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Original Research Article

Potentials of in situ monitoring of aluminum alloy forging by acoustic emission

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ABSTRACT

Deviations during forging processes lead to workpiece failure when the forming limits of the material are exceeded. In production processes an early detection of manufacturing faults is preferred. The acoustic emission (AE) technique is examined with respect to its ability to detect deviations in lubrication conditions and in the structural integrity of different aluminum part geometries and alloys during forming. In a first step, an upsetting of varying specimen shapes was performed in order to study correlations of occurring defects as well as changing friction conditions with acoustic emission response. Afterwards, a cross joint was forged and AE was analyzed. The results suggest that crack detection during forging is feasible but limited by material ductility. In addition, it is shown that the characteristics of the acoustic emission during forming strongly depend on the respective alloy. With respect to faultless warm forging it is found that different stages are reflected in the AE signal, facilitating the detection of process deviations.

1. Introduction

1.1. *Forging of Al-alloys*

Forged components are characterized by high mechanical strength under static as well as dynamic loads. These properties can be attributed mainly to a process-related reduced grain size, the well-distributed microstructure and their structural integrity compared to cast parts. With respect to energy and environment considerations lightweight material alloys are continuously gaining importance. Most processed metallic construction materials for lightweight applications are based on aluminum and there is an increasing trend of substituting bulk formed steel products with non-ferrous metal parts [1]. Aluminum alloys are characterized by a low density accompanied by a high mechanical strength compared to Fe-based alloys. Cold [2], warm [3] and hot forging [4] are possible with their respective advantages and disadvantages. In order to reduce long production times due to heat treatment and enhance shape accuracy, lower practicable forging temperatures are preferred in some cases. Here, the formability is reduced and the workpiece can react sensitively to changing process conditions resulting in a higher cracking risk. Generally, an early detection of failures is aimed at in production. In fast and automated forging processes cracks cannot always be recognized immediately.

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Another important aspect with regard to forging quality is friction. Adequate lubrication conditions between die and part play a crucial role with respect to the tool life and quality of finished parts. Insufficient lubrication can lead to excessive tool wear and improper strain distribution which in turn can result in defective parts or insufficient die filling.

Most commonly, the regularity of the forging process is inferred on-line from the force and displacement measurement of the ram. Nevertheless, process deviations are not always reflected by these signals.

A known non-destructive technique which has the potential to overcome the shortcomings of conventional measuring methods is the acoustic emission technique. Its capability to detect cracking in metallic materials and changes in the friction conditions between metals has been proven before [5,6].

1.2. *General aspects of acoustic emission technique*

The acoustic emission (AE) technique is a non-destructive evaluation technique enabling the user to draw conclusions in situ about the structural integrity of an object. Commonly, AE is defined as elastic waves which develop during the spontaneous release of energy in a solid body. According to this definition, it is an integral and passive inspection method with which an event can be detected during its occurrence, and only then. In view of their frequency range (50 kHz to several MHz), AE signals are considered as ultrasonic waves. In a typical measurement system these waves are received from solid body surfaces and are converted into a voltage signal by highly sensitive piezoelectric sensors. This signal passes a preamplifier, a frequency filter and an analog digital converter in order to finally be recorded by a storage medium. Much effort has already been put into understanding the mechanisms of acoustic emissions of static structures, but also into those of light metal alloys under plastic deformation [7,8]. Deformation, or more precise, dislocation glide is a strong source of acoustic emission. A further origin of AE is crack growth. Intensity and characteristics of the emitted waves depend on numerous material and testing variables including strain rate, forming temperature, grain size, solute content and stress state. The detection of crack growth is related to the ductility of a material. While one alloy can emit AE with high energy during cracking, other materials remain quiet which has been termed the ductile-crack problem [9]. The AE amplitude is connected to the velocity at which a crack propagates. That implies that sudden, fast propagating cracks will produce higher amplitudes than a slowly advancing crack tip over the same distance [10]. Moreover, the type of crack plays an important role: the tensile type is generally connected with a faster arrival time of peak amplitudes than the shear type [11].

The ability of monitoring friction conditions by means of AE was shown for different material combinations in tribometer test rigs [12,13]. Commonly, these studies are performed under stationary test conditions and in absence of macroscopic plastic deformation.

The property of an AE measuring system to detect structural changes at their moment of occurrence makes it a promising potential tool for the detection of process deviations during metal forming operations [14,15].

1.3. *Acoustic emission in aluminum forging*

Most research concerning AE during forming is done under idealized and highly controlled test conditions for comprehensible reasons. By using standardized and simply shaped specimens, conclusions can be drawn easily and reliably. Since the user is often confronted with unstable and more complex operation conditions, the research outcomes cannot always be transferred to industrial cases. Great part of this research work is focused on the characterization of AE in dependence of deformation parameters and the material state of Al-alloys. The detection of process deviations in industrial forging processes is often not the point of concern. The principal applicability for the determination of defects within light alloy forging parts during forming processes has been proven before, also under idealized conditions but closer to conventional forging in respect of forming speed and temperature [16]. It was also used to determine the limit criterion due to crack initiation in upsetting under superimposed pressure [17]. Despite all efforts undertaken so far, the AE technique is still not sophisticated enough for industrial forging applications. The challenge in establishing a reliable use of the AE technique in forging processes lies in their highly dynamic and transient character in contrast to static structures with a constant basic level of AE. Moreover, the harsh conditions in a forging environment and the multiple AE of tool and machine can complicate the analysis considerably. Another question is the general ability to detect the cracking of a certain alloy. The amount of AE energy emitted depends on material and deformation and is not known ex ante.

In another study it was found that a correlation between AE and lubrication condition in hot forging of aluminum exists [18]. It remains unanswered if such a correlation holds true for other forging processes. On the one hand high energy emission due to deformation could overlay friction signals, on the other hand surface condition and speed of the relative movement play a role.

The aim of this study is to investigate AE with regard to process deviations, namely cracking and lubrication, in the forging of different aluminum alloys from a practical point of view. For this purpose, upsetting and forging experiments were carried out and the recorded signals were correlated to the process deviations.

2. Material and methods

2.1. *Experimental setup*

For the experimental work, cylindrical specimens of the Al-alloys AW 5083, some strain-hardened (H112), AW 6082, AW 7075, solution heat-treated and artificially aged (T6/T6511) were used. The alloy 5083 was essentially recrystallized with peripheral coarse grains. The other two alloys showed a fibrous grain structure in extrusion direction, cf. Fig. 1.

The temperature of the specimens at the start of deformation ranged between room temperature and 450 °C. A hydraulic press with a maximum force of 12500 kN was used. The ram velocity was set to 1 mm/s and 28 mm/s. Additionally, a screw press with a gross energy of 15 kJ, a nominal force of 2500 kN and