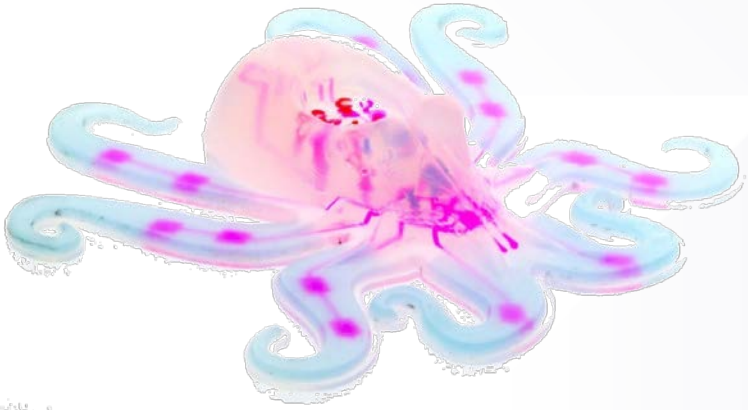
Design strategy of metal alloys for robust bonding between hydrogels

Seoul National University

Won Jun Song, Min Seok Kim

Hybrids of soft and rigid components



So far, rigid-bodied robots and soft-bodied robots
have been actively researched

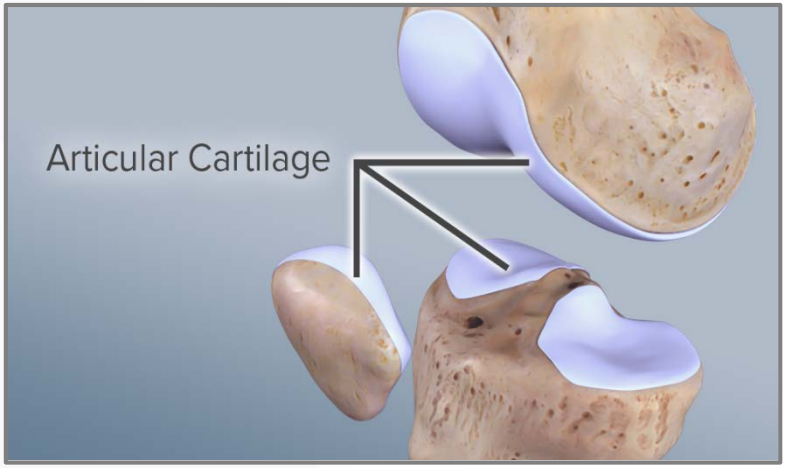
Michael Wehner, et.al. *Nature* (2016)

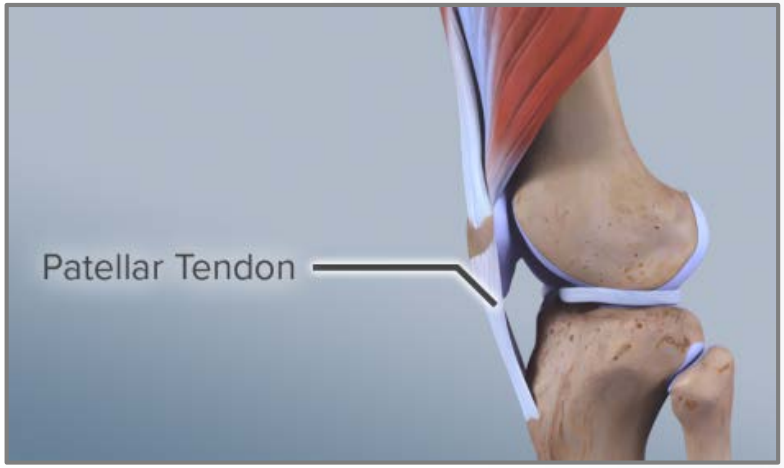
Hybrids of soft and rigid components

However, little research has been done on hybrid robots

Michael Wehner, et.al. *Nature* (2016)

Hybrids of soft and rigid components





In nature, hybrids of soft and rigid components generate synergy

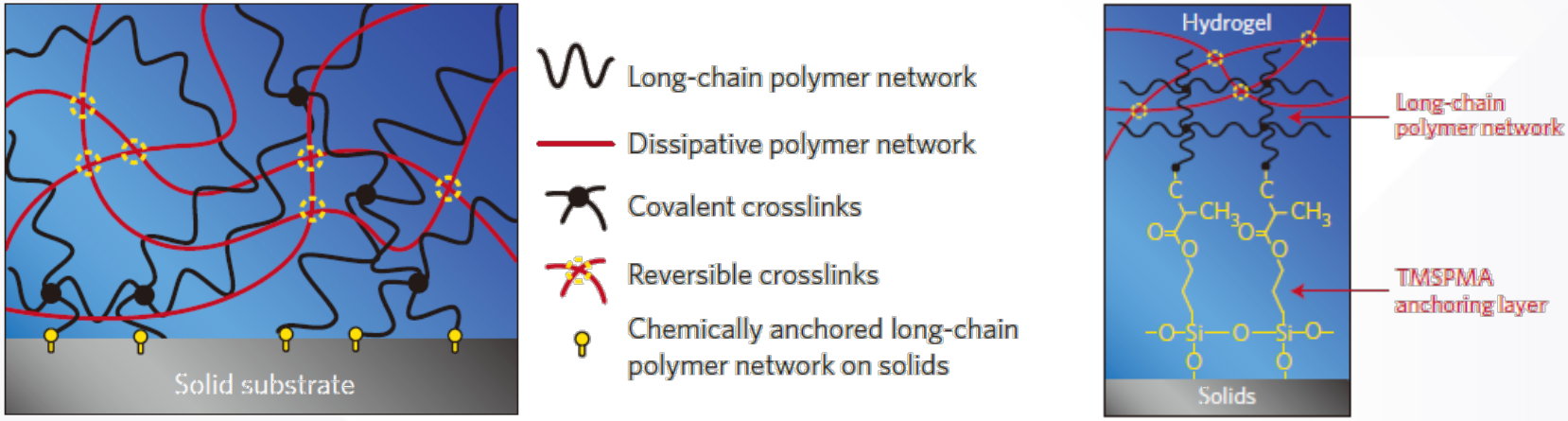
Tough interfaces between metals and hydrogels

Metal

Hydrogel

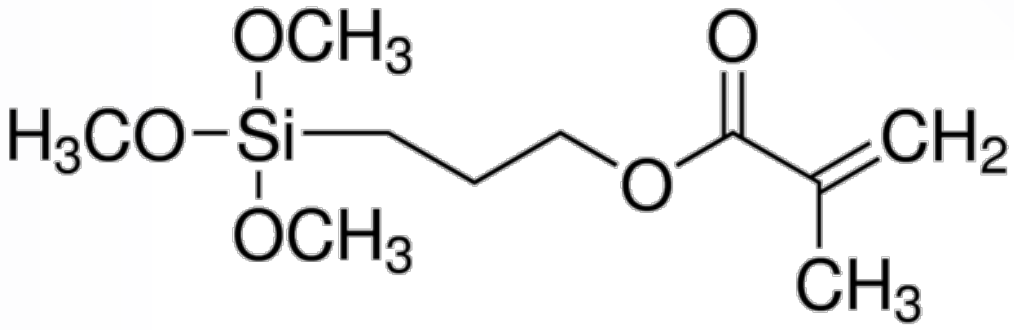
For hybrid combinations of rigid and soft materials,
achieving tough interfaces is most important

Tough interfaces between metals and hydrogels



Hyunwoo Yuk, et.al. *Nature Materials* (2016)

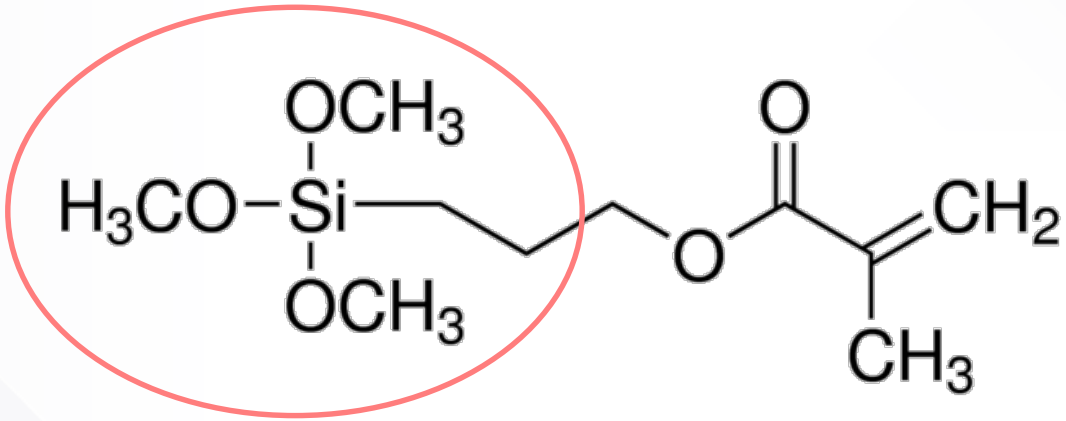
Tough interfaces between metals and hydrogels



3-(trimethoxysilyl) propyl methacrylate (TMSPMA)

Tough interfaces between metals and hydrogels

Covalently anchored
to solid substrate

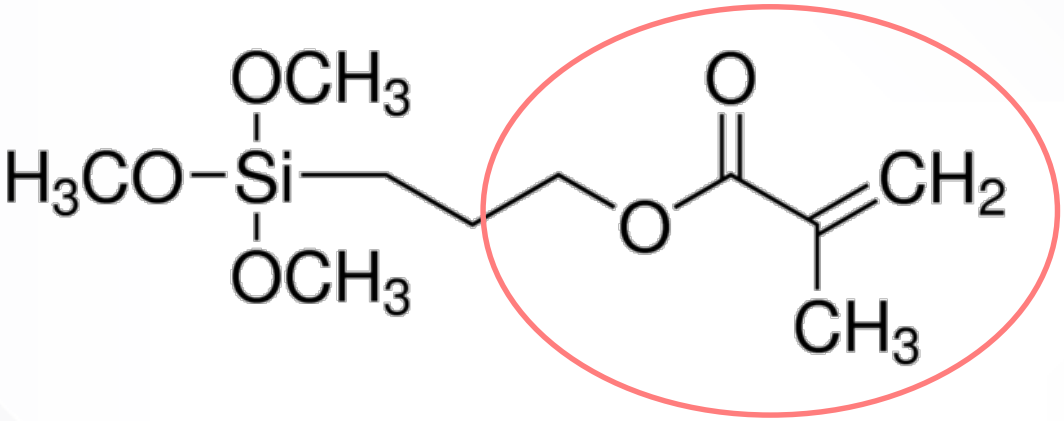


3-(trimethoxysilyl) propyl methacrylate (TMSPMA)

Tough interfaces between metals and hydrogels

Covalently cross-linked

to long chain polymer network



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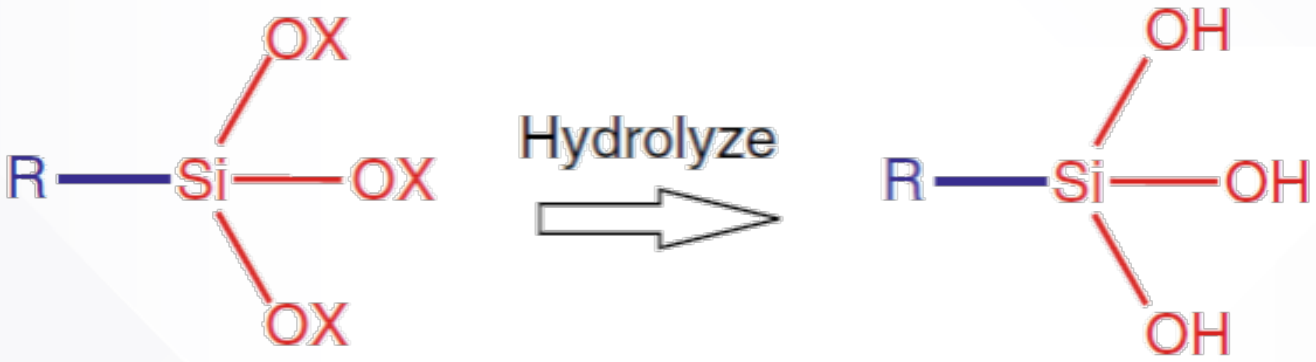

Qihan Liu, et.al. *Nature Communications* (2018)

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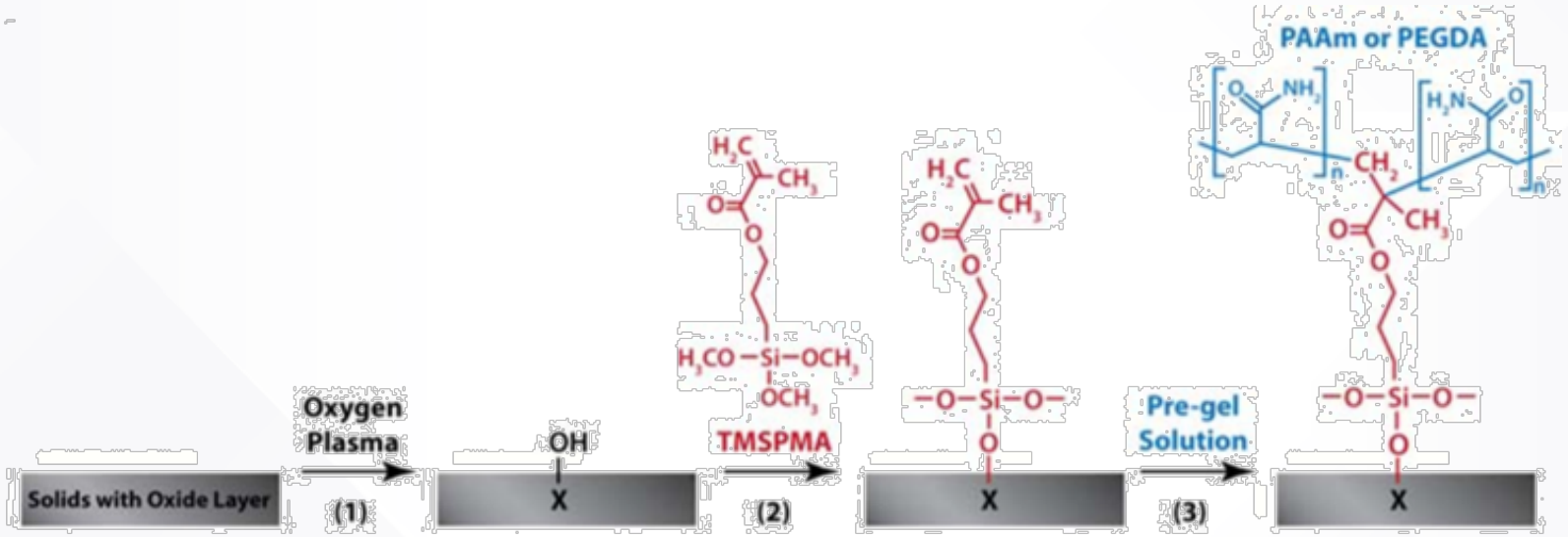

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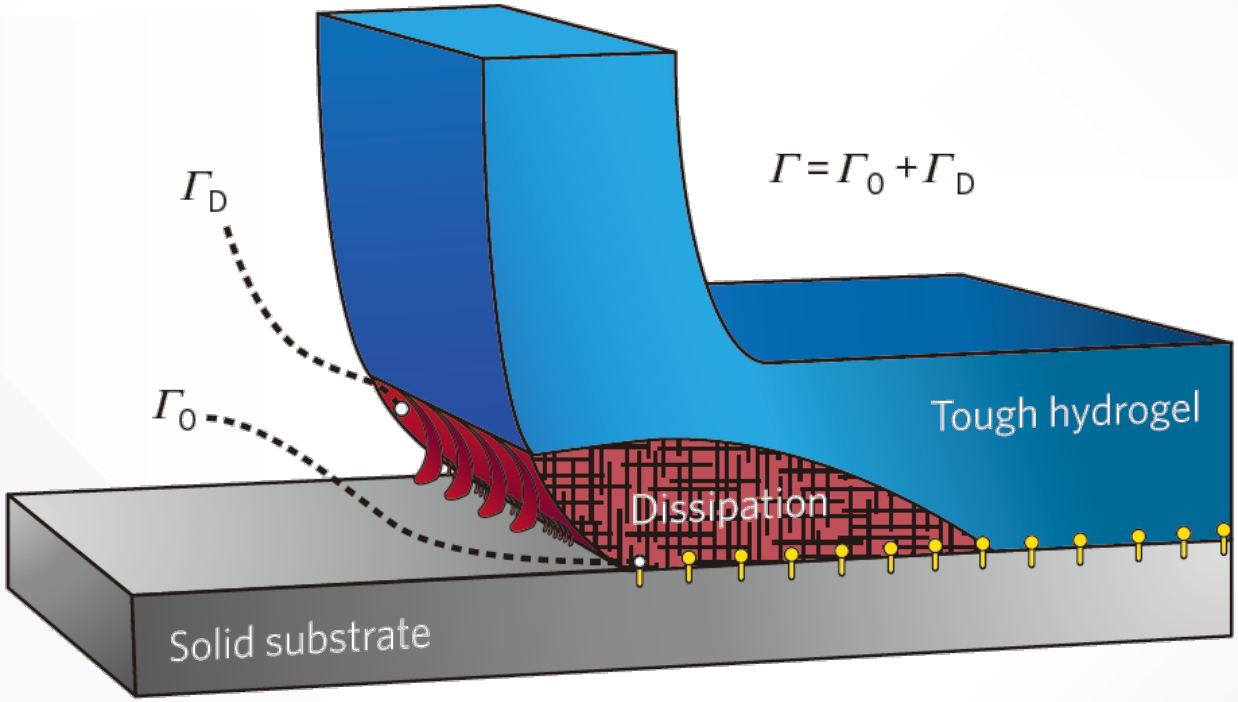

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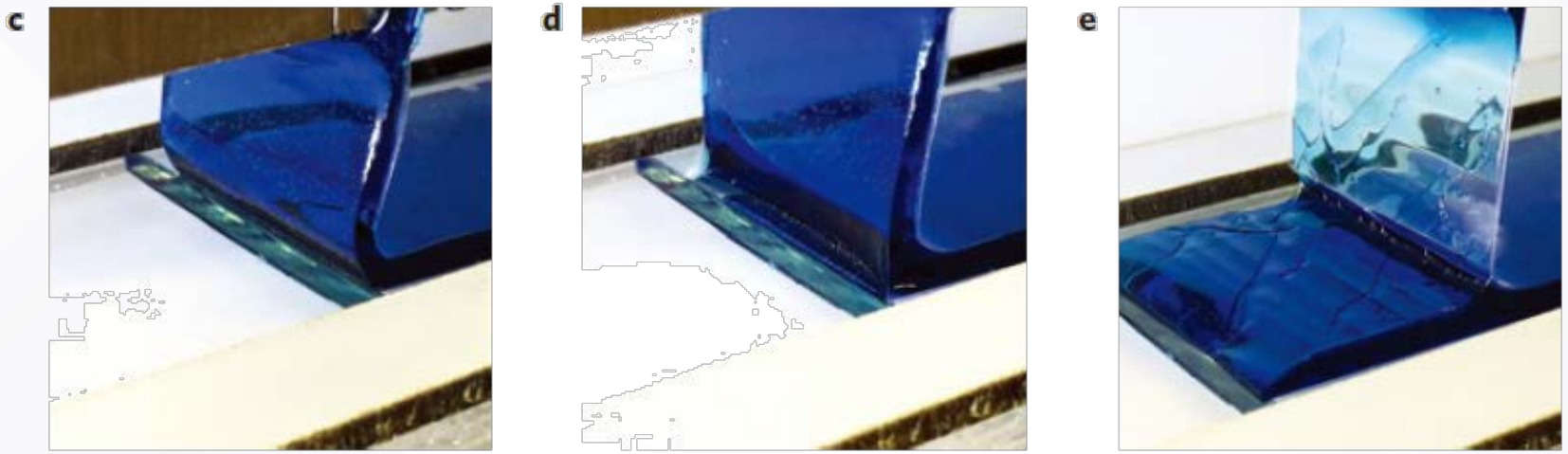

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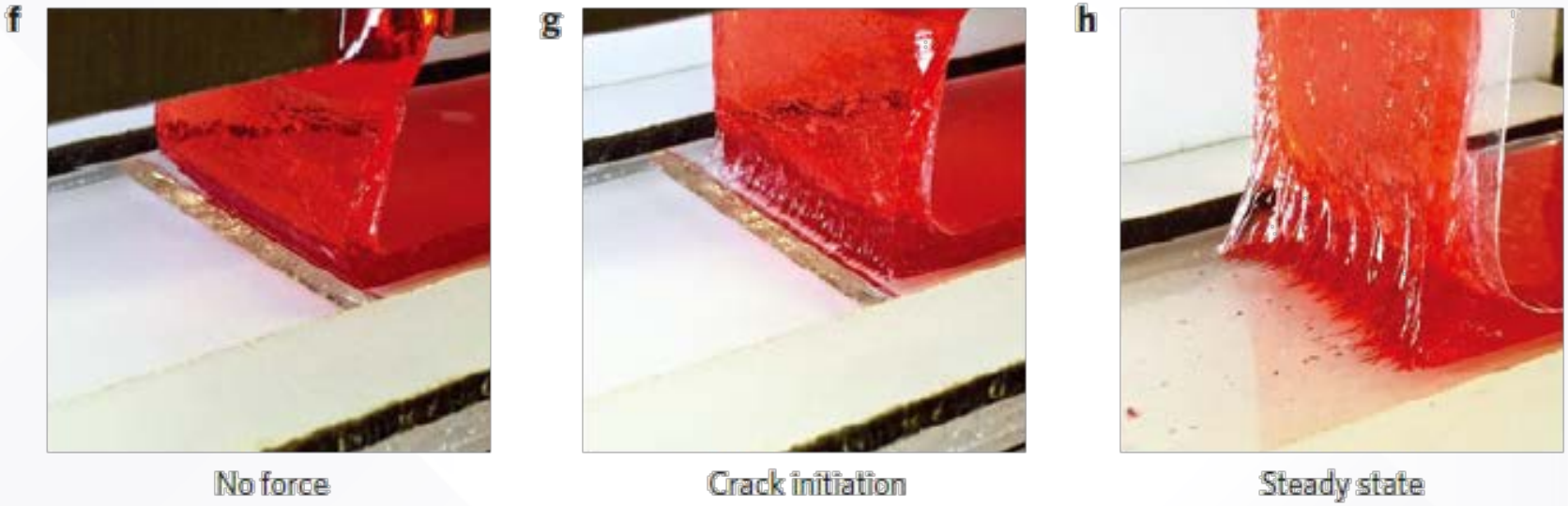

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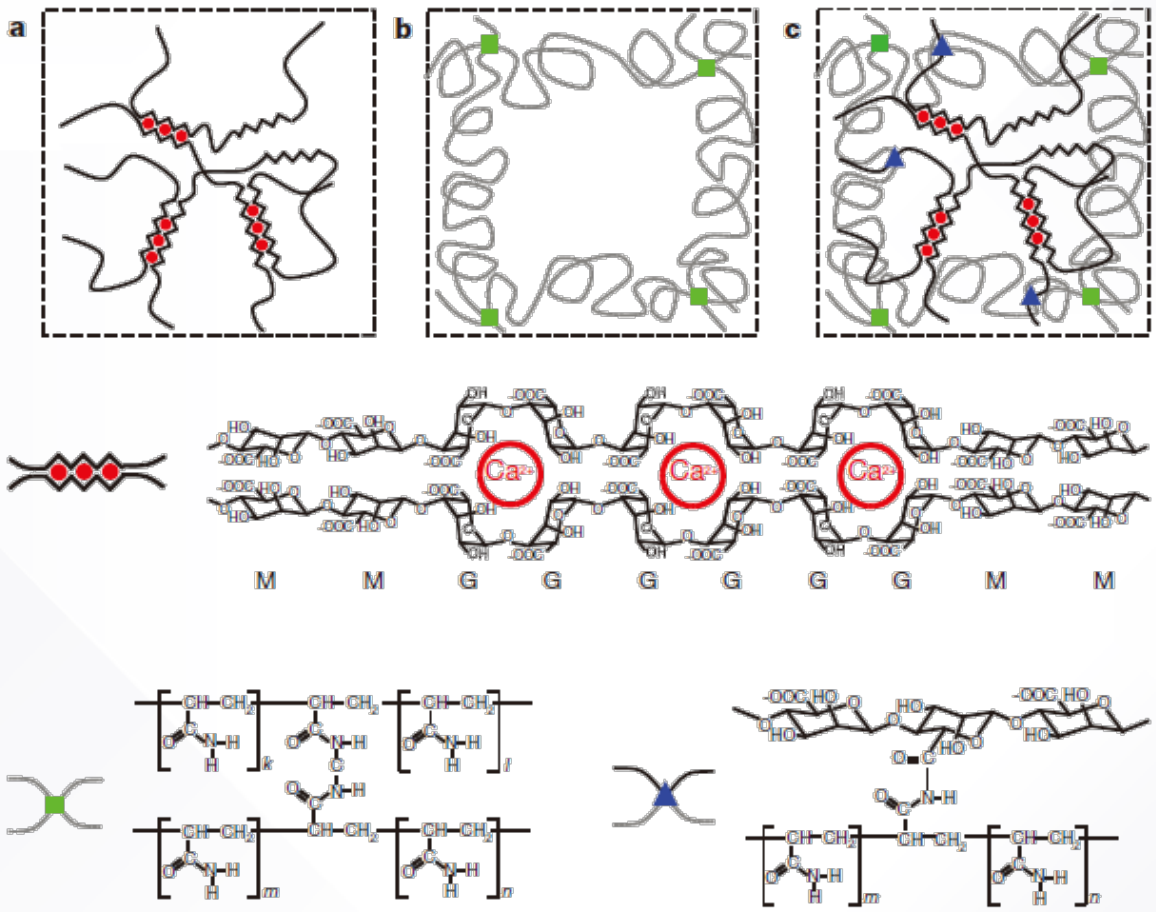

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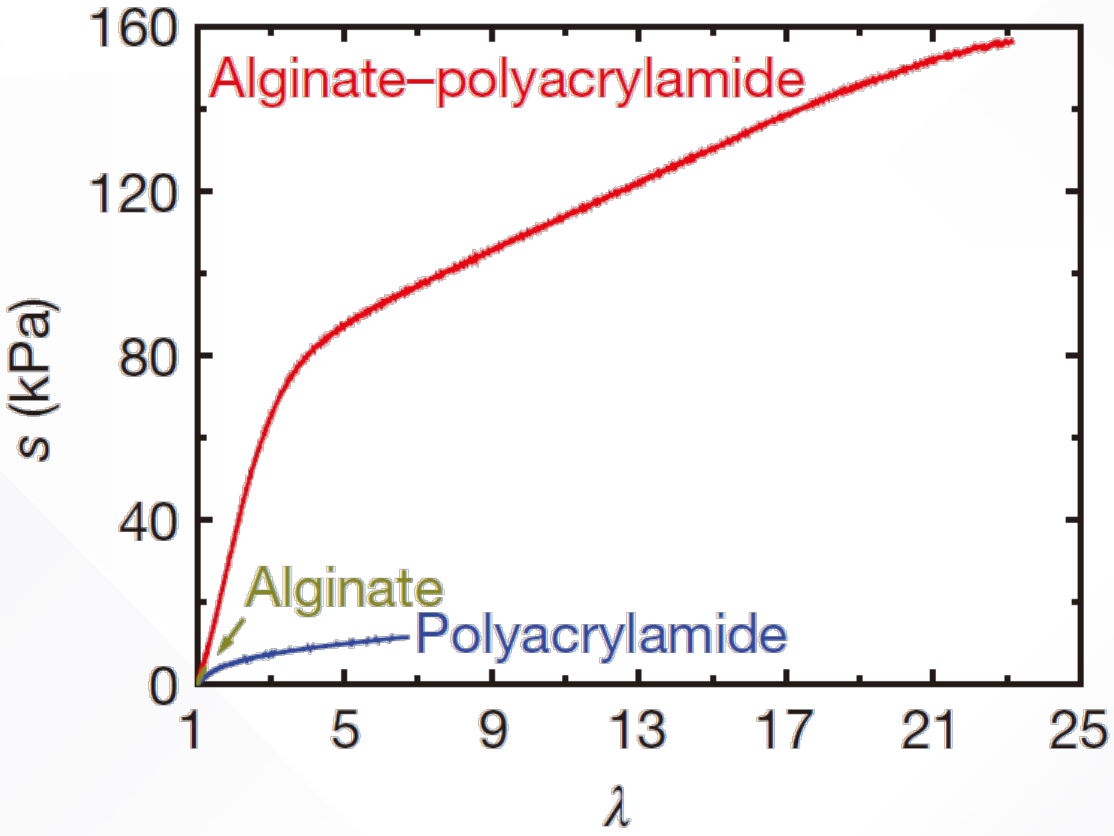

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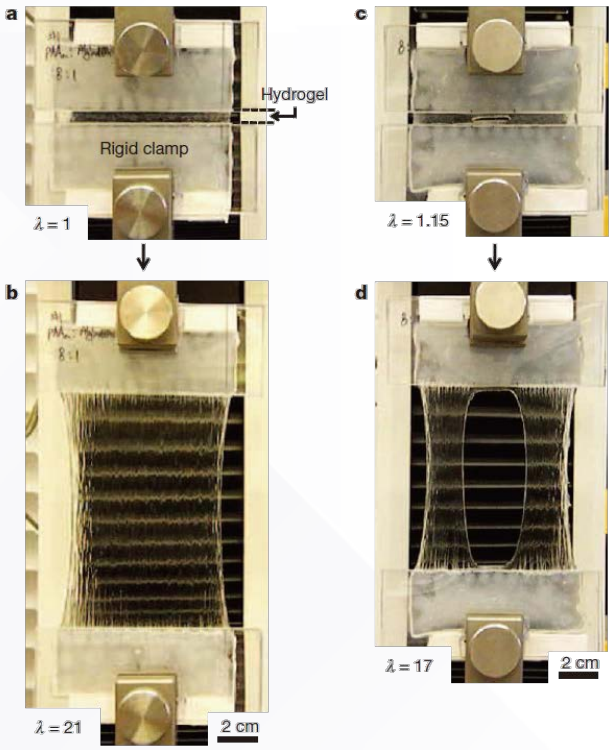

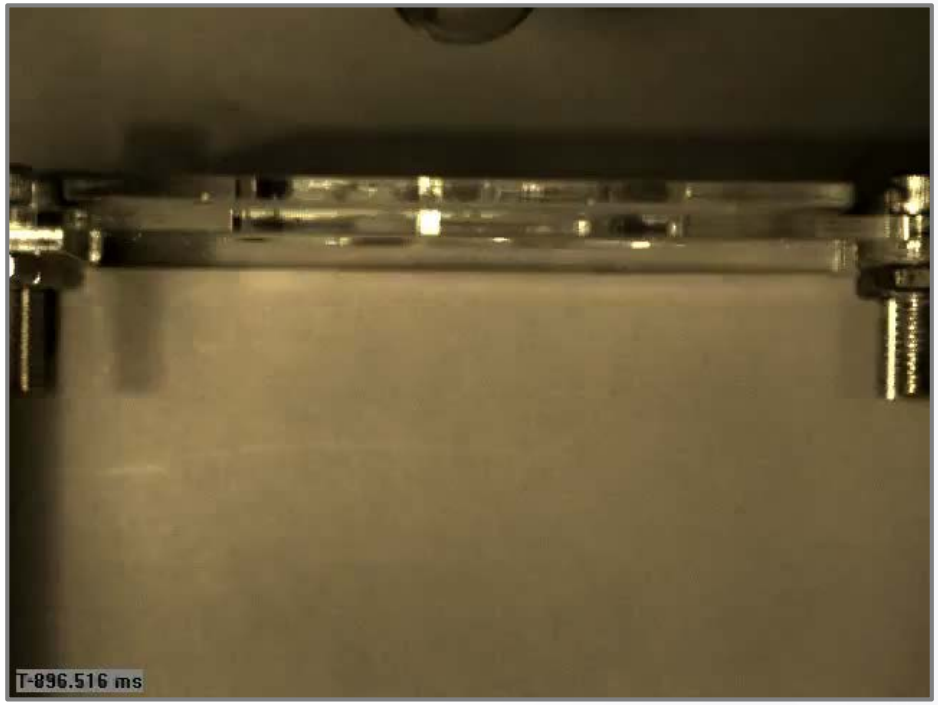

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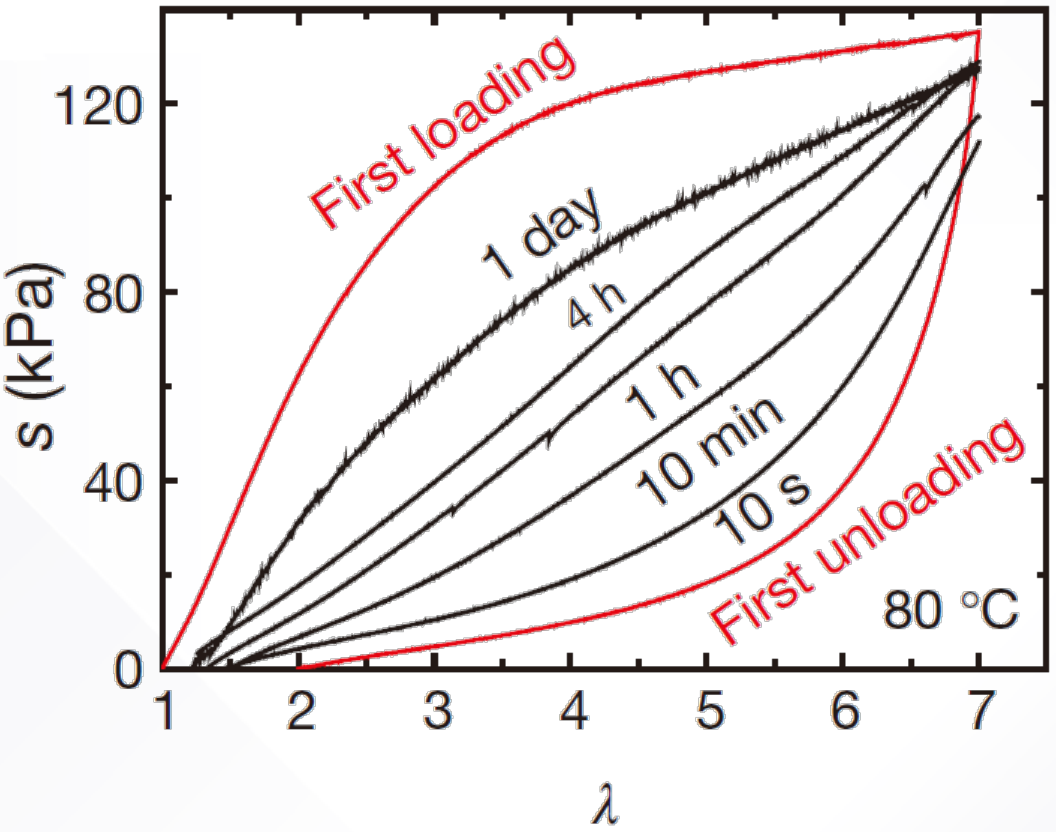

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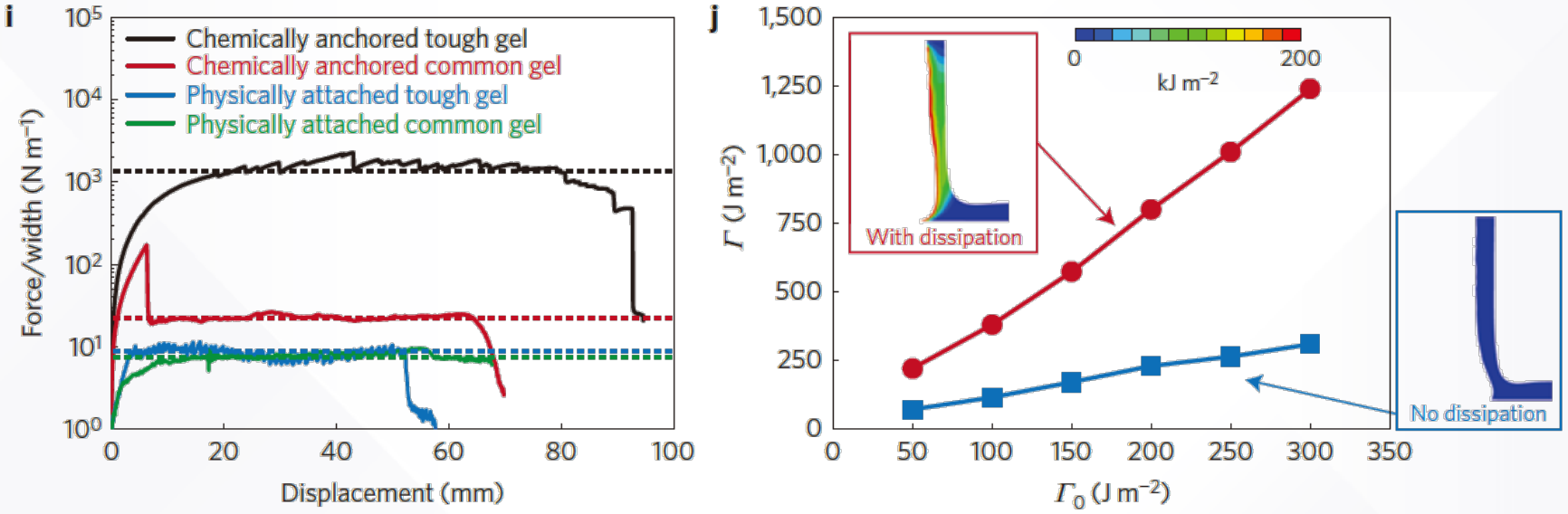

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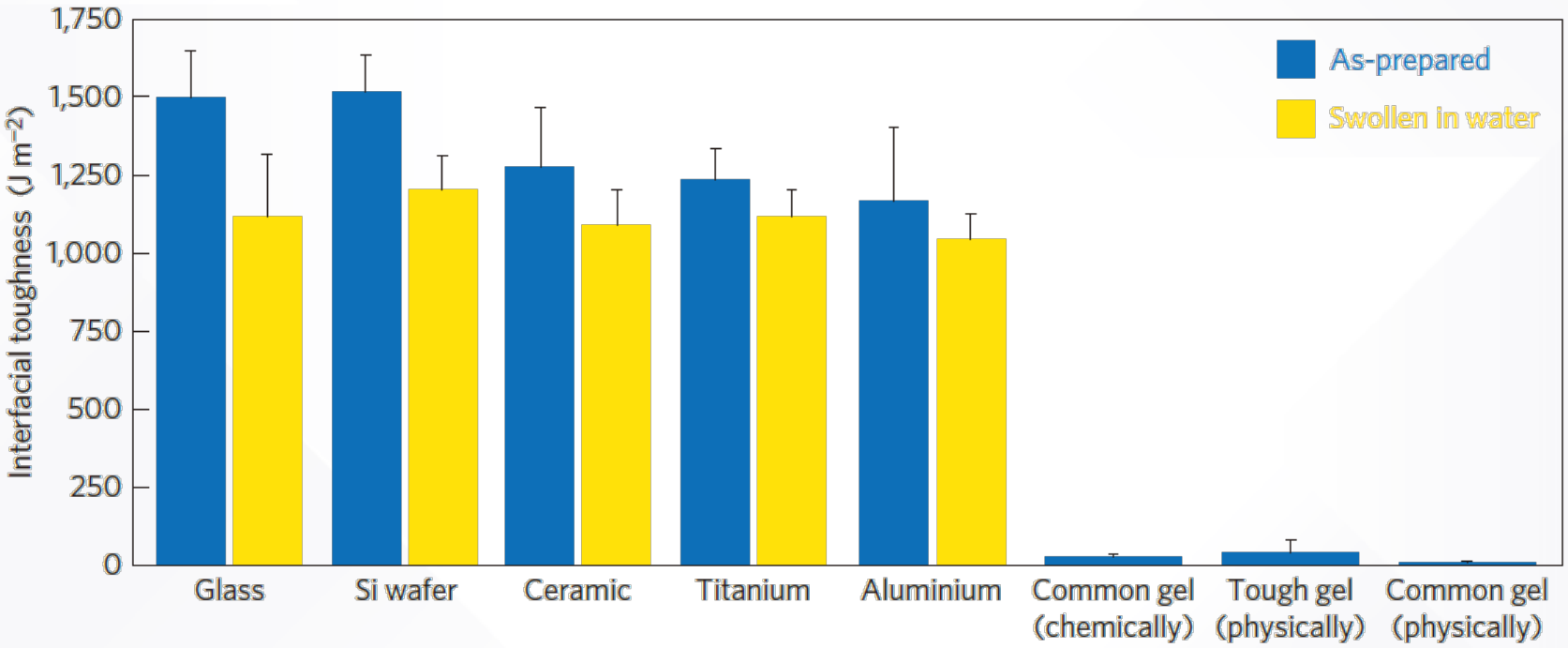

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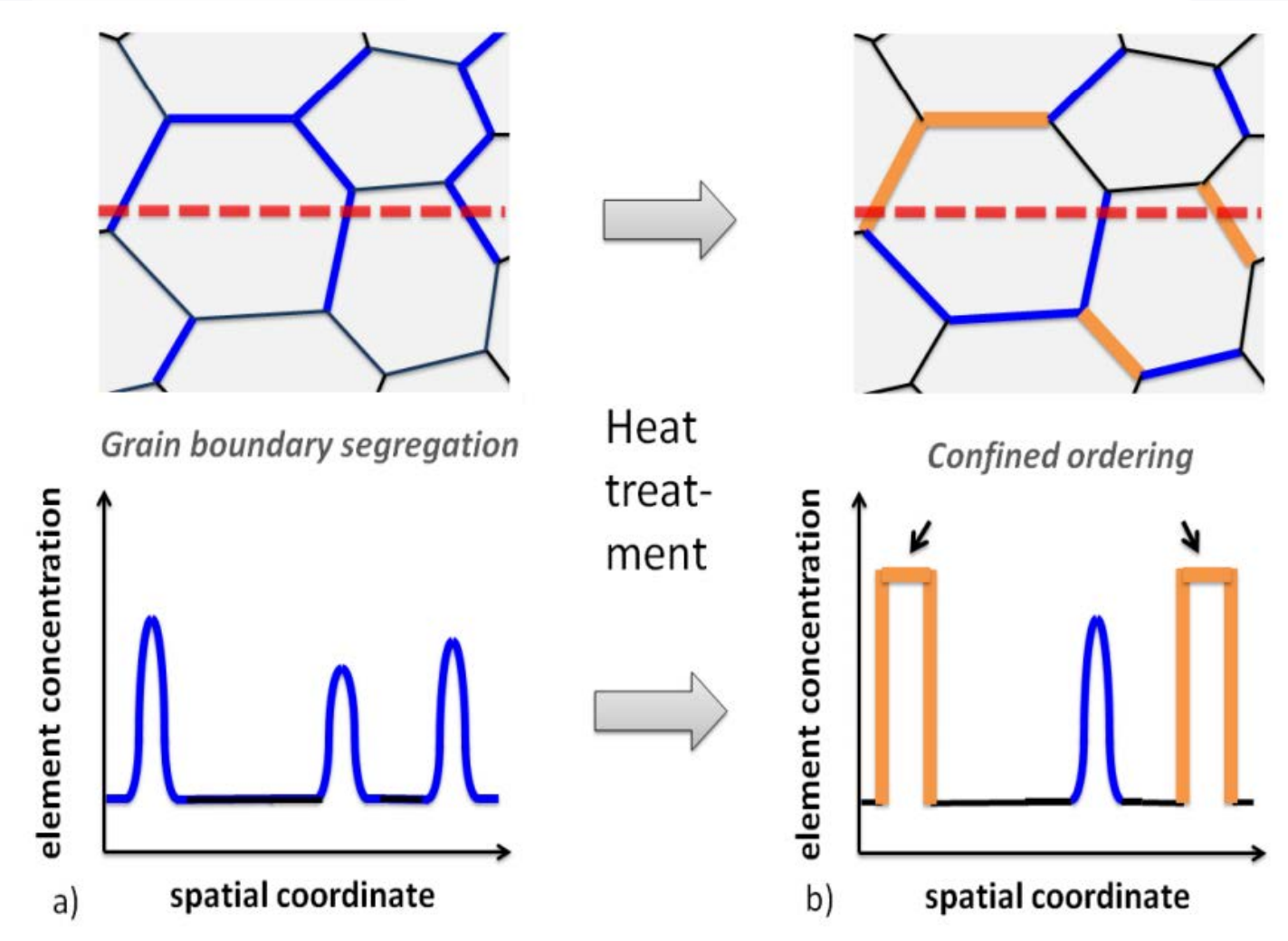
Segregation engineering

Segregation engineering



Alloy design

$$(Fe_{68.76}Cr_{10.73}Co_{7.67}Ni_{6.71}Al_{3.76}Mo_{1.62}W_{0.75})_{98}X_2\ (at.\%)$$

Low Ni Maraging Steel

X = Cu, Ti, Mn ⟶ **High tendency to go to free surface**

$\Delta H_{segregation}$ (J/mol)		Solvent			
		Fe	Cr	Co	Ni
Solute	Cu	18932	16041	15989	12325
	Ti	22337	16737	17815	11767
	Mn	16605	15095	13781	10005

Alloy design

$\Delta H_{segregation}$ (J/mol)		Solvent			
		Fe	Cr	Co	Ni
Solute	Cu	18932	16041	15989	12325
	Ti	22337	16737	17815	11767
	Mn	16605	15095	13781	10005
	Fe	0	-1676	-527	-4765
	cr	3737	0	2720	-728

Alloy design

Question

1. Is the solute concentration sufficient for observing segregation effect?

2. GB segregation -> Free surface segregation?

Alloy design

Segregation engineering enables nanoscale martensite to austenite phase transformation at grain boundaries: A pathway to ductile martensite

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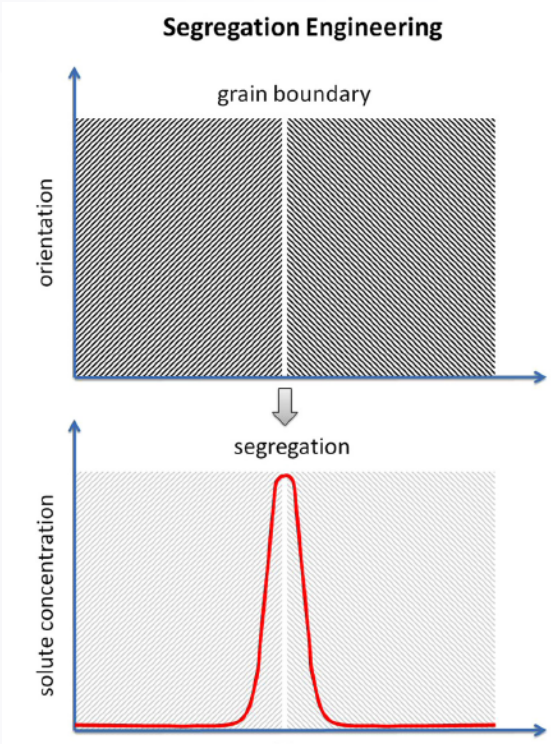
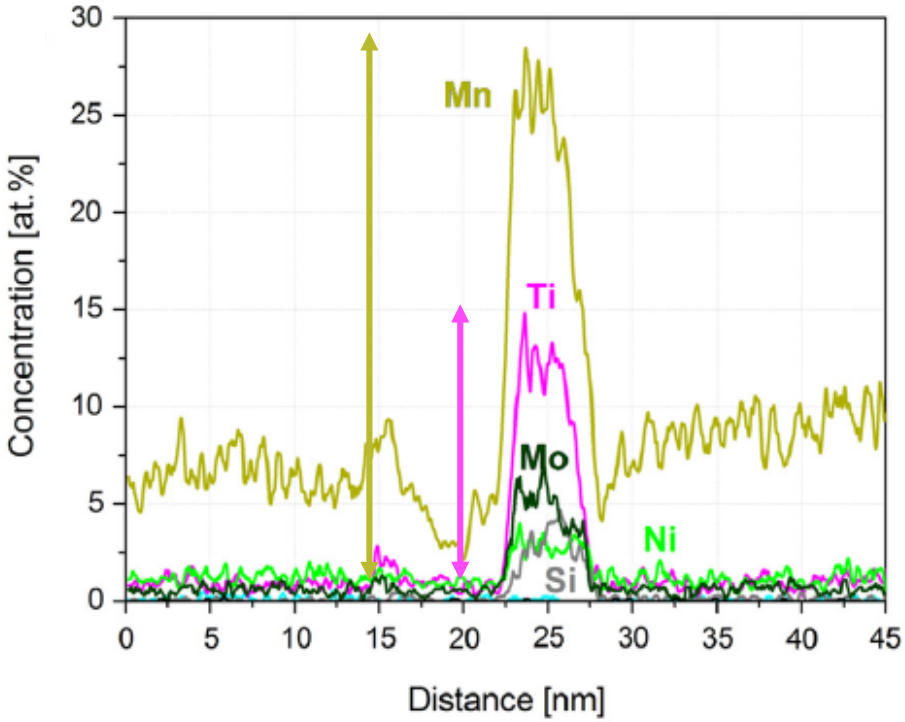




$(Fe_{68.76}Cr_{10.73}Co_{7.67}Ni_{6.71}Al_{3.76}Mo_{1.62}W_{0.75})_{98}X_2$ $(at.\%)$

$Fe - Mn_{12.2}\ Ni_{1.9}Mo_{0.6}\ Ti_{1.2}Al_{0.3}$,
$450\ C,\ 48\ h$

Alloy design

Question

1. Is the solute concentration sufficient for observing segregation effect?

2. GB segregation -> Free surface segregation?

Alloy design

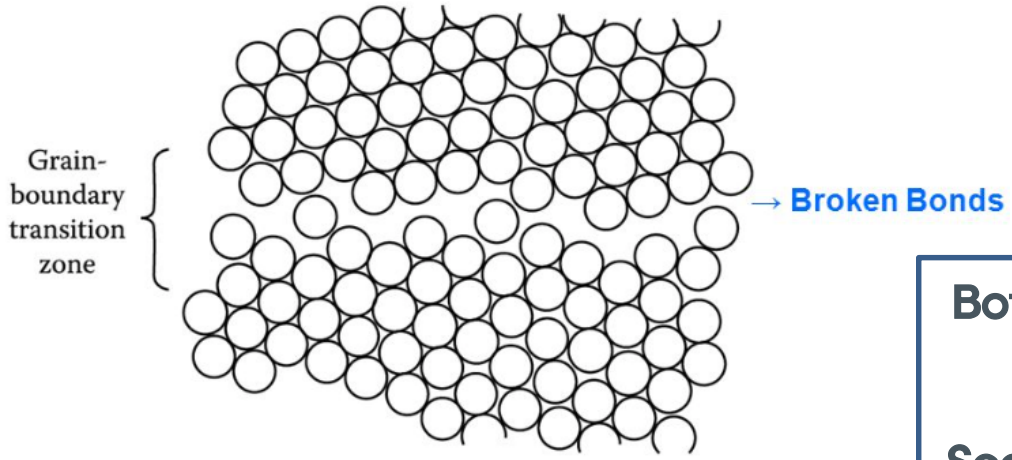
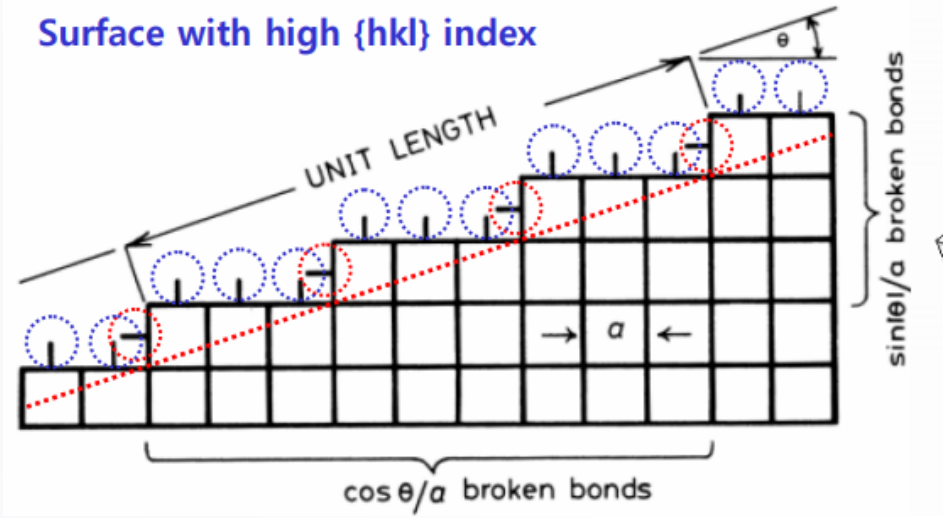


Fig. 3.10 Disordered grain boundary structure (schematic).



Both boundary energy comes from broken bonds

Segregation phenomenon occurs to lower the boundary energy

High GB segregation tendency
-〉 High free surface segregation tendency (in general)

Alloy design

$\Delta H_{segregation}$ (J/mol)		Solvent	
		Cu	Pd
Solute	Cu	0	10747
	Pd	-12850	0

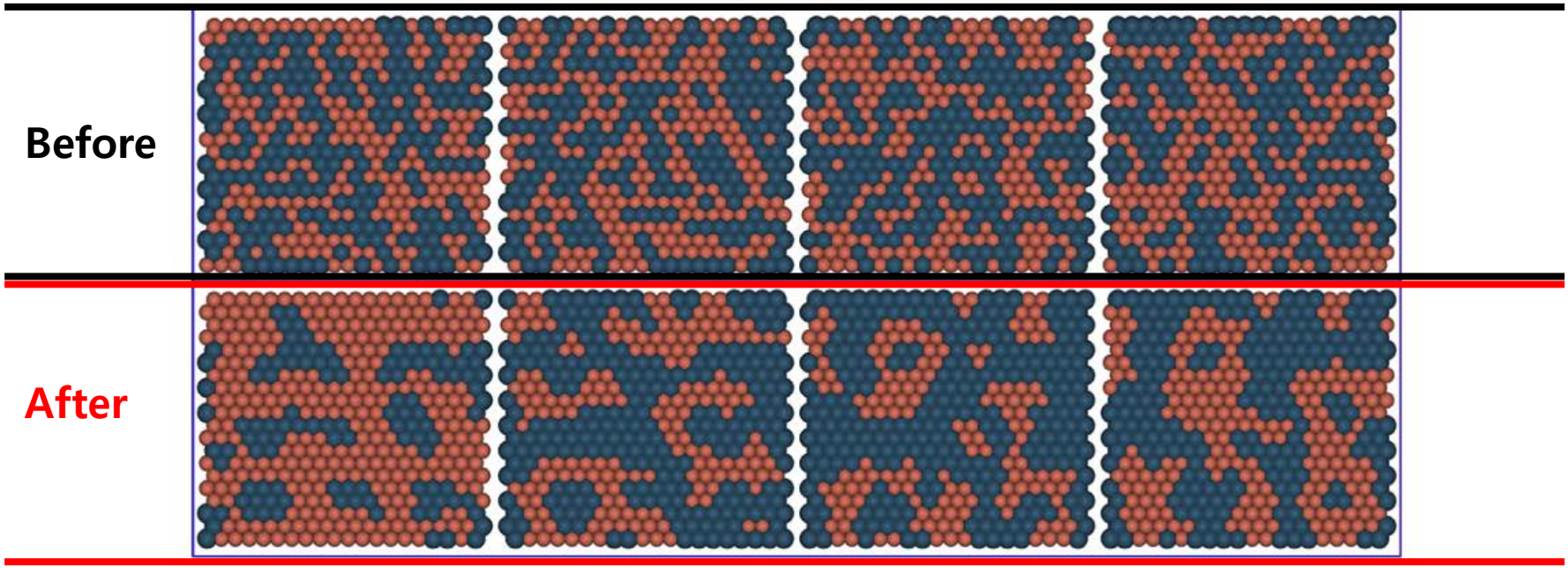
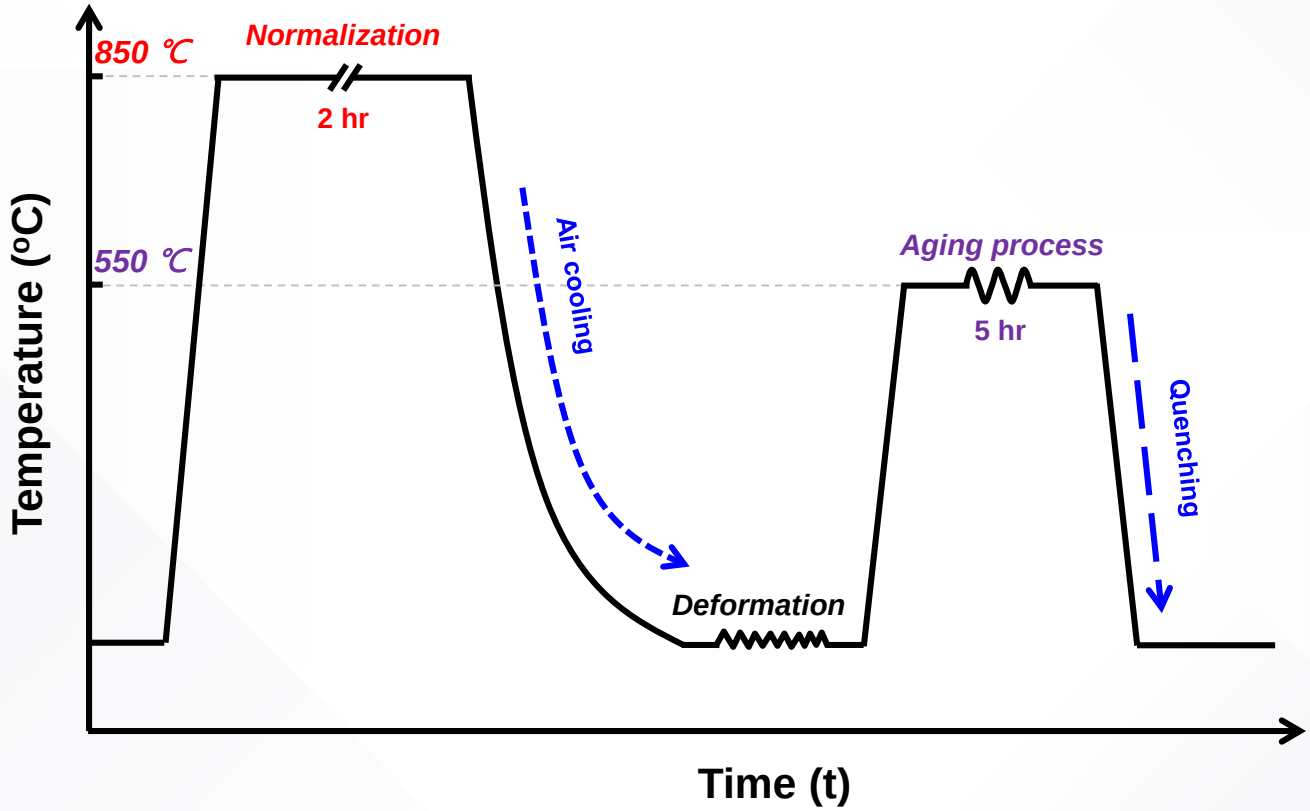
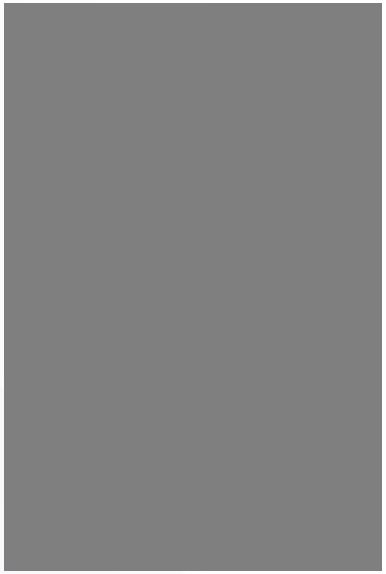


Fig. 4. Atomic arrangements of the top four layers (from left to right: 1st to 4th layer) of 52% Pd–Cu alloy. Upper panels are initial configurations and lower ones are annealed after 20 min at 500 K. Red spheres: Cu; dark blue: Pd. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Processing design



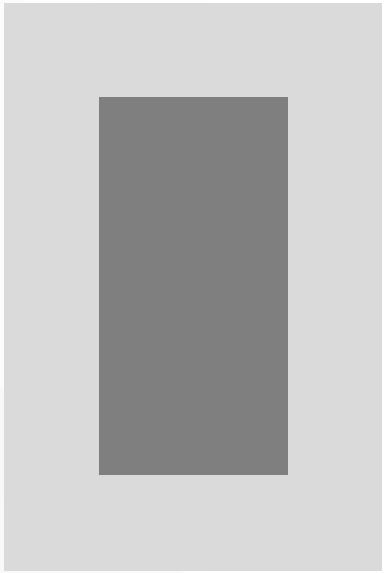
Tough interfaces between metals and hydrogels



Top view

Cross section

Tough interfaces between metals and hydrogels



Top view

Cross section

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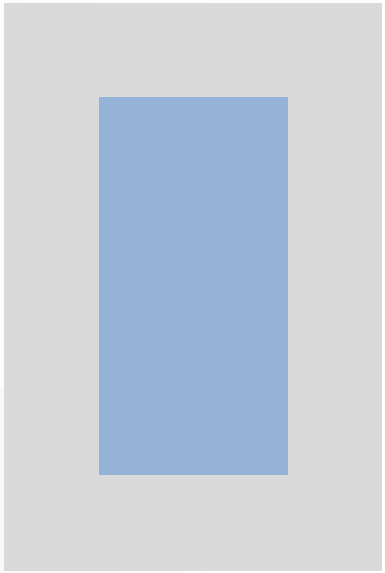

Top view

Cross section

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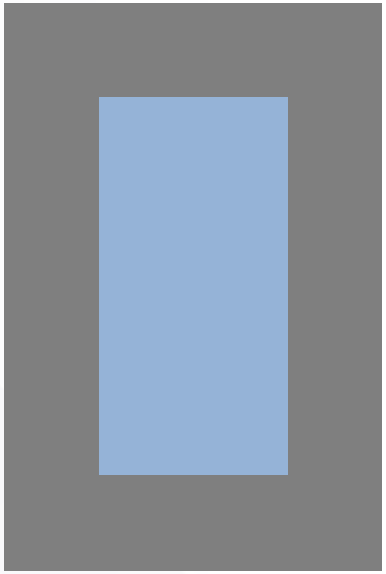

Top view

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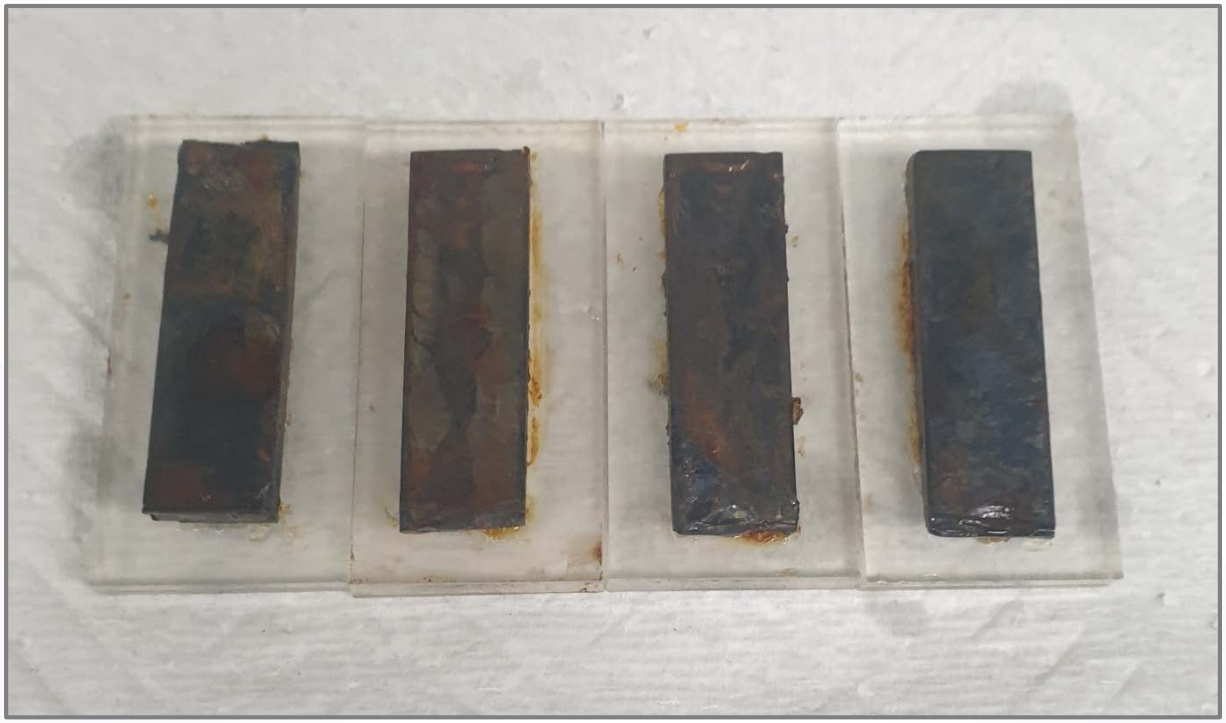

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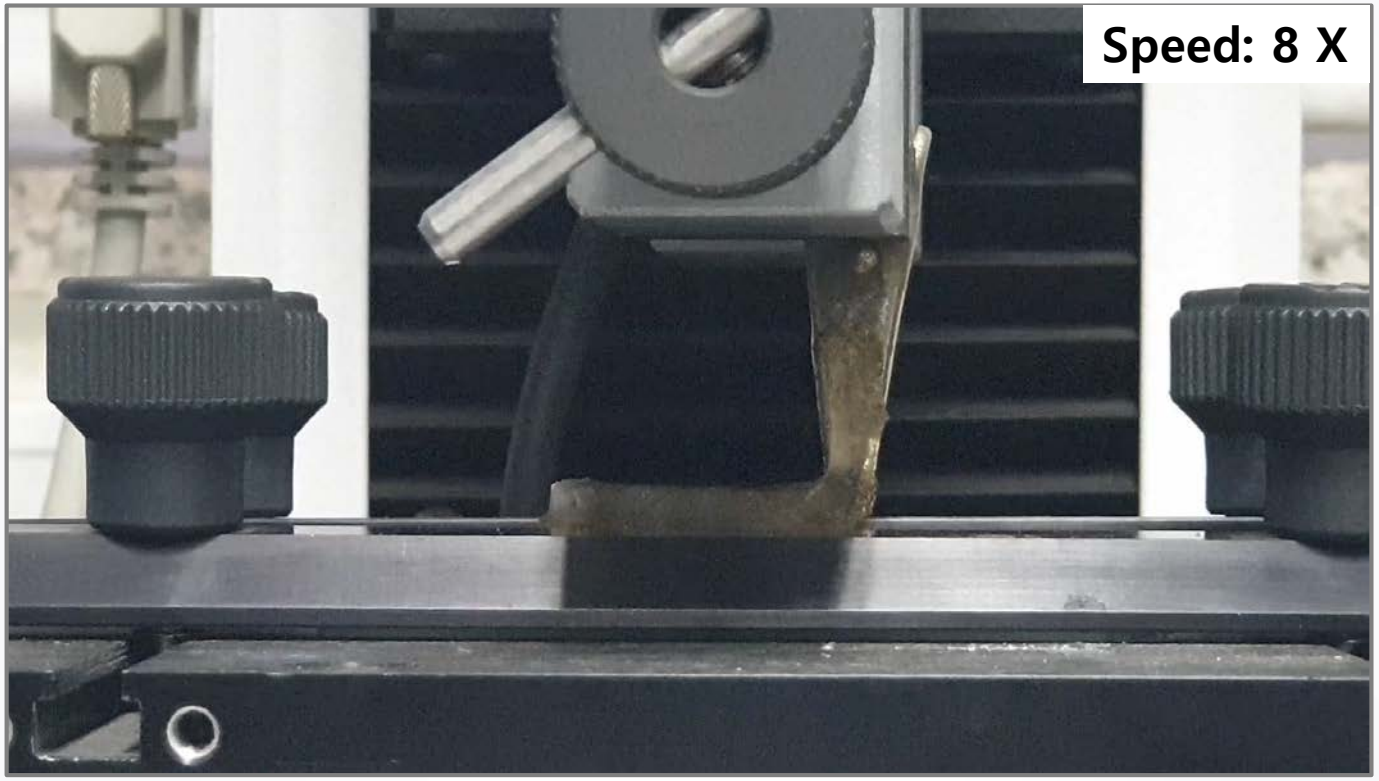
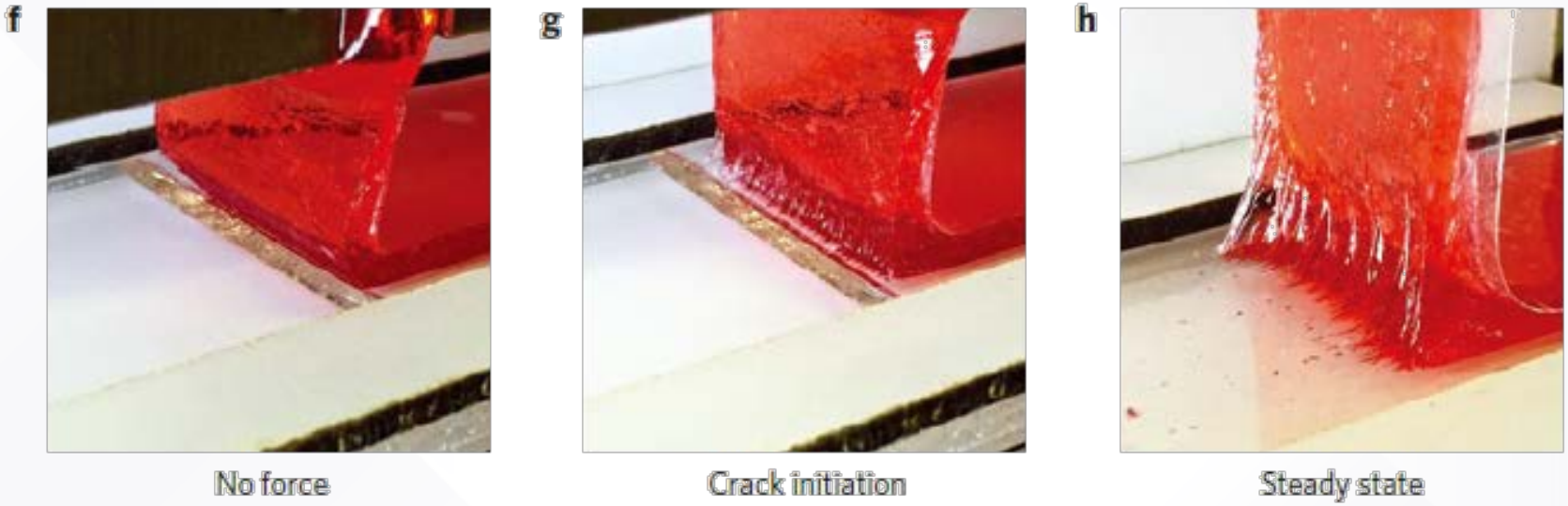


Strain rate: 1 cm/min

Tough interfaces between metals and hydrogels



Hyunwoo Yuk, et.al. *Nature Materials* (2016)

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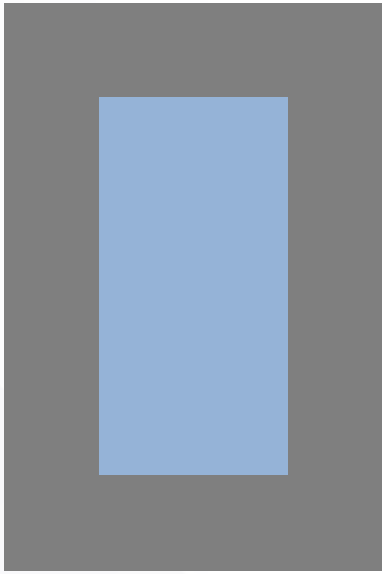

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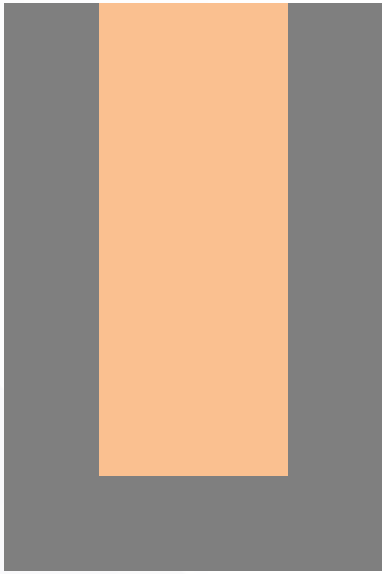

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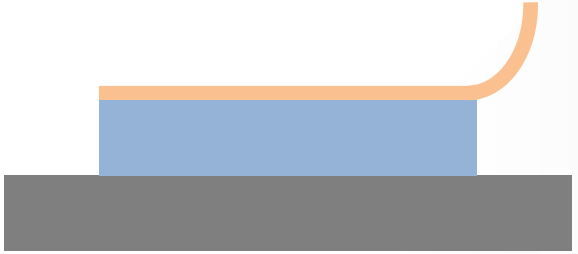

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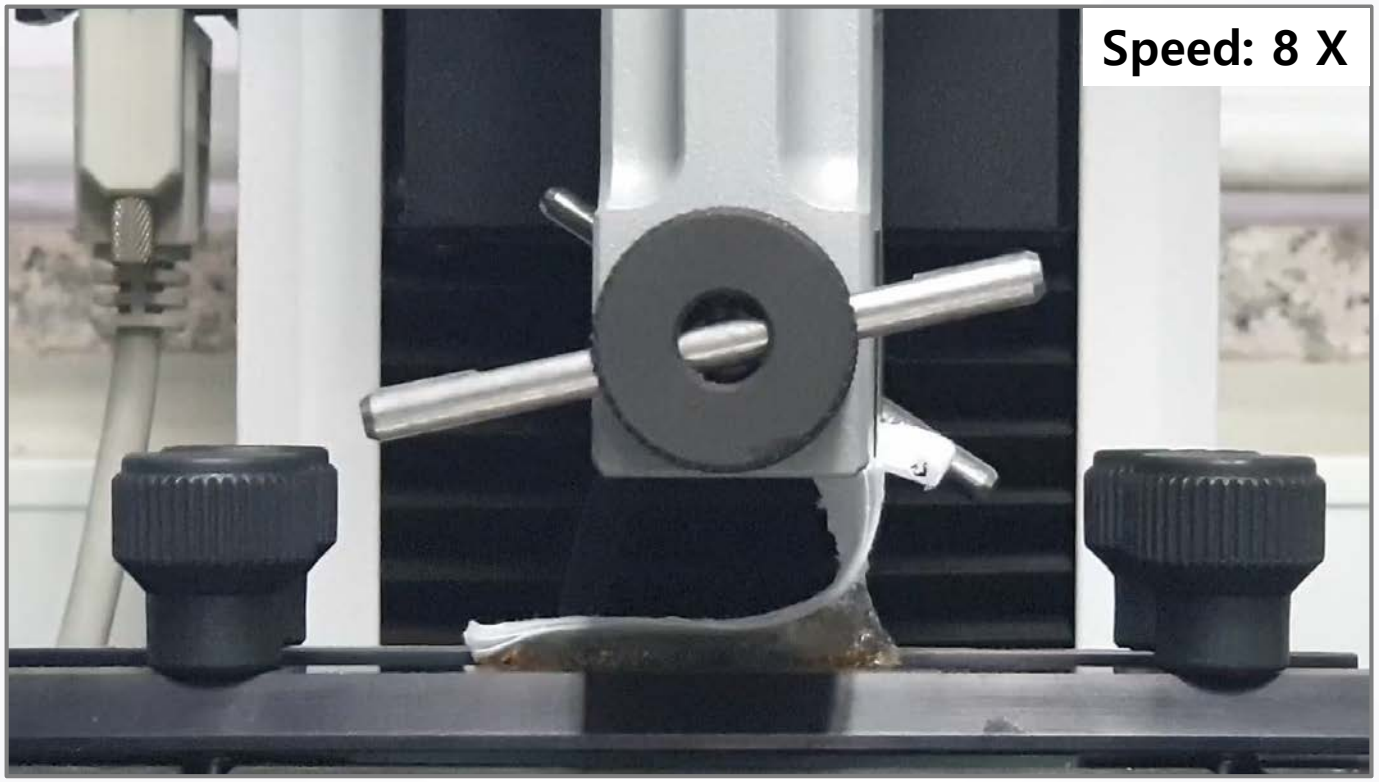

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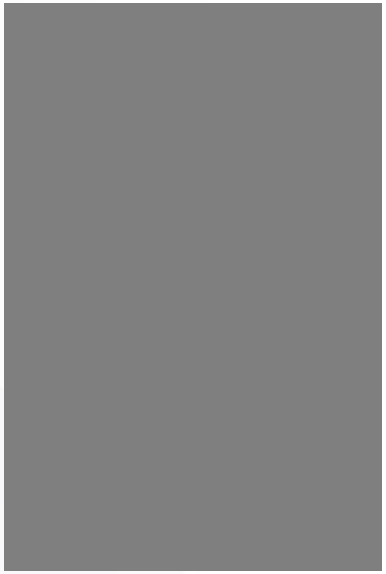

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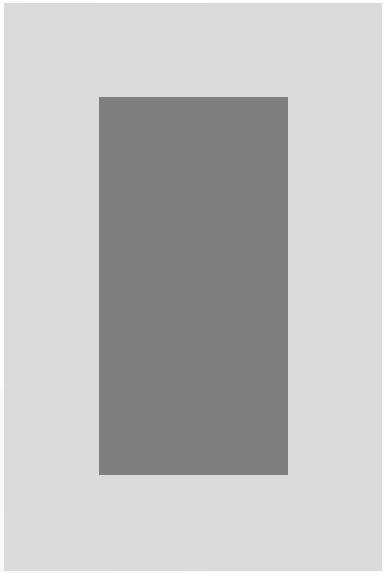

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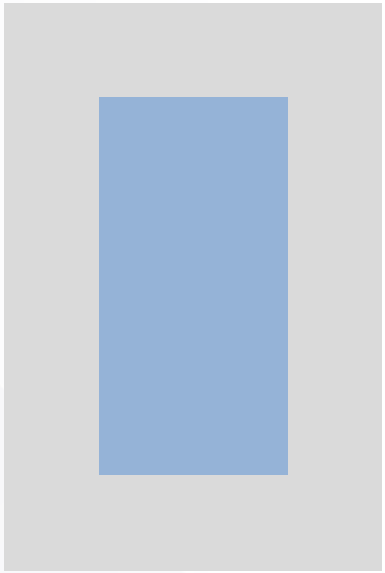

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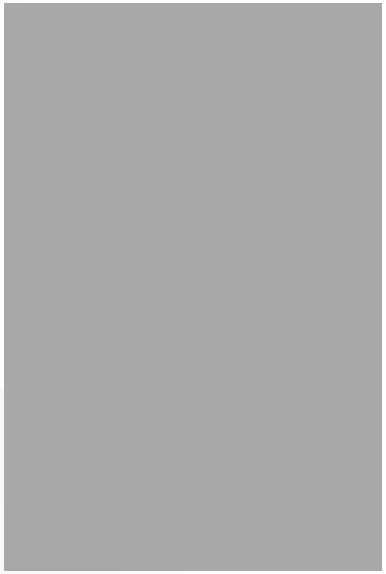

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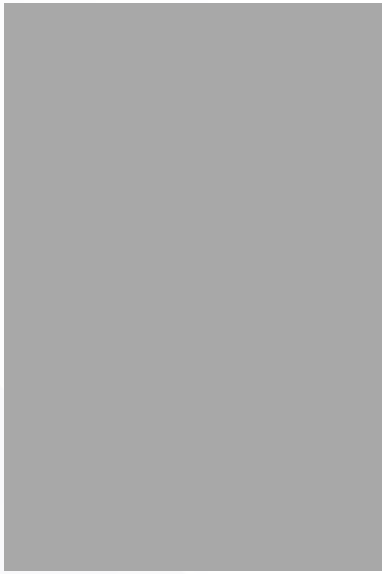

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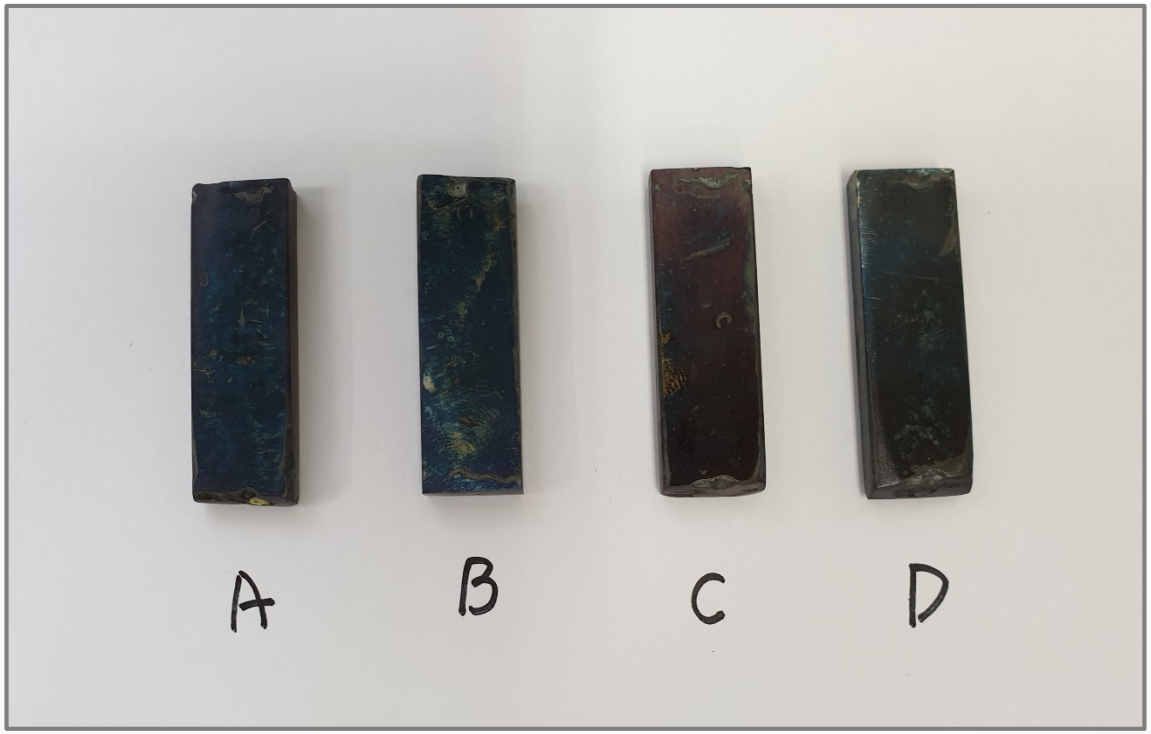

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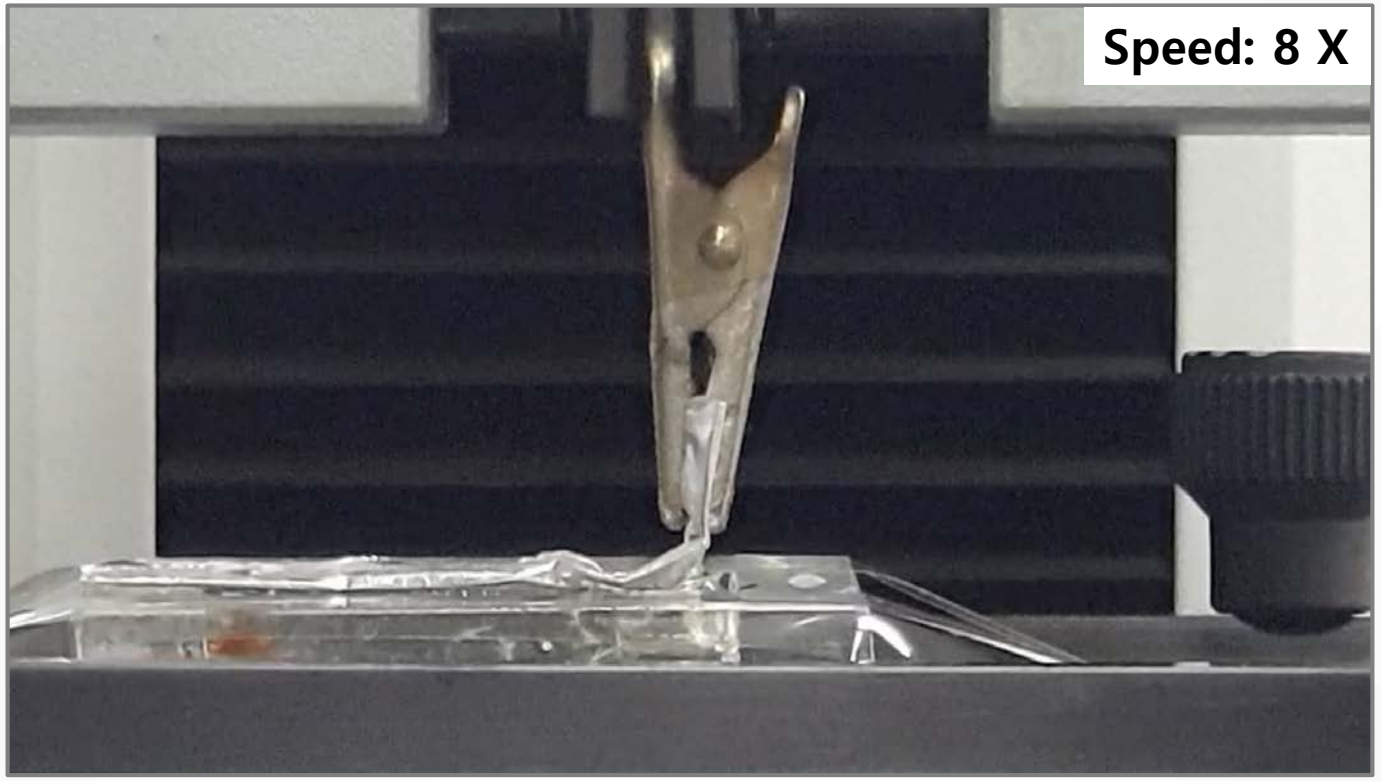

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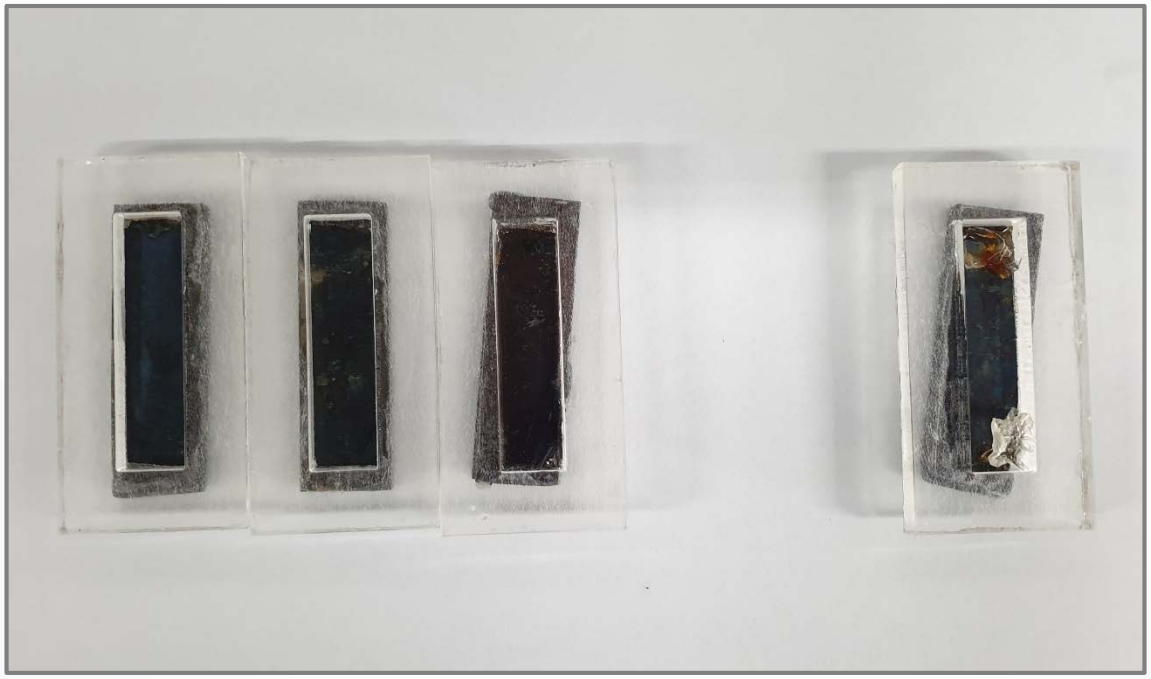

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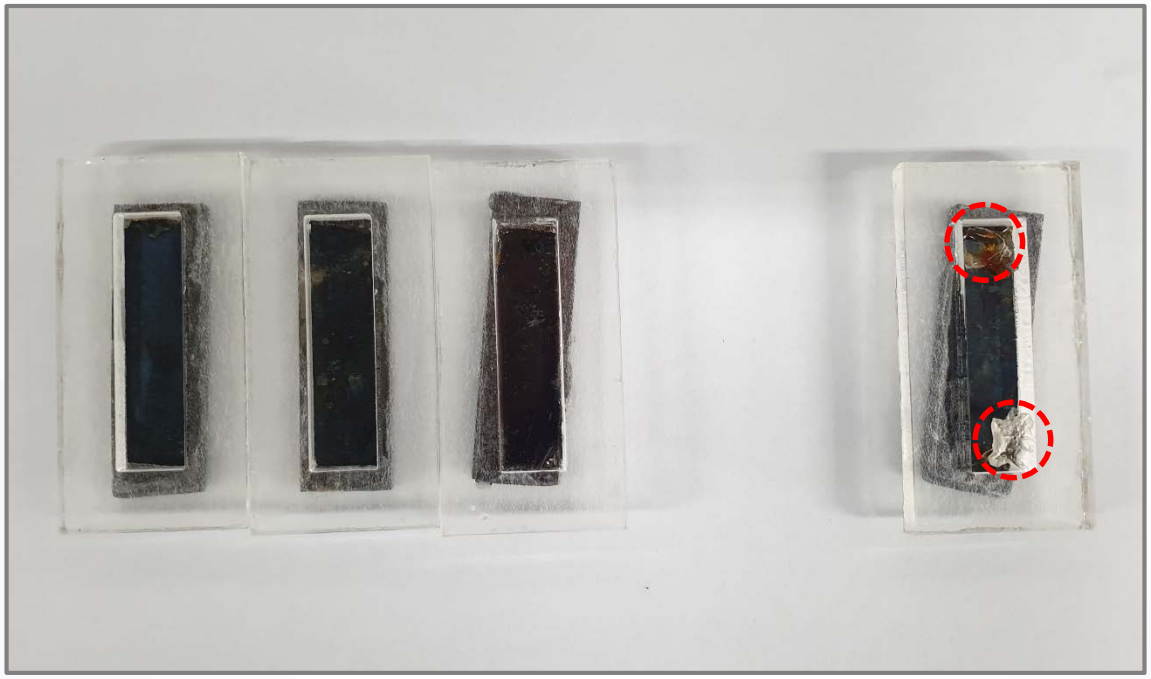

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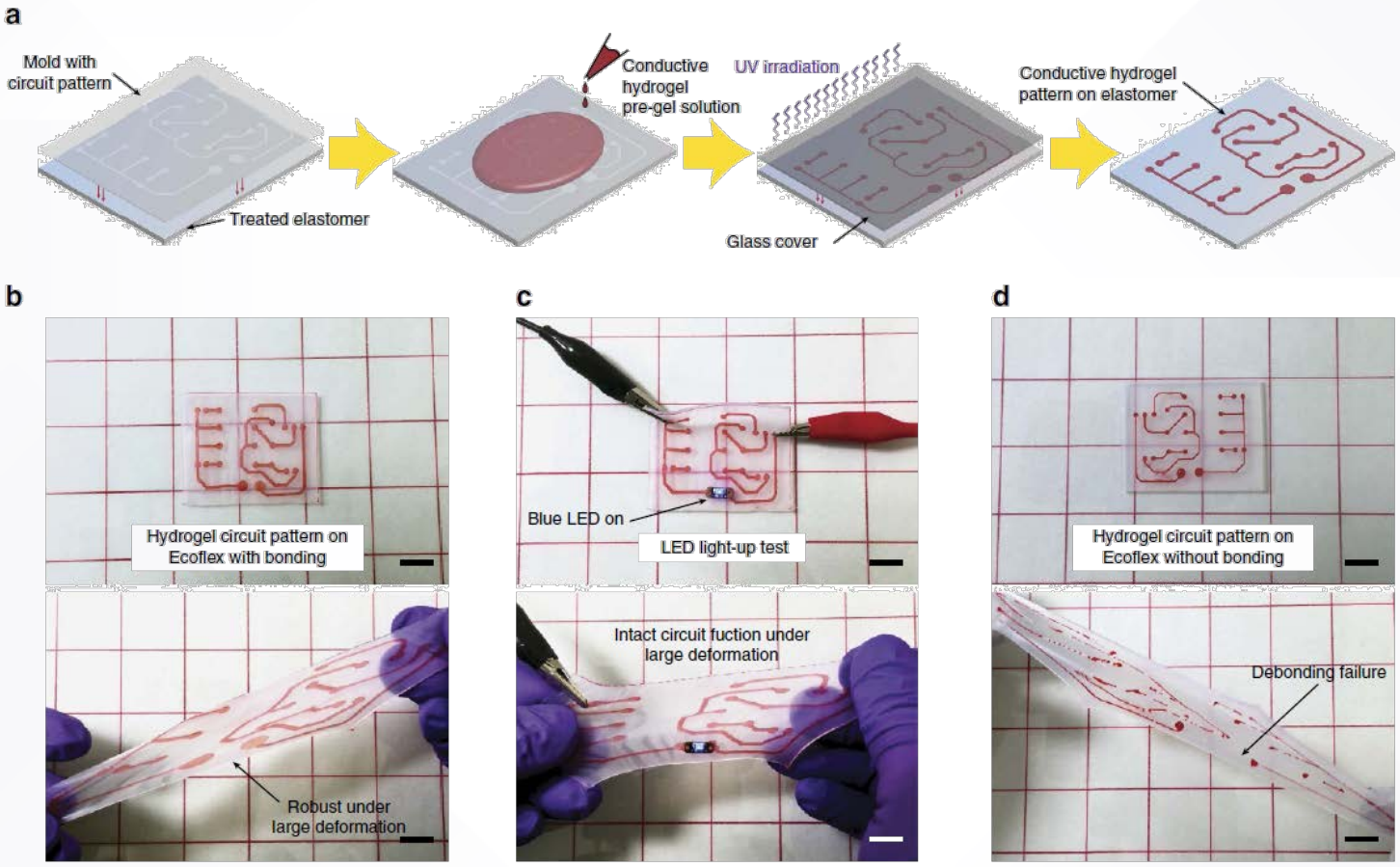
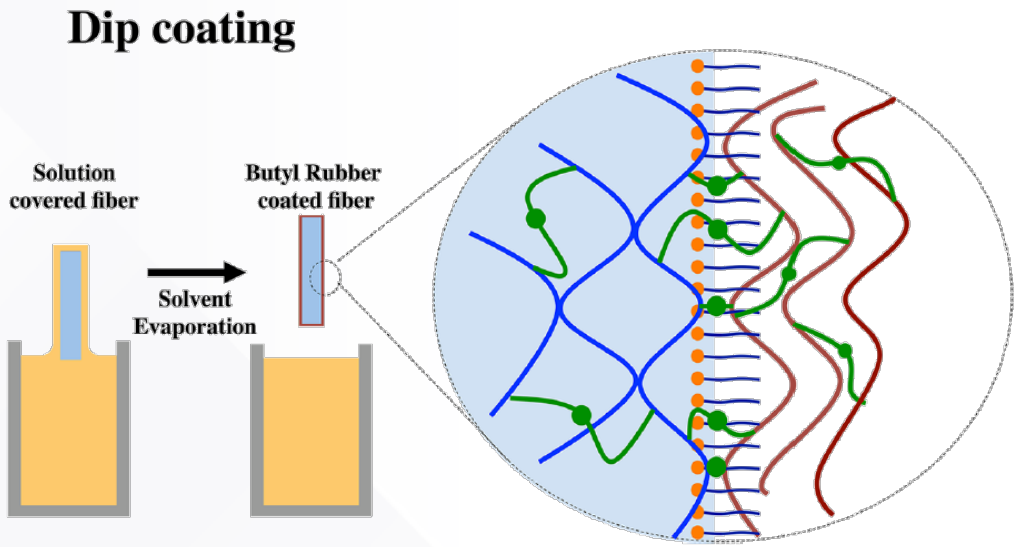


Hyunwoo Yuk, et.al. *Nature Communications* **(2016)**

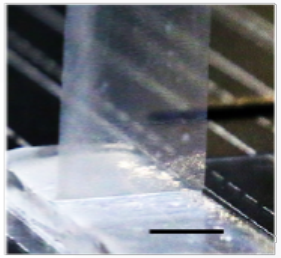
Tough interfaces between metals and hydrogels



a

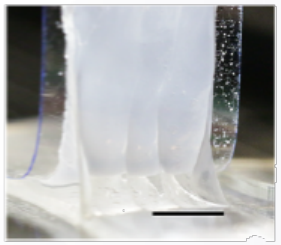
Butyl rubber A

$\Gamma = 2.4 \pm 0.04$ J/m^2



Butyl rubber B

$\Gamma = 79.3 \pm 13.9$ J/m^2



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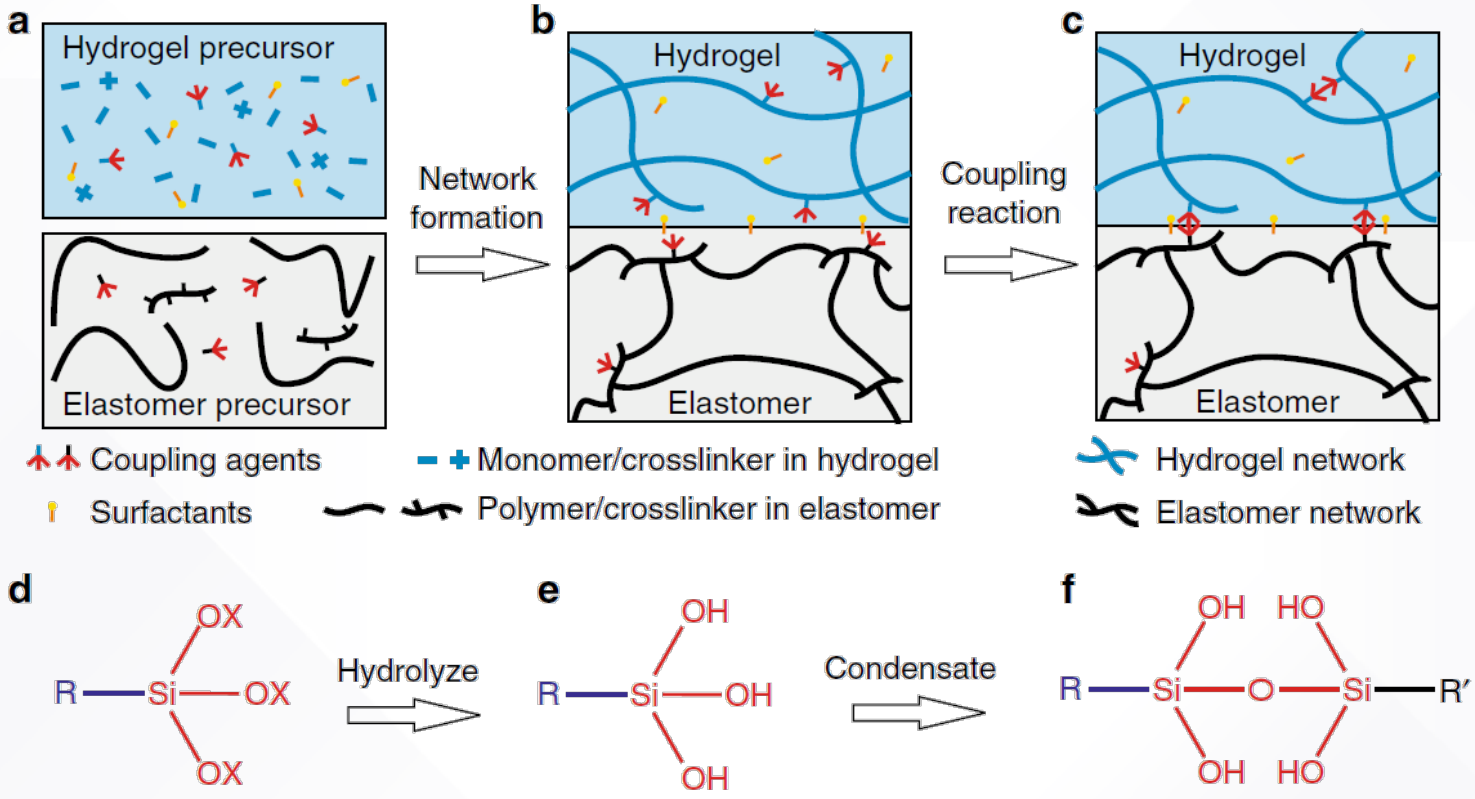
Tough interfaces between metals and hydrogels



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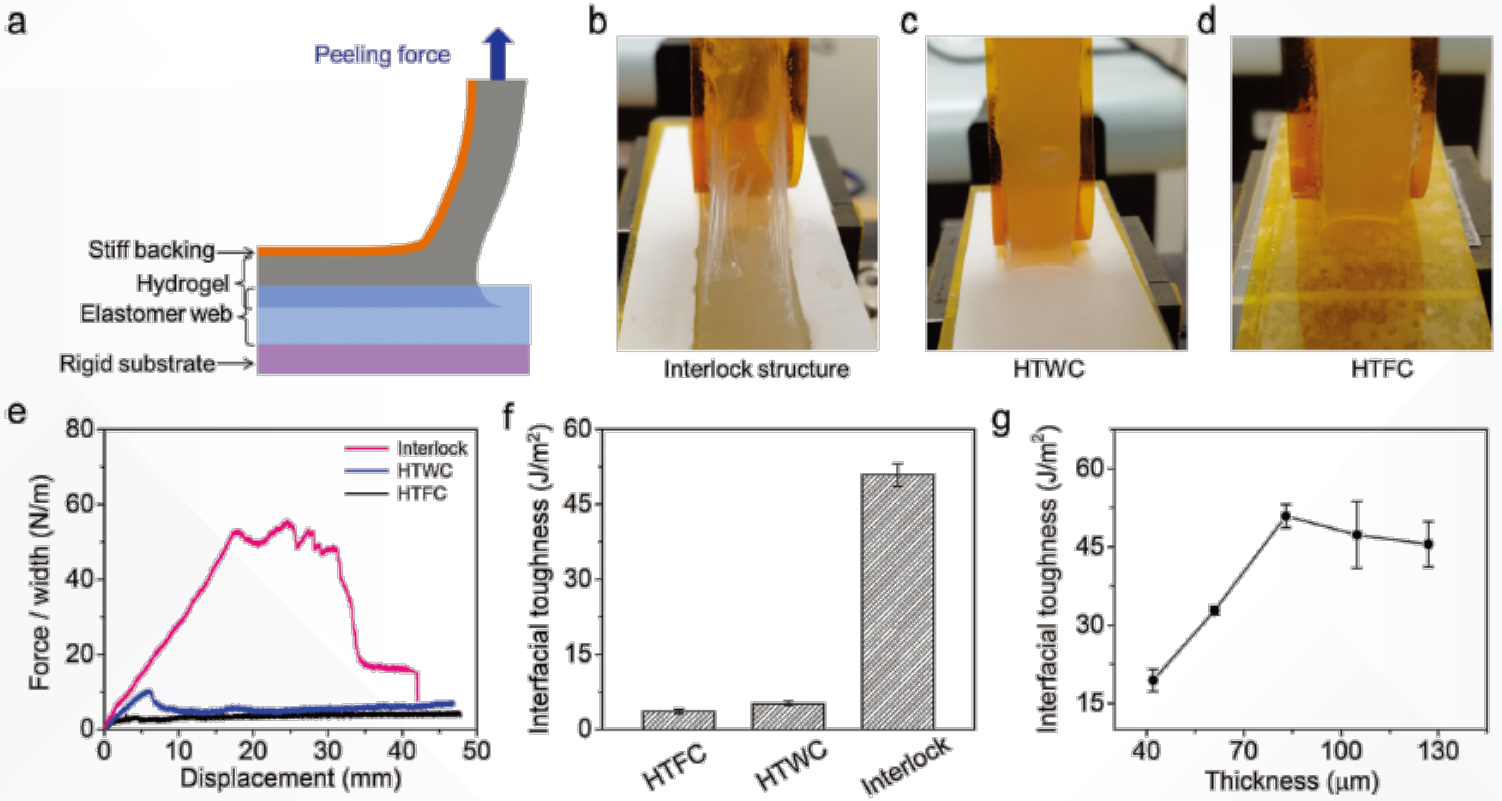
Tough interfaces between metals and hydrogels



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THANK YOU

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