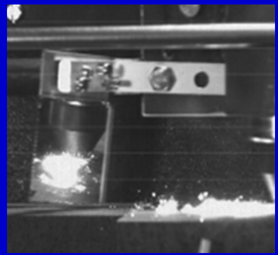
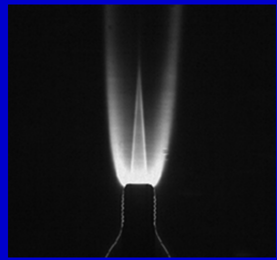
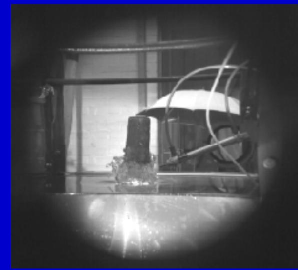
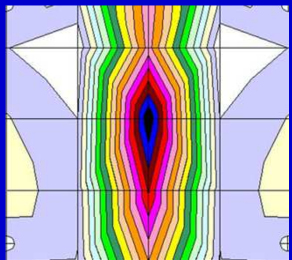
London South Bank University

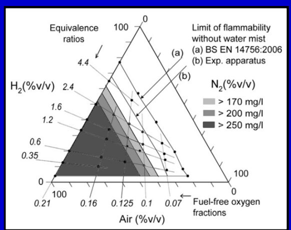
Hydrogen Hazards Unit











The centre has 12 years experience providing knowledge and expertise on hydrogen safety in sensitive environments.

We are also exploring new methods for the mitigation of ignition and suppression of hydrogen in air mixtures, such as using fine water mists and chemical additives.

Our work incorporates a range of hydrogen visualisation and modelling techniques.

We are proud to have joined with Sellafield Ltd. in a long-term partnership agreement to provide the scientific advice to their Flammable Gases Centre of Expertise.

A major aspect of our experimental work is looking at the ignition of hydrogen by various stimuli, including mechanical and electrostatic.

Ignition of flammable hydrogen/air mixtures by controlled glancing impacts in nuclear waste decommissioning

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The problem

- In nuclear waste silos, slow corrosion of waste metals forms a sludge from which a chronic evolution of hydrogen occurs
- Radiolysis will result in further hydrogen evolution
- The waste metals may be partially uncorroded and be capable of pyrophoric reaction.
- An ignition source may result from a glancing blow of a dropped robotically controlled tool (for example) initiating a pyrophoric reaction of metal at the impact area

Pyrophoric reactions

Magnesium burning in air involves both 0_2 and N_2

$Mg + ½O_2 \rightarrow MgO$ (ΔH = - 598 kJ/mol)

$3Mg + N_2 \rightarrow Mg_3N_2$ (ΔH = - 461 kJ/mol)

Ignition occurs at temperatures exceeding ~ 500℃.

If a thermite reaction is involved, burning can be initiated at a lower temperature (~ 450℃).

$3Mg + Fe_2O_3 \rightarrow 3MgO + 2Fe$ (ΔH = - 981kJ/mol)

Principal aim

To examine and clarify:

conditions whereby mechanical stimuli produced by glancing blows on magnesium contaminated surfaces can result in ignition of hydrogen in air mixtures.

Influencing parameters studied

Impact velocity

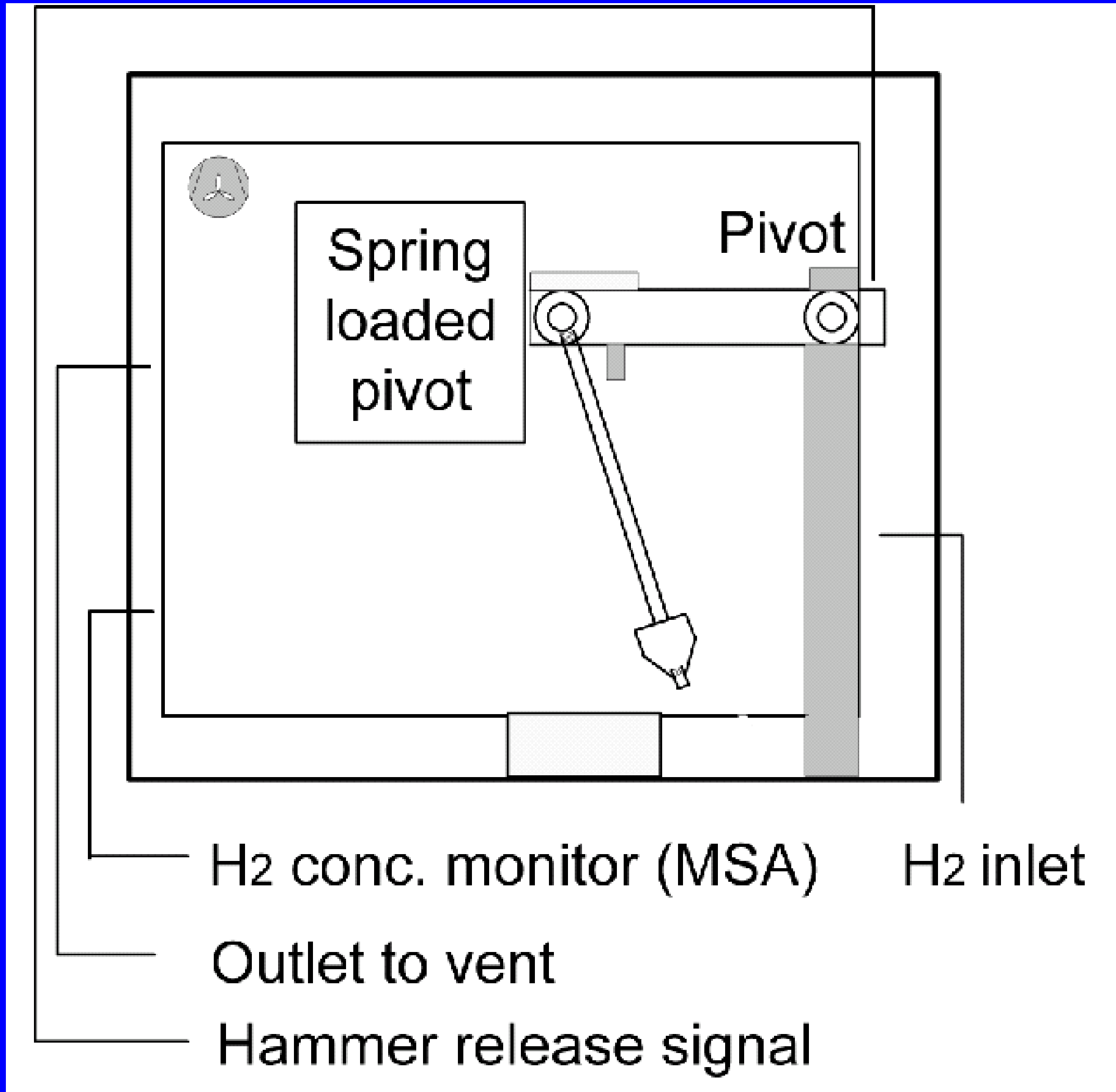
Hydrogen concentration

Glancing angle

Hardness of the impacting tip

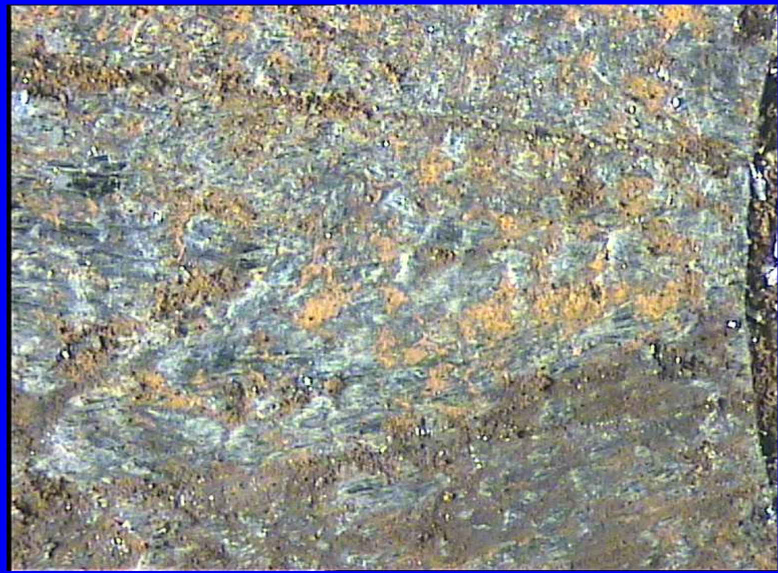
Weight acting on the tip

Ignition test apparatus



Preparation of the impact plate

Rusted



Rusted with Mg smear

Parameter levels chosen

Impact velocity:

(1) 6.7m/s and (-1) 3.9m/s

Hydrogen concentration:

(1) 8% and (-1) 15%

Glancing angle of impact:

(1) 8° and (-1) 4°

Hardness of the (0.4% carbon steel) tip:

(1) tempered: 680 HV and (-1) normalised: 200 HV

Weight acting on the tip:

(1) 3.4 kg and (-1) 2.25 kg

Summary of the experimental design

Half fractionated design (2^{5-1})

5 parameters and two levels

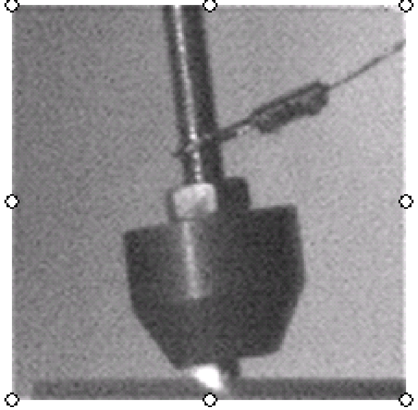
16 sets of experimental conditions

10 ignition tests for each condition

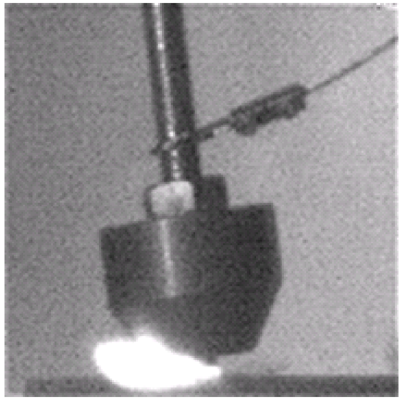
Experimental order randomised

Ignition frequency results transformed to allow for fraction defective response

Progress of thermite sparking and burning in H_2 /air. Impact angle 7 degrees. Tip velocity 5.8 m/s. 11,200 fps

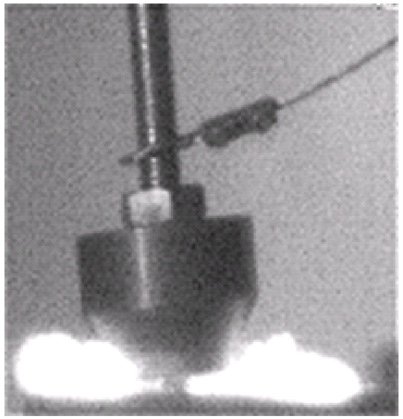


On Impact

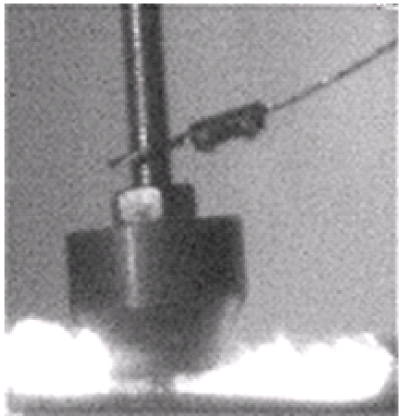


+ 0.00009 s

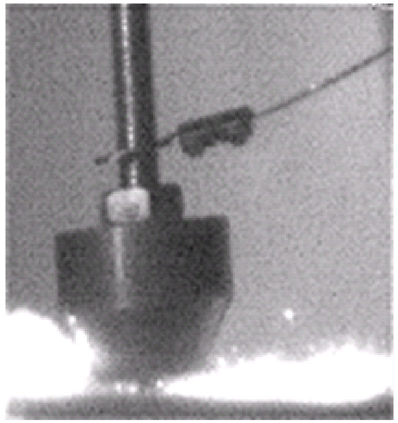
+ 0.00018 s



+ 0.00027 s

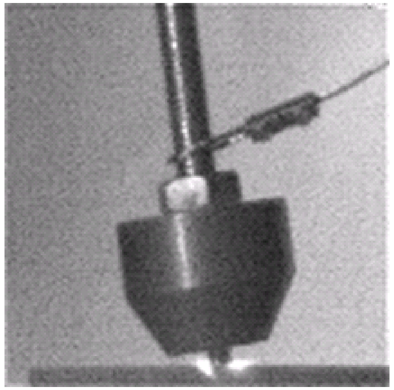


+ 0.00036 s

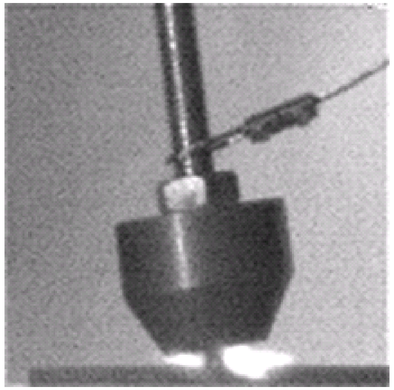


+ 0.00045 s

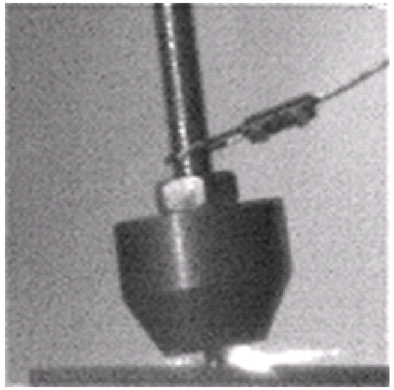
Progress of thermite sparking in air. Impact angle 7 degrees. Tip velocity 6 m/s. 11,200 fps



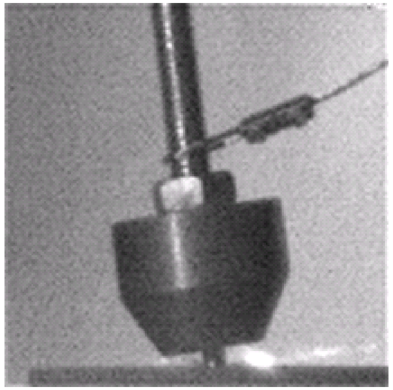
On Impact



+ 0.00009 s



+ 0.00018 s



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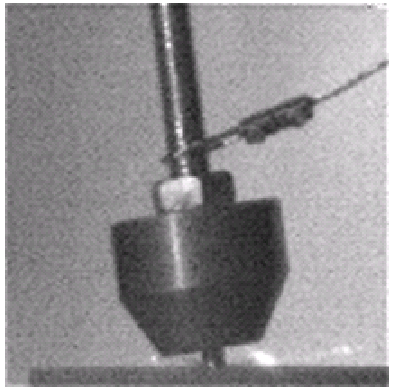
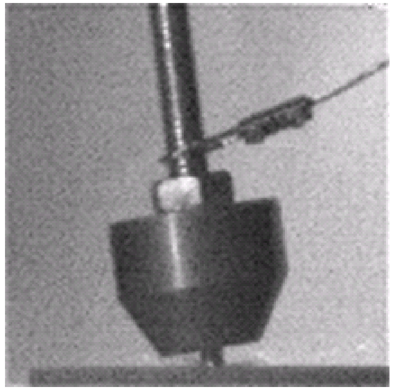


+0.00036 s



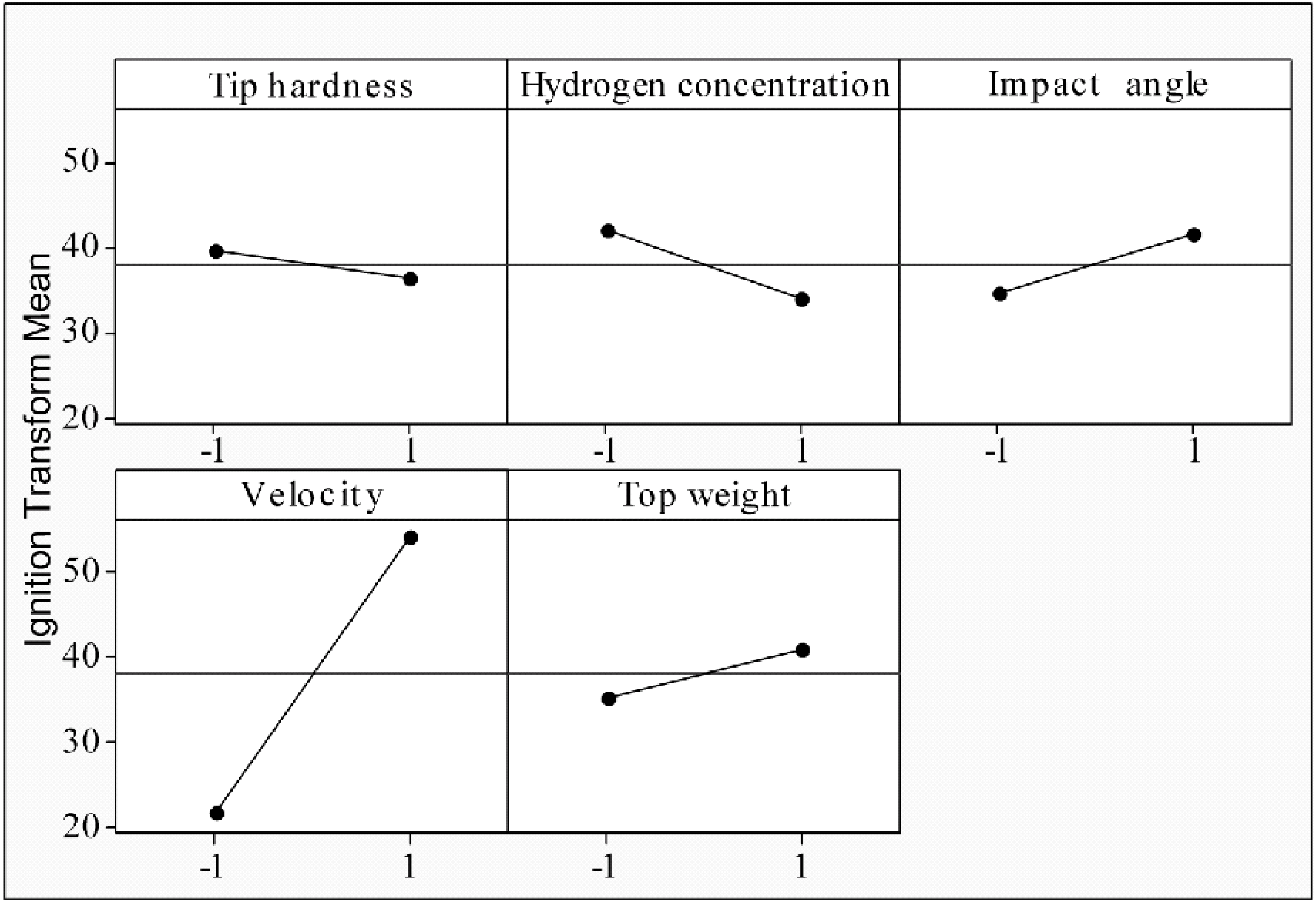
+ 0.00045 s

Results of ignition of H2/ air by glancing mechanical impact

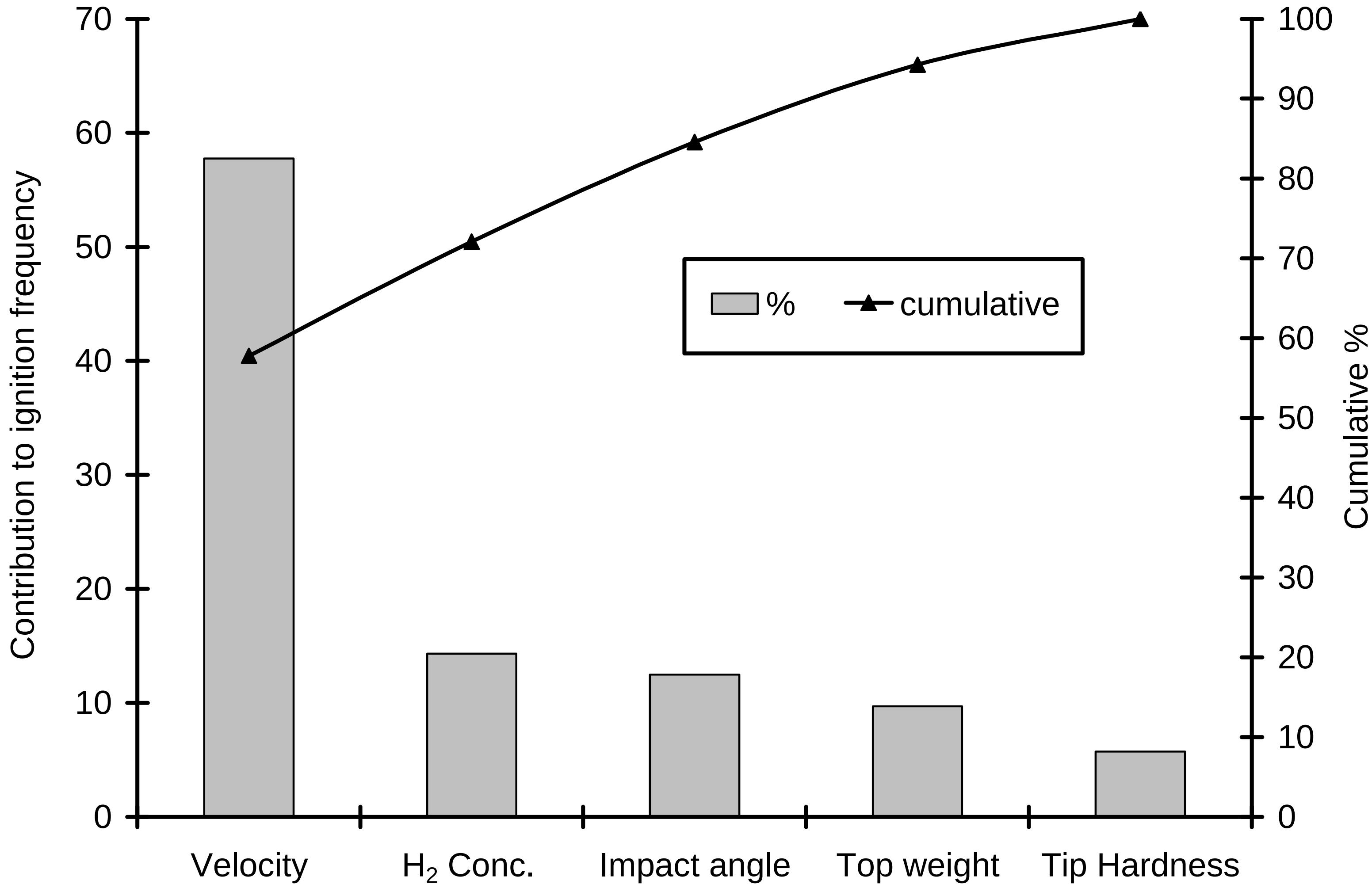
Run order	Standard.order	Tip (HV)	H_2 /air (%)	Impact angle °	Strike velocity.(m/s)	Wt.(kg)	Ig. freq.	IgT*
1	12	680	8	4	6.7	2.25	0.6	50.76
2	8	680	8	8	3.9	2.25	0.1	18.43
3	6	680	15	8	3.9	3.4	0.2	26.56
4	15	200	8	8	6.7	2.25	0.7	56.78
5	11	200	8	4	6.7	3.4	0.6	50.76
6	16	680	8	8	6.7	3.4	0.7	56.78
7	4	680	8	4	3.9	3.4	0.3	33.21
8	5	200	15	8	3.9	2.25	0.3	33.21
9	9	200	15	4	6.7	2.25	0.9	71.56
10	3	200	8	4	3.9	2.25	0	9.1
11	14	680	15	8	6.7	2.25	0.8	63.43
12	1	200	15	4	3.9	3.4	0.1	18.43
13	13	200	15	8	6.7	3.9	1	80.89
14	2	680	15	4	3.9	2.25	0	9.1
15	7	200	8	8	3.9	3.4	0.2	26.56
16	10	680	15	4	6.7	3.4	0.3	33.21

* Arcsine root transforms (degrees)

Main effects plots



Contribution of the variables to the ignition frequency



Predicting the surface temperature during sliding with plastic deformation (Pe No >10)

$$\theta_{\max} - \theta_b = \frac{1.6 \mu p_f^{3/4} F_n^{1/4} v^{1/2}}{\pi^{1/4} (k \rho c_p)^{1/2}}$$

c_p	specific heat
F_n	normal force
k	thermal conductivity
p_f	material flow stress in pure shear
v	velocity of sliding
μ	dynamic coefficient of friction
ρ	density
θ_b	bulk temperature
θ_{max}	maximum (flash) temperature

Averill et al., Trans. IMF, Vol. 91 No 5, Sept. 2013

Conclusions

- In any analysis of the likelihood of a mechanical stimuli to cause ignition –

  (i) the maximum surface temperature that could be generated needs to be determined *and*

  (ii) considered in relation to the temperatures that would be required to initiate hot surface reactions sufficient to cause sparking and ignition.

- Velocity and the properties of the interacting metals are of major importance.

- Glancing hammer impact blows, even with low impact energy can result in sufficient interfacial temperatures for ignition to occur because of the additional normal force applied

Thank you for listening

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