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Deep drawing process without lubrication – an adapted tool for a stable, economic and environmentally friendly process

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Abstract

In today's industry, waste prevention and an efficient use of resources are becoming more important due to economic and environmental requirements. Especially in forming processes such as deep drawing, a reduced use of lubricants is highly promising for saving resources and reducing production costs. Ultimately, the highest savings can be realised by a complete lubricant free deep drawing process - namely dry deep drawing. In this paper, a combined approach consisting of a new tool design for deep drawing in lubricant free applications and development of a protective tool coating is presented. The combination of macro and micro structuring of the tools and the protective coating ensure a stable process with a sufficiently wide process window under dry conditions. Since the friction in the flange area and die radius has the largest contribution to the drawing force, these parts of the tool will be adapted for the new tool design. In order to decrease the level of friction force in flange area for a given friction coefficient, the integral of the contact pressure over the contact area has to be reduced. This is achieved by macro structuring of the tool. The absence of lubricants in drawing die radius has to be compensated by tetrahedral amorphous carbon ta-C films, which combine low friction coefficients and anti-adhesive behaviour with a high hardness and wear resistance. The ta-C films can additionally be micro structured by Direct Laser Interference Patterning (DLIP) to further improve their tribological performance.

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Keywords: Deep drawing; Dry forming; ta-C Coating; DLIP structuring

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1. Introduction

Sheet metal forming by deep drawing is widely used in automotive, aerospace, and appliance manufacturing industries. The large contact area and high normal surface pressure lead to high friction forces during the process. Therefore, effective lubrication systems are needed. Currently, in almost all forming processes lubricants are used to reduce friction forces between work piece and tool, to reduce tool wear and also to protect semi-finished goods from corrosion. Lubricants are, however, often either harmful to health or harmful to the environment. Therefore, new more restrictive laws have been issued in Europe and Japan since 2000 with respect to the industrial application of hazardous lubricants to establish safe and healthy working conditions [1]. Consequently, increasing efforts have been made to gradually decrease the amount of mineral oil used or to replace it with environmentally friendly lubricants [2]. Chlorine-, amine- and bond rite-free lubricants, closed systems of lubrication and cleaning and semidry forming processes are practically discussed as feasible alternatives [3]. KLOCKE et al. [4] show the development and application of a new, graded ZrC tool coating which allows chlorinated paraffin oil to be replaced with a new environmentally benign, biodegradable, rape oil based lubricant, HIGTO.

Regarding economic aspects, VOLLERTSEN et al. [5] show that, using mineral oil based lubricants leads to an increase of production steps, because an additional post-treatment process is required for cleaning the workpiece by means of degreasing agents which are usually solvent-based. Most of them are toxic and harmful substances. Consequently, from both an economic as well as an ecological point of view, a strong demand of a total lubricant free processes for industrial applications exists. Within the scope of this paper, a new lubricant free deep drawing process is designed by means of an adapted tool, which ensures a stable, economic and environmentally friendly process.

2. Methodology and approach

In deep drawing processes, the occurrence of wrinkles and bottom cracks define the process limits. In a lubricant free deep drawing process the friction forces will increase leading to an increase of the punch force. As a result, there is a higher probability of a bottom crack during the process. Therefore, the acting friction forces in critical frictional areas of the tools, namely the flange area and the die radius, should be minimised to ensure a large process window. The integrative approach to minimise the friction forces during the process is based on macro structuring of flange area with a combination of wave and rotatable structures, coating and micro structuring of die radius. In the following these measures are described in detail and their suitability for lubricant free deep drawing application is evaluated.

2.1. Macro structuring of flange area for friction reduction

In order to decrease the acting friction forces for a given friction coefficient, the integral of the contact pressure over the whole contact area should be reduced. Therefore, macro structured deep drawing tools are developed, in order to reduce the contact area to contact lines or points. Nonetheless, this increases the risk of wrinkling which is caused by compressive tangential stress (σ_t) in the free, non contact areas of the sheet metal.

To avoid wrinkling, the sheet metal in flange area should be stabilised by increasing the geometrical moment of inertia. This can be achieved by immersing the blankholder slightly into the drawing die, inducing an alternating bending mechanism, see Fig. 1A and Fig. 1B. The resulting structure stabilises the sheet metal against wrinkling in flange area, which can be seen in Fig. 1B were no wrinkles occur during the experimental verification. Using the macro structured deep drawing tools can reduce the contact area up to 80% by wave structures and 95% by rotatable spherical elements. The blank holder force is reduced up to 90% compared to the standard process. Additionally, it also increases the resistance of the sheet metal against wrinkling and it allows the control of the material flow by adjustment of the immersion depth [6]. The wavelength λ and immersion depth δ are two process parameters which define the geometry of alternating bending and are used as setting parameters to stabilise the process against wrinkling. Obviously, a smaller immersion depth and higher wavelength induce smaller curvature in sheet metal, leading to decreasing buckling stiffness in the flange area. As a result, the risk of wrinkling increases. Oppositely, a higher immersion depth and smaller wavelength induce a bigger curvature in sheet metal resulting in an increasing deep drawing force, possibly causing bottom cracks. Therefore, for a given geometry, the wave length and immersion depth should be determined in dependence of material properties in such a way that a stable process can be realised. In order