

Impact studies of shear thickening fluids incorporated within composite structures

C. Trigg

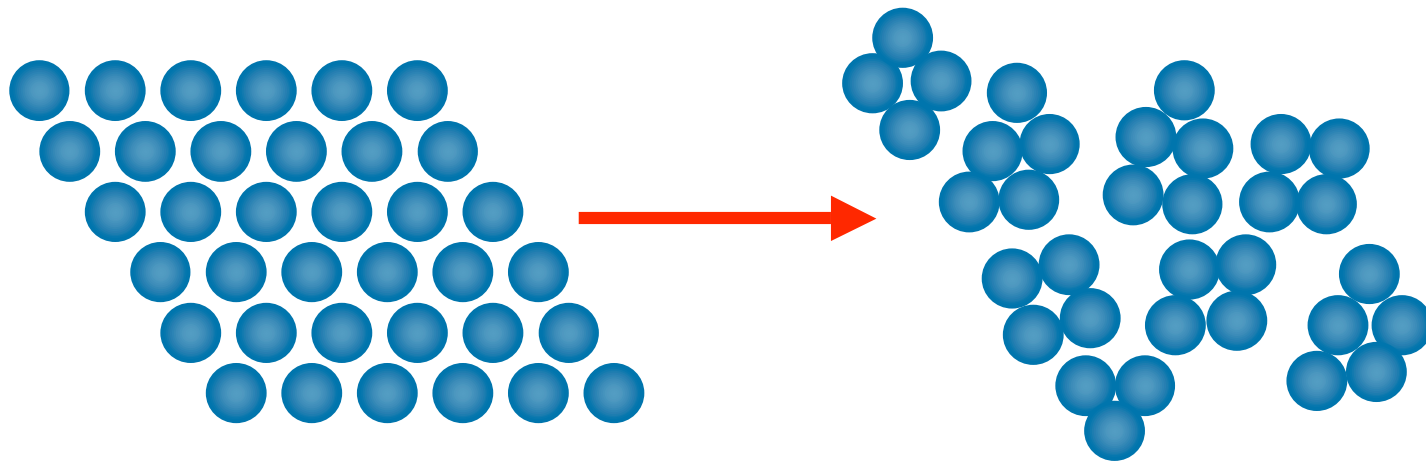


Overview

- 1) Introduction to shear thickening fluids
- 2) Explanation of characterisation method developed for shear thickening fluids
- 3) Experimental: Comparison of titania and silica based shear thickening fluids
- 4) Mechanical testing: spike impact tests
- 5) Conclusions

Shear Thickening Fluids

- What is a shear thickening fluid?
 - Increase in viscosity with shear rate
 - Reversible
 - “Discontinuous” – liquid to solid transition at critical shear rate
 - High volume fraction dispersions (typically >40%)
 - Mechanism for discontinuous shear thickening is due to order to disordered flow

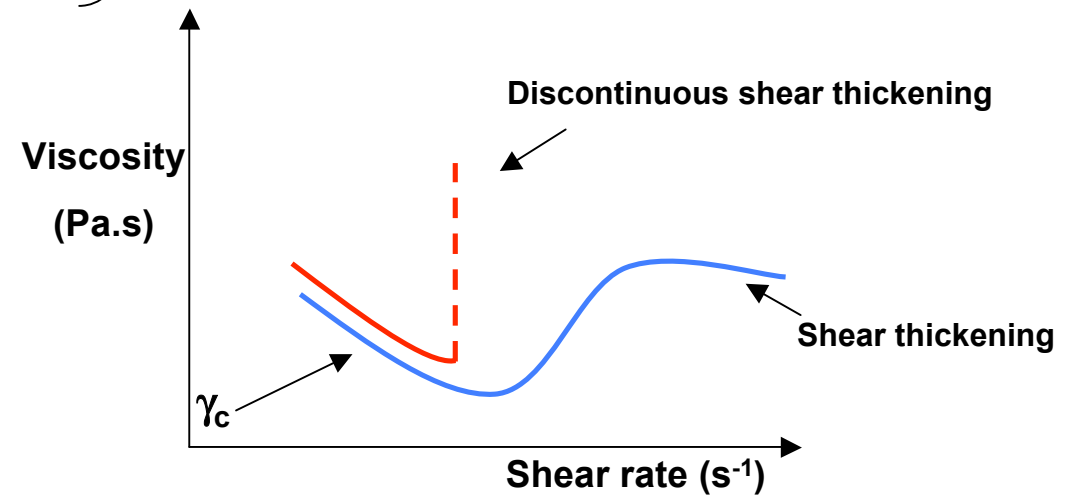


Shear Thickening Fluids

Factors:

- Particle size
- Particle size distribution
- Particle-particle interaction
- Particle-fluid interaction
- Particulate morphology
- Volume fraction

Affect whether dispersion critically shear thickens



Why Shear Thickening Fluids?

Proposed: Shear thickening properties of these fluids could enhance fabric performance against a variety of threats:

- Spike
- Knife
- Ballistic projectiles (e,g shrapnel and bullets)



Lighter weight, flexible armour providing multi-threat protection

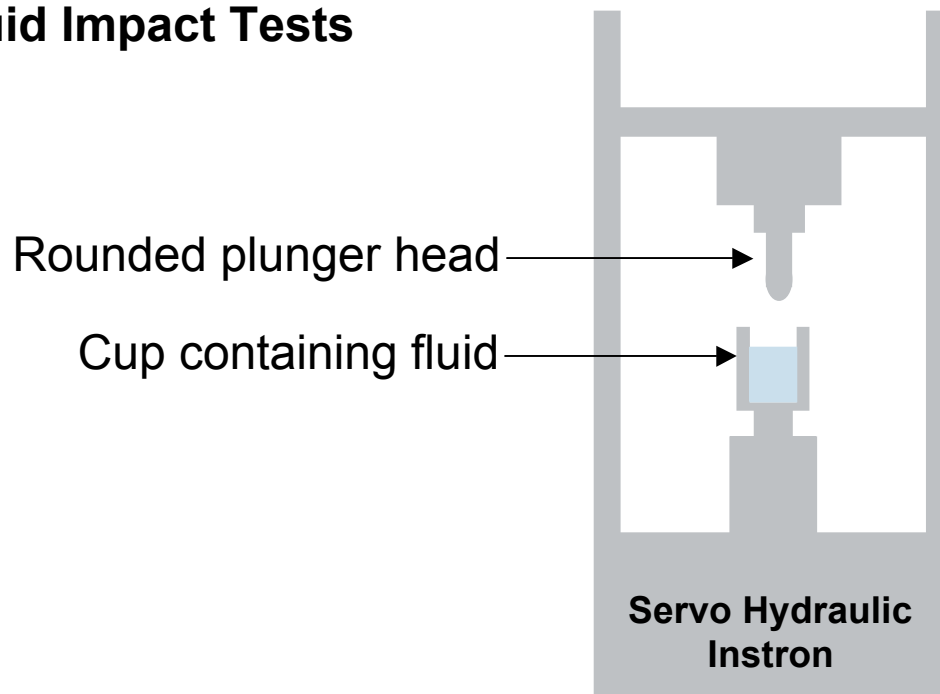
Characterisation of Shear Thickening Fluids

Convention – Rheometer

Tells you whether a fluid discontinuously shear thickens and critical shear rate

No indication of the energy absorbed by the fluid upon impact

Fluid Impact Tests



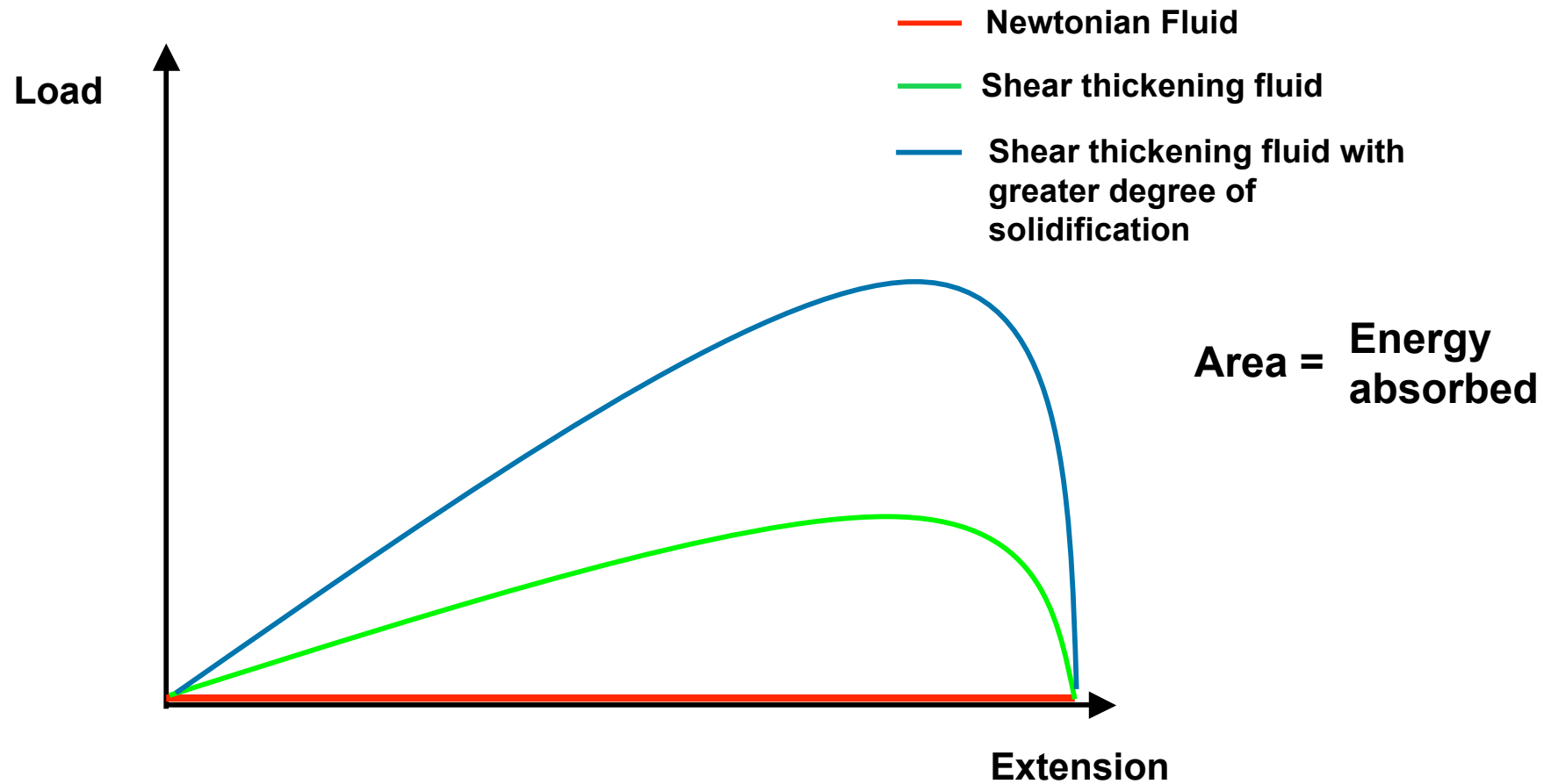
Load cell attached to base of cup used to measure stress generated upon impact from the plunger head

Increase in stress generated indicates increase of solidification in fluid

➔ More energy absorbed

Characterisation of Shear Thickening Fluids

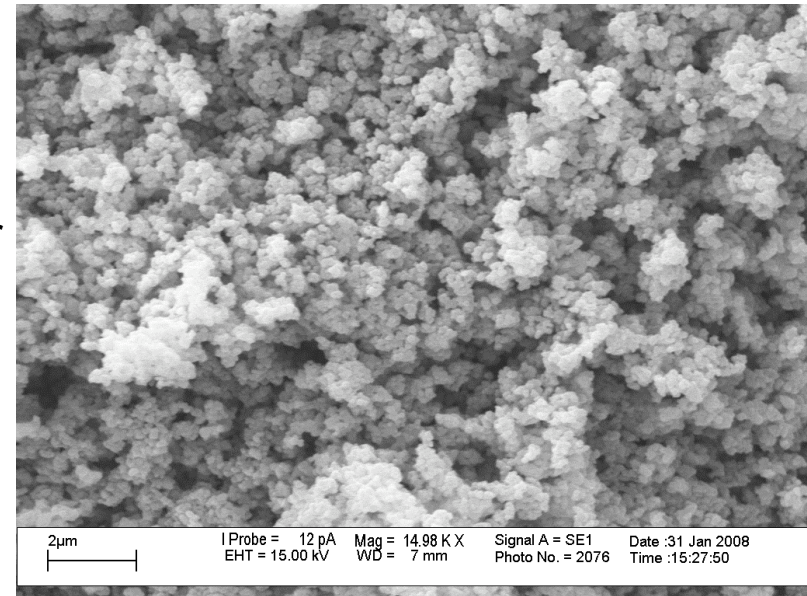
Fluid Impact Stress Strain Graph



Titania Based Shear Thickening Fluids

Why?

- 140nm particle size
- Discontinuously shear thickens when in water
- Abundant supply
- Ease of processing
- Cost effective



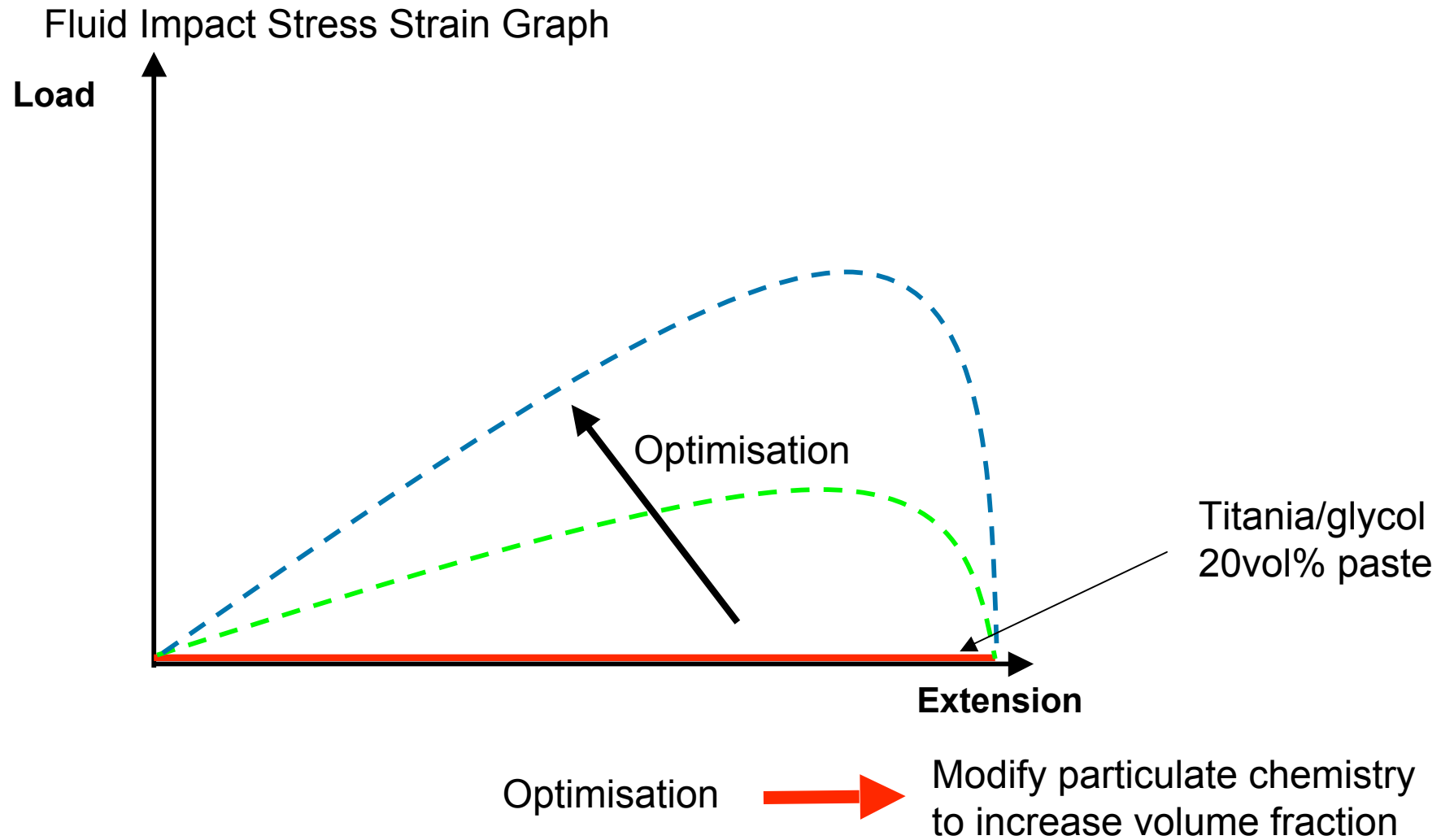
Problems

Disperses well in water but water evaporates

Does not disperse easily in alternative carrier fluids

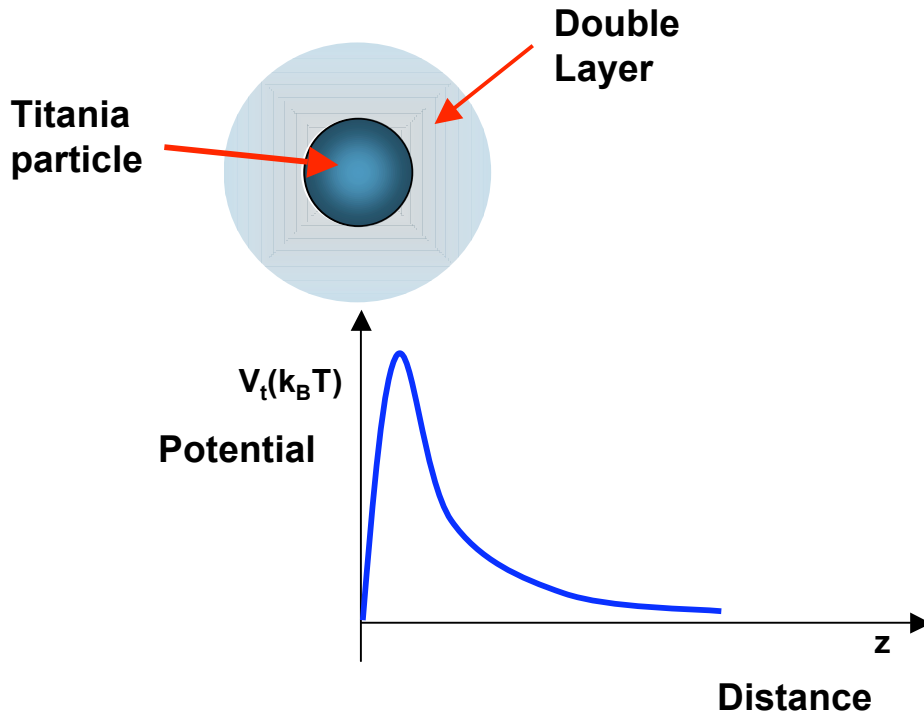
e.g. pastes form at ~20vol% when in ethylene glycol

Characterisation of Shear Thickening Fluids



Tailoring Particulate Surface Chemistry

Objective: Modify the range and strength of the electric double layer



Affects: Particle-particle interaction
Particle-fluid interaction



Governs

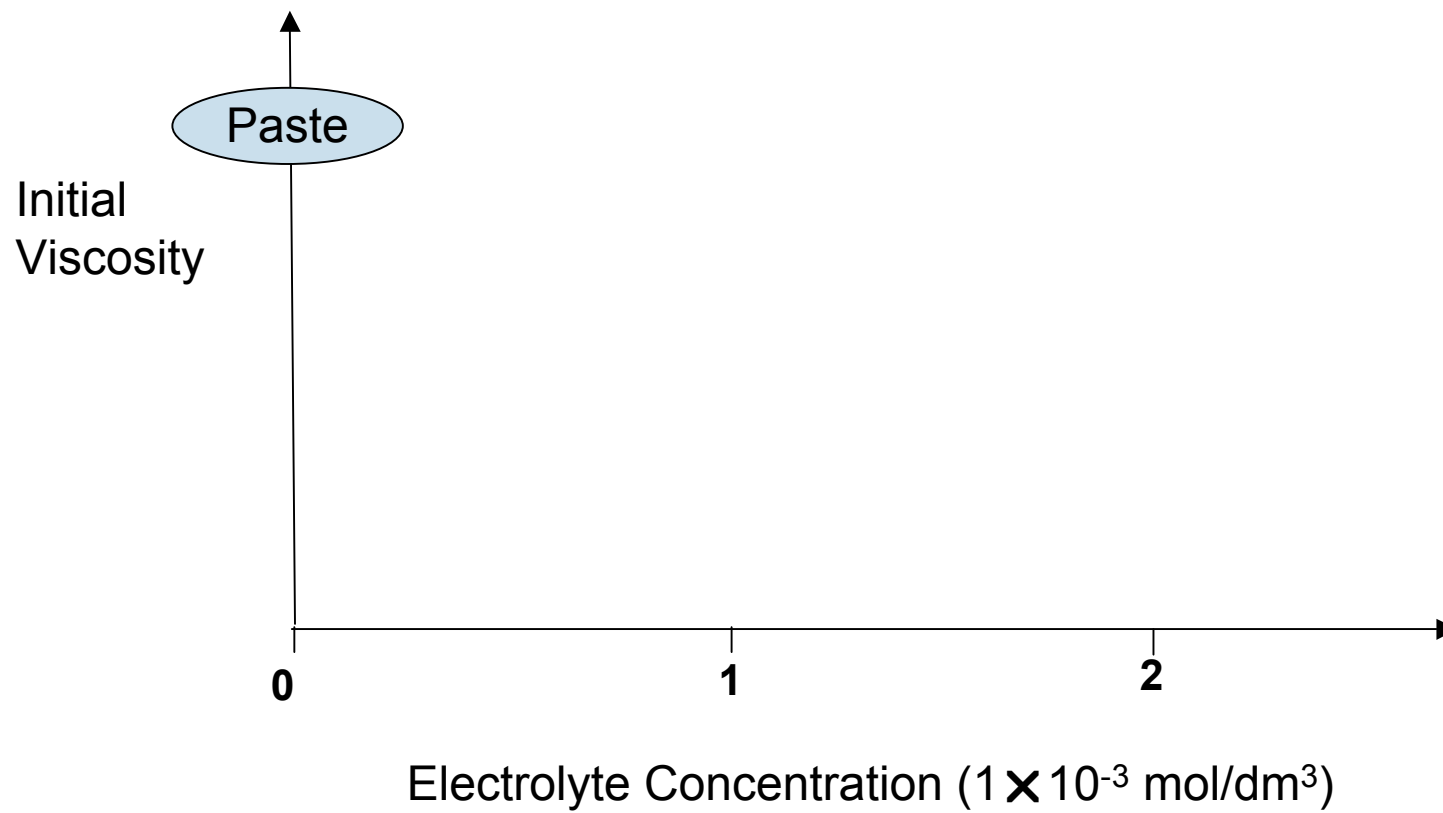
Volume of titania dispersed

How? Change ion concentration surrounding particle

- Add a suitable electrolyte
- Change pH level

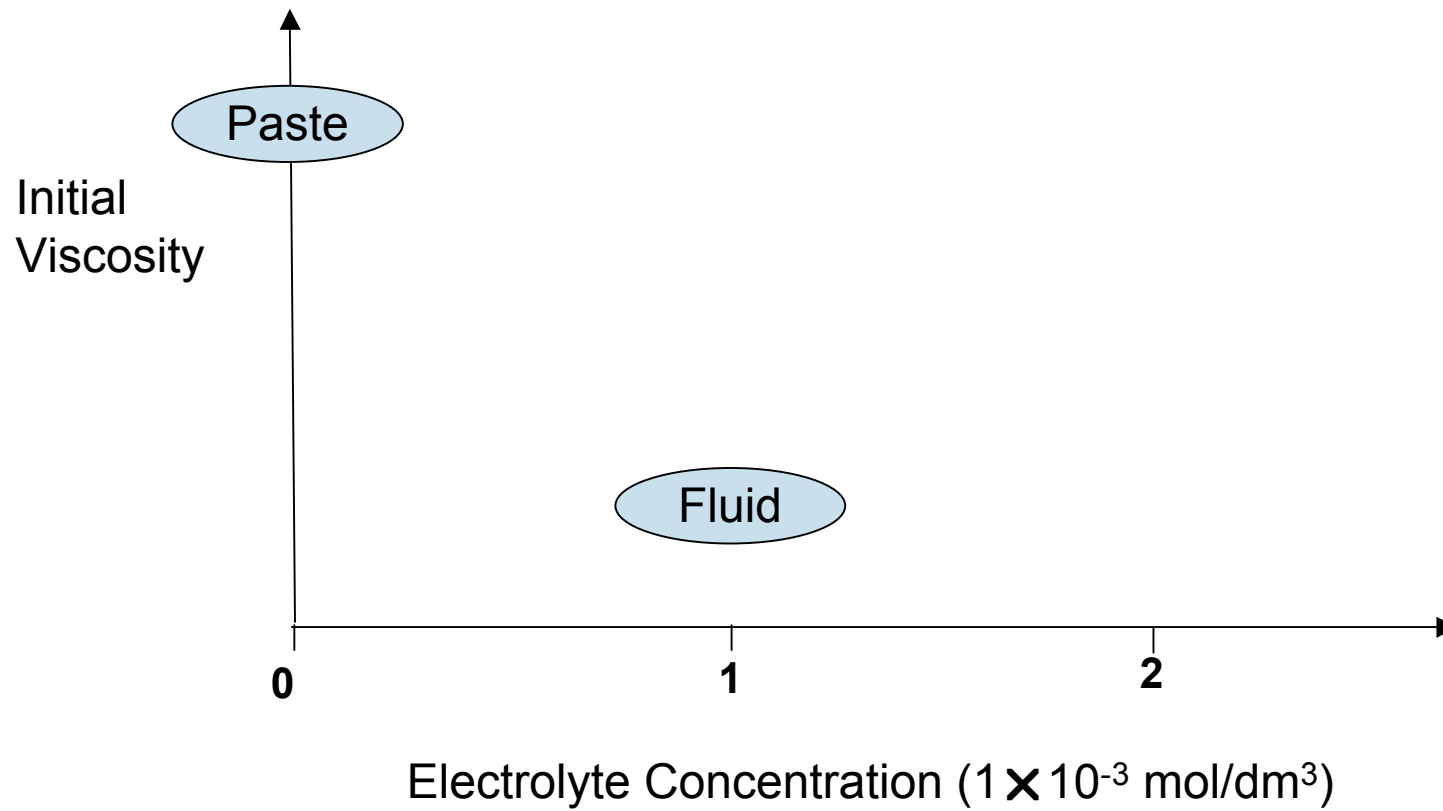
Electrolyte Concentration

Suitable electrolyte: Ammonium Acetate



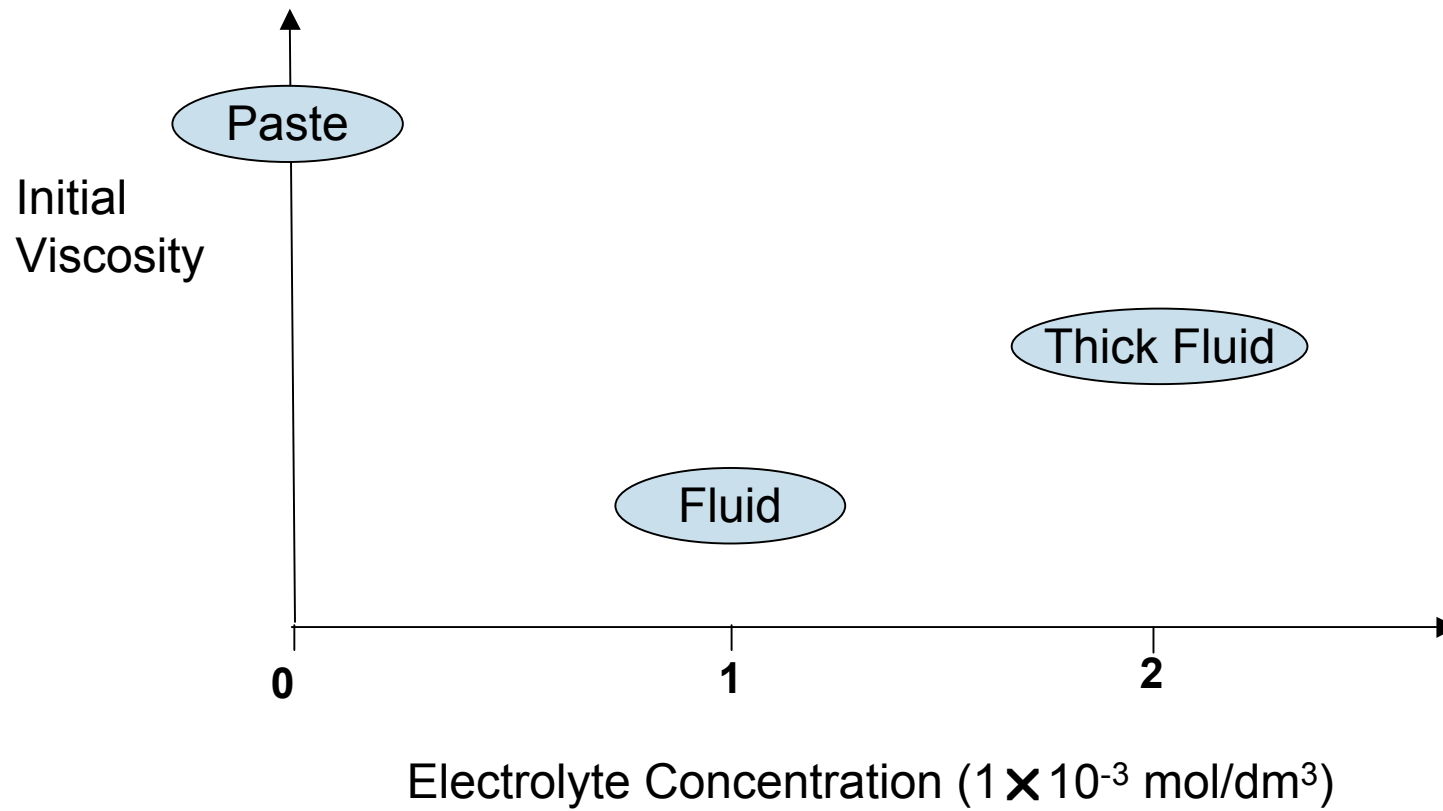
Electrolyte Concentration

Suitable electrolyte: Ammonium Acetate



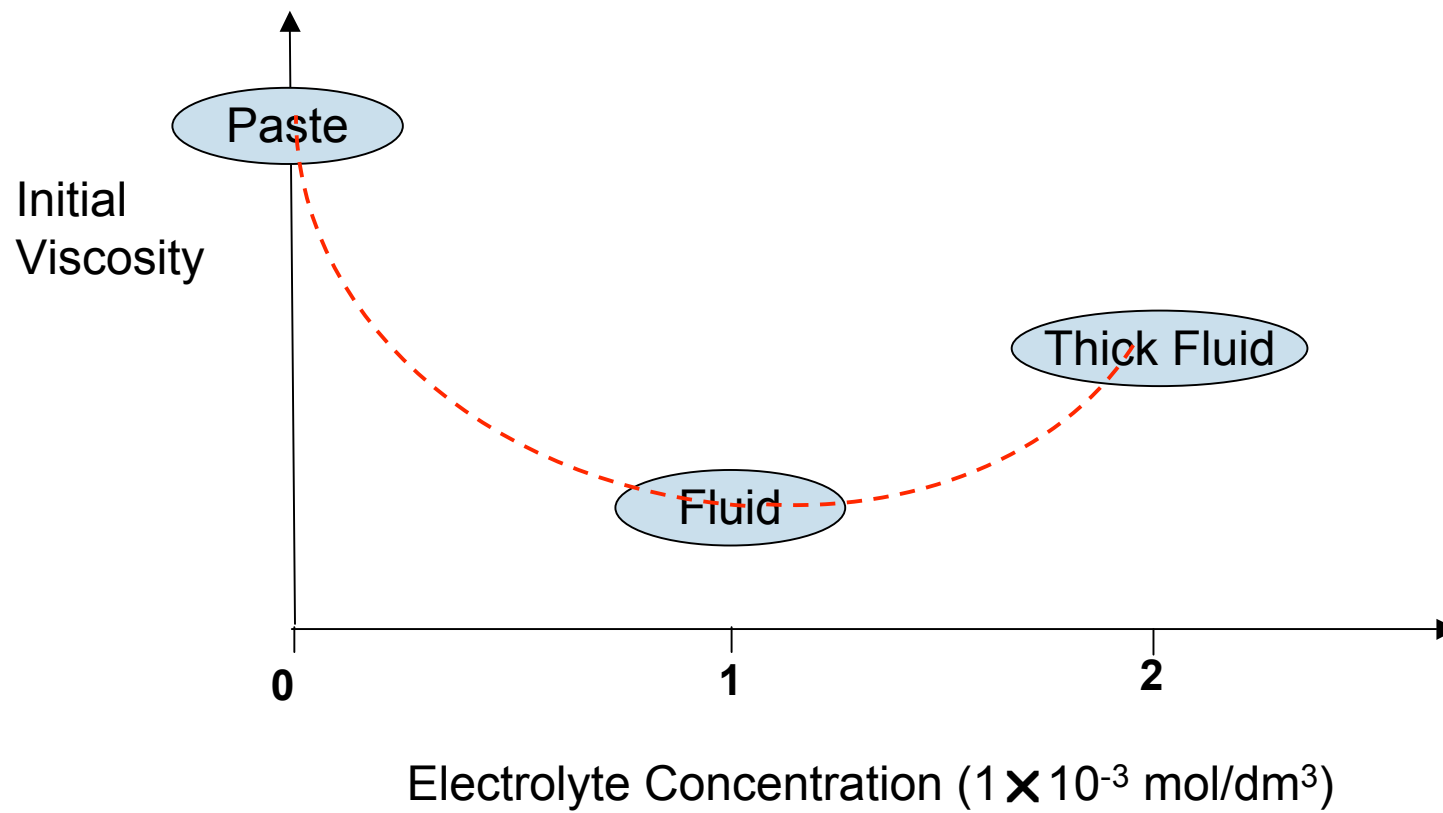
Electrolyte Concentration

Suitable electrolyte: Ammonium Acetate



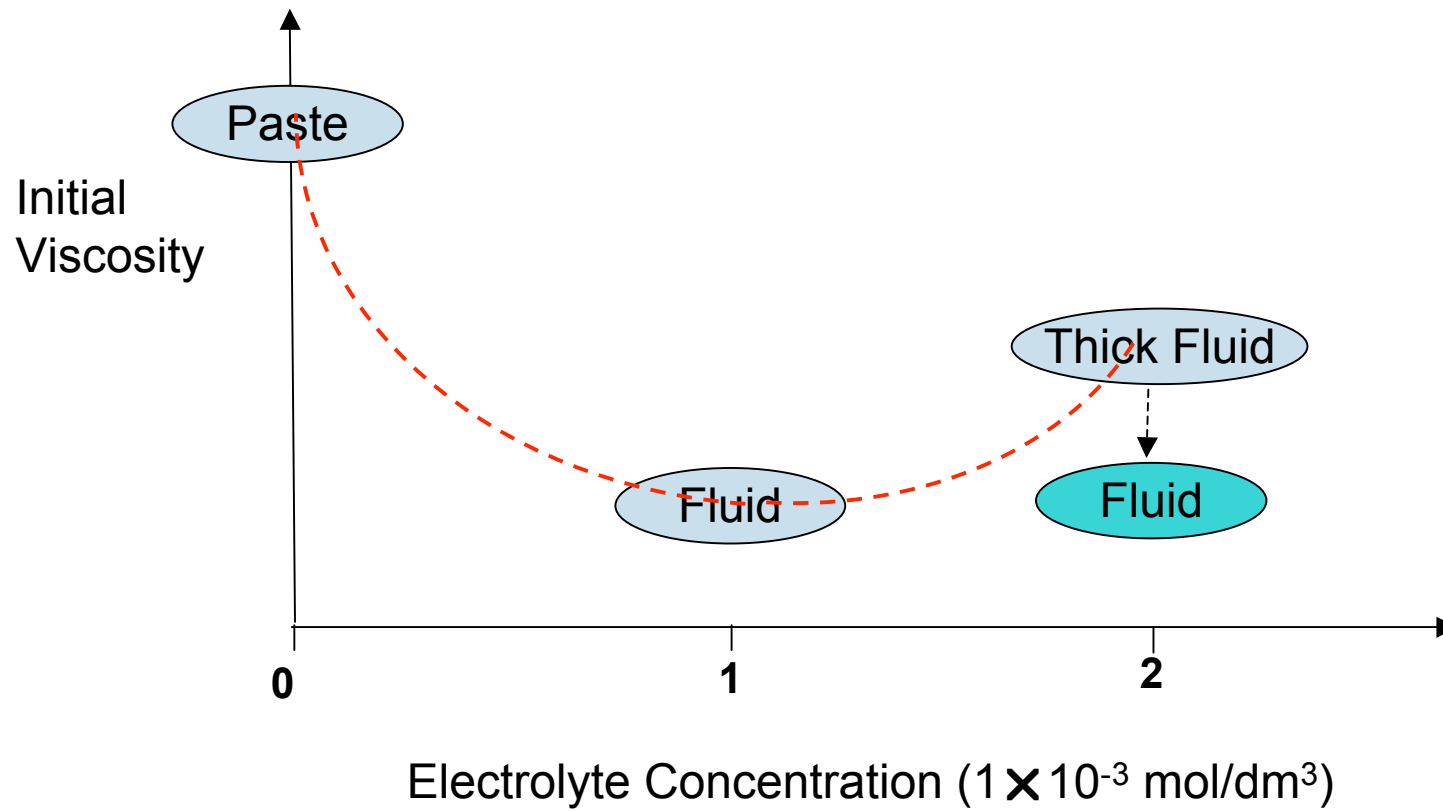
Electrolyte Concentration

Suitable electrolyte: Ammonium Acetate

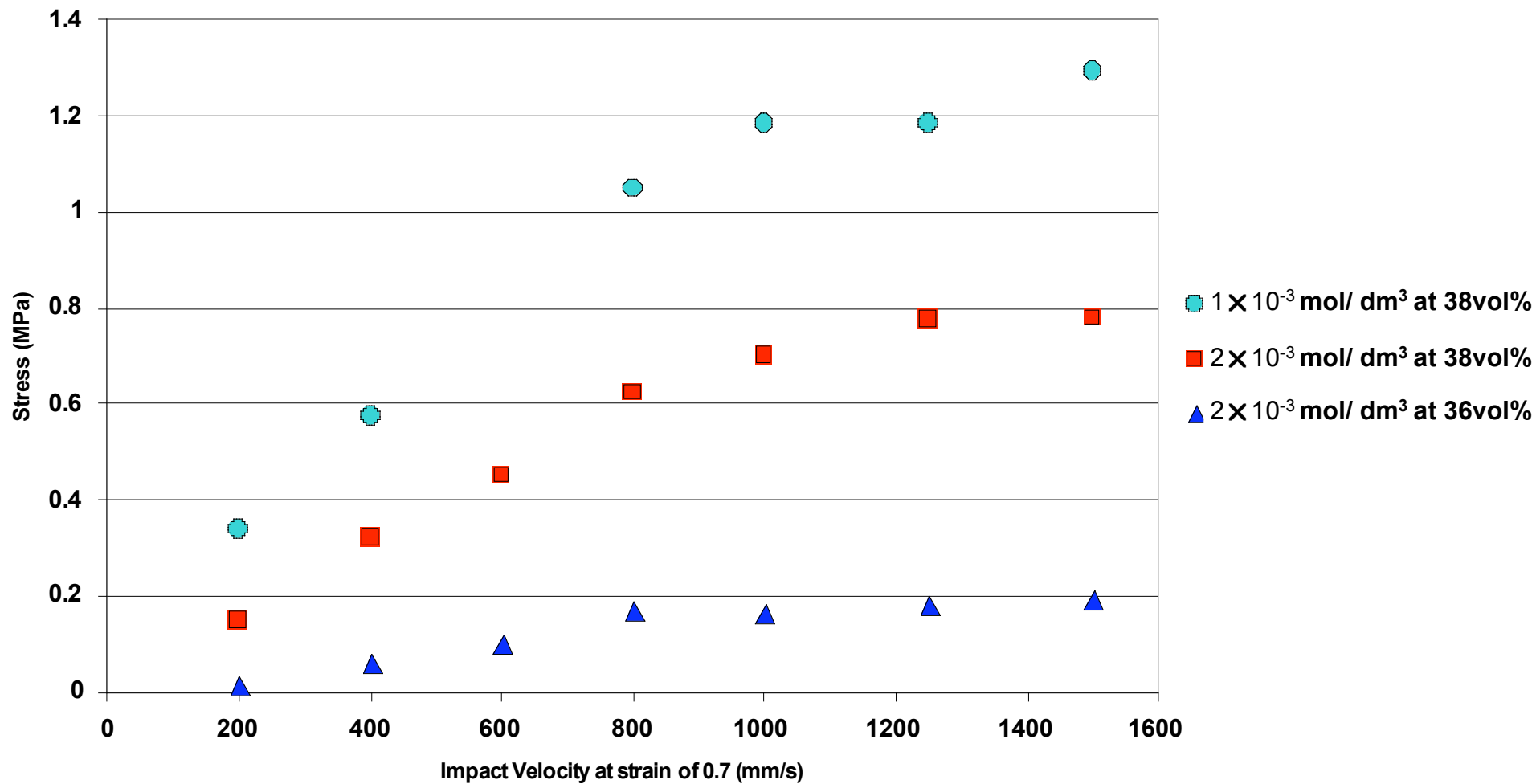


Electrolyte Concentration

Suitable electrolyte: Ammonium Acetate



Electrolyte Concentration



Electrolyte Concentration

Conclusions

- **Higher volume fraction** dispersions result in **greater degree of solidification** upon impact (higher stresses generated)
- **Electrolyte** is required to **increase** volume of titania dispersed (from 20vol% to 38vol%)
- **Too high** an electrolyte concentration is counter productive – **lowers** the **maximum volume fraction** which can be dispersed



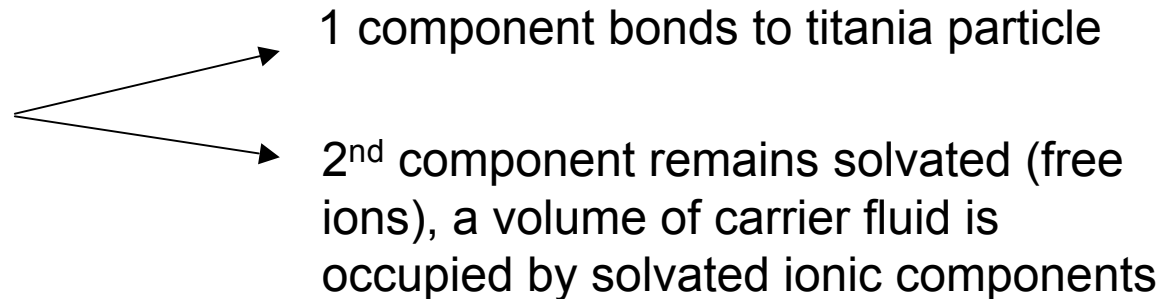
**Optimum double layer
strength and range**

Carrier Fluid pH

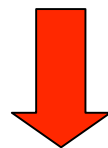
Tailor pH level – add a suitable acid base or salt

Salt – 2 components, one with positive ions and the other negative ions

As salt dissolves



When changing pH level there are 2 components affecting volume of fluid occluded in solvating salt

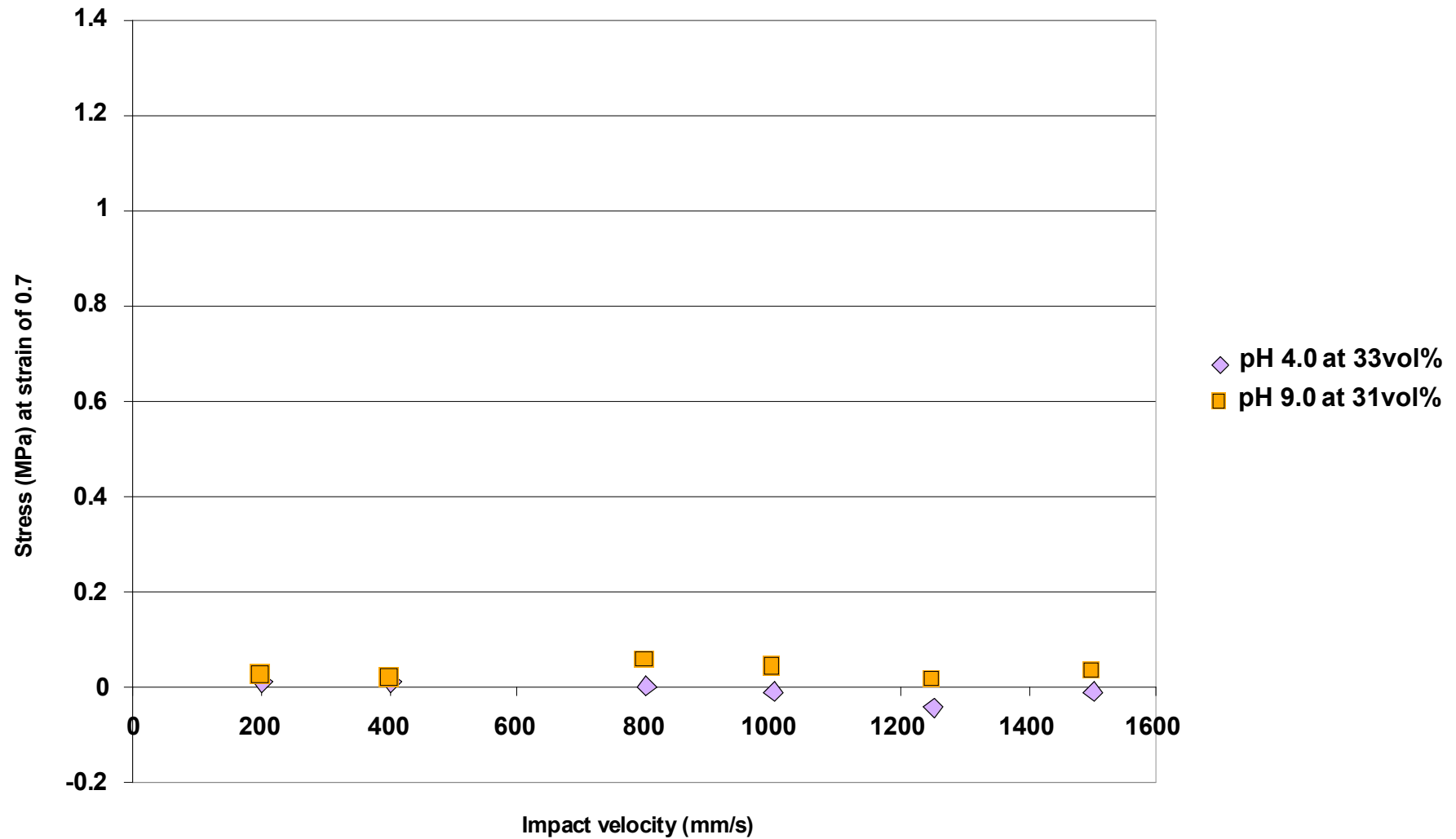


Affects volume of titania dispersed

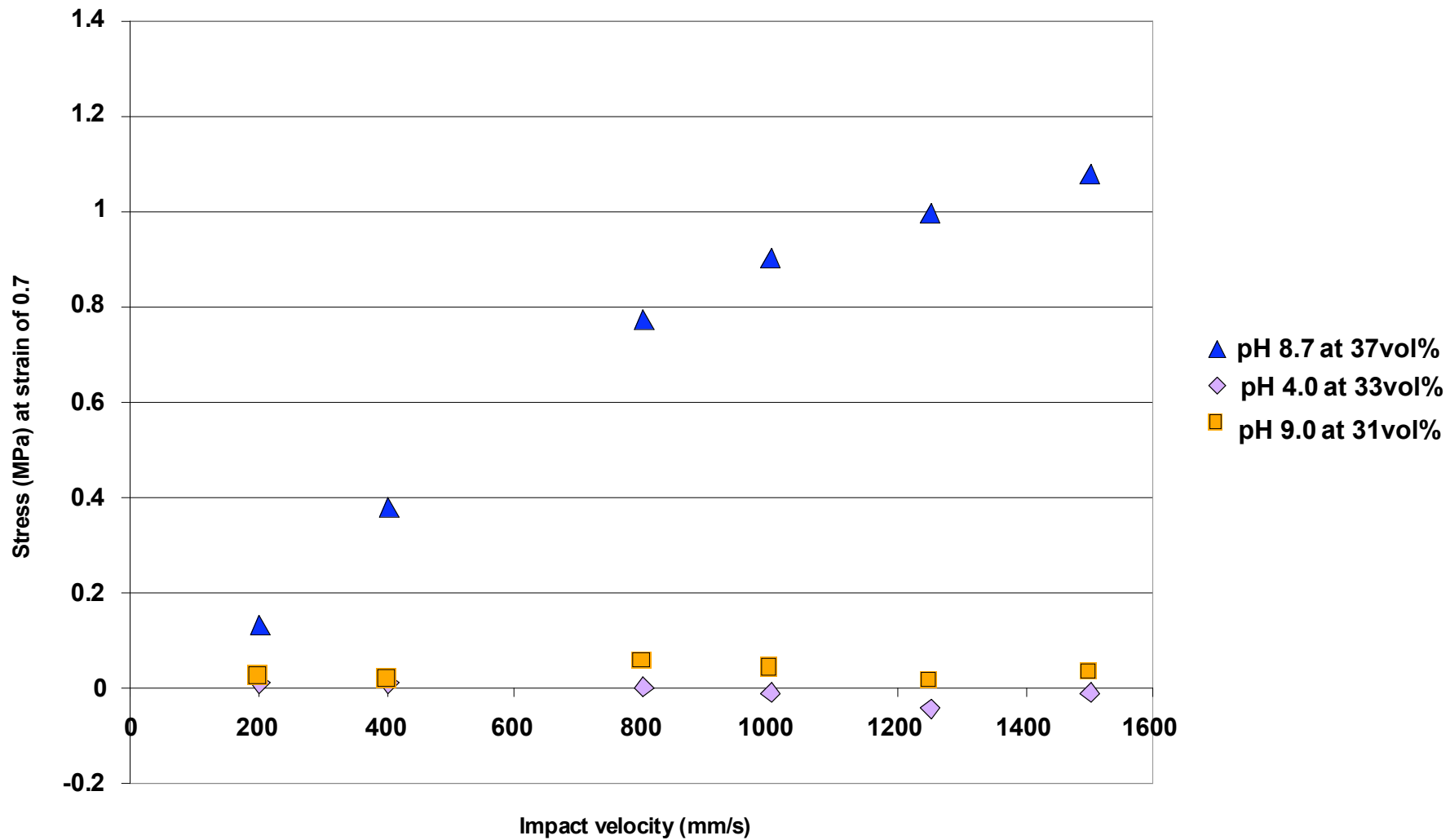
Carrier Fluid pH

	Additive	Volume Fraction	pH	Consistency
Electrolyte Mixture	Ammonium Acetate - electrolyte	38±0.2 %	6.4	Fluid
Alkaline Mixture	Sodium Hydroxide	37±0.2 %	8.7	Thick Fluid
Acidic Mixture	Acetic Acid	33±0.2 %	4.0	Paste
Alkaline Mixture	Sodium Hydroxide	31±0.2 %	9.0	Thick Fluid

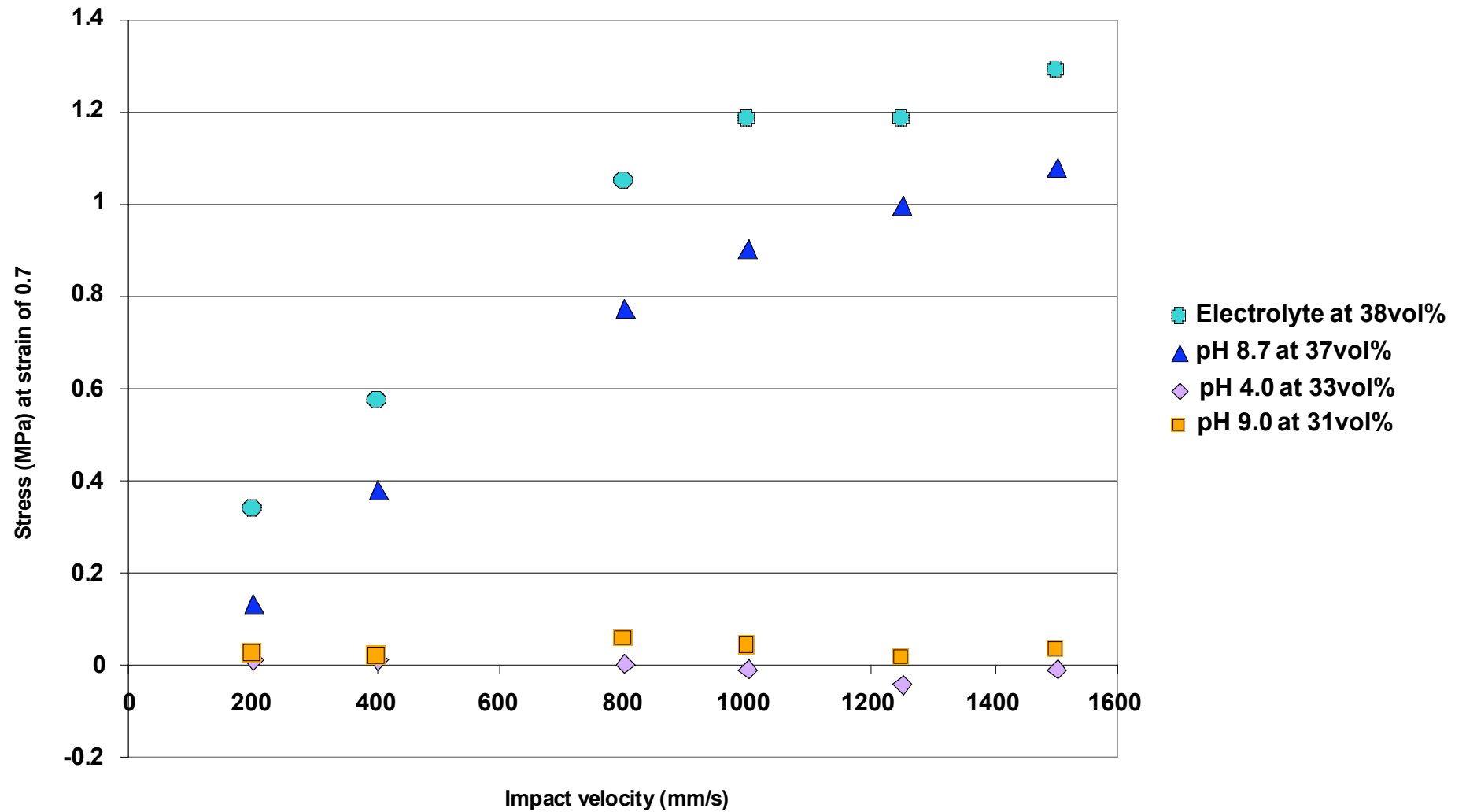
Carrier Fluid pH



Carrier Fluid pH



Carrier Fluid pH



Carrier fluid pH

Conclusions:

- **Weak** alkaline – **Increased** volume fraction titania dispersed
- **Weak** acid – **Decreased** volume fraction titania dispersed
- **Strong** alkaline or acid - Significantly **decreased** volume fraction titania dispersed (volume of fluid occluded for free solvated ions)
- **Weak** alkaline gave similar result as low concentration electrolyte
 - 2 avenues available for exploration to increase volume fraction dispersed further

Silica Based Shear Thickening Fluid

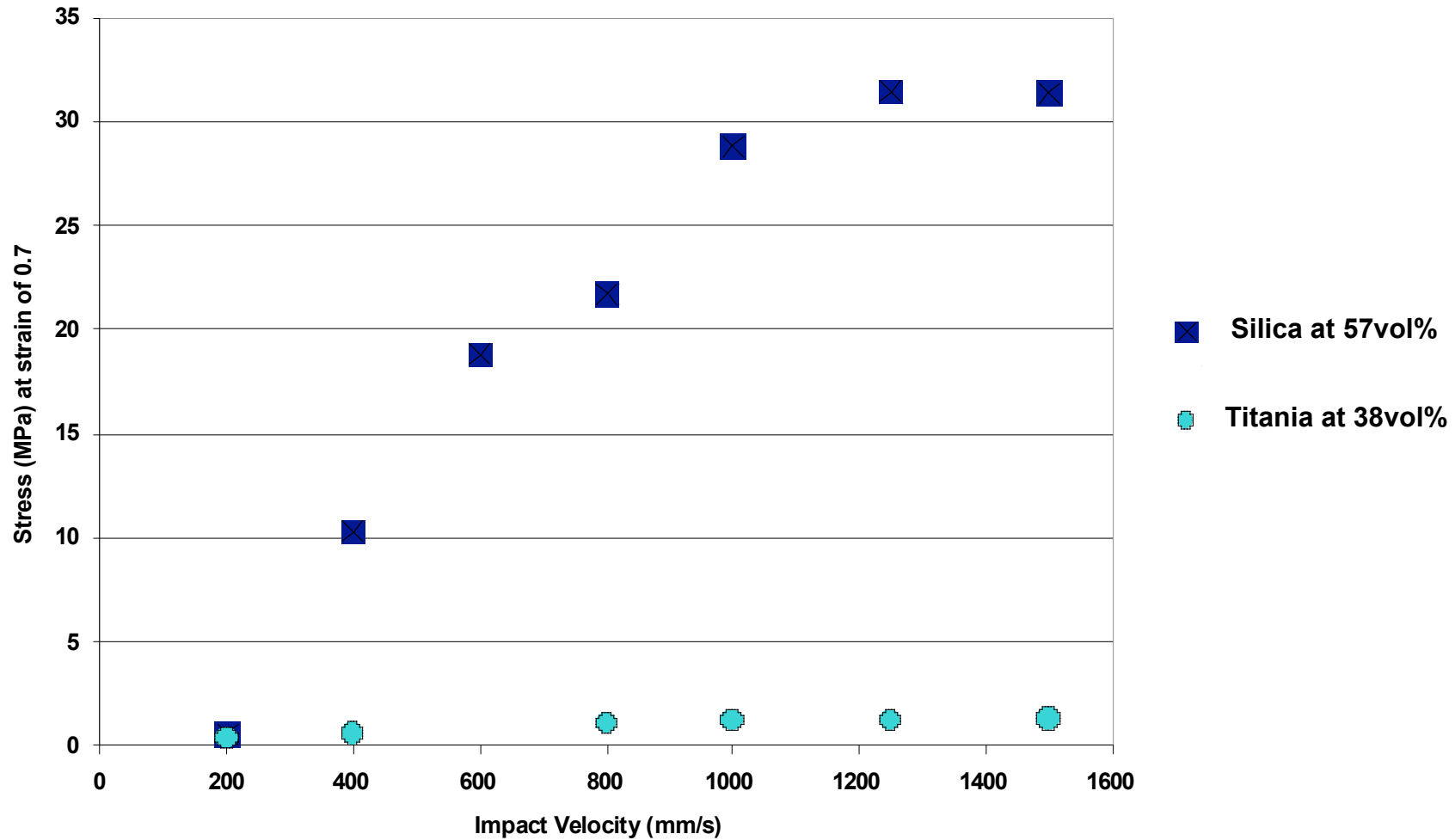
Composition: 450nm colloidal silica
Ethylene glycol carrier fluid

Maximum volume fractions achievable:

Silica/ethylene glycol STF is 57vol%

Titania/ethylene glycol STF is 38vol%

Comparison to Silica Based Shear Thickening Fluid



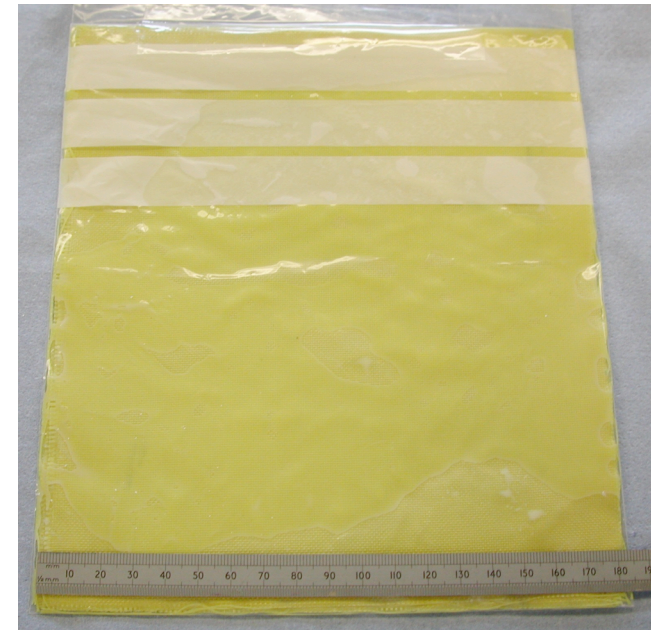
Target Preparation

STF Impregnated Targets

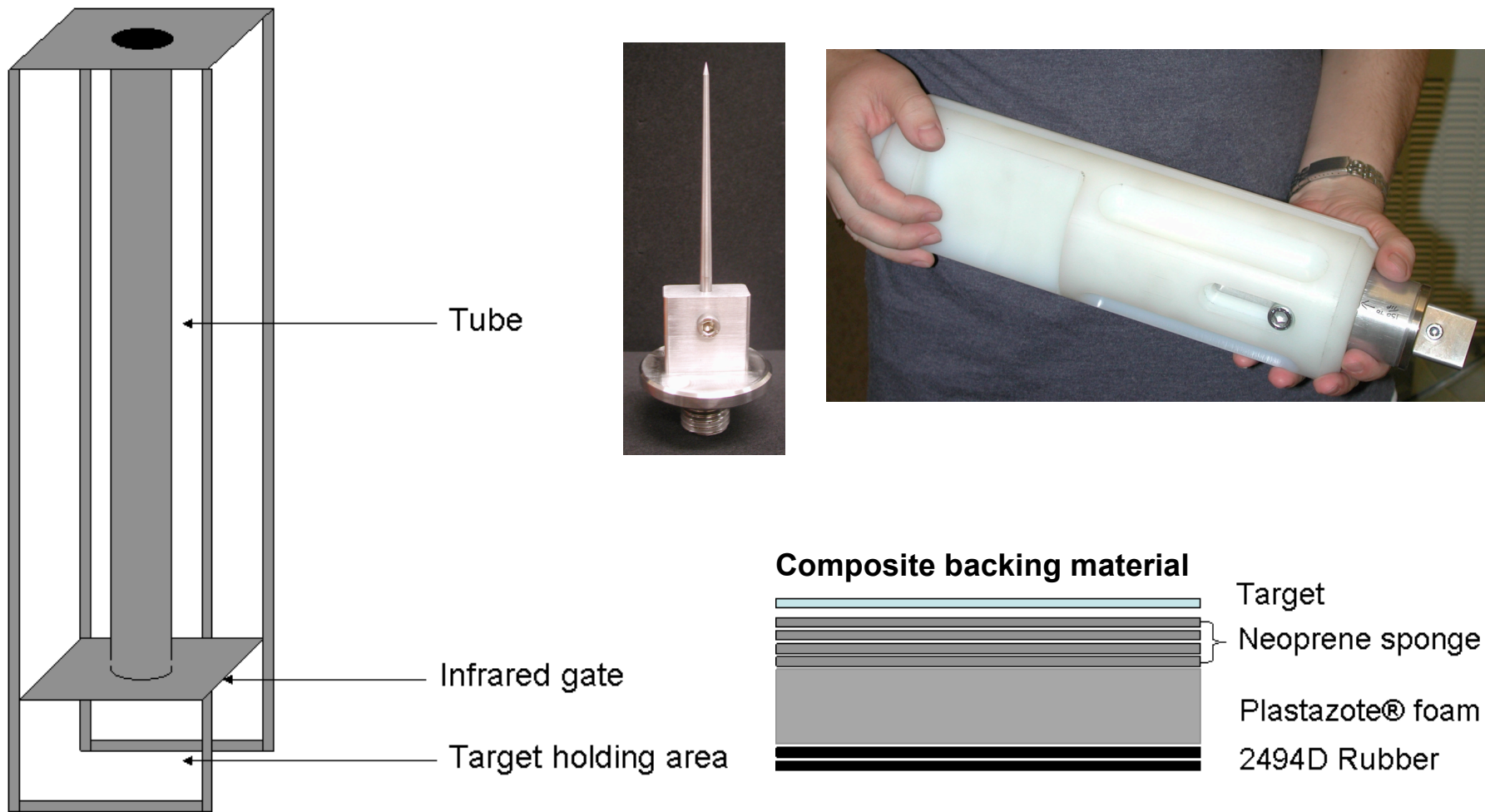
- 4 layers of Kevlar®
- Target size 180mm by 200mm
- 40g of STF added (dispersed evenly throughout the layers)
- Areal density 1.8kg/m²

Untreated Kevlar® Targets

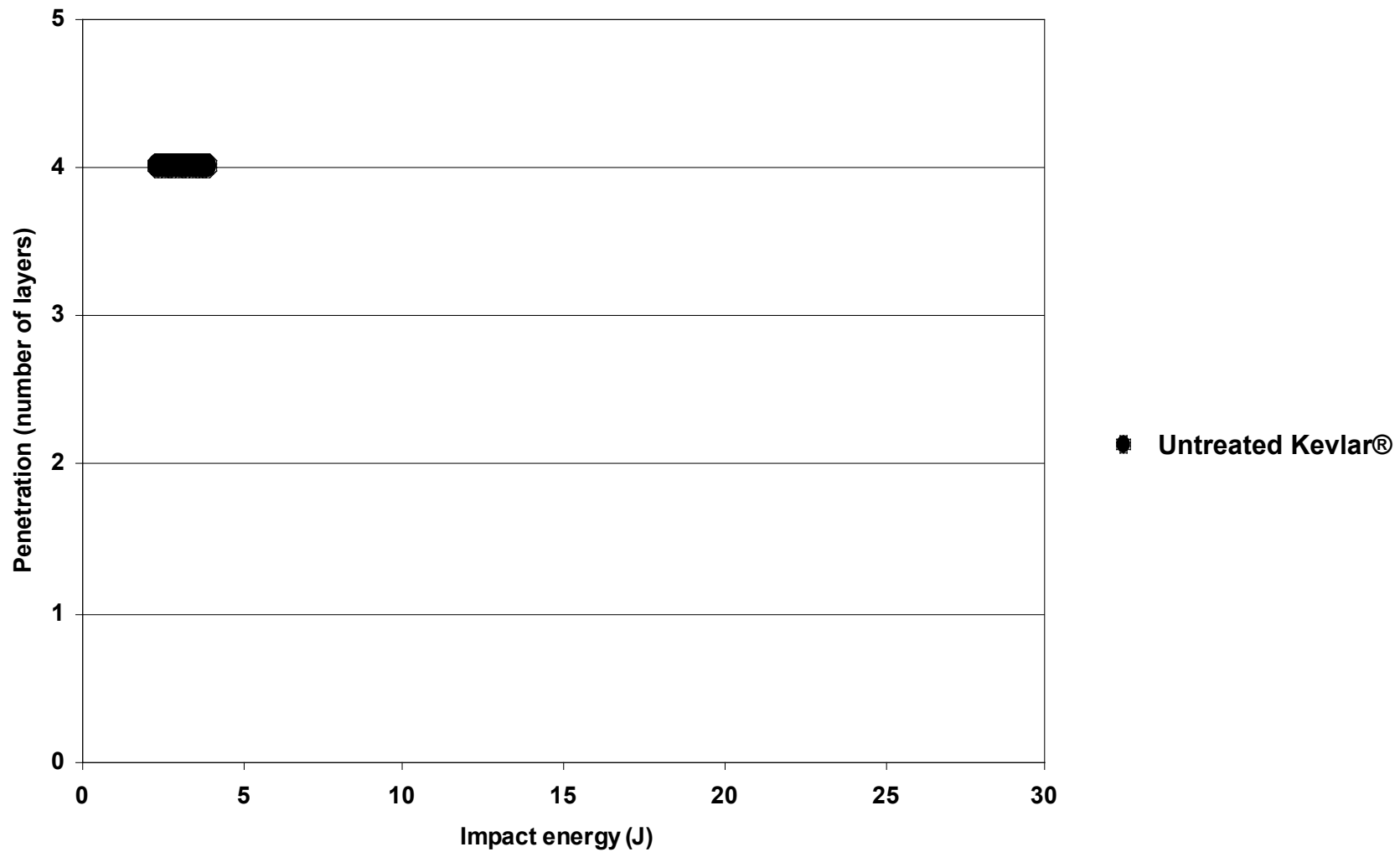
- 10 layers of Kevlar®
- Target size 180mm by 200mm
- Areal density 1.8kg/m²



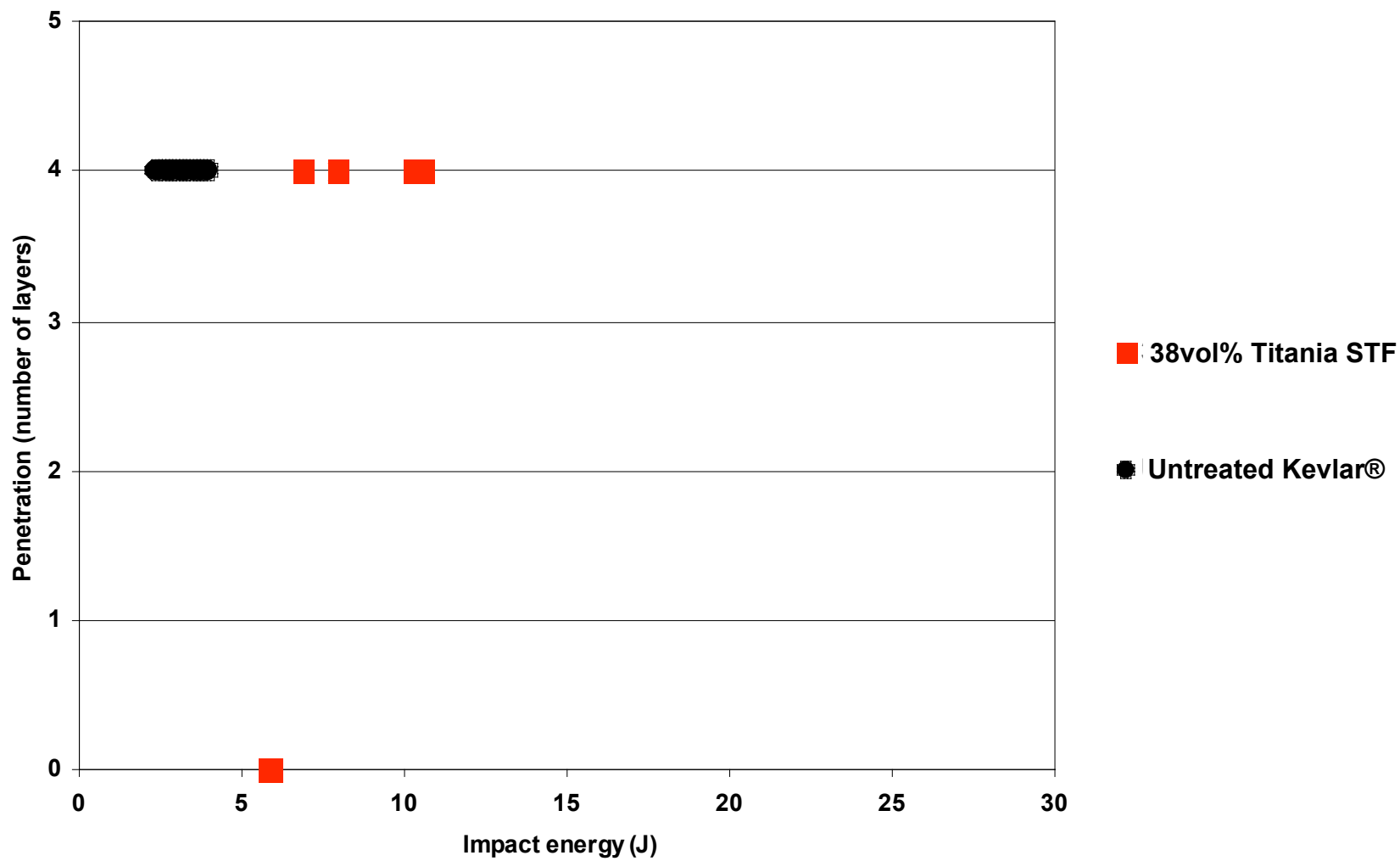
Spike Drop Test



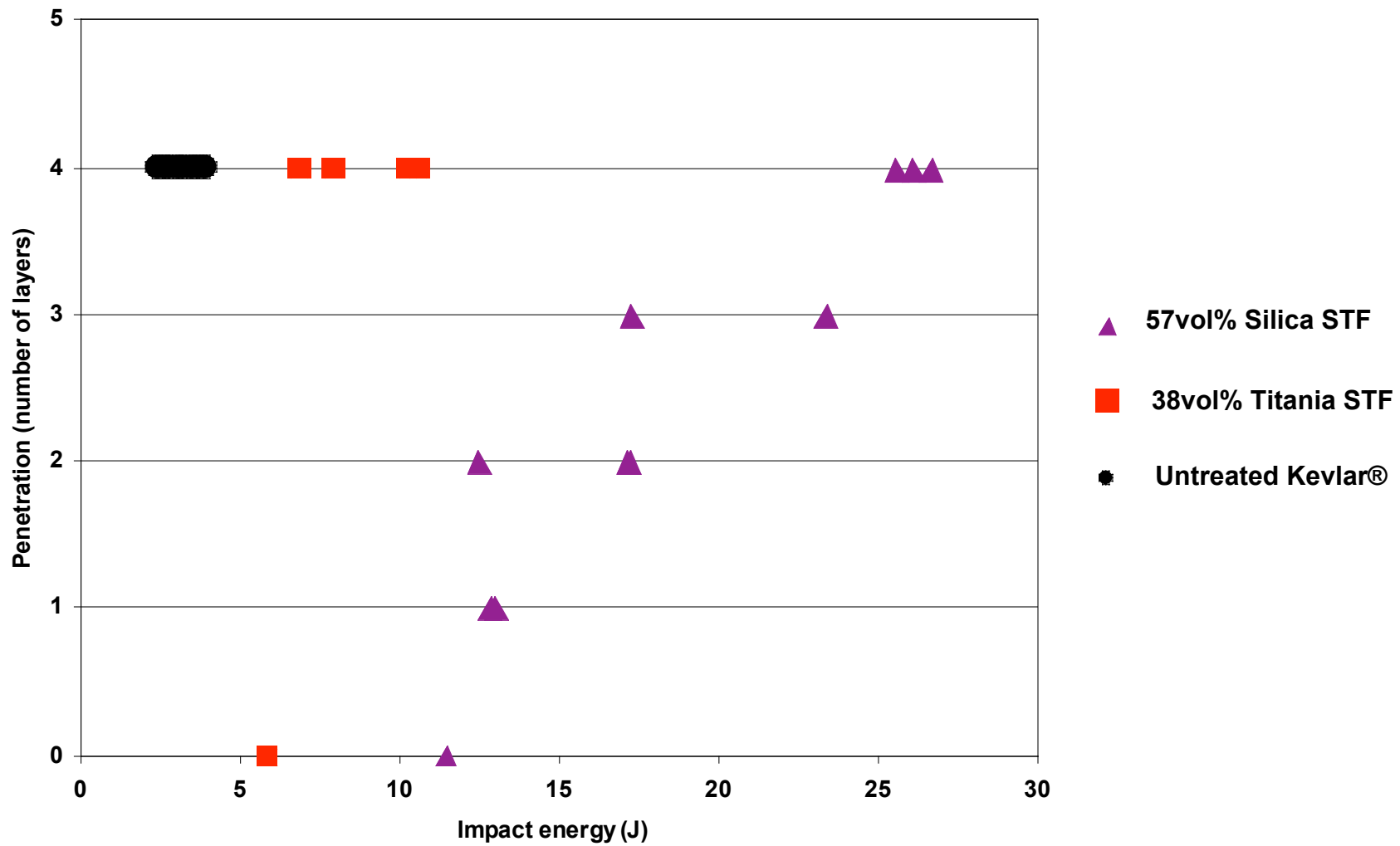
Spike Test Results



Spike Test Results



Spike Test Results



Conclusions

- Maximum volume fraction of titania/glycol dispersions is sensitive to particulate surface chemistry
- Surface chemistry tailored by changing ion concentration in double layer to produce high volume fraction dispersions which solidify upon impact
- Extent of solidification is related to the volume fraction of dispersion
- 2 methods for tailoring double layer
 - electrolyte
 - pH level of carrier fluid
- Maximum volume fraction of **titania/glycol** dispersions – **38vol%**
- Maximum volume fraction of **silica/glycol** dispersions – **55vol%**
- Impregnating Kevlar® with titania based STF **increases** the impact resistance for spike threats
- Silica based STF provides greater penetration resistance compared to titania STF developed to date

Acknowledgements

A Dyke, J Davies, N Park, D Townsend, E Siggs at the Advanced Technology Centre for their hard work and dedication to this work

This work was carried out under research contract to the Defence Technology and Innovation Centre (UK MoD) and supported by DSTL.