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Hot surfaces generated by sliding metal contacts and their effectiveness as an ignition source

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ABSTRACT

Frictional processes caused by malfunctions may lead to hot surfaces and mechanical sparks. Whenever mechanical sparks occur due to friction, there are also hot surfaces. The time until the ignition source becomes effective is largely dependent on the thermal conductivity of the friction partners. Based on this, it was examined whether classification into the explosion groups and temperature classes of IEC 60079-0 is possible and useful. This research therefore focuses on the development of hot surfaces and their effectiveness. To assess the formation of hot surfaces, tests for temperature development according to the applied power density and the different materials were performed in a friction apparatus. The experimental setup is realised via a friction pin which is pressed onto a rotating friction disc. The variation of the power density was carried out by changing the velocity and load per area. The temperature distribution was detected by thermocouples, two pyrometers and an infrared camera. For the investigation of the incendivity of hot surfaces, the ignition curves were determined by characteristic reference gases and vapours of the IEC explosion groups and temperature classes. Tests have been carried out with hydrogen, ethylene, diethyl ether, propane and pentane. The experiments have shown that a larger thermal conductivity of the steel used can lead to slow down heating of the pin material. With an increasing wear rate the maximum temperature decreases. It was possible to determine the maximum temperatures at specific power inputs. The ignition tests show that ignitions are possible even at low velocities. The effective ignition source was thereby always the hot surface. The result was a graduation of the explosion limits analogous to the order of Maximum experimental safe gap (MESG) values. In contrast, no significant relationship between the ignition limits and the temperature class of the respective substances was revealed.

1. Introduction

Typical ignition sources when using mechanical equipment are hot surfaces and mechanically generated sparks. In the friction processes of steel contacts, both ignition sources are coexistent and may ignite explosive atmospheres. The aim of this research project is to find out under which conditions hot surfaces become effective. Criteria for the avoidance of these ignition sources might be helpful for the safety design of mechanical equipment.

The friction of elements which move in opposite directions cannot be ruled out. 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 (Ritter, 1984; Bartknecht, 1989; Proust et al., 2007). In addition to improving fundamental knowledge, results have been integrated into European standards.

Following this, a limiting value of $v = 1.0$ 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 the usual steel materials (Bartknecht, 1989). Other investigations have reported ignitions below this limit (Hawksworth et al., 2004; Welzel et al., 2011). The surface-related power density is the proper criterion for the ignition of explosive atmospheres by mechanically generated ignition sources (Welzel et al., 2011).

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2. Theory

2.1. Mechanically generated ignition sources

The wear point may be characterised 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 may vary with time. Our experience has shown that, in practice, the calculation of the friction coefficient is associated with some difficulties, because the measured individual values show a considerable scatter ($f = 0.74 \pm 0.24$ at $v < 3$ m/s). To avoid the dynamic determination of the friction coefficient in this paper, a constant friction coefficient of $f = 1.0$ will be used here. However, the limiting power densities specified should give only a qualitative indication of the relationship between the investigated substances and should be compared to existing safety characteristic data. The surface-related power density $q = v \cdot p_A \cdot f$ is characteristic of a friction situation. With a constant friction coefficient it is then constant with time. The duration of the contact may in practically relevant situations vary typically between a few seconds and some minutes. In a friction process, mechanically generated friction sparks are often formed in addition to a hot surface, which represents an additional potential ignition source. Mechanically generated friction sparks are particles, whose surface temperature is significantly higher than the temperature of the wear point (DIN EN 1127-1, 2011). They oxidise after separating from the wear point and thereby heat up further. In contrast, the temperature of hot particles is highest at the time of separating from the wear point. During their ‘flight’, they lose heat continuously and therefore cannot cause an ignition (Welzel et al., 2010a). Separated particles and friction sparks detract heat from the wear point and reduce its further heating.

The ignition sensitivity of explosive atmospheres of the characteristic reference gases and vapours of the IEC explosion groups (IEC 60079-20-1, 2010) by mechanical sparks were investigated in the past (Grunewald and Grätz, 2007; Grunewald and Finke, 2009). However, this paper shows investigations into the incendivity of these reference gases and vapours by hot surfaces that represent other mechanically generated ignition sources.

2.2. Thermal conductivity

To describe the thermal development in the friction zone, tests were performed with materials with different thermal conductivities. The materials were selected on the basis of the thermal conductivities specified in their data sheets. Prior to the experiments, the thermal conductivities of the selected materials were determined experimentally.

The thermal conductivity of steels and alloys correlates with the electrical conductivity. The relationship is established using the Wiedemann–Franz law (Klemens et al., 1991). The ratio of electrical conductivity σ to the thermal conductivity λ is equal to the absolute temperature T in consideration of the Lorenz number L (Equation (1)). The electrical conductivity σ is the reciprocal value of the electrical resistance ρ.

$$\frac{\lambda}{\sigma} = \mathrm{L} \cdot T \qquad \lambda = \frac{\mathrm{L} \cdot T}{\rho} \tag{1}$$

With the Lorenz number L:

$$\mathrm{L} = 2.44 \cdot 10^{-8} \mathrm{V}^2 \mathrm{K}^{-2}$$

However, Bungardt and Spyra showed that the relationship described is dependent on the alloy (Bungardt, 1965). They classified the materials into one of four groups depending on the prevailing structure and the alloy content and developed one empirical power function for each group. The following equations are relevant for the materials selected in this paper. Within this study the equations given in (Bungardt, 1965) were extended by a conversion factor to calculate the thermal conductivity in SI units (1 cal/(cm grd s) = 418.68 W/(m K)). The values shall be used in the following units: T in [K]; ρ in [Ohm cm] and λ in [W/(m K)].

The following function applies to ferritic and martensitic steels with an alloy content ≤10 atomic-%:

$$\lambda_f = \left(1.533 \cdot 10^{-8} \cdot \mathrm{T}^{0.895} + 1.3 \cdot 10^{-8}\right) \cdot \rho^{-1} \cdot 418.68 \tag{2}$$

The following function applies to ferritic and martensitic steels with an alloy content >10 atomic-%:

$$\lambda_m = \left(10.73 \cdot 10^{-8} \cdot \mathrm{T}^{0.605} + 1.8 \cdot 10^{-8}\right) \cdot \rho^{-1} \cdot 418.68 \tag{3}$$

The following function applies to austenitic steels and alloys with an alloy content ≤50 atomic-%:

$$\lambda_a = \left(5.705 \cdot 10^{-8} \cdot \mathrm{T}^{0.684} + 0.7 \cdot 10^{-8}\right) \cdot \rho^{-1} \cdot 418.68 \tag{4}$$

3. Experimental set-up

To assess the formation of hot surfaces, tests for temperature development according to the applied power density and the different materials were performed in a friction apparatus. In addition to the experiments on temperature development, outgoing ignition tests were conducted in the friction apparatus to determine the ignition capability of these hot surfaces. The experimental set-up of the friction apparatus is realised via a friction pin which is pressed with constant contact force onto the sliding surface of a rotating friction disc (Fig. 1). The pin is 23 mm long and has a diameter of 8 mm. The diameter of the friction disc is 150 mm and the width of the friction surface is 20 mm. The variation of the power density was carried out by changing the relative velocity and load per area. This arrangement is located in a pressure-proof explosion chamber which can be filled with a fuel- and gas/air mixture of any concentration. To observe the processes at the wear

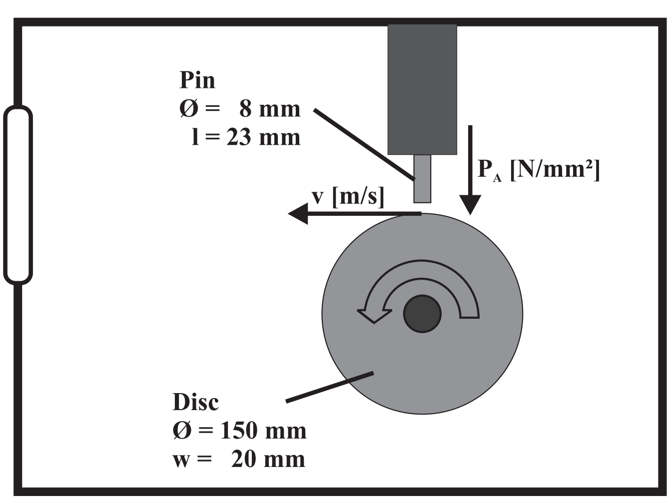

Fig. 1. Experimental set-up.