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Fatigue Performance of Proton Irradiated Ti6Al4V Alloy

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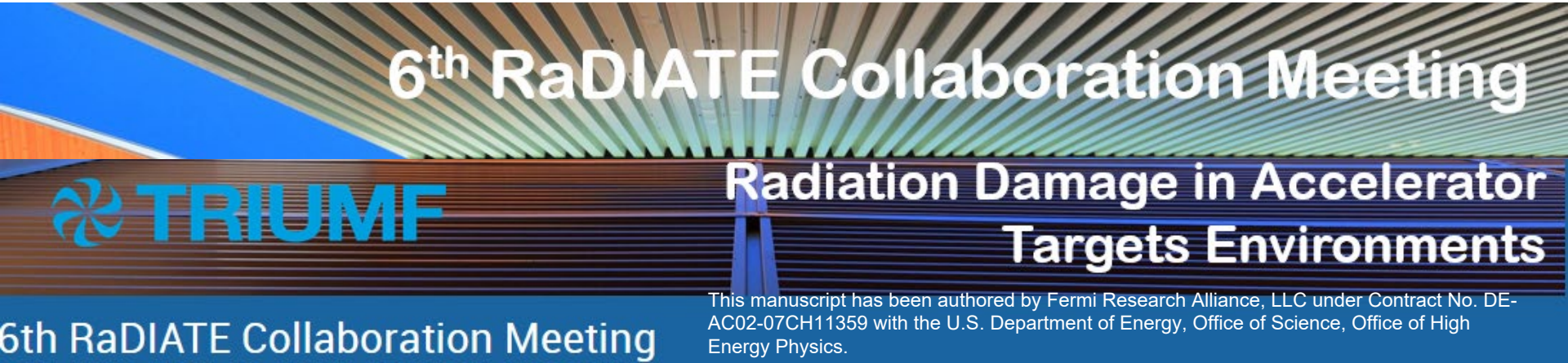
Dec 10, 2019



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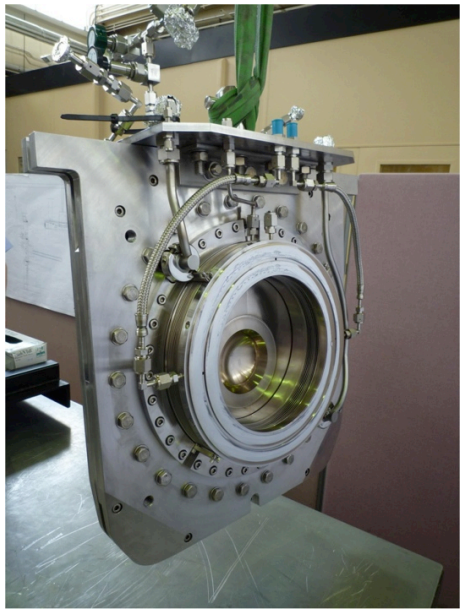
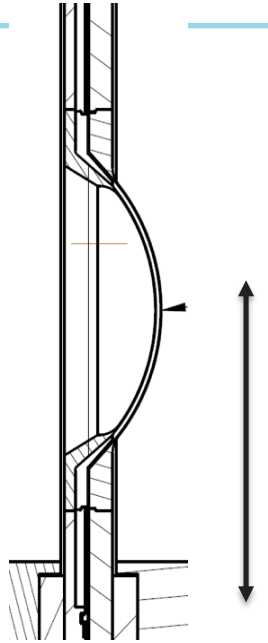
Outline

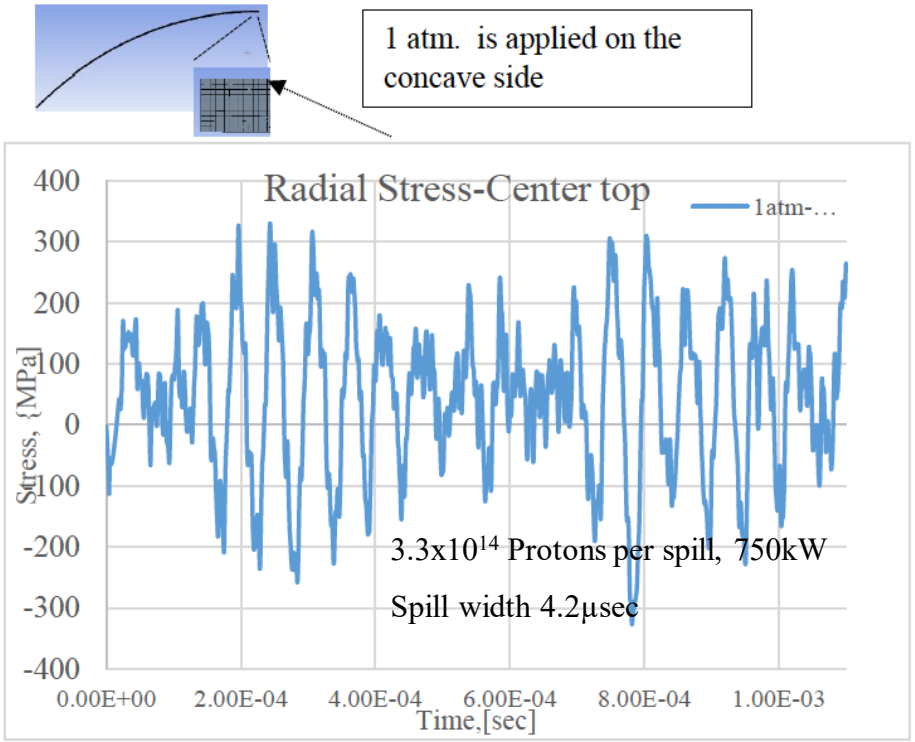
- Background
- Sample preparation
- Custom-made fatigue tester
- Non-irradiated and Irradiate SN Curves
- Summary

Background





T2K window Ti-6Al-4V



Stress wave simulation

Ti-6Al-4V alloys are used in accelerator environment.
Beam Windows are subjected to thermal fatigue load due to pulsed beam

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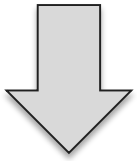
Motivation and Objectives

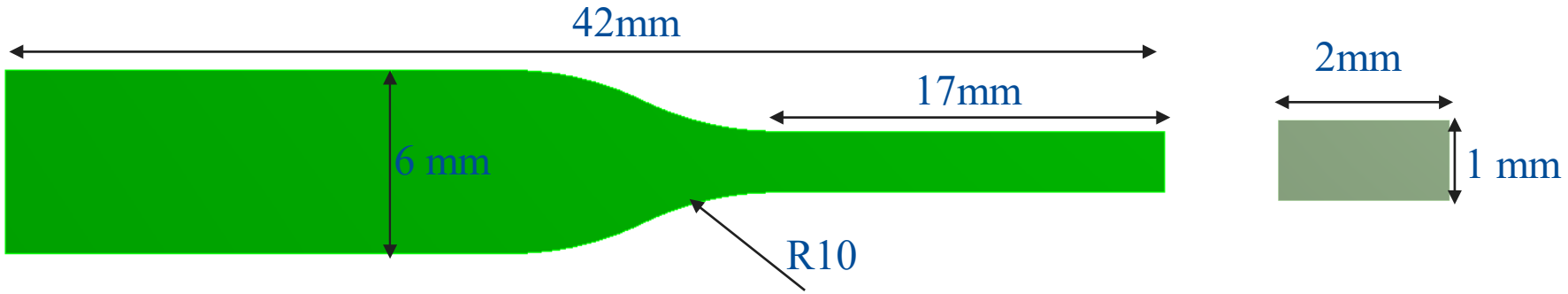
- Irradiation effect on Titanium alloy is sparse – nuclear reactors
- Few fatigue studies with high energy proton irradiation*→low cycle fatigue



- ➢ To estimate high cycle fatigue life of proton-irradiated Ti6Al4V
- ➢ Performance of custom-made fatigue tester

*Marmy & Leguey, PIREX PSI, 2001

Fatigue Sample



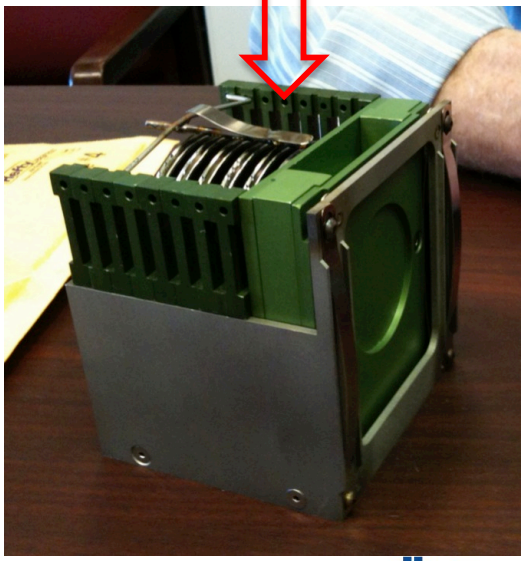
Material : Ti-6Al-4V
Grade 5 : larger β-phase
Grade 23: smaller β -phase, reduced oxygen content, increased fracture toughness and ductility

Young's Modulus : 114 Gpa
Tensile strength : 1045 Mpa (Grade 5), 1000 Mpa (Grade 23)*
Yield stress : 1000 Mpa (Grade 5), 937 Mpa (Grade 23) *

Samples are Wire EDM, grinded and polished

Capsule and Basket -For BLIP Irradiation

Sent to BLIP
BNL



Irradiation:181MeV, for 8 weeks
Only 10 samples could be recovered

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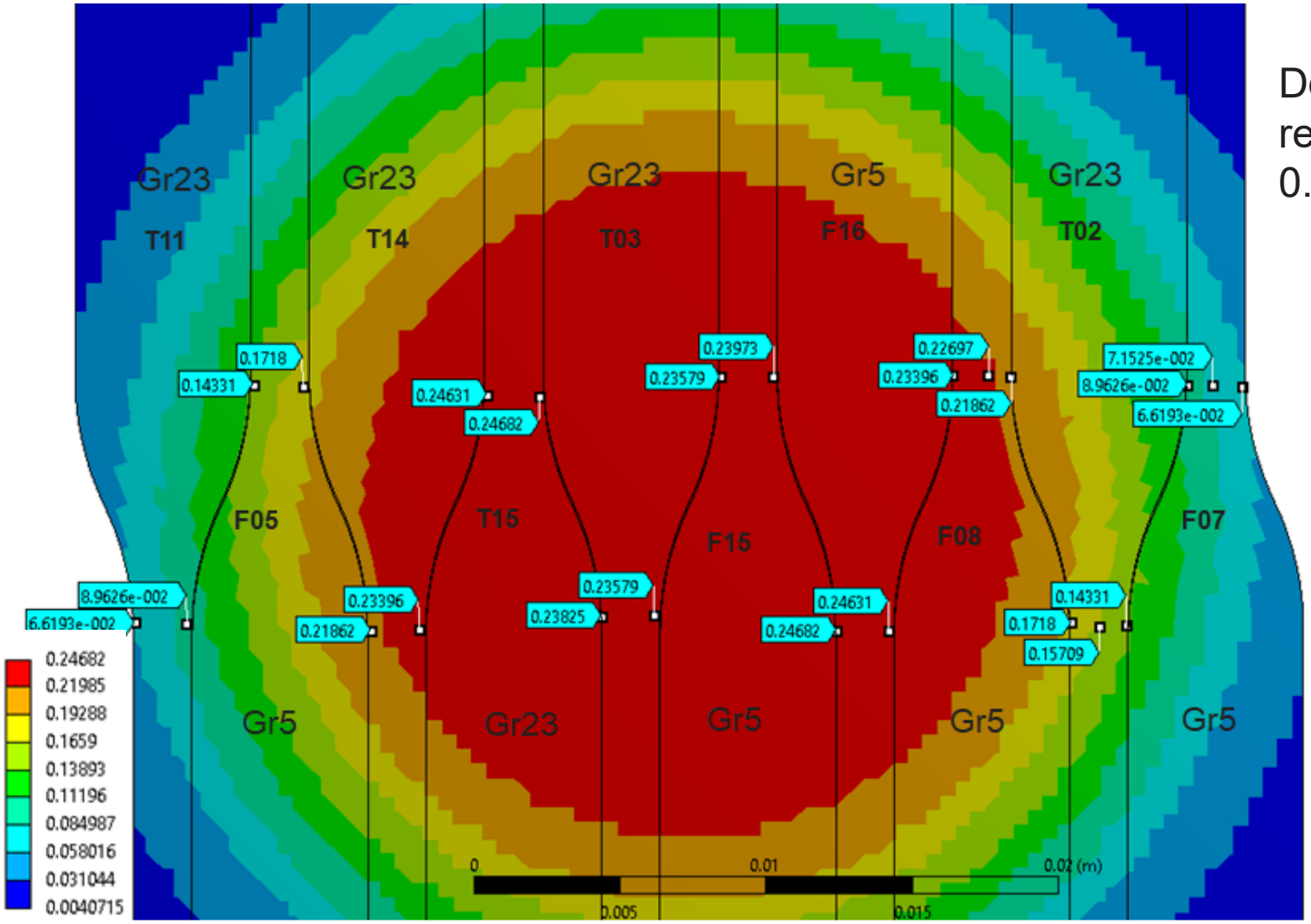
Dose Map



Dose at neck region
0.06~0.24 DPA

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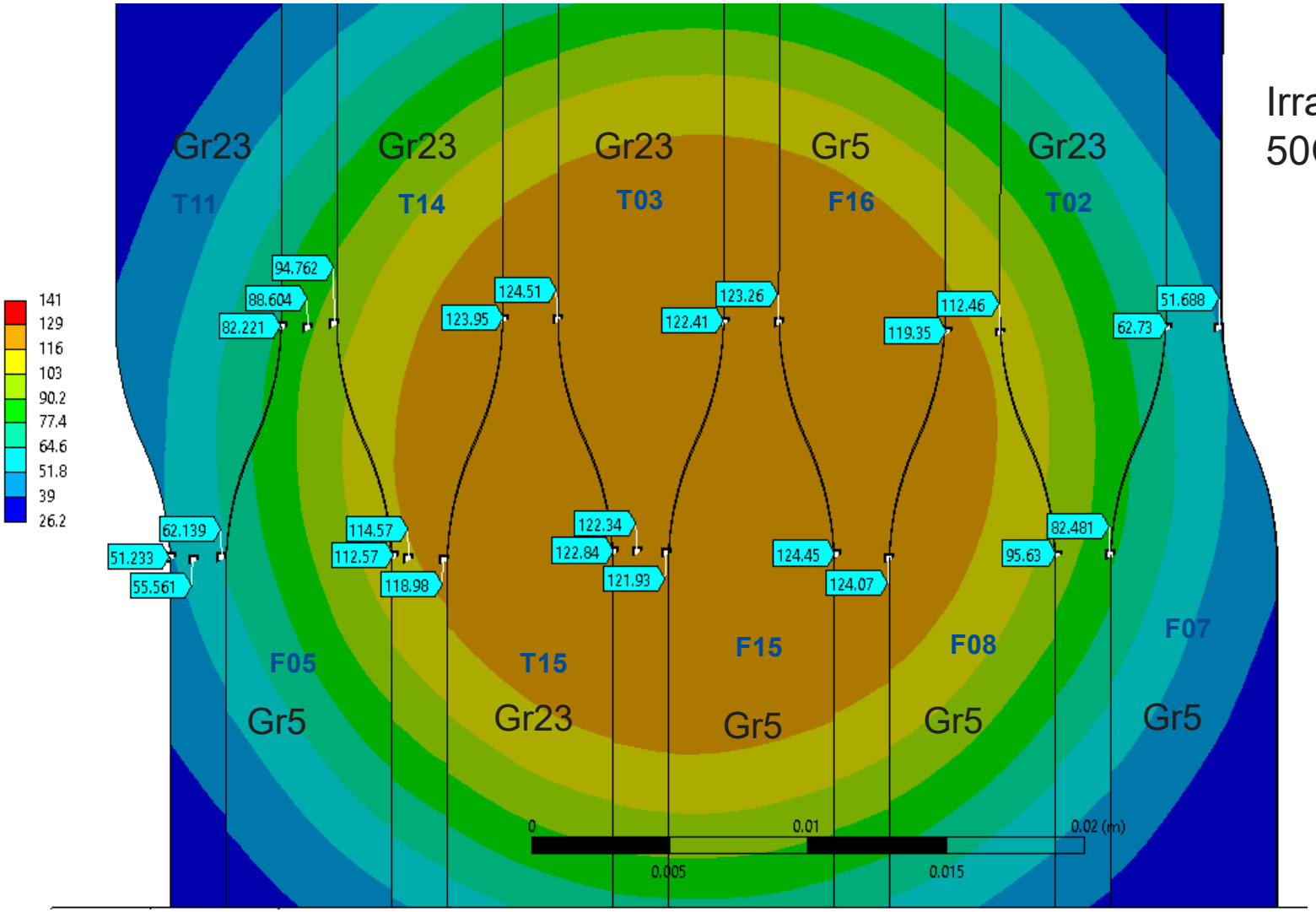
Irradiation Temperature Map



Irradiation temp
50C~125C

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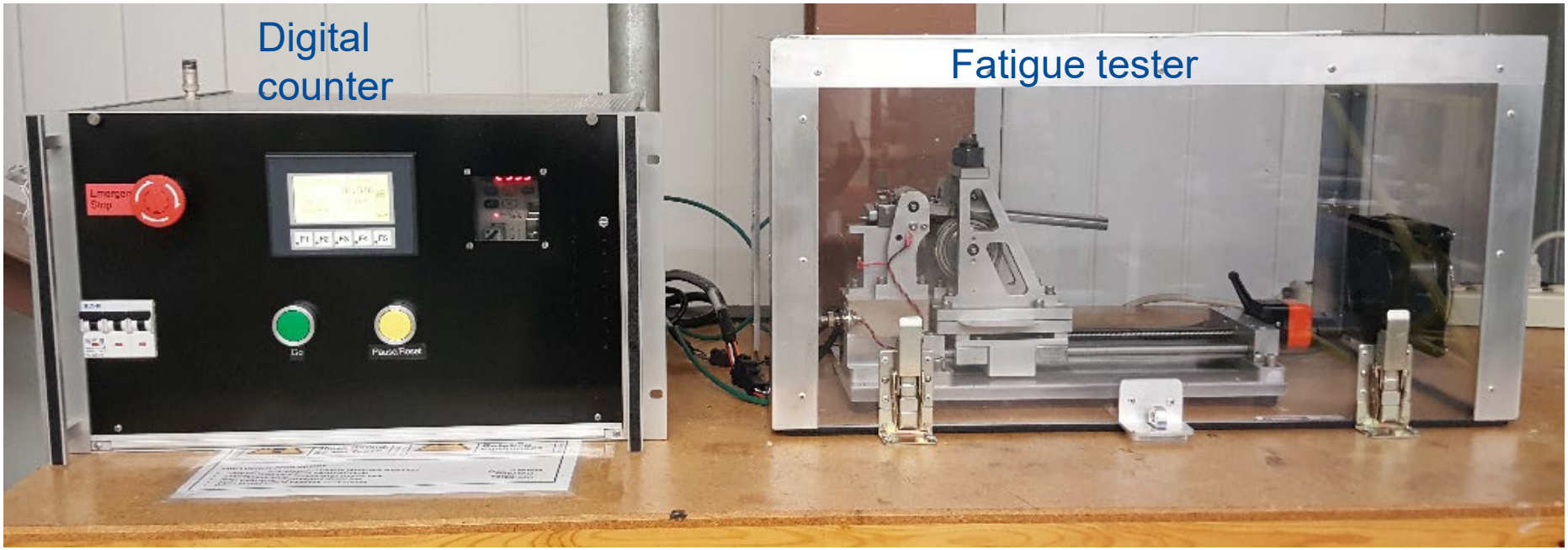
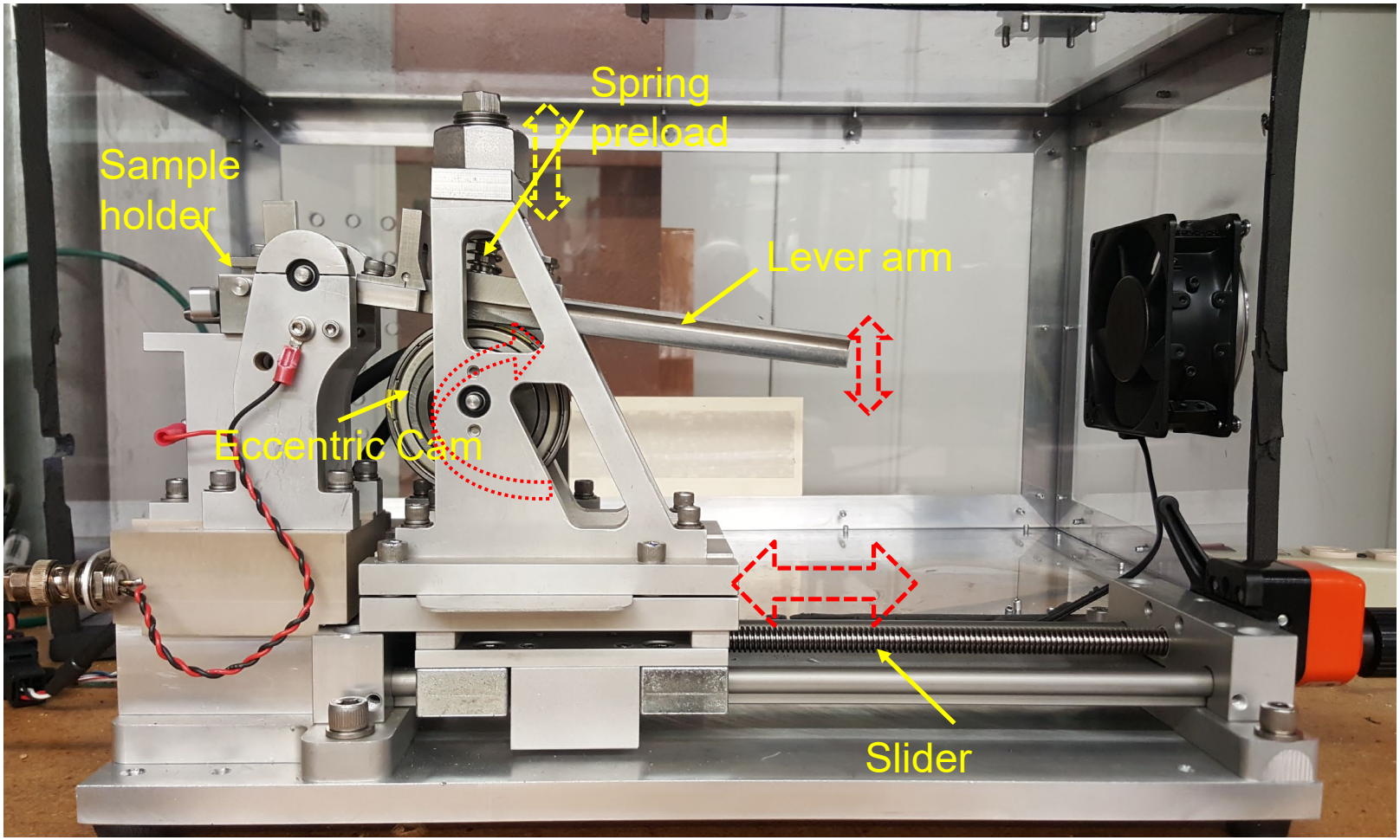
Custom-made Fatigue Tester



Bending Fatigue testing

- Overall size of 300mmX200mmX200mm
- Weight approximately 13lb.
- Cyclic load frequency of 15 Hz
- Stress range of 375MPa - 1250 Mpa
- Automatically stops when sample cracks.

Fatigue Test Machine



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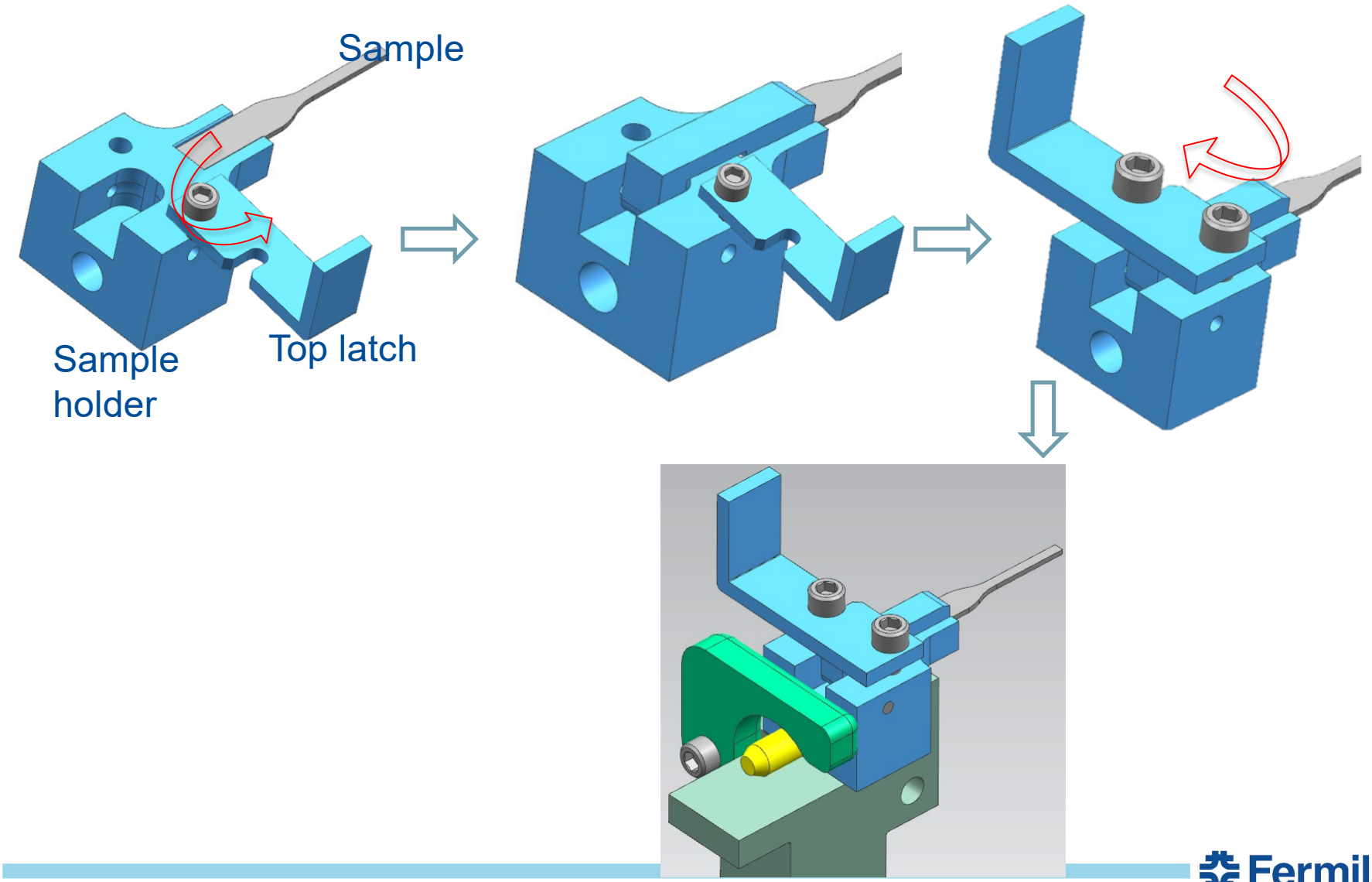
Component– Sample Mounting



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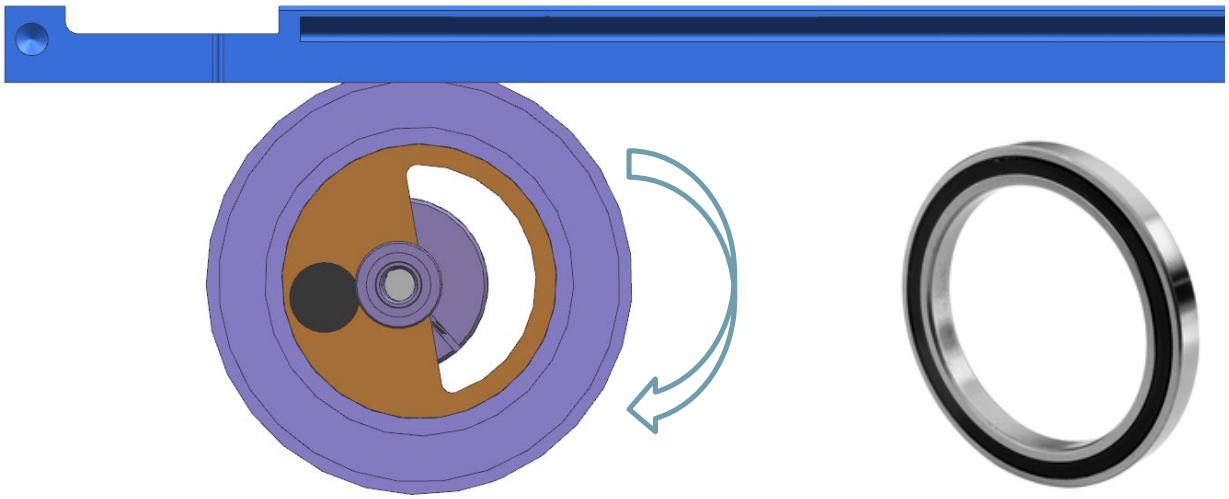
Component– Cam mechanism



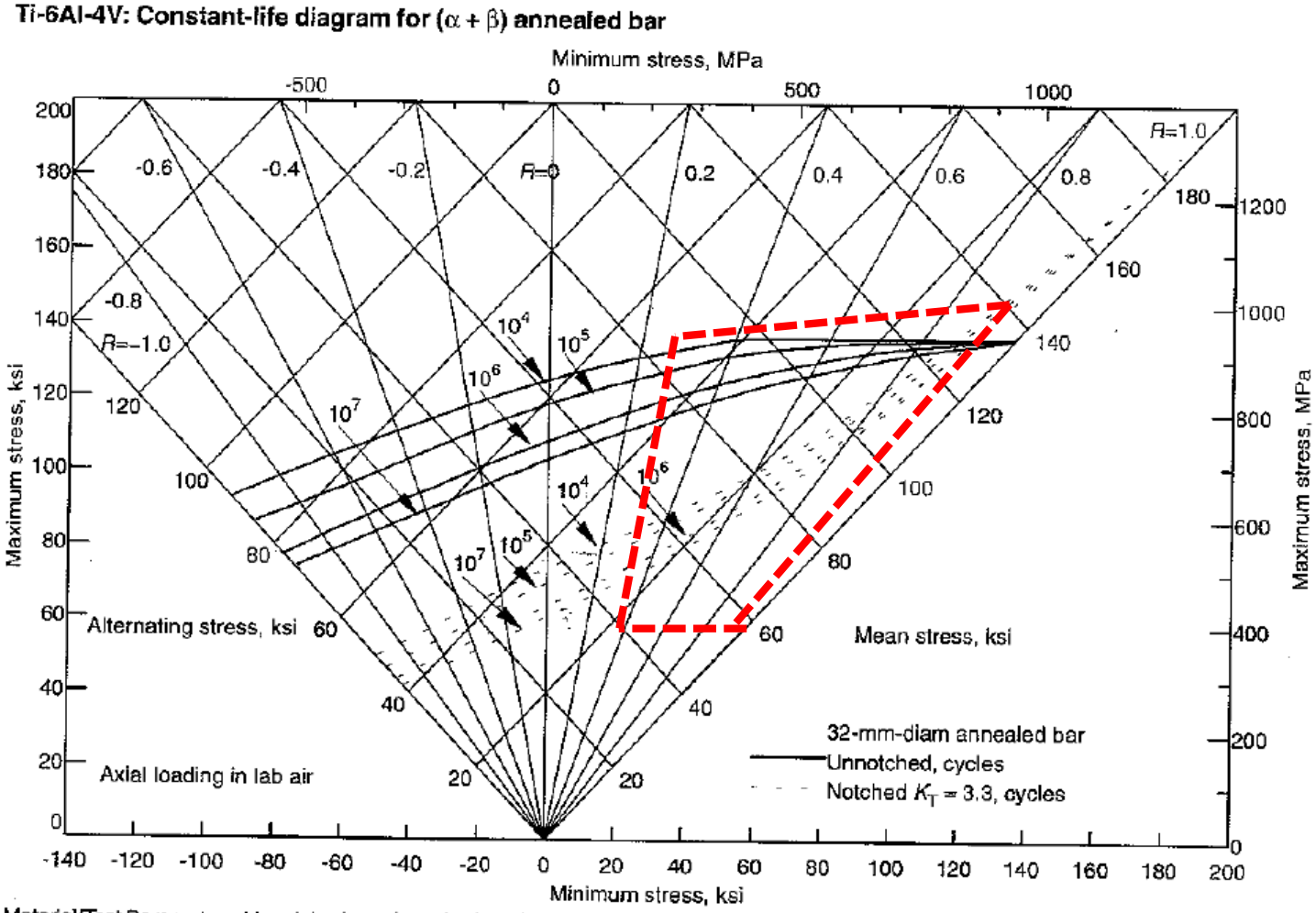
Lever arm

3mm
eccentricity

Deep groove
bearing wrapping
the cam

Outer surface of the bearing is in static contact with lever arm, thus reducing wear

FTM operation range



Material/Test Parameters: Unnotched specimen had a 5.15-mm (0.203-in.) diameter, a tensile strength of 940 MPa (136.5 ksi), and was polished longitudinally with 240, 400, and 600 emery belts. Notched specimen had a gross diameter of 8.4 mm (0.331 in.), a net diameter of 6.4 mm (0.252 in.), and was machined into a V-groove followed by polishing notch root with 600-grit slurry and rotating copper wire. Test frequency: 1750 cycles/min.

Source: R. Wood and R. Favor, *Titanium Alloys Handbook*, MCIC-HB-02, Battelle Columbus Laboratories, p 5-4:72-23

Stress range of 375MPa - 1050 Mpa

Issues >850MPa for lower R(0.2~0.3)

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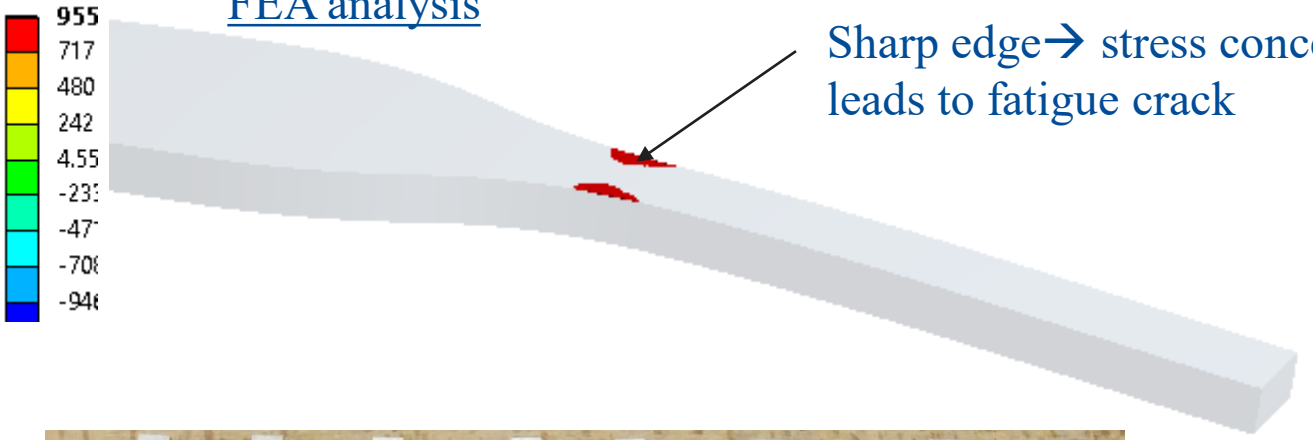
Procedure for stress measurement

1. Strain gaged sample is loaded to Fatigue tester
2. Cam is rotated manually to bend the gaged sample
3. Multiple Strain readings are noted at the lowest and highest cam vertical position
4. Use the slider to adjust maximum stress and stress ratio.
5. Remove the strain gaged sample. Load the real sample and start the fatigue test.

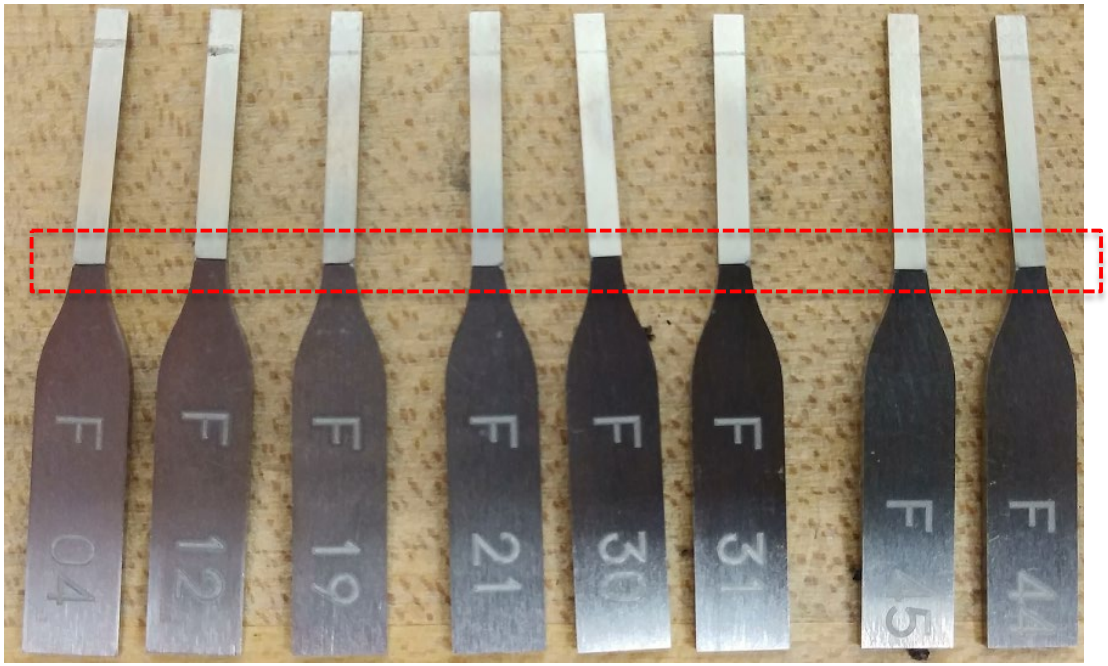
There is 2~3% error in measurement

Fatigue Crack Initiation

FEA analysis



Sharp edge→ stress concentration leads to fatigue crack



Crack occurring at same location in all specimen

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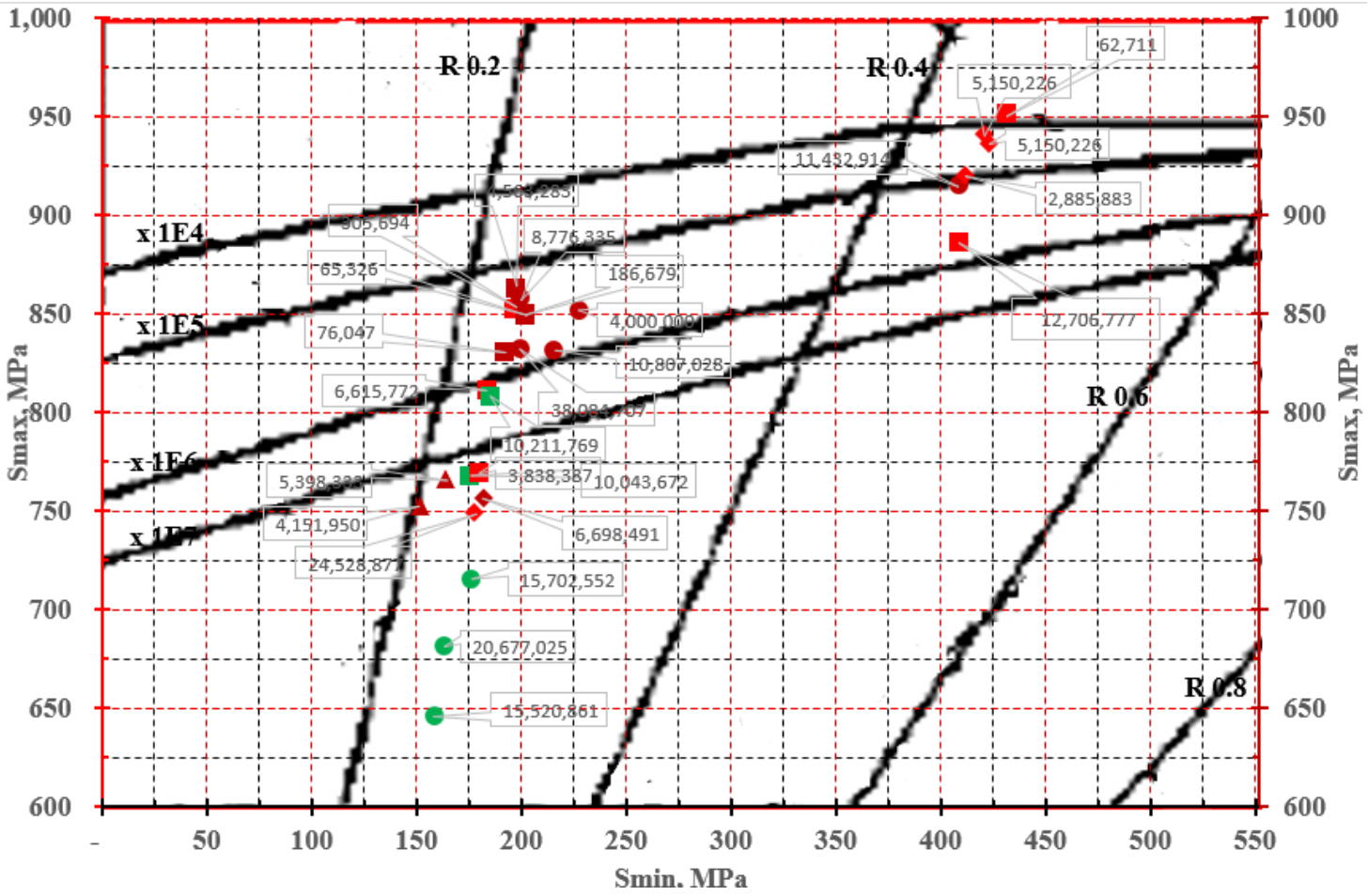
Fatigue life-Non Irradiated samples



Fatigue life shifted by order of magnitude with respect to Hand book Data

- Effect of surface finish

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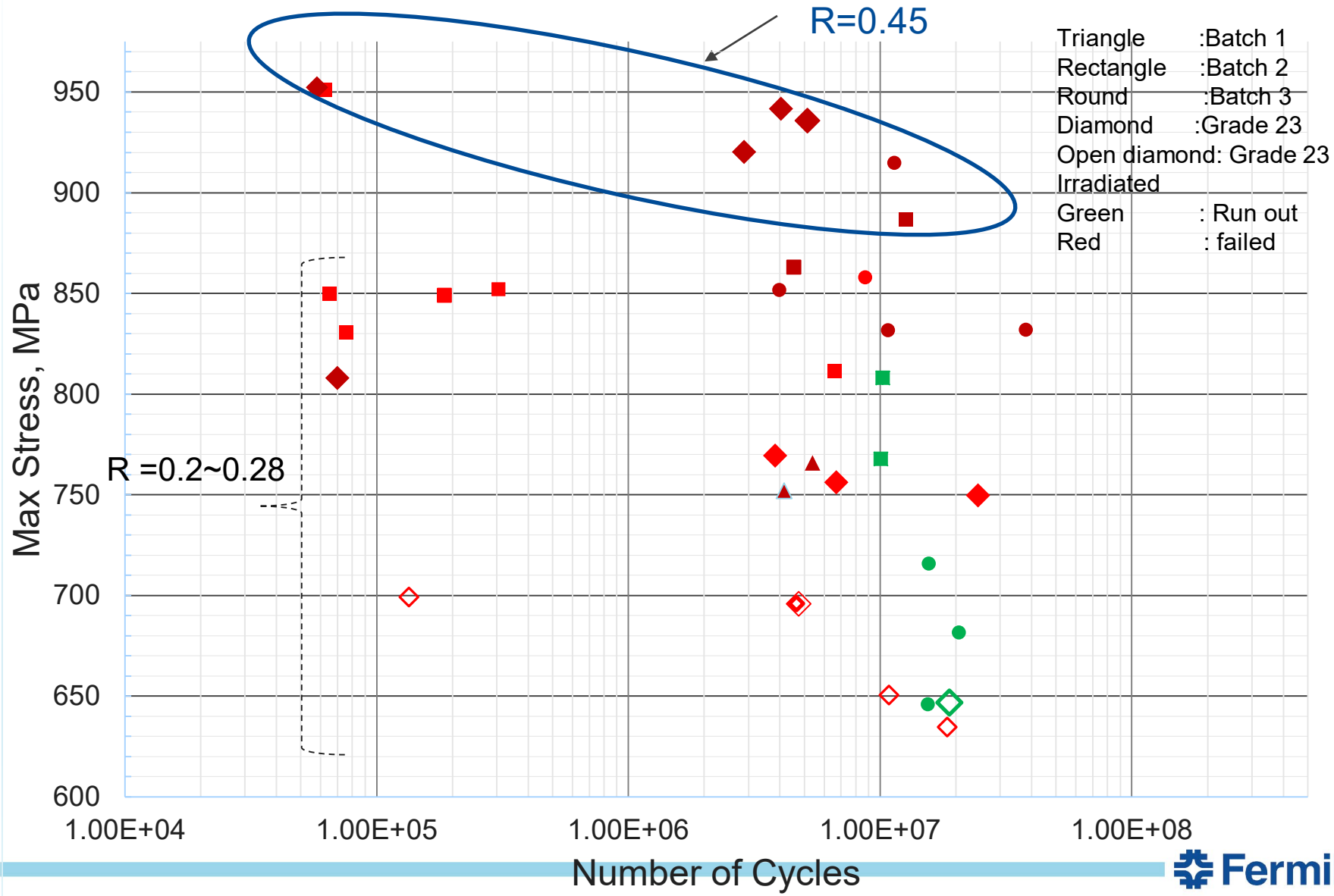
SN Curve- all specimen



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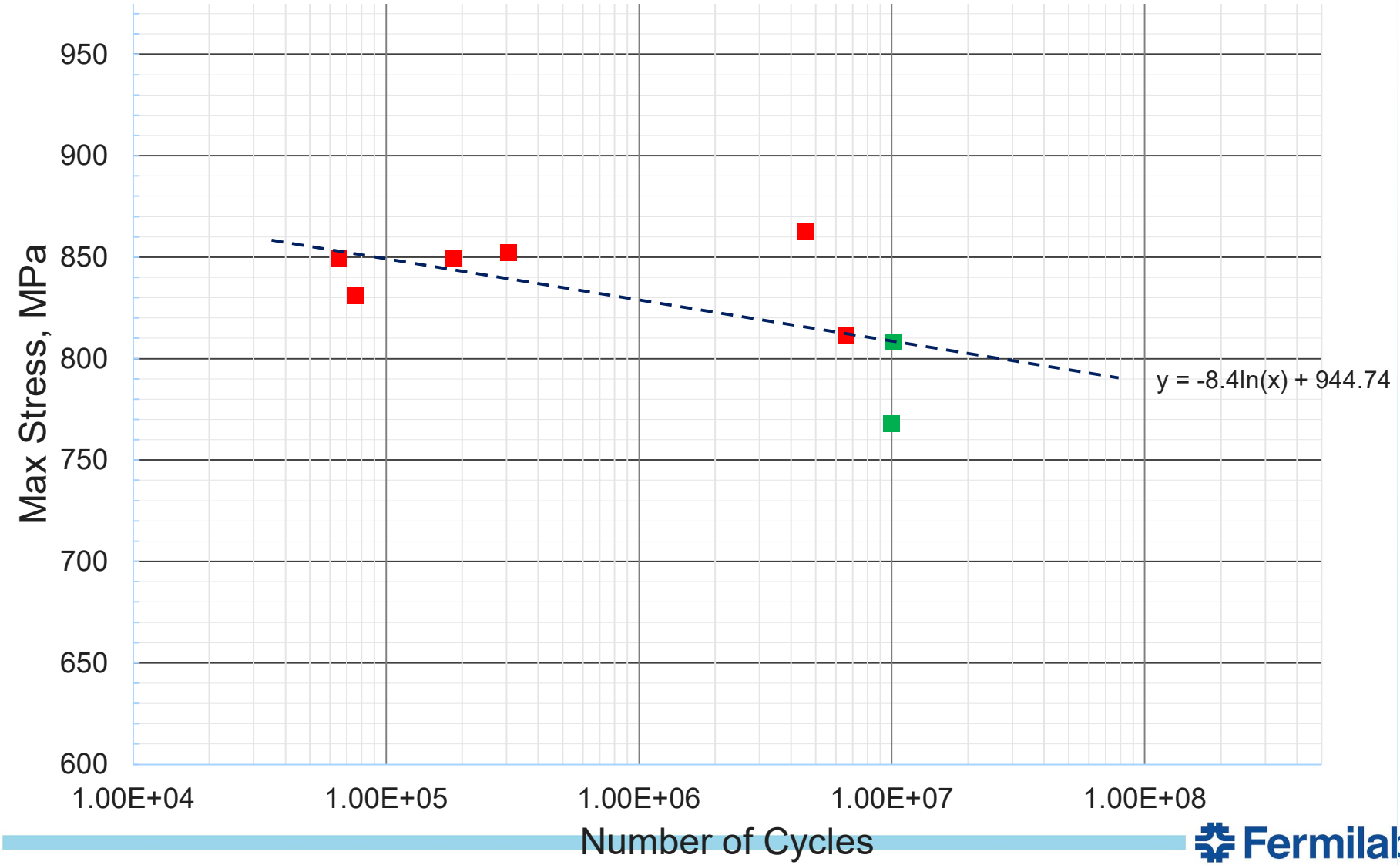
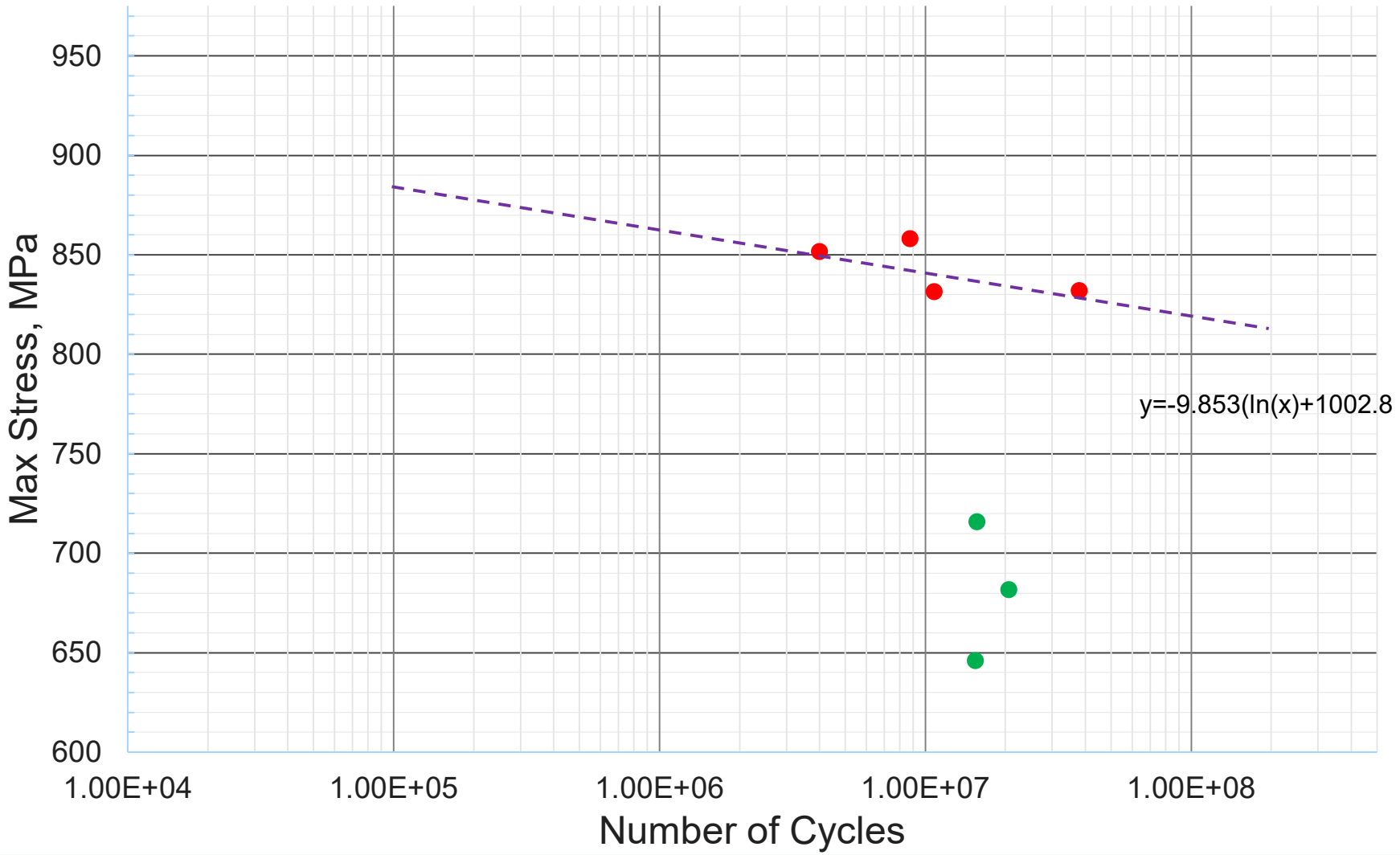
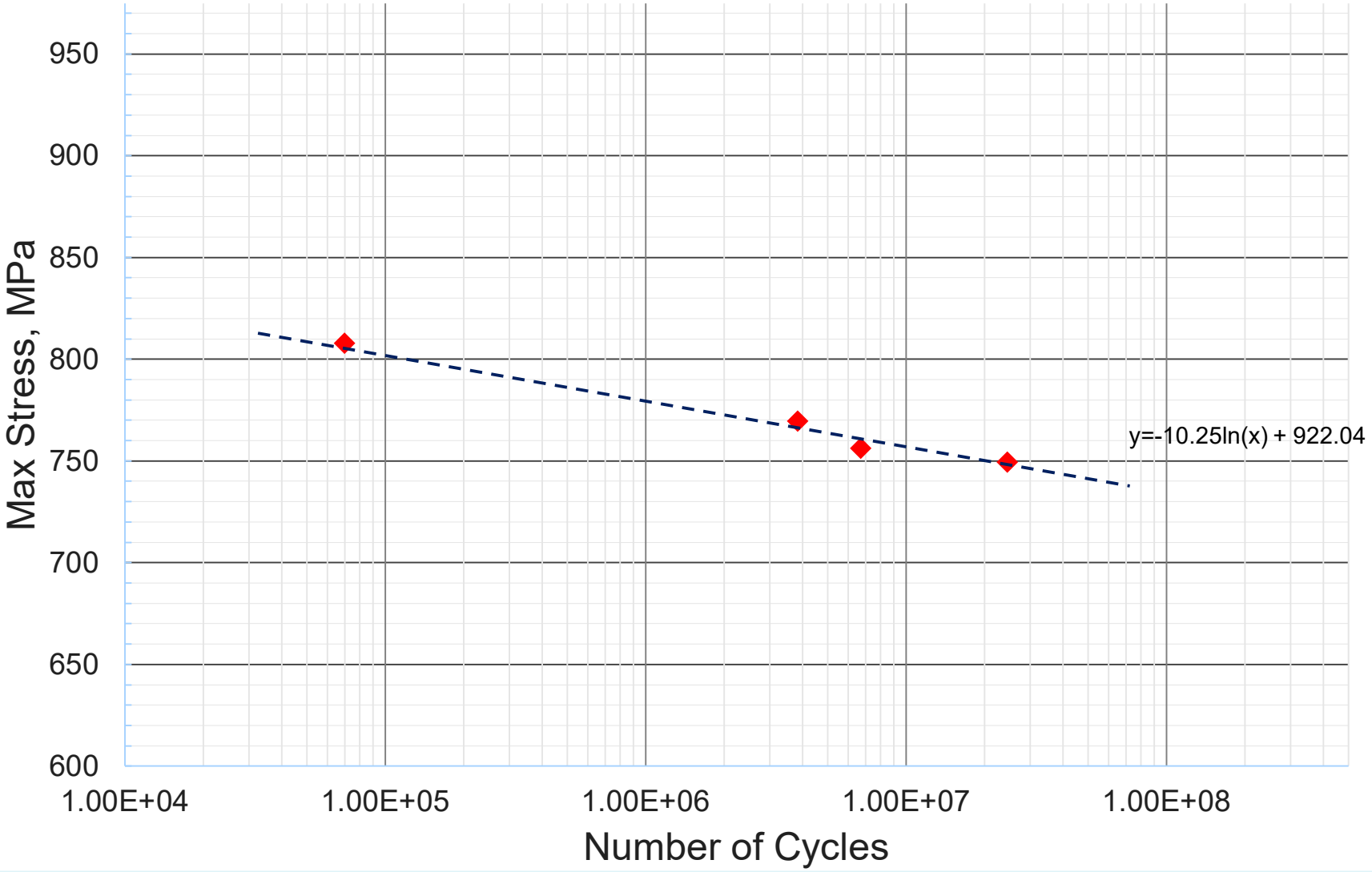
SN Curve- Grade 5 Batch 2



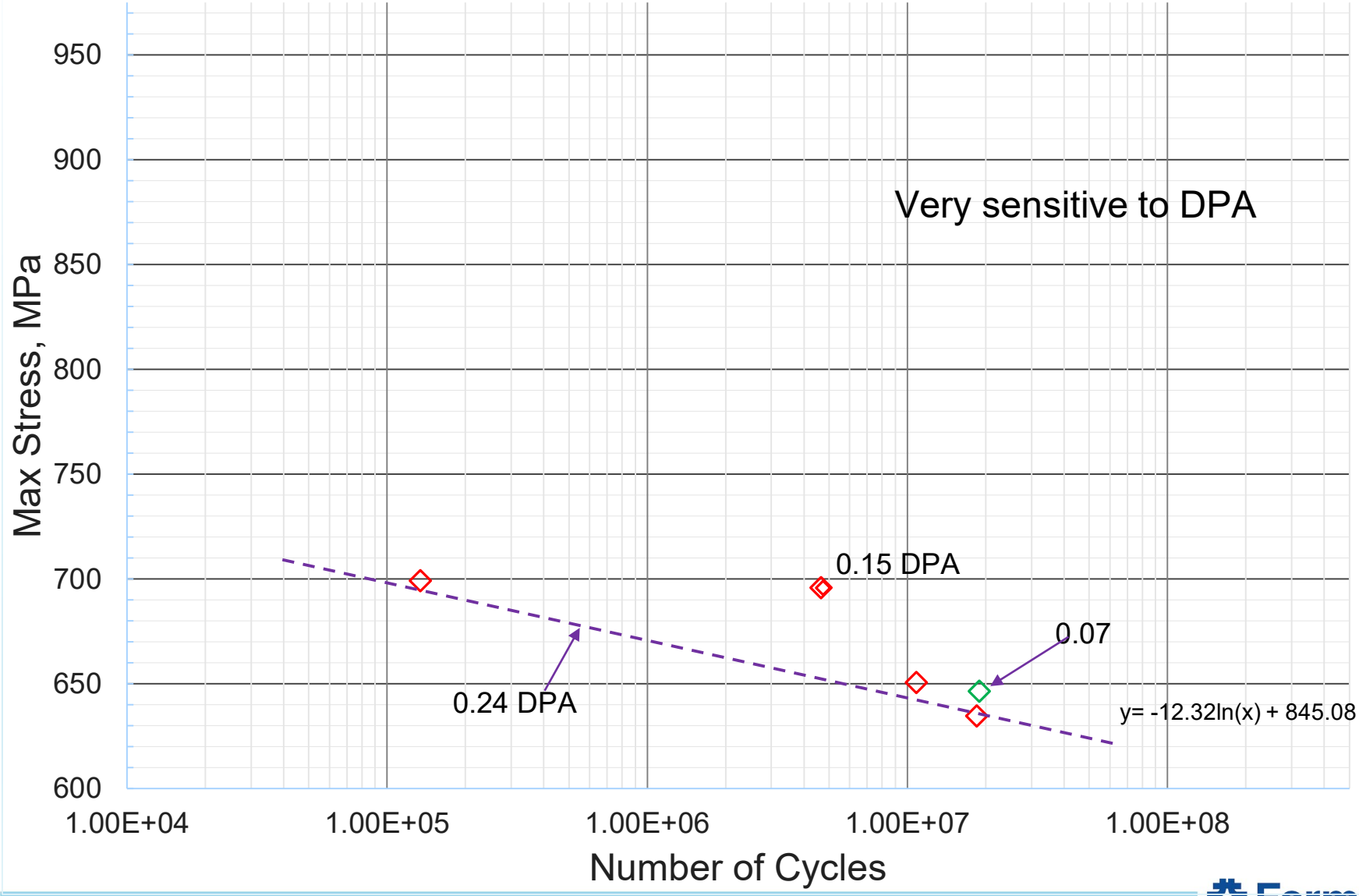
SN Curve- Grade 5 Batch 3



SN Curve- Grade 23



SN Curve- Grade 23 Irradiated



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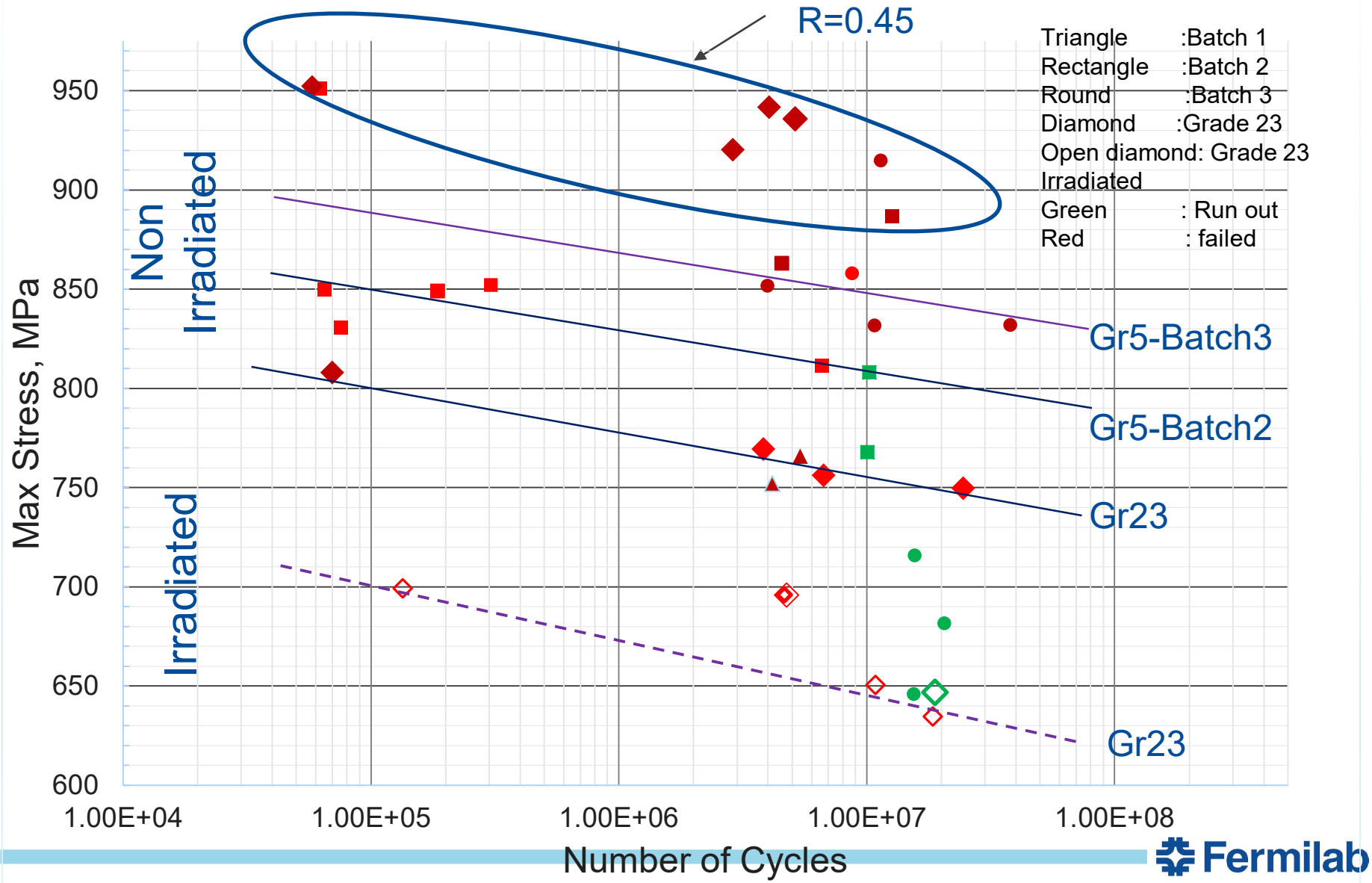
SN Curve- all specimen



Discussion

Curve fitting to fatigue data

y =	-8.4 ln(x)	+ 945	Grade 5, Batch 2	Non-Irradiated Room temperature
y=	-9.85 ln(x)	+ 1003	Grade 5, Batch 3	
y=	-10.25 ln(x)	+ 922	Grade 23	
y=	-12.32 ln(x)	+ 845	Grade 23, Irradiated (125C Irradiation temp)	

Similar slope

Yield strength

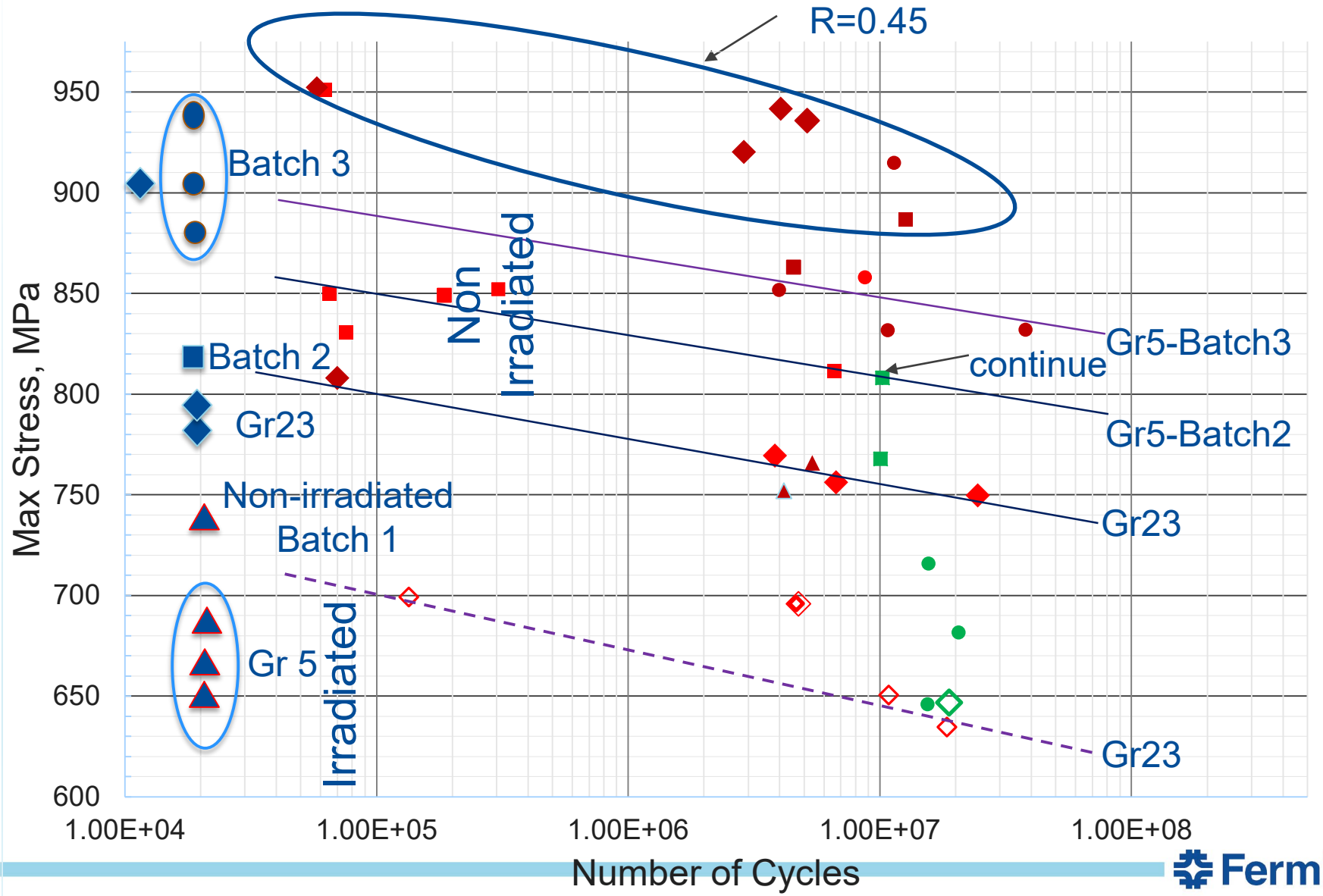
SN Curve failure strength prediction close to vendor's data
→ Custom-made Fatigue tester data are reasonable

Fatigue life(>10million cycles)
Gr5_Batch3(830)>Gr5_Batch2(800)>Gr5_Batch1=Gr23(750)
>Irradiated_Gr23 (635)

Specimen inventory

			Tested	Available
Non Irradiated	Grade 5	Batch 1	2	1
		Batch 2	10	1
		Batch 3	8	3
	Grade23		8	4
Irradiated	Grade 5		1	4
	Grade 23		5	0
Total			34	13

Future Schedule



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Summary

- Upgraded custom-made fatigue test machine works satisfactorily → variable R, stress range 350~1050MPa
- Fatigue life variation within Grade5 for different batches
- Gr5_Batch3(830)>Gr5_Batch2(800)>Gr5_Batch1=Gr23(750) >Irradiated_Gr23 (635)
- Fatigue life sensitive to DPA within same grade

Further work

- Continue testing irradiated Grade 5 and left over non-irradiated samples.
- Fractography of fracture surface
- R=-1 Design