VIBRATION ASISTED PROGRESIVE-DIE MICRO-BLANKING

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Abstract

The progressive development of microprocessors and piezoelectric actuators causes the development of micro-machines and the need for micro parts. For these reasons, accelerated development of microforming technology should be anticipated. This technology is able to ensure high smoothness of the surface created by plastic separation of the material and sharpness of the edges - very difficult to achieve by other methods. Attention should be paid to micro-punching processes that can be used not only to make a hole, but above all to produce an exact shape / blank. This approach defines a further possible difference between micro-blanking and conventional blanking. The difficulty in addition to the so-called the effect of scale is also the need for very little clearance and strict geometric conditions. In micro-blanking processes suggested for the billet production one should take into account relatively large ratios of height to diameter of the punched holes. Currently, micro-blanking processes are carried out in the mass production of electronic components. Within this work micro-blanking tests were carried out on an industrial stand with a progressive die, holes made of aluminum sheet and stainless steel sheet. Punches with piezoelectric vibrators were used. For aluminum sheet, the galling phenomenon was stopped as a result of the self-cleaning process of punches. In the case of stainless sheet metal, a slowing of the build-up process was observed. Structure was determined using TEM tests and a build-up mechanism was suggested, consisting in returning successive shearing of micro-asperities, which leads to the creation of an ultra-fine grained structure.

Keywords: Microforming, blanking, vibrating punch, galling, progressive die

1. INTRODUCTION

The progressive development of miniature systems is the driving force and challenge for miniaturization in all areas of life such as telecommunication, transport and electronics [1,2]. These sectors experience the increasing demand for miniature products. Micro-electro-mechanical systems, micro-sensors, micro-machines and micro-robots are no longer futuristic, but reality. These advanced systems require parts and, to a large extent, metal parts. Parts that must meet high requirements for dimensional accuracy and surface quality. These requirements can be met by parts made using metal forming technology [3]. In this technology considerable diminishing sizes of products gets completely new dimension and enters in yet weakly recognized areas of knowledge. The so-called "scale effects" [4] – the consequences of similarity theory and additionally in the area of metal forming – grains and “surface layer” as 3d “object” cause creation of Microforming Technology – MT [5,6]. It has been isolated from the metal forming area and is now a separate field. In MT special emphasis is placed on precise control of the structure of the material [7] and the structure of the surface layer, which have a large impact on process and product [8]. Surface layer and contact phenomena affecting friction, lubrication and galling [9-11], increase the role of methods for preparing surfaces and lubricants [12-13]. They also refer to the internal structure [14], which affects surface quality and cracking mechanisms [15]. The scale effect even applies to machine construction, instrumentation and tools [16-18] and to the design of the technological process plan [19]. Materials and friction tests using micro-samples are also created because their results differ from those obtained in macro tests. Reducing the size of manufactured parts on the one hand is a major challenge for traditional technologies, but on the other hand, mainly by removing the energy barrier opens the possibility of using other unconventional techniques. Electrical assistance, magnetic waves [20], laser processing [21] and mechanical vibrations at different frequencies [22,23] are such examples of alternative techniques.

The first applications of vibrations during deformation of metals was reported by Blaha and Langekert [24] who used ultrasonic vibrations in tensile tests of a Zink monocrystal. That time industrial applications mainly regarded wires and tubes drawing [25]. The prevailing opinion is that the influence of vibrations on metal forming processes refer to two phenomena. First, the so-called *volume effect* links yield stress decrease with the influence of vibrations on the dislocation movement and structural changes [26]. Second, *surface effect* [27-28] explains drop of the effective coefficient of friction by a periodic reduction in the contact area and/or periodic changes of direction of the friction force vector and lubricant pumping. The method of applying tool vibration depends on the frequency range: high frequencies consist of causing a standing wave (in resonance) in the volume of the tool, and lower frequencies utilize *Direct excitation*, which consist in the periodic motion of the entire tool.

Very high pressure, surface expansion and elevated temperature occur in the tool-workpiece contact area during metal forming processes. These are ideal circumstances for braking the lubricant film off, that causes a direct contact between metallic surfaces. It usually leads to undesirable phenomena called galling. Galling is recognized as catastrophic buildups creation, that mostly results with very big damages of not only product surface, but also the surface of the tool. Unfortunately, decreasing the size of formed component to the micro scale additionally increases the risk of galling because of lubrication conditions degeneration [29]. This problem becomes particularly important with reference to mass production with multi punches progressive tooling. It happens that galling on the side surface of micro-punches leads to very intensive pickups formation and finally drives to tearing off the end of micro-punch. In the case of multi-punches tooling the consequences are very serious thus reducing such events becomes a prior consideration.

Since the positive influence of tool vibrations on surface phenomena has been widely reported, the assistance of punch vibration has been chosen to improve the micro-blanking process with progressive die.

2. EXPERIMENTAL SETUP

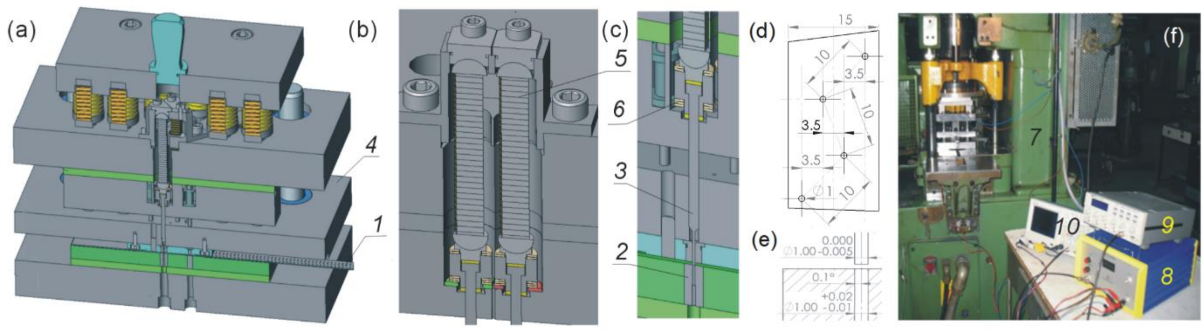

Figure 1 Experimental stand: (a) progressive die design, (b) piezo-vibrators, (c) detail of punch assembly, (d) strip dimensions, (e) tools dimensions, (e) the stand overview: 1- strip, 2- die, 3- punch, 4- blank holder, 5- piezo-stack, 6-prestressing springs, 7-Bruderer BRDR 30 Press, 8-power supplier, 9- function generator, 10- oscilloscope

The test stand consists of a specially designed progressive die, a high-speed press with a strip feeder and a vibration control system. The die shown in **Figure 1a** provides the process of simultaneous micro-cutting of 4 holes with a diameter of 1 mm with punches made of High Speed Steel (HSS) SW7M, **Table 1,** and dies made of the same steel. The main dimensions of the tools and tapes are given in **Figure 1d**. Two vibrating punches

VP - are equipped with piezo-electric vibrators, built in housings enabling their pre-compression, as is shown in **Figure 1 b**. The other two punches are marked as classic punches - CP. Vibrators based on stacked ceramic multilayer actuators of dimensions 6x6x48 mm are controlled by a set shown in **Figure 1f**, consisting of a power supplier- *8*, shape generator -*9* and oscilloscope -*10*. The set allows the generation of sinusoidal oscillations safe for the stack, which amplitude is controlled by the input voltage in the range of 0-150 V. It results in the amplitude adjustment in the range depended on frequency (max. 16 μm). The function generator allows to change the oscillation frequency in the range of 0-450 Hz.

3. EXPERIMENTAL PROCEDURE

The tests were carried out on a Bruderer BSTA 30 high speed press at a speed of 100 strokes per minute with 20 mm ram stroke. An automatic feeder with 3.5 mm stroke was used. The pressure of the blank holder is set at 100 MPa. Tapes are spray-lubricated with Neutol 1333 oil (Pol-Sil company) intended for use in metal forming processes. Micro-blanking of holes with a diameter of 1 mm was carried out in aluminum strip A1070 (Al≥99.7%) with a thickness of 1 mm and stainless steel strip (SS) 1H18N9T (**Table 1**) with a thickness of 0.7 mm at 250 Hz frequency. A sinusoidal supply voltage in the range of 0-150 V, which corresponds to a vibration amplitude of 12 μm was applied. In the case of aluminum, 6000 strokes were done. In the case of SS, micro-blanking, due to the small clearence and large relative height of the blank, the number of strokes was limited to 185. The chemical composition of the materials used during investigations is shown in **Table 1**.

Table 1 Chemical composition of HSS - SW7m (1.3343) (punch and die) and SS - 1H18N9T (1.4541) (strip)

	C	Si	Mn	Cr	Mo	Ni	V	Cu	S	P	W	Co
Punch/die	0.82	max	max	3.5	4.5	max	1.7	max	max	max	6	max
62 HRC	0.92	0.5	0.4	4.5	5.5	0.4	2.1	0.3	0.03	0.03	7	0.5
Strip	max	max	max	17	-	8	-	-	max	Max	-	-
215 HB	0.1	0.8	2	19	-	10	-	-	0.03	0.045	-	-

4. EXPERIMENT RESULTS

Figure 2 shows the punches after 6,000 cuts in Al strip. The phenomenon of inhibition of buildups was observed. After completing 6,000 of holes, the VP punch has a buildups-free surface, **Figure 2b**, while the CP surface in the working part is completely covered with buildups, **Figure 2a**. In the case of SS steel the use of vibrations reduced the tendency to galling – compare **Figure 2d** and **Figure 2c –** but did not stop the buildups formation. In relation to the surface quality of punched holes, the use of vibration not only reduces surface damage, but also smoothest it. The hole surface after 185 strokes is smoother than after one.

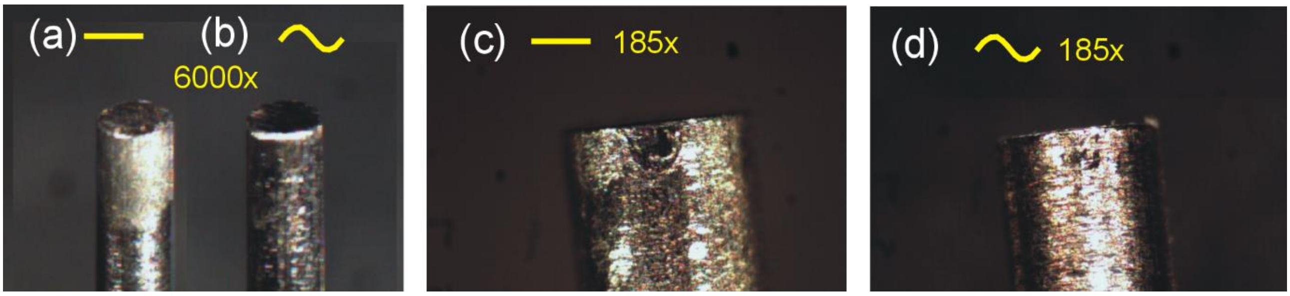

Figure 2 Punches after microblanking: (a) Punch CP, Al, 6000 strokes, (b) Punch VP, Al, 6000 strokes, f=250 Hż, A=12 μm, (c) Punch CP, SS, 185 strokes, (d) Punch VP, SS, 185 strokes, A=12 μm, f =250 Hz

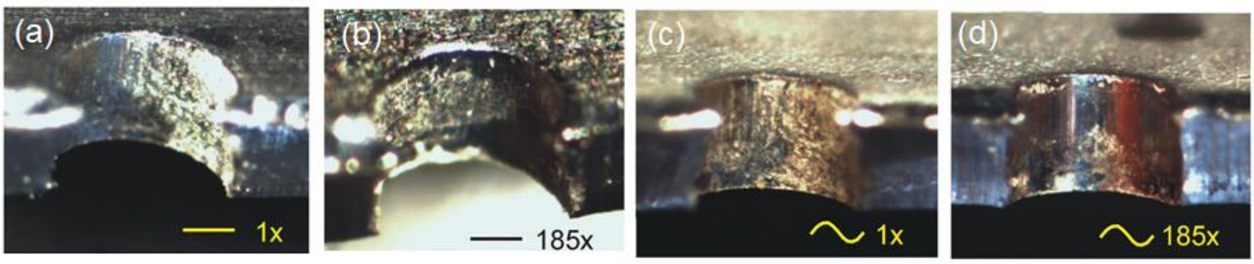

Figure 3 Internal surface of a hole: (a) CP, SS after 1 stroke, (b) CP, SS, after 185 strokes, (c) VP, SS after 1 stroke, (d) VP, SS after 185 strokes

RESULT ANALYSIS

Cross-sections were formed on VS after blanking the SS strip. The punch was cut with a wire saw at the buildup position along and across the axis. Then samples were made using the thin film method. The samples were subjected to TEM analysis, **Figure 4.** The microstructure is ultra-fine, sub-cellular, where the boundaries of the sub-grains are the dislocation tangles. Sub-grains are visible in the photographs of both cross-sections in the form of light and dark fields. It can be assumed that they are associated with the phenomenon of dynamic recovery after deformation. From the diffraction images, **Figures 2c,d**, it appears that the material is ultra-fine grained and has a very diverse orientations of grains. In the longitudinal section, **Figure 4b** and **Figure 4d**, the grains show a subtle orientation, suggesting the "fibrous" structure. The build-up process is very complex.

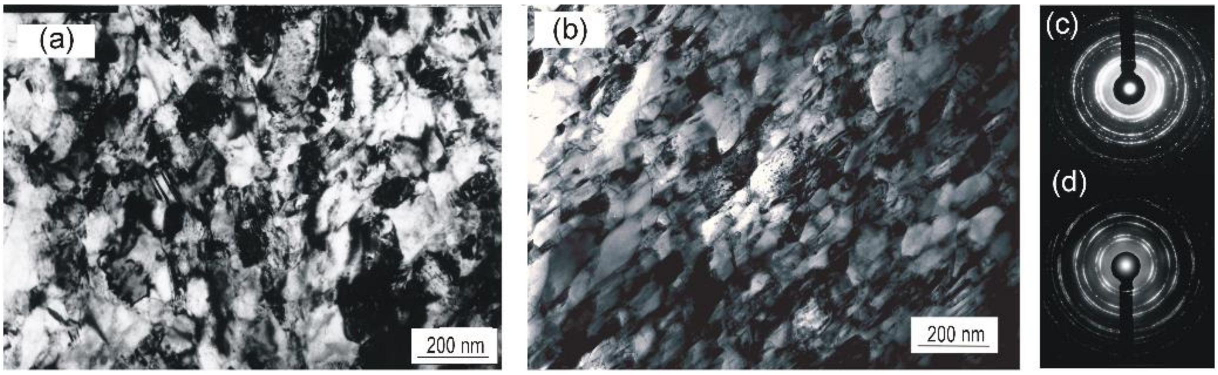

Figure 4 TEM of a SS – VP - buildup sections: (a) – cross section and (c) its diffraction; (b) longitudinal section and (d) its diffraction

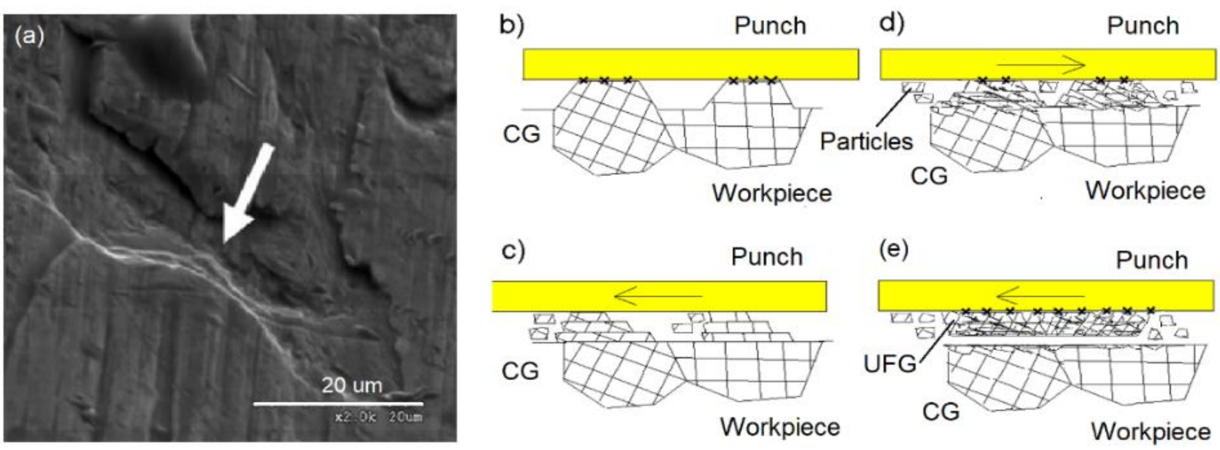

Figure 5 (a) SEM the lateral surface of the punch; (b), (c), (d), (e) phases of a build-up creation

The structure adopts a layered system, which results from the way it is formed. The grain system in the structure is characterized by a large angle of disorientation, and the material is practically free of dislocations. The only observed dislocations are at the grain boundaries. The phenomenon of smoothing the inner surface of the blanked holes with the use of vibrations was observed. In this case, the material is distributed more evenly than in the process without the use of vibrations. The probable mechanism of the initial changes in the surface structure of the blanked material is shown in **Figure 5**. After a certain cumulative path of friction, adhesive joints of deformed asperities occur, **Figure 5a**. As a result of further movement of the punch, shear stresses appear in the unevenness leading to the formation of shear bands dividing the asperities, **Figure 5b**. The return movement of the punch causes the material to rotate and changes the direction of shear stress causing the generation of shear band in a slightly different direction, **Figure 5c**. The next steps result in the formation of subsequent shear bands resulting in successive smoothing and the formation of an ultra-fine grained structure – UFG, forming a build-up, **Figure 5 e**. The characteristic steps resulting from shearing the material layer can be observed on the edge of the built-up edge shown in **Figure 5a**. At the same time, slipped and hardened layers tend to separate small portions of material, **Figure 5** - particles, which are removed from the contact area due to vibrations and occurrence of the lubricant pumping. This results in a mechanism similar to abrasive wear, which is not as catastrophic phenomenon such as galling is. The role of surface roughness is important in inhibiting the galling phenomenon by vibration. Roughness cavities provide the opportunity to relieve areas at risk from adhesive joints. Roughness depressions give the opportunity to relieve areas threatened by adhesive connections. There are two opposite phenomena: cleaning the cavities of separated particles and the accumulation and joining of shear layers. Depending on which mechanism prevails, the course of the process also varies. In the case of aluminum, the process of cleaning the surface of the punch from micro-buildups by means of vibrations dominated and, as is shown in **Figure 2b,** the galling phenomenon did not occur. In the case of SS steel, the vibrations only slowed down the build-up process. Repeated shearing of the surface layers of the hole surface caused by the vibrating movement of the punch creates UFG structure of the build-ups.

6. CONCLUSIONS

A progressive blanking die was designed and constructed enabling the use of longitudinal vibrations of the punches and was successfully used to work on an industrial press operating at 100 strokes per minute. Completed tests of the micro-blanking process of 1 mm diameter holes in aluminum and stainless steel strip at an industrial stand with the use of a progressive die were carried out. The die was equipped with piezoelectric vibrators enabling the introduction of punches with longitudinal vibrations with a frequency of 250 Hz and an amplitude of 12 μm allowed to formulate the conclusions presented below.

- The introduction of punch longitudinal vibrations in the micro-blanking process changes the nature of the contact of the side surface of the punch with the blanked material. Sinusoidal excitation of the piezoelectric vibrator causes periodic changes in the direction of the friction force causing tangential stresses within the surface layers.
- The use of a vibrating punch causes the phenomenon of smoothing the inner surface of the blanked hole. In this case, the material is distributed more evenly than in the process without the use of vibrations
- In the process of micro-blanking of aluminum, the use of vibrations resulted in cleaning the punch surface and inhibiting the build-up process.
- In the process of micro-blanking of stainless steel, the use of vibration slowed the build-up process.
- The build-up made of 1H18N9T stainless steel formed on a vibrating punch during the micro-blanking process has an ultra-fine grained structure with dislocation-free grains of a size about 100-200 nm with a high degree of misorientation.

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