NUMERICAL ANALYSIS OF BI-METALLIC EXPLOSIVE SHOCK-LOADING AND RELEASE EXPERIMENTS

(Wave Interaction)

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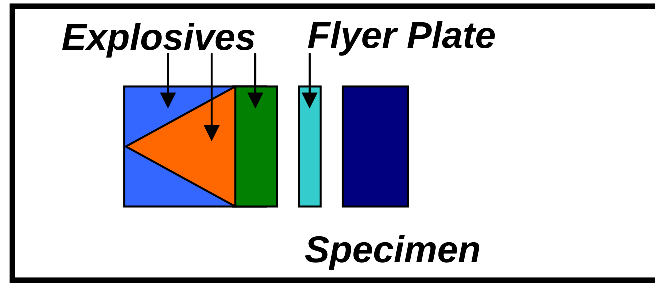
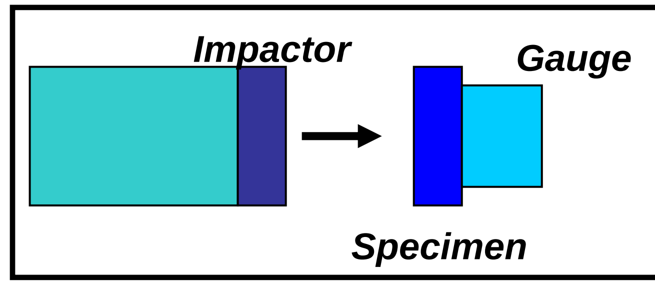
Shock Loading Techniques

Established Techniques

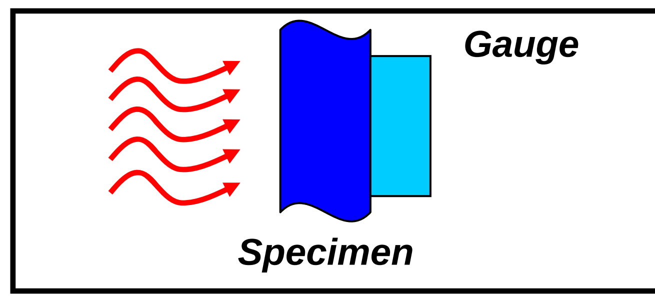
- **Explosive Loading**
  1. Plane wave lens
  2. Explosively-driven flyers



- **Smooth-bore guns**
  1. Single-stage compressed gas
  2. Propellant
  3. Two-stage light gas
  4. Rail guns
  5. Three-stage light gas

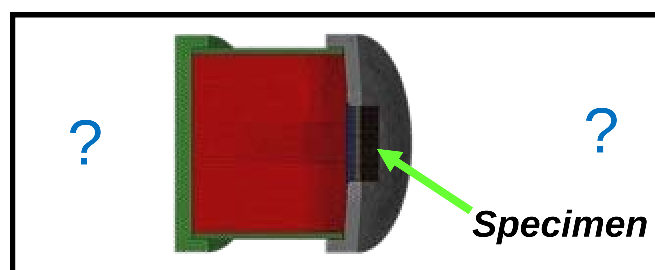


- **Radiation**
  1. Electron beams
  2. Nuclear explosions
  3. Laser beams
  4. Z machine (X- rays, magnetic flux)



Evaluate Explosive End-Projector

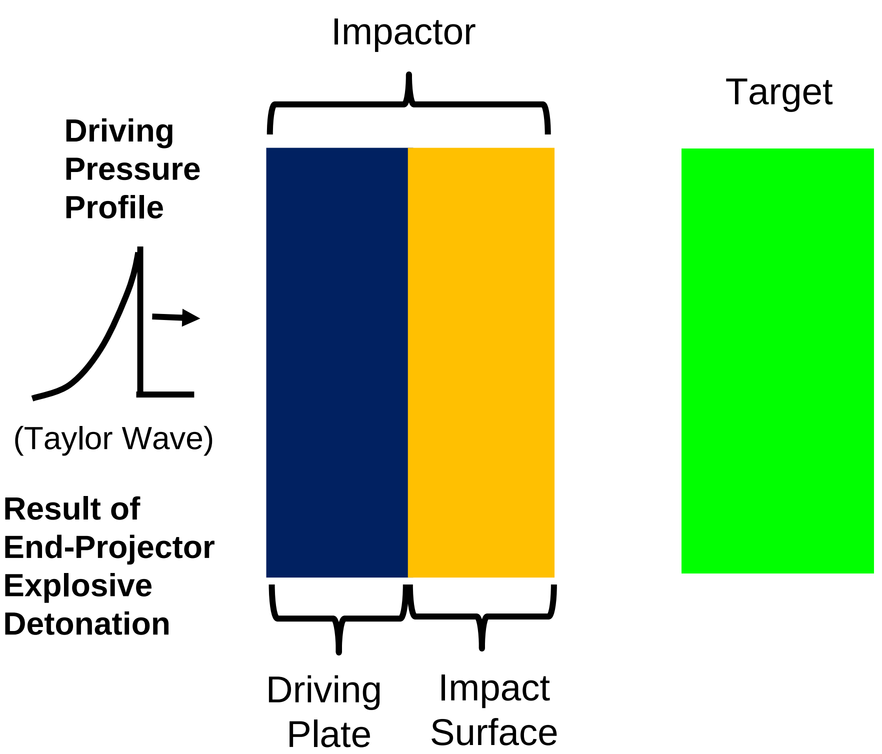
In-house capability but not an established technique

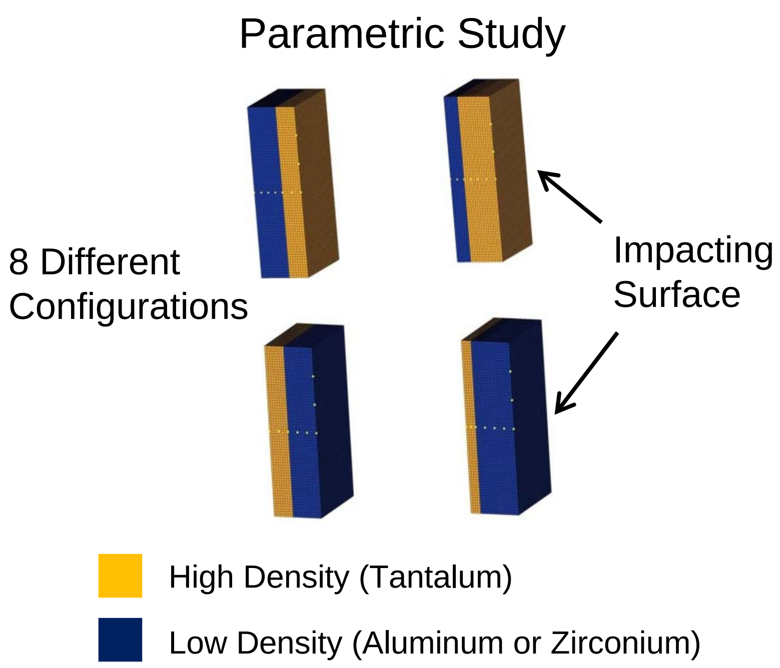


Objective

Effects of the End-Projector on Terminal Velocity

Evaluate loading conditions and its effects (pressure, velocity, strain) through the bonded plates using the End-Projector, and its effects on terminal velocity



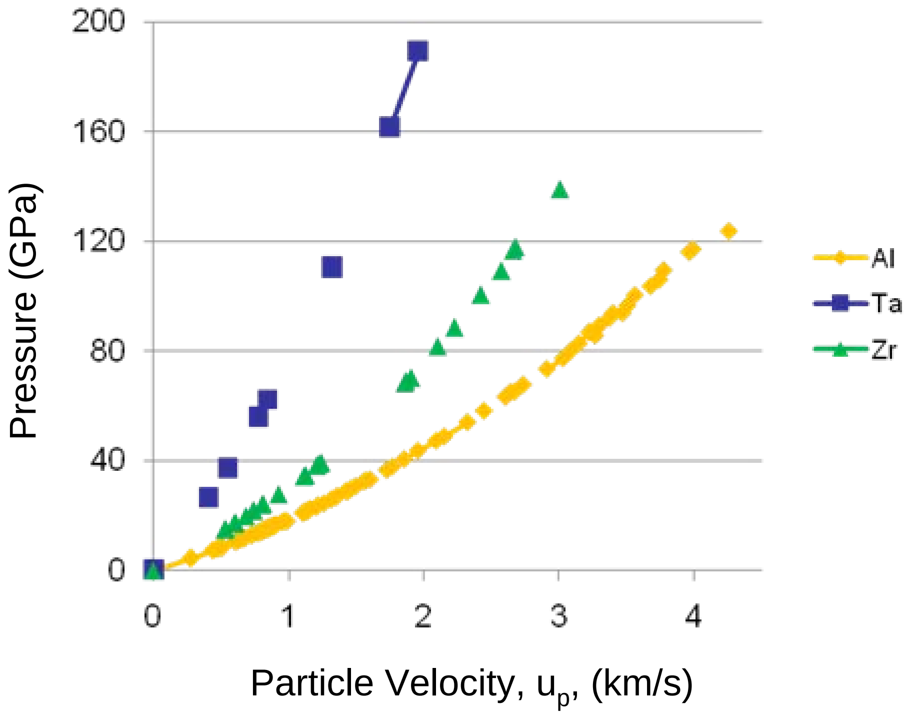


Equation of State & Constitutive Parameters
Used to Simulate Material Response - EPIC Hydrocode

Materials:
- Aluminum – Al
- Tantalum – Ta
- Zirconium - Zr

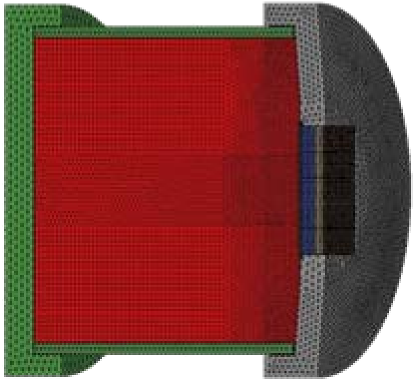
Strength Properties: Johnson-Cook Model
EOS: Mie-Gruneisen Model 2

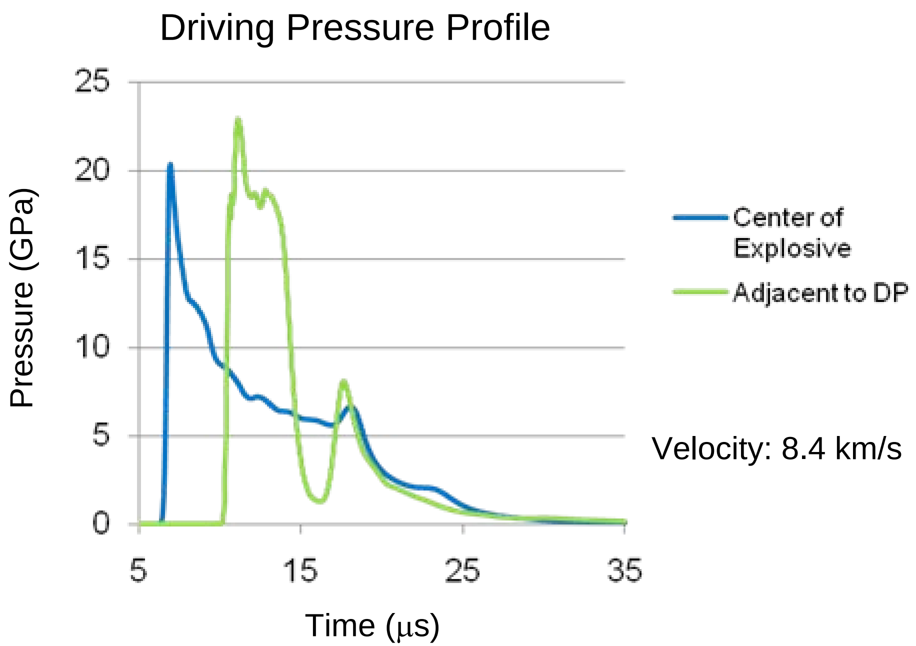
Property	Al	Ta	Zr
Density, ρ_o (g/cm^3)	2.78	16.6	6.65
Yield Stress (GPa)	0.310	0.170	0.230
Poisson Ratio	0.33	0.34	0.34
Bulk Sound Velocity, C_s (km/s)	5.328	3.414	3.757
U_S / u_P Slope (S)	1.338	1.201	1.271
Spall Strength (GPa)	1.7	6.5	2.16
Impedance , $Z = \rho_o U_S$	14.8	56.7	25.0

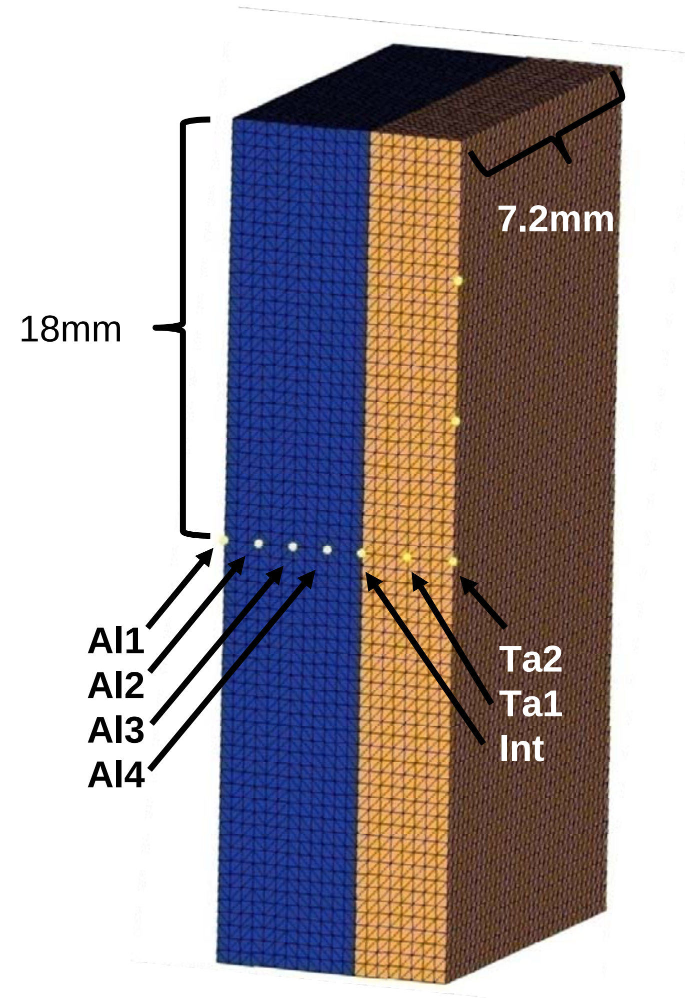


Numerical Configuration

Monitor Through-thickness and Lateral Dimensions

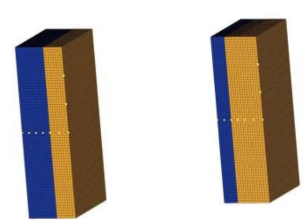
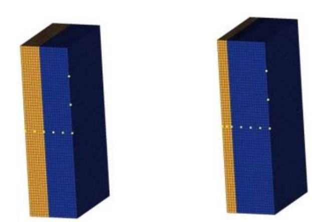




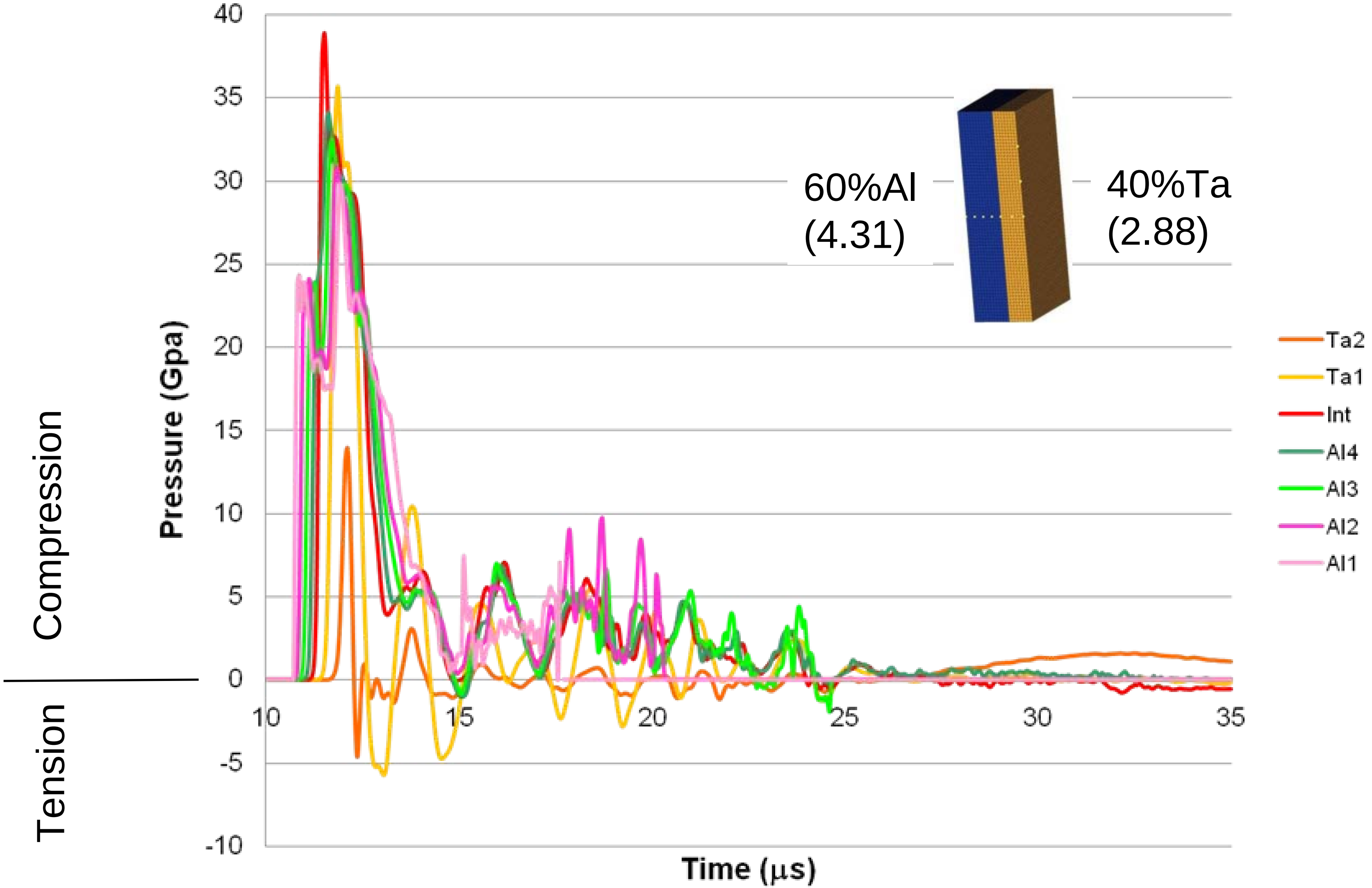


Code: EPIC; 1.1 Million Constant-strain Tetrahedral Elements

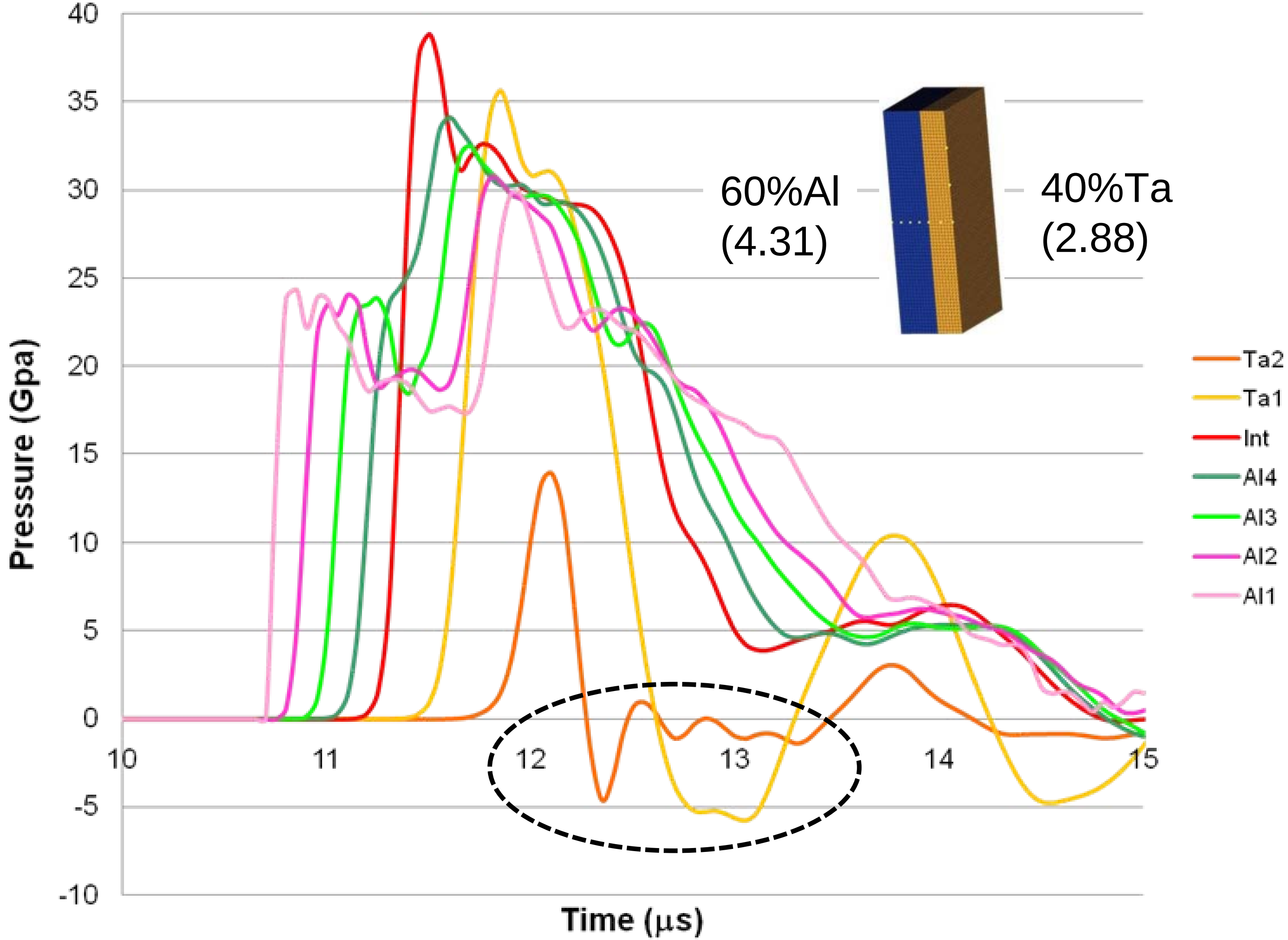
Bimetallic Plate Configuration

Configuration	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Driver Plate Material (Explosive Surface)	Al	Al	Zr	Zr	Ta	Ta	Ta	Ta
Driver Plate Material Thickness (mm)	4.31	2.16	4.31	2.16	2.88	1.44	2.88	1.44
Impactor Surface Material	Ta	Ta	Ta	Ta	Al	Al	Zr	Zr
Impactor Surface Material Thickness (mm)	2.88	5.03	2.88	5.03	4.31	5.75	4.31	5.75
Type	Shock / Release				Shock / Reshock			
High Density (Tantalum) Low Density (Aluminum or Zirconium)								

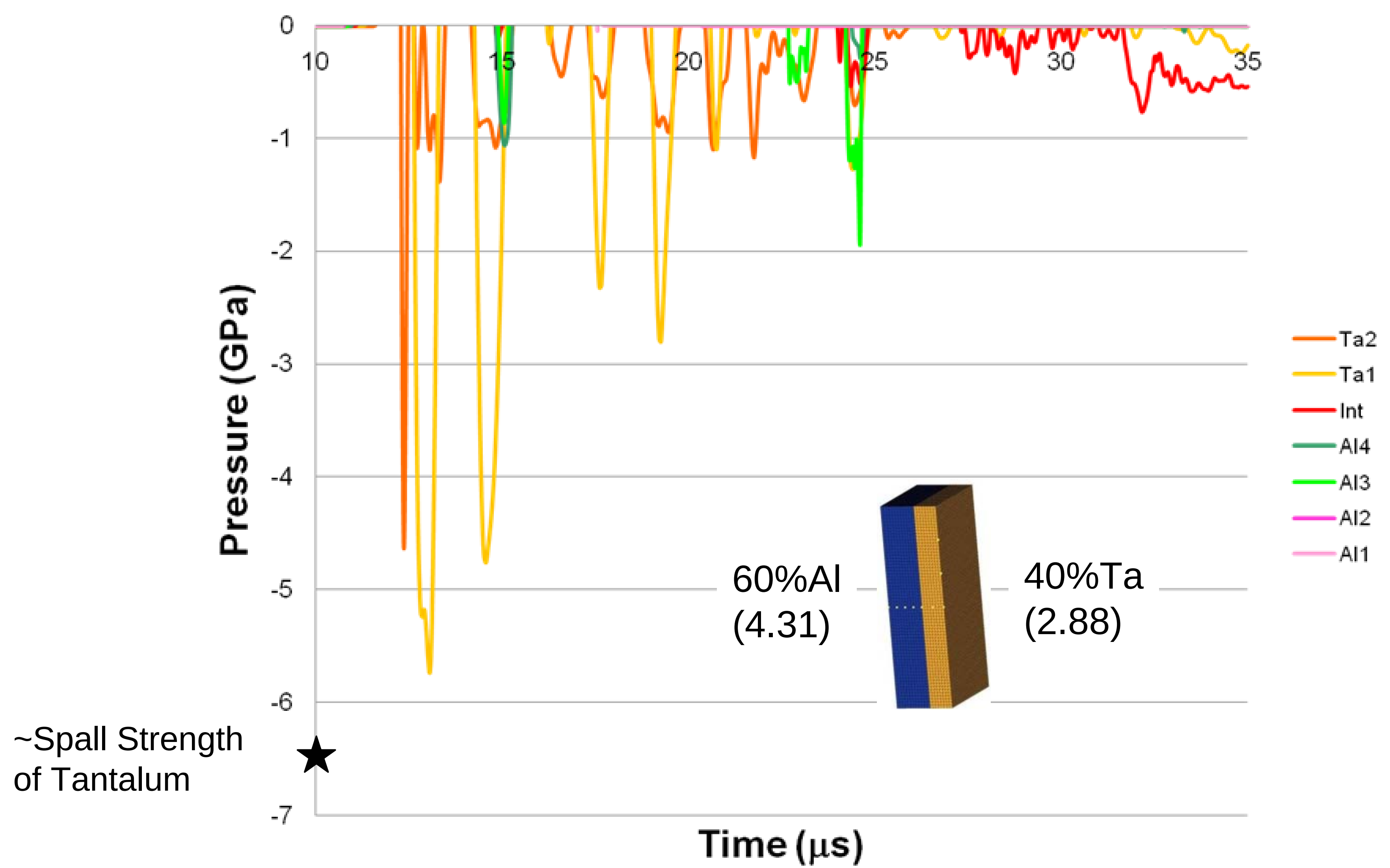
Through Thickness Pressure (Configuration 1)



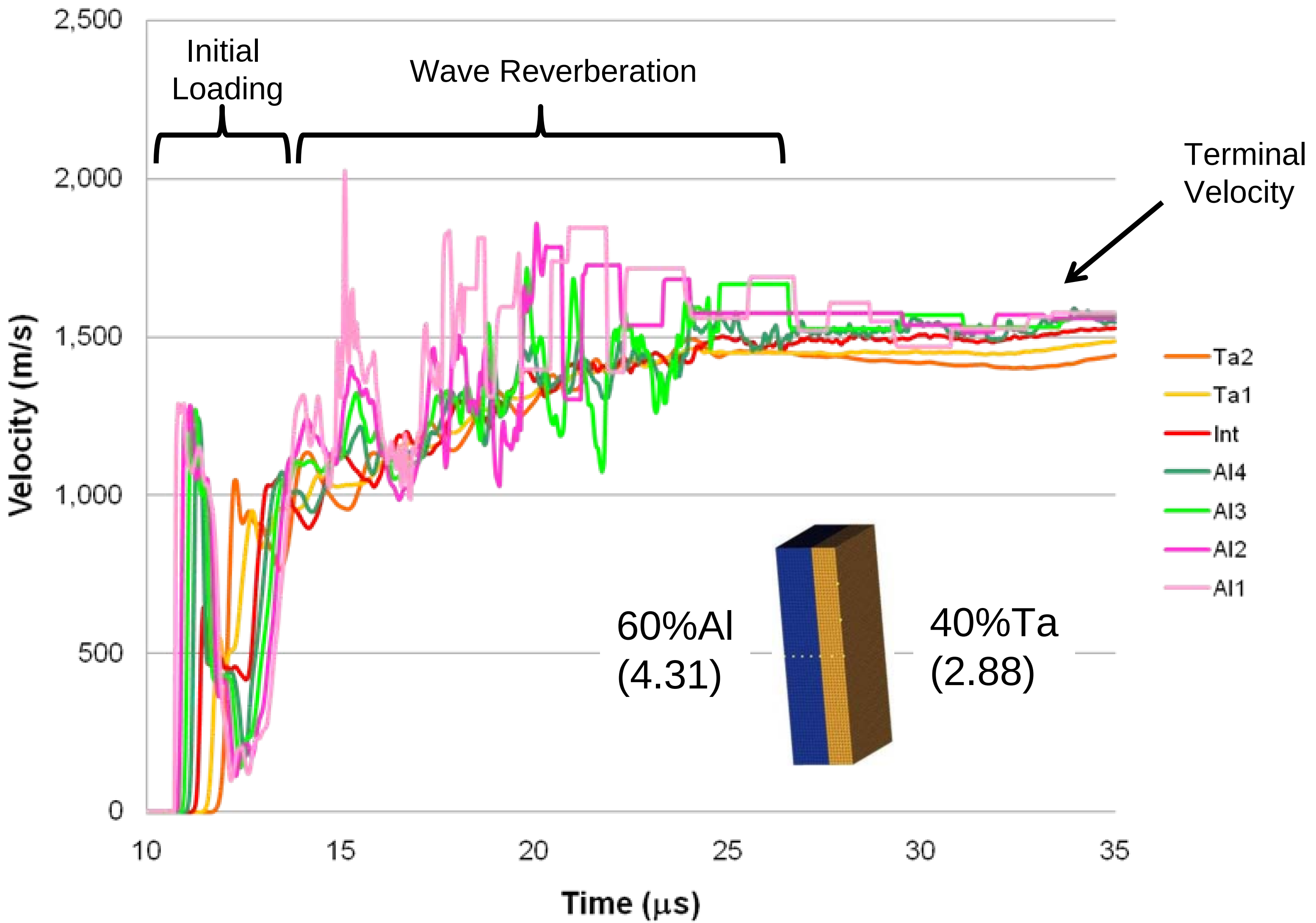
Through Thickness Pressure (Configuration 1)



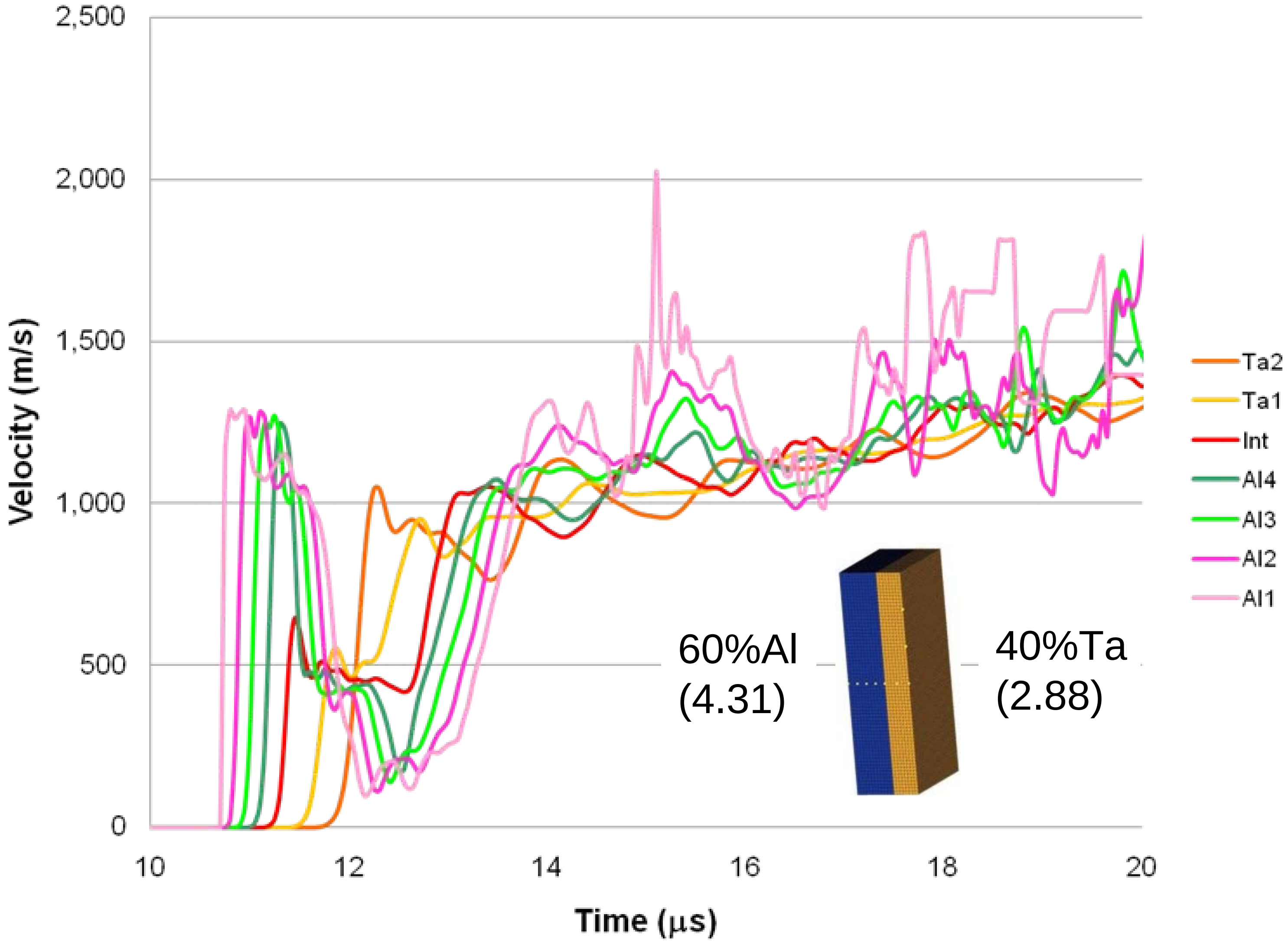
Through Thickness Tension (Configuration 1)



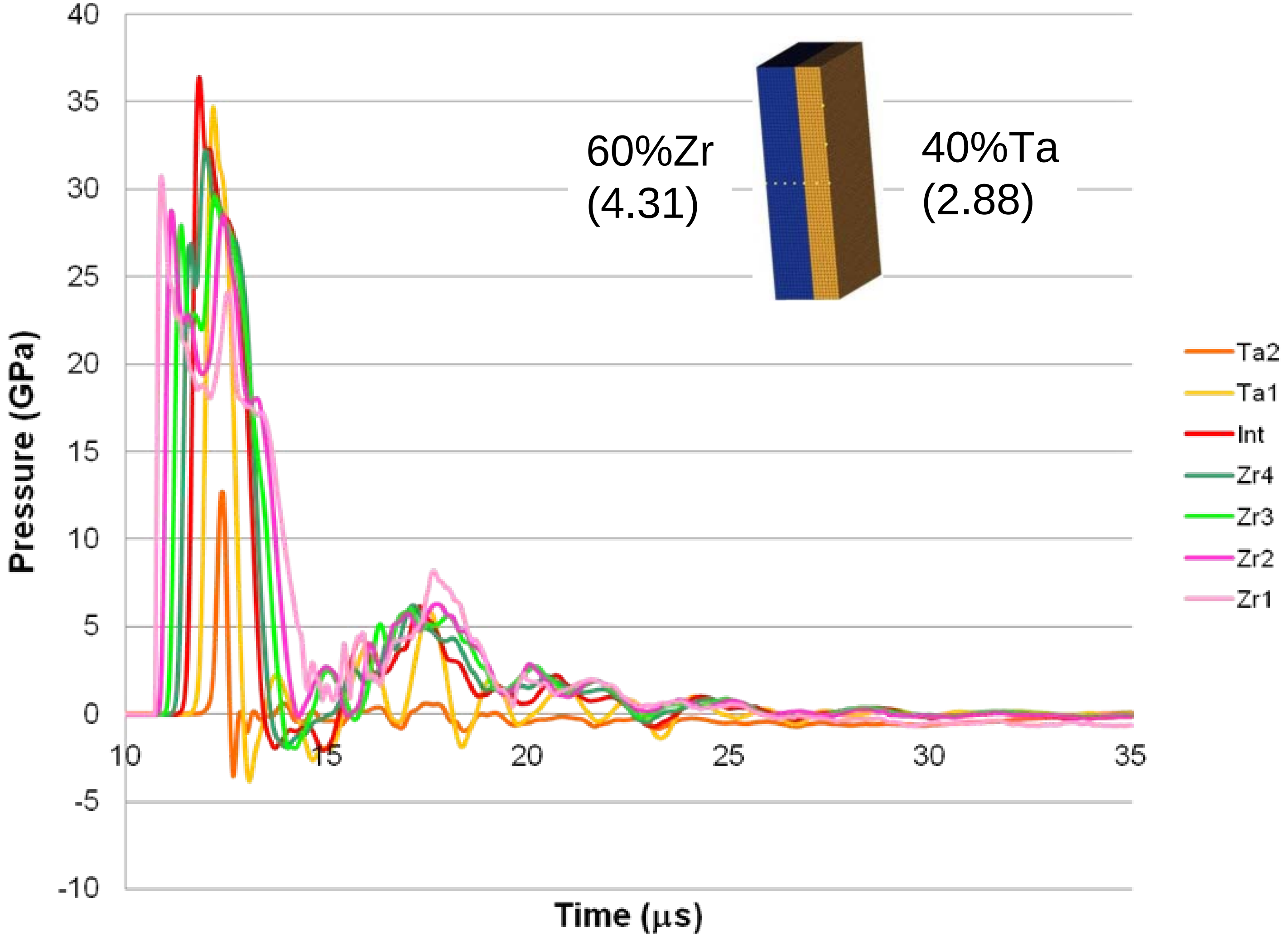
Through Thickness Velocity (Configuration 1)



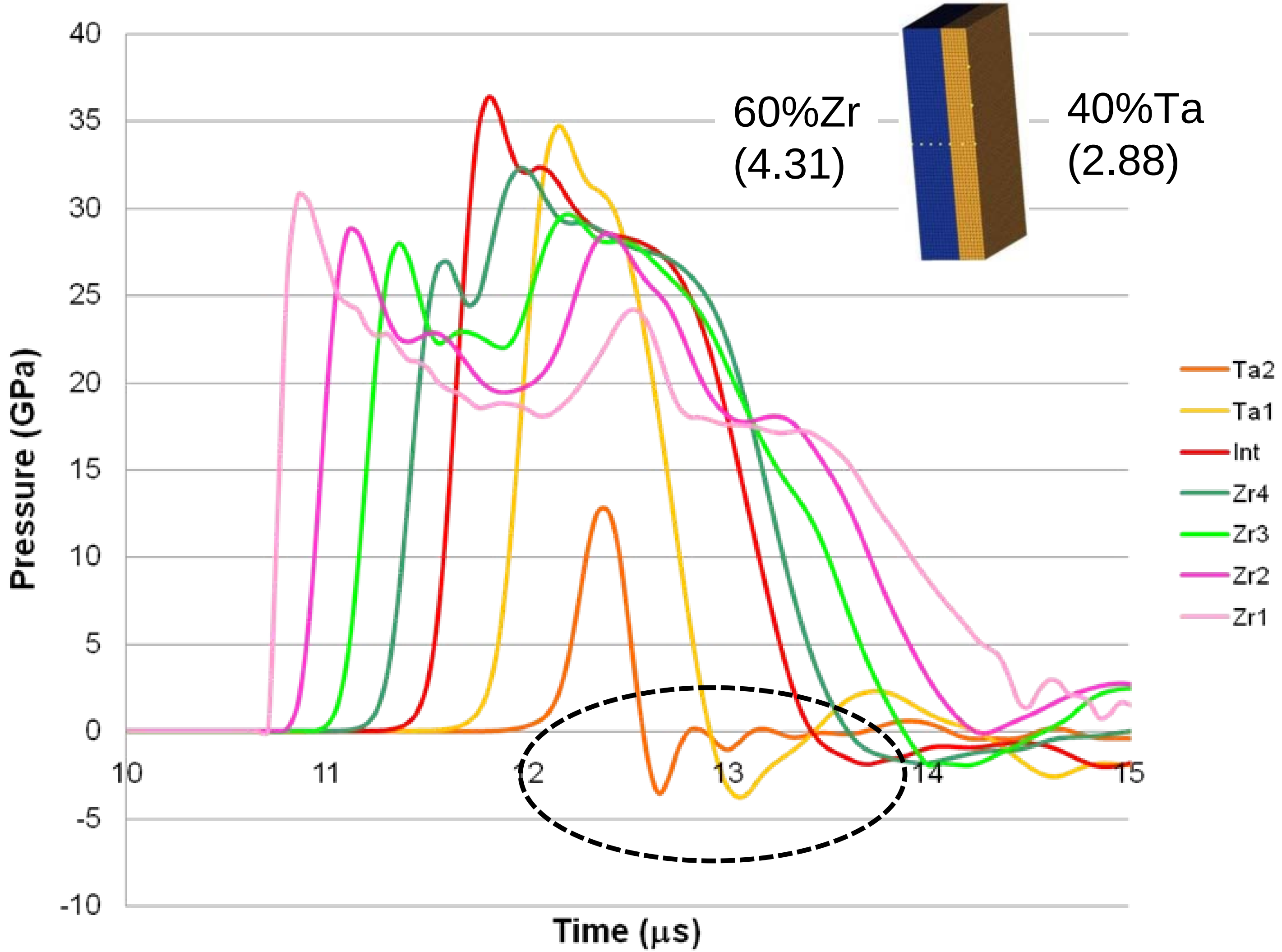
Through Thickness Velocity (Configuration 1)



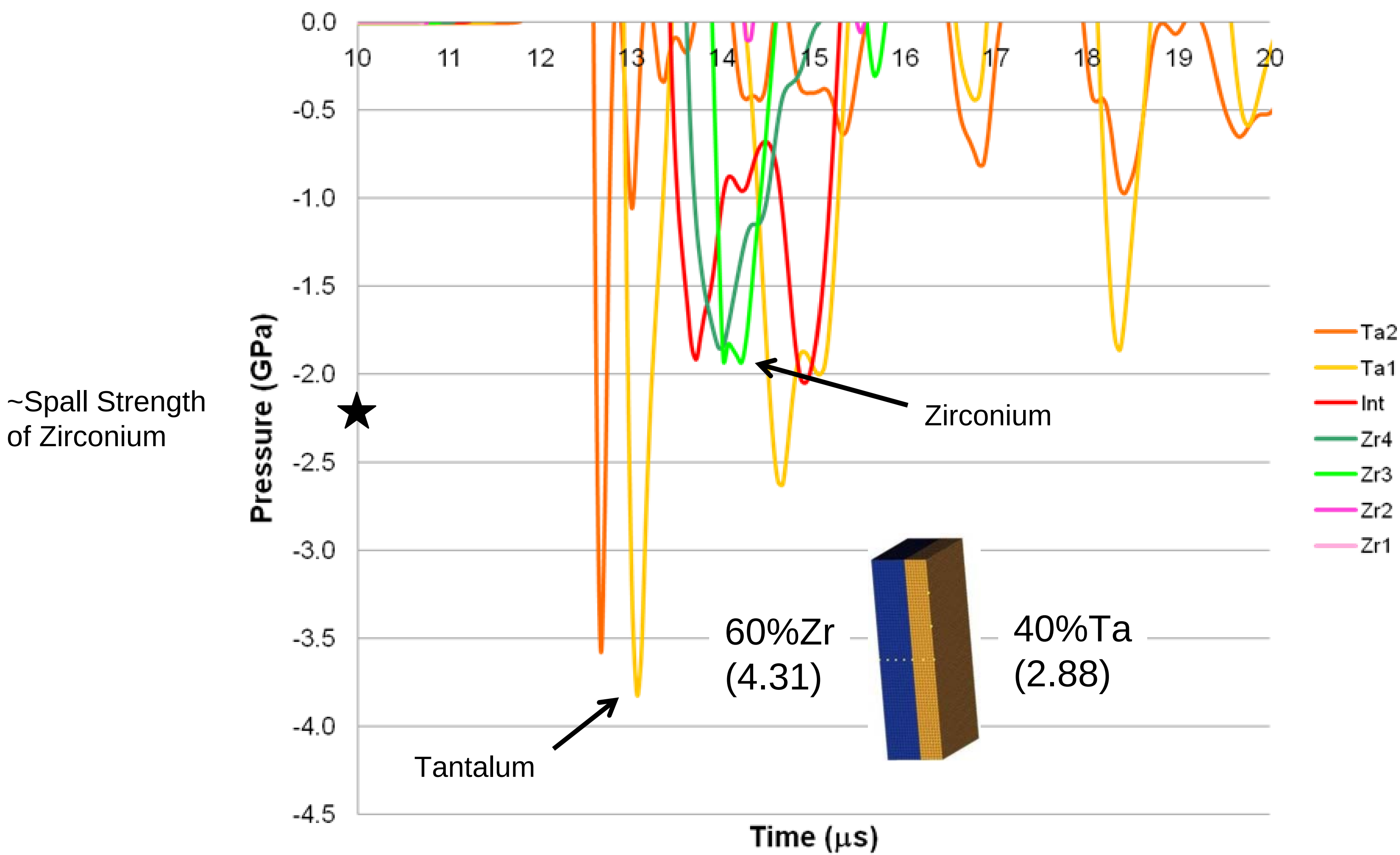
Through Thickness Pressure (Configuration 3)



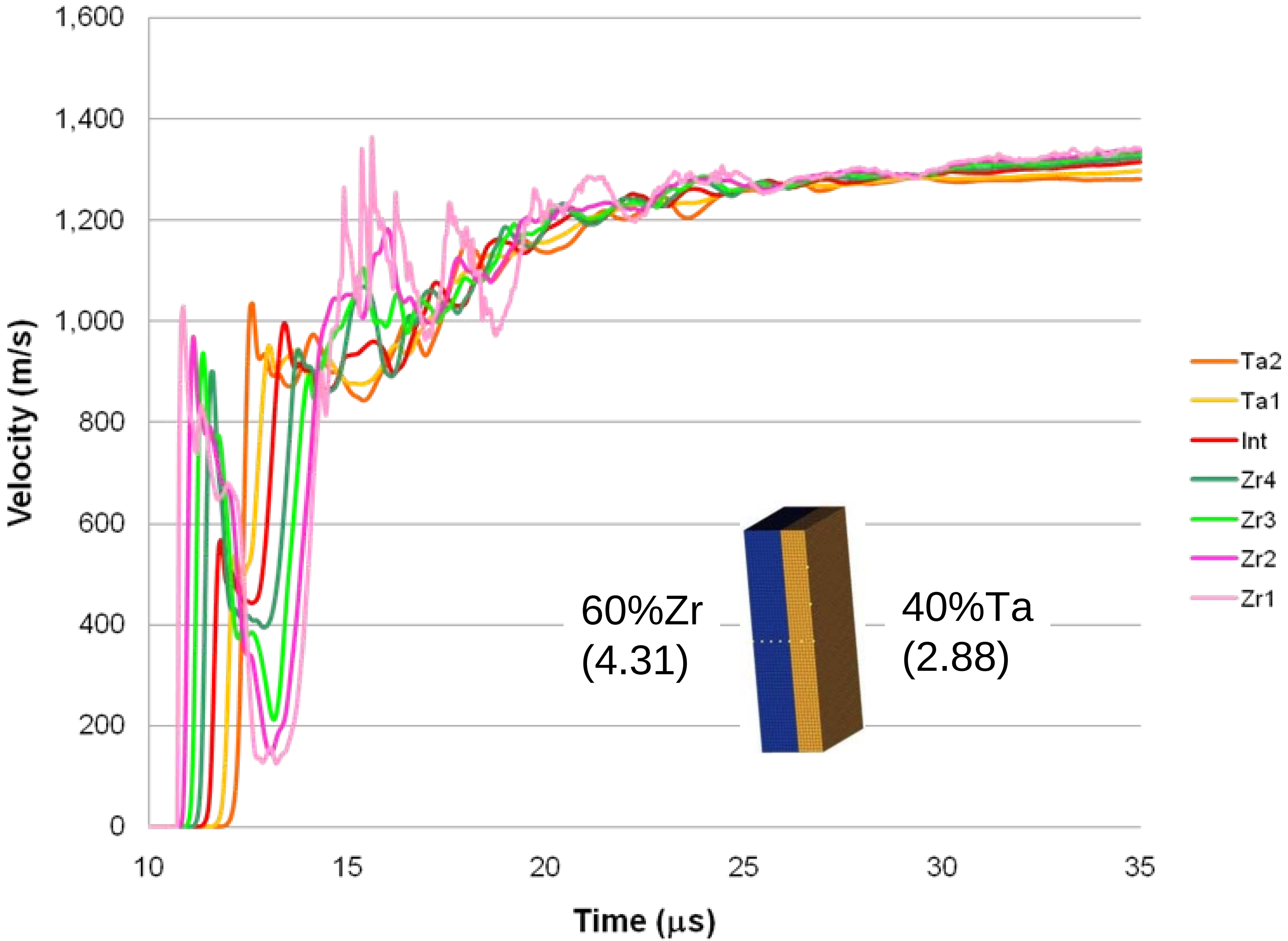
Through Thickness Pressure (Configuration 3)



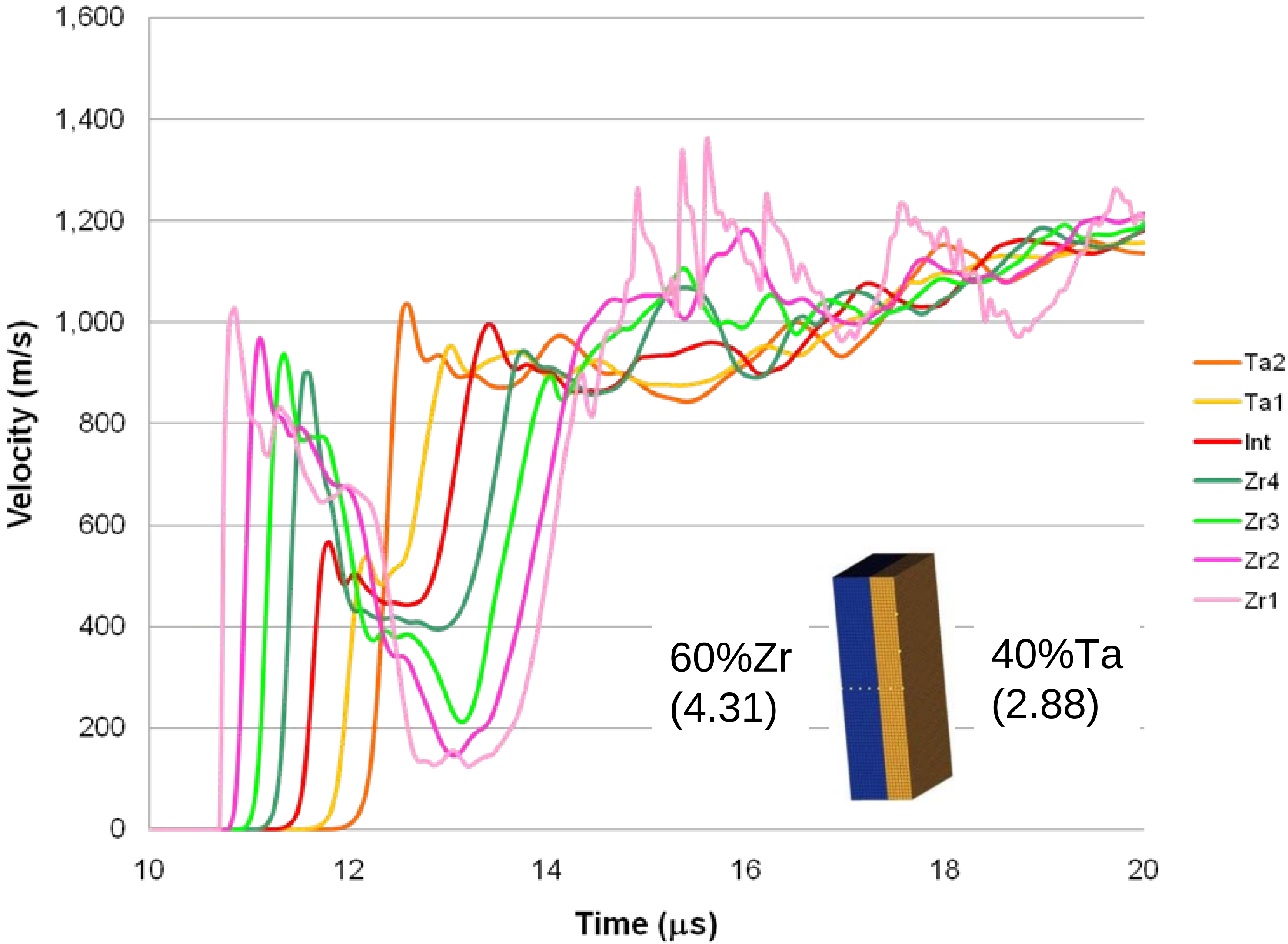
Through Thickness Pressure (Configuration 3)



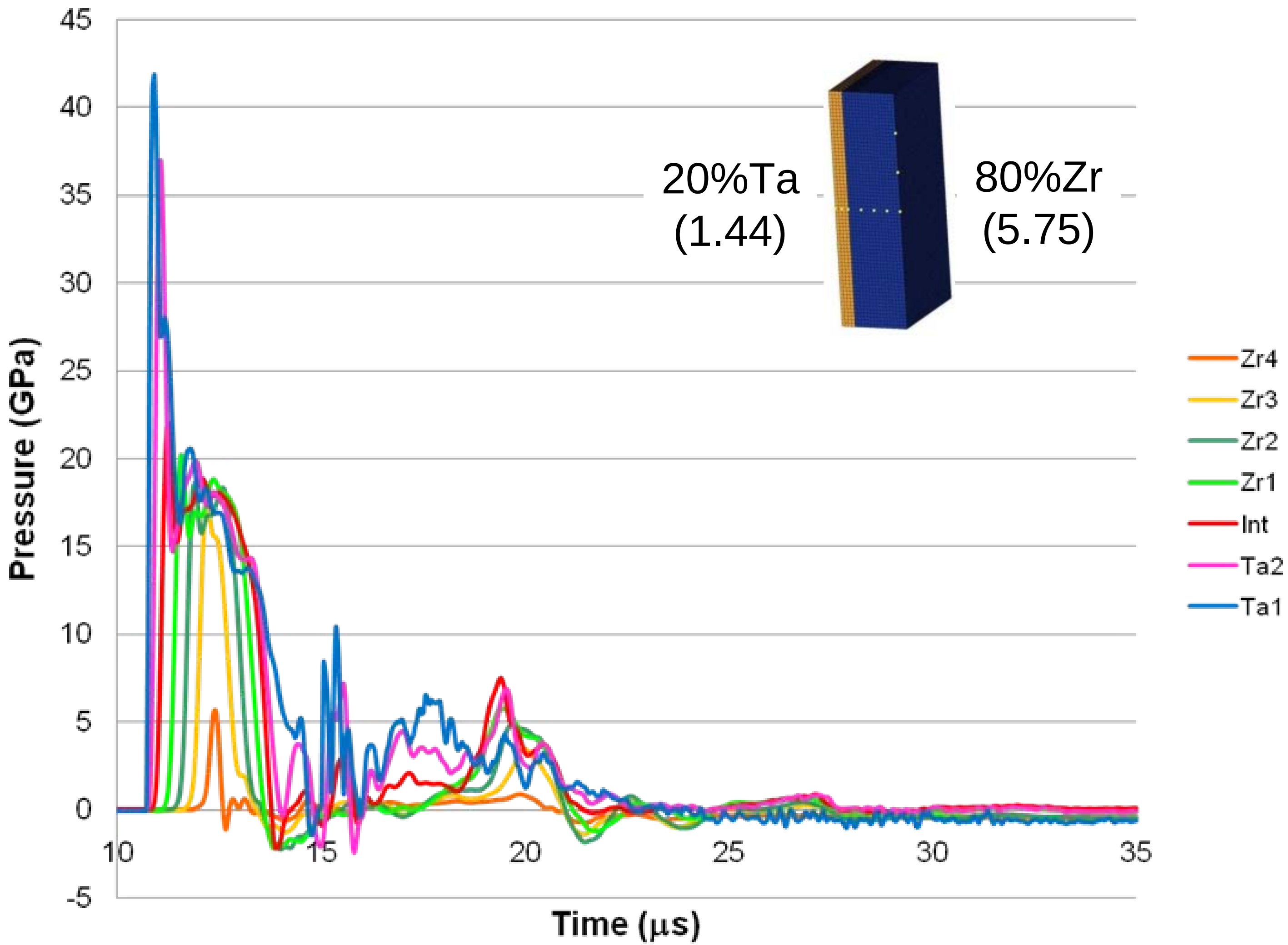
Through Thickness Velocity (Configuration 3)



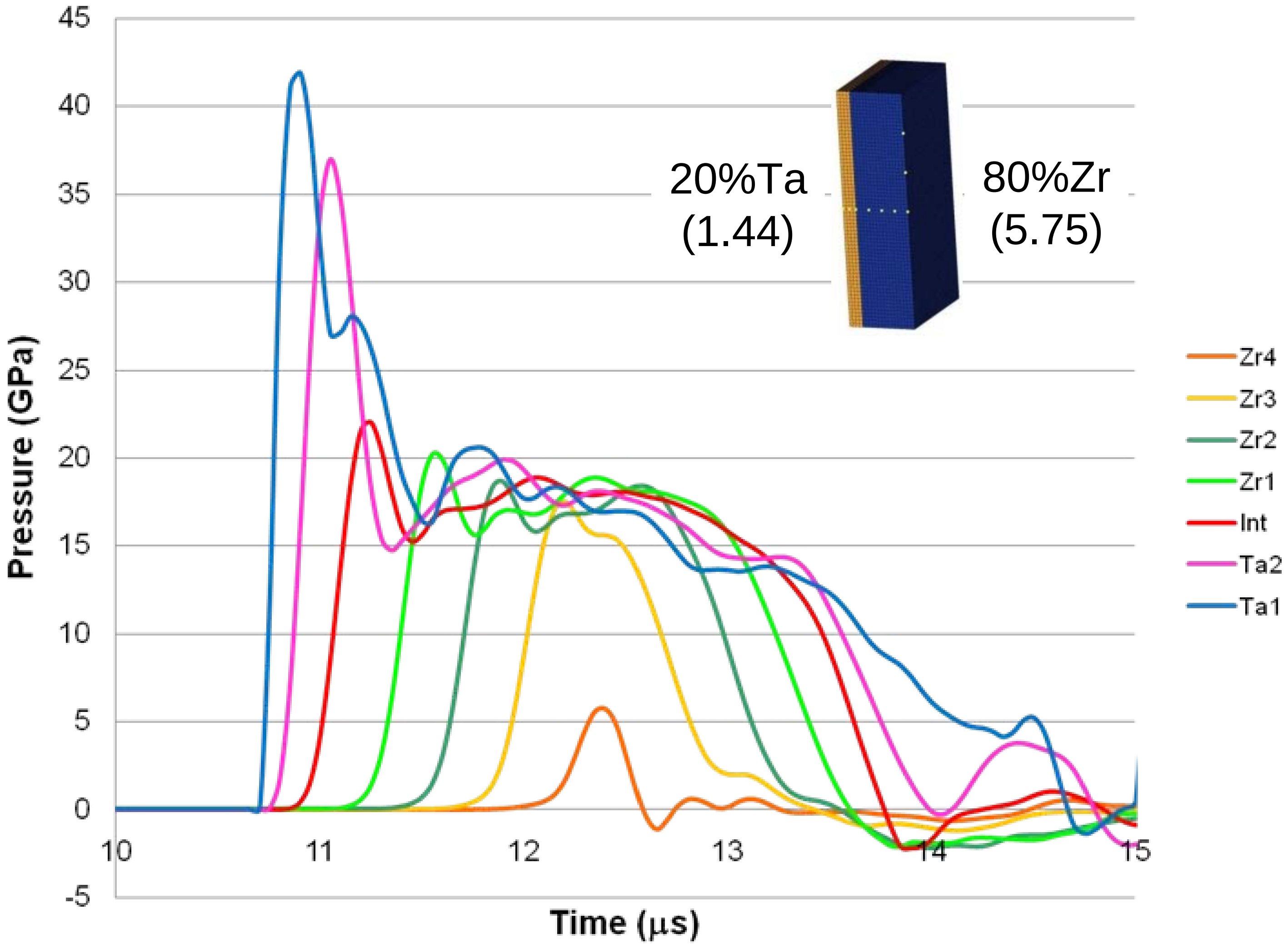
Through Thickness Velocity (Configuration 3)



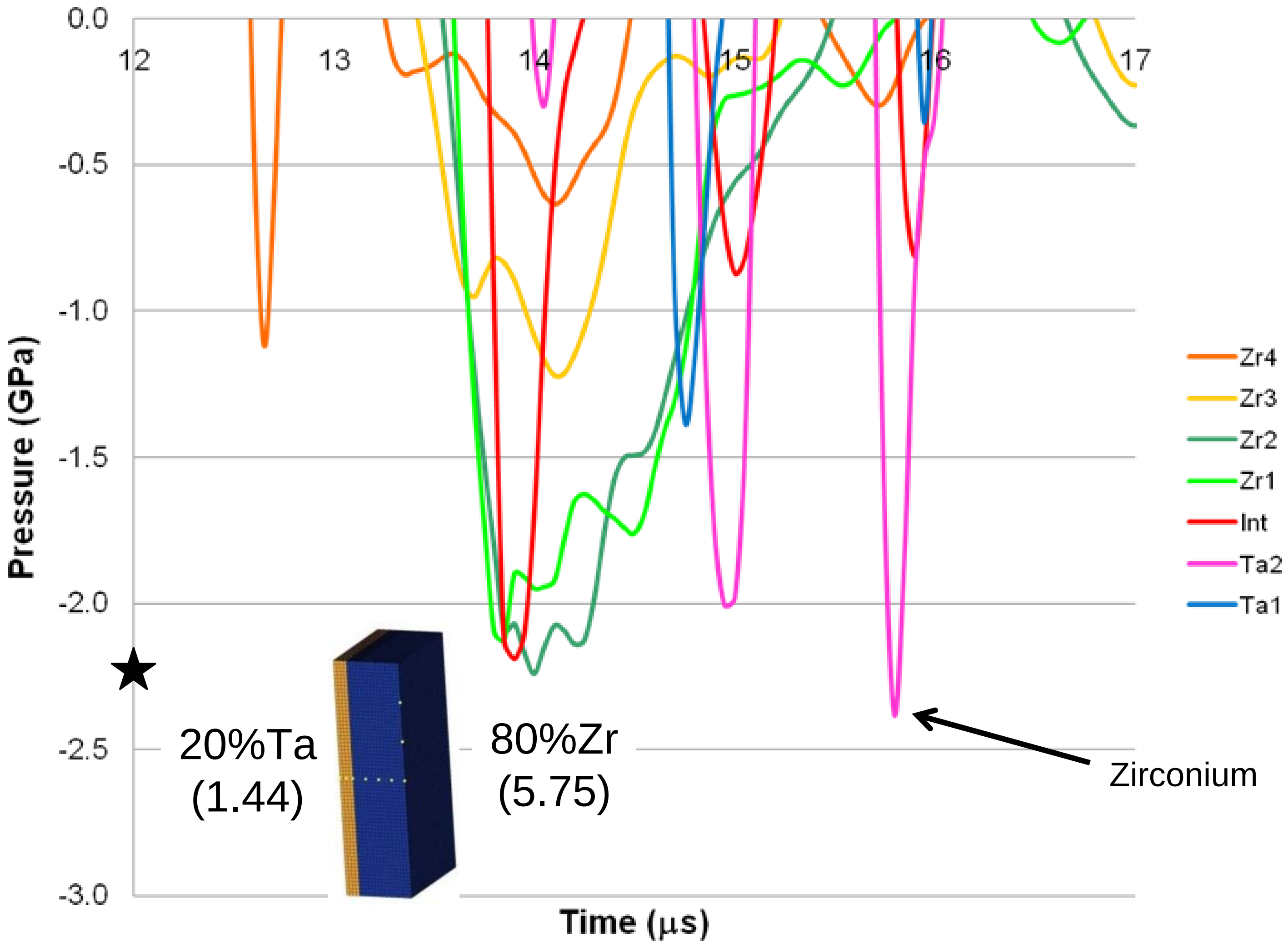
Through Thickness Pressure (Configuration 8)



Through Thickness Pressure (Configuration 8)

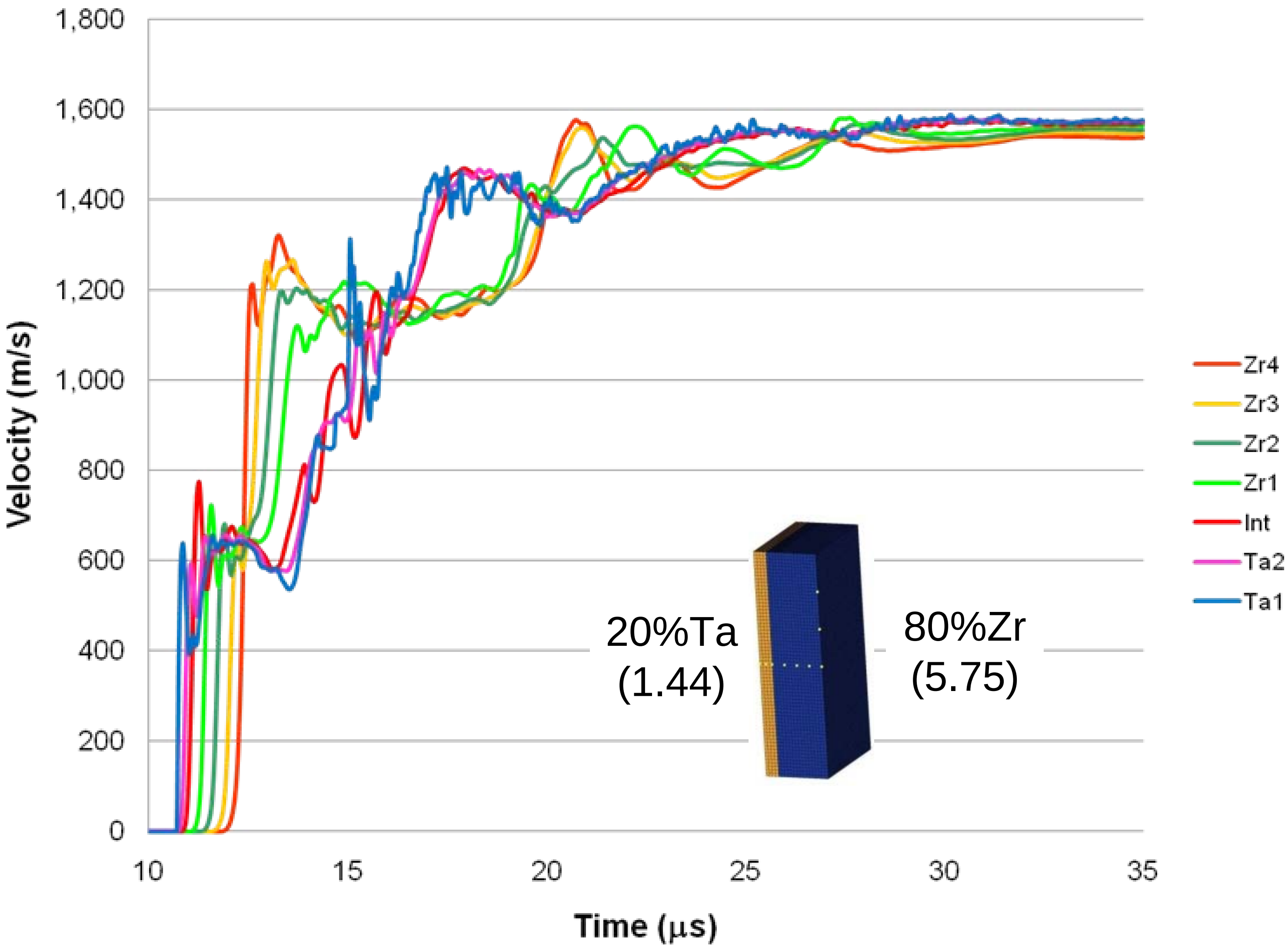


Through Thickness Pressure (Configuration 8)

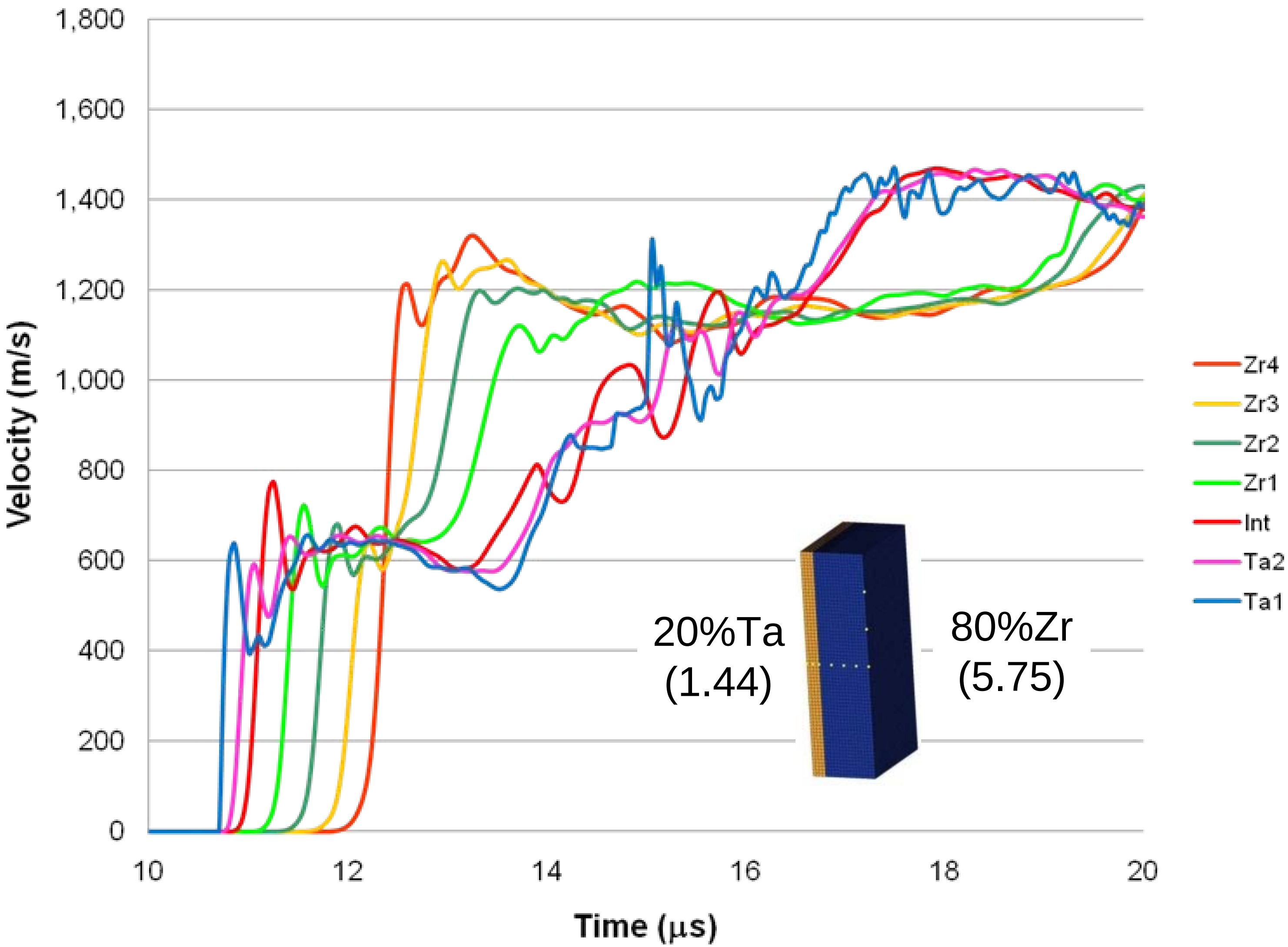


~Spall Strength of Zirconium

Through Thickness Velocity (Configuration 8)



Through Thickness Velocity (Configuration 8)



Summary

Configuration	1	2	3	4	5	6	7	8
Driver Plate Material (Explosive Surface)	Al	Al	Zr	Zr	Ta	Ta	Ta	Ta
Max Compression (GPa)	32.5	35.5	32.2	34.1	41.9	41.9	41.9	41.9
Max Tension (GPa)	1.88	0.76	1.93	0.83	5.90	4.56	4.26	2.38
Impactor Surface Material	Ta	Ta	Ta	Ta	Al	Al	Zr	Zr
Max Compression (GPa)	35.7	38.8	34.7	37.9	13.3	14.8	18.5	20.2
Max Tension (GPa)	5.7	7.15	3.82	6.86	3.74	4.22	1.51	2.23
Interface								
Max Compression (GPa)	38.9	41.2	36.4	39.8	14.5	15.7	20.4	22.0
Max Tension (GPa)	0.76	1.21	2.05	0.21	5.13	4.08	2.19	2.19
Velocity								
Terminal Velocity (m/s)	1500	1150	1300	1050	1575	2150	1300	1575

Anticipated Spall (highlighted cells: Config 1 driver plate max tension 1.88; impactor max tension 7.15, 3.74, 4.22, 2.23; interface max tension 5.13, 4.08)

Conclusions

- Good potential for explosively launched bimetallic plates regarding shock loading experiments
- As expected, material choice and dimensions play a key role in the survivability of launching the bonded plates. Lower impedance mismatches reduce spall susceptibility but at expense of reshock
- Shock / Re-shock experiments are more susceptible to spall and thus more challenging to design
- Additional system features may be introduced such as an air gap between the explosive and driver plate which would result in a lower driving pressure and therefore reduced susceptibility to spall.
- It is encouraging that these initial studies are quite promising. Further studies should include using an optimization routine which would include controlling the dimensions of the air gap, and the relative thicknesses of the driver plate and impactor plate.