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Friction coefficients in cold forging: A global perspective

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ABSTRACT

Worldwide, at least twenty different tribological tests have been proposed for the empirical determination of friction coefficients in cold forging processes. Due to the varying test setups, means of measurement, and level of abstraction, the comparability of the outcomes is, however, disputable. Within this work, six established test principles are compared using identical tribological systems. Large differences between the empirically determined friction coefficients are observed but can be explained under consideration of the respective tribological loads. Additional investigations of an extrusion process reveal that friction models also have to take into account the varying local thickness of the lubricant film.

1. Introduction

Numerical simulations are essential for the efficient design of modern process chains. The quality of the herewith gained results depends heavily on the input parameters of the numerical model. These input parameters refer mainly to the description of material as well as frictional behaviour. Both groups of parameters are preferably determined empirically beforehand with the help of model tests. Whereas the process of gaining material modelling parameters has been widely standardized, the determination of frictional coefficients is still carried out heterogeneously. No universally agreed upon test procedure has been established to characterize friction in cold forging operations. Thus, at least 20 different tribotests for cold forging have been proposed. Actually, the development of new friction tests is an ongoing topic of research [1]. Due to the differing test setups, means of friction measurement, and level of abstraction, the comparability of the determined friction coefficients is highly disputable. Yet, no empirical comparison of the most commonly used tests is available to the knowledge of the authors. Benchmark studies of sheet metal forming friction tests have shown that large deviations between the determined friction coefficients exist for different friction tests [2]. With friction being a relevant system parameter that affects the result of the numerical simulations of cold forging operations substantially [3], a systematic comparison of friction tests and their outcomes is of high significance.

Within this paper, six established friction tests for cold forging operations are used to determine friction coefficients (Amontons–Coulomb) of one state of the art industrial tribosystem. The setups of the friction tests are designed according to a reference forming operation. Consistency in between the studied tests is ensured by reproducing the tribological loads of the reference forming operation within each of the frictional tests. The factored tribological loads comprise the contact normal stress, surface enlargement, relative sliding velocity, and temperature at the interface. However, due to the individual frictional test setups, not all of the mentioned tribological loads can be set independently [4]. Thus, accompanying numerical analyses of the frictional tests and the reference forming operation are used to gain additional insight into the impact of the tribological loads.

2. Experimental and numerical procedure

The reference forming operation is a single stage extrusion process [5] as depicted in Fig. 1(a and b). All specimens consist of a case hardening steel (16MnCrS5, DIN 1.7139, SAE 5115). The flow curves (see Fig. 1(c)) are determined empirically by cylinder upsetting with strain rates of $\dot{\varphi}$ = 0.1 and $\dot{\varphi}$ = 1 at temperatures of T = 25 °C, 100 °C, 200 °C, 300 °C, and 400 °C according to the procedure described in Ref. [6]. Work pieces of the reference extrusion process and samples for the friction tests are all numerically modelled elastic-plastic with these flow curves. A *Young's* modulus of E = 210 GPa and a *Poisson's* ratio of $\nu = 0.3$ is assumed.

All employed tools are made of M2 grade tool steel with a hardness of H = 61–63 HRC. The tools surfaces are coated with an AlCrN based coating (*Balinit Alcrona Pro*) and polished to a roughness of $Ra < 0.2$ μm. The specimens are sandblasted to a roughness of $Sq = 3.64 \pm 0.20$ μm. Consecutively, the lubrication

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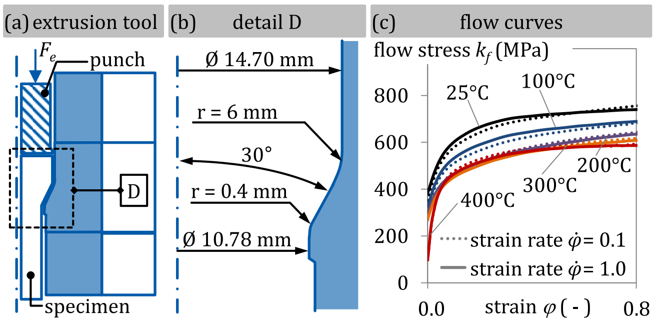

Fig. 1. Tool geometry of reference forming process (F_e: extrusion force), (a), detail of forming die (b), experimentally determined flow curves (c).

system, consisting of a zinc-phosphate conversion coating and reactive soap, is applied. As a result, the specimens feature a combined lubrication layer weight of $w = 22\ g/m^2$. The main steps of the lubrication process are displayed in Table 1.

Table 1
Process of application of the lubrication system.

Step	Description
1. Cleaning	GardoClean 350, 50 g/l at 90 °C for 10 min
2. Pickling	Hydrochloric acid (15%)
3. Activation	Gardolene V 6522, 2 g/l at 20 °C
4. Phosphating	Gardobond Z 3190 at 65 °C for 6 min
5. Lubricant application	Gardolube L 6176 (soap), 4%, at 85 °C for 5 min

In total, six tribological tests, which account for 80% of all carried out tests in cold forging, are investigated: two indirect tests, in which the friction coefficients are determined by measurement of geometric properties, and four direct tests, in which the friction coefficients are determined by force or torque measurements. All tests feature an open tribological system [7]. The empirically determined friction coefficients are based on at least three test runs. In Fig. 2 (top), a schematic overview of the employed tests, along with the relevant quantities to be measured, is illustrated. The dimensions of the used samples are given in the respective publications.

The first representative of the indirect tests is the Ring Compression Test with Boss (RCT-B) [8]. Friction is determined by compression of the rings in between two platens. By geometrical measurement of the reduction of height $R_H = (H_0 - H_1)/H_0$ as well as the increase of the outer diameter $R_D = (D_1 - D_0)/D_0$, friction coefficients are determined by comparing these parameters to numerically generated calibration curves. These are generated with friction coefficients of $\Delta\mu = 0.01$ spacing. Within the present study, the specimens were upset to three different heights up to $R_H = 58.9\%$.

The second indirect test is the Combined Forward Rod Backward Can extrusion Test (CFRBCT) [9]. Here, a cylindrical specimen is extruded simultaneously in forward and backward direction. Analogous to the RCT-B, the friction coefficient is determined by measuring the forward extruded rod length B and can height H_b and comparing these parameters to numerically determined calibration curves. Within the present study, the friction coefficient is determined based on specimens with a stroke length of $S_p = 15$ mm; 17 mm; 19 mm; 20 mm.

The Backward Can Extrusion Test (BCET) is the first representative of the investigated direct tests [10]. This test method is based on a backward can extrusion operation. By measuring the pullback force F of the punch after the backward extrusion, a friction coefficient can be determined by division of the pullback force F with the numerically determined radial force F_r acting during the pullback sequence. Friction coefficients are determined with cups extruded to a cup depth of $c = 51$ mm.

The Backward Can Extrusion with simultaneous Rotation Test (BCERT) [11] is based on a backward can extrusion process with superimposed rotation of the die together with the work piece. Measurement of the torque during the extrusion combined with Finite Element Analysis (FEA) of the contact normal stress and relative sliding velocity allows subsequently to determine the local

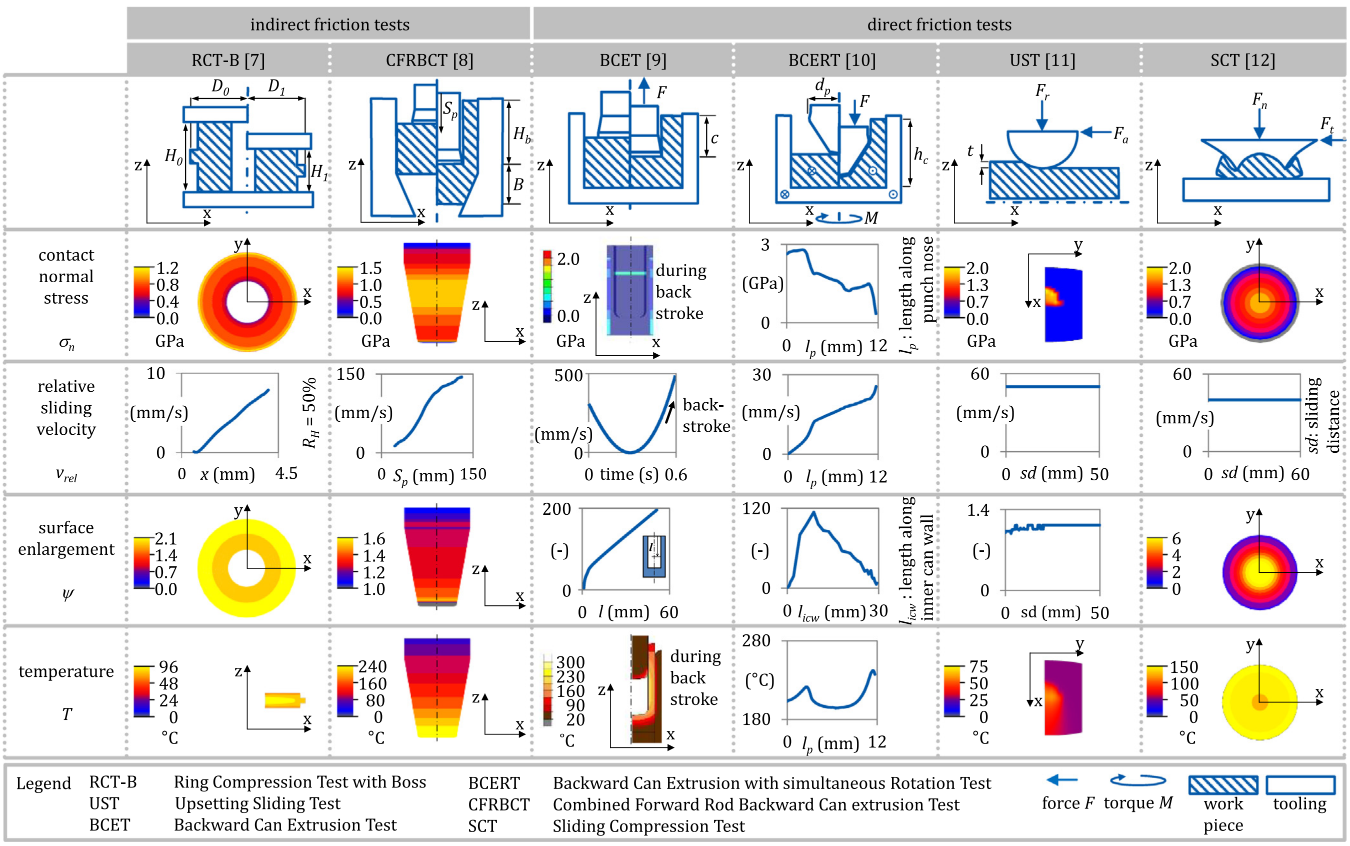

Fig. 2. Comparison of tribological loads of the investigated friction tests at the in Section 2 described process states.

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