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Ignition of hydrogen/air mixtures by glancing mechanical impact

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ABSTRACT

Conditions are examined under which mechanical-stimuli produced by striking controlled blows (onto Magnox contaminated surfaces) can result in ignition of hydrogen/air mixtures. The most influential parameter in determining ignition probability is the velocity of sliding movement during mechanical stimuli. It is clear that the impact kinetic energy associated with the inertial mass of the hammer head is of lesser importance than the combined effect of (i) the torque of the coiled springs which continues to drive the hammer head arm and determine its velocity after initial impact and (ii) the normal force which is applied during contact. This explains the apparent discrepancy in previous studies between the minimum kinetic energy thought to be necessary to allow thermite sparking and gas ignition to occur with drop weight impacts and glancing hammer blows. In any analysis of the likelihood of mechanical-stimuli to cause ignition, the maximum surface temperature generated should be determined and considered in relation to the temperatures required to initiate hot surface reactions sufficient to cause sparking and ignition.

Introduction

During nuclear waste decommissioning there exists the possibility of generating hydrogen/air atmospheres which could be ignited by some mechanical stimuli resulting from the operations. Such mechanical stimuli can be associated with either normal operation of the decommissioning plant or to a fault condition which arises. It could include bodies falling under gravity to impact the waste containment vessel walls or machinery, sliding surfaces which produce excessive frictional heat or a controlled glancing blow or impact, such as from a robotic arm losing its control function.

Although it is usual to use the concept of overall kinetic energy when considering the likelihood of an ignition event [1], with sparking due to glancing impacts, velocity is known to be an important parameter. At the former UK Safety in Mines Research Establishment, Rae [2] investigated the ignition of methane/air by the glancing impact of metals on smears of light alloys formed on rusty surfaces. He concluded that a light fast blow (250 g at 2.6 m/s with kinetic energy 0.9 J) can readily cause ignition whereas slower and more ponderous impacts do not appear to do so. In contrast to this, where drop weight impacts on inclined plates are involved the minimum kinetic energy associated with initiation of thermite sparking is of the order of at least 20–40 J [1]. This apparent difference in the kinetic energies involved, clearly requires further consideration. The nature of the corroded sludge beds in a nuclear waste containment is such that there will be very large amounts of partially corroded surface active

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or pyrophoric materials present. Of these, magnesium and its corrosion products often represent the most likely source to initiate an ignition event.

The intensely exothermic reaction that results when magnesium containing particles burn in air or react with iron or other oxides (thermite reaction) can result in temperatures in excess of 2500 °C being reached: burning products can spray out in liquid form to generate a highly incendiary ignition source for flammable gas mixtures. Consequently, ignition of a flammable hydrogen/air mixture can result from a mechanical-stimuli event if a surface temperature is achieved that exceeds the initiating temperature for a pyrophoric surface reaction to occur.

This paper examines the conditions under which mechanical-stimuli produced by striking controlled blows can result in sparking and ignition of hydrogen/air mixtures. It principally focuses on the conditions and mechanical parameters that are involved in determining the probability of an ignition event.

Impact apparatus and experimental method

The apparatus used was similar in its major design features to that used by Rae [2]. Essentially, impacts occur due to a double pendulum system where one pendulum allows vertical freedom of movement of the striker on impact. As shown in the schematic diagram given in Fig. 1, a hammer head made of mild steel with a screwed-in test tip to act as a striker was attached to the end of a steel hammer arm. After release, the test tip struck a target plate at an angle (α) which was preset by altering the protruding length of the test tip. The velocity achieved by the test tip at impact was altered by releasing the hammer arm from different raised positions.

A high speed digital camera was used to supply a kinetic record of the impact and to determine the relevant angular and linear velocities. Three test tips of varying hardness were prepared by appropriately heat treating 15 mm diameter threaded 0.4% carbon steel rods. The target plate was machined from 100 mm diameter steel bar (BS 80A15 with

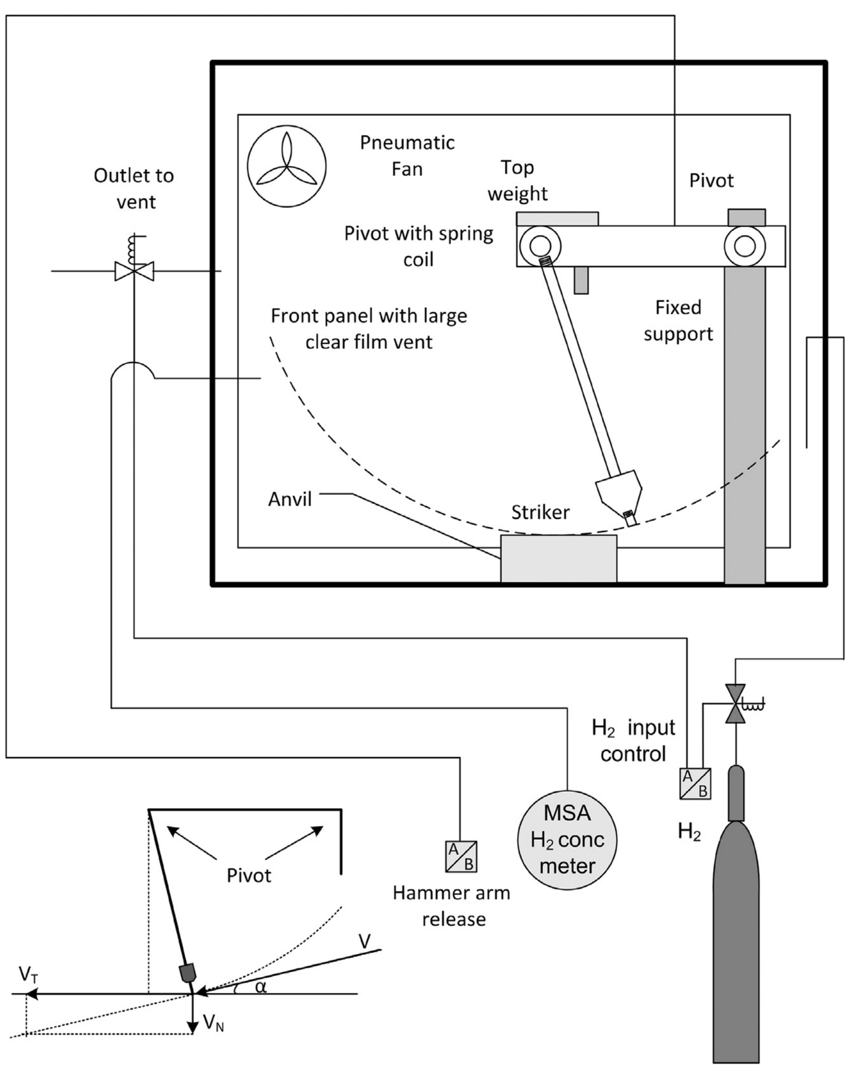

Fig. 1 – Double pendulum impact apparatus. Normal (V_N) and tangential (V_T) components of the impact velocity are shown inset.

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