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Evaluation of the potential of tool materials for the cold forming of advanced high strength steels

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ABSTRACT

The increasing relevance of lightweight design intensifies the use of advanced high strength steels (AHSS). However, the use of AHSS causes higher stresses on the forming tools, thus reducing tool life and making it impossible to achieve the aspired process reliability.

Since there is no reliable information on the wear behavior of tool materials for the forming of AHSS, this study aims to investigate wear and wear development of different tool materials. For this purpose, a strip drawing test with drawbead geometry is used as a model test. Continuous measurements of forces, temperatures of tool and sheet metal, and the roughness of sheet metal allow accurate and detailed analyses of wear.

The investigation shows distinct differences in wear resistance of the tested tool materials and reveals characteristic wear development. Furthermore, the results of this study broaden knowledge on dependencies between tool wear, process temperature, and surface changes.

1. Introduction

The development and manufacturing of sheet metal parts are more and more affected by demands for lightweight design. The occurrence of this trend is especially prominent in the automotive industry. In this industry, the improvement of crash worthiness and the steadily increasing significance of reduced fuel consumption add up to the mentioned development [1].

In the car body production, steel is still the most common material in use. Due to the fact that the body shell represents a large proportion of the total vehicle weight, this area provides a high potential to reduce vehicle weight [2]. In order to meet the requirements for lightweight design, car manufacturers have intensified the use of advanced high strength steel (AHSS) and ultra high strength steel (UHSS) [3,4]. These steel grades allow weight reductions for components, since less material is required for load bearing, due to the high strength [5]. Despite the reduced weight, the strength of these components remains constant or even increases.

Compared to conventional steels, AHSS and UHSS are characterized by a reduced formability and a higher strength. As a consequence, the use of AHSS or UHSS leads to several challenges. For example, higher forming loads are required thus causing higher contact pressures and an increased process temperature [6]. The increased stresses on the forming tool, especially at radii or drawbeads, cause severe wear rates and shorten tool life. Resulting maintenance or replacement costs together with a reduced process liability impact on the economic efficiency of the use of AHSS or UHSS.

Consequently, tool materials and tribosystems for the forming of advanced high strength sheet metal have to be optimized. Current wear protective measures include the use of high strength tool materials and coatings. However, there is only little knowledge on quantitative dependencies between tool life and tool materials or coatings and the processed sheet metal. The approach of replacing a tool material by a more wear resistive material would not be sufficient, since it cannot be assumed that this substitution affects the tribological system positively in the aspired way. Feedback from industrial users proves that expert knowledge is not sufficient to forecast the lifetime of tribosystems. In order to evaluate the potential of tool materials for the cold forming of AHSS or UHSS, it is necessary to take a holistic approach that considers all aspects of the tribological system and interactions between its components.

It is the objective of this paper to evaluate the potential of tribosystems for the forming of AHSS and to gain further knowledge on wear development. For this purpose, the study deals with the question how tool life is affected by different tool materials. Furthermore, the influence of a zinc coating on wear and occurring wear mechanisms is examined. Additionally, this study addresses the question of how wear development can be mapped during experimental tests.

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2. State of the art

Wear occurs during a relative movement between tool and sheet metal under a surface load [7]. This surface load does not only consist of compressive forces and friction induced shear forces, but also of thermal loads, resulting from forming and friction energy, and chemical loads, attributed to interactions with the environment [8].

Due to the fact that it is almost impossible to conduct comparative wear analyses of different tribological systems on real forming tools, several experiments have been developed to evaluate the conditions between tool and sheet metal. The strip drawing test is one of the most common experimental setups for tribological analyses in sheet metal forming [9]. This experimental method allows the depiction of different contact areas between sheet metal and tool surface in deep drawing operations. Furthermore, the strip drawing test enables exact measurements of forces in different tool areas. Additionally, it is possible to vary single process parameters, like contact pressure systematically, so that their influence can be evaluated independently. Fig. 1 shows different model geometries for strip drawing purposes.

The plain geometry (A) allows the analysis of tribological conditions in blankholder areas. In addition to the evaluation of tribological conditions, the plain geometry is also used for the determination of friction coefficients of material combinations. Tribological conditions of draw radii can be depicted with the strip drawing test with bending (B). The wedge-drawing test is used to simulate corner areas of deep drawing tools (C). Tool geometry (D) depicts drawbeads in deep drawing tools. This geometry is particularly appropriate for the aspired wear investigations. Due to the multiple deflection of the strip in this tool geometry and the comparatively small contact areas, very high contact pressures are generated [10]. The resulting stresses on the tool lead to tool wear at an early stage. With regard to the purpose of this investigation, namely the analysis of wear behavior, this is very important. Only the choice of a suitable experimental model enables a defined and reproducible investigation of wear and wear development with reasonable effort.

3. Wear analysis

Due to these reasons, the strip drawing test with drawbead geometry has been used for the analysis of wear behavior of different tool materials and sheet metal combinations. The experimental setup and measurement methods are described in the following paragraphs.

3.1. Experimental setup

Experimental analyses are conducted on the strip drawing test stand of the Institute for Production Engineering and Forming Machines (PtU). An illustration of the test stand is shown in Fig. 2. The test stand is fully automated and allows the use of single sheet metal strips, as well as sheet metal coils. An additional cleaning and lubrication module is included, so that equal surface conditions for every test series are guaranteed. In the test stand, the required normal force is applied by four hydraulic cylinders. The movement of the sheet metal strip is applied by a gripper. The gripper is attached to a mechanical transmission and pulls the strip through the closed tool. Every stroke has a length of 100 mm and the gliding speed is variable up to a maximum of 100 mm/s. The automation of the test stand enables the generation of friction paths of several thousand strokes. Hence, it is possible to generate sets of stress that produce practice-relevant wear patterns and make them accessible to extensive investigation.

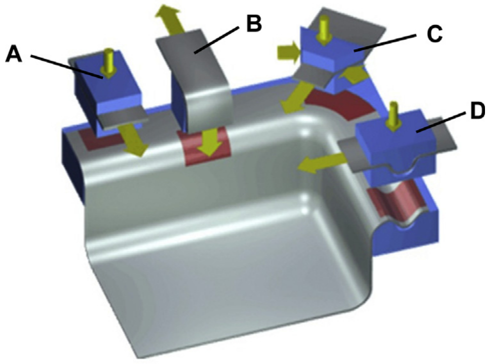

Fig. 1. Model geometries for strip drawing test.

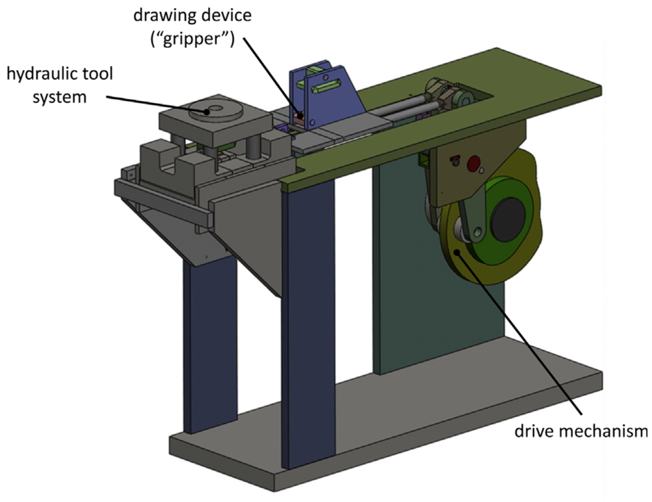

Fig. 2. Strip drawing test stand.

The experimental investigations have been carried out with a dual phase steel DP980. The steel has been used in two configurations, without and with a zinc coating, which was applied by electrolytic galvanization. The strip has a width of 50 mm and a thickness of 1.14 mm (uncoated) and 1.20 mm (electrolytically galvanized). In each experiment, the strip drawing test has been continued until the strip tears off and its surface reaches a roughness of more than 15 µm. Feedback from industrial users say that these constraints would cause a termination of any industrial deep drawing processes.

Three different tool materials have been used during the investigations. The cold work steel CP4M (all tool materials wear manufactured by Dörrenberg Edelstahl) is used as a reference. Two other tool materials, a powder metallurgical PMD M4 and a CP4M with a TIC/TIN coating have been used as alternative tool materials. As recommended by the manufacturer and by several industrial users, the CP4M was hardened to 62 HRC and the PMD M4 was hardened to 64 HRC. All tools are fabricated with a surface finish of $R_z < 0.8$ µm and $R_a < 0.1$ µm. The main alloying elements and the chemical composition of CP4M and PMD M4 are given in Table 1.

The geometry of a drawbead toolset used for the experimental investigations is depicted in Fig. 3. Altogether, a toolset consists of five segments: two blankholders, two dies and a drawbead. The edges of the blankholder that are in contact with the sheet metal strip are rounded with a radius of 3 mm. The cylindrical side of the drawbead has a diameter of 10 mm. The depth of penetration in the metal strip is set to 3 mm. In order to guarantee equal experimental conditions, a constant lubrication film of 1.8 g/m^2 is applied on the sheet metal. The lubricant is a deep drawing oil (PL61, Zeller+Gmelin) with a viscosity of 80 mm^2/s. A matrix