Combustion Joining for Composite Fabrication

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Joining Using Heterogeneous Combustion Systems

- Thermite Reactions
  - Used mostly to produce steels and copper alloys
  - Common example: Joining railway tracks
- High-Temperature Synthesis Reactions (Combustion Synthesis)
  - Similar and dissimilar materials
  - Refractory alloys, intermetallics, ceramics, etc.

Motivation

- Refurbishing of components

  e.g., carbon brakes (Honeywell Aerospace)

  – Carbon-carbon (C-C) composites have low density, high strength-to-weight ratio, and withstand high temperatures

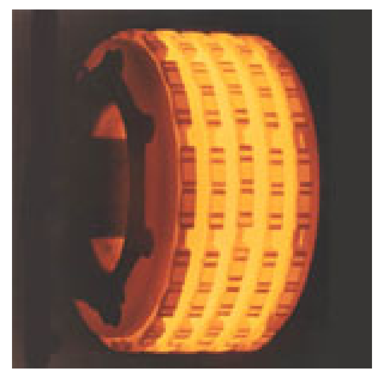
- Development of functionally graded materials

  e.g., composite armor

- Honeywell Corp (South Bend, IN)
- Currently build aircraft brake disks from carbon fibers
- use a long (~ 100 day) CVD process to densify
- Brake wear/oxidation with every landing

C-C brakes

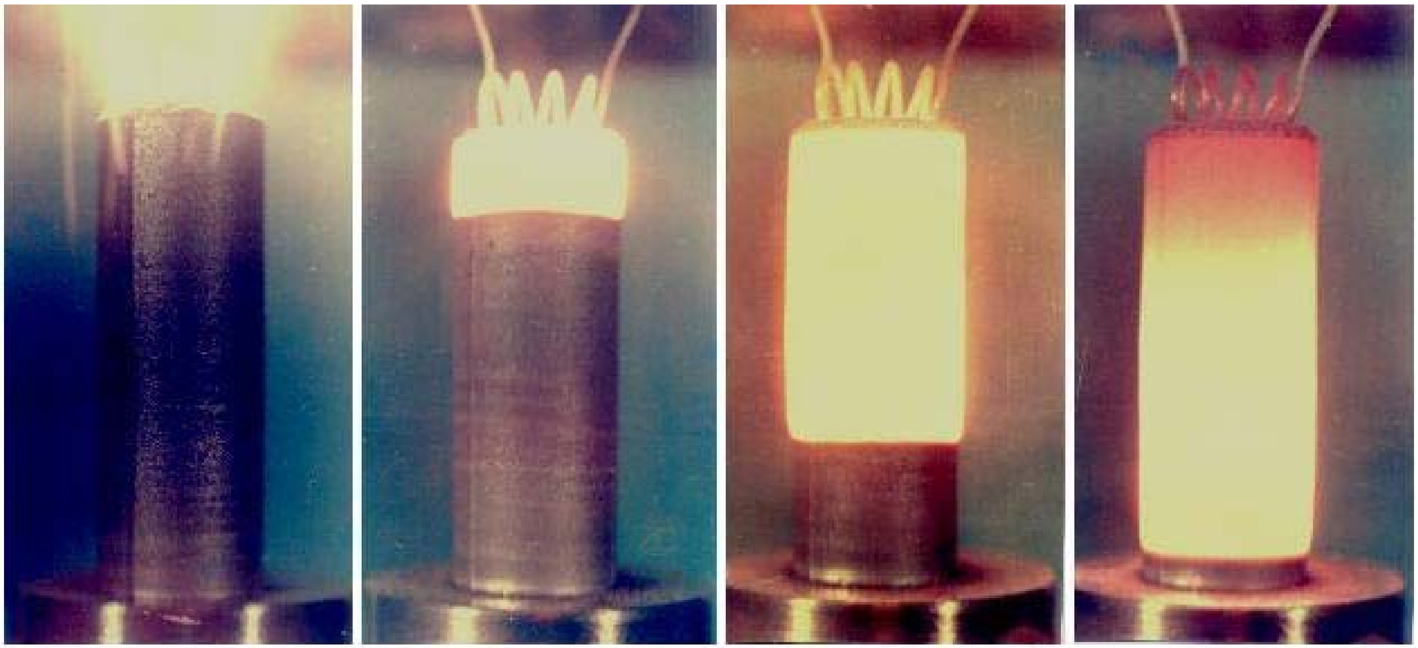
A380 -rejected take off test



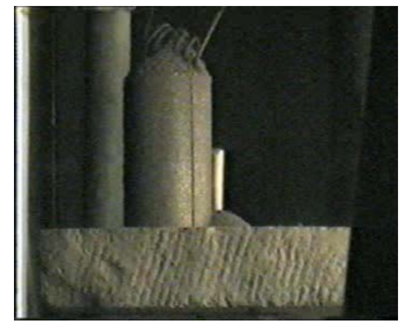
Joining C-Based Materials

- Difficult task
  - Carbon cannot be welded (T_{mp}~3800 K)
  - Little or no wetting with conventional braze or solder compositions
- Mechanical or adhesive means – limited application
- Solid-state bonding takes a long time at high temperatures
- Chemical joining in liquid state –attainable with *combustion reactions*

Self-Sustained High-Temperature Reactions



t=0s t=0.1s t=2.7s t=4.0s



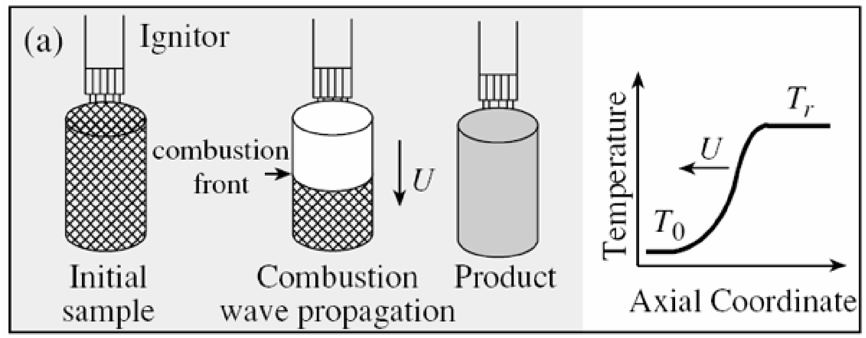
Example:
$Ti + C \rightarrow TiC$ + 230 kJ/mol
T_{ad} = 3200 ^{o}C

Characteristic Features:
- **High temperatures (> 2000 K)**
- **High temperature gradients (10^3-10^6 K/s)**
- **Short reaction times (0.1-10 s)**
- **Low energy consumption**
- **Simple equipment**

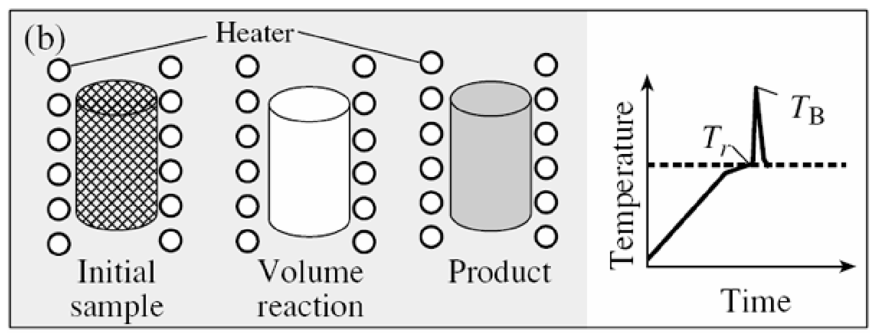
- Carbides, Borides, Nitrides
- Intermetallic Compounds
- Alloys
- Ceramics
- Functionally Graded Materials

Modes of Combustion Synthesis

Self-Propagating High-Temperature Synthesis (SHS)



Volume Combustion Synthesis (VCS)



Initiation Methods

- SHS Joining
  - Advantages: No additional energy to propagate reaction
  - Disadvantage: Finite rate of reaction
- VCS Joining
  - Advantages: Uniform combustion and distribution of temperature
  - Disadvantage: Relatively slow process

VCS Joining

- Relatively slow preheating (up to 10^2 K/min)
  - Solid state reactions could impact final composition/ gradients
  - Limiting case: reactive sintering
- Materials to be joined also heated to T_{ig} (not just the reactive media)
- For most systems, $T_{ig} \sim T_{mp}$ of least refractory component (eutectic temperature)
  - Could be difficult to reach for refractory reagents

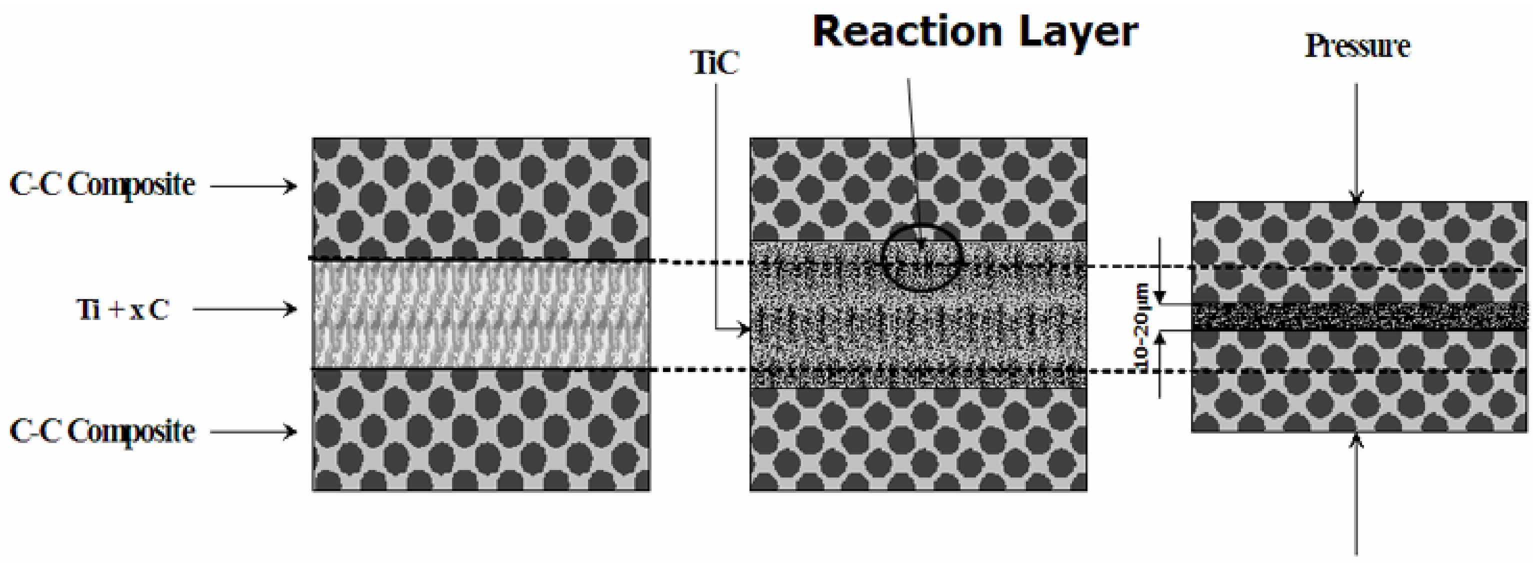
Reactive Resistance Joining

Place a thin layer of desired reaction composition between two disks of the material to be welded

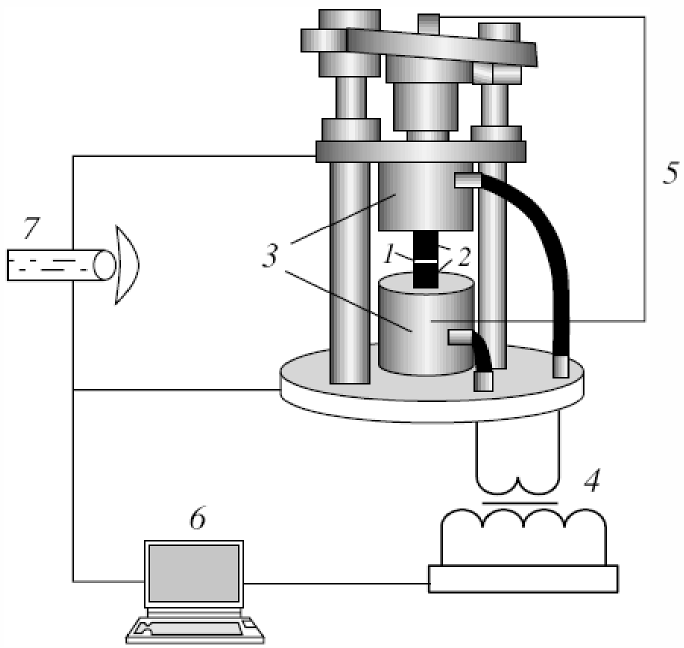
Preheat to the ignition temperature.

After initiation, a rapid (up to 10^4 K/s) high temperature (up to 3000 K) reaction occurs in a thin layer in the vicinity of the joint $\rightarrow$ leads to chemical interaction between the melt and disks to be joined.

A rapid press allows instant loading of the stack: enhancing the mechanical properties of the joint.

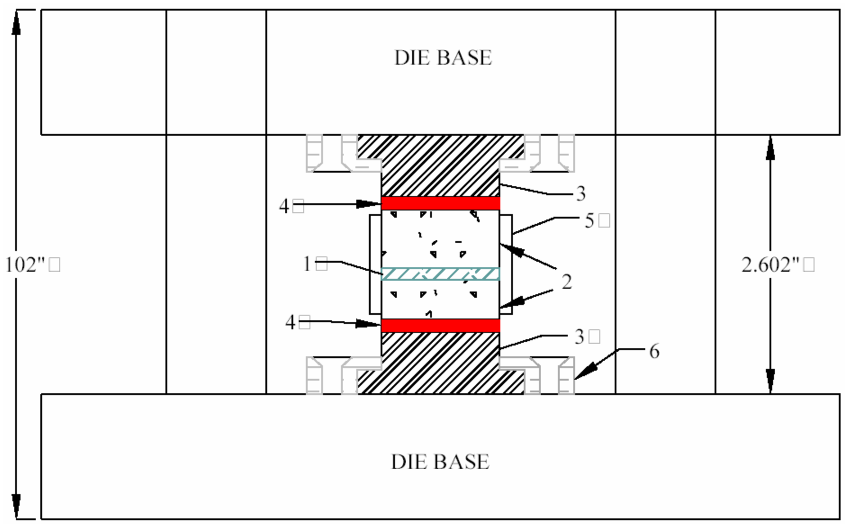


System for Rapid Joining of C-C Composites

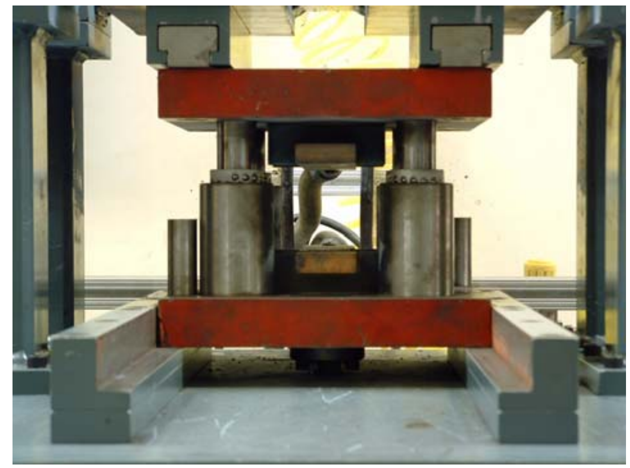


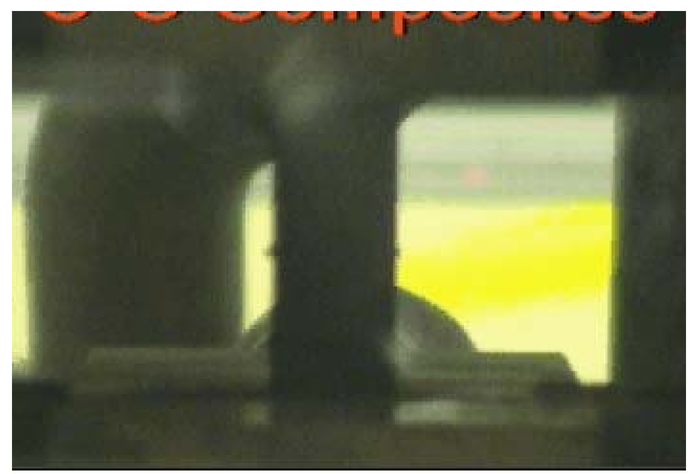
- **Max. Current: 950 A**
- **Max Voltage: 44 V**
- **Max Load: 35,000 N**
- **Press Response Time: 10 ms**

Press Die Design and Construction



1 - Reaction Layer ; 2 - C-C Disks; 3 - Dielectric Layers ;
4- High Current Power Supply; 5 - Thermo Insulator: 6 - Retainer Ring:





Reaction zone is observable: can measure temp.!

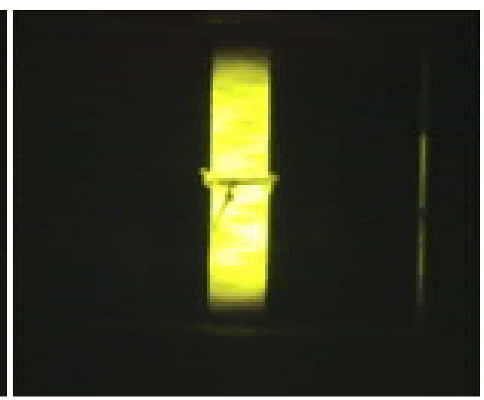
Frames of a Joining Process

t = 0.00 s

t = 0.30 s

t = 1.20 s

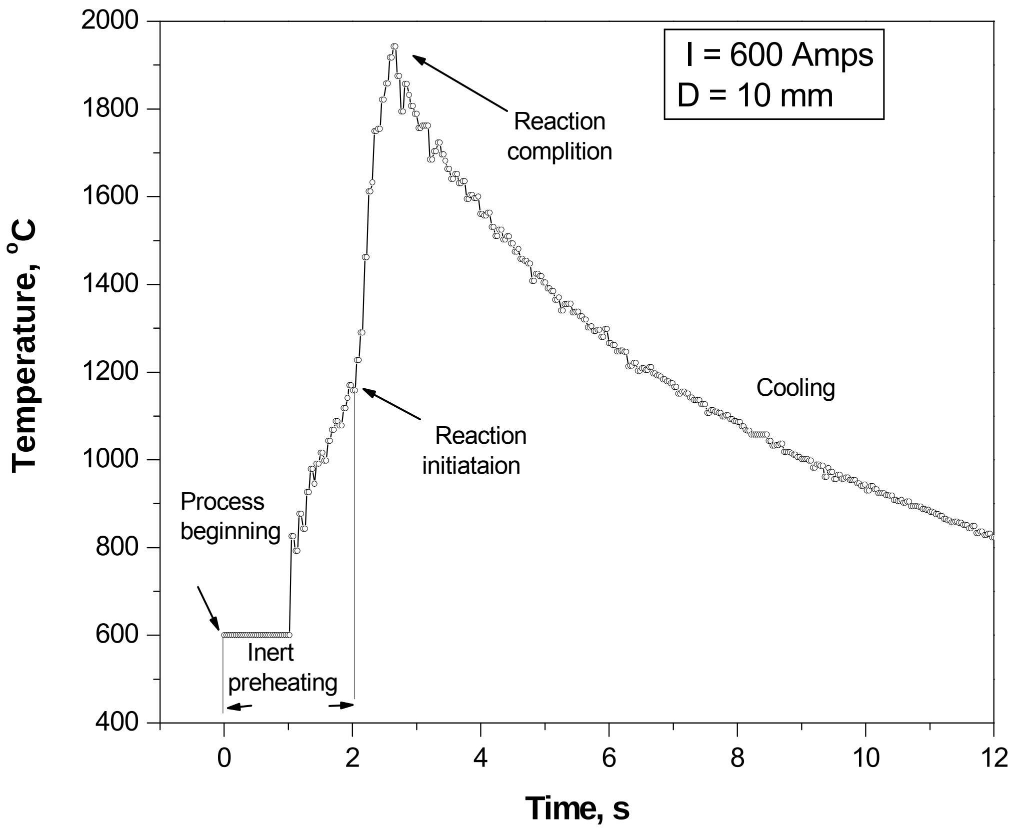
t = 3.00 s



t = 5.00 s

t = 7.50 s

Typical Temperature Profile of Joining Process



Joule preheating only up to T_{ig}

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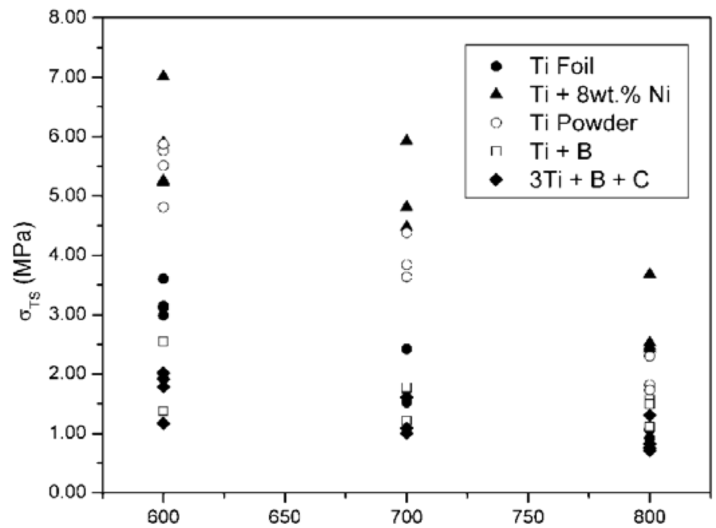
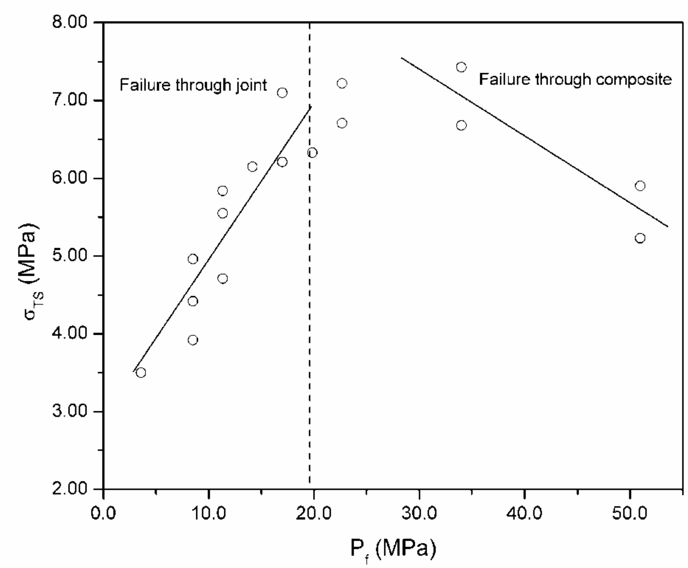
- **C-C composite highly reactive** – don’t need carbon in joining layer (Ti foil, Ti powder, *Ti + 8wt% Ni*, Ti + B, 3Ti + B + C)

- Don’t need highest current

- Applied pressure affects composite properties

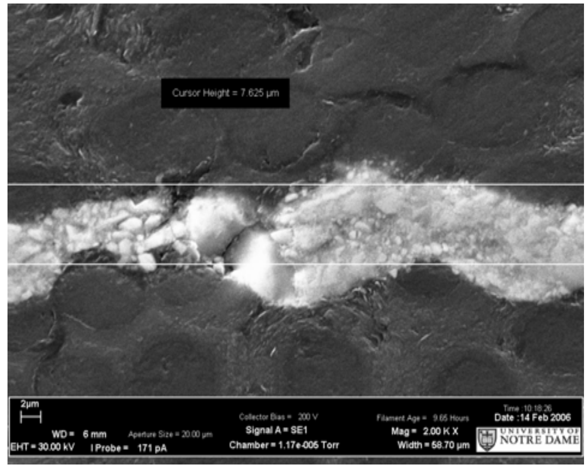
- Final layer thickness independent of initial media thickness



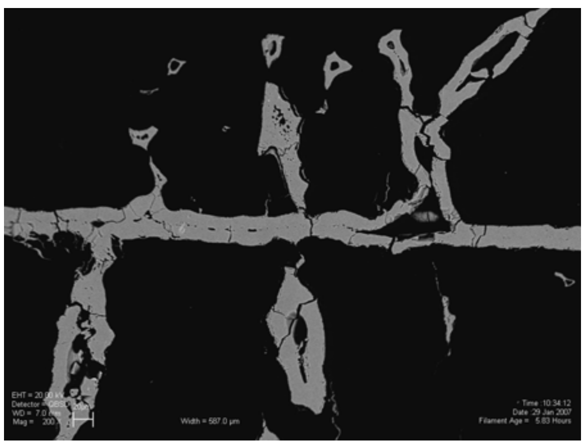


TS of samples joined w/ Ti+8 wt% Ni

Final join structure



final product layer independent of initial layer



Ti powder: h_i = 3000 μm

Ti foil: h_i = 25 μm

characteristic squeezing rate is much higher than the characteristic diffusion time of C into Ti, the thickness of the final joining layer is essentially independent of h_o.

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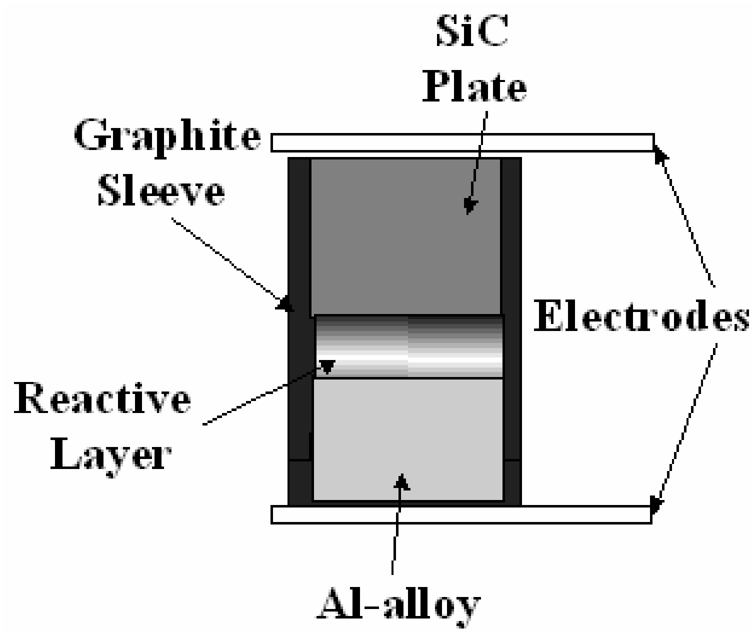
Al – SiC Composites

"The three-quarter-ton armor that gets plated onto the humvees, for example, limits its carrying ability and puts additional strain on the transmission, according to service officials... "

http://www.defensetech.org/archives/001349.html

Sample Configuration



Disks of SiC / reaction layer / Al 5083 alloy

Reaction layer = Ti; Ti+C, Ti-Al gradient

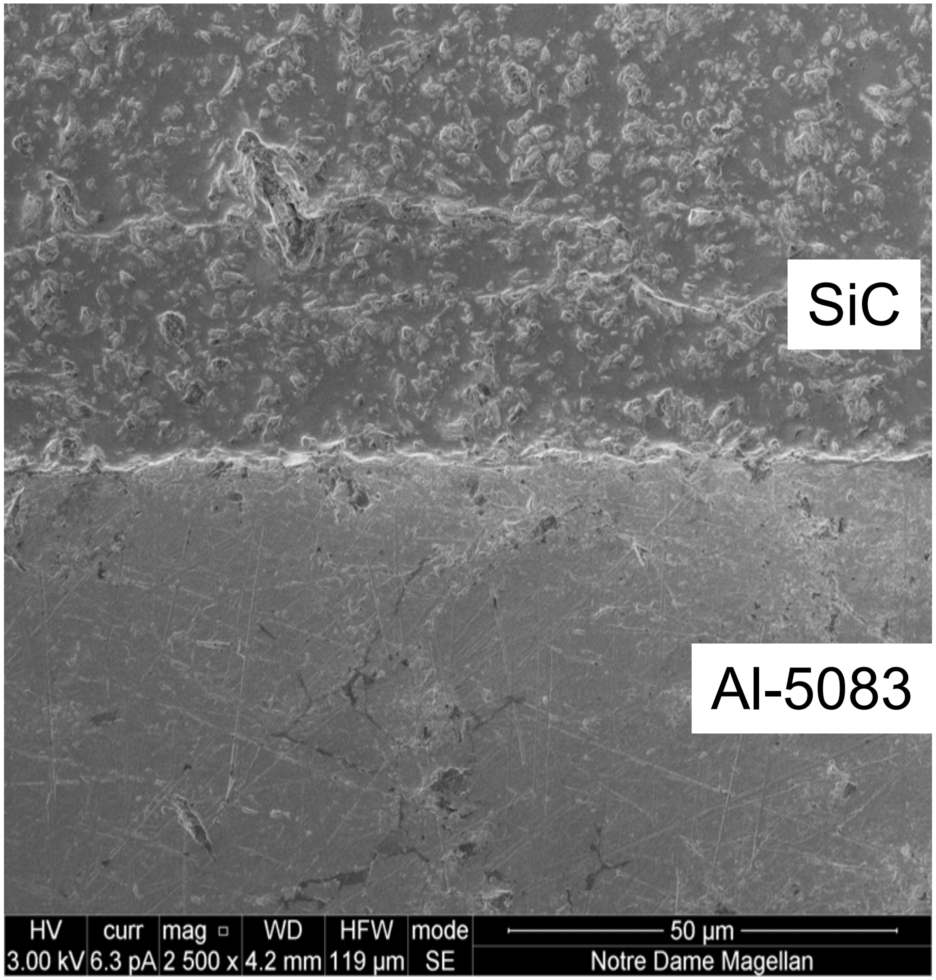
Thermo calcs: Ti + SiC $\rightarrow$ TiC, $TiSi_x$, possible

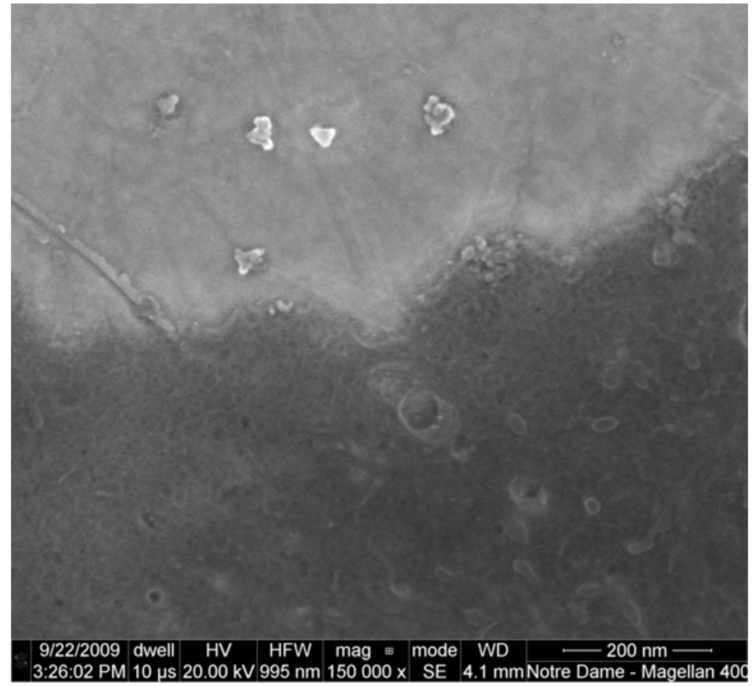
reaction temperature > Al_{mp}, close to Ti_{mp}, < SiC_{mp} (3100K).

Conductivity of stack too low; pass current through **graphite** to preheat

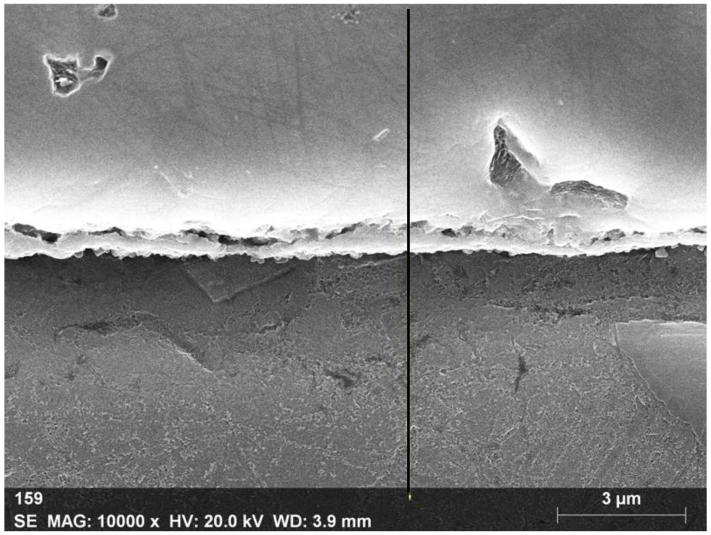
This design does not allow for compaction during reaction

different die design now being used



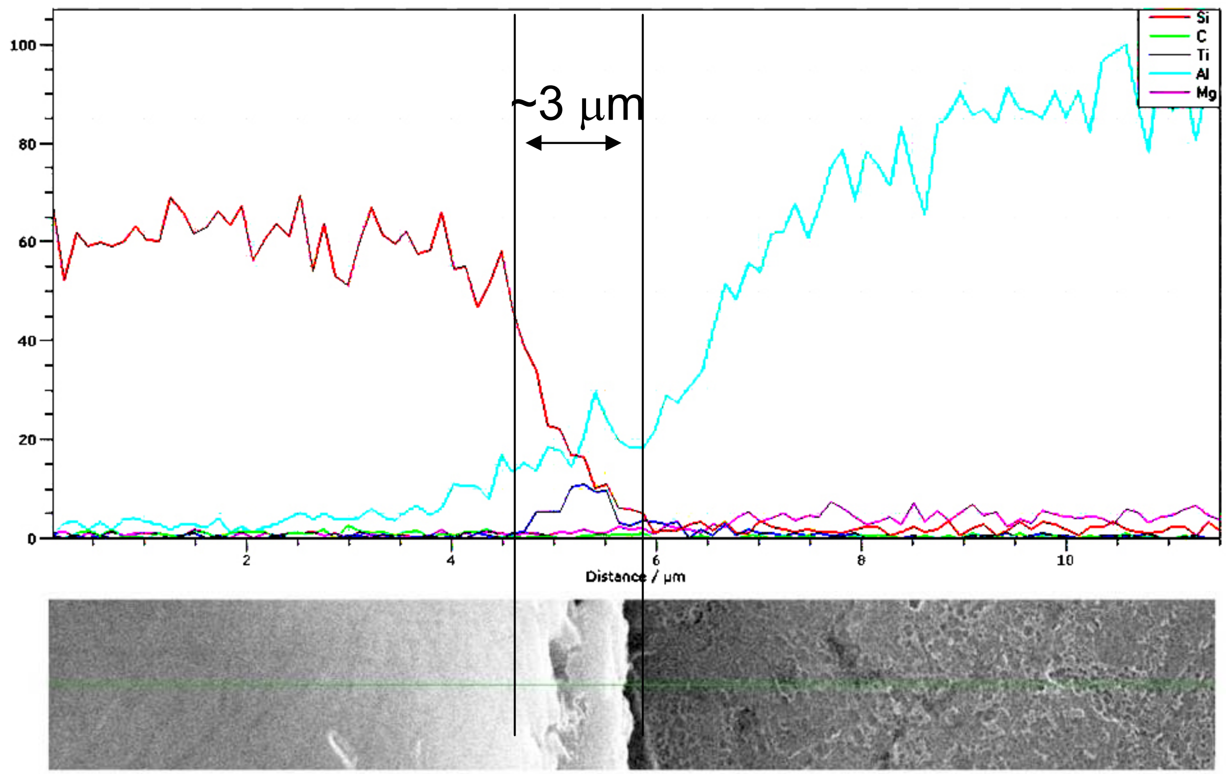


(i) Reaction starts at melting point of Al (~ 932K).
(ii) Ti layer reacts with Al-alloy, elevating temperature (~2000K) in the boundary layer



2mm Ti+C rxn disk

Ti confined to region ~3 μm wide near interface



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Summary

- Combustion Joining of refractory materials has great potential for low cost, rapid fabrication of composites, esp. for some materials that are difficult or impossible to join using more conventional techniques:

- Rapid combustion reactions provide a unique set of conditions for synthesizing functionally graded layers:
  - short reaction times (~1–10 s) allow the desired functionally graded material structure to be maintained
- Demonstrated the concept for joining of SiC-Al-alloy using a combustion-based approach
- Need to determine optimum reaction layer composition and heat-treatment conditions to form various phases:

  - Ti_3SiC_2 (ductile), Si(Al)CO, TiC-SiC-Al
- New press set-up /die design implemented to produce optimized materials for sub-scale ballistic tests