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Ignition probability of fuel gas–air mixtures due to mechanical impacts between stainless steel components

Lars Holländer*, Thomas Grunewald, Rainer Grätz

Federal Institute for Materials Research and Testing, Unter den Eichen 87, D-12205 Berlin, Germany

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ABSTRACT

The ignition probability of gaseous mixtures of acetylene, hydrogen and ethylene with air due to mechanical impacts between stainless steel components was examined for various impact energies. Additionally, the sources of ignitions were identified by infrared high-speed recordings. The stainless steel types used had different chemical compositions in order to investigate the influence of the chromium content on the ignition probability. The investigations reveal different ignition probabilities of the gas mixtures as well as different sources of ignitions depending on the steel type used and the impact energy applied. Impact energies below 126 J resulted in ignition of the gaseous mixture at the hot surfaces of the pin or the plate in most of the cases. At higher energies, initiation of ignition due to abraded particles was more probable when using stainless steel components with lower chromium content whereas the source of ignition was almost exclusively limited to the hot surfaces of pin and plate for the steel with the highest chromium content. However, as opposed to the source of ignition, the probability of ignition could not be correlated to the chromium content of the stainless steel.

1. Introduction

Explosive atmospheres can be ignited by mechanically generated hot particles or surfaces. These ignition sources can be caused by friction or impacts. Friction is characterised by a comparatively long contact time between two materials with different velocities whereas a mechanical impact is characterised by a short contact time during which kinetic energy is partially or fully transformed into material deformation and heat. Consequently, friction and mechanical impacts generate hot surfaces at the contact areas as well as separated hot particles.

Since several decades the hazards due to mechanical impacts are being investigated. There are three main concepts of inducing a mechanical impact: shooting of small spheres towards a metal plate (Müller, 1972; Powell, 1969; Röschenbleck, 1960), the free fall of a sample onto an inclined metal plate (Brenner and Eversheim, 1958; Komai et al., 1994; Proust et al., 2007; Reimer, 1957; Schultze-Rhonhof, 1956; Weichsel, 1955) and the grazing strike (Dittmar et al., 1960; Gibson et al., 1968; Grunewald and Finke, 2009; Grunewald et al., 2010; Grunewald and Grätz, 2007; Ritter, 1984; Schultze-Rhonhof, 1956; Schulz and Dittmar, 1963; Welzel et al., 2011). Despite the different experimental setups and various material combinations and gas mixtures investigated, there is still only limited knowledge about ignition hazards due to mechanical impacts. Nevertheless, some correlations between the experimental conditions and the ignition probability are known. The ignition probability increases with increasing impact energy. Furthermore, involvement of harder materials was found to cause a higher ignition probability (Dittmar et al., 1960; Reimer, 1957). Schultze-Rhonhof (1956) claimed the grazing strike to be more effective in igniting a combustible gas mixture than the obtuse angled impact.

Amongst others, the ignition probability is influenced by the involved materials. The impact of aluminium containing materials on rusty steel can easily lead to ignition of the gaseous mixture due to the heat generated by a thermite reaction initiated by the impact (Gibson et al., 1968). Also the exothermic oxidation of hot steel particles abraded by the impact increases the probability of ignition. Based on the results of grinding experiments, Voigtsberger (1955) concluded that a chromium content of more than 18.11% prevents oxidation of the steel particles. Also tungsten and silicon hinder the oxidation of iron (Konschak and Voigtsberger, 1957). Nevertheless, ignitions due to the impact of nickel–chromium steel on sandstone in a methane–air atmosphere were observed (Powell, 1969). Up to now, only few investigations were performed regarding the ignition hazards due to mechanical impacts of stainless steel. However, as stainless steel is a widely-used material

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* Corresponding author.
E-mail address: lars.hollaender@bam.de (L. Holländer).

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in the chemical and food industry, a better knowledge about the possible hazards of mechanically generated hot surfaces and particles is necessary.

In this paper, we present the results of grazing impact experiments using three different types of stainless steel in gaseous mixtures of acetylene, hydrogen and ethylene with air. In order to investigate the influence of the chromium content of the stainless steel on the ignition probability, three steel types with different chromium contents were used.

2. Experimental details

The ignition probabilities of fuel gas–air mixtures due to mechanical impacts of stainless steel were investigated by performing grazing impact experiments as this is the most incendive impact. Three different types of stainless steels were used, namely 1.4313, a martensitic steel, 1.4541, an austenitic steel and 1.4462, a duplex stainless steel. The composition of these steels is given in Table 1. The gas mixtures used consisted of air and one of the typical fuel gases acetylene, hydrogen and ethylene. In order to compare the results with data of previous investigations using mild steel (Grunewald and Finke, 2009; Grunewald et al., 2010; Grunewald and Grätz, 2007), the ratio between the flammable gas and air was set to 8 vol-%, 10 vol-% and 6.5 vol-% for acetylene, hydrogen and ethylene, respectively. The experiments were performed at room temperature and atmospheric pressure of the gaseous mixture.

The experimental setup consisted of a hammer which was connected to a torsion spring at one end. A pin made of stainless steel of one of the types according to Table 1 was mounted to the other end of the hammer (cf. Fig. 1). A steel plate consisting always of the same type of stainless steel as the pin was placed below the hammer. The plate had grooves parallel to the direction of movement of the hammer on its surface. The positioning of the plate could be adjusted in height in order to ensure optimum grazing. The whole setup was contained within a steel chamber which could be filled with the gaseous mixture (cf. Fig. 2). The chamber had a circular opening which was covered with a transparent polymer film. In case of an explosion of the gas mixture this film burst to release the flue gas thereby preventing the build-up of high pressure inside the setup.

Before each experiment the hammer was fixed with a hook so that the angle of deflection was the same for every experiment. Energy of the spring was stored due to its distortion. The amount of potential energy thus could be varied by using different torsion springs. Abrupt release of the hammer results in a conversion of potential energy to kinetic energy of the hammer. The pin hit the plate near the initial position of the hammer and the hammer was decelerated due to frictional forces between pin and plate. Thus, a portion of the kinetic energy was converted to thermal energy which resulted in a temperature increase of the grinding areas of pin and plate. Another portion was converted to kinetic energy of released particles. In the majority of the experiments the hammer hit the plate more than one time until it came to rest. Neglecting frictional losses, the complete kinetic energy of the torsion spring is converted during this process.

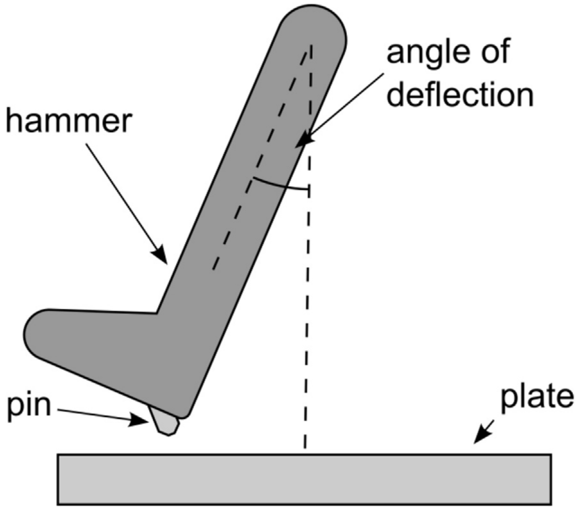

Fig. 1. Schematic illustration of the experimental setup for the impact experiments.

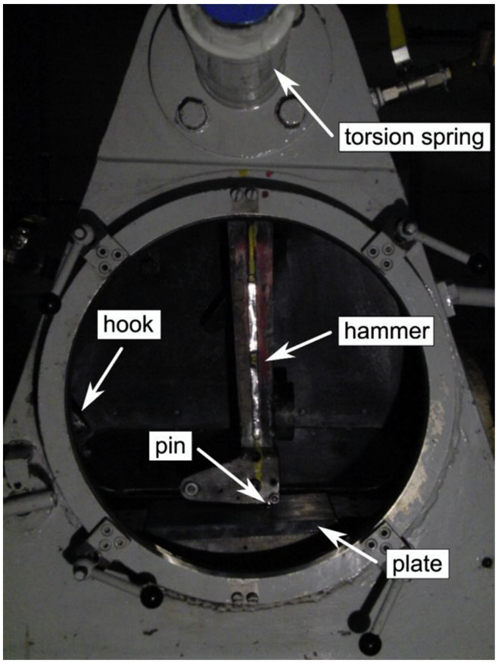

Fig. 2. Picture of the experimental setup for the impact experiments.

The experiments were performed with decreasing kinetic energy for each type of stainless steel. If no ignition could be detected in at least 200 impacts of the same energy, no further experiments with lower kinetic energies were performed with the respective type of steel.

Each experiment was recorded by means of a high-speed infrared (IR) camera (ThermoVision SC4000, FLIR) with a frame rate

Table 1
Chemical composition of the investigated stainless steels according to the information of the suppliers.

Material number	Content in %									
	C	Si	Mn	P	S	Cr	Mo	Ni	Ti	N
1.4313	0.026	0.35	0.73	0.025	0.0007	12.6	0.61	3.8	–	0.034
1.4541	0.028	0.47	1.64	0.040	0.001	17.71	–	9.18	0.212	0.0097
1.4462	0.020	0.48	1.43	0.030	0.001	22.49	3.12	5.23	–	0.1600