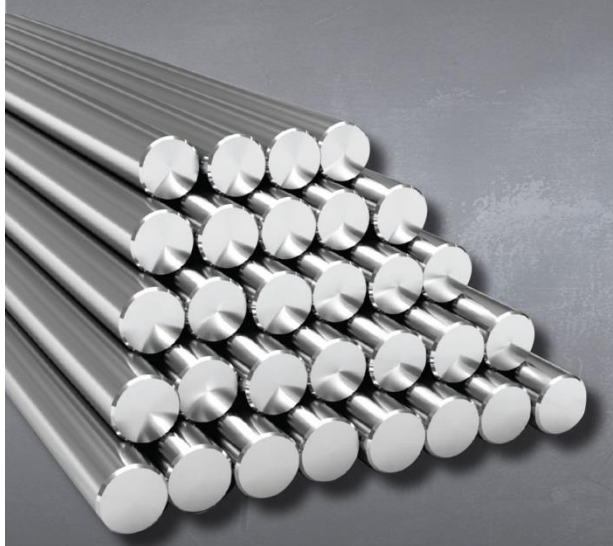
259th OMICS International Conferences

International Conference on

Smart Materials & Structures

June 15 -17, 2015 Las Vegas, USA



Exploring the Fusion of Intelligence with Materials

Operated by: Editors- Journal of Material Sciences & Engineering, Journal of Vortex Science and Technology and Journal of Nanomaterials & Molecular Nanotechnology

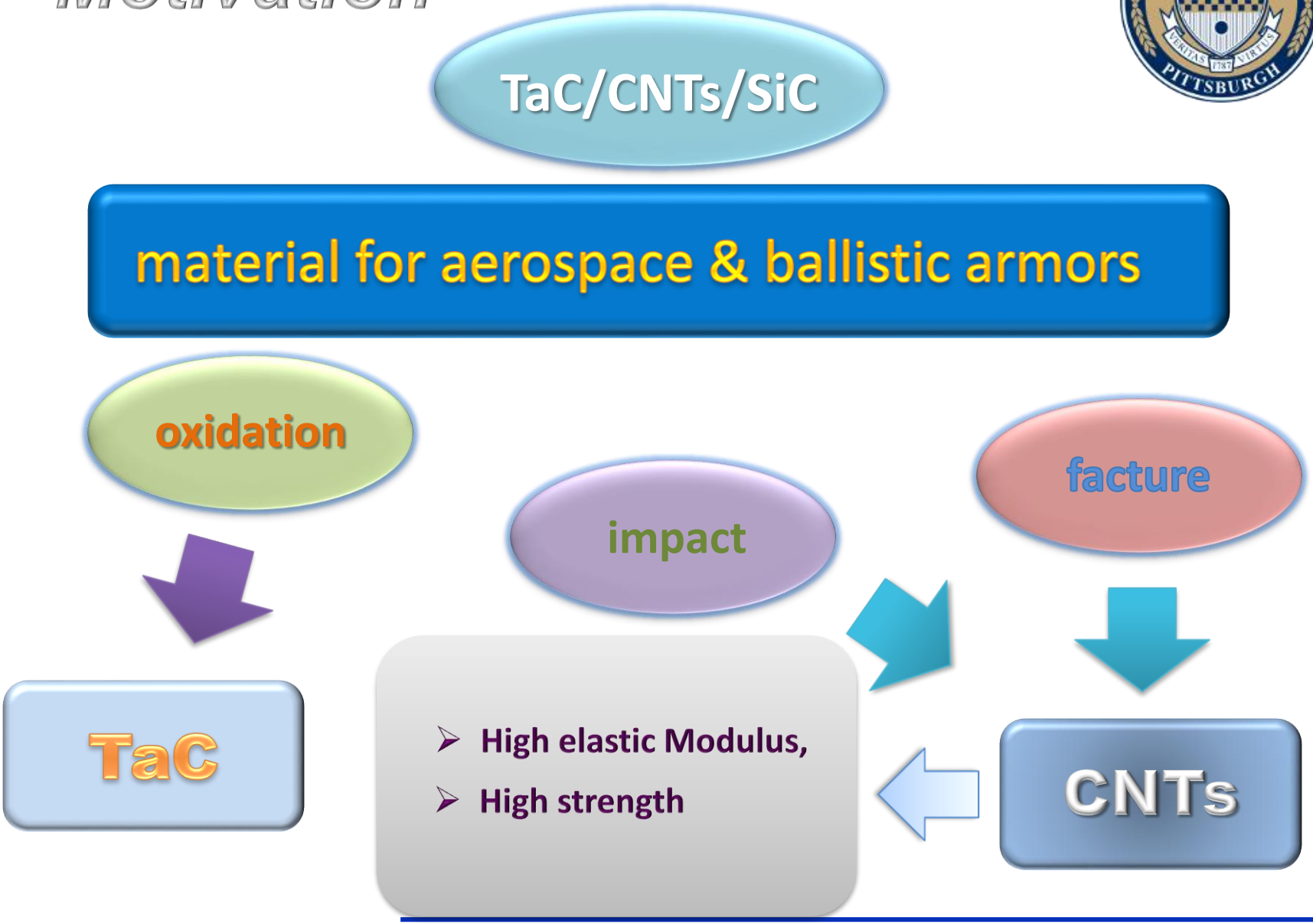
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DYNAMIC FRACTURE TOUGHNESS of TaC/CNTs/SiC CMCs PREPARED by SPARK PLASMA SINTERING

Qiaoyun Xie

Advisor: Dr. Sylvanus N. Wosu

Motivation


TaC/CNTs/SiC
material for aerospace & ballistic armors
oxidation
impact
facture
TaC
High elastic Modulus,
High strength
CNTs

Work Focus

static ASTM —(3/4 -point)→ dynamic (SHPB, drop weight tower, Charpy tester)

- Geary et al., dynamic fracture toughness for glass reinforced polymer
- Samborski, facture toughness for alumina and magnesia ceramic
- Rubio-Gonzalez, dynamic fracture toughness for composite material by Hopkinson bar

NO STANDARD MEASUREMENT

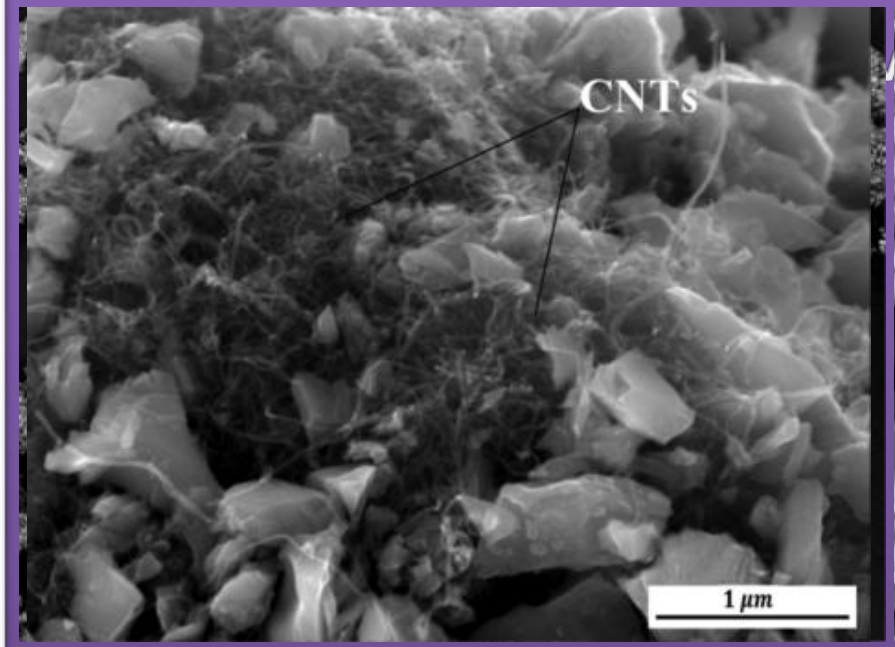
Vickers indentation	SEM	SHPB
static fracture toughness	crack propagation	dynamic facture toughness

Powder Property

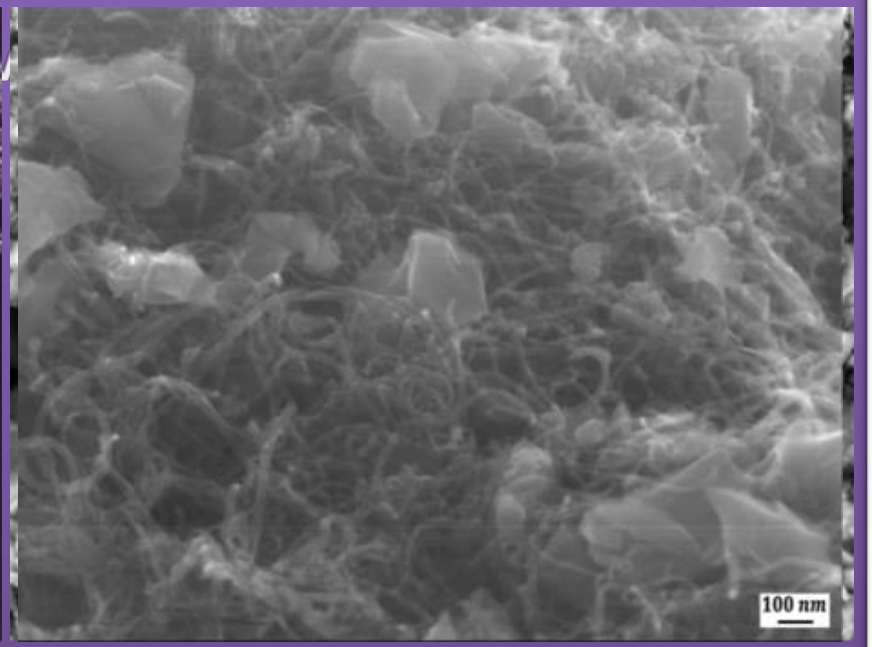
material	density (g/cm^3)	average size	purity, %
SiC	3.216	800 nm	>99
TaC	13.9	1000 nm	>99
MWCNTs	2.1	D_o<20 nm, D_i: 4 nm, L: 1-12 µm	>99 wt
B_4C	2.51	45-55 nm	>99

Powder Mixture

Mixing Process:

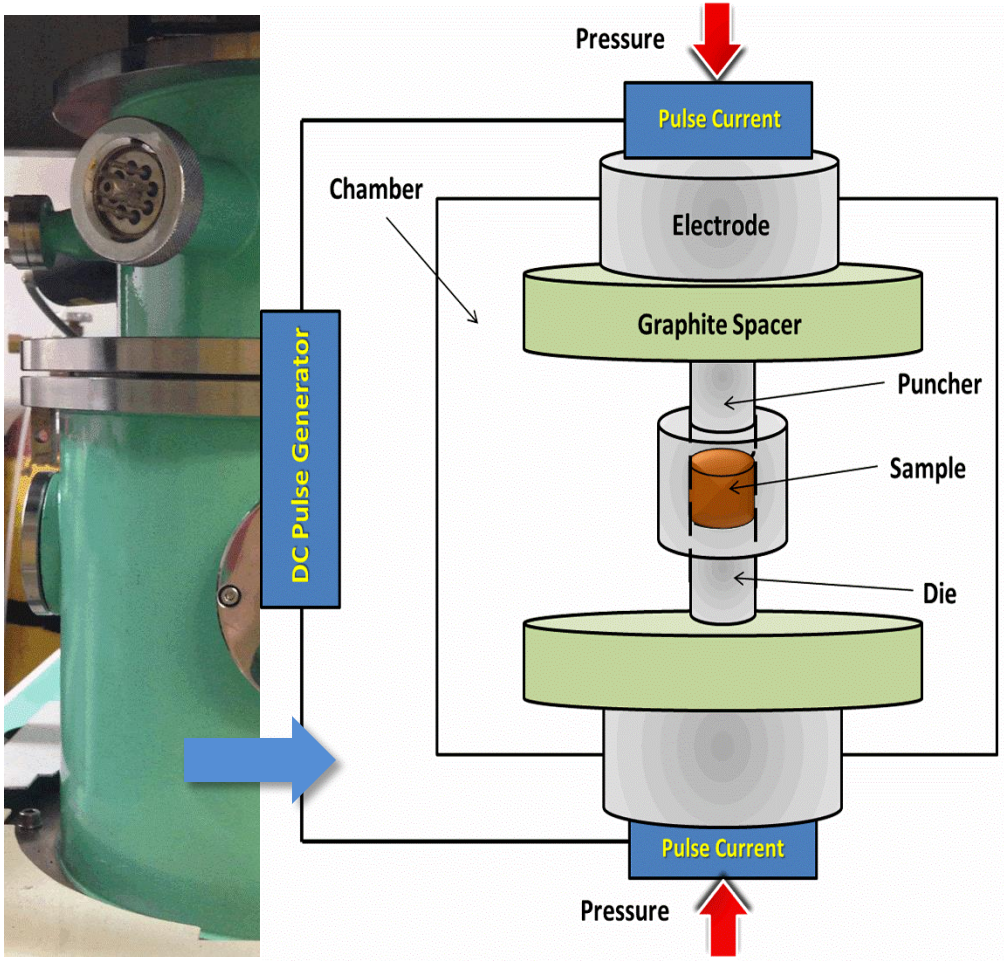


CNTs in mixed powder



Higher magnification

Spark Plasma Sintering (SPS) System



Stage 1:

$\dot{Q} = 133℃/min$, 9min

$T = 1200℃$

Hold 3min

$P = 30\ MPa$

Stage 2:

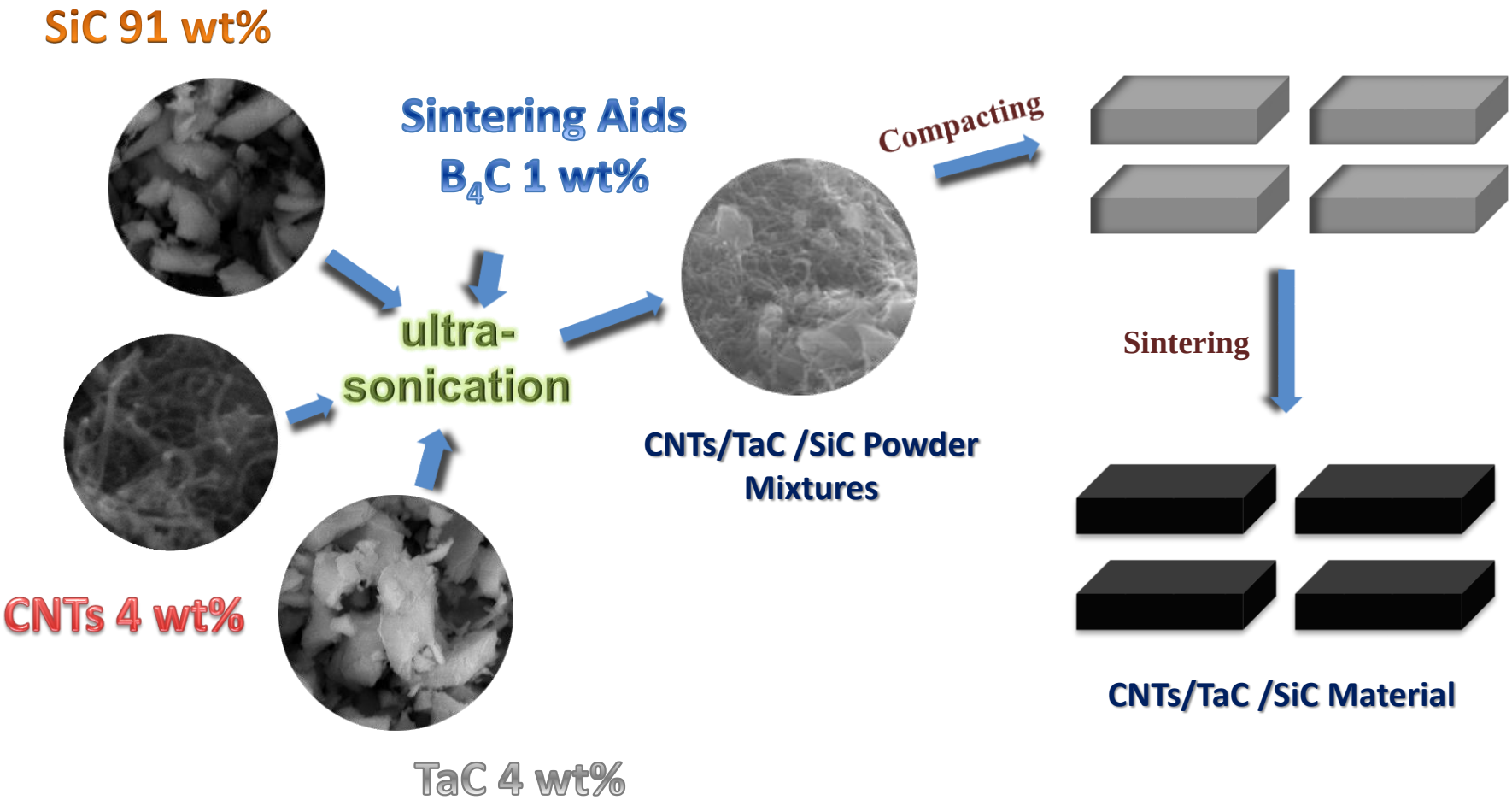
$P = 90\ MPa$

$T = 1800\ ℃$

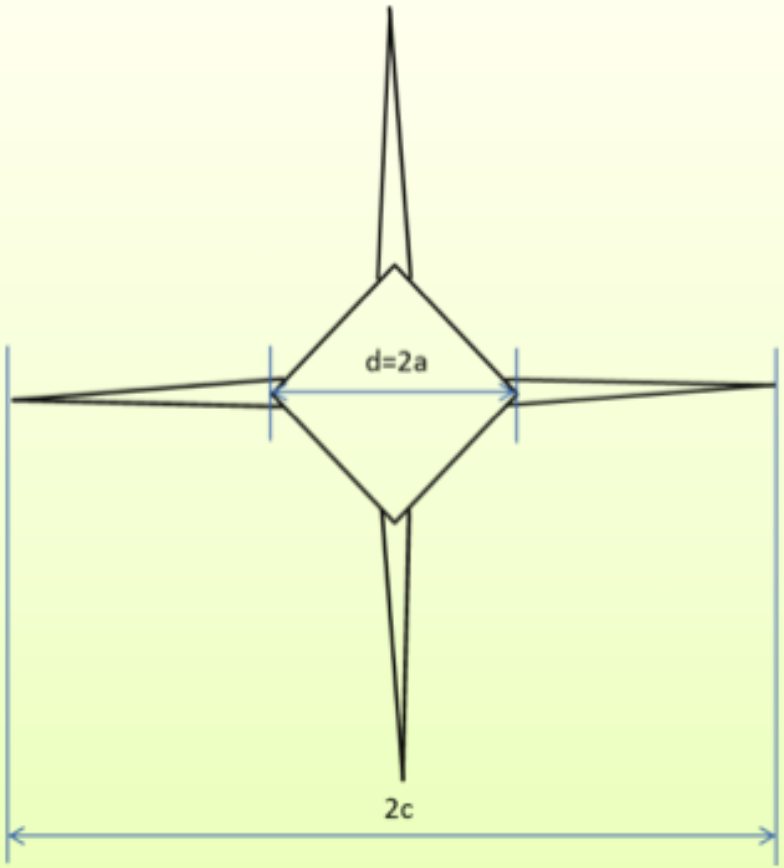
Hold 10 min

Densification
98.4%

Sample Fabrication



Vickers Indentation (static)



$$HV = \frac{F}{A} \approx \frac{1.854F}{d^2}$$

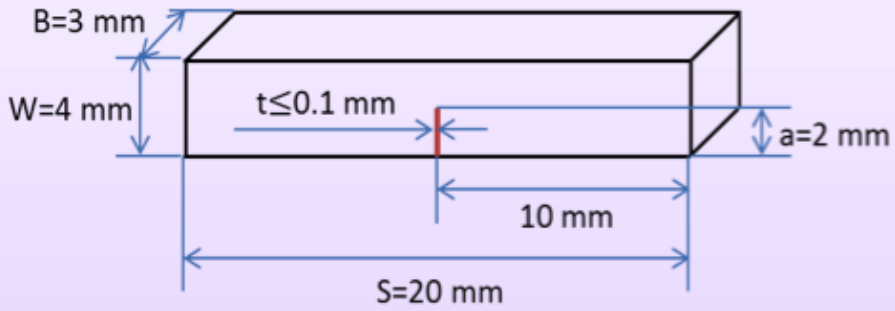
HV: Vickers hardness
F: loading force
A: indentation area
d: average length of the diagonal left by the indenter

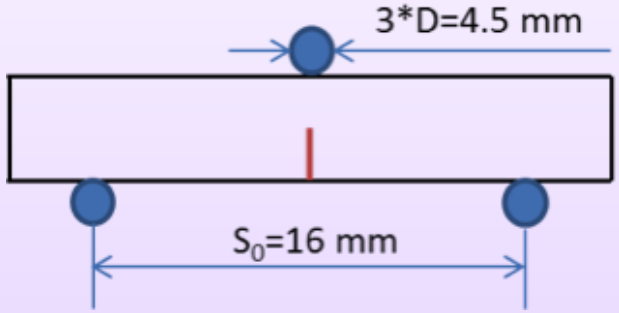
$$K_{IC} = 0.016\sqrt{\frac{E}{HV}}\frac{F}{c^{3/2}}$$

K_{IC}: mode I fracture toughness
E: Young's modulus
c: crack length from the impression center

Sample Requirement

ASTM C1421-10 three-point bending test





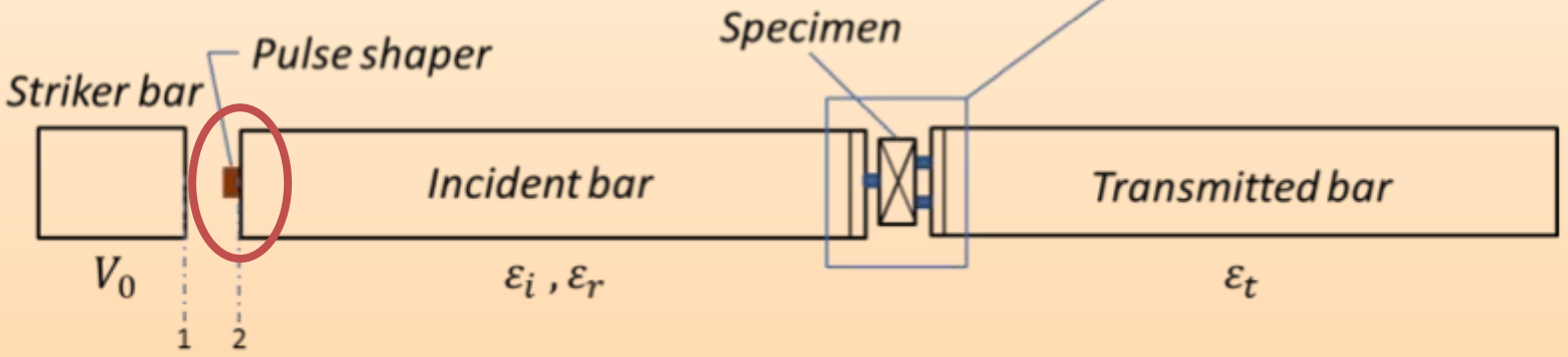
$0.12 \le a/W \le 0.30$

$4 \le S_o/W \le 10$

S_o: three-point test fixture outer span
B: side to side dimension of the test specimen
W: top to bottom dimension of the test specimen parallel to the crack length
a/W: normalized crack size

SHPB Set-up (dynamic)





To obtain a constant loading rate

copper pulse shaper 3.2 mm diameter × 3.2 mm thickness

Theoretical Background

strain rate, energy absorption and force measurement

$$\dot{\varepsilon}_s(t) \approx \frac{-2c}{L_s}\varepsilon_r(t)$$

$$F(t) = A_b E(\varepsilon_i(t) + \varepsilon_r(t))$$

$$E_A(\mathrm{t}) = \frac{A_b c}{E}\int_0^t (\sigma_i^2(t) - \sigma_r^2(t) - \sigma_t^2(t))\,dt$$

$\dot{\varepsilon}_s$: strain rate
c: wave velocity
L_s: specimen thickness
E_A: energy absorption
A_b: cross sectional areas of bars

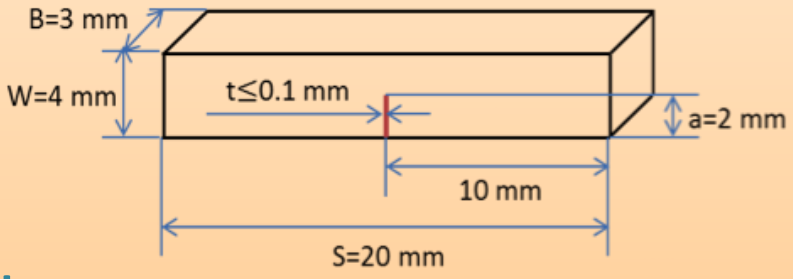
E: Young's modulus of the bars
σ_i , σ_r , σ_t : incident, reflected, transmitted stress
F : force at the incident bar/specimen interface
ε_i, ε_r: incident, reflected strain

Dynamic Fracture Toughness

quasi-static method expression for dynamic calculation

$$K_{IC} = f(a/W)\left[\frac{P_{max} S_o 10^{-6}}{BW^{3/2}}\right]\left[\frac{3(a/W)^{1/2}}{2(1-a/W)^{3/2}}\right]$$

$$f(a/W) = \frac{1.99 - (a/W)(1-a/W)[2.15 - 3.93(a/W) + 2.7(a/W)^2]}{1 + 2(a/W)}$$



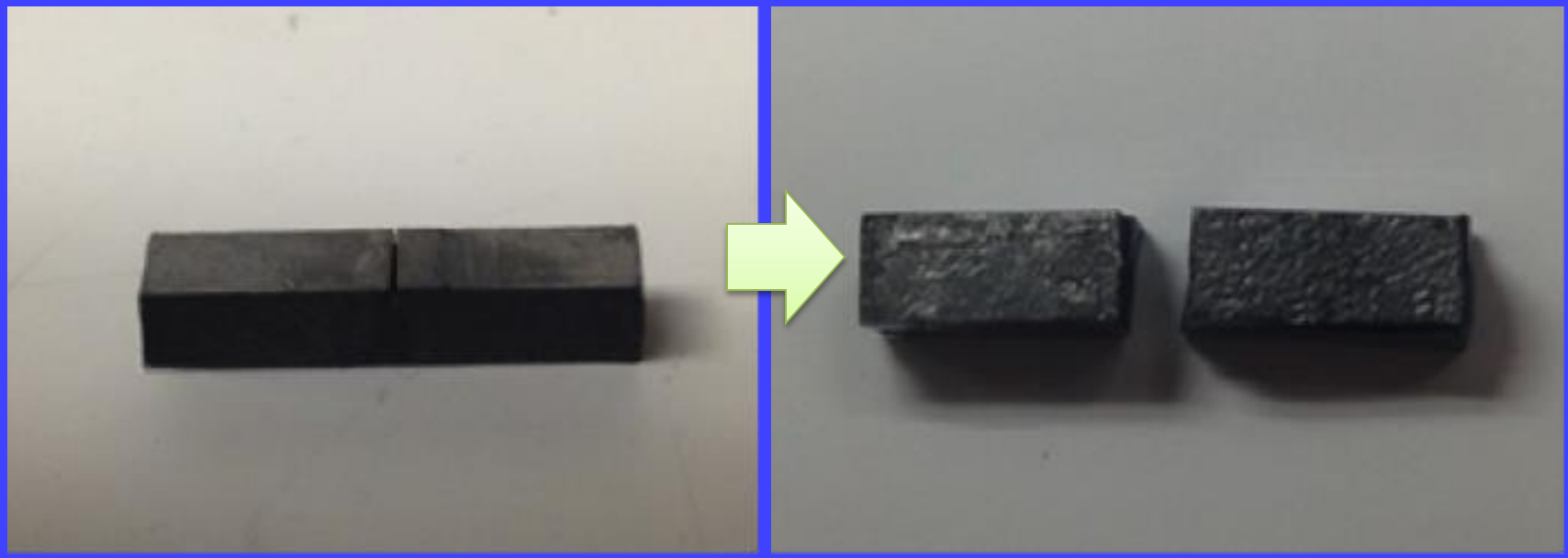
P_{max}: maximal dynamic force

S_0: the three-point test fixture outer span

B: side to side dimension of the test specimen

Sample Response

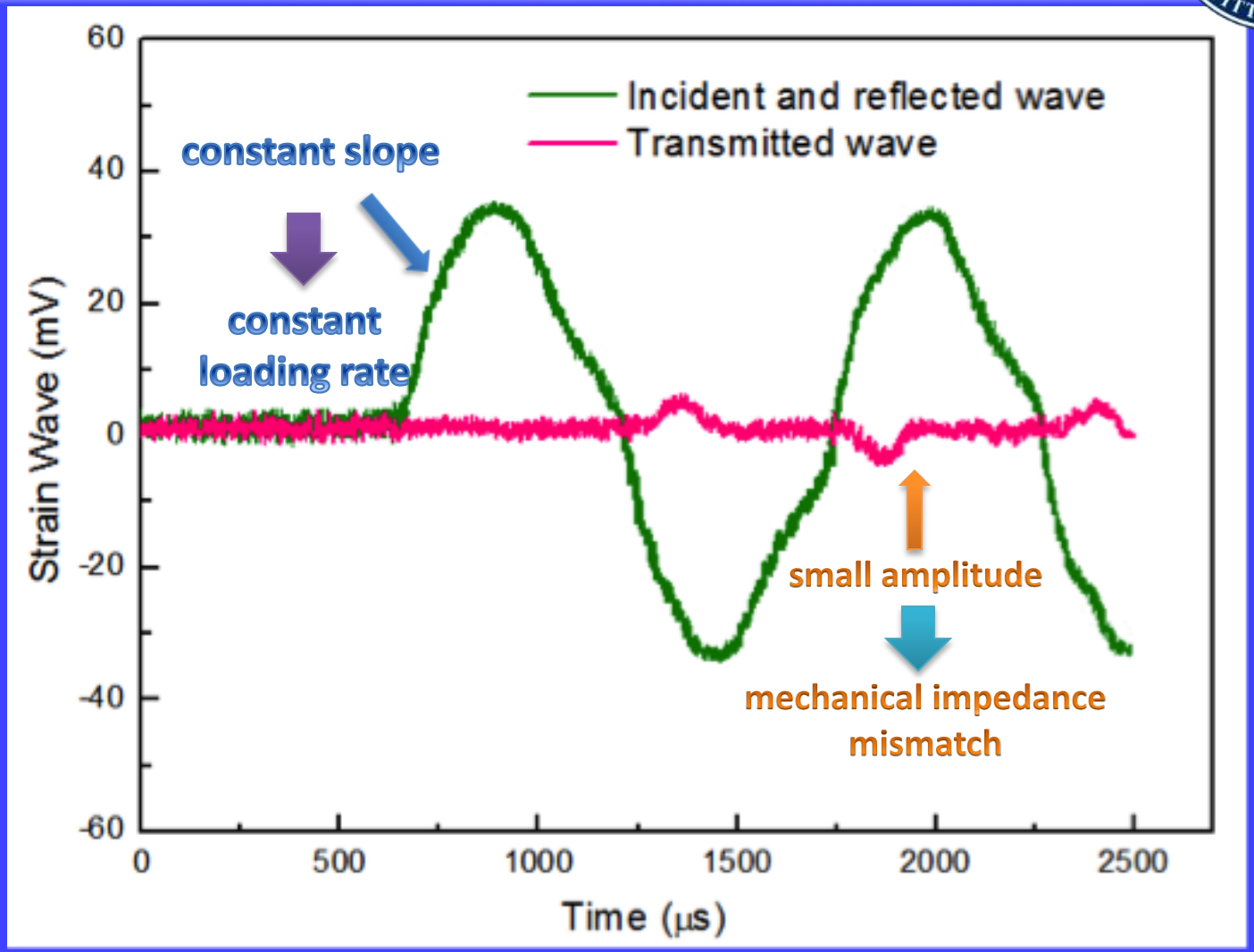
TaC/CNTs/SiC CMCs



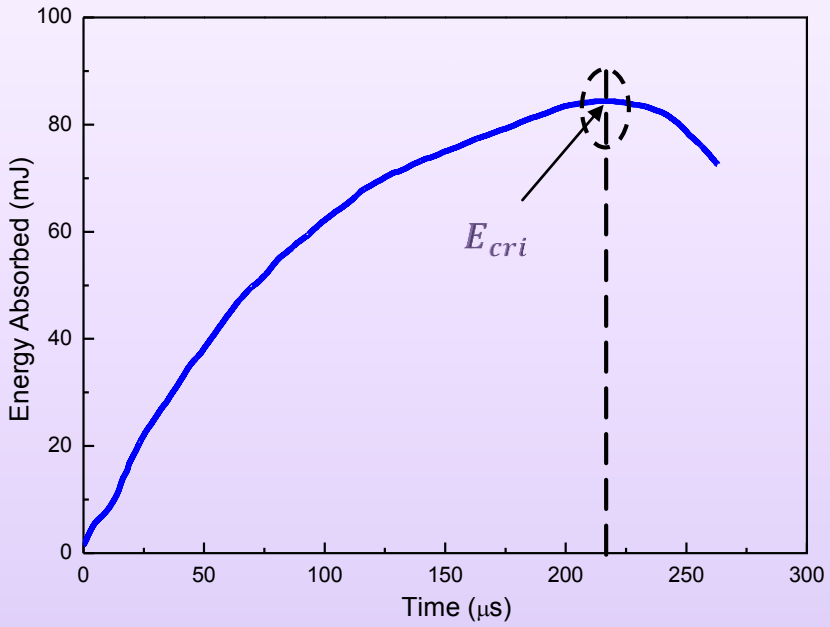
three-point dynamic fracture test:

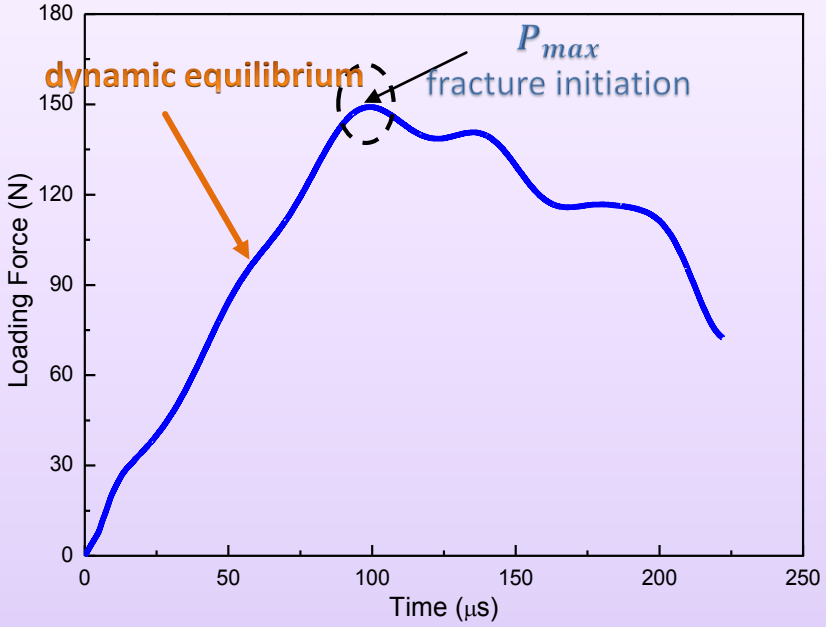
770 mJ impact energy

Strain Wave


Incident and reflected wave
Transmitted wave
constant slope
constant
loading rate
small amplitude
mechanical impedance
mismatch
Strain Wave (mV)
Time (μs)
60
40
20
0
-20
-40
-60
0
500
1000
1500
2000
2500

Dynamic Loading



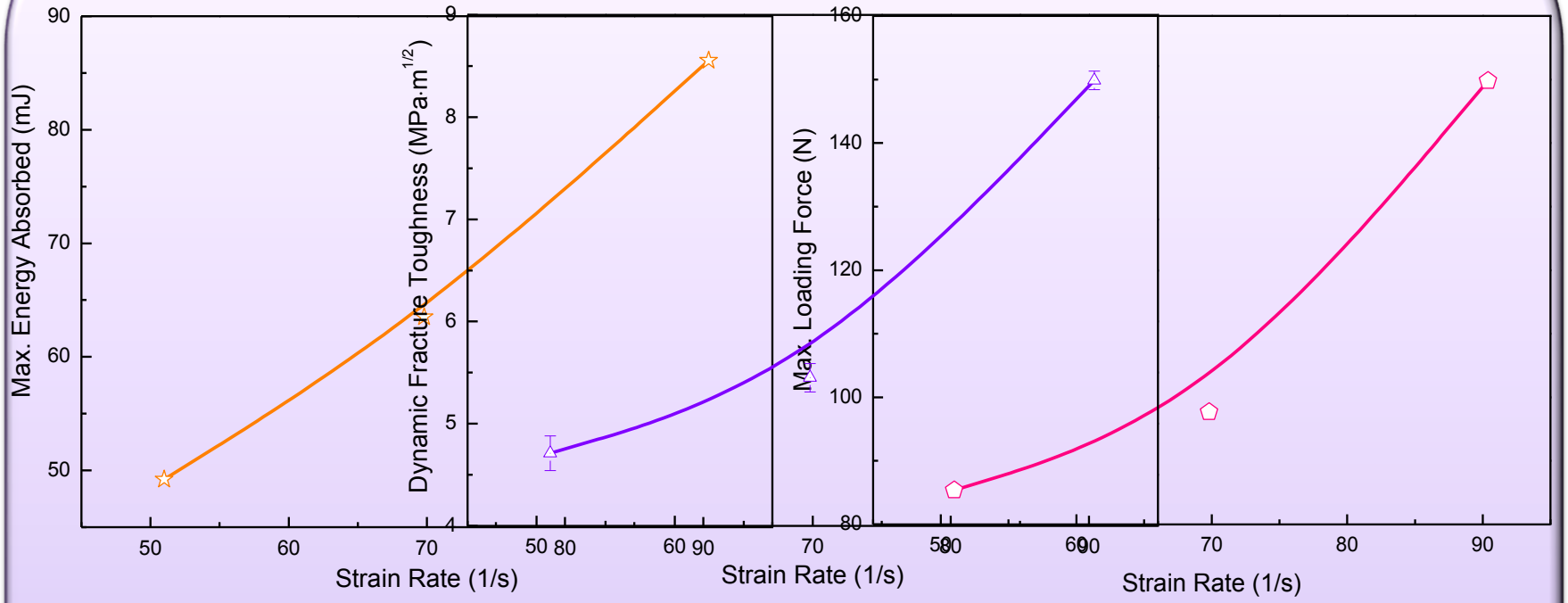


loading history

⇕

the stress intensity factor history

Strain Rate Effect



$\dot{\varepsilon} \uparrow, E_{max} \uparrow$ $\dot{\varepsilon} \uparrow, K_{IC} \uparrow$ $\dot{\varepsilon} \uparrow, P_{max} \uparrow$

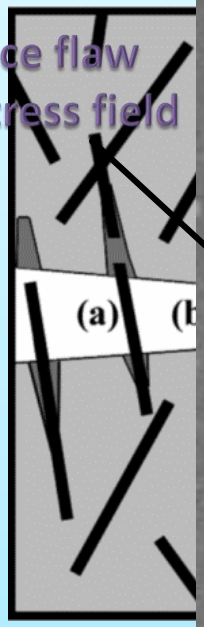
Fracture Toughness

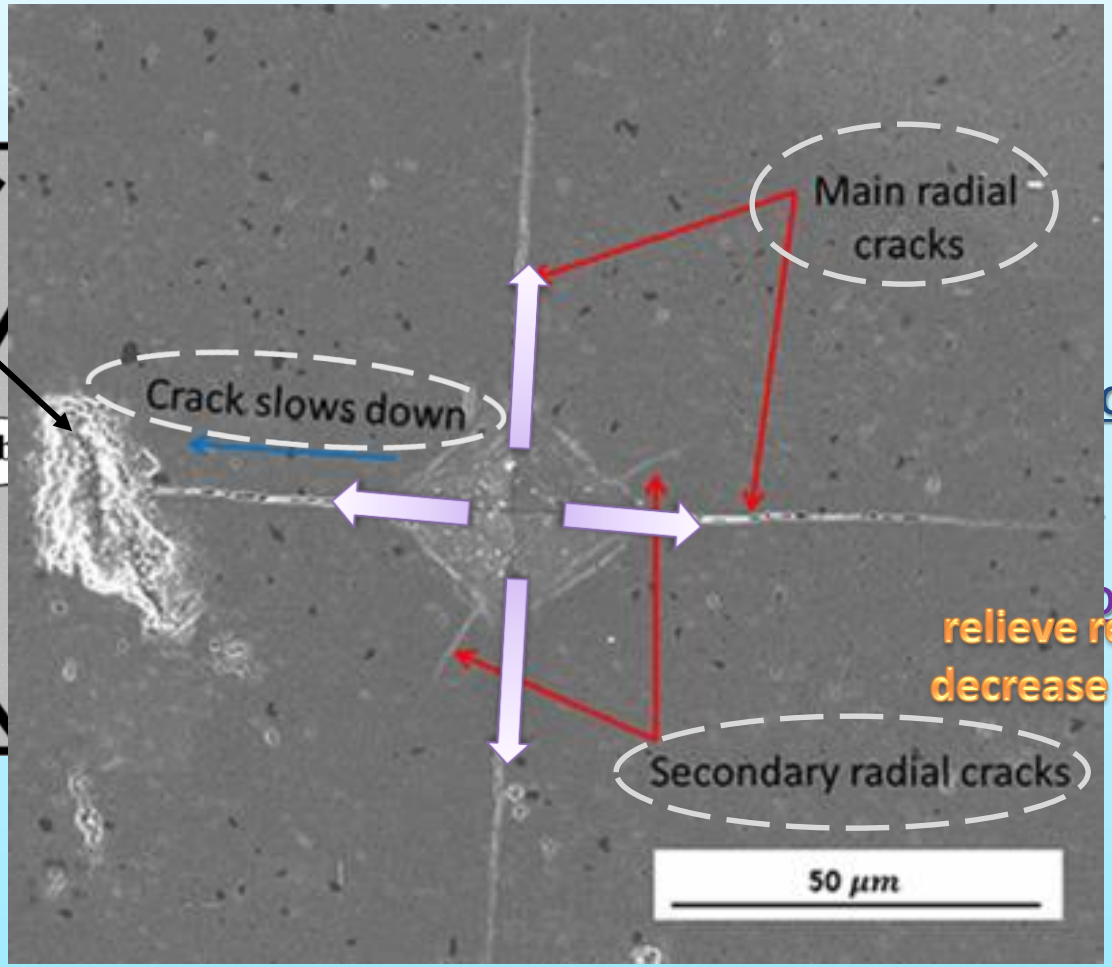
Impact Energy (E_I, mJ)		Vickers Hardness (HV, GPa)	Strain Rate ($\dot{\varepsilon}$, 1/s)	Max Energy Absorbed (ΔU_A, mJ)	Max Loading Force ($P_{max,}$ N)	Fracture Toughness (K_{IC}, Mpa •$m^{1/2}$)
Static		24.55±1.32	/	/	/	3.88±0.28
dynamic	445	/	51.0	49.2	85.4	4.71±0.17
	790	/	69.8	63.5	97.7	5.45±0.14
	1235	/	90.4	86.1	149.8	8.36±0.09

different failure modes

Toughening Mechanisms

surface flaw
relax stress field



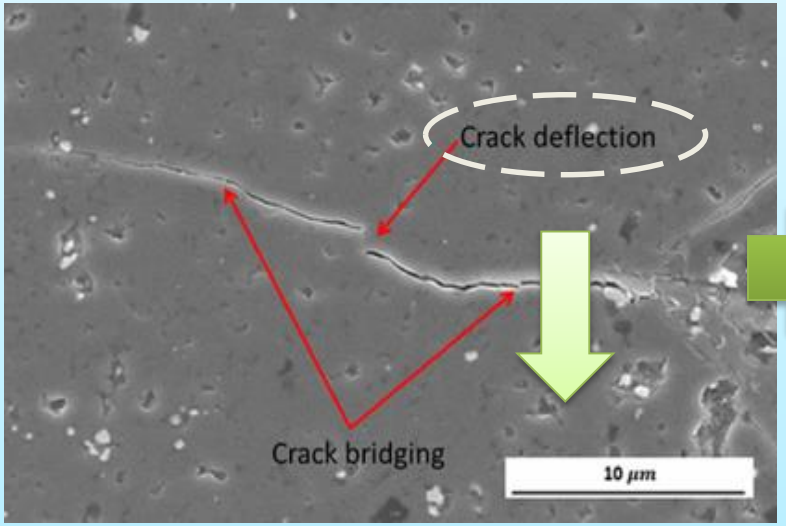


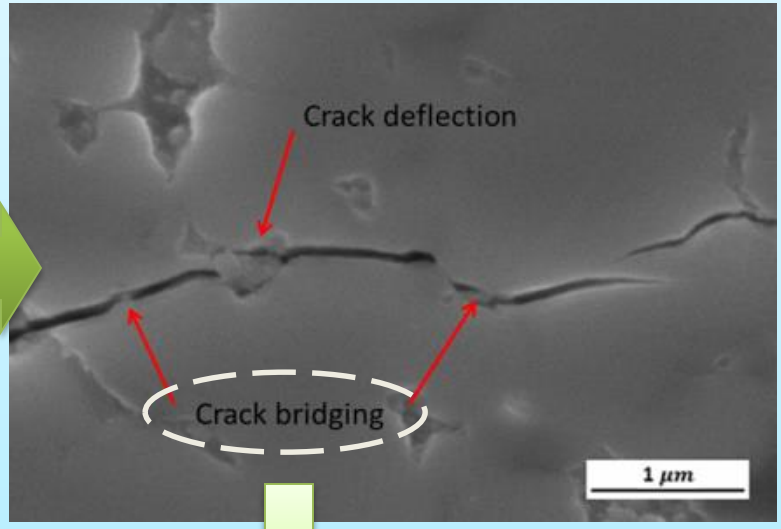
onding

on
relieve residual stress
decrease crack opening

Toughening Mechanisms

SEM image





interaction between cracks and CNTs
Interface has a lower toughness

perpendicular cracks reach interface and propagate along the interface

perpendicular to axial direction of CNTs

- restrain crack opening
- reduce driving force for crack propagation

Conclusions

- TaC/CNTs/SiC CMCs were prepared by spark plasma sintering
- Dynamic fracture toughness by SHPB w/ copper pulse shaper was investigated based on the static ASTM C1421-10
- K_{ICd} (4.71-8.36 MPa•m$^{1/2}$) > K_{IC} (3.88 MPa•m$^{1/2}$)
- SiC CMCs exhibited a more strain rate dependent property for higher strain rate
- Toughening mechanisms (CNTs deflection, CNTs bridging): restrained the crack to open and to grow further under the loading


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UNIVERSITY OF PITTSBURGH
Thank You!
Qiaoyun Xie