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ECONOMIC MICRO FORMING USING DLC- AND TIN-COATED TOOLS

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ABSTRACT

In the micro forming the application of lubricants complicate the cleaning of work pieces after micro forming, which due to small dimensions is more complex than in the macro range. Moreover, saving of lubricants might help limiting harmful effects on the environment and establishing healthier working conditions. However, the thin work piece material in micro forming usually has a lower maximum elongation compared to thicker materials in macro forming, which leads to a more sensitive dependence of the forming limit on the friction between work piece and forming tools. Therefore, it is highly desirable to precisely control friction conditions as well as reduce or even avoid the use of lubricants in micro forming. Possibilities to enable lubricant-free forming include various coatings of forming tools. In this work, the possible field of application of DLC-coated, TiN-coated as well as of uncoated tools from a tool steel (Germany standard 1.2379) were characterized in micro deep drawing. It was concluded that the DLC- and TiN-coating both show a significant advantage in lubricant-free micro deep drawing compared to a standard tool steel tool, and thus have a great application potential in micro forming.

Key words: *Micro forming, DLC and TiN coated tools*

1. INTRODUCTION

Environmentally conscious behaviour in the manufacturing industry considers especially the application of lubricants and the durability of the tools in the manufacturing processes [1]. Bay divided the environmental problems in metal forming tribology into 3 areas: (a) health and safety of people, (b) influence on equipment and buildings, and (c) destruction and/or disposal of waste and remaining products. Much research work was done in order to save or substitute environmentally hazardous lubricants in the forging, sheet metal and punching industry [2]. However, saving of lubricants does not only help limiting harmful effects on the environment and establishing more healthy working conditions. Especially in micro forming processes it could help avoiding complicated cleaning processes of the formed components, which due to the small dimensions is more complex than in the macro range.

Micro formed components can be found in micro system technologies (MST) or micro electro-mechanical systems (MEMS). Leverages, connector pins, resistor caps, contact springs and chip lead frames are typical micro components [3]. However, when scaling to smaller parts, so-called size effects can appear. A comprehensive review about size effects is given in [4], which shows that there are size effects in the material strength [5], the lubricated friction [6] and the formability [7]. Based on these challenges and the rising trend towards miniaturization, improvement of micro forming processes are needed [8].
Possibilities to enable lubricant-free forming in the micro range are various coatings of forming tools. The amorphous, diamond-like carbon coatings (DLC coatings) currently play an important role in the field of tribology of tool surfaces. The tribological behaviour of the amorphous carbon coatings in artificial joints [9] and seals [10] was already investigated. Reisel et al. [11] showed that the DLC-coating can also be tested using a massive forming process. Another possibility is the TiN-coating, which according to Franklin and Beuger [12] has a relatively low friction coefficient and wear factor in the pin-on-disk test. In this work, the possible field of application of DLC-coated, TiN-coated as well as of uncoated tools from standard tool steel (Germany standard 1.2379) were be characterized in micro deep drawing. Special attention was paid to the so-called "eggshell effect" [13], which can due to the involved local pressure in micro deep drawing [14] play a role in the failure of the films. Moreover, the punch force vs. stroke curves were obtained from experiments and compared to the uncoated tool.

2. EXPERIMENTAL METHODS AND MATERIALS

2.1 Micro forming machine

All experiments were carried out on a double-axis micro forming press, which was developed at BIAS [15]. This micro forming press is a highly dynamic press. It is driven by electrical linear motors with a maximum acceleration of 17 g and a maximum velocity of 3.2 m/s. The positioning error of this press is below 3 µm at maximum acceleration. Its repeat positioning error is below 1 µm up to a stroke of 8 mm. The two movable slides of this machine can move independently from each other. The experimental setup described below was installed on the micro forming press including a force measurement system with an accuracy of 0.01 N.
Micro deep drawing was performed with DLC-coated, TiN-coated and uncoated forming tools. Due to the large friction coefficient between blank and uncoated forming tool, no sound parts can be acquired without lubricant. Therefore, the mineral oil HBO was used as lubricant for the experiments with uncoated forming tools. Lubricant-free deep drawing was carried out only on the DLC-coated and TiN-coated forming tools.
In the setup, the punch and the blank holder are driven by the upper slide and the lower slide, respectively. This allows controlling the blank holder force precisely, while the punch moves into the die. The principle of the experimental setup is shown in Fig. 1. The geometrical parameters of micro deep drawing with laboratory setup are shown in Table 1.

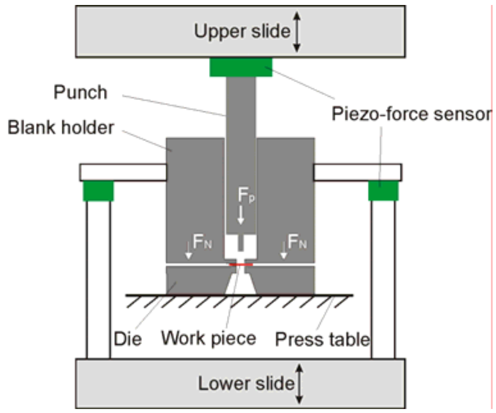


Fig. 1 - Principle of the experimental laboratory setup for micro deep drawing.

Table 1: Geometrical parameters for micro deep drawing

Punch diameter d_p [mm]	1
Die inner diameter D_Z [mm]	1.056
Punch radius r_p [mm]	0.1
Drawing radius r_Z [mm]	0.12
Blank thickness s_0 [mm]	0.02

2.2 Materials

Blank material of stainless steel (German standard: 1.4301) with a thickness of 0.025 mm was used in this investigation. The yield strength of 1.4301 is about 320 MPa. The blanks for micro deep drawing were cut by a Nd:YAG laser with a wavelength of 1064 nm. During this deep drawing, a constant blank holder force with an initial blank holder pressure of 1 N/mm^2 was applied.

3. RESULTS

Micro deep drawing with both coated forming tools (Fig. 2) was successfully carried out without using any lubricant. As an example, a sound part from this micro deep drawing is shown in Fig. 3. On the wall of this sample, no damages due to friction can be detected. During the experiment, the punch force was measured. As more experiments were repeated, the corresponding measured punch force vs. stroke curves varied within a certain range. For example, the maximum punch force using the DLC-coated forming tool ranges between 41 and 46 N, which corresponds to a deviation of about ±6.1%, see Fig. 4. Using the TiN-coated forming tool the maximum punch force ranges between 53 and 63 N, which corresponds to a deviation of about ±9.4%, see Fig. 5. For further analysis, only the punch force vs. stroke curve out of average values is taken into account. For comparison, more experiments were also carried out with lubricant on the coated as well as the uncoated forming tools. These results will be shown in section discussion.

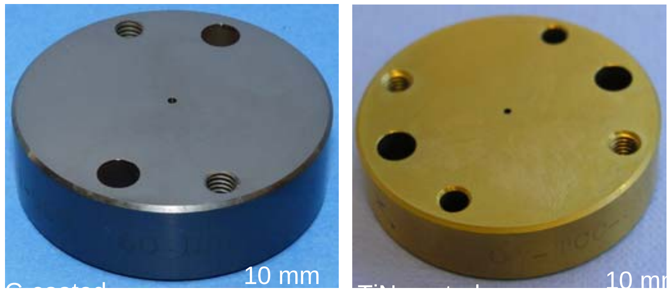
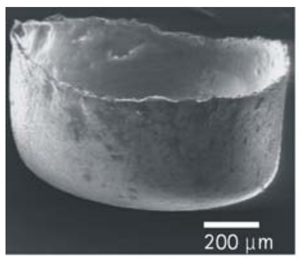
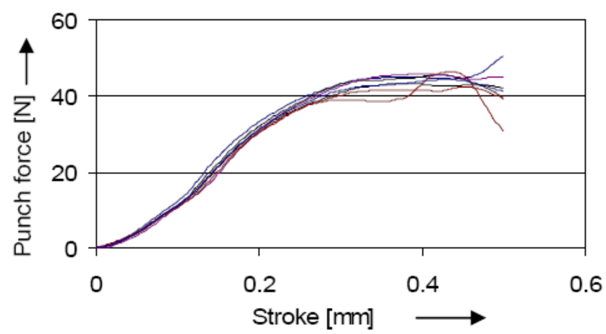


Fig. 2 - Coated micro deep drawing dies.



Blank material:	1.4301
Tool material:	1.2379
Die surface:	DLC-coated
Blank thickness:	0.025 mm
Punch diameter:	1 mm
Punch radius:	0.1 mm
Drawing radius:	0.12 mm
Drawing ratio:	1.8
Lubricant:	no
Punch velocity:	1 mm/s

Fig. 3 - Sound part of lubricant-free micro deep drawing.



Punch diameter:	1mm	Blank thickness:	0.025 mm
Drawings radius:	0.12 mm	Blank material:	1.4301
Drawn clearance:	0.03 mm	Lubricant:	no
Punch velocity:	1mm/s	Initial blank holder pressure:	1 N/mm²
Tool material:	1.2379		
Drawing ratio	1.8		

Fig. 4 - Punch force vs. stroke curves of micro deep drawing using DLC-coated forming tools.

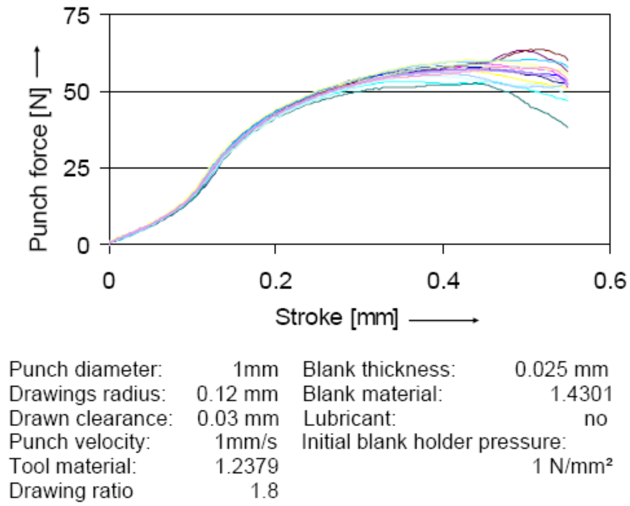


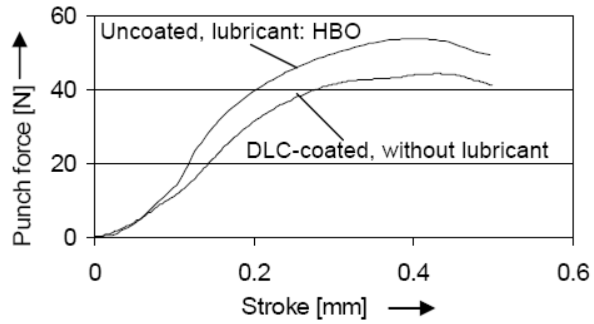
Fig. 5 - Punch force vs. stroke curves of micro deep drawing using TiN-coated forming tools.

4. DISCUSSION

During micro deep drawing with coated forming tools no cracks or similar damages, caused by the so-called eggshell effect, were observed on the surface of the forming tools. The reason for that might be the plasticity of the coatings. This indicates that the coatings can bear a small plastic forming. As long as the plastic forming resulting from loads does not exceed the plastic limit of the coatings (which, however, is unknown yet) no cracks will occur. This should allow the application of thin coatings in micro deep drawing, in which only a small forming force is involved.

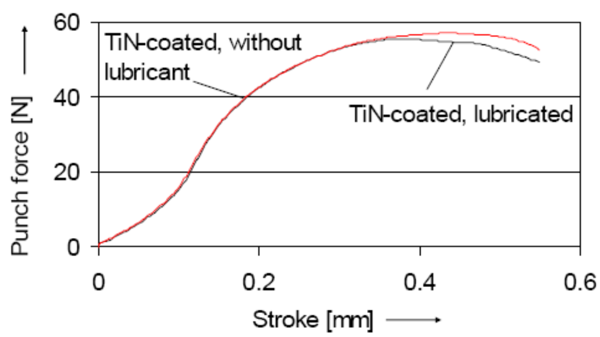
A comparison of the average punch force vs. stroke curves of the micro deep drawing with DLC-coated and uncoated forming tools is shown in Fig. 6. The measured punch force vs. stroke from the deep drawing with uncoated forming tools is higher than the one with DLC-coated forming tools, although a lubricant (mineral oil HBO) was used for deep drawing with uncoated forming tools. This indicates that the DLC-coating can reduce friction between blank and forming tool in deep drawing more than the lubricant.

As lubricated und unlubricated micro deep drawing was performed using the same TiN-coated forming tool, the punch force vs. stroke curves show nearly no difference from each other, see Fig. 7. It means, for this case the lubricant (mineral oil HBO) has no influence on the friction between the forming tool and the blank at all. However, the friction between the TiN-coating and 1.4301 is relatively high, since the maximum punch force is nearly 15 N larger than that using the DLC-coated forming tool. Therefore, DLC-coated forming tools have more advantages. In spite of that, both DLC and TiN films have a greater application potential in micro forming under dry condition.



Punch diameter:	1mm	Drawing ratio:	1.8
Drawings radius:	0.12 mm	Blank thickness:	0.025 mm
Drawn clearance:	0.03 mm	Blank material:	1.4301
Punch velocity:	1mm/s	Initial blank holder pressure:	
Tool material:	1.2379		1 N/mm²

Fig.6 - Punch force vs. stroke curves of micro deep drawing using TiN-coated forming tools.



Punch diameter:	1mm	Drawing ratio:	1.8
Drawings radius:	0.12 mm	Blank thickness:	0.025 mm
Drawn clearance:	0.03 mm	Blank material:	1.4301
Punch velocity:	1mm/s	Initial blank holder pressure:	
Tool material:	1.2379		1 N/mm²

Fig. 7 - Punch force vs. stroke curves of micro deep drawing using TiN-coated forming tools.

5. CONCLUSIONS

From the reported work it can be concluded:

- the DLC-coated and TiN-coated forming tools can be used for micro deep drawing under dry condition and therefore show a great application potential in realization of an economic and environmentally friendly process,
- no damage of the thin coatings due to eggshell effect could be observed,
- applying the DLC-coated forming tools in micro deep drawing can reduce the punch force more than usual lubricant such as mineral oil,
- the friction between the DLC film and the stainless steel 1.4301 (dry friction without lubricant) is lower than that between TiN film and 1.4301.

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EKONOMIČNO MIKRO OBLIKOVANJE POMOĆU ALATA SA DLC i TIN PREVLAKAMA

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REZIME

U postupcima mikro deformisanja podmazivanje komplikuje čišćenje gotovih delova, više u mikro oblasti nego u makro. Štaviše, izbegavanje podmazivanja može pomoći u limitiranju štetnih uticaja na okolinu i usloviti zdravije uslove za rad. Međutim, tanki pripremci u oblasti mikro deformisanja imaju malo maksimalno izduženje u poređenju sa tankim pripremcima u makro oblasti, što dovodi do mnogo veće zavisnosti granične obradivosti od trenja između alata i obradka. Zbog toga je preporučljivo precizno kontrolisanje uslova trenja kao i redukcija ili čak izbegavanje korišćenja lubrikanata u mikro deformisanju. Mogućnosti ostvarivanja deformisanja bez podmazivanja uključuje razna premazivanja alata. U ovom radu je dat prikaz mogućih polja primene DLC premaza, TiN premaza kao i nepremazanih alata od alatnog čelika (DIN 1.2379) i karakterizacija pri mikro dubokom izvlačenju. Zaključeno je da DLC i TiN premazi pokazuju značajne prednosti u mikro dubokom izvlačenju bez podmazivanja u poređenju sa standardnim alatnim čelicima, i da imaju veliki potencijal u primenu u oblasti mikro deformisanja.

***Ključne reči**: Mikro oblikovanje, alati sa DLC I TiN prevlakama*