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Damage minimised ball spinning process design

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ABSTRACT

Ball spinning is an incremental forming process for tubes and rods. The deformation of this process is limited by surface cracking. A closer look pointed out the dependence of some process parameters. The most influencing parameters are the workpiece diameter ratio D_1/D_2, the tool diameter ratio D_1/d and the axial feed rate v. A vast number of experiments would be necessary to study all interactions between these parameters and a 3D FEM simulation would have limitations in the computing time. Hence, this investigation proposes a 2D FEM model to predict the damage during ball spinning and gives a detailed view into a statistical design of experiments. The results show a trend to increase the axial feed rate for a damage minimised process design.

1. Introduction

Engineers are forced to come up with better prognoses for forming processes. Therefore, it is important to provide a practical and efficient method to predict deformation behaviours. Sivanandini et al. (2012) describe flow forming generally as an incremental forming process for tubes. One process modification, postulated by Birk (1985), is ball spinning. Similar to a ball bearing, the balls are controlled by a cage (Fig. 1). The diameter of the tube or rod is reduced by the rotating balls and is adjusted by the diameter of the leading ring. This process is applied in the production of cookware, automobile parts and military applications (Hofen and Wenke, 1986).

The ball spinning process is characterized by a complex stress state (Kuss and Buchmayr, 2015). Since this stress state is overlaid with the local stress state of the ball-plane contact to a significant damage at the workpiece. This ball-plane contact was firstly described by Heinrich Rudolf Hertz (1857–1894). The particular feature of the ball-plane contact is, that the highest surface pressure occurring at the top of the plane, injects shear stresses underneath the surface. The position of the highest shear stresses is also the location of the highest equivalent stresses and therefore the place where the first deformations occur.

This study proposes a simple 2D FEM model to analyse damage effects during ball spinning and show the dependence to the process parameters. This dependence is explained by experiments.

2. Experimental details

Two experiments were carried out to show the influence of process parameters to the damage behaviour of the surface. In the experiments, a rod (D_1 and a length of 120 mm) made of 37MnSi5 was used as workpiece, the tool was made of a ball bearing SKF 7301B.JP with 8 balls (Fig. 2).

The parameters for the experiments are listened in Table 1. The diameter D_2 after the deformation is higher than the minimal diameter of the ball bearing (16.5 mm) due to the elastic relaxation of the workpiece and the widening of the tool during deformation.

The experiment was carried out on a friction welding machine at the Chair of Metal Forming at the Montanuniversitaet Leoben (Fig. 3).

The balls and the cage are turned by the tool support. The workpiece is tangentially fixed and axially moved by the workpiece support. A hydraulic cylinder does the axial movement and during the deformation, the process is oiled to reduce the forming forces and to forestalled surface wear between tool and workpiece.

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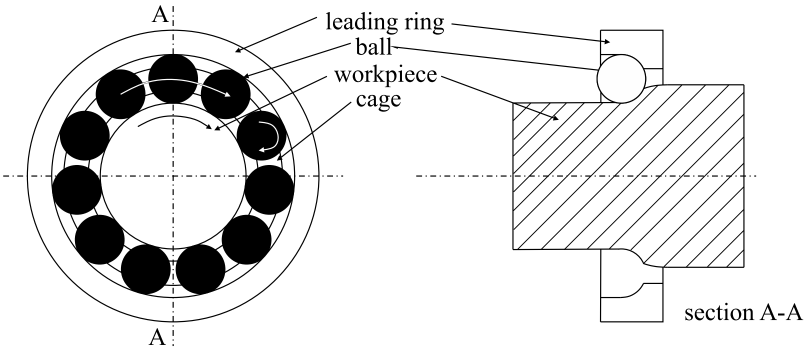

Fig. 1. Set up of a ball spinning reduction process.

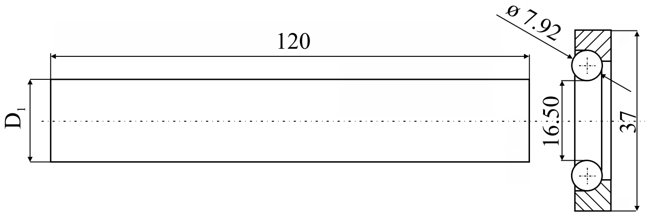

Fig. 2. Workpiece and tool geometry.

Table 1
Parameter of real experiments.

D_1 [mm]	D_2 [mm]	v [mm/rev]	d [mm]	D_1/d [–]	D_1/D_2 [–]
17.0	16.8	1	7.89	2.1546	1.0089
16.9	16.8	1	7.89	2.1420	1.0030

Table 2
Fictitious values of the flow curve.

Plastic strain [–]	Yield stress [MPa]
0	650
0.13	900
5	900

Roughness measurements were conducted with an optical surface measuring system “Alicona Infinite Focus G4” and the measuring length of the roughness was 2.2 cm.

3. FEM simulation

The FEM simulation is set up to predict the damage behaviour of the ball spinning reduction process. Fig. 4 shows the assembly of the FEM simulation in Abaqus 6.12.

Generally, the process is performed as an isotropic elasto plastic simulation. The Youngís Modul of 210 GPa and a Poissonís Ratio of 0.3 are used and the values of the fictitious flow curve are listed in Table 2. It can be assumed, that the gradient of the strain hardening curve and the strain rate has only an influence on the bulges level in front of the deformation zone and therefore only on the damage level, but not on the variation of the damage. A coulomb friction coefficient of 0.5 is used for the tangential behaviour and a “hard contact” respective to the classical Lagrange multiplier method of constraint enforcement is performed for the normal behaviour. Preliminary investigation showed that the friction coefficient provides no significant influence in the FEM simulation. For the implementation of the kinematic behaviour, the rod is modelled as a thick-walled tube. The FEM model is created as a 2D simulation with generalized plane strain elements (Dassault Systemes, 2015). The mesh is separated into a quart with fine elements with a length of 0.12. The residual elements are modelled with element lengths of 0.20 mm. The balls spin around their own centre point and simultaneously the workpiece turns around the centre of the rod.

The damage factor (Eq. (1)) of Ayada et al. (1987) is employed with a “User-Routine” into the simulation to estimate the damage behaviour of the ball spinning process. Ayada includes the medial stress σ_m divided by the equivalent stress σ_V, which take the triaxiality of the stress state into account and is consequently suitable for the ball spinning process.

$$D = \int_0^{\phi} \frac{\sigma_m}{\sigma_V} \cdot d\phi \tag{1}$$

Every partition of the workpiece in this process undergoes a few contact situations with balls as displayed schematically in Fig. 5. The number of contacts and the geometrical conditions are influenced by the process parameters.

The first step is the calculation of the simulated length and time. The parameters h and a are calculated by the initial workpiece diameter D_1 [mm], the final workpiece diameter D_2 [mm] and the ball radius r [mm].

$$h = \frac{D_1 - D_2}{2} \tag{2}$$

$$a = \sqrt{r^2 - (r-h)^2} \tag{3}$$

The incremental distance dz is the feed rate v [mm/rev] divided by the number of balls n [–].

$$dz = \frac{v}{n} \tag{4}$$

The parameter a is doubled to ensure, that the elastic relaxation has enough time in the simulation. This is primarily important for low diameter changes.

$$z = 2 \cdot a \tag{5}$$

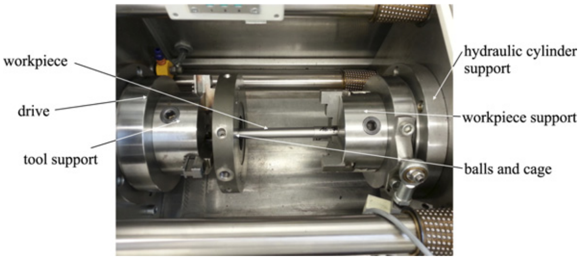

Fig. 3. Experimental setup of the friction welding machine.