Acoustic process monitoring during transient precision forging of high strength components

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ABSTRACT

The structure-borne sound, displacement and continuous acoustic emission measuring systems provide new possibilities for detecting very short term transient events over a broad frequency range during the precision forging of gear toothed parts such as gearwheels and pinion shafts. It is also possible to analyse these events by employing wavelet analyses over these frequency ranges. With the aid of these methods, the compressive-deformation, flow and frictional processes as well as the filling were evaluated during precision forging by selectively using the displacements and frequencies in order to recognise early damage and to sensitively monitor the forging process. The influence of the temperature, lubrication and impurities on the forming behaviour and on the quality features of the precision forged high strength components were recorded and assessed during the process sequence. A novel sensitive monitoring technology for transient production processes with respect to early damage recognition resulted from analysing the signal profiles using the wavelet transformations of a feature and vector analysis.

1   INTRODUCTION

Precision forging is a production process which uses forming technology for manufacturing near-net shaped, highly loaded components. Subject to special circumstances, tolerance classes up to IT grade 7 can be obtained. In comparison to machining production processes, significant shortening of the process chain and improvement in the energy and material efficiency can be gained. The Collaborative Research Centre 489 "Process chain for manufacturing precision forged high performance components", which was initiated for this purpose, intended laying the fundamental developments and qualifying new technological and logistical methods for manufacturing such forged parts. The demands on the dimensional and geometric accuracy during precision forging places high demands on the design and control of the forming process.

Drawing on the research work in sub-project B6 "Non-destructive component testing", measuring and analytical equipment based on structure-borne sound and acoustic emission (AE) technology was developed for assessing transient precision forging events in gear toothed forged parts such as gearwheels and pinion shafts.

In order to gain information about the forming method's process sequence, the loading, the tool's wear behaviour and the component's quality, the top and bottom tool are instrumented using displacement, structure-borne noise and acoustic emission transducers. The aim is to assess the influence of factors, such as temperature, lubrication and impurities, on the forming behaviour and quality features of precision forged high strength components during the process sequence. During the course of events in transient forging, the displacement instruments provide a clear correlation of the process information to the forge displacement. By using wavelet-analyses, the continuous acoustic emission equipment provides new possibilities of recording and analysing, within the relevant process-window and time-frequency range, short-term transient events during precision forging. This is a measuring tool for both early damage recognition in highly loaded components as well as for sensitively and selectively, using displacements and frequencies, monitoring and evaluating the flow, frictional and compression processes as well as the damage events during precision forging.

2   MEASURING ACOUSTIC EMISSIONS FOR EARLY DAMAGE ANALYSIS

To monitor the running and operating behaviour of industrial machines and plants, structure-borne sound measurements are particularly suitable as a non-destructive testing method [1-6]. Apart from early recognition of defects or, as the case may be, damage, production processes are more reliably designed in order to increase the productivity and the availability of machines, to optimise the process and to improve the product's quality. By means of structure-borne sound and acoustic emission measurements, damage and unfavourable plant operating conditions can be verified without intervening in the running process. Fields of application consist of monitoring

for leaks in liquid containments, crack initiation and cracking in components during their production or under high operating loads as well as identifying component corrosion damage [7-10].

Acoustic emission transducers operating within their resonant ranges are extremely sensitive within the ultrasonic range of approx. 20 kHz to 2 MHz and can detect acoustic emissions from cracks, impacts, corrosion processes or dislocation movement.

Statistical parameters (AE data) enable relevant signals to be separated from spurious signals without knowledge of the signal's characteristics and to describe the plant's current status. The most important features are the arrival time, maximum amplitude, rise time, signal duration, overshoot of a hit, energy and effective value [7, 11, 12].

For a nuanced treatment of the relevant transient process sequences, the acoustic emission signal is continuously recorded within the entire process-window. The acoustic-emission sensor's recorded transient time-signals form the basis of the wavelet analysis.

The so-called wavelet analyses are employed in the case of transient processes taking place over short time durations where not only frequency-dependent signal intensities are prominent in the time interval under consideration but also their time-dependent behaviours, or where the resolution of the FFT-analysis is not sufficient, owing to the shortness of the occurring event [13]. Whereas with spectral analyses, one performs the computation using a fixed time frame, with wavelet analyses, the signal's so-called wavelet-level is specified for various lengths of time frames as a function of the excitations contained in the signal. The potential for carrying out a local analysis of the frequency components in such a limited time interval is the real advantage of this analytical method [11, 14, 15].

3 PRECISION FORGING OF GEAR-WHEELS

Gearwheels are precision forged in an energy controlled, direct-drive screw press SPR 500 made by the company Lasco, *Fig. 1*. The use of structure-borne sound and acoustic emission measurements during forging is scheduled in order to retrieve information about the process sequence as well as the loading and the wear behaviour with regard to the tooling and process optimisation.
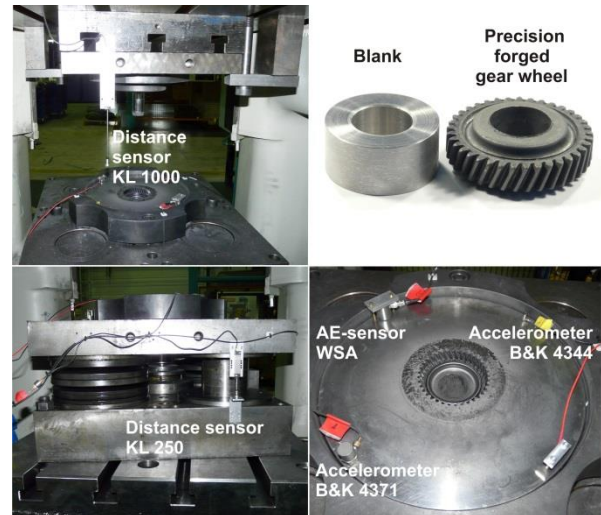

Fig. 1 Test set-up [16-18]

A precondition for detecting specific process information and its classification is that the acoustic emission signal is synchronously recorded with the press' displacement signal. Definite events in the forming process, such as the insertion of the pin into the blank and thrust bearing, closing of the tool and deflection of the tooling can be clearly attributed to the individual excitations in the acoustic-emission signal with the aid of the displacement signal, *Fig. 2*.
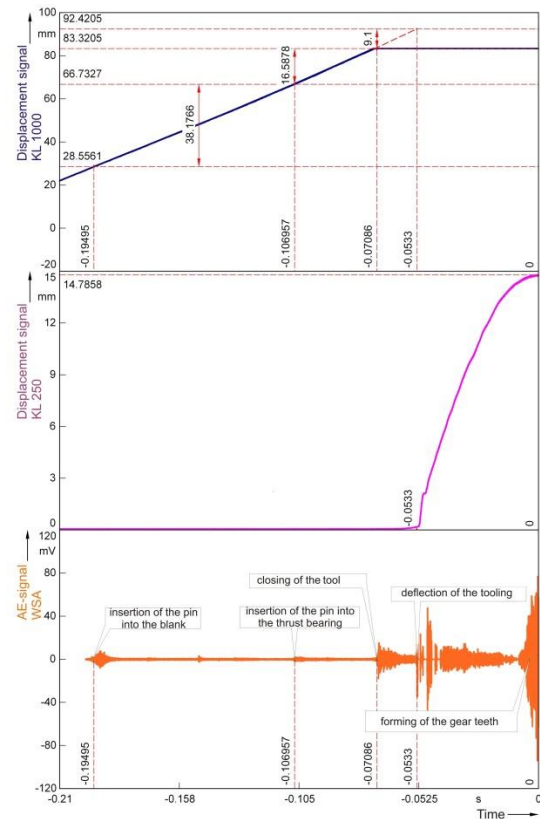

Fig. 2 Displacement dependent acoustic emissions during the precision forging of gearwheels [16-18]

Apart from the excitations initiated by the machine and the tooling, contributions from the friction are depicted by means of the relative movement and the blank's flow into the cavity.

4 RESULTS

In order to investigate the influence of friction on the forming process and the component's quality, gear wheels were forged using different amounts of lubricant, *Fig. 3*.
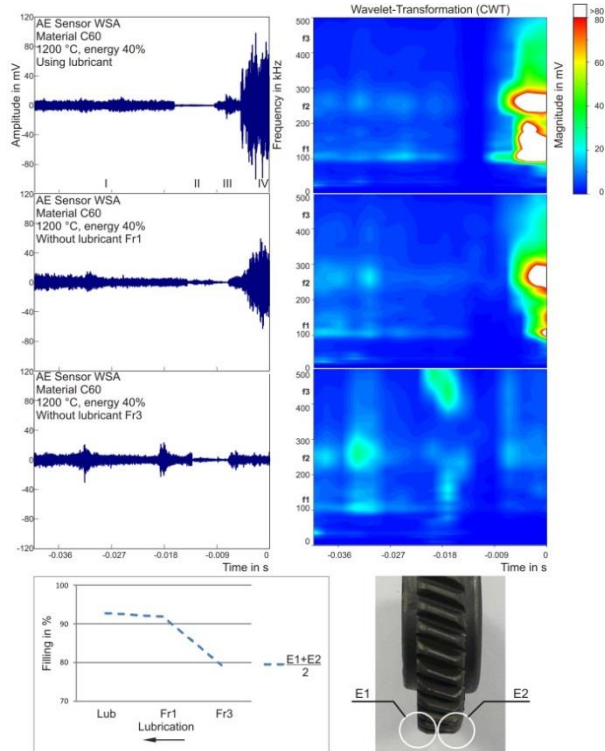

Fig. 3 Influence of friction [16-18]

In *Fig. 3*, the acoustic emissions during the precision forging of a gearwheel are depicted in the time and frequency ranges for the process sequence using lubricant, in the 1st and the 3rd process cycle without lubricant. The signal curves are divided into four time segments; the wheel forming I, the force application II, forming of the hub III and the forming of the gear teeth IV. With the aid of the wavelet transformation, transient signals can be simultaneously considered in the time and frequency ranges. According to the diagrams, the loss of net energy is larger without lubrication in the first and second time segments. This leads to a poorer shaping of the gear teeth in the time segment IV and to a rounding off of the teeth's edges. For the acoustic emission's measuring sequence used here, the characteristic information dominates the frequency range from 105 kHz, 260 kHz and 450 kHz. The characteristic information dominates the frequency

range from 30 kHz, 72 kHz and 116 kHz for the structure-borne sound's measuring sequence.

To investigate the influence of the forging temperature on the component's forming behaviour, the forging temperature was elevated from 1 100 °C in 50 °C steps, *Fig. 4*.
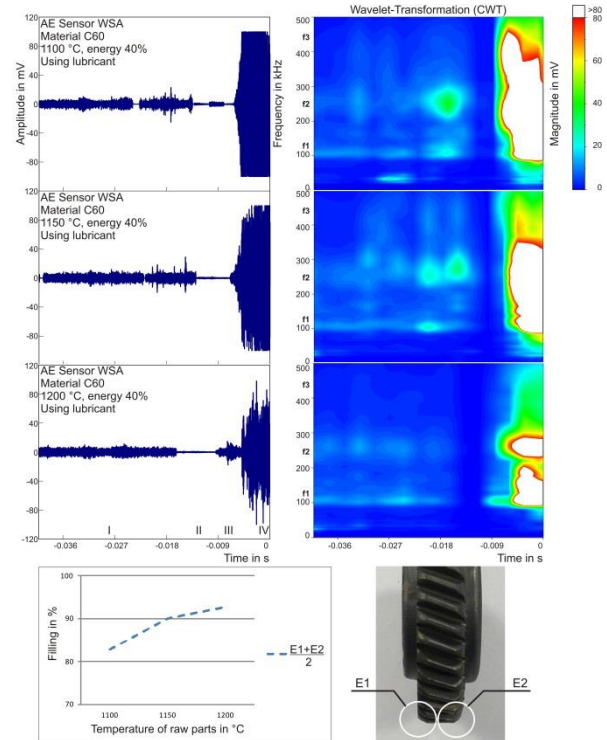

Fig. 4 Influence of temperature [17, 18]

Elevating the forging temperature leads to decreasing of flow stress, to significant changes in the process' and in the acoustic emission's signal curve, which is manifested in an improved component and tooth shape.

Carburising granule residues from the furnace, which are carried by the blank into the cavity, lead to forging flaws and cause the component to be locally malformed, *Fig. 5*. During forming, carburising granule residues lead to strongly elevated acoustic emissions in another frequency range, which clearly deviate from the signal curve for a normal process sequence.

In order to exploit the features of acoustic signals to classify components, the signal's curves are analysed from the wavelet transformations at characteristic frequencies. The effective and peak values which are computed in each time segment and at each frequency are normalised with respect to the values for a reference, good part. The coefficient vectors determined from these coefficients are depicted in *Fig. 6* for the wheel forming, the force application and the forming of the gear teeth.
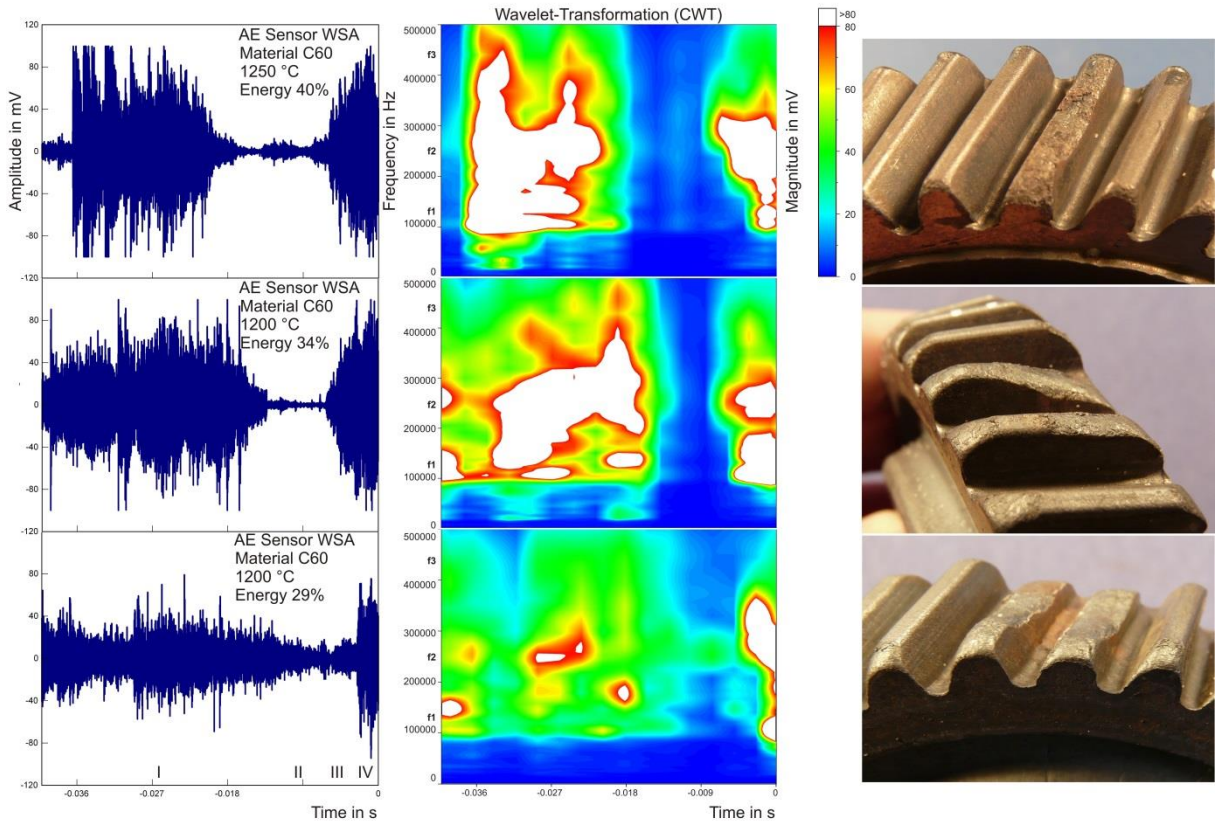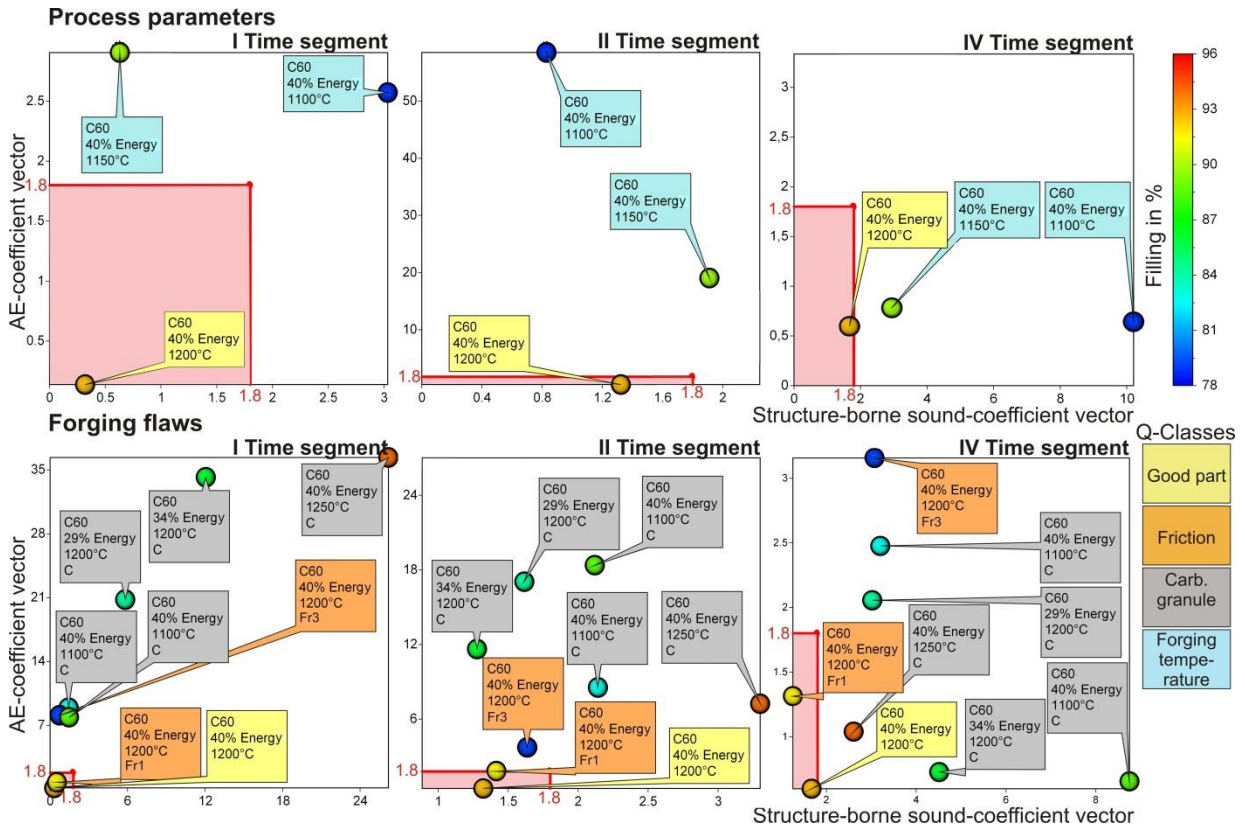
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Fig. 5 Influence of impurities [16-18]

Fig. 6 Classification of features from acoustic
signals [17, 18]

In order to detect irregularities in the process sequence, the deviation of the vector reference value should be less than or equal to 1.8. In the first time segment, the non-lubricated in the 3rd process cycle forged gearwheels to which carburising granule residues adhere can be clearly differentiated from the forged good parts. In the second segment, both the forged parts which have adhering carburising granule residues as well as those parts forged without lubrication in the 3rd process cycle and at lower blank temperatures also clearly deviate from the region of good parts. Less significant, and therefore less informative, is time segment III. In contrast, all the good parts in time segment IV can be explicitly classified from the defective gearwheels possessing forging and geometric flaws.

5 SUMMARY

Based on these research results, the structure-borne sound and acoustic emission measuring technology and the wavelet analysis provide new approaches to detect as measured data, to analyse and to assess very short term transient events during precision forging. For this reason, new possibilities result for both sensitively monitoring transient manufacturing processes as well as detecting damage early and evaluating component quality.

6 ACKNOWLEDGEMENTS

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