Comparison of the formation of ignition sources due to continuous and repetitive metallic friction

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1 Introduction

Within mechanical components, friction situations of metallic surfaces can appear. Thereby, the two ignition sources ”hot surfaces” and ”mechanically generated sparks” may occur. These studies have shown that with the use of stainless steels, incendive hot surfaces may occur even before the conditions for spark formation are achieved [1–4]. Previous studies have only considered friction situations with continuous friction, which may occur in bearings, seals and couplings in the case of a malfunction. In addition to the continuous friction situations, repetitive friction can be expected in fans, pumps and agitators in the event of a malfunction. In this work, the formation of ignition sources by repetitive friction was investigated and compared with the formation of ignition sources due to continuous friction.

2 Basics

The friction zone can 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 friction zone, the friction coefficient f varies with time. To avoid the dynamic determination of the friction coefficient, in this paper, a constant friction coefficient of $f = 1.0$ will be used. The surface-related power density $q = v \cdot p_A \cdot f$ [W/mm^2] is therefore characteristic of a friction situation [5]. With a constant friction coefficient, it is then constant with time during the period of friction. The surface-related power density corresponds to the heat flux which is dissipated in the friction zone and flows into the friction partners. This heat flux is distributed in a ratio of 1:4 in a pin and disc [6]. The calculations of Ashby have been confirmed in numerical simulations by Welzel [3].

3 Experimental set-up

The experimental set-up corresponds to the friction apparatus described in [4], where the friction zone is realised via a pin which is pressed with constant contact force onto the sliding surface of a rotating

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disc (figure 1). For the modelling of the repetitive contact, two variations were used. First, the repetitive friction was realised by an up-and-down movement of the pin, so that friction and no friction alternate. Due to the existing set-up, this leads to relatively long contact- and no-contact phases of less than 1 s. For shorter alternations of contact and no contact, special friction discs were created that can model the repetitive friction by its wavelike surface. In order to allow a variation of the contact frequency, three different discs with two, four and eight waves were created (figure 2). Renewable steel sheets which are applied to the friction surface of the discs, ensure consistent and reproducible testing conditions for each attempt. Therefore, the friction pin is also replaced after each test. The friction partners were made of stainless steel (material number: 1.4541). This heats up very quickly due to its low thermal conductivity and thus represents the worst-case scenario [7].

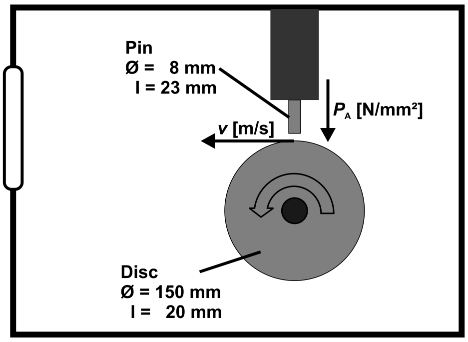

Figure 1: Experimental set-up for the continuous friction.

Figure 2: Friction discs with wavelike surface for modelling the repetitive friction.

To observe the processes in the friction zone, the tests are recorded with a high-speed camera. For detecting the temperature in the friction zone, the pins were prepared with three type K thermocouples on the surface, and a pyrometer was used to measure the temperature of the ridge that was forced out of the friction zone. The thermocouples are attached at a distance of 2.5 mm, 5 mm and 7.5 mm to the friction zone. The entire friction process with the pin and disc was observed with an infrared camera in order to be able to describe the temperature distribution.

The experiments were performed with four significant parameter combinations of relative velocity and surface pressure (1 m/s 10 N/mm^2, 2 m/s 5 N/mm^2, 5 m/s 2 N/mm^2 and 10 m/s 1 N/mm^2). These combinations have the same power density of 10 W/mm^2. With the same power density but different combinations of surface pressure and relative velocity, almost the same maximum temperatures are reached. Only the slope of the temperature rise varies slightly. Therefore, only the results at 2 m/s and 5 N/mm^2 will be further discussed in the following.

4 Results and discussion

At the beginning of the experiments, the heat input $\dot{Q}_{in}$ is greater during the contact time than the heat loss $\dot{Q}_{out}$ during the break, so that the temperature rises. After about 15 s, the heat input and output are the same, so that the measured temperatures fluctuate around a mean value. The variability of the values depends on the duration of contact- and pause times. For longer periods, the fluctuation range of the temperature is greater than for shorter periods, however, the average value is almost constant (figure 3). The observations from the two different series of experiments with shorter and longer friction- and pause times are described in the following. The temperature measurements of the experiments with contact- and pause times of ≥ 1 s show a characteristic zigzag curve. The heating and cooling phases of the friction partners can be clearly identified.

By changing the ratio of the contact time and pause time, both the slope of the temperature rise, and the mean value of the maximum temperature reached, vary. The greater the contact time in relation to the pause time, the steeper the temperature rise and the higher the average maximum temperature. The comparison of different contact ratios is shown in figure 4. For better clarity this figure only shows the smoothed mean values of the graphs.

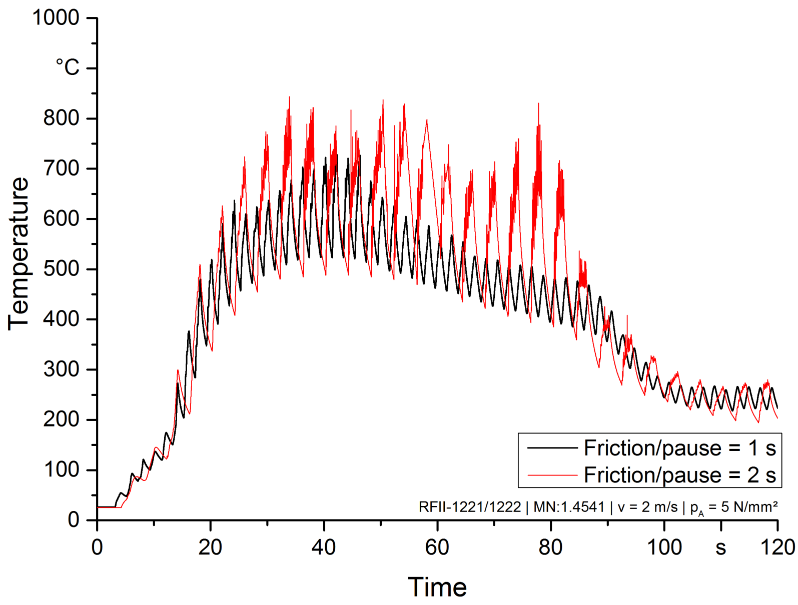

Figure 3: Zigzag curve of the temperature values for friction and pause periods of 1 s and 2 s.

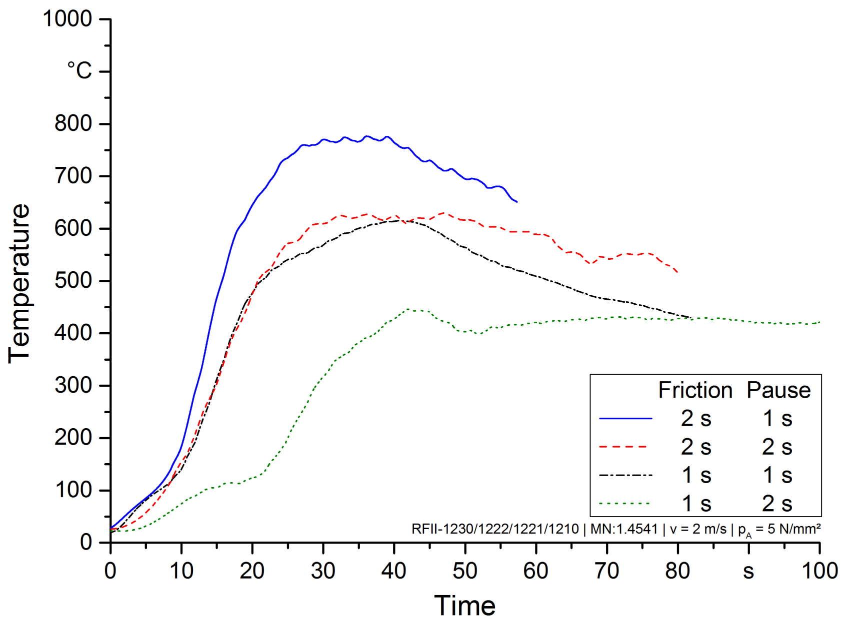

Figure 4: Influence of the contact ratios on the maximum temperature and the rate of temperature rise.

In the test series with shorter contact- and interval times ≤ 0.5 s, the temperature graphs show no zigzag curve. The individual heating and cooling phases are so short that the amounts of the temperature changes are smaller than the measurement uncertainty.

For the same relative velocity, the three friction discs (with 2, 4 and 8 waves) generate different contact- and interval times. At a speed of $v = 2$ m/s, the contact time for these discs is 0.089 s, 0.041 s and 0.017 s. Higher contact frequency leads to an increase in the number of friction pauses and consequently reduces the friction power implemented. In figure 5, this is illustrated by the stacked temperature curves.

In addition to the temperature curves of the experiments with repetitive friction, here also the temperature curve from an experiment with the same experimental parameters but continuous friction is shown. In comparison, it is clearly visible that the maximum temperature of the continuous friction is higher and the temperature rise is steeper. This can be explained with the cooling phases and the reduced energy input due to the pause time for the repetitive friction.

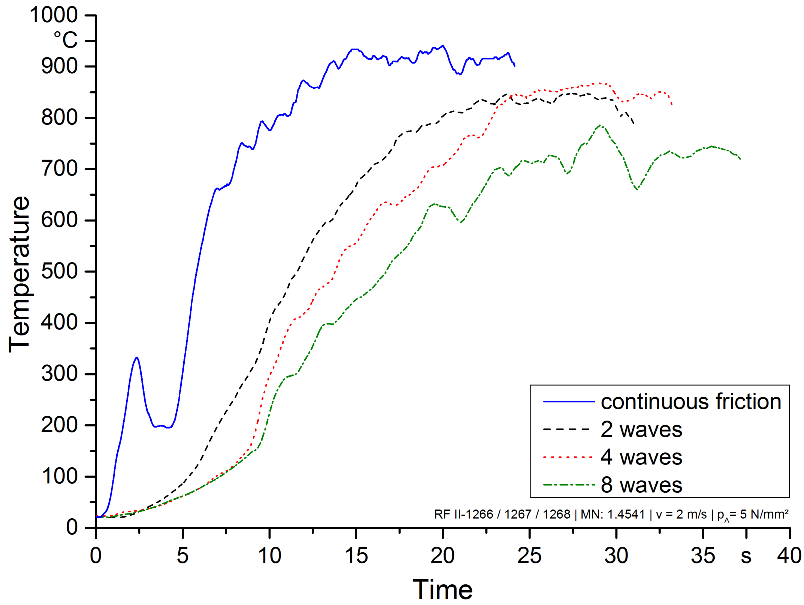

Figure 5: Comparison of the experiments with three discs of repetitive friction with the continuous friction experiment.

The two test series with repetitive friction (up-and-down movement of the friction pin or the specific friction discs) show both a slower temperature rise and lower maximum temperatures than in the experiments with continuous friction. Regarding the formation of hot surfaces, repetitive friction is less hazardous than continuous friction.

In order to prepare the comparison to the temperature development of continuous friction, tests were carried out with repetitive friction, in which the power density was increased. The increase of the power density was carried out by raising the surface pressure at a constant relative velocity. Due to the increased power density, the energy input that was reduced by the pause time should be compensated for. In figure 6 an example is shown. In this experiment, the contact time is 2 s and the pause time is 1 s. In order that the maximum values of the temperature values at repetitive friction are in accordance with the temperature curve of the continuous friction, the power density was increased by 50 %. This increase corresponds to the ratio between pause- and contact time.

5 Conclusion

The investigations showed that in the case of repetitive frictional contacts and otherwise identical test conditions, the temperature development is slower than in the case of continuous friction. The dissipated

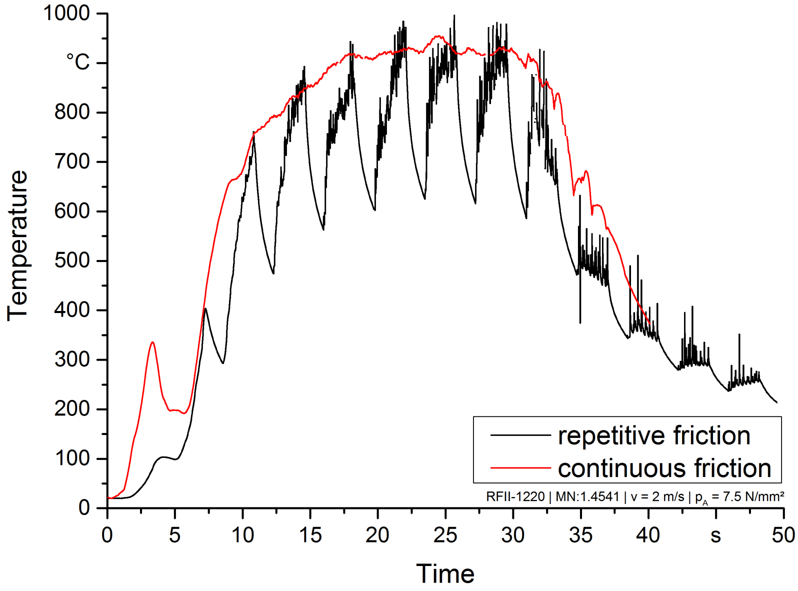

Figure 6: Comparison of the temperature development by repetitive friction with an increased power density relative to continuous friction.

energy in the ratio of pause time to contact time is low, compared with the case of continuous friction. Therefore, the temperature rise is slower and the maximum temperature reached is lower. Repetitive frictional contacts are, with regard to the formation of the ignition source ”hot surface”, under otherwise identical test parameters, less hazardous than continuous friction contacts.

In addition to the formation of ignition sources, the effectiveness of the potential source of ignition must be examined. This must be done by ignition tests. In the ongoing experiments, the incendivity of this ignition source is investigated in explosive hydrogen-air mixtures. Initial results indicate that the incendivity of repetitive friction is worse than that of continuous friction. For the same fuel concentration and the same relative velocity, a higher surface pressure than in the case of continuous friction is necessary to ignite the mixture [4]. This would confirm the results of these studies on temperature development. A precise conclusion may be given only after completion of the current investigation.

In spite of careful consideration during the planning phase, an overlay of impact and friction processes could not be completely ruled out in modelling repetitive frictional contacts in this study. Especially in view of the incendivity, the repetitive friction situations with the possibly occurring sparks and their ignition mechanism must be considered additionally in the future.

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