

Formation of Mechanical Sparks in Sliding Metal Contacts

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For the use of mechanical equipment in explosive atmospheres, their ignition sources must be considered. Frictional processes caused by malfunctions can lead to hot surfaces and mechanical sparks. Sparks are defined as particles whose surface temperatures significantly exceed that of the wear contact. Responsible for that is the exothermic combustion of the particle. If both ignition sources, sparks and hot surfaces, appear in a wear contact, the predominant ignition source is unknown. Therefore, tests regarding spark formation were performed in a friction test bench using mild steel and stainless steel.

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 can ignite explosive atmospheres. The aim of the present research project is to find out under which conditions sparks occur. A criterion for the avoidance of one or both of those ignition sources might be helpful for the safety design of mechanical equipment. This work shall compare previous and ongoing experiments with a view to the ignition of explosive atmospheres.

2 Hot surface and mechanical sparks

A friction contact consists of many microscopic asperity contacts whose total surface is less than the nominal one. The lengths of the asperity contacts at small pressures typically amount to a few μm [1]. Therefore the heat flow is higher, and in some cases the melting temperature of the material can be reached. Due to heat dissipation to the surroundings, the average temperature in the friction zone is rarely influenced by melting [2].

Separated particles detract heat from the wear point and prevent from further heating. In this case, the heat removal by abrasion adds up to 80 % of the friction power, particularly with regard to cutting

processes [3]. A limiting temperature for the formation of sparks is given by Dittmar, who specifies the ignition temperature of carbon steels as 500 °C [4]. In the MECHEX project, temperatures of 400-450 °C were determined for hardened stainless steel on the carbon steel EN3B in the center of the pin [5]. Malkin calculated, using theoretical studies, a critical temperature of 675 °C for *workpiece burn* in wear points. However, the experimentally corrected data has reduced this limit by 20-30 % [6].

3 Equipment

The tested steels were high-alloyed stainless steel (1.4541) and mild carbon steel (1.0038). The friction disc and the pin always consisted of the same material combination. In contrast to former tests by different authors [7, 8], the friction time was prolonged to 25 s minimum.

The test set-up was located in an explosion-proof vessel ($V = 34\text{ l}$). It was used for recent studies regarding spark formation and ignition of explosive atmospheres [9]. For the visual observation of the wear contact with the high-speed camera (125 fps, 1024×512 pixels), a window was mounted at one side of the explosion-proof vessel. The revolution counter and the torque sensor were located between vessel and engine, and a pneumatic cylinder with a piezoelectric force sensor is positioned on top of the vessel. To detect the real contact time of disc ($\varnothing = 150\text{ mm}$, $l = 20\text{ mm}$) and pin ($\varnothing = 8\text{ mm}$, $l = 23\text{ mm}$), an electrical contact was used. This signal as well as the torque, the rotation speed (rpm), the pneumatic pressure and the force applied to the pin were measured at a sampling rate of 100 Hz. The constant force which could be applied to the pin pneumatically was limited to 500 N. Converted to the maximum surface of the pin, pressures of up to $10\frac{\text{N}}{\text{mm}^2}$ were possible. The minimum step width was $\Delta p_A = 0.5\frac{\text{N}}{\text{mm}^2}$, which was also the lowest possible pressure. Velocities were varied stepwise between 1,66 and $11,5\frac{\text{m}}{\text{s}}$.

The friction pins used had a length of 23 mm. Due to the needed clamping length, only 9 mm could be used for grinding. For detecting the temperature at the wear contact, pins were prepared with a type K thermocouple in the middle of the friction zone. The temperature signal was measured at a sampling rate of 4 Hz.

4 Results and Discussion

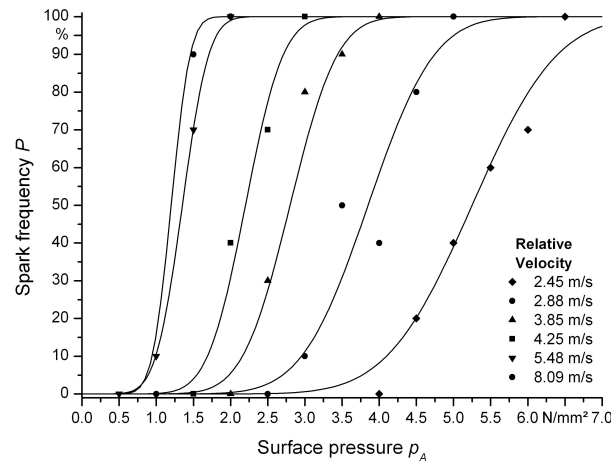


Figure 1: Spark frequency for stainless steel (1.4541)

The spark formation in homogeneous 1.4541 combinations is subject to statistical variations (Fig. 1). Therefore each combination of pressure and velocity was performed ten times. It can be seen that the

statistical transition region expands for increasing relative velocity. The same dependence of velocity appears for mild steel (1.0038), but spark formation starts at lower pressures at fixed velocities than for stainless steel combinations.

The spark formation starts in homogeneous 1.0038 combinations at a lower nominal heat flux $q = p_A \cdot v$ in the friction zone than in high-alloyed steel combinations. Limits for spark formation were found at $4.7 \frac{W}{mm^2}$ for mild steel and $6.2 \frac{W}{mm^2}$ for stainless steel (Fig. 2). For higher values of q , the spark formation starts earlier. In these cases, the thermal conditions of the friction zone change significantly. In stainless steel combinations, less sparks are observed than in combinations with mild steel.

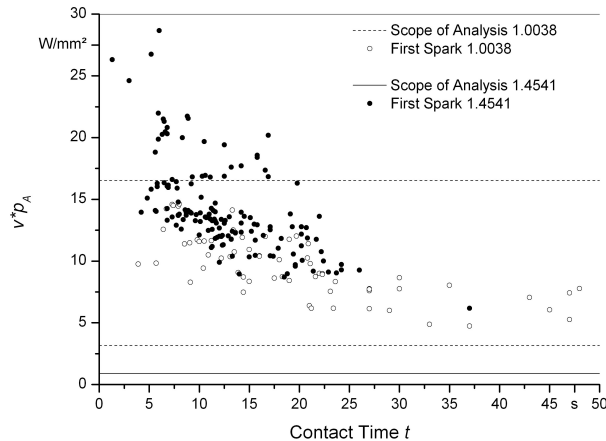


Figure 2: Time for spark initiation in homogeneous combinations

The measured temperatures in the contact zone differ for 1.0038 and 1.4541 at the same pressures and velocities. The peak temperature and heating velocity of mild steel (1.0038) is lower than in the case of stainless steel (1.4541). In the case of 1.4541, the temperature needed for a particle to start burning is higher than in the case of mild steel 1.0038. This interrelationship was already shown by Ritter [8] for chrome and nickel. Chrome as well as nickel are less ignitable than iron or steel. This characteristic is compensated for by the low heat conductance of chrome-nickel alloys as 1.4541 (factor 4 less than mild steel). The result is a significantly higher measured friction temperature. At different combinations of surface pressure and relative velocity but at a constant nominal heat flux q , minimum temperatures of about 400 °C (1.0038) and 650 °C (1.4541) have been determined. This is in good accordance with literature values.

During the tests, the agglomeration of material on the side and behind the pin was detected. Red heat was visible for those agglomerations. It can be assumed that the melting point was reached in some of the temporal contacts. One further indication is the observation of cold welded particles on the disc surface. First welded particles at the disc could be observed after about 7 s and led to bouncing of the pin. These observations lead to the conclusion that after a certain time, the melting temperature is reached at some local contact spots. The molten material does not totally vanish from the pin but is partly transported sideways and to the trailing edges of the pin. Due to that behaviour, the heat partition will not be ideal. These influences will be part of further investigations.

5 Conclusion

There is only a small difference between the spark formation of high-alloyed stainless steels like 1.4541 and mild carbon steels like 1.0038 regarding the product of surface pressure and relative velocity. The lower heat conduction of stainless steels compensates its lower ignitability. Therefore their surface temperatures are conspicuously higher than that of mild steel. Whereas carbon steel generates many sparks

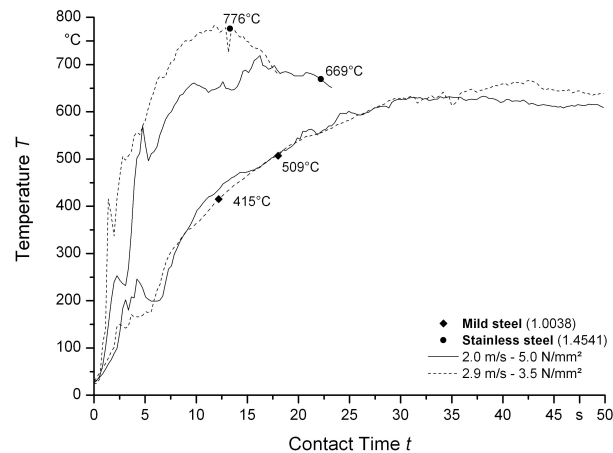


Figure 3: Temperature rise in sliding steel contacts

there are only a few using high-alloyed steel. In many cases, material from the friction zone clings to the pin and enlarges the hot surface. For long contact times, the ignition hazard of the hot surface becomes more important and might not be observed adequately.

Spark formation requires a minimum temperature at the friction spot. In accordance with literature values, minimum temperatures for spark formation of about 400 °C (1.0038) and 650 °C (1.4541) were found. Further investigations, especially experiments in explosive atmospheres, are necessary for a safety-related evaluation.

References

- [1] H. Blok, *IMechE* **1937**, 2, 222.
- [2] B. Bushan, in *Modern Tribology Handbook*, Principles of Tribology, CRC Press, **2001**, 1.
- [3] Z. B. Hou, R. Komanduri, *Tribol. Int.* **2001**, 34, 653.
- [4] P. Dittmar, in *Handbuch der Raumexplosionen* (Ed.: H. H. Freytag), 1. Ed., Verlag Chemie, Weinheim, Germany **1965**.
- [5] S. Hawksworth, J. Gummer, *Mechanical Ignition Hazards in Potentially Explosive Atmospheres (MECHEX) Final Report*, EU Contract GRD2-2000-30035, EC/05/27, Buxton, UK **2006**.
- [6] S. Malkin, *Ann. CIRP* **1978**, 27 (1), 233.
- [7] W. Bartknecht, *Zündwirksamkeit von mechanisch erzeugten Funken und heißen Oberflächen*, Bonn, Germany **1989**.
- [8] K. Ritter, *Die Zündwirksamkeit mechanisch erzeugter Funken gegenüber Gas/Luft- und Staub-Luft-Gemischen*, Karlsruhe, Germany **1984**.
- [9] T. Ott et al., *Criteria for the formation of sparks in wear points*, 7th ISHPMIE Proceedings, St. Petersburg, Russia **2008**.