Limiting values for the ignition of hydrogen/air mixtures by mechanically generated ignition sources

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1   Introduction

Mechanical equipment for use in explosive atmospheres can feature ignition hazards through hot surfaces and, in particular due to malfunctions, through mechanically generated sparks. At present, an international standard[1] is being developed for the safety requirements of explosion-proof mechanical equipment. In this regard, igntion tests were done in two different hydrogen/air mixtures.

The friction of elements which move in opposite directions cannot be ruled out. If the contact zone reaches a sufficiently high temperature, the removed particles, combined with the oxygen contained in the air, can combust. Both the high surface temperatures and the mechanical sparks can thereby be a potential ignition source for explosive atmospheres. Therefore, in the last few decades the formation of mechanically generated ignition sources has been the subject of many research activities [1–3]. In addition to improving fundamental knowledge, results were integrated into European standards.

Following this, a limiting value of 1 m/s for relative velocity has often been used, below which mechanically generated ignition sources are not capable of igniting an explosive atmosphere. This standard gives a hint that experimental tests have confirmed this for many situations except for ignition-sensitive gas atmospheres with hydrogen or ethylene at high contact loads [4]. Other investigations have reported ignitions below this limit [5]. However, the surface-related power density maybe describes the friction process more precisely than a relative velocity of the friction partners. The aim of this research is to verify the power density as a criterion for ignition in hydrogen/air mixtures.

2   Mechanically generated ignition sources

By deformation and - in particular - cutting-off processes, particles of increased temperature can be detached from a wear point. They subsequently oxidize as ignitable sparks under specific limiting

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[1]ISO 80079-36. Non-electrical equipment for use in explosive atmospheres - Basic method and requirements. / ISO 80079-37. Non-electrical equipment for explosive atmospheres - Non electrical type of protection constructional safety 'c', control of ignition source 'b', liquid immersion 'k'.

process conditions and depending on the material. The wear point can be characterized by a constant relative velocity v and a constant load per area p_A between the friction partners. Due to the tribological processes which take place in the wear point, the friction coefficient f can vary with time. The surface-related power density $q = v \cdot p_A \cdot f$ is characteristic of a friction situation. The duration of the contact may in practically relevant situations vary typically between a few seconds and some minutes.

In a friction process, a hot surface is often formed in addition to the mechanically generated friction sparks, representing a secondary potential ignition source. The heat quantity applied into the particles by the deformation and cutting process is first of all characterized by the starting temperature of the removed particles. Although the ignition temperature of most fuel gas/air mixtures is exceeded, it is, however, rarely sufficient to ignite an explosive fuel gas/air mixture as the duration and the energy content are too low [6]. If these particles pass through an oxidation process, the occurring sparks are called mechanically generated sparks [7]. They reach a higher temperature level (2000 - 2400 K, [8]) and can then ignite the mixture with a clearly higher probability.

The limiting value $v = 1.0$ m/s has been determined as the minimum relative velocity between two friction partners, under which no sparks capable of causing ignition or hot surfaces are formed in the case of usual steel materials [2]. In cases of very high loads per area ($p_A > 10$ N/mm^2), ignitions were already observed at 0.7 m/s [5]. The dependence of material properties and load per area on the formation of sparks has been investigated in more recent research activities. Here, it has been possible to measure necessary minimum temperatures for the formation of sparks in homogeneous material combinations. For stainless steel a minimum temperature of 650 °C has been determined [9]. The friction coefficient - the ratio of the friction load F_R and the normal load F_N - can be calculated by measuring the normal load F_N and the torque M

$$f = \frac{F_R}{F_N} = \frac{M}{F_N \cdot r}$$

using the radius of the friction disc r. The surface-related power density as an ignition criterion for friction processes is still to be verified.

3 Equipment and experiments

The experimental arrangement of the friction spark forming apparatus is realized via a friction pin which is pressed with constant contact force onto the sliding surface of a rotating friction disc (Fig. 1). This arrangement is located in a pressure-proof explosion chamber which can be filled with a fuel gas/air mixture of any concentration. To observe the processes at the wear point and the particles, the tests are recorded with a high-speed camera. The evaluation of the video sequences then allows the spark formation, the ignition cause and the location of the ignition source to be detected.

Ignition experiments are conducted with homogeneous combinations of stainless steel (EN 1.4541, AISI 321) and mild steel (EN 1.0038, AISI A283) in 10 % and 30 % hydrogen/air mixtures to determine the effective ignition source. The relative velocity can be varied, the load per area is set in spans of 0.5 N/mm^2. Dynamic load and torque are measured at 500 Hz to calculate the friction coefficient. Tests are limited to durations of 50 seconds. From this follows that the amount of data for the friction coefficient can be up to 25000.
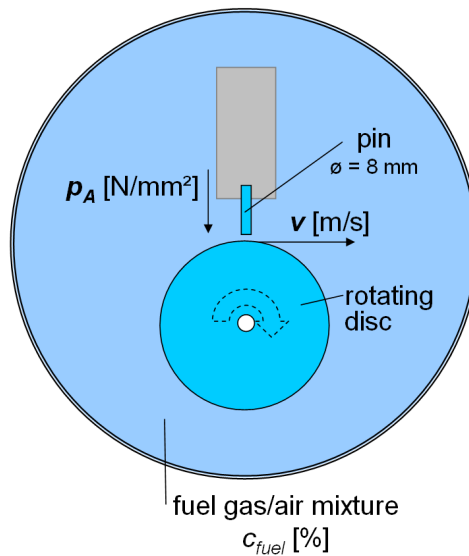
Figure 1: Sketch of the friction spark forming apparatus

4   Results

Currently, a limiting value for the incendivity of mechanically generated ignition sources is described only by the relative velocity. But the load per area is similarly relevant for friction processes. Ignition tests in 10 % and 30 % hydrogen/air mixtures show that ignitions are possible at even less than 1 m/s. In our tests every ignition with stainless steel was caused by a hot surface. Mixtures of 10 % hydrogen in air with mild steel were ignited by sparks - at 30 % hydrogen the hot surface was exclusively responsible for the ignition. The duration of friction until the ignition occurred varied between 10 and 50 seconds.
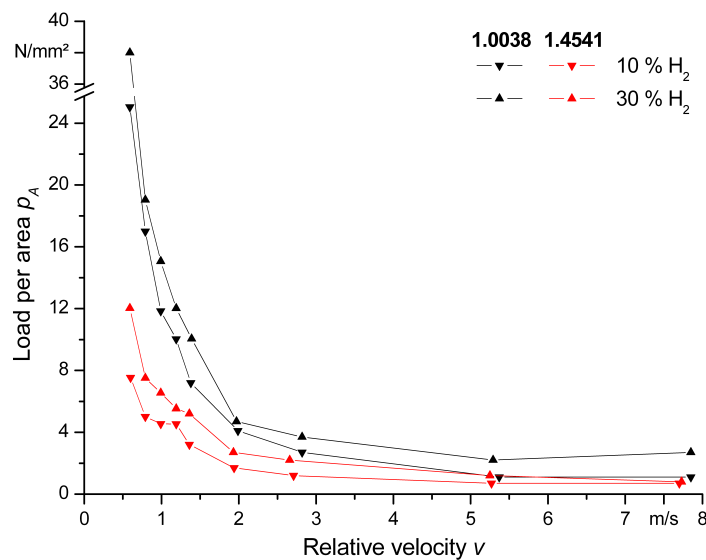

Figure 2: Ignition of hydrogen/air mixtures by mechanically generated ignition sources

Furthermore, the friction coefficient varies during the test and its values are distributed approximately normally (Fig. 3). The determination of the friction coefficient ends with the ignition of the mixture. Average values for the entire test are reproducible and can be used to determine the surface-related power density. Mean values of the friction coefficient were determined to be $f_{mild} = 0.66 \pm 0.06$ for mild steel and $f_{stainless} = 0.73 \pm 0.08$ for stainless steel.
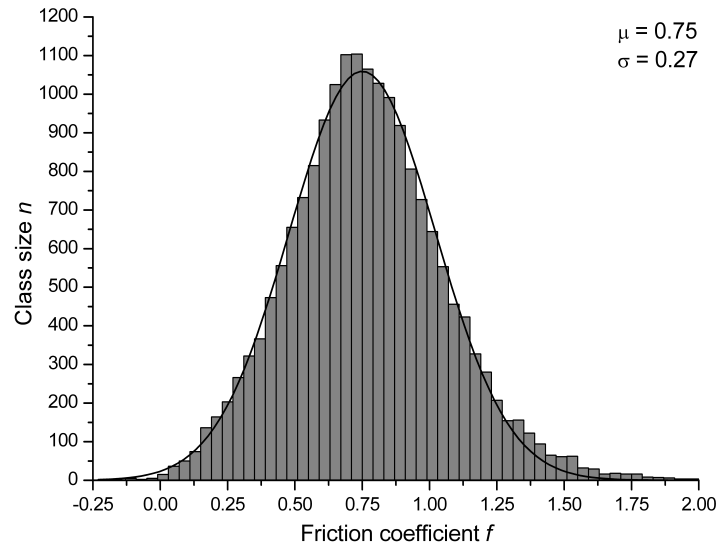

Figure 3: Distribution of friction coefficients during an ignition test with mean value μ and variance σ

The variance σ of the normal distribution of the friction coefficient (Tab. 3) illustrates the dynamic wear in the friction zone. In consideration of the power density of the ignition tests in hydrogen/air mixtures, limiting values could be identified (Fig. 4). The limiting values for stainless steel are lower than these for mild steel. Furthermore, ignitions in 10 % hydrogen occurred at lower power densities than ignitions in 30 % hydrogen.
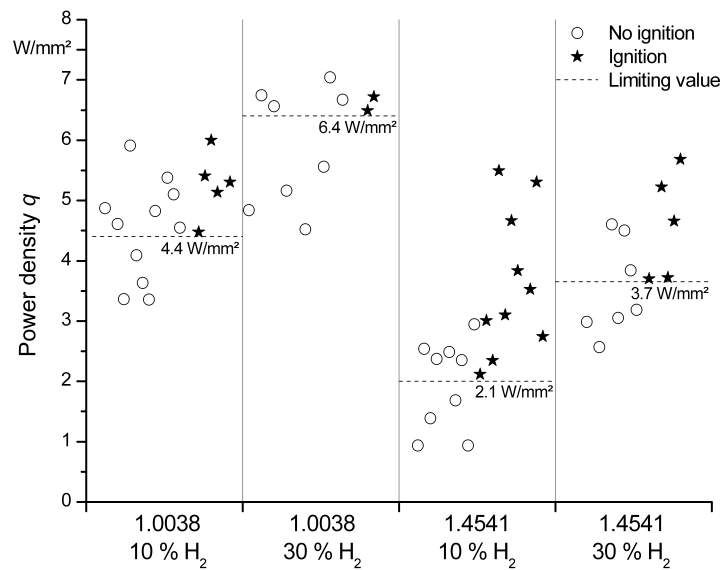

Figure 4: Power density of the minimum parameters for ignition

Table 1: Uncertainty of measurement for the main parameters

Relative velocity	Δv	rel.	1.3 %
Load per area	Δp_A	rel.	2.2 %
Time	Δt	abs.	8 ms
Concentration	Δc	abs.	0.02 %
Temperature	ΔT	abs.	2 °C
Friction coefficient	Δf	rel.	26 %

5 Discussion

A hot particle needs oxygen to oxidize as a spark. The fraction of oxygen in a 30 % hydrogen/air mixture is about 15 % - in 10 % hydrogen about 19 %. Because of this reduced amount of oxygen, the ignition limit moves to higher power densities at 30 % hydrogen. As a result, hot surfaces are exclusively responsible for the ignition. For concentrations of hydrogen near its lower explosion limit ($c = 4{,}0$ %), an intensified formation of sparks could be expected at least for mild steel.

The surface-related power density seems to be a proper criterion for the ignition of hydrogen/air mixtures by mechanically generated ignition sources. Limiting values for more widely differing mixtures and materials now have to be determined.

6 Conclusion

In friction processes, two potential ignition sources are generated simultaneously. The effectivity of each ignition source is connected to friction parameters, material properties of the friction partners and the conditions and properties of the explosive atmosphere. Whereas a limiting relative velocity was used to describe these ignitions in the past, the surface-related power density connects the relative velocity, the load per area and the friction coefficient. Ignitions are possible even below a relative velocity of 1 m/s. This work points out limiting power densities for the ignition of 10 % and 30 % hydrogen/air mixtures in friction processes with mild and stainless steel. Limiting values in 10 % hydrogen/air mixtures are lower than those in 30 % hydrogen. Limiting power densities for stainless steel are lower than those for mild steel.

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