ULTRASONIC ASSISTED MICROFORMING

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Abstract

Within this work an experimental set-up was designed and constructed. It allows axial vibrations application to replaceable punches with a frequency of 20 kHz. Specially designed sonotrode allows amplification of the vibration amplitude of the piezoelectric vibrator. An unique power system allows smooth reduction of maximal amplitude within two ranges of peak to peak amplitude: 1-8 um and 30-50 um. The ultrasonic system is mounted on precision testing machine. Processes of micro-upsetting of cylindrical aluminum 1x1 mm samples were carried out in a special miro-die set. The methodology has been developed to prevent the swelling specimens from the forming area and the method of indirect amplitude control on the punching face. A 40% reduction in process power was observed with a doubling of vibration amplitude. A mechanism has been observed for the creation of multiple parallel fracture surfaces that have merged during the process so that the samples did not lose cohesion. This phenomenon was not reflected in the course of process forces. It was only possible during the structural analysis.

Keywords: Microforming, Ultrasonic-assisted, micro-upsetting

1. INTRODUCTION

Since the beginning of the twenty-first century one can observe rapid and growing development in the field of micro-electro-mechanical devices. This means the growing demand for micro-parts, which occupy a large group of manufactured metal parts forming technology. This technology, in respect of products miniature, has become so common that it was established a separate branch, ruled by slightly different laws - microforming [1]. This differences are due to so called size effects observed on a different aspects of forming processes as a grain size [2], friction phenomena [3], [4] or tool design [5]. In the area of microforming a dedicated methods [6] as well as trial of unconventional methods and materials [7] usage be observed for supporting the industrial processes design [8], [9], which are largely associated with small dimensions [10], and therefore with small - compared to standard metal forming processes - costs of supporting systems. One of the research directions in microforming is related with the application of vibrations [11] and also ultrasonic vibration tools support [12]. Attempts to use vibrations support for microforming processes have a long history, started by Garskii and Efromowa [13] and Blaha and Langenecker [14] in the 50s of the twentieth century. In the following years, a lot of research in this area were done. They led to the formation of opinion about the beneficial effects of vibrations on the process of forming due to the presence of two effects, so called surface and volume effects. The former usually leads to reduction of friction forces, the latter influence the widely understood course of plastic deformation in microstructure. Despite these widely accepted opinions, there were no spectacular industrial applications assistance of ultrasound so far. The causes might be sought in the restrictions of energy consumption resulting from the necessity of spending large vibration energy in relation to the average volume of products plastically formed. The situation changed noticeably with the development of micro-forming, due to the low average weight of the micro-parts - usually less than 1g.

2. EXPERIMENTAL SET-UP

2.1. System design

The testing stand, **Figure 1**, consists of a precision Hounsfield H10KS strength machine (a1) with a beam position accuracy of 1 μm. On the table machine is mounted (a2) with the micro-device on it (a4) and the ultrasonic head (a3) connected with sonic blaster (b1).The ultrasonic energy is applied on the punch, **Figure 2.** The electric signal (from Sonic Blaster is applied to piezo-electrical ceramics (included in the Sandwich Transducer - *1*) that will convert this signal into mechanical oscillations. The converter converts electricity into high frequency (20 kHz) mechanical vibration. The active elements are usually piezoelectric ceramics. The booster - *2* serves as an amplitude transformer. Amplitude magnification or reduction is achieved by certain design features or the geometrical shape of the booster. The Sonotrode - *3*, is the active part of the ultrasonic unit. It, when is in contact with the specimen perform the desired process task. The amplitude distribution along the ultrasonic head shows **Figure 2a.** Ultrasonic system works in resonance frequency and has possibility to follow small changes in a resonance frequency during the process flow. It is possible to control a power of the Sonic blaster on a two ways: 1. Changing a percentage of driving power on a range of 20-100 %, 2. apply voltage from the outside transformer directly to the power unit of Sonic blaster - in the range of 20 - 90 V.

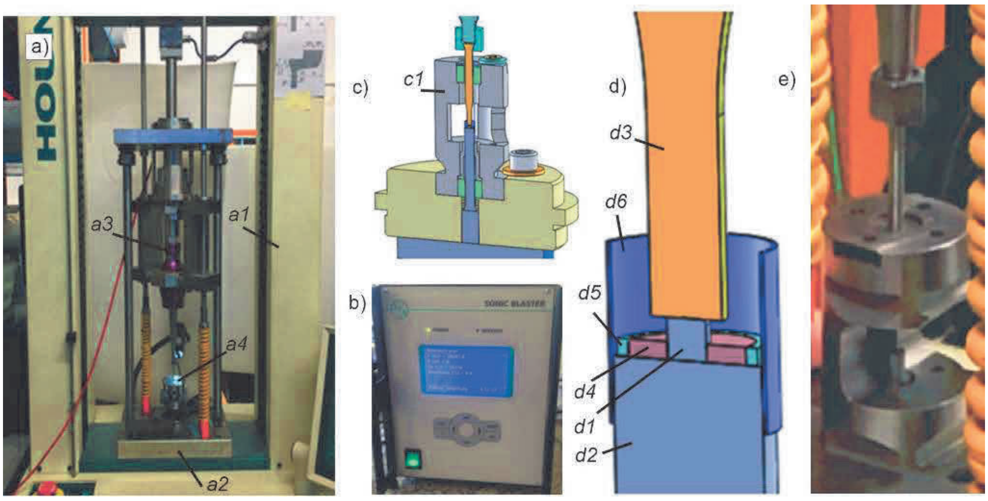

Figure 1 Experimental set-up: a) overview, b) sonic blaster, c) micro-set with counter punch, d) close-up of plastic deformation zone - further described, e) overview of micro-set

2.2. System testing

The High-Speed/High-Accuracy Laser Displacement Transducer is used for calculating Peak to Peak amplitude. This device is used by setting averaging measurements set to 10000 and the sampling cycle to 392 kHz (2.55us) for calculating amplitude behaviour on the punch nose. Result of testing amplitude are shown in the **Figure 2**.

2.3. Amplitude control method on the stamp face during micro-forming

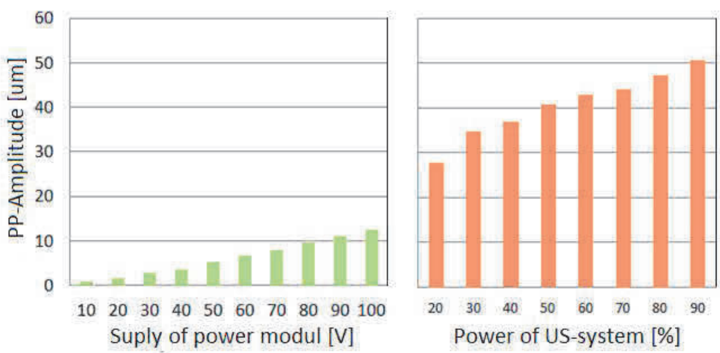

Figure 2 Tested performance of ultrasonic system: peak to peak (PP) amplitude on the punch nose - free oscillation

Since it is not possible to directly measure the amplitude on the stamp face during the microforming process, an indirect method is proposed. The method is to measure the amplitude on the buster surface area available and multiply it by the empirically determined gain factor. Appropriate research was conducted to measure the amplitude of the punch face and the bust area without load within the range of power used.

Then the gain factor as a function of the power is determined. The results are shown in **Figure 3**. It was necessary to check whether there is no amplitude attenuation during the plastic micro-shaping process. For this purpose, a process of upsetting was performed during which the vibration amplitude was recorded on the buster surface. Damping was reported for only 20% of power. The rest of the range of attenuation was not recorded.

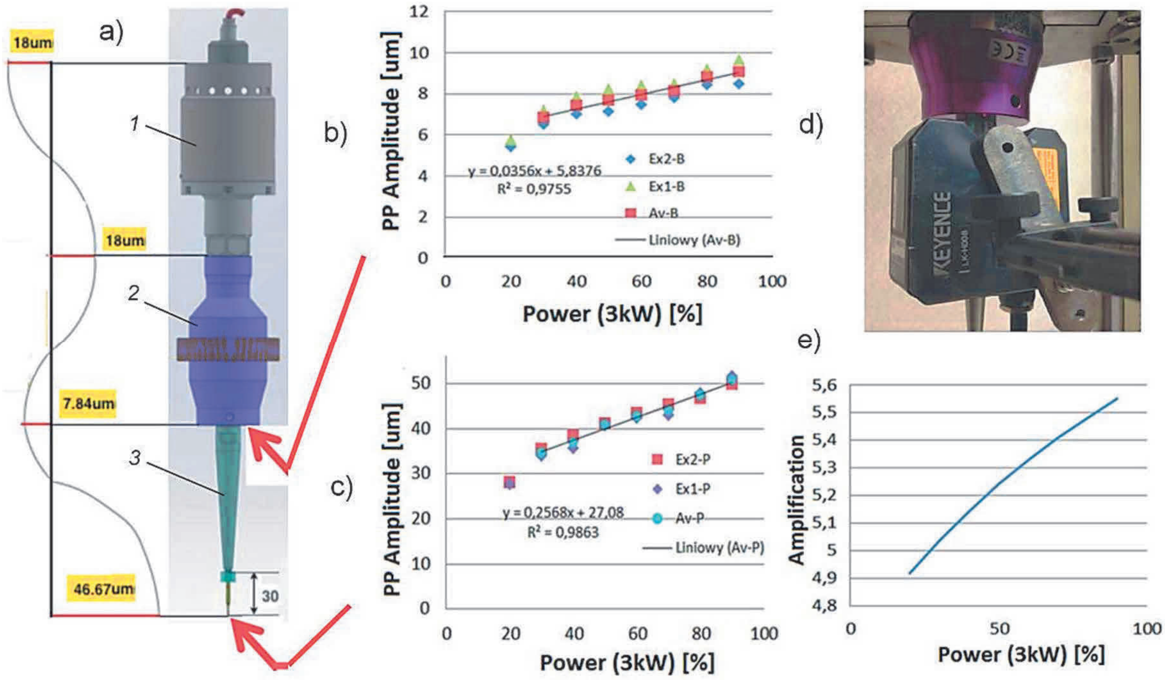

Figure 3 Testing of ultrasonic system: a) example of amplitude distribution along the axis of US-head, b) amplitude on a buster surface, c) amplitude on a punch nose, d) overview of a High-Speed/High-Accuracy Laser Displacement Transducer, e) Amplification factor as a function of applied power

3. EXPERIMENTAL RESULTS

3.1. Specimen preparation

Test samples were prepared by micro-punching of aluminum sheet 1050 in hardened z4 condition. As a result of this process, samples were created with the dimensions: d = 0.97 ± 0.01 h = 0.97 ± 0.01 with a characteristic punching process. It is shown in **Figure 4** together with the sample SEM sample.

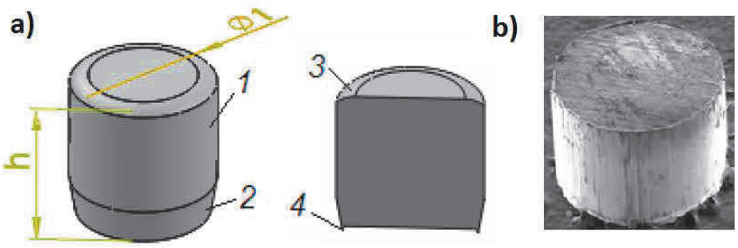

Figure 4 Test sample: a) sample pattern after micro-punching,
1 - glossy surface, 2 - crack surface, 3 - radius, 4-burr, b) SEM of example specimen

3.2. Research procedure

Conducting a free upsetting process with vibration-assisted handling encounters severe difficulties in advancing the sample from the area between the punch and the counterpunch. To overcome this phenomenon, the solution shown in **Figure 1d** is used. Sample - d1, placed between the counter-punch - d2 and the punch - d3, inside the inner ring of soft plastic - d4, which is surrounded by a harder intermediate ring - d5. Ring movement d5 limits the outer ring d6 fixed on the counter-punch.

3.3. Results

There are results obtained in the micro-upsetting processes under the conditions shown in **Table 1**.

Table 1 Experiment result of ultrasonic upsetting

Specimen Al state z4	Deformation velocity	Initial height	Final height	PP-Amplitude	Max Force
	mm/min	mm	mm	um	N
(a)	0.5	0.996	0.558	5.4	133.3
(b)	0.5	0.985	0.578	8.4	80.0
(c)	0.5	0.985	0.655	11.1	82.3

Figure 5 shows the flow patterns as a function of machine beam displacement, and in **Figure 6** the corresponding SEM samples.

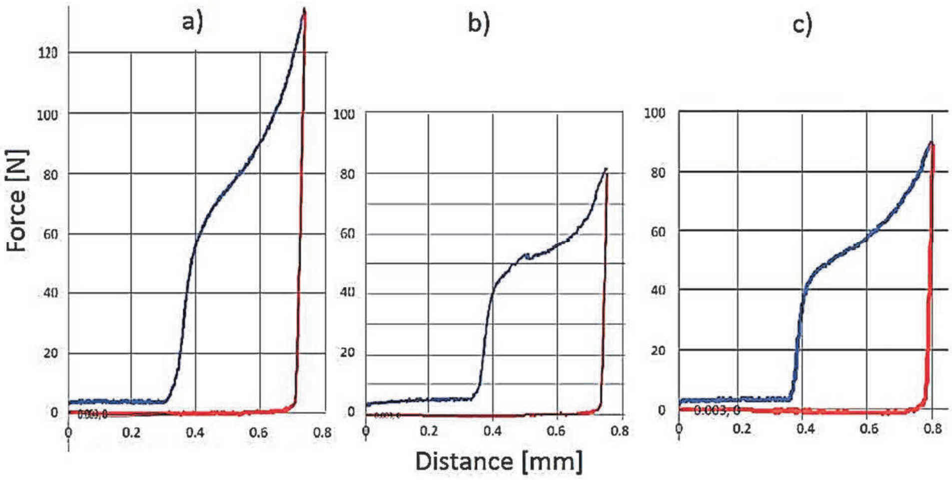

Figure 5 Ultrasonic assisted upsetting of specimen: (a), (b) and (c) - see **Table 1**

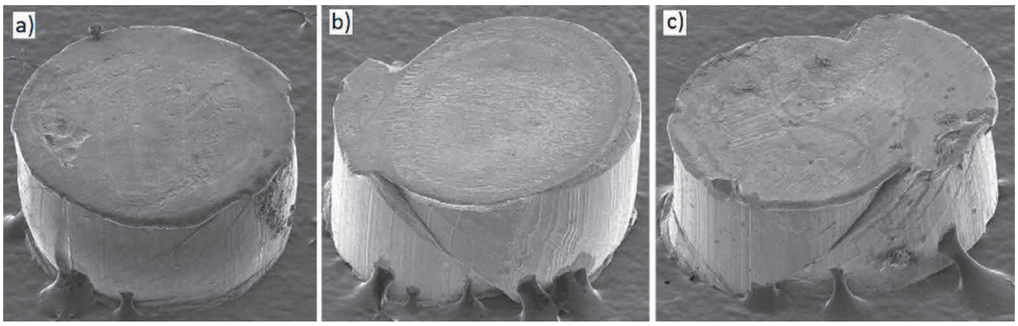

Figure 6 SEM of specimens (a), (b) and (c) after ultrasonic assisted upsetting - see **Table 1**

4. RESULTS ANALYSIS

Using a PP amplitude of 5.4 - 11.1 µm range, causes the samples to burst in volume along the surface of the maximum tangential stresses. This process is different. In general, it can be said that there is a "i" cracking surfaces, where "i" can take values from 1 to a significant number. The effects of this process can be clearly seen in the figure.

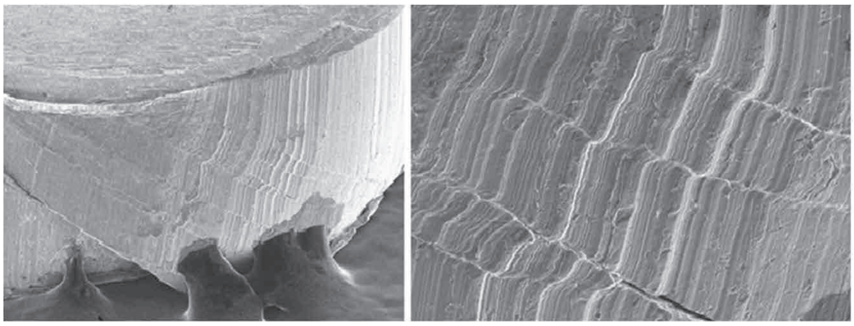

Figure 7 SEM close ups of specimen (b) after ultrasonic assisted upsetting - PP amplitude 8.4 um

Additionally, these surfaces can have a different participation in the whole phenomenon. During the process, vibrations are likely to contribute to local "healing" of cracks and subsequent cracking. The sample then assumes successive shapes without losing stability. At the same time, the cracks are formed and are "healed". The mechanism of "healing" of internal microcracks may coexist with a larger-scale mechanism, which is surface "welding" of the separated parts of the product, **Figure 6 b,c.** This process is so strong, that no "main" fracture of the object in the waveform graph can be observed in the force flow graph, **Figure 5 b**. The formation of a "major" break in the vicinity of formation of equivalent fractures, is a very unstable process and may occur for the "same shaping conditions". It should be noted that the reproducibility of the conditions is a matter of discussion in case of resonant systems.

5. CONCLUSION

Experimental stack-up

- A test stack-up was completed to perform micro-forming processe involving ultrasonic vibration of the punch.
- An ultrasonic system of micro-forming processes was designed and tested by generating a standing 20 kHz ultrasound waveform in a punch. The system is capable of smoothly varying the amplitude of the vibration on the stamp face in two ranges: 1-6 µm and 16-25 µm.
- It has been found that the amplitude of the punch face vibration that is not directly measurable during the process can be measured indirectly by measuring the amplitude of the vibration at the sensor surface accessible by the amplifier: no vibration amplitude was observed during the process.
- The frequent occurrence of the swelling of the upsetted sample from the area between the tools can be eliminated by using plastic positioning rings.

Process of upsetting with amplitude in the range PP 5.4 - 11.1 um

- Force of the aluminum sample upsetting process decreases as the amplitude of the vibration increases. Increasing the PP amplitude from about 5 to about 10 um resulted in a decrease of approximately 40% of the process force. However, after the structural investigation turned out to be the following.
- Supporting the upsetting of aluminum samples with a 20 kHz ultrasonic vibration in the amplitude range of 5.4 - 11.1 µm results in the simultaneous formation of multiple fracture surfaces parallel to the typical fracture surface along the maximum tangential stress. These surfaces are sealed during the process

and the samples do not lose cohesion. This process is not visible in the upsetting graph. Although the effects of this phenomenon are visible only during structural analysis, this phenomenon should be regarded as destructive.

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