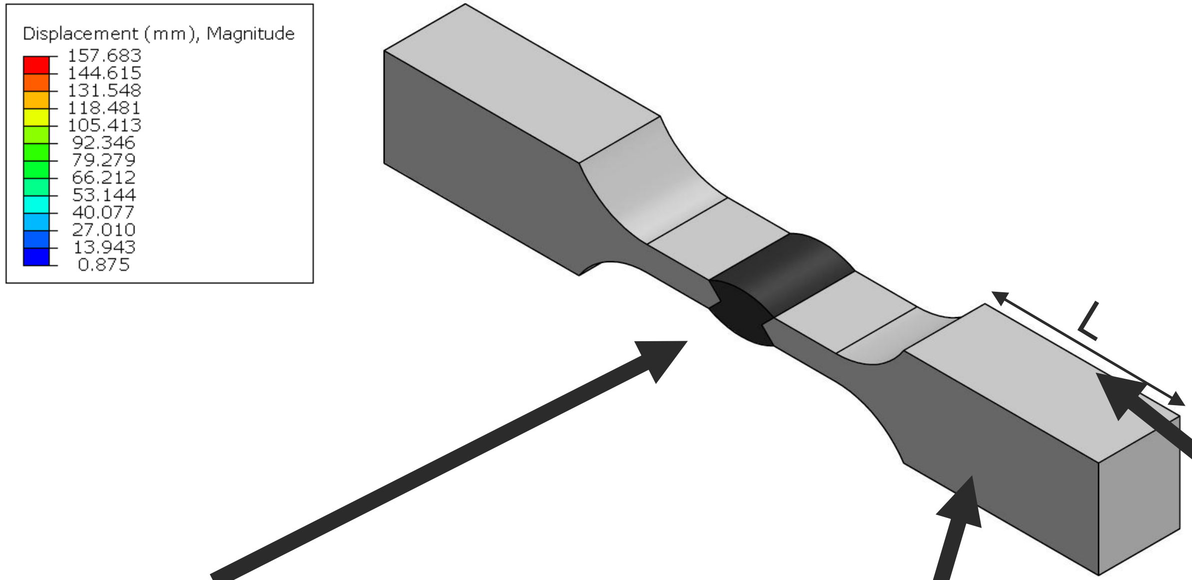
- Design a novel specimen design and develop a robust testing method for as-welded specimens
- Conformation with UFT standard
- Compatibility with fatigue improvement methods



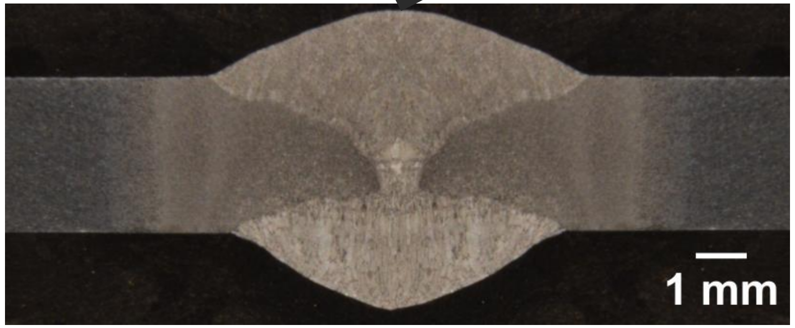
Commonly used UFT specimen [3]

[3] Tecquipment https://www.tecquipment.com/mild-steel-fatigue-specimen

Specimen design



mode of
a natural
20 kHz



Trial double sided weld bead geometry

Material properties:

- Density
- Elastic modulus

Iterative tuning of shoulder length, L

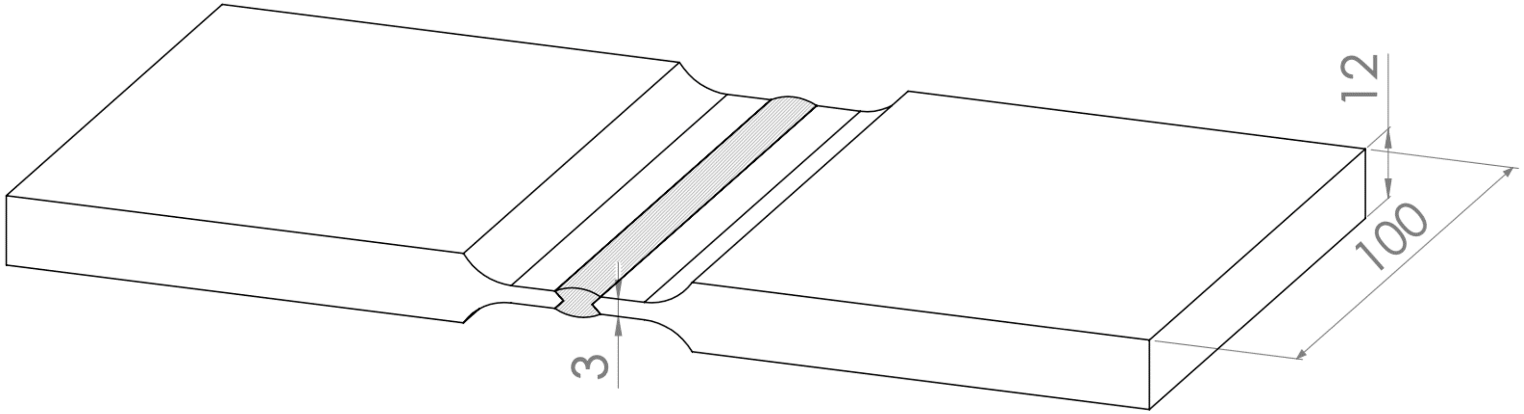
Materials and welding

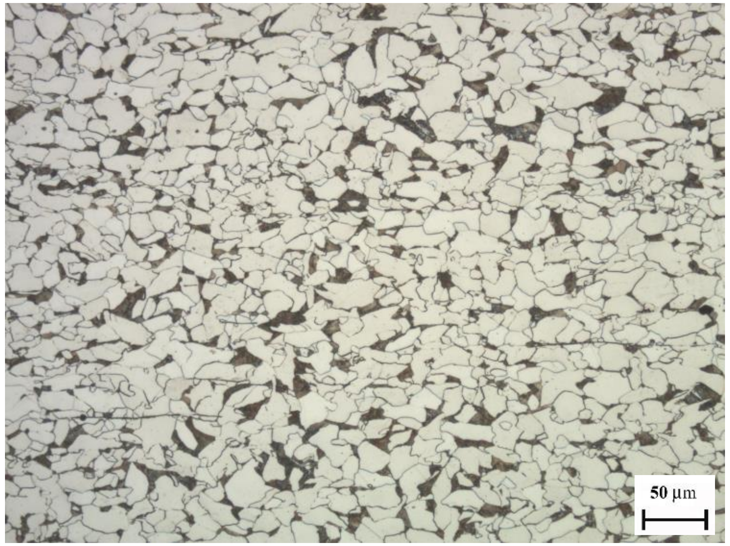
Material	C (%)	Mn (%)	P (%)	S (%)	Si (%)	Cu (%)	Yield Strength (MPa)	Elongation (%)
EN3B base material	0.15	0.7	0.016	0.010	-	-	340	23
SF1-A welding electrode	0.05	1.36	0.010	0.008	0.41	0.26	530	28

- Semi-automated flux core arc welding process
- 20% CO_2 / 80% Ar shielding gas

Materials and welding

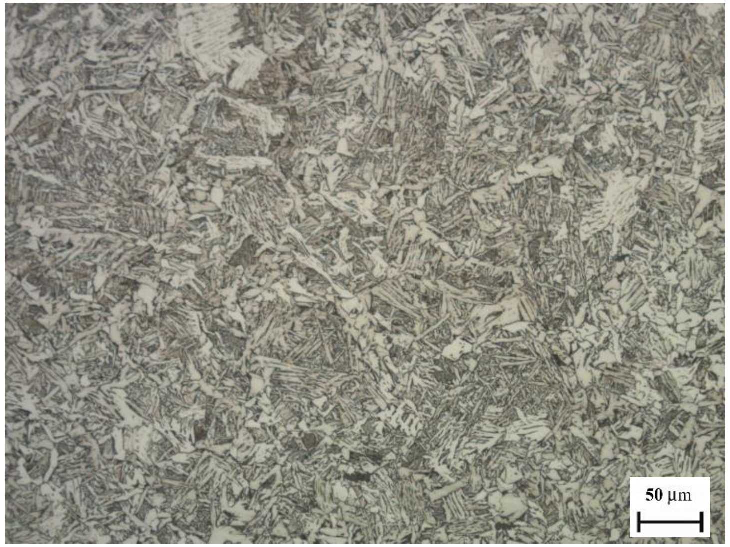
Voltage	19 V
Current	110 A
Travel Speed	5 mm/s





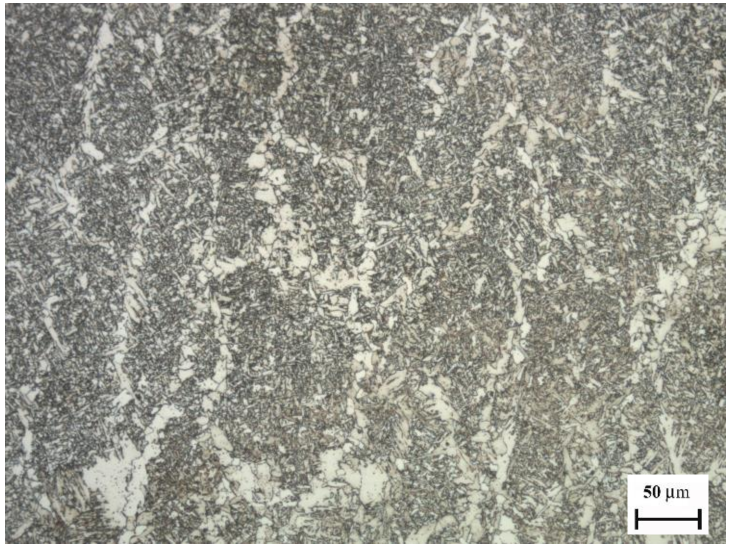
Parent material [x200, etched]

172 HV



HAZ [x200, etched]

219 HV



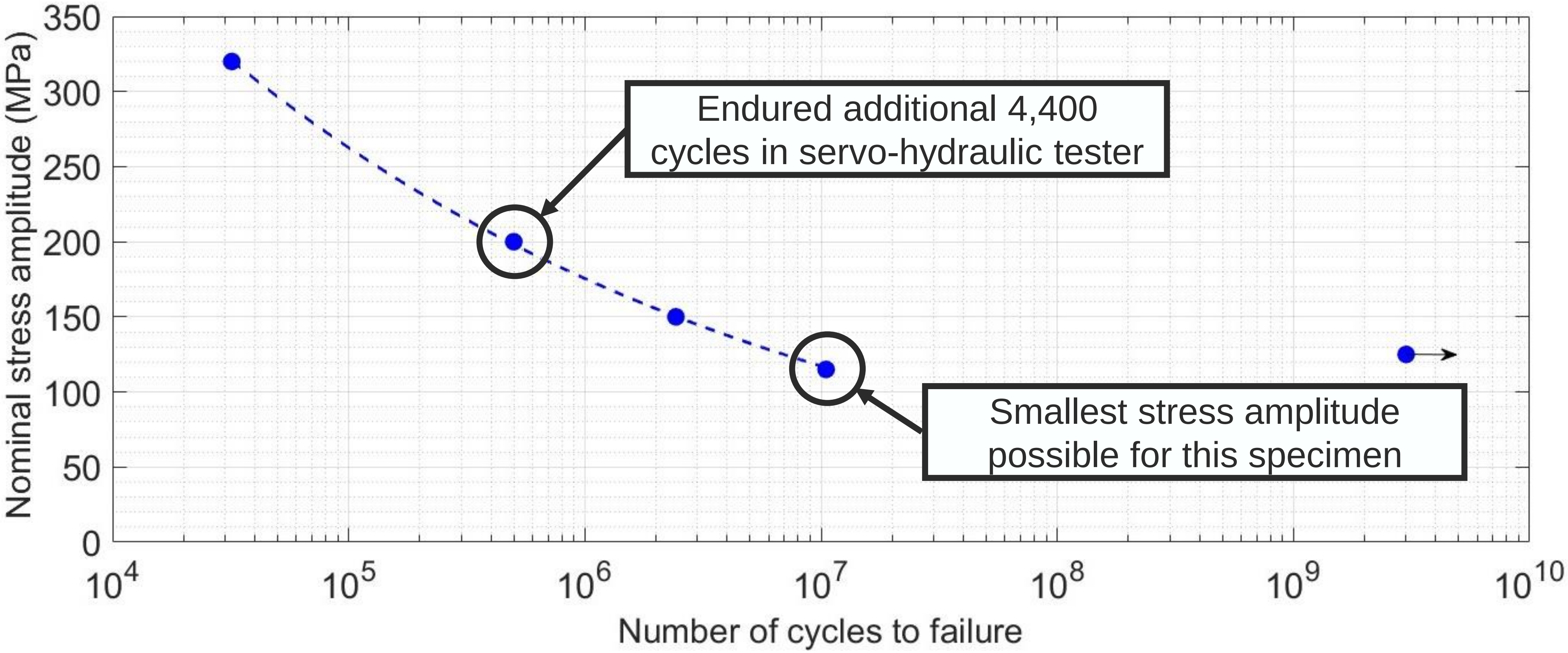
FZ [x200, etched]

195 HV

Test conditions

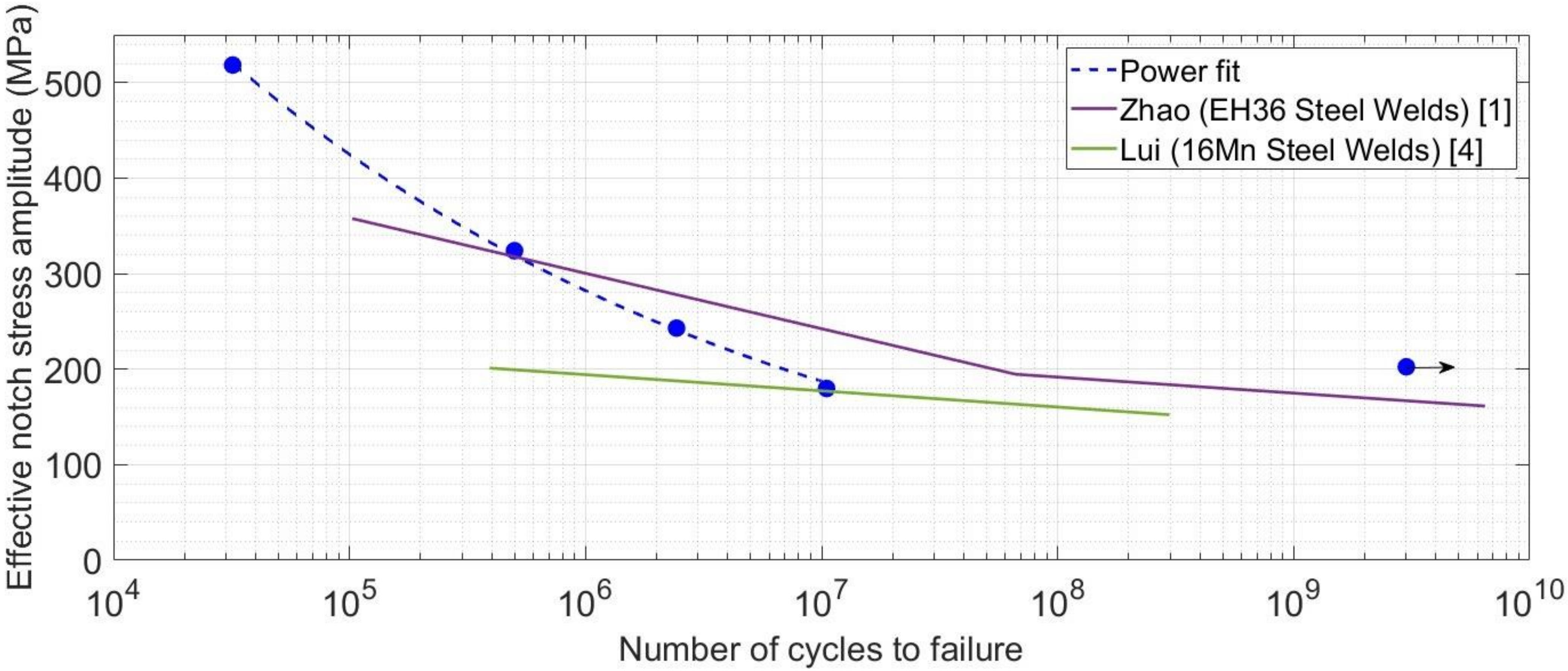
- Shimadzu USF-2000A ultrasonic testing machine
- Fully reversed axial loading, R = -1, at 20.04 kHz
- Specimen cooling and temperature monitoring implemented
- Test stopped when the natural frequency of the specimen changed

Fatigue testing results



- Limited number of failed specimens show expected fatigue trend
- No conclusive fatigue limit observed

Fatigue testing results

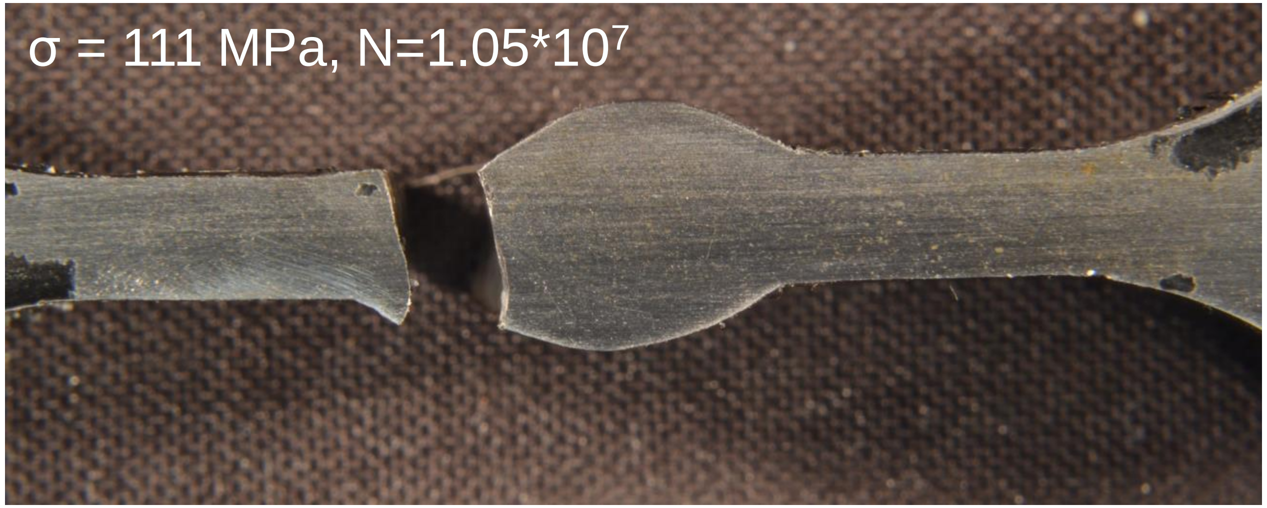


- Within same range of fatigue strength for similar steels
- Slightly higher rate of reduction in fatigue strength

[1] Zhao et al., *Int J Fatigue 36* (2012) 1-8
[4] Lui et al., *Struct Eng Mech 52* (2012) 889-901

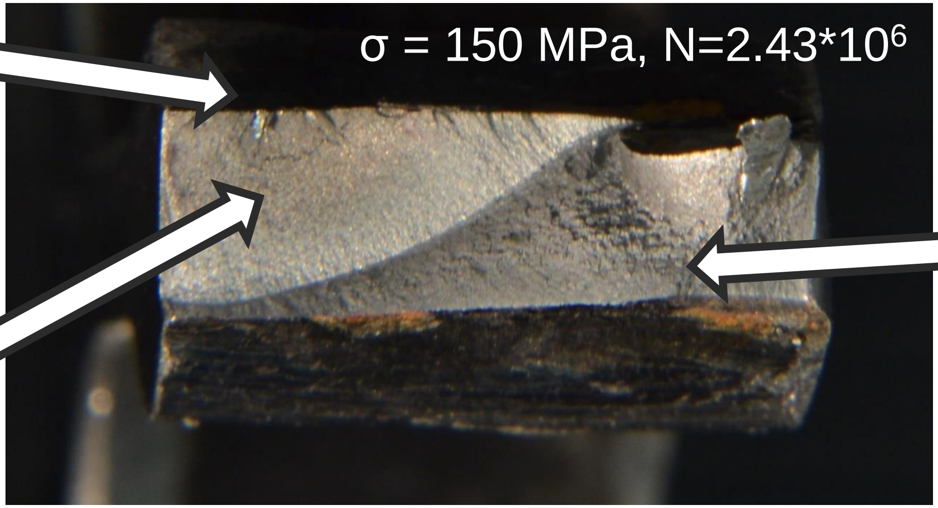
X THE FACULTY OF ENGINEERING

Fractography



Similar fracture mode was shown for all failed specimens

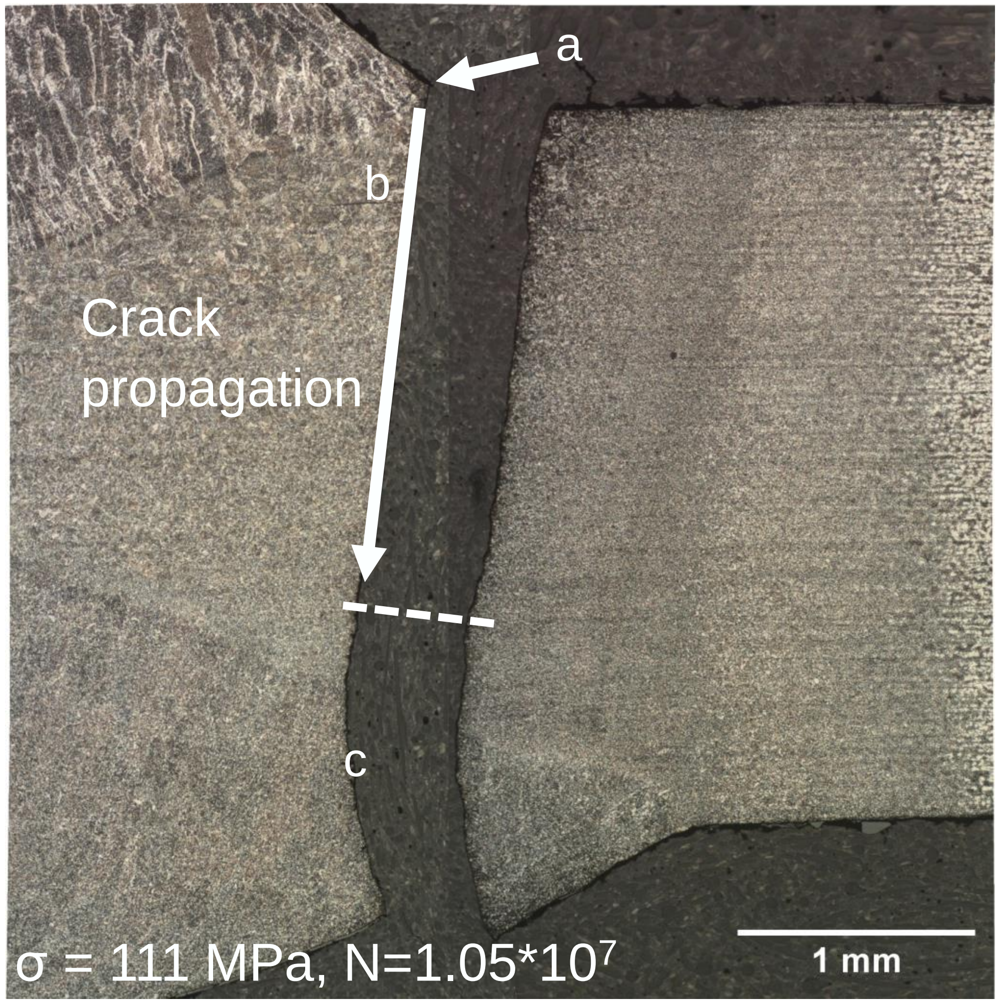
Initiation site



Crack propagation region

Tensile ductile fracture

Fractography



Cross section transverse to fatigue crack
[x50, etched]

a: Crack initiation in fusion zone at weld toe

b: Propagation through inner heat-affected zone

c: Shear lip tensile fracture

Preliminary conclusions

- Novel specimen design successful – slight modification needed
- Fatigue behaviour showed expected trend
- No clear fatigue limit observed

Future work

- Expanded testing regime
- Assessment of frequency effect by comparison to conventional loading

Questions?

University of Strathclyde Engineering