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Technical paper

Ultrasonic vibration assistance in shear cutting of electrode materials for lithium-ion batteries

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ABSTRACT

The electrodes of today's lithium-ion cells are produced as a compound made of copper or aluminium foil several micrometres thick. This film functions as a conductor and is coated on both sides with an active material with the capacity to store energy. In battery production, shaping by shear cutting of these planar electrodes is an essential stage in the process chain. However, advanced techniques established in mass production, such as laser cutting and water jet cutting, are not always suitable for the manufacturing process particularly in case of avoiding thermal and chemical impact on the composite material. Conventional shear cutting (fine shear cutting) is also problematic, since the very thin film makes for very tight clearances.

One way to circumvent the problems in shear cutting described above results from superposing the punch with vibrations. In the example described in the paper, frequencies from 20 to 40 kHz at vibration amplitudes greater than 3 μm were used. It was recognised that superposition of vibrations enhances breakage at the cutting edge and, consequently, reduces formation of flash on the electrode contour.

1. Introduction

In the production of lithium-ion batteries, cutting electrodes out of a continuous band is an important process stage in shaping the coated aluminium and copper films [1]. Advanced techniques already established in mass production, such as laser cutting [1], are only applicable to a limited extent for the manufacturing process, if the thermal and chemical impact on the composite material is too high. Considering the stated limitations, conventional methodes for thin films cutting should be taken into account [2,3]. Cutting itself is subordinated to the manufacturing group of cutting off (DIN 8580). Herein, according to DIN 8588, cutting off is subdivided in six procedures, i.e.:

- crushing/breaking,
- slitting,
- tearing,
- cutting with two approaching blades,
- cutting with a single blade or wedge-action cutting, and
- shear cutting.

For classification, the number of blades and their interaction with one another are regarded as distinct features. Evaluating the feasibility of the cutting off procedure the following criteria are to be met:

- accuracy of the technology,
- robustness of the technology,
- punch and die wear,
- tool life,
- feasible level of automation,
- low damage of workpiece (carrier film and coating) during the process,

then shear cutting is qualified as the optimal technology to solve the given problem. In traditional sheet metal processing, shear cutting is among the most frequently applied manufacturing techniques. Shear cutting is understood as a chipless cutting procedure, whereby the material is sheared between two blades with a defined clearance which move alongside one another. The principle of punch and die configuration in shear cutting is illustrated in Fig. 1 (U – clearance, α – clearance angle, a_1 – punch diameter, a – diameter due to puncturing of punching die).

In the shear cutting process, the part contour is generated in one operation by means of a single edge of cut. The slug is the electrode

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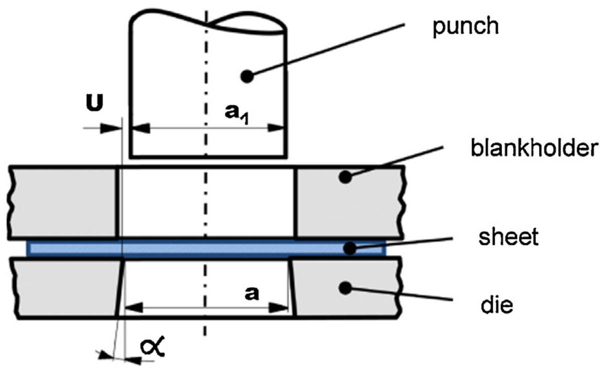

Fig. 1. Shear cutting die.

ready for use. Dimensioning of clearance is very important for the quality of the shear cutting of the slug. As a guideline, a range of 2–5% of sheet thickness, given with the film thickness described here, may be assumed. This would give a die clearance of 5–15 μm for the electrode films to be cut out. For near-net-shape "fine shear cutting" with less formation of tearing flash, this value must be reduced much more, to a clearance of less than 2 μm. Further, the accuracy requirements to be met by the guidance of the shear cutting die or the presses to be used are so great that, in practice, it is close to be impossible to shear cut the electrode films in an economical manner [4]. As an alternative method, in the following sections the present work outlines an approach of ultrasonic assisted shear cutting for battery electrodes and gives results on an experimental evaluation.

2. Approach

2.1. Method

A proposed way to overcome the above mentioned challenges is to superpose vibrations on the punch. Vibrations assist the punch in the procedure by means of having an optimal vibration amplitude at the cutting edge. As can be seen from the evaluation of the authors' studies on ultrasonic support for metal machining and forming procedures [5], vibrations of a frequency range from 20 to 40 kHz at vibration amplitudes >3 μm should provide an applicable solution.

In traditional shear cutting processes, the material is formed by the two blades until their forming capability has been exhausted, and material cohesion is overcome by fracture. The idea behind superposing vibrations is to assist this deformation process through additional incitement of fracturing, realised via superimposing repeated harmonic stress and relief on the material to be cut. The intensity of this support is influenced by the absolute vibration amplitude as well as by the ratio of sinusoidal speed mode to the magnitude of the constant speed component [6] and is schematically illustrated in Fig. 2.

Assuming that shear cutting conditions are analogous to those of chipping processes, it may be assumed that an optimal effect is achieved if the speed mode value of the vibration is equal to or greater than the constant punch speed during shear cutting. Considering Eq. (1), where v is the punch speed, ω is the oscillation frequency and A is the vibration's amplitude,

$$\hat{v} = \omega \cdot \hat{A} \tag{1}$$

at a constant punch speed of $v = 0.4$ m/s, for the aforementioned cut-off frequencies of the applied frequency range, the necessary vibration amplitudes of the ultrasonic vibration at the punch's cutting end are obtained (given in Table 1).

To investigate whether and to what extent shear cutting can be assisted by vibrations, sample parts (round plates of 40 mm diameter) were produced. These round plates were made of electrode materials:

- cathode electrode: aluminium film (thickness t is approx. 20 μm) with a coating based on lithium iron phosphate (t is approx. 40 μm at each side),

Fig. 3. The cathode-, anode material under under investigation.

Table 1
Correlation between frequency and amplitude.

Frequency (kHz)	Vibration amplitude (μm)
20	>3.2
40	>1.6

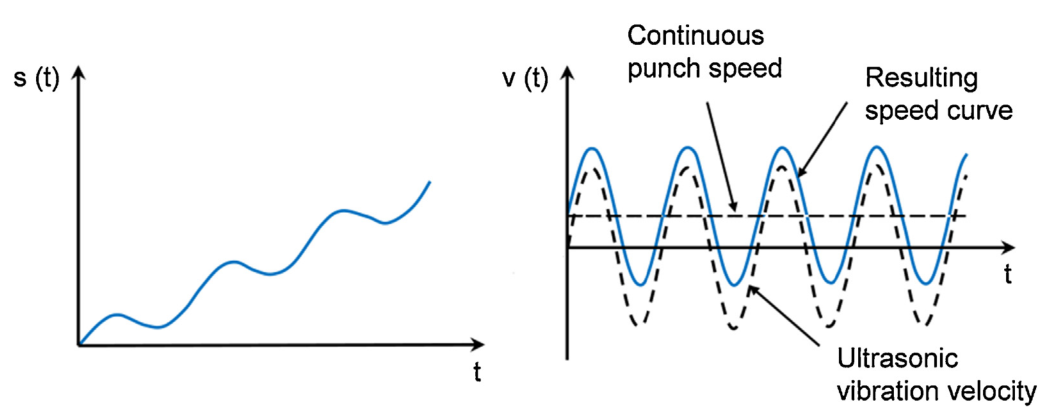

Fig. 2. The resultant punch path (left side) and the punch speed components (right side).