Universidad del País Vasco / Euskal Herriko Unibertsitatea

ERASMUS +

IESRES

INNOVATIVE EUROPEAN STUDIES ON RENEWABLE ENERGY SYSTEMS

02-06 OCTOBER 2017

VITORIA-GASTEIZ -SPAIN

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TESTING MATERIALS FOR RENEWABLE ENERGY APPLICATIONS

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Spain

BACKGROUND: RENEWABLE ENERGIES, SUSTAINABILITY

DELAMINATION TESTING: composites for wind turbine blade materials

MECHANICAL TESTING: performance of PLA vs PLA+carbon fiber

SUMMARY AND CONCLUSION

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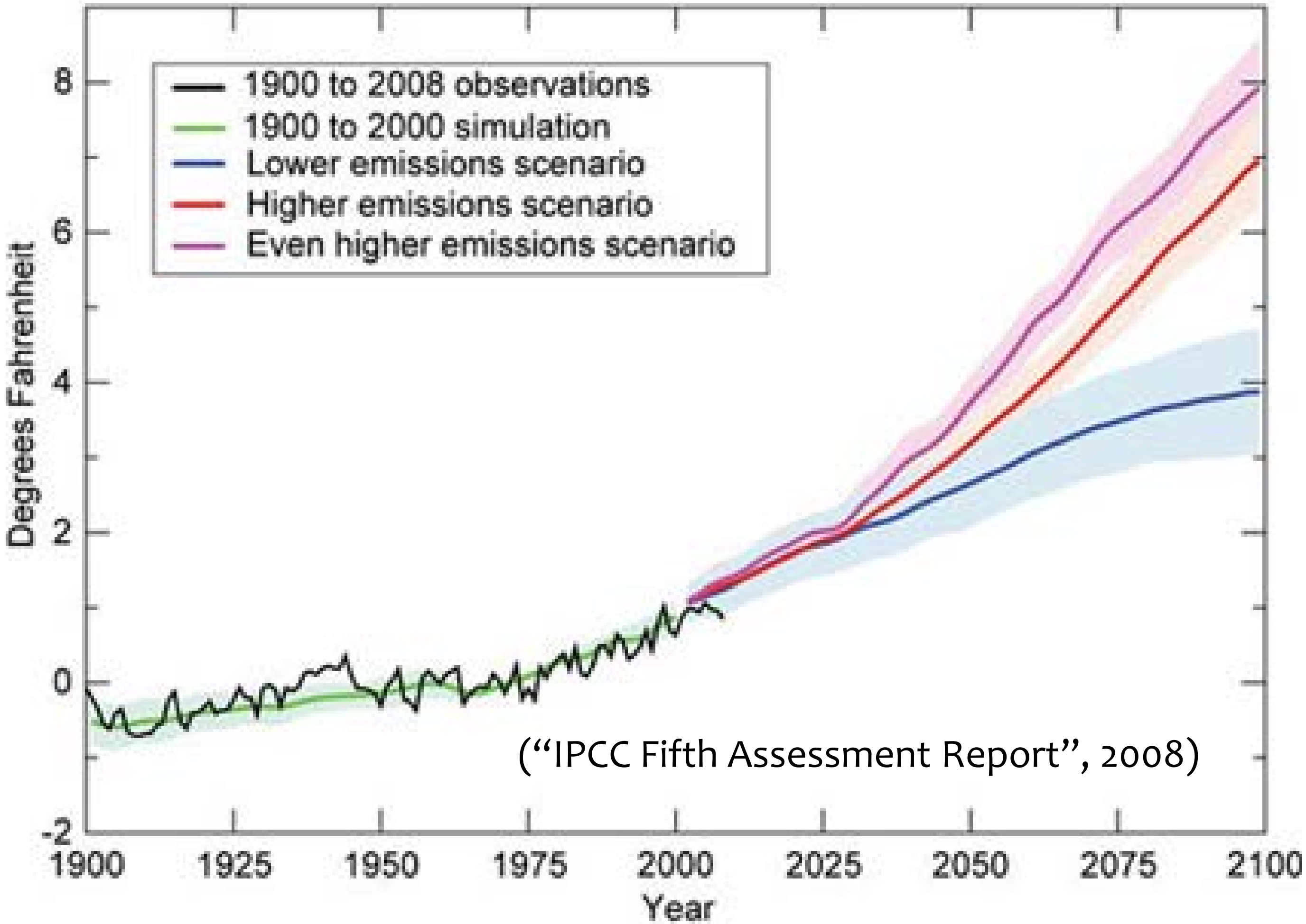
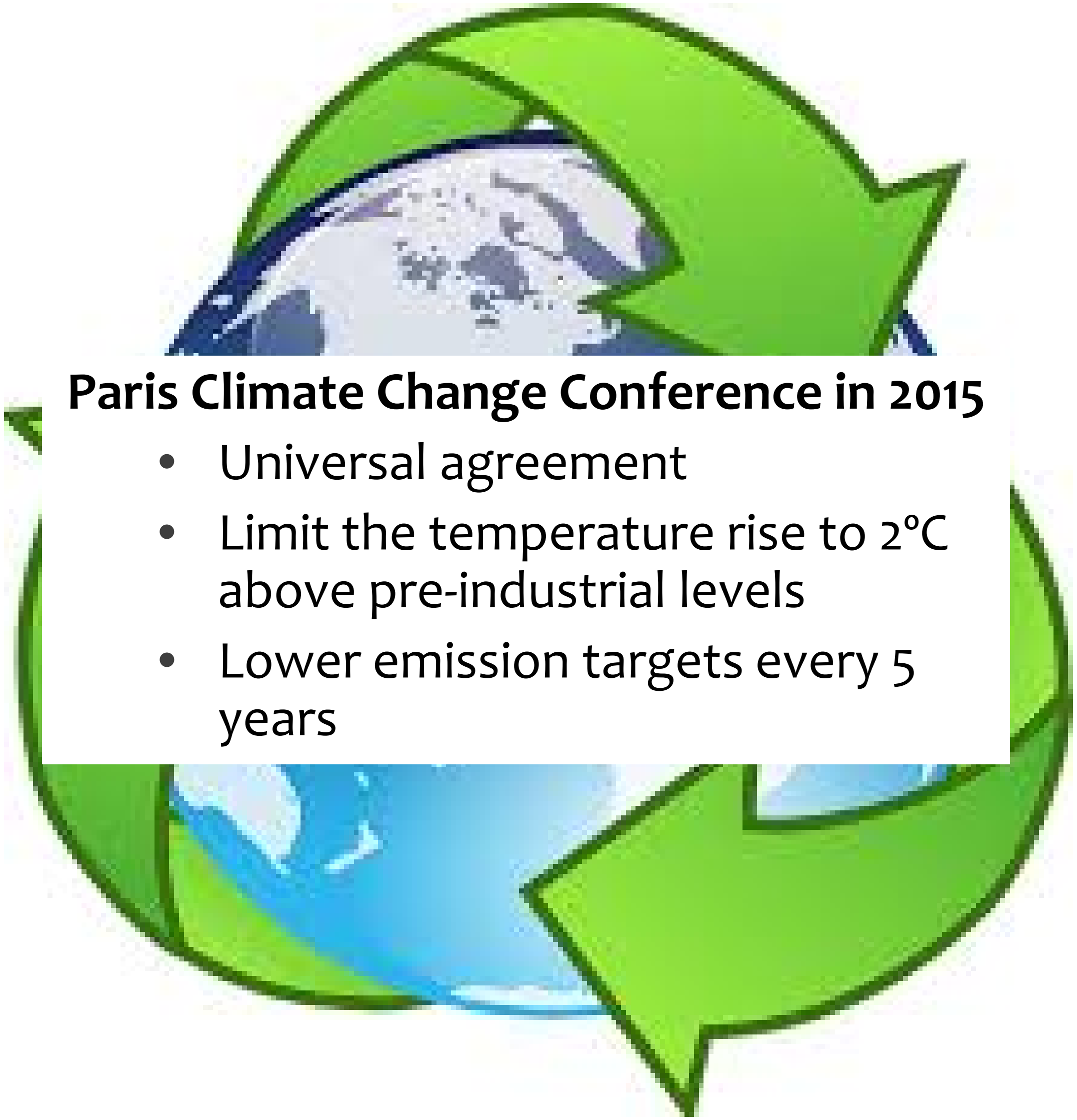


EROI
(Energy Returned on Energy Invested)

LCA
(Life Cycle Assessment)

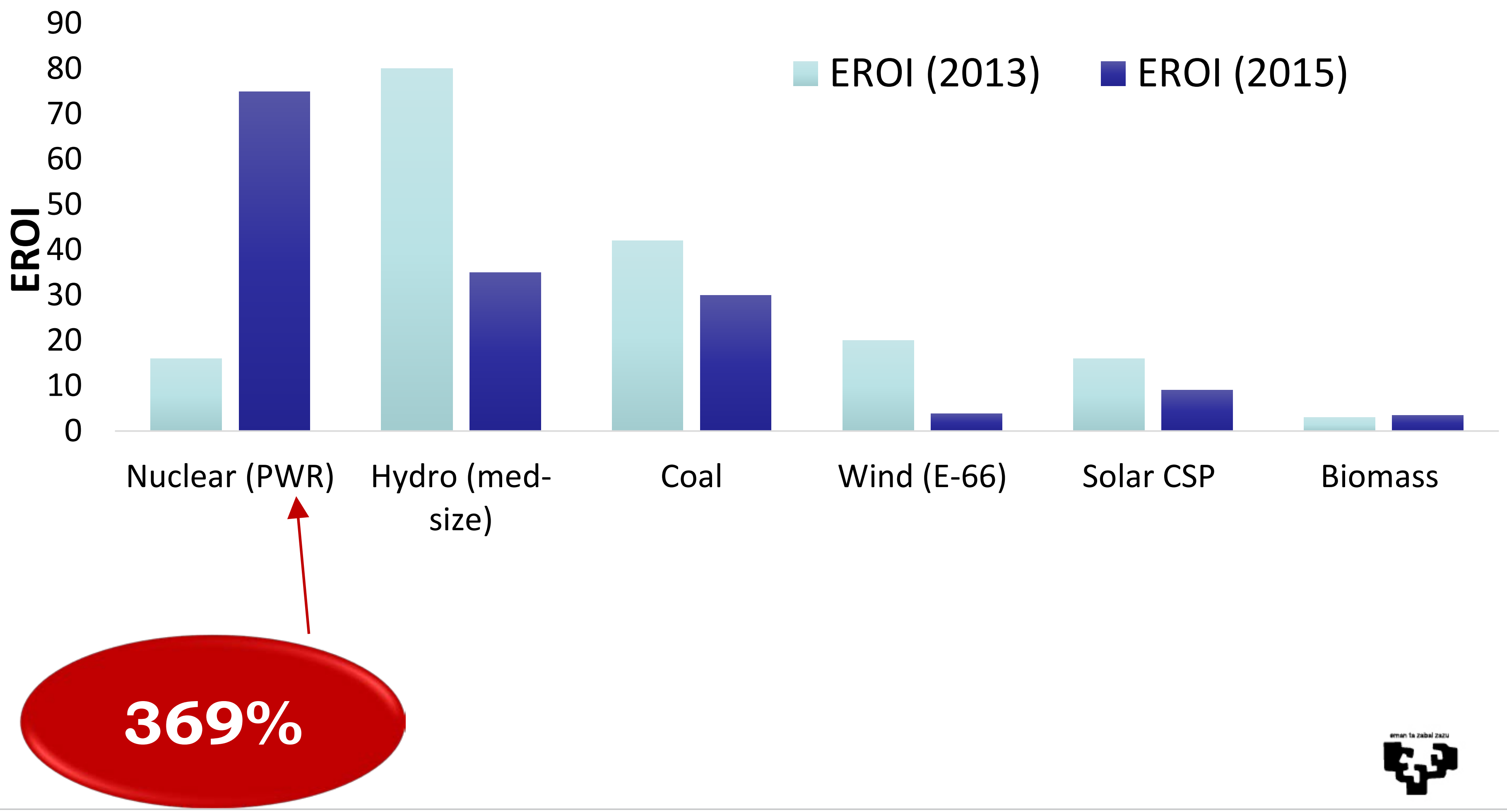


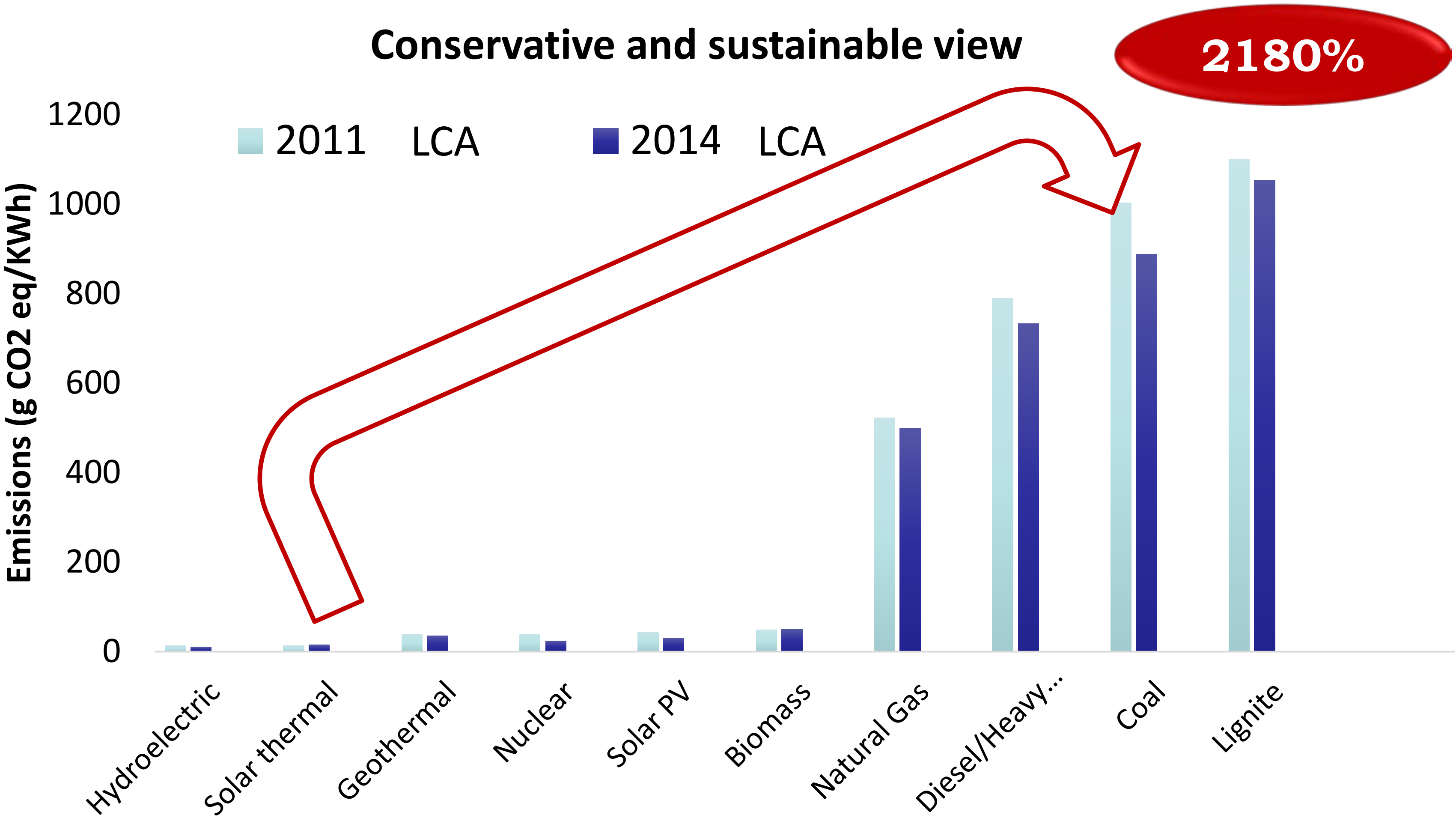
Paris Climate Change Conference in 2015

- Universal agreement
- Limit the temperature rise to 2°C above pre-industrial levels
- Lower emission targets every 5 years

shift to renewable energies

"Business as usual" and sustainable view




Conservative and sustainable view
2180%
2011 LCA
2014 LCA
Emissions (g CO2 eq/KWh)
1200
1000
800
600
400
200
0
Hydroelectric
Solar thermal
Geothermal
Nuclear
Solar PV
Biomass
Natural Gas
Diesel/Heavy…
Coal
Lignite

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SUMMARY AND CONCLUSION

Picture taken from: https://www.mitchelltech.edu

Picture from geograph.org.uk Author David Dixon /

DESIGN OF WIND TURBINE BLADES

Structural configuration

Material selection

Picture from: http://www.compositestoday.com/category/green-composites/wind-energy-green-composites/


BLADES
mass

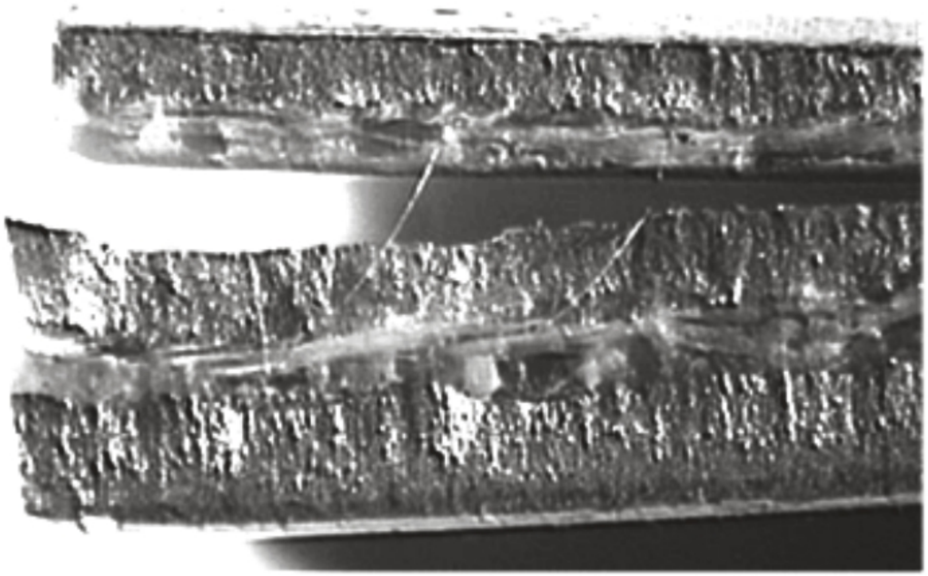
MECHANISMS OF FAILURE IN COMPOSITE MATERIALS

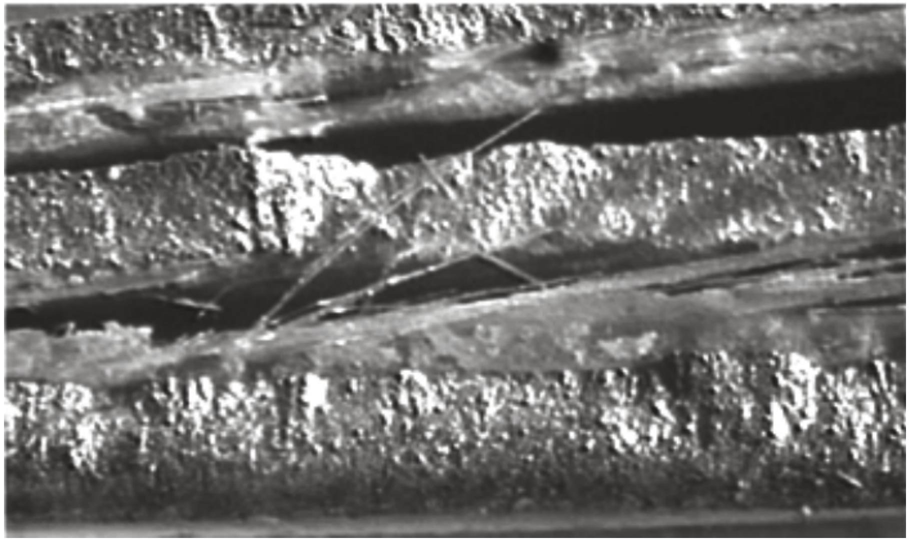
Main failure modes in COMPOSITE LAMINATES

- Fibre failure
- Matrix failure
- Fibre-matrix debonding
- Inter-laminar failure (delamination)
- Buckling instability

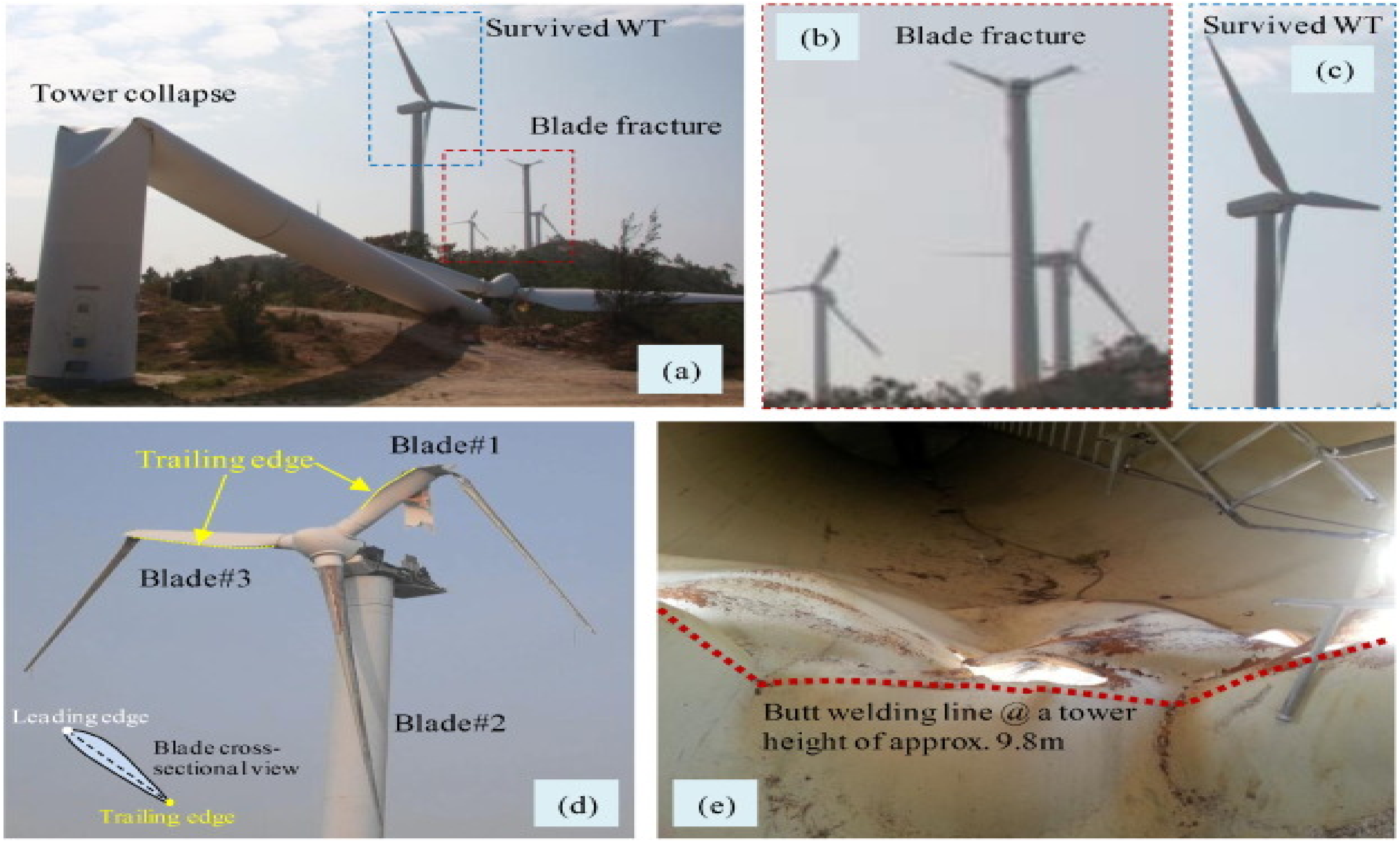
MECHANISMS OF FAILURE IN COMPOSITE MATERIALS

- Inter-laminar failure **Delamination**



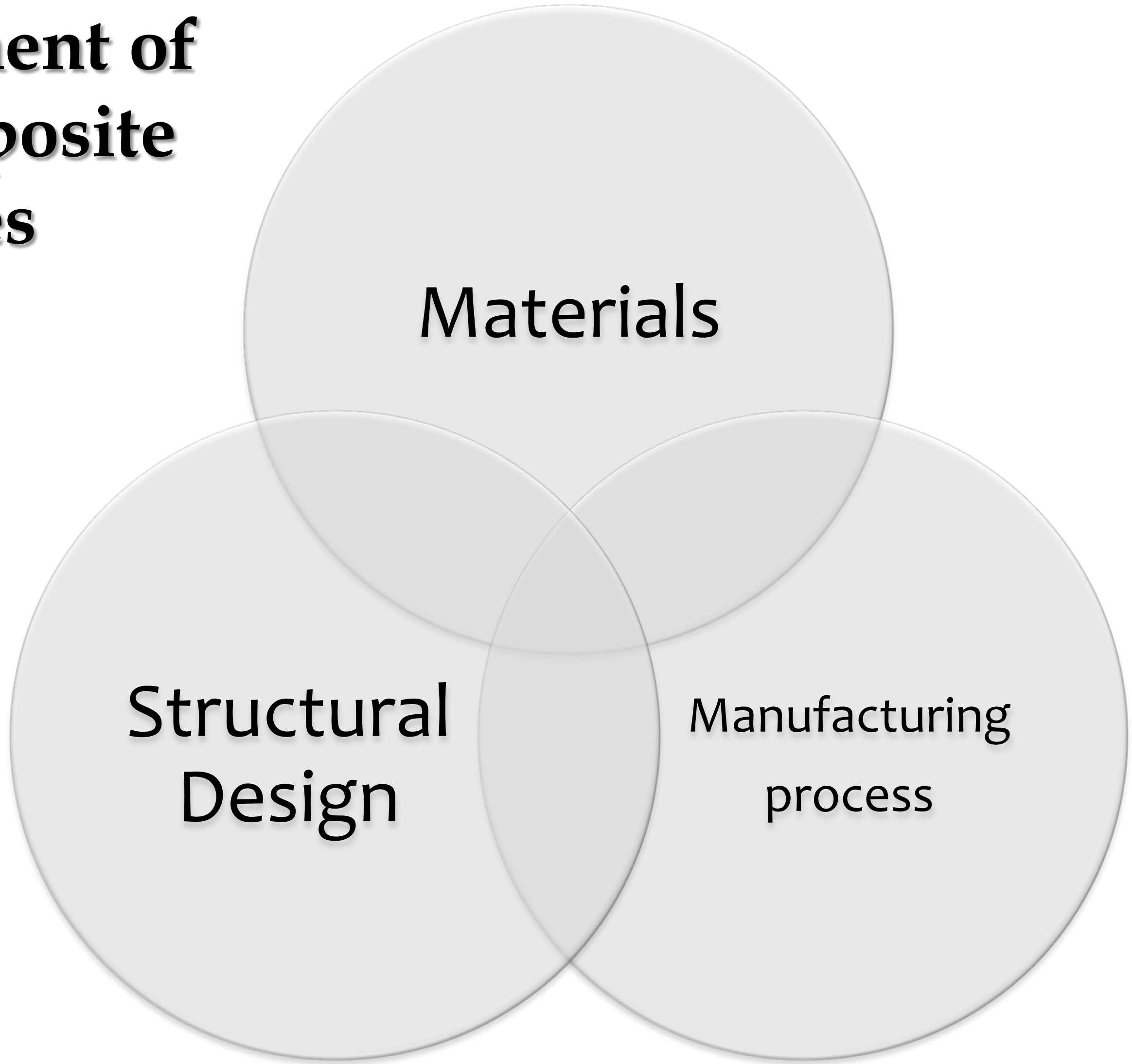


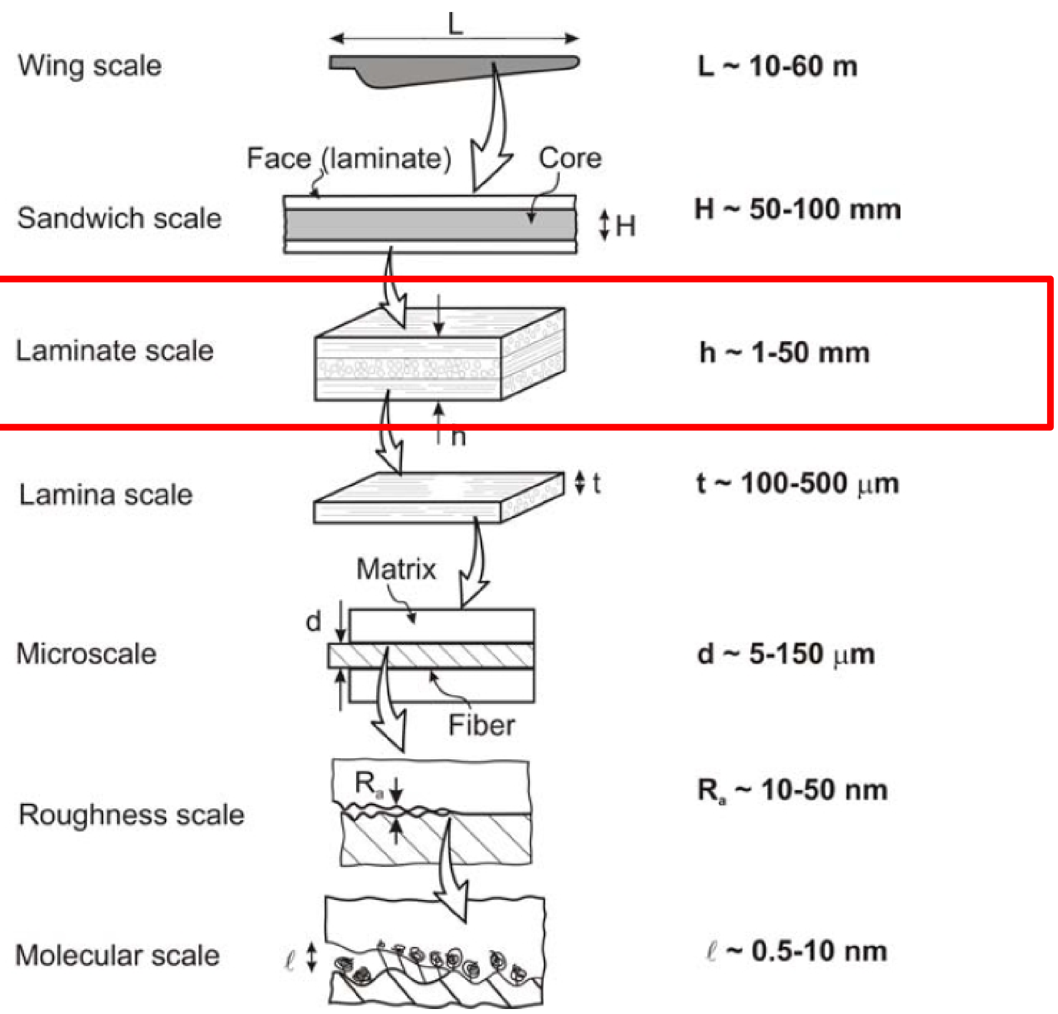
MECHANISMS OF FAILURE IN COMPOSITE MATERIALS



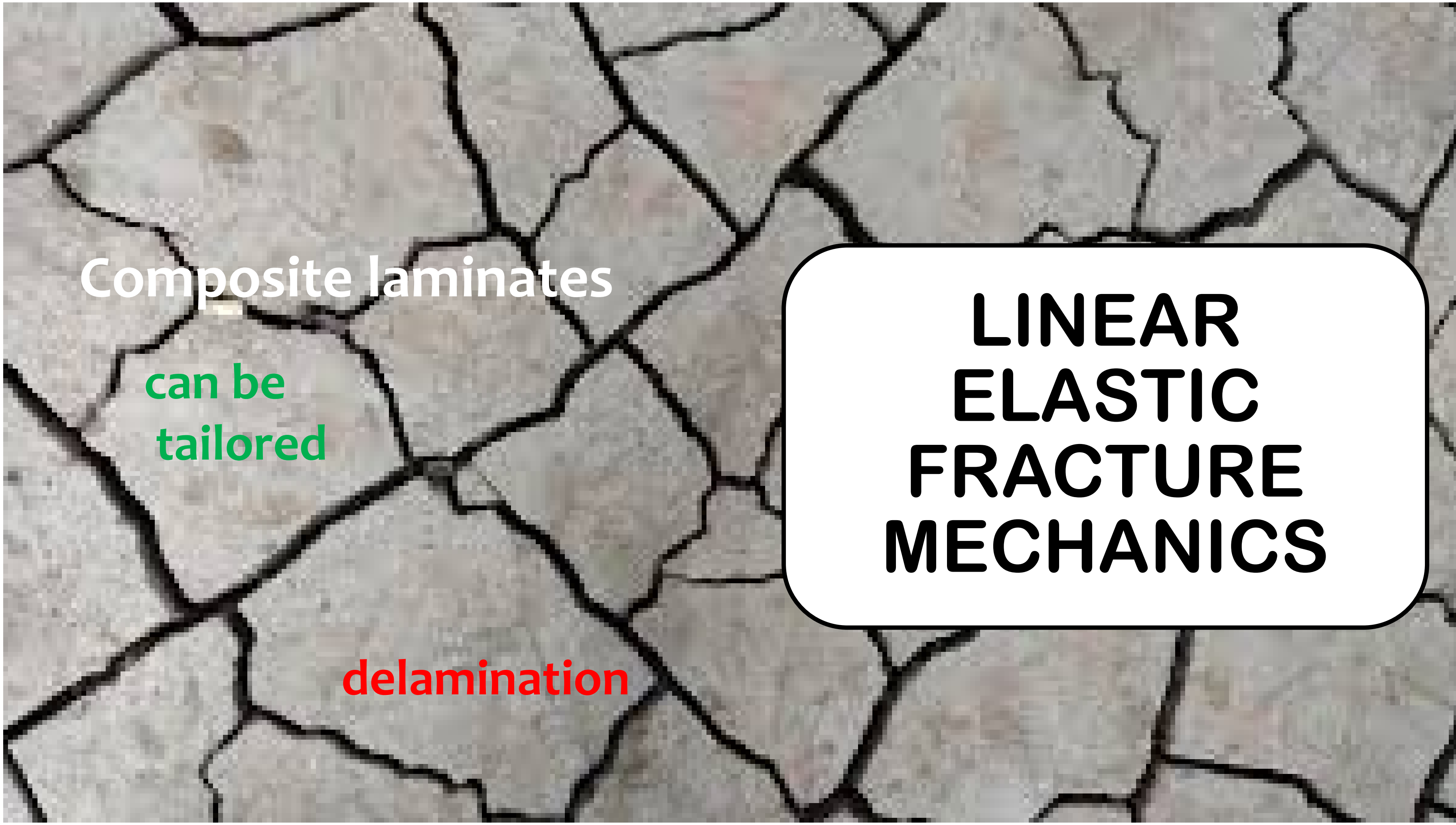
Chen X., Xu J.Z.: Structural failure analysis of wind turbines impacted by super typhoon usagi. Eng.Failure Anal. 60, 391-404 (2016).

Development of new composite blades





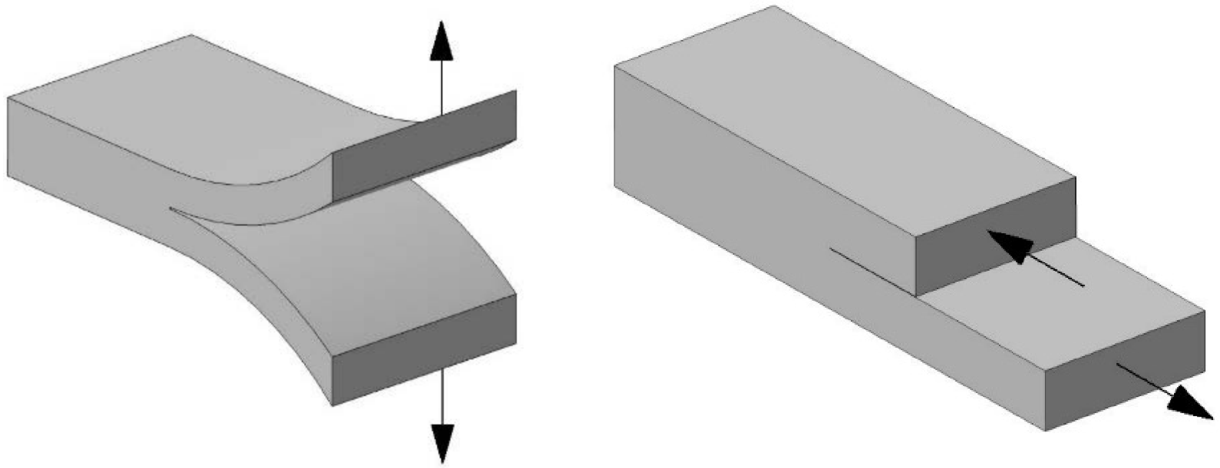
Sørensen, B. Materials and structures for wind turbine rotor blades–an overview, Proceedings of the 17th international conference on composite materials (ICCM 17), Edinburgh, 2009; , pp. 31


Composite laminates
can be
tailored
delamination
LINEAR
ELASTIC
FRACTURE
MECHANICS

Energy Criterion : $G > G_c$

G : Energy release rate
G_c : Fracture toughness

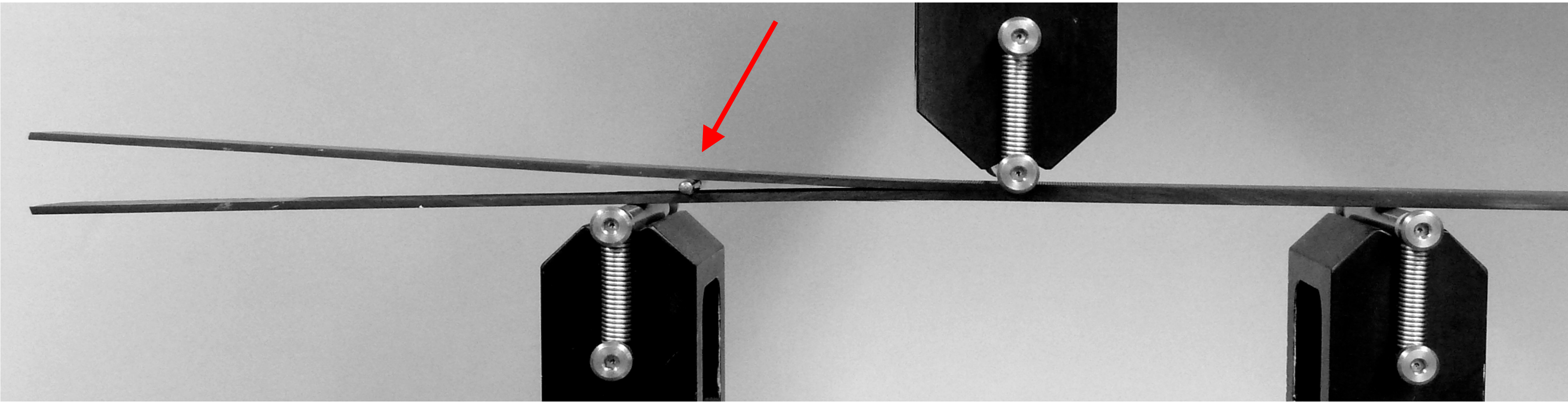
Mode I | Mode II | Mode III



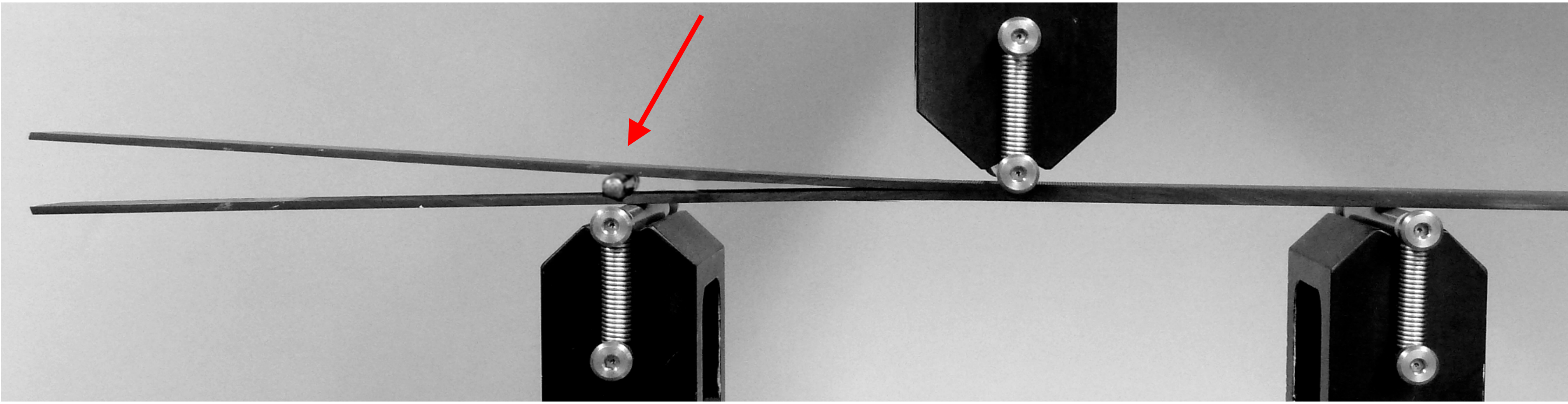
$$G=G_I+G_{II}+G_{III}$$

Mixed-mode I/II fracture is commonly observed

ENFR test:
End Notched Flexure test with inserted Roller



ENFR test:
End Notched Flexure test with inserted Roller



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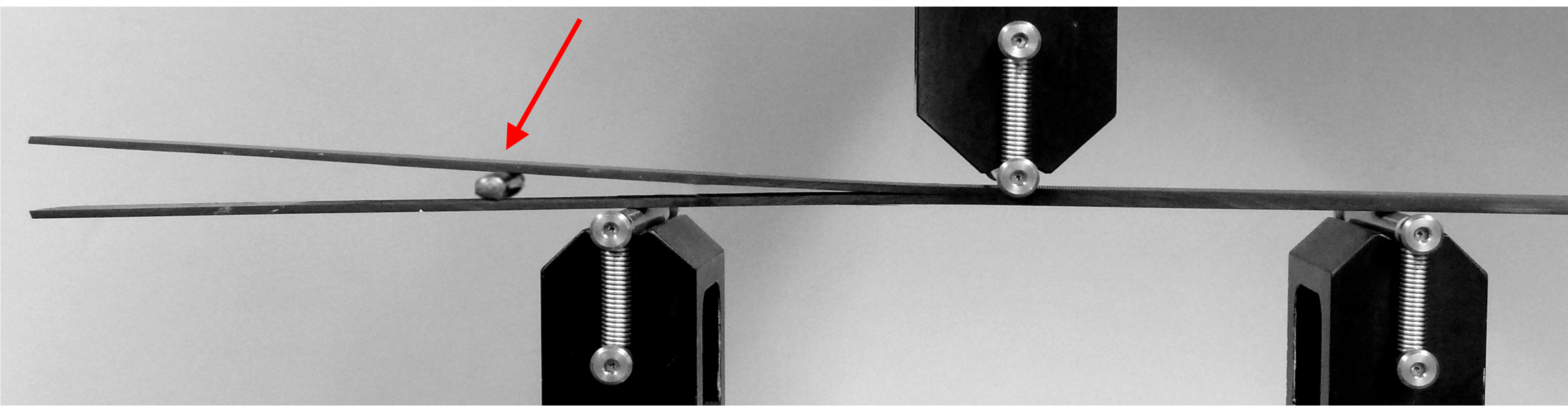
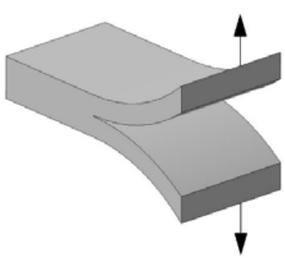


ENFR test:
End Notched Flexure test with inserted Roller

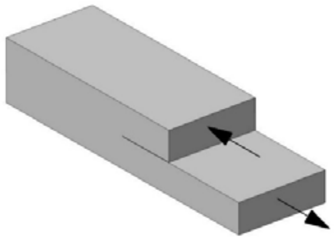
Load
+
Load application point displacement → Compliance → Crack length

Mode I



GI

Mode II

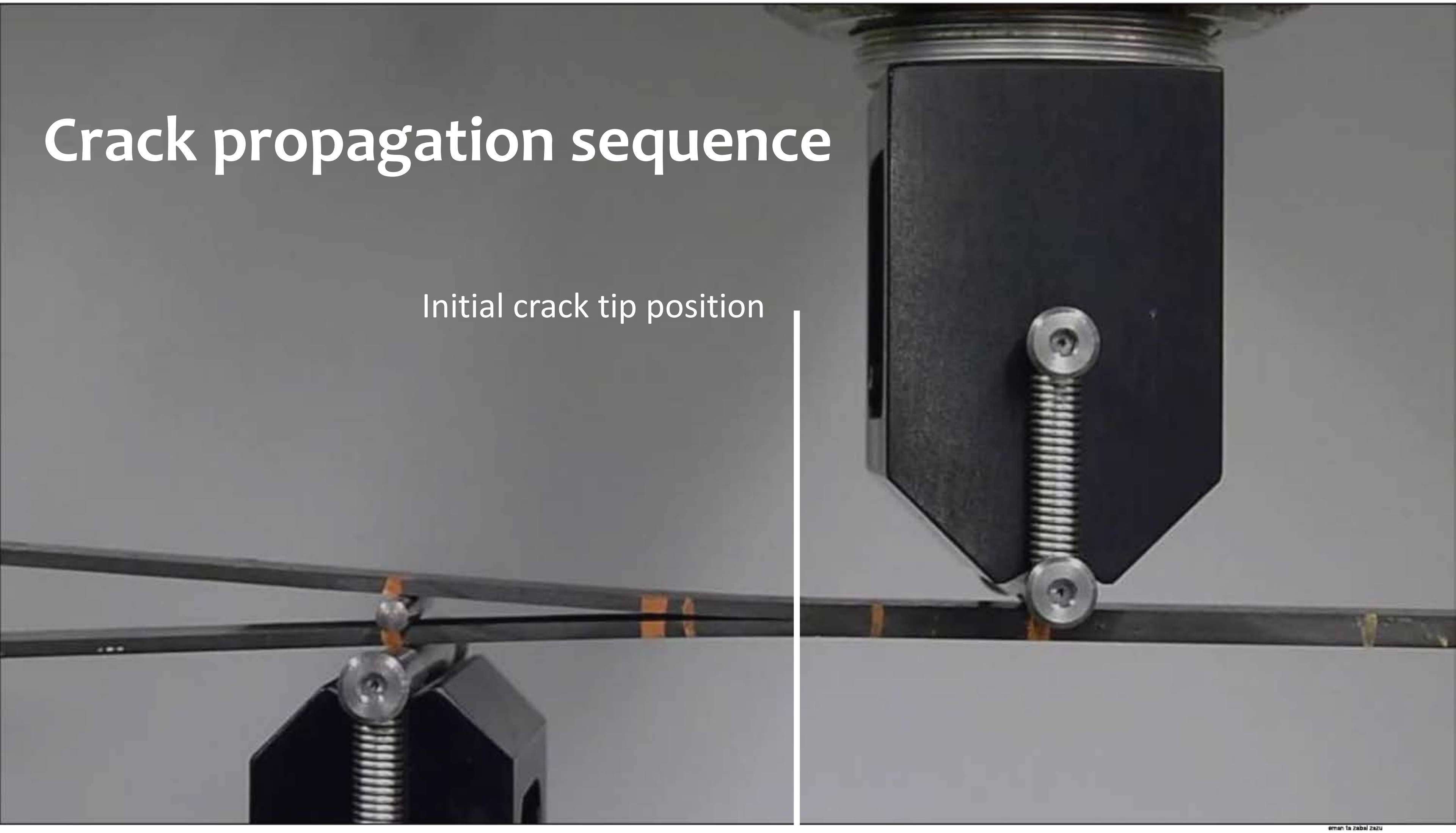


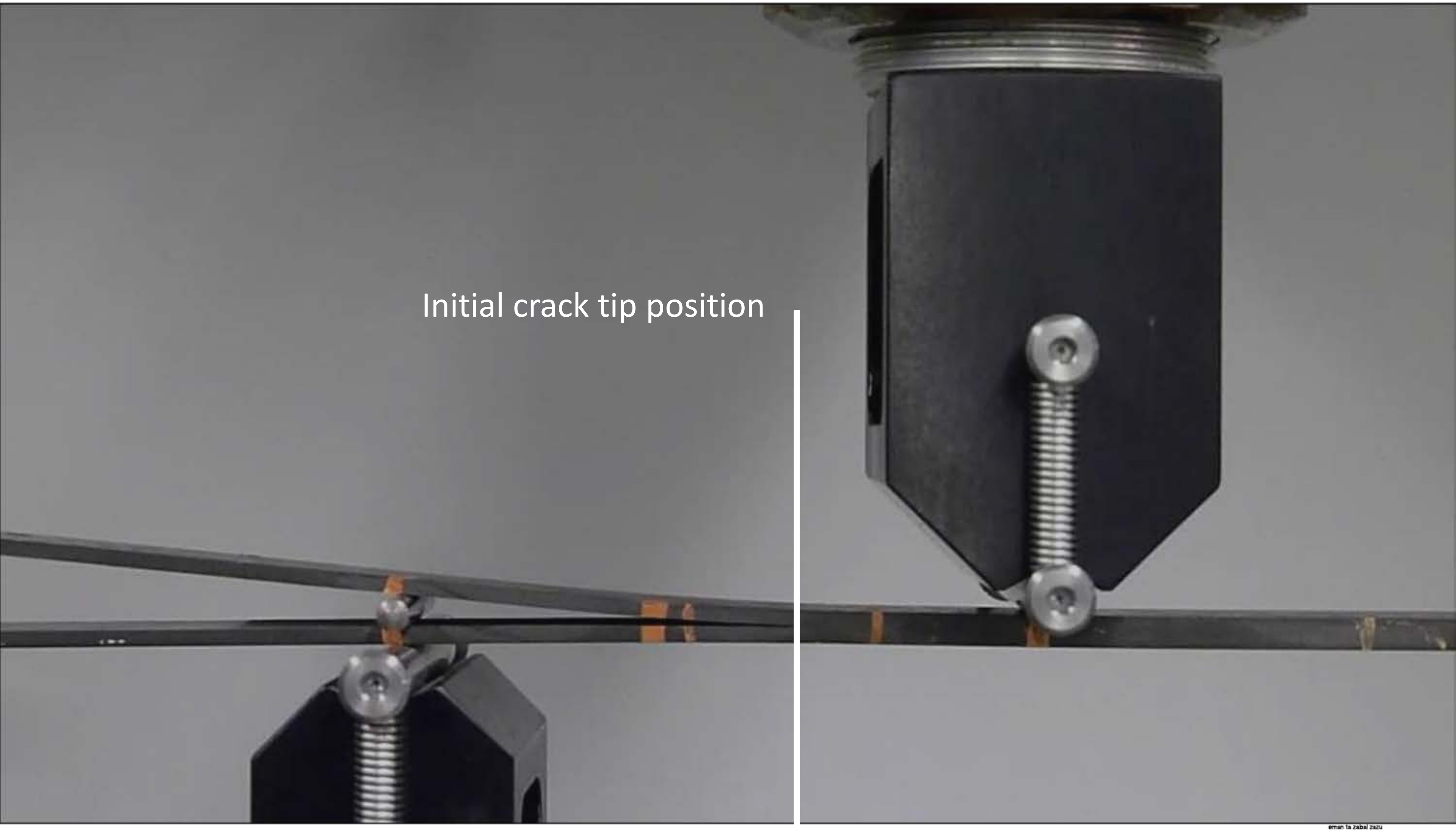
GII

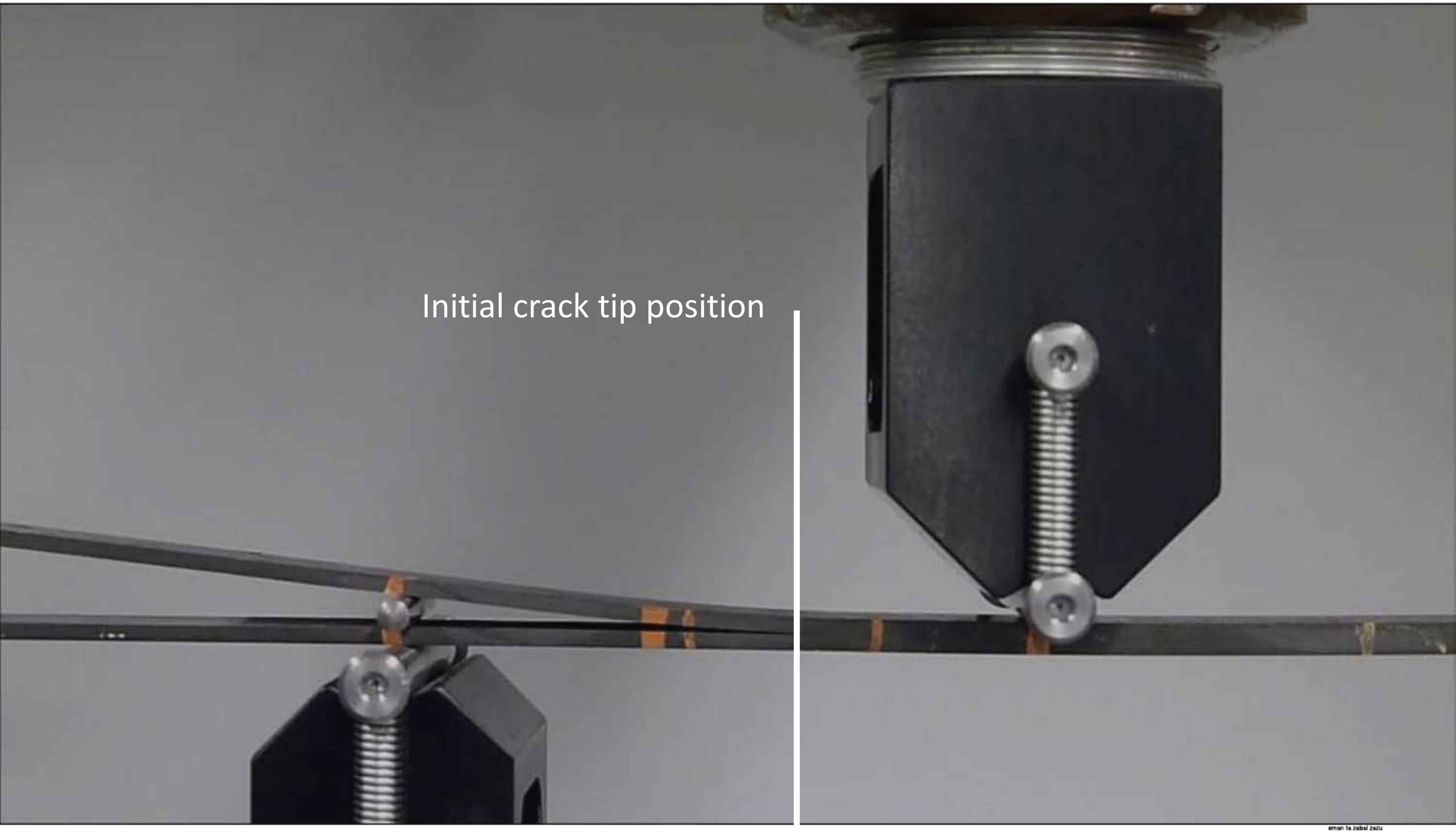
Mixed-mode ratio

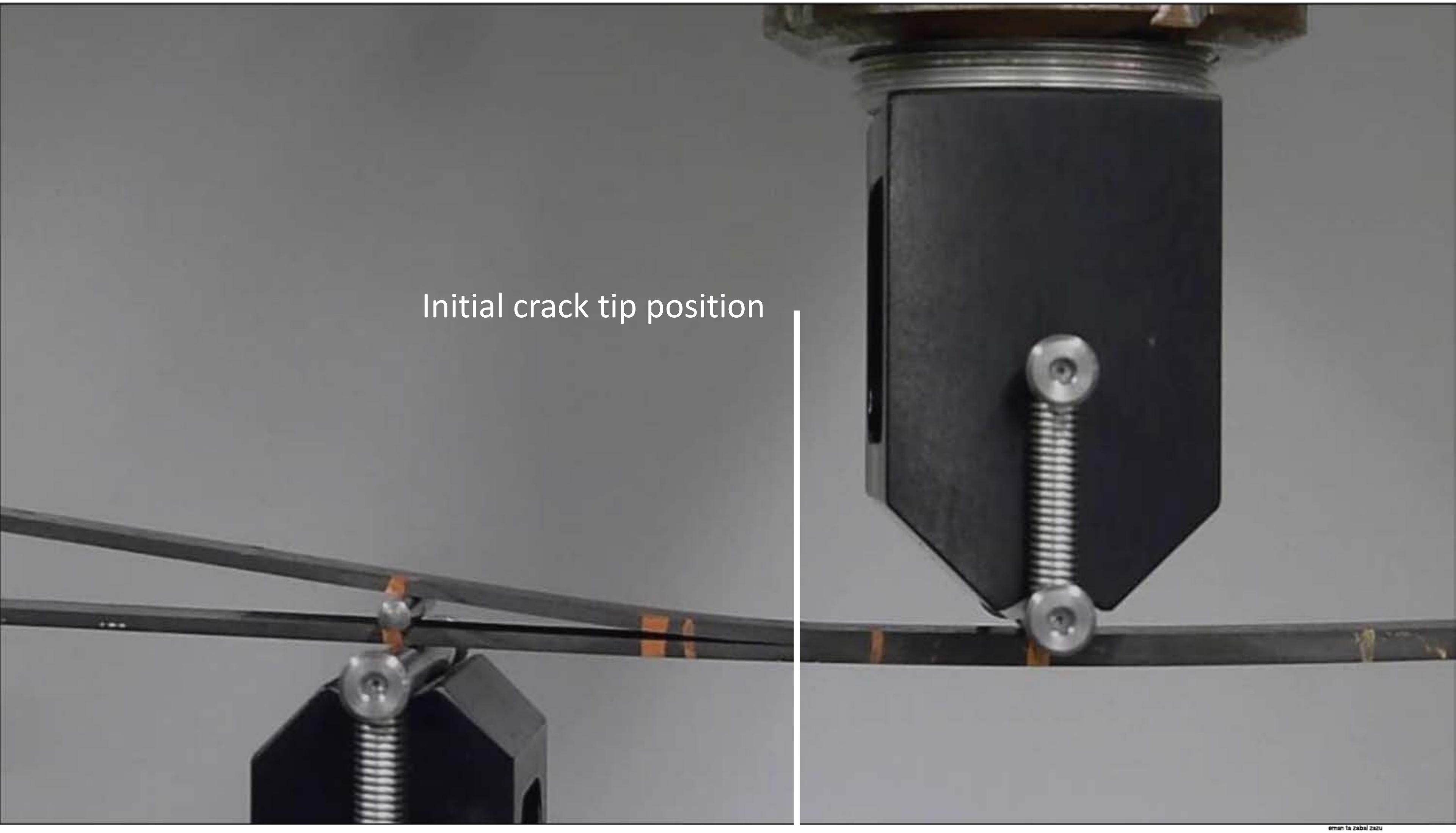
GII/G

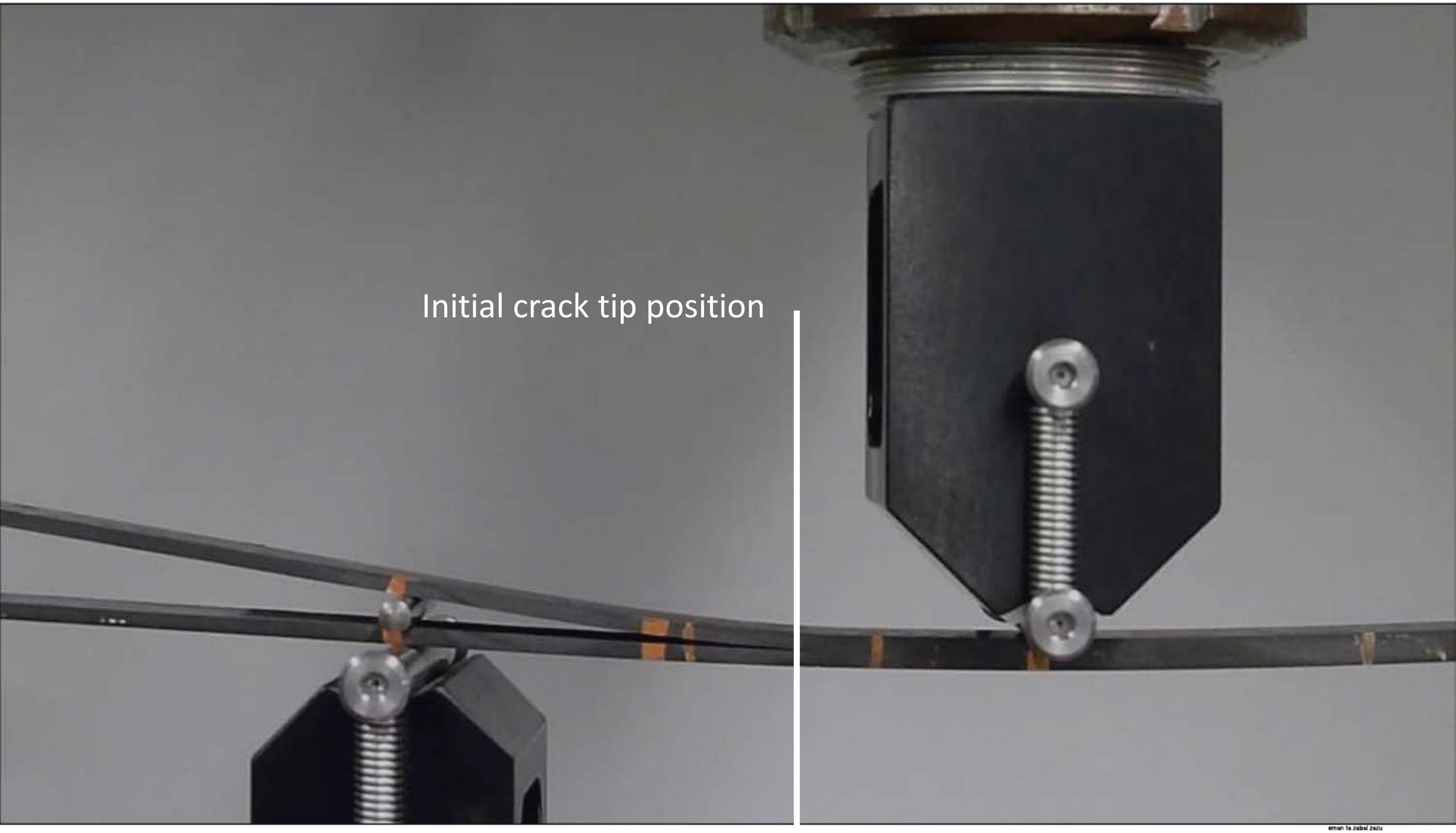
G=GI+GII

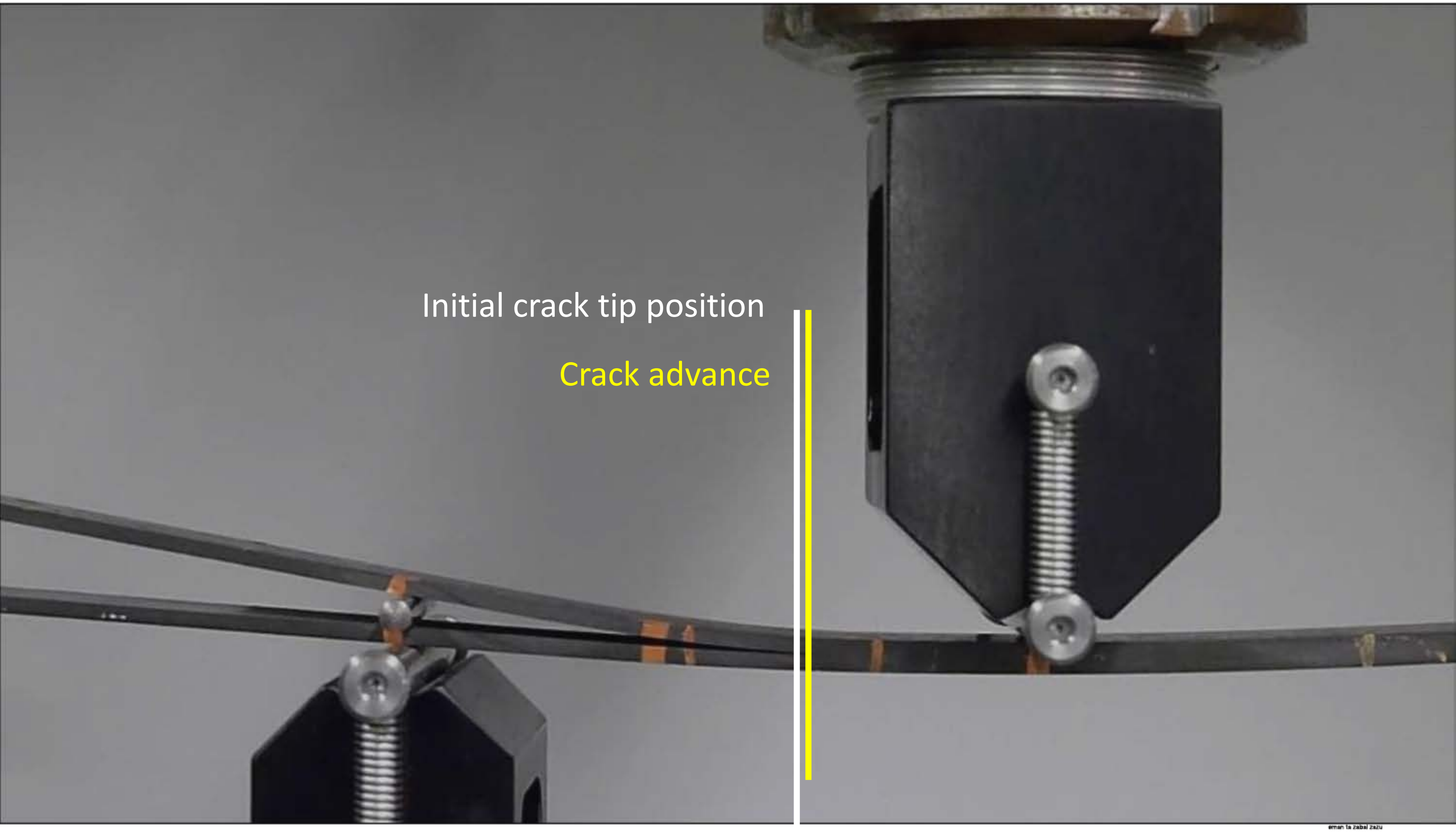

Crack propagation sequence
Initial crack tip position

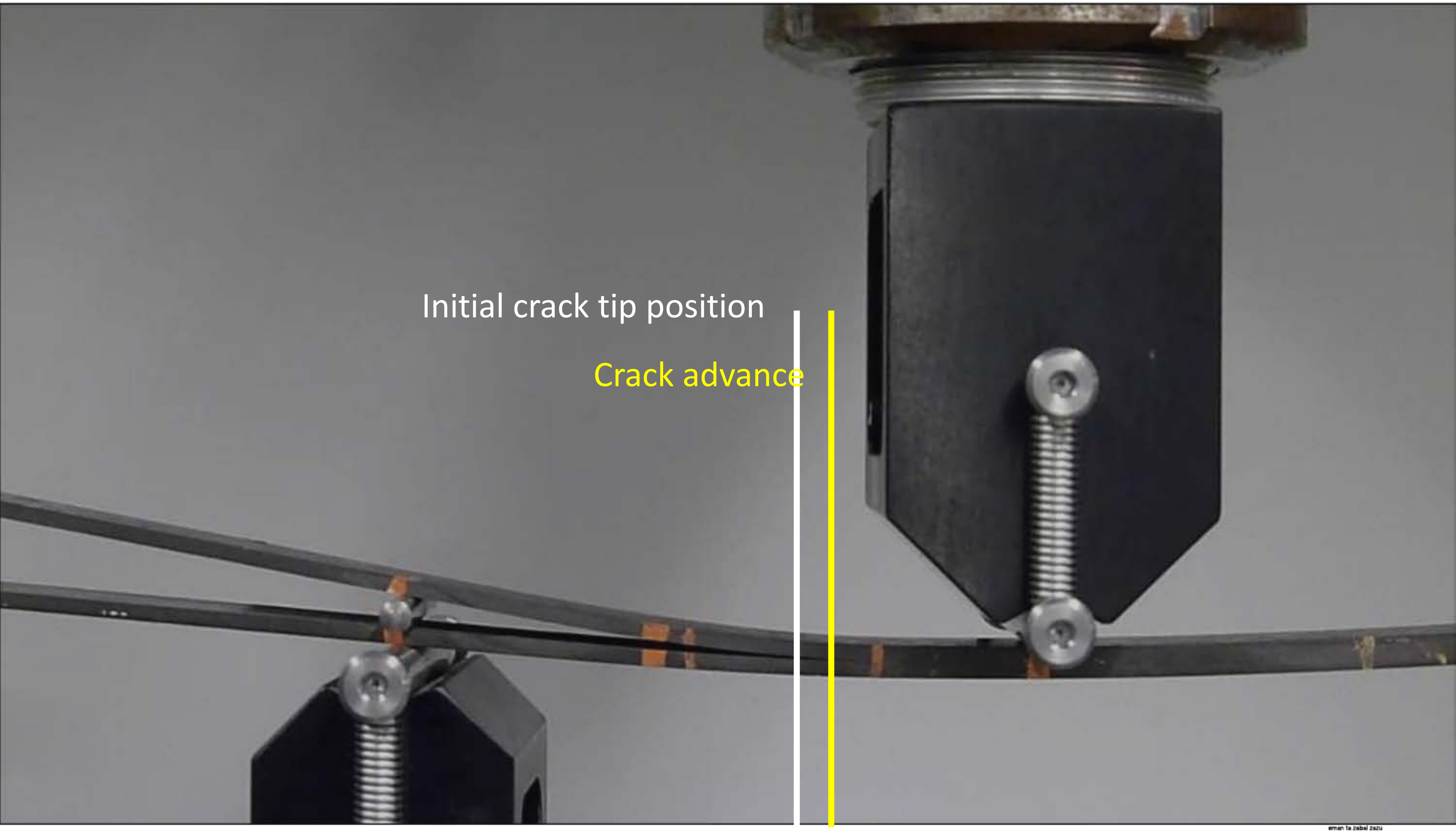

Initial crack tip position

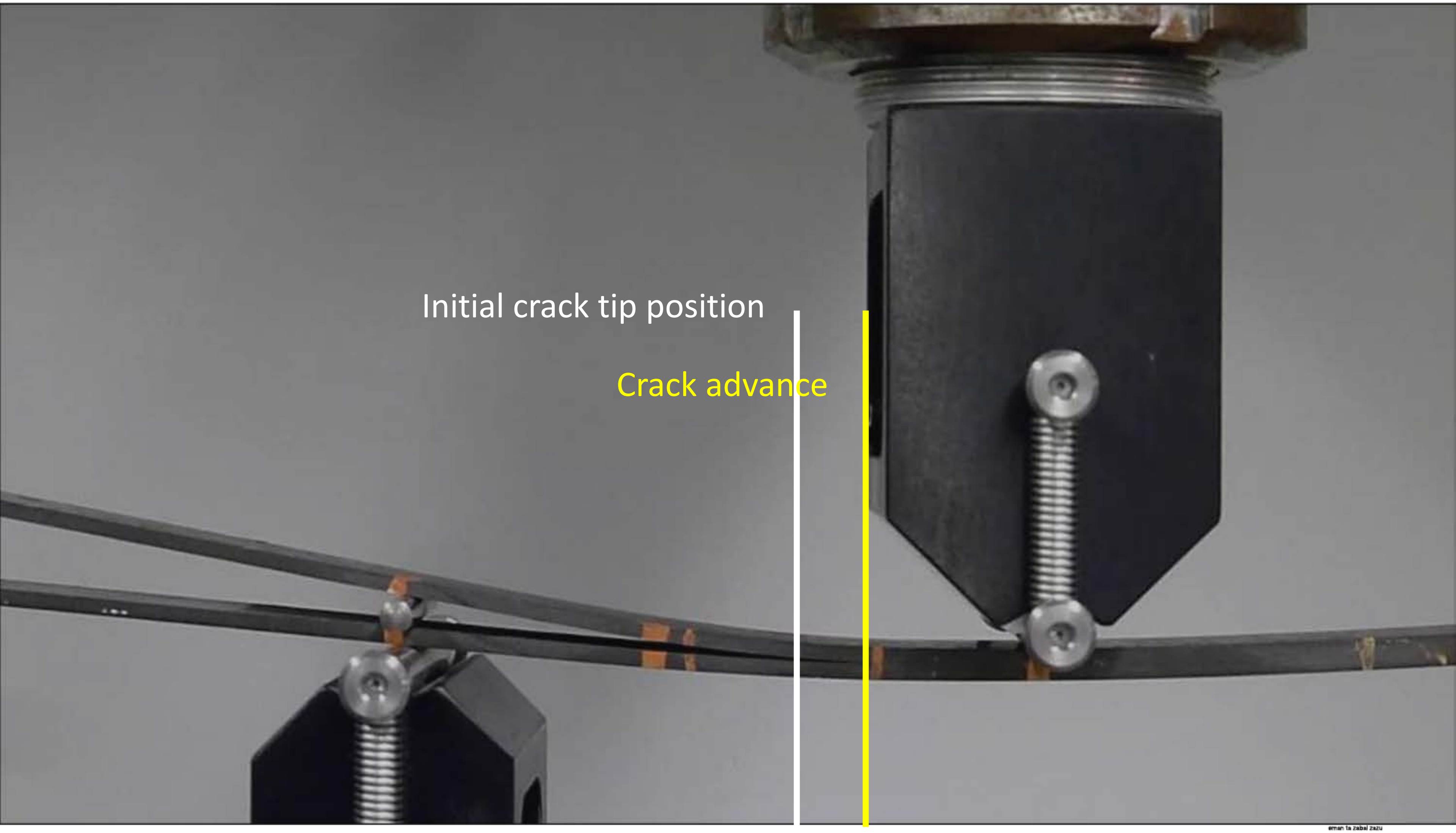

Initial crack tip position

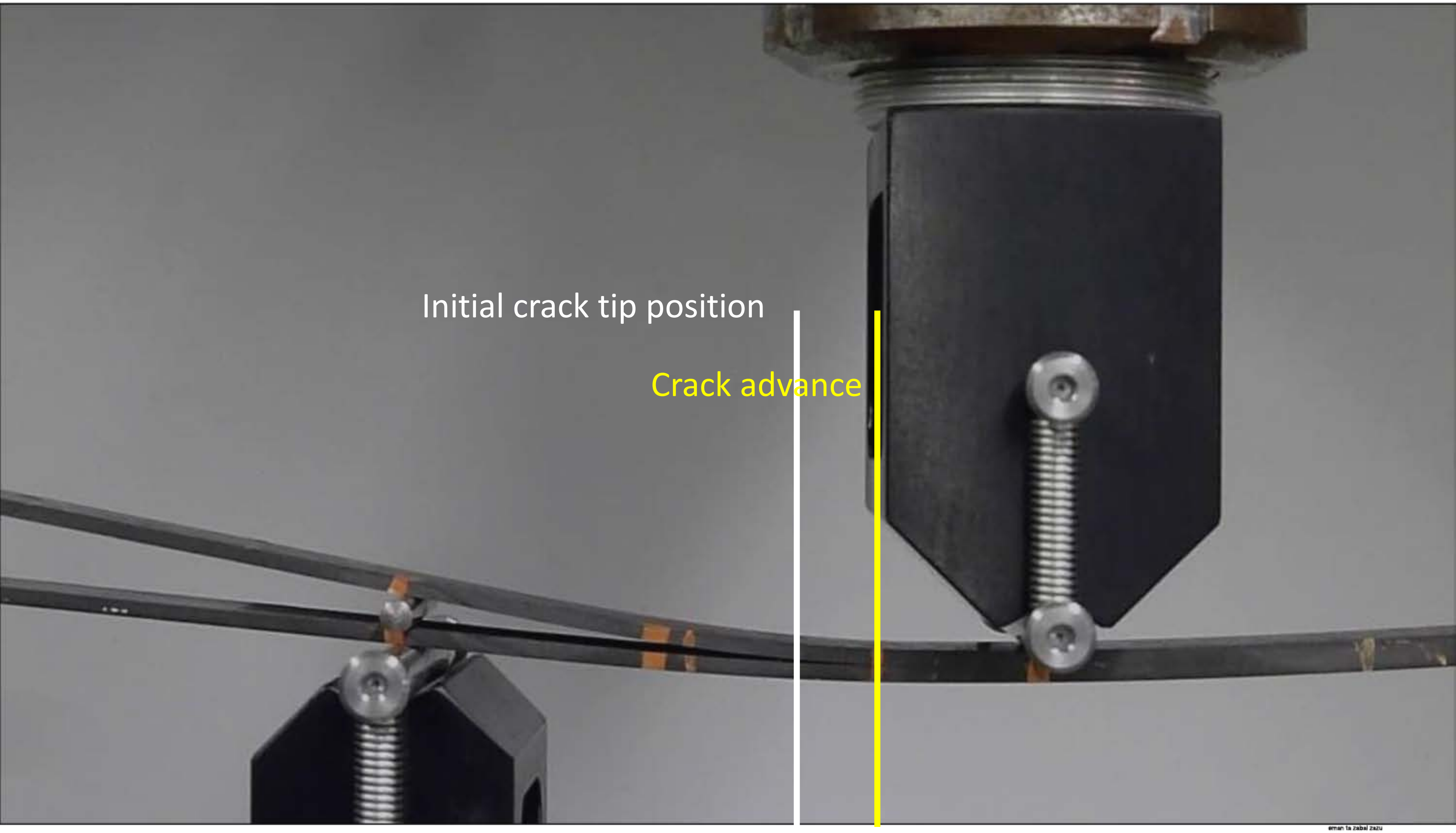

Initial crack tip position

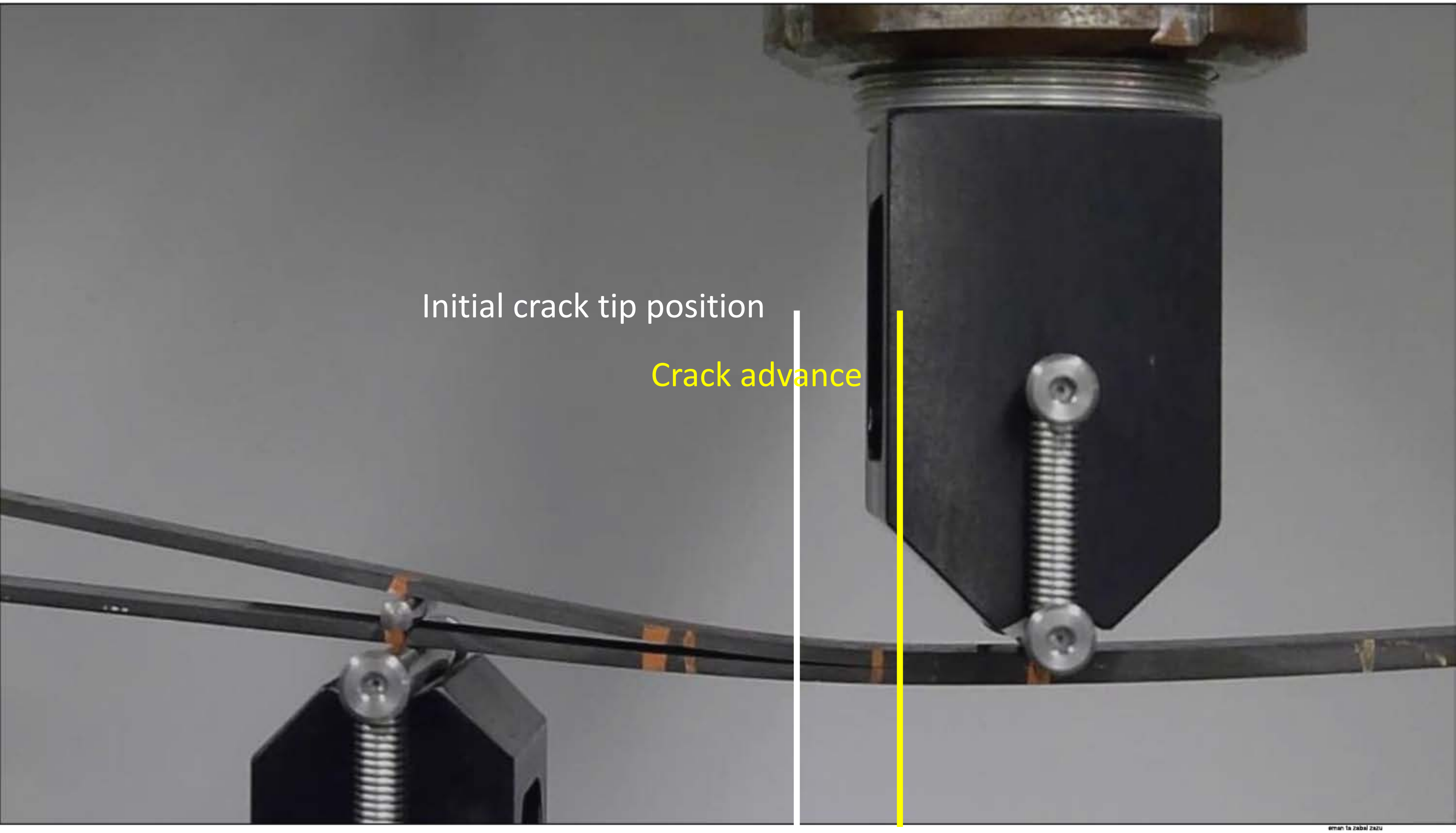

Initial crack tip position

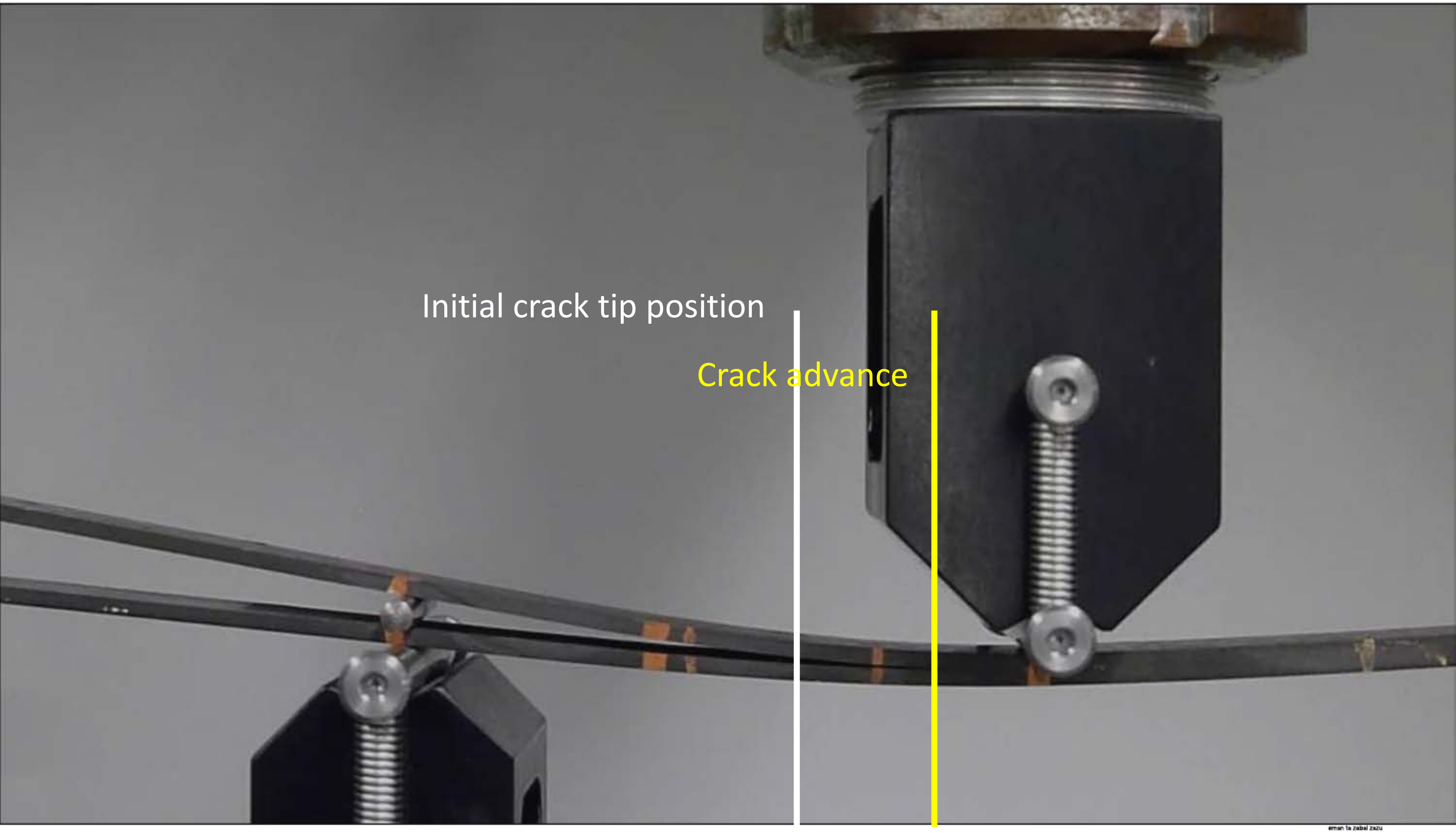

Initial crack tip position
Crack advance


Initial crack tip position
Crack advance


Initial crack tip position
Crack advance

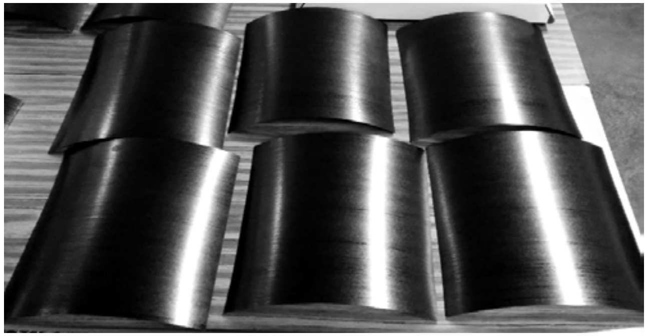

Initial crack tip position
Crack advance

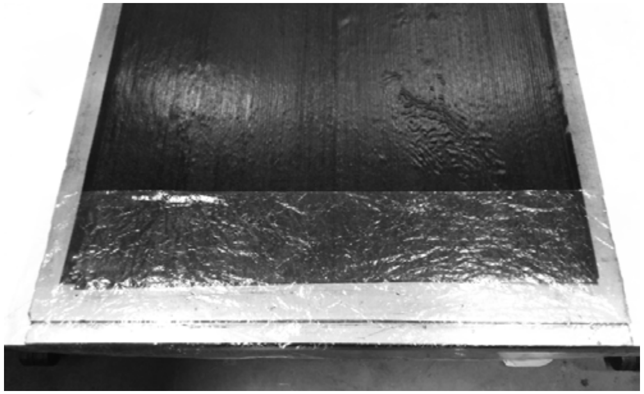

Initial crack tip position
Crack advance

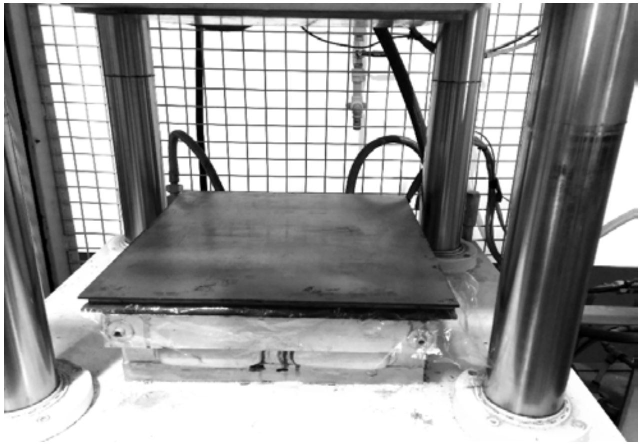

Initial crack tip position
Crack advance

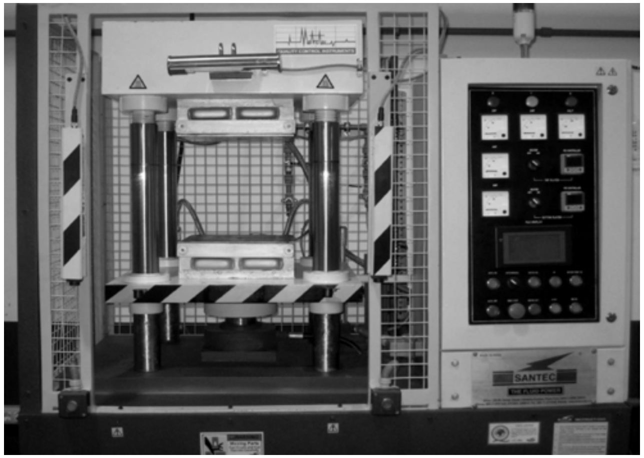
Specimen manufacturing

Unidirectional $[0]_{16}$
T300/F593
Carbon fiber Epoxi matrix









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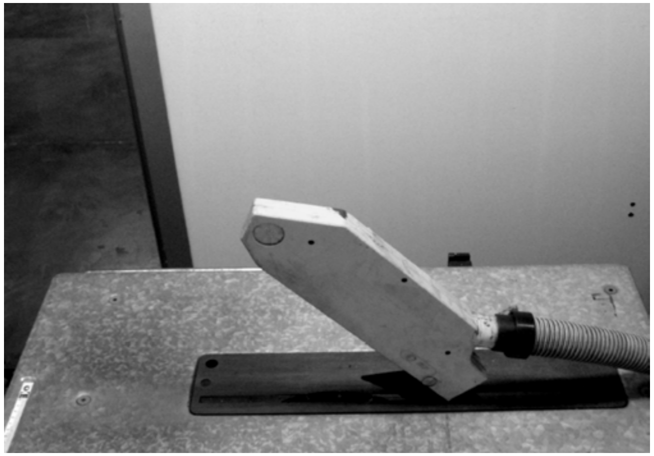
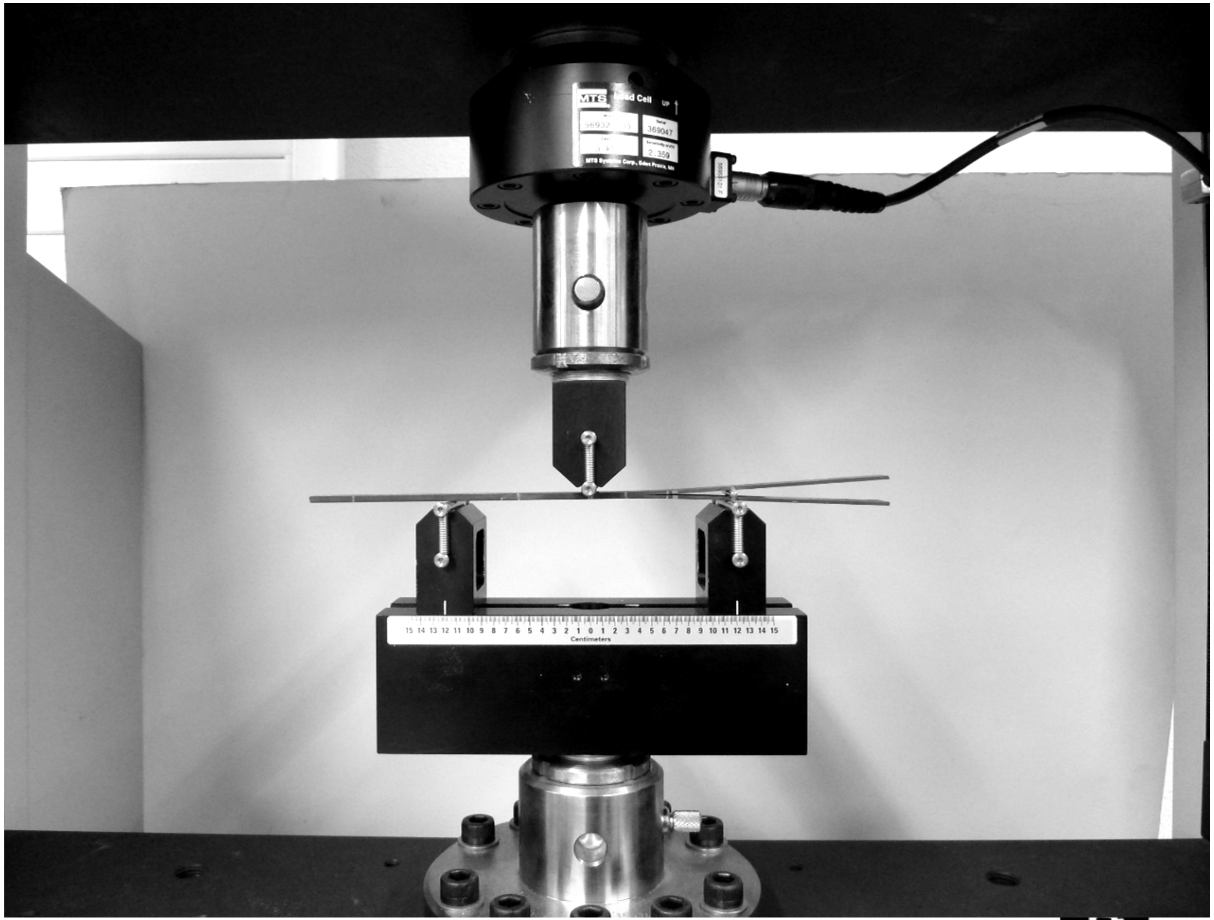


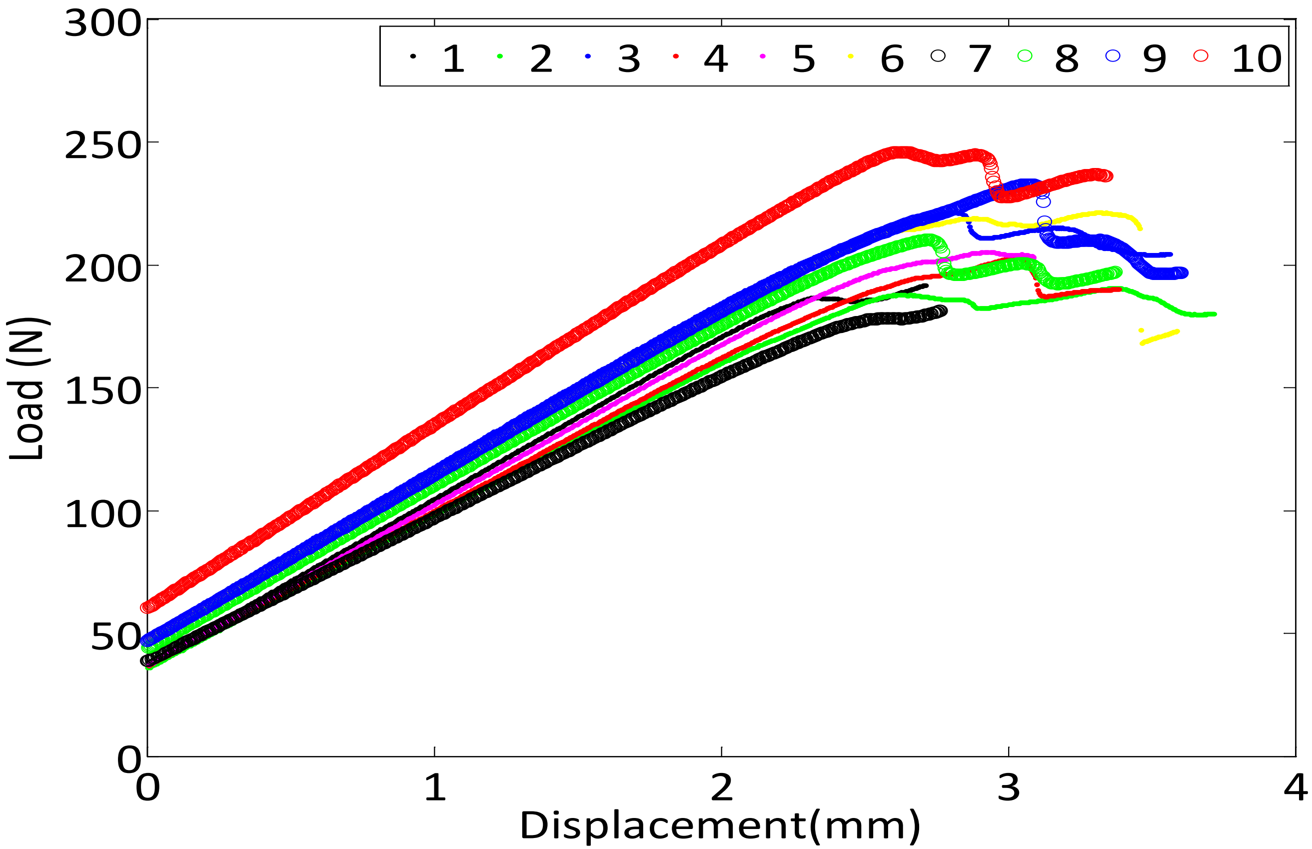

metkon
FORCIPOL
300 - 1V
GRINDER - POLISHER
POWER
WATER


MTS
Load Cell
Centimeters

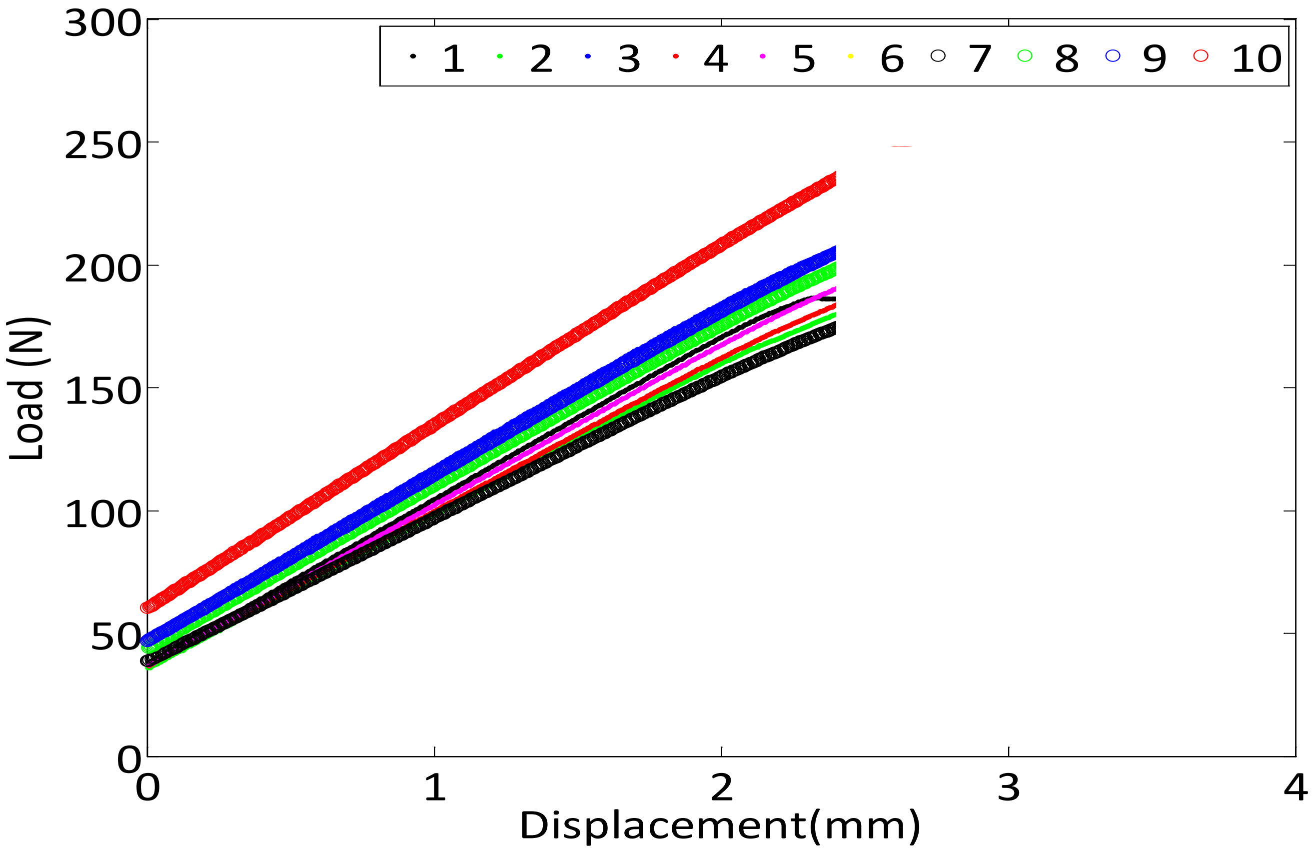
Summary of experimental test conditions

ID	Nomenclature	Initial G_{II}/G (%)
1	a40-R1-c5	65
2	a42-R0.9-c8	65
3	a42-R1.5-c0	67
4	a43-R0.9-c8	67
5	a41-R1-c5	68
6	a42-R1.5-c0	68
7	a45-R1-c8	68
8	a40-R1.25-c0	71
9	a43-R1.5-c0	72
10	a46-R1.5-c0	77

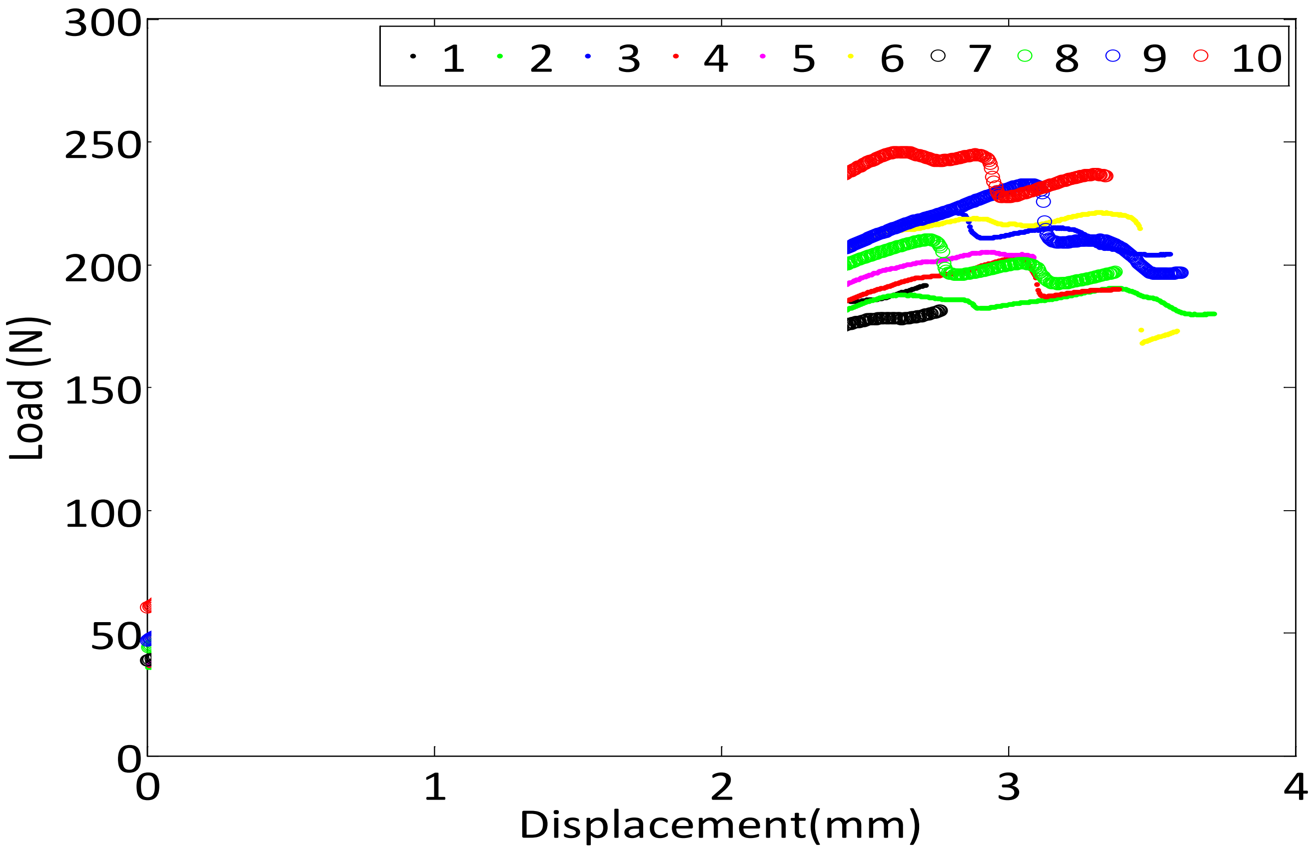
Load - displacement



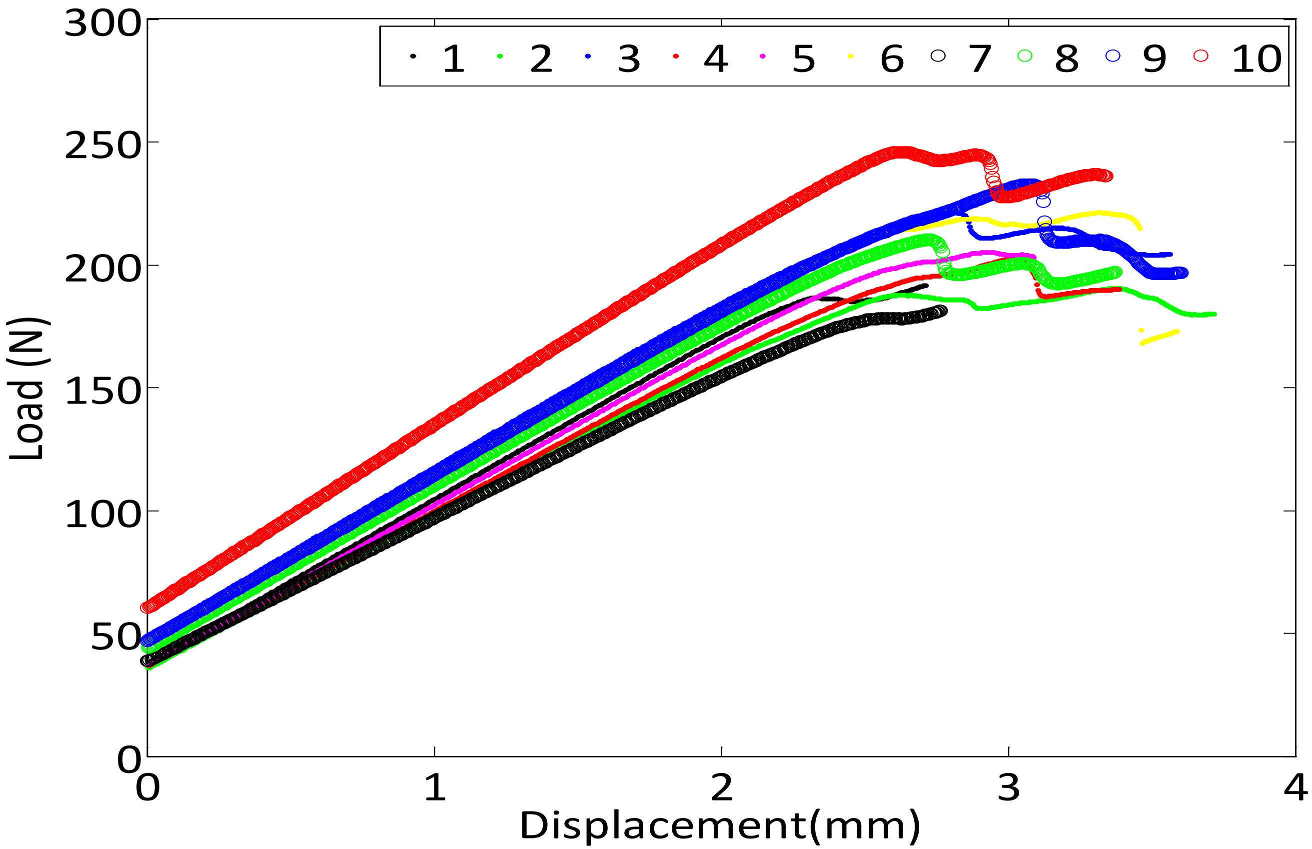
Load - displacement



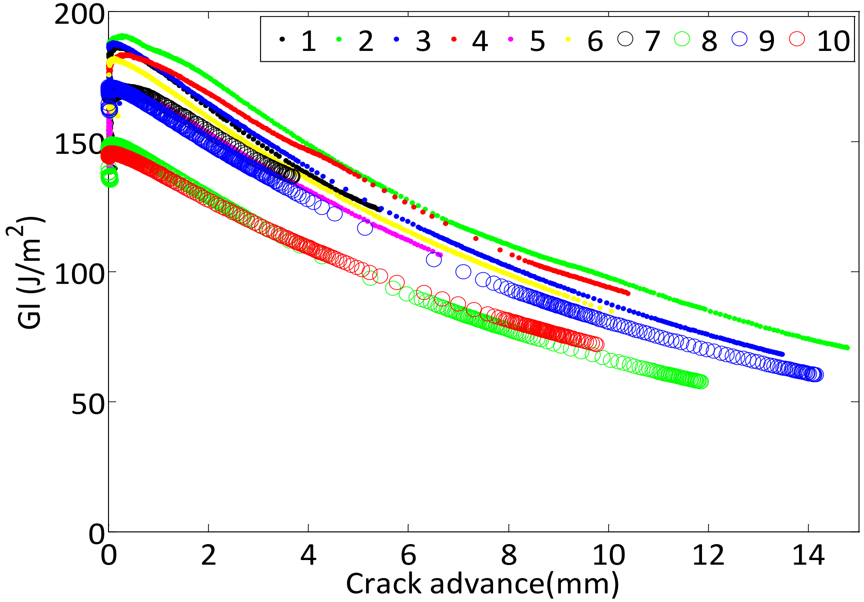
Load - displacement



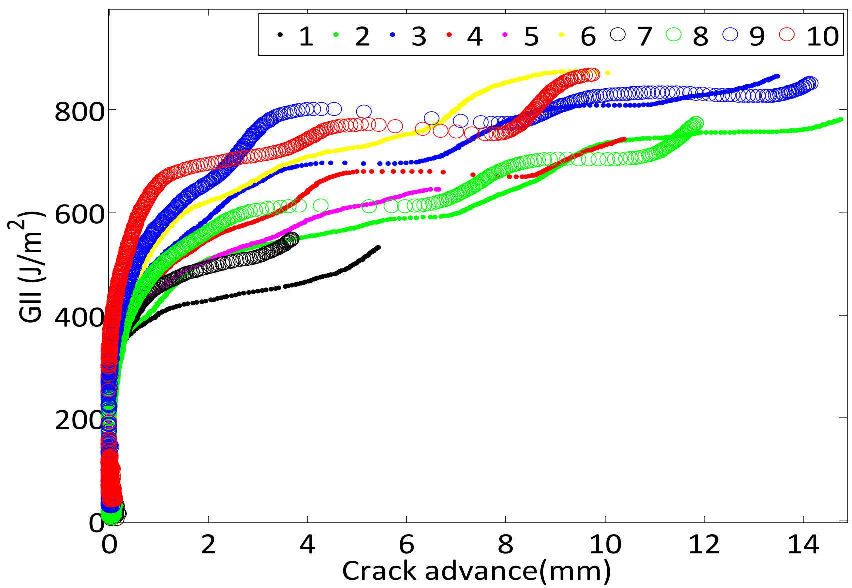
Load - displacement



GI



GII



Mixed-mode ratio

GII/G

LINEAR ELASTIC FRACTURE MECHANICS

Energy Criterion : $G > G_c$

G : Energy release rate
G_c : Fracture toughness

Pure modes

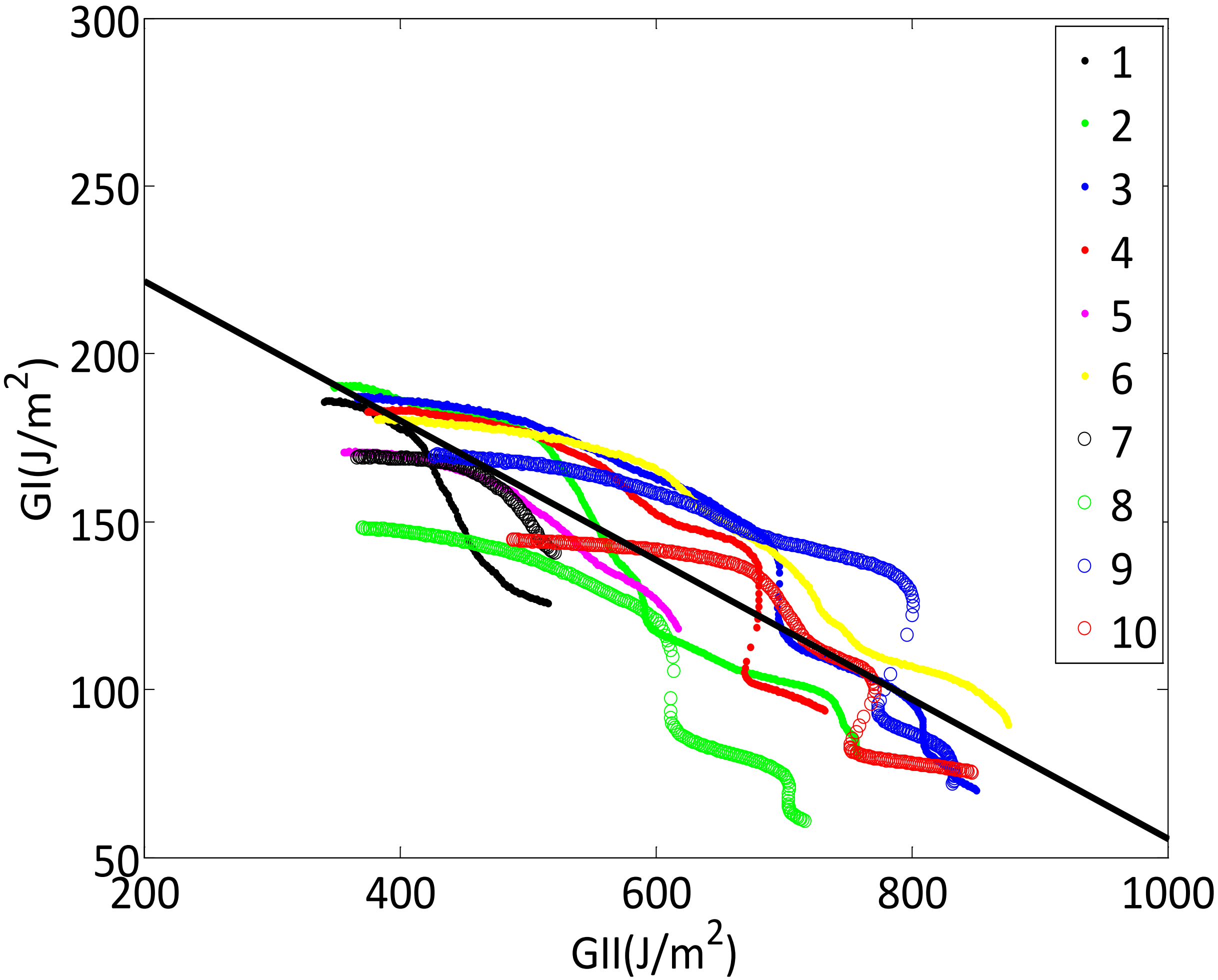
$$G_I > G_{Ic}$$

$$G_{II} > G_{IIc}$$

Mixed-mode

$$\frac{G_I}{G_{IC}} + \frac{G_{II}}{G_{IIC}} = 1$$

GIc and GIIc (fracture toughness) → material property)



$$\frac{G_I}{G_{IC}} + \frac{G_{II}}{G_{IIC}} = 1$$

Test	G_{IC} (J/m^2)	G_{IIC} (J/m^2)	R2	Geqc (J/m^2)
1	344	798	0.951	524
2	309	1042	0.948	568
3	304	1174	0.918	598
4	298	1159	0.827	588
5	252	1241	0.936	559
6	274	1359	0.937	611
7	237	1405	0.786	577
8	265	986	0.882	511
9	278	1312	0.753	604
10	277	1179	0.829	571
Mean value	284 ± 31	1165 ± 184		571 ± 33
All data	263	1267	0.716	578
Mode I	240	-		
Mode II	-	1063		

LINEAR ELASTIC FRACTURE MECHANICS

Energy Criterion : $G > G_c$

G : Energy release rate
G_c : Fracture toughness

Pure modes

$$G_I > G_{Ic}$$

$$G_{II} > G_{IIc}$$

Mixed-mode

$$\frac{G_I}{G_{IC}} + \frac{G_{II}}{G_{IIC}} = 1$$

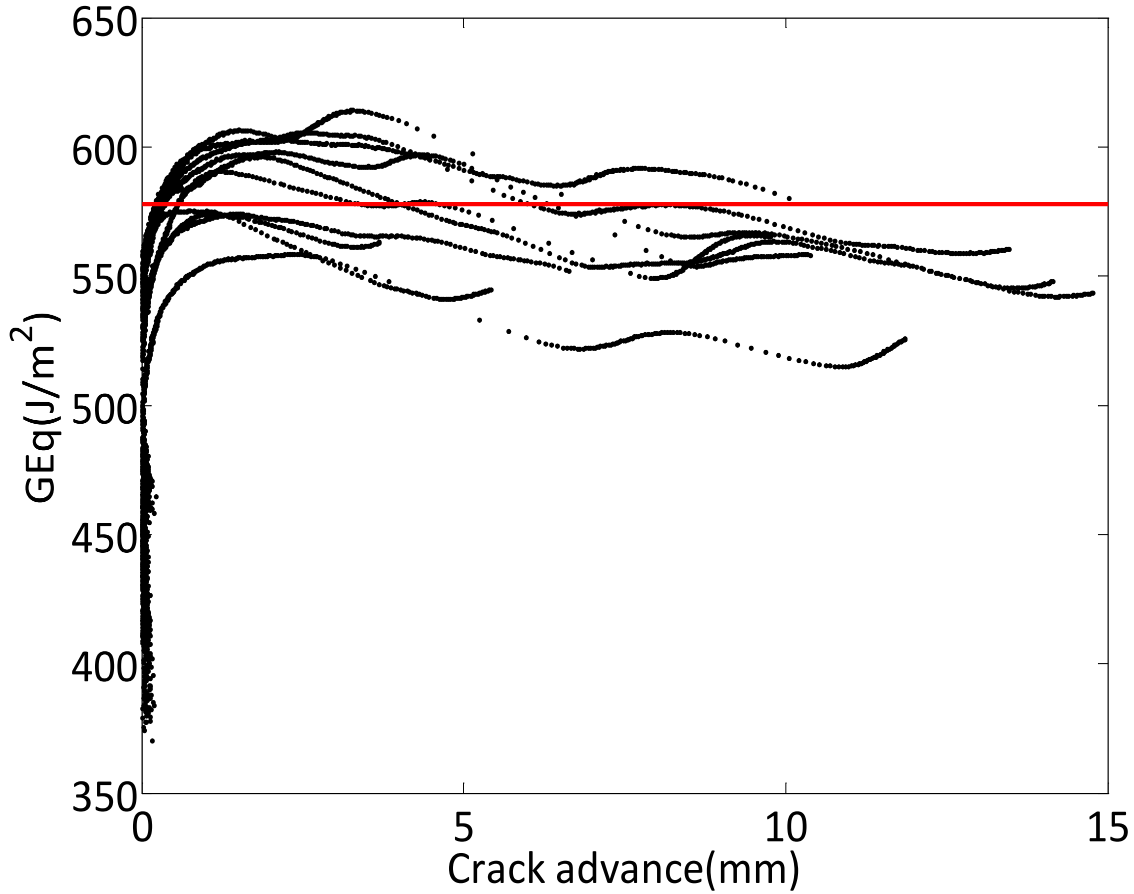
ENFR test End Notched Flexure test with inserted Roller

$$G_{eq} = \left(G_I G_{IIc} + G_{II} G_{Ic}\right)^{1/2}$$

$$G_{eqc} = \left(G_{Ic} G_{IIc}\right)^{1/2}$$

$$\Rightarrow \quad G_{eq} \geq G_{eqc}$$

Geq Equivalent Energy Release Rate



- **Wind turbine blades are made of layered materials→ mixed mode failure**
- **ENFR test proposed for analyzing mixed-mode fracture**

An equivalent energy release rate for mixed-mode propagation proposed: experimental results show a good agreement

Future line:

Apply the results to

a cross section of a wind turbine blade

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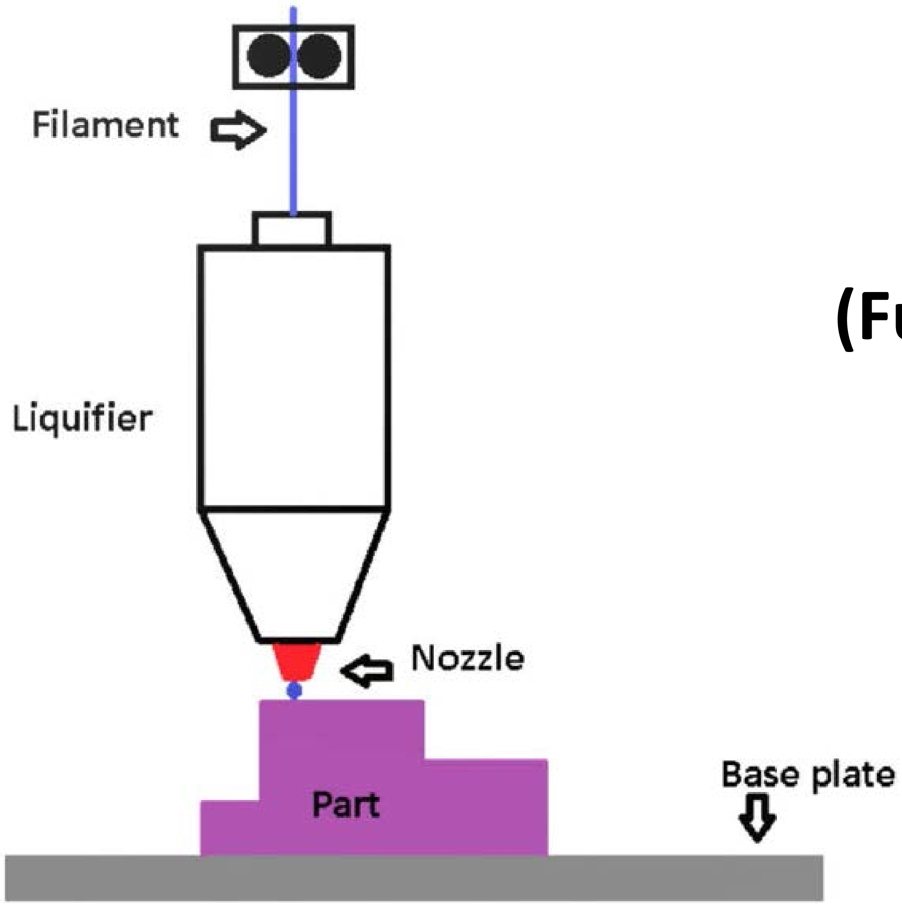
SUMMARY AND CONCLUSION

Addition Manufacturing (AM)



FDM
(Fused Deposition Modelling)

MATERIALS

Poly Acid Lactic (PLA/1.75 mm)

Biodegradable

Flexural modulus → 3,500 MPa

Bending strength→ 80 MPa

Shear modulus→ 2,400 MPa

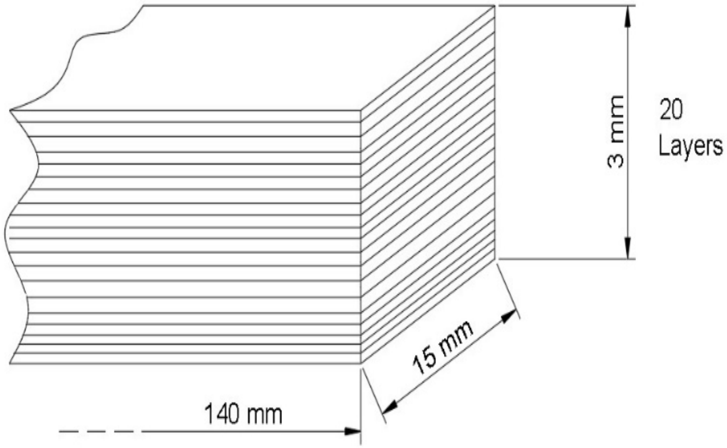
MATERIALS

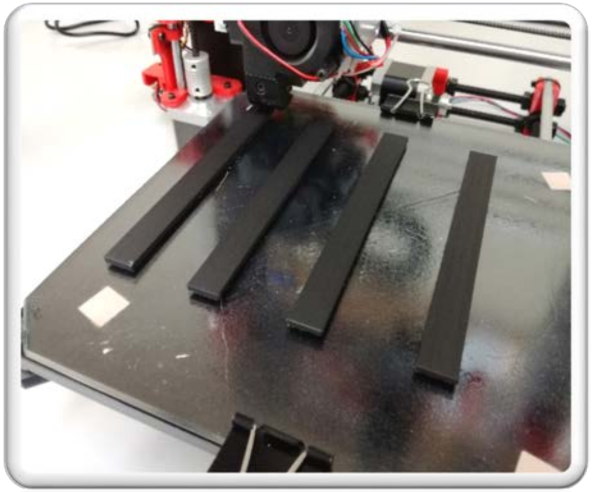
Carbon-fibre reinforced PLA (1.75 mm)

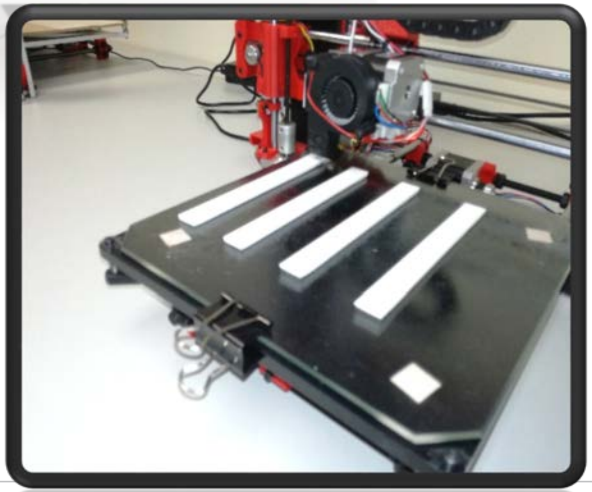
Low impact material

15% of fibres in weight

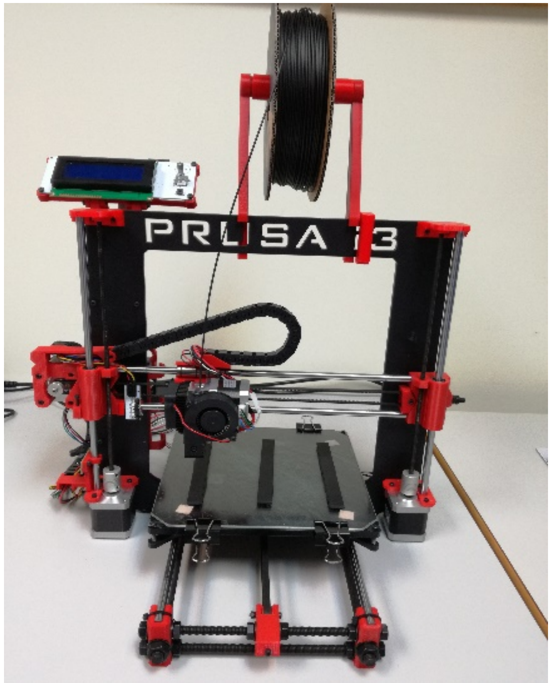
Specimen manufacturing: 3D printing

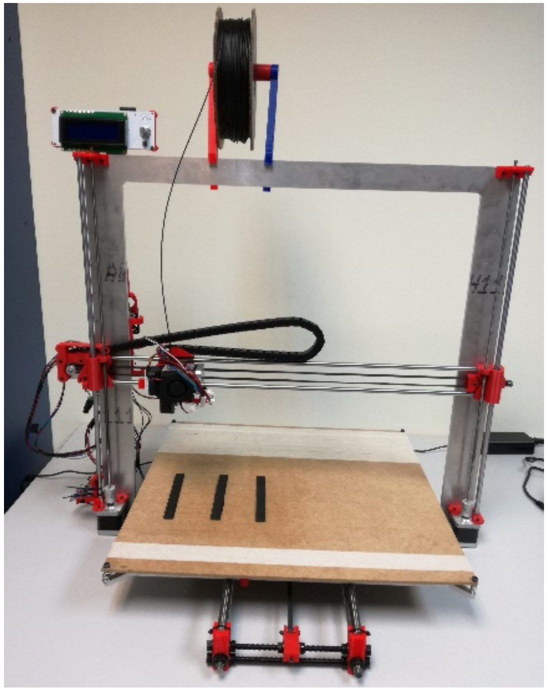






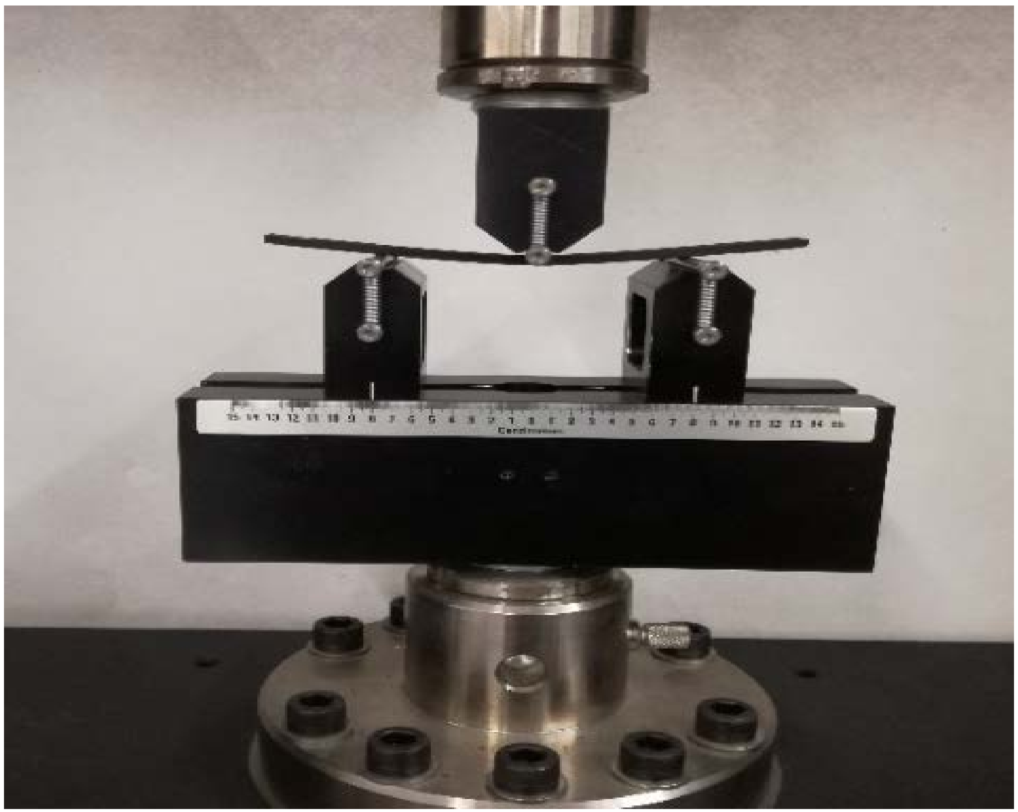
Specimen manufacturing: 3D printing





MECHANICAL TESTING

3point bending testing fixture



$$\partial_b = \frac{P(2L)^3}{48EI}$$

$$I = \frac{1}{12} b(2h)^3$$

ISO 14125:1998

Different spans (mm)
35, 50, 80,100, 120

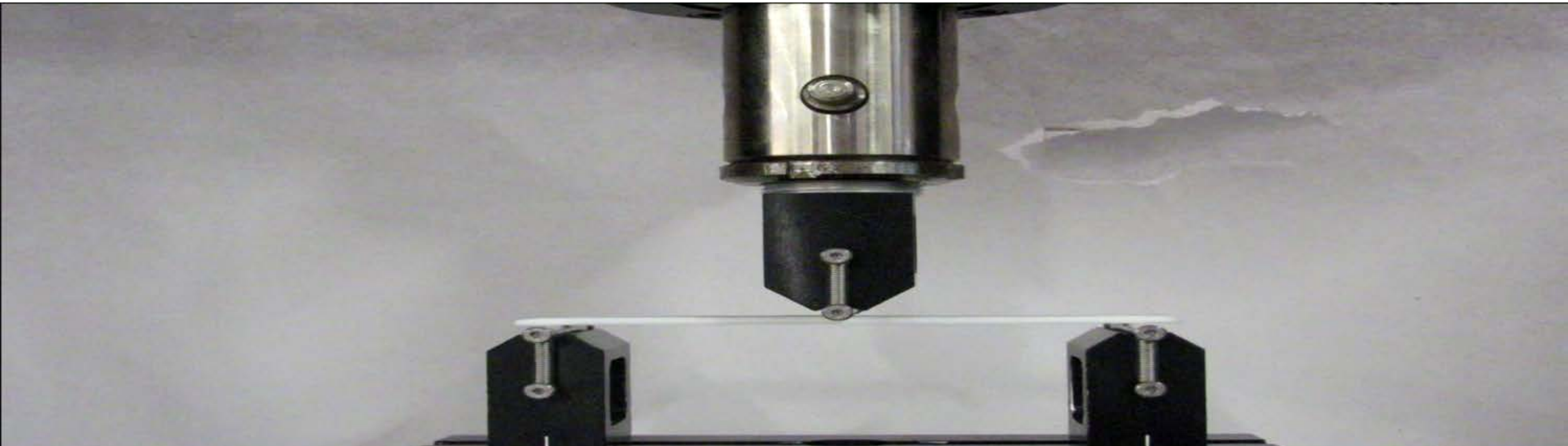
Strain Range
0.05-0.25%

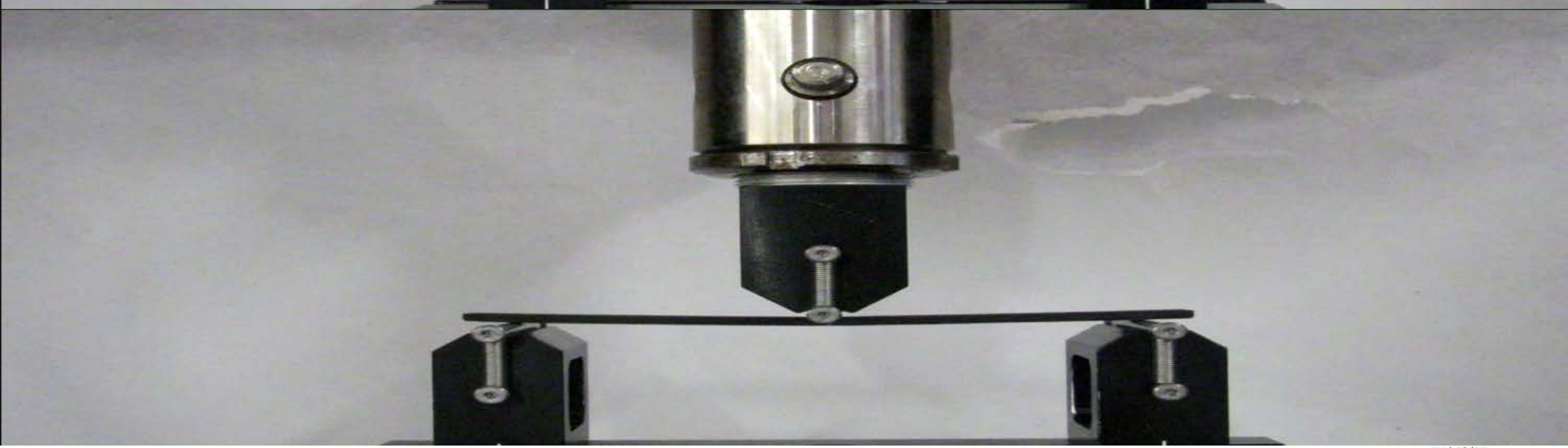
$E_{f\_PLA} = 3848.8 \pm 492.45$ MPa

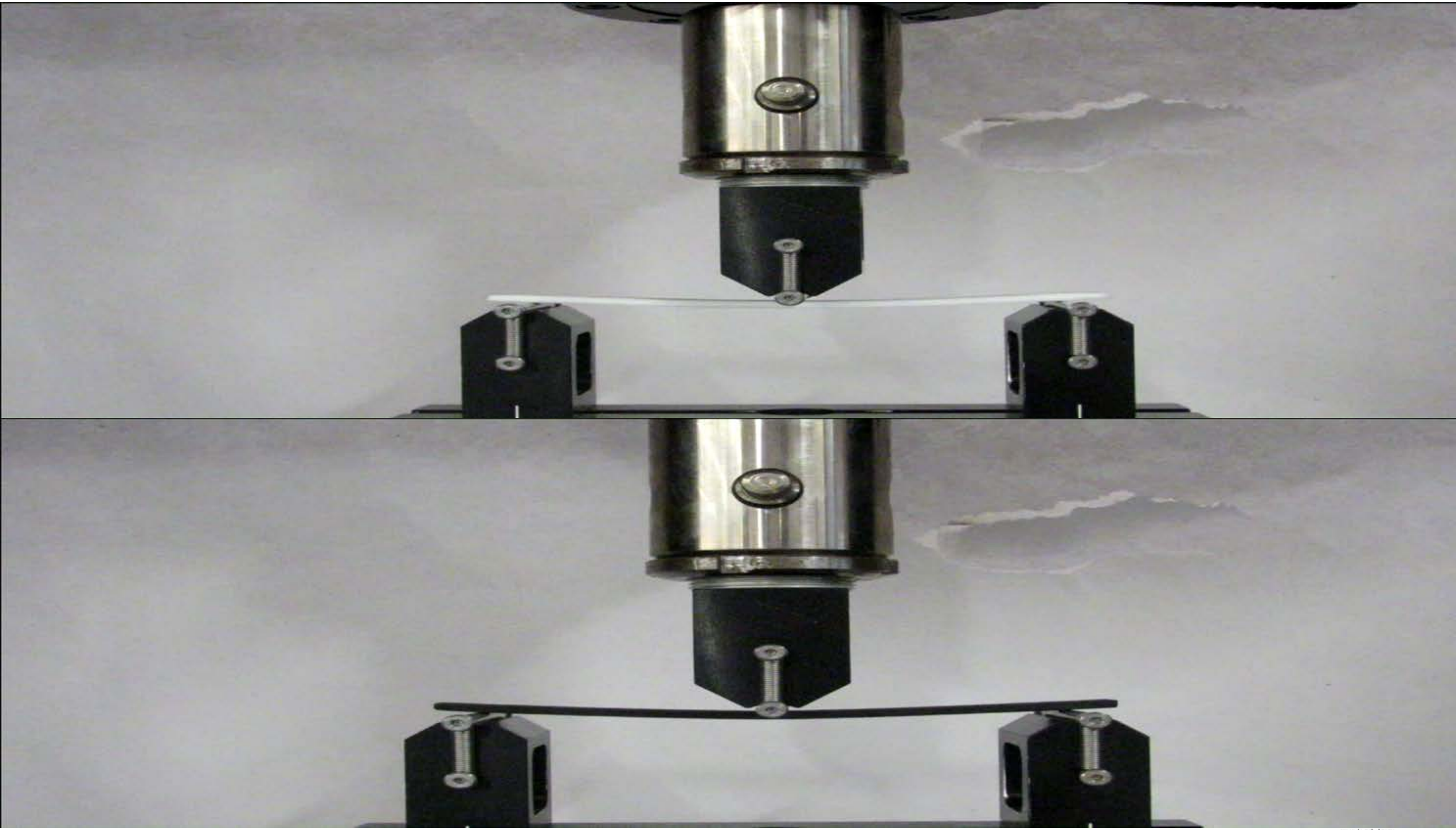
$E_{f\_PLA\_REAL} = 3236.64$ MPa

$E_{f\_CF\text{-}PLA} = 5702 \pm 620.78$ MPa

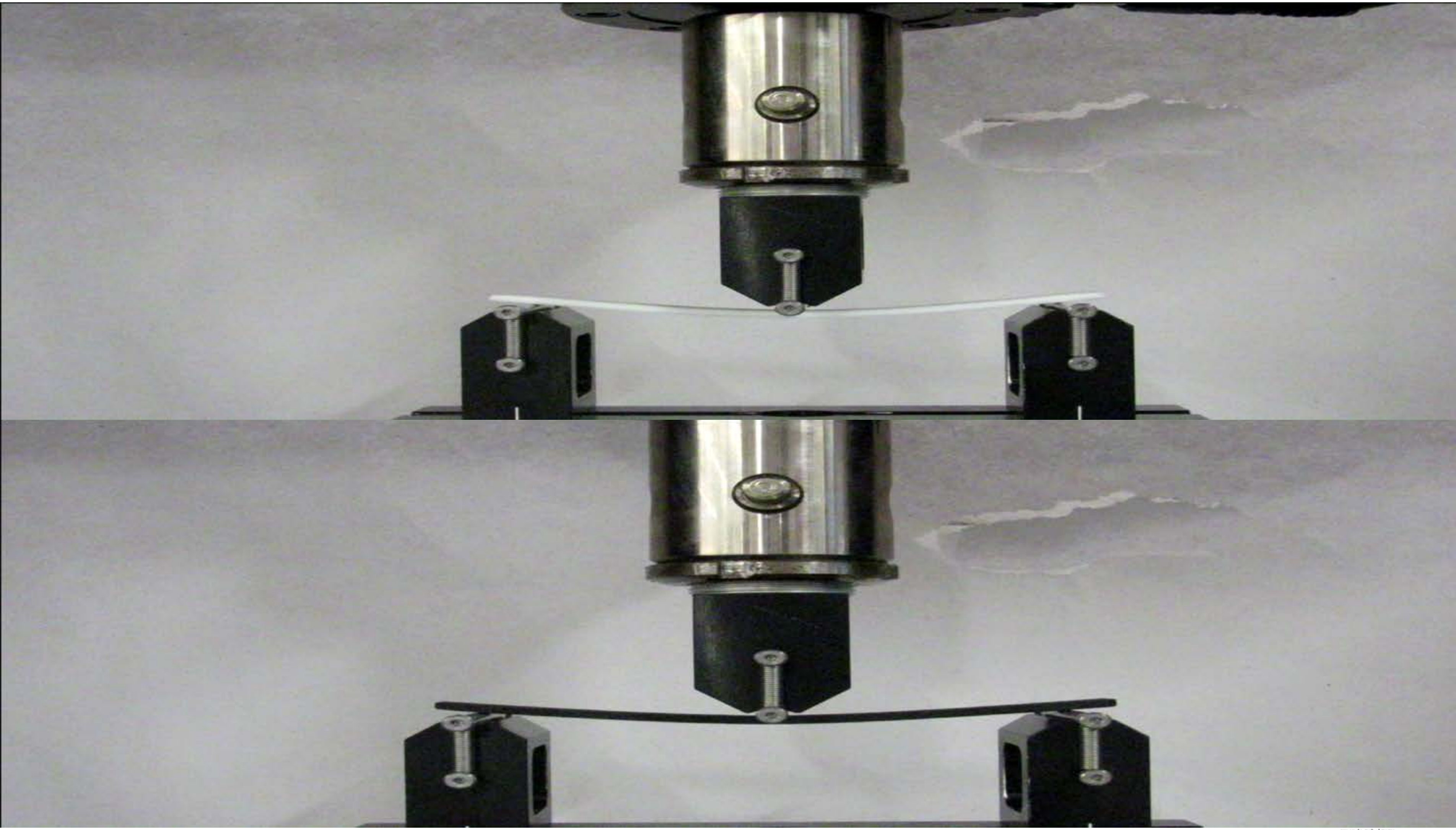
$E_{f\_CF\text{-}PLA\_REAL} = 5910.02$ MPa

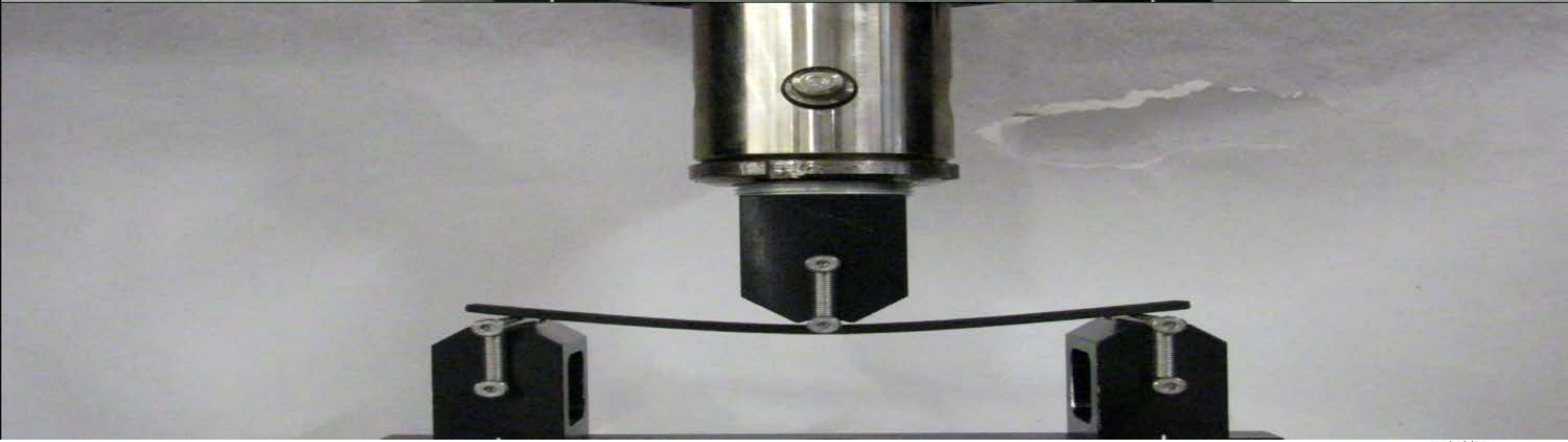


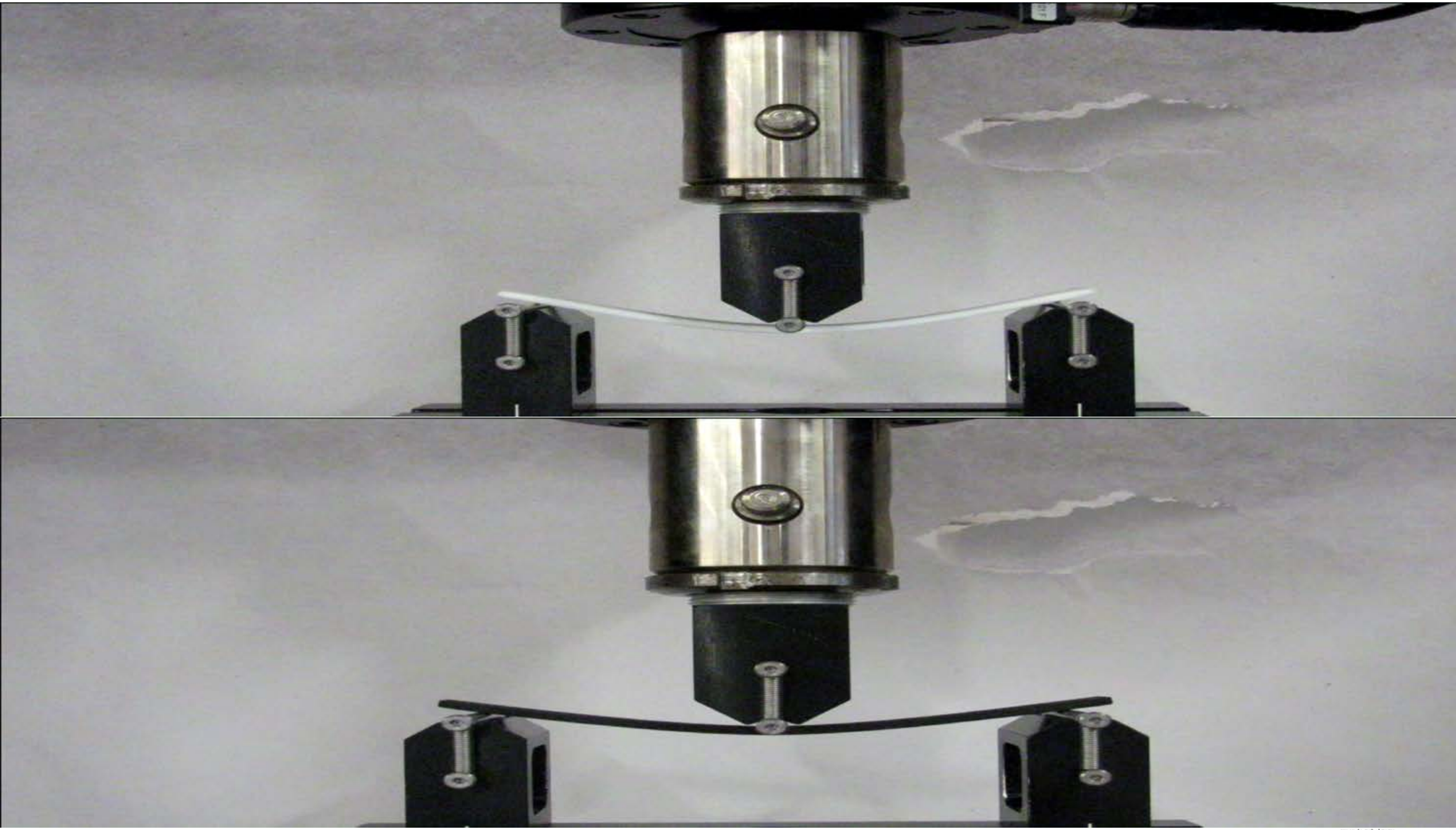




Res







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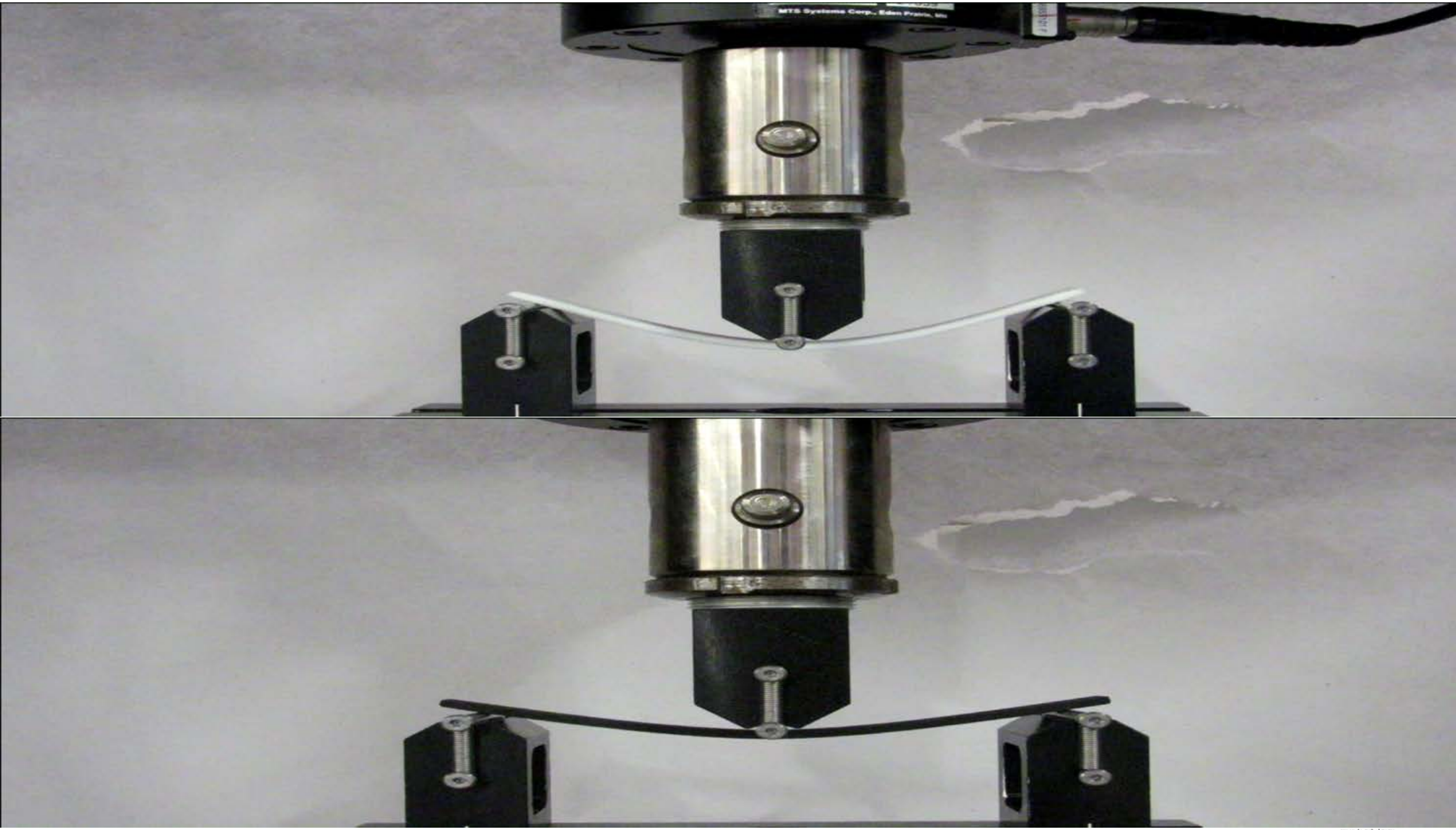
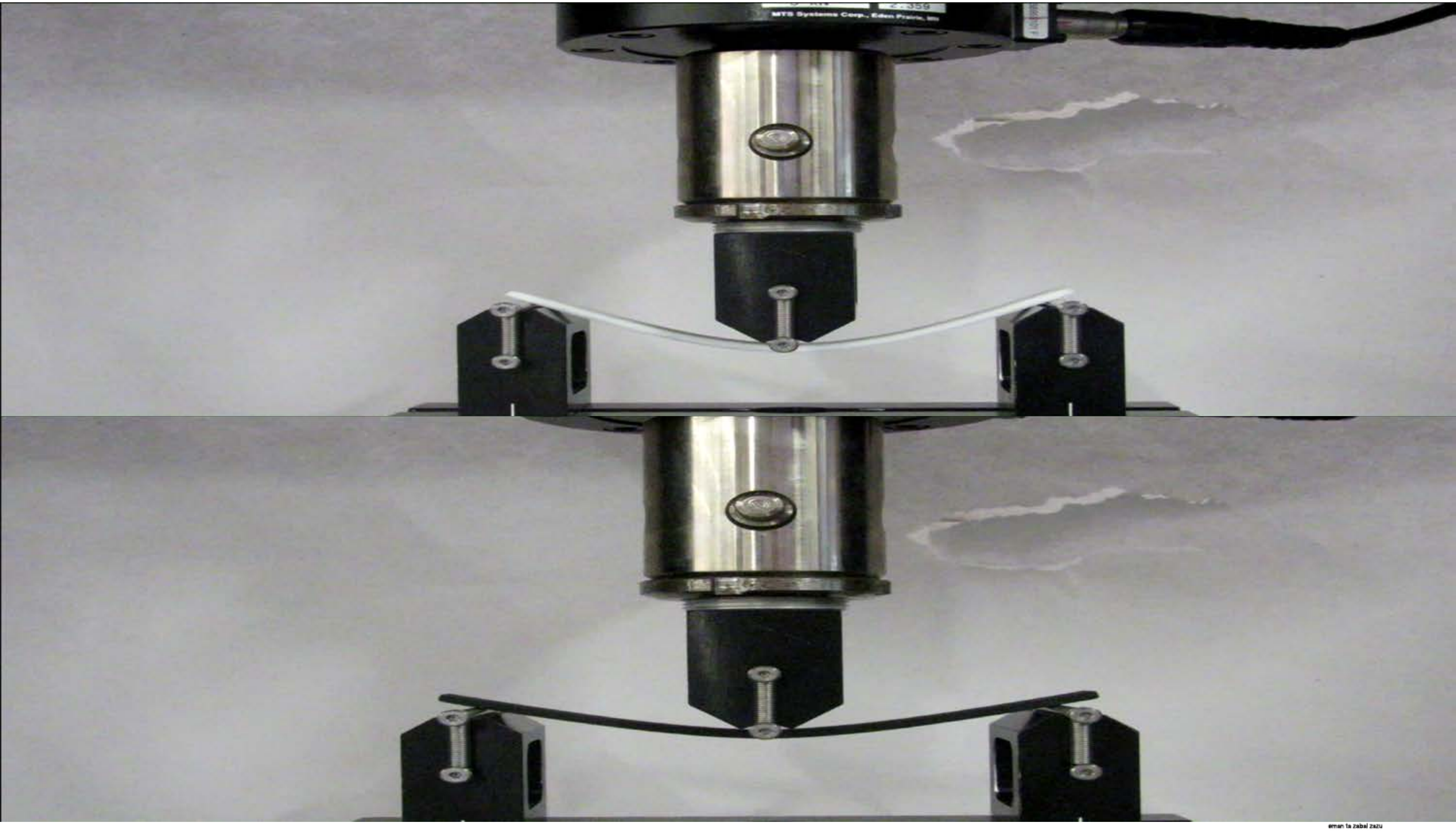


eman ta zabal zazu



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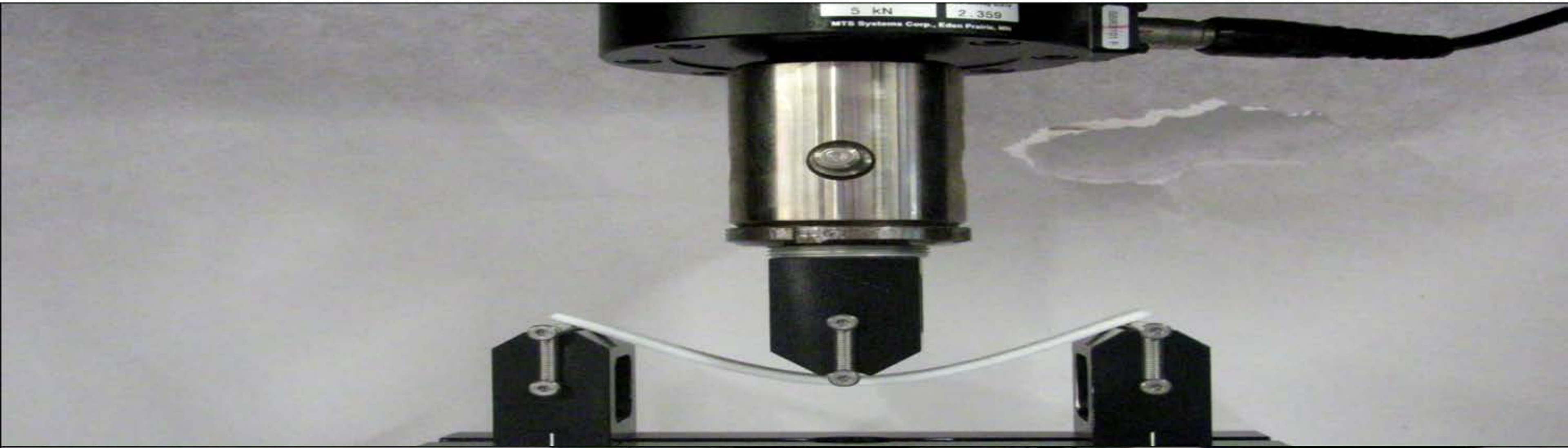

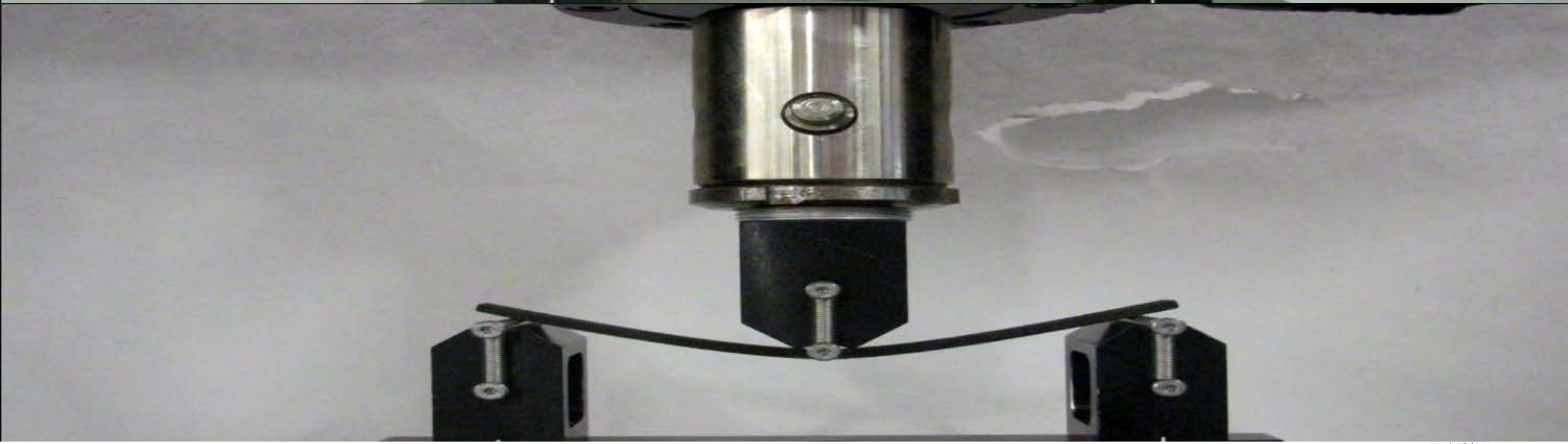

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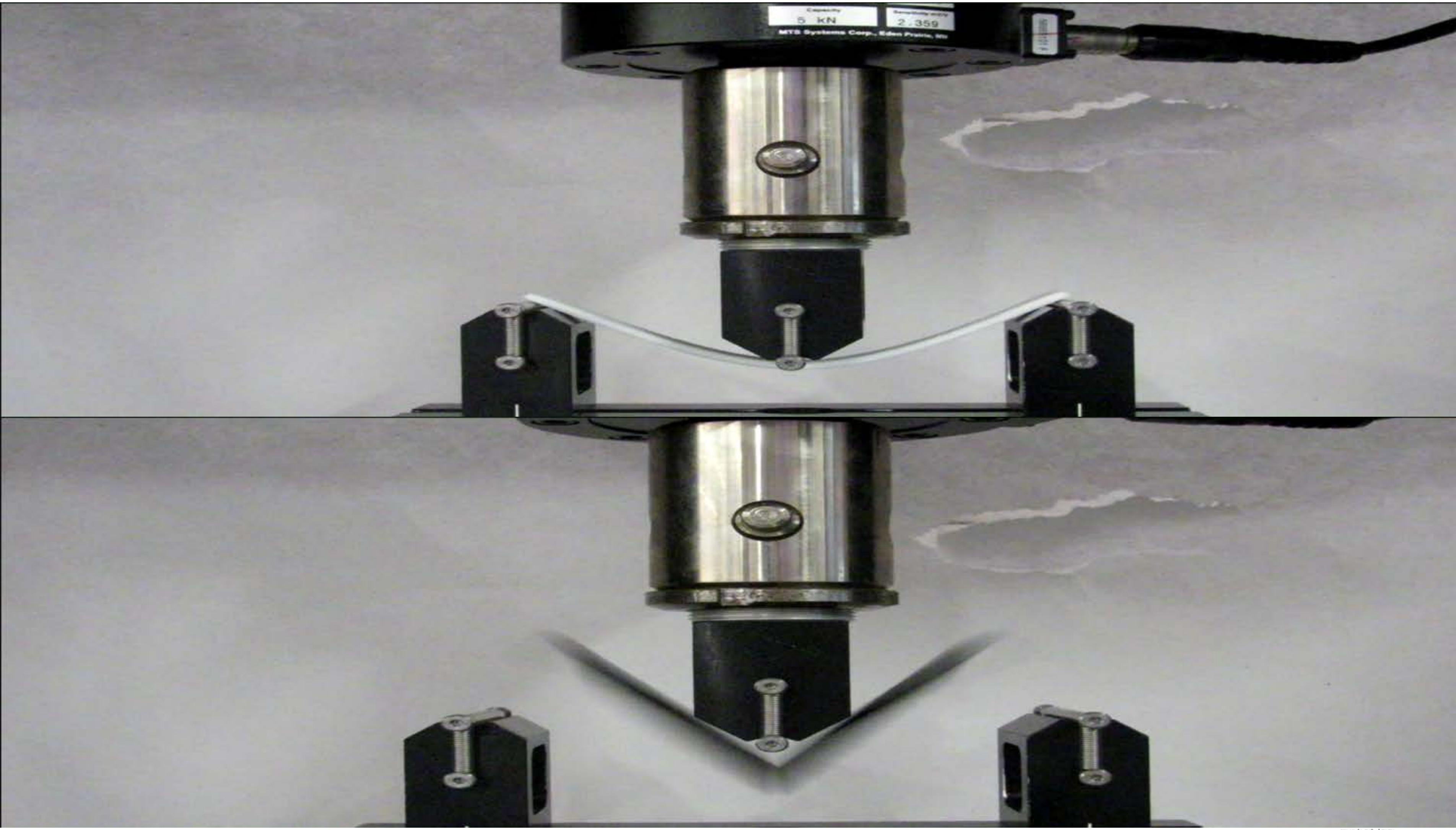
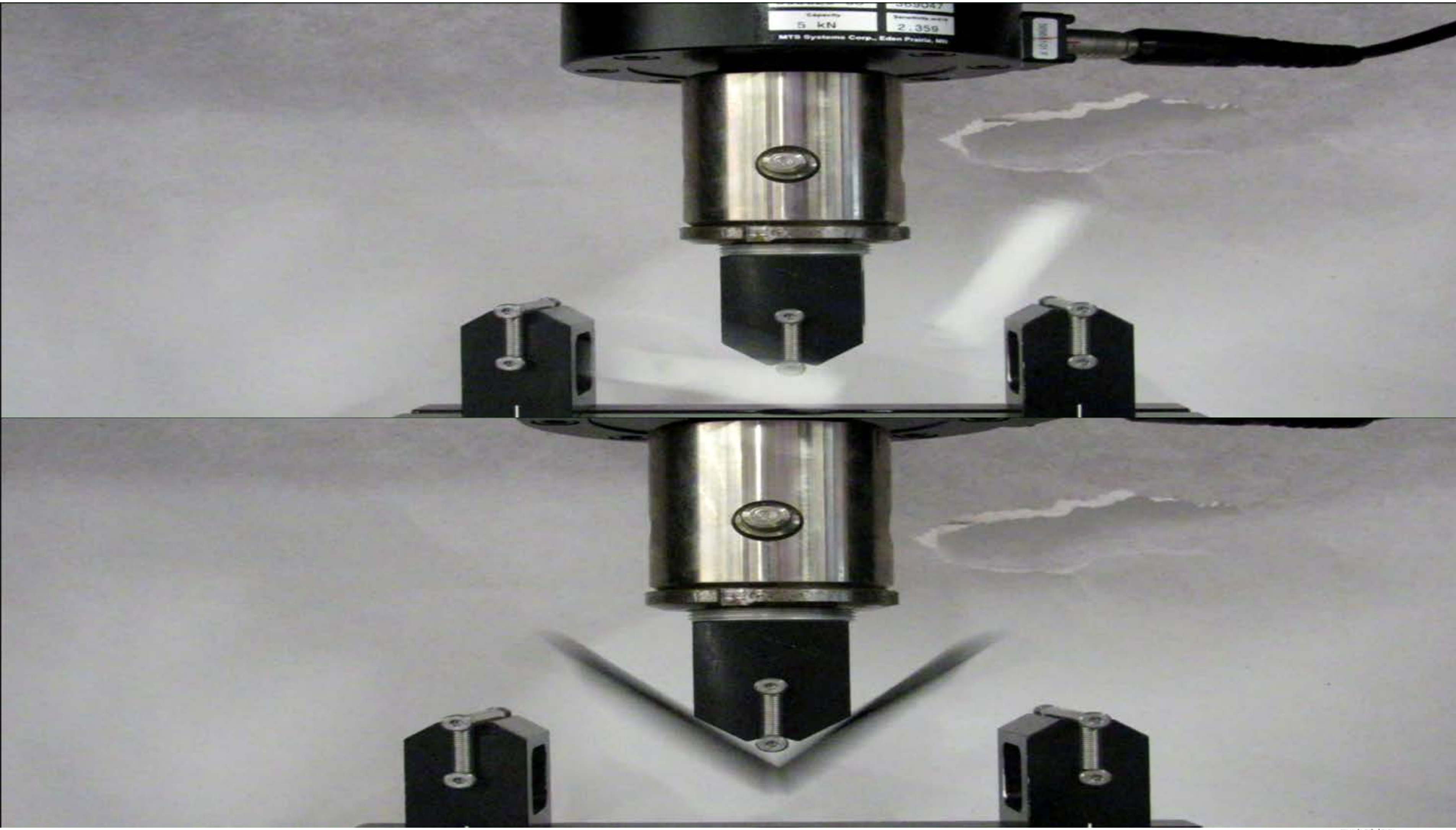

Capacity
5 kN
2.359
MTS Systems Corp., Eden Prairie, MN



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Conclusions

CF-PLA

1. Good compliance of expected material properties
2. Increase of flexural modulus → 83.16%
3. Adequate to the use as low impacts materials for renewable structures

Still a long way

Future

1. Closer approximation to aluminium
2. Shear modulus and other mechanical modulus calculation for deeper researches

Thank you for your attention