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Technical Paper

Statistical analysis on the impact of process parameters on tool damage during press hardening

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ABSTRACT

Automotive parts made of ultra-high strength steels are produced by press hardening in order to obtain high-strength components. During this process, formed parts are pressed against tools at high temperature, which ultimately yields to tool damage. Tool damage is especially detrimental since it not only affects the quality of the parts but also causes higher material consumption and reduces maintenance intervals. The extent of tool damage is determined by the process parameters but their influence is not yet clearly understood. The aim of this work is to investigate the influence of input process parameters on tool wear and maximum drawing force. To this end, a novel test rig is designed in order to reproduce typical press hardening conditions under well-controlled laboratory conditions. This set up is used to modify selected input parameters according to a Design of Experiments in order to investigate their impact on tool wear and drawing force. The results obtained can be summarised into two simple equations, which depend only on the most dominant parameters. This method allows a quantitative optimisation of the press hardening process, as illustrated by a practical example.

1. Introduction

Modern cars are required to fulfil high security and environmental standards. The dramatic strengthening of fuel economy and emission regulations in Europe, China and the US is driving manufacturers to raise the amount of lightweight components used in cars. Simultaneously, these lighter cars are expected to keep or even improve crashworthiness in order to achieve maximum scores in more demanding crash tests like NCAP or RCar insurance ratings. Among the possible ways to reduce car weight, the body in white plays a crucial role due to its significant contribution to the total car weight. The use of lighter materials such as aluminium or magnesium poses an option and threatens steel components to be replaced, at least partly. To remain competitive, the steel industry is constantly required to improve their products in order to allow further weight reductions while maintaining strength [1]. One of these methods was patented in the middle 1970s by Jaernverk [2] and consists in applying a hot stamping process to form and harden steel via thermal treatment. This process, called press hardening, combines in a single step high temperature deformation with in situ quenching of the steel part. Press hardening, when it was firstly introduced in the middle of the 80s in the Saab 9000, was a technology exclusively used for premium cars. However, nowadays press hardening is widely used in middle class mass production cars and constitutes a growing market, in particular for structural automotive parts such as A-pillars, B-pillars and bumpers. The steel grades typically used in press hardening are ultra-high strength steels, such as the 22MnB5. A typical commercially available 22MnB5 ultra-high strength steel such as the USIBOR 1500P increases its tensile strength from 350 MPa in as-received ferritic-pearlitic microstructure to a final yield strength of up to 1250 MPa in quenched martensite, as reported by Merklein et al. [3]. During press hardening, 22MnB5 can oxidise at high temperature due to the presence of oxygen in the furnace or during the transfer time between the furnace and the press. In order to reduce oxidation during the austenitisation of 22MnB5, hot dip aluminised as well as electro-plated Zn-Ni coatings are increasingly used. These coatings reduce oxidation, and consequently, the presence of scales at the contact interface between tool and part, which possibly improves the tribological performance by reducing tool wear [4].

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The press hardening process is complex and relies on the precise control of a large amount of process, material and environmental parameters. Many of the tribological aspects of press hardening still pose a technological challenge [5]. The final goal is to provide reliable parts by controlling and keeping friction at an adequate and constant level, while simultaneously reducing tool wear. This objective requires a profound scientific understanding of the process in order to reveal the correlation between input and output process parameters and its impact on friction and wear. One way to gain this knowledge is by performing laboratory tests under well-controlled and defined conditions. For this, a large variety of laboratory testing methods have been applied or developed based on both, model and component tests. A comprehensive overview of some of the latest methods for measuring the coefficient of friction (CoF) has been reported by Karbasian and Tekkaya [6] and showed that the measurements are strongly dependent on experimental the method. The measured CoF reported in literature vary from 0.3 to 0.8. The test configurations and approaches to study wear in press hardening operations are mostly based on model tests. For instance, Hernandez et al. [7] used pin on disc tests under unidirectional sliding for developing friction and wear maps. These maps provide the dominant wear mechanism for a given contact pressure and temperature. In general, they found a reduction in friction and the formation of a wear protective layer with increasing testing temperature. Ghiotti et al. [8] used similar tests but cycled the tool temperature in order to reproduce the thermal and mechanical stresses found under factory conditions. The reduction of friction and wear for higher testing temperatures was recently verified using a reciprocating sliding contact [9]. In some cases, the influence of tool coatings and surface treatments has been addressed. Hardell et al. [10] studied the high temperature friction and wear behaviour of coated and uncoated high-strength steel under reciprocating sliding against coated and uncoated tool steels and found a temperature dependence on friction. Later, Hardell and Prakash [11] focused on Al–Si coated high-strength steel sliding against coated tool steels and found changes in the Al–Si coating morphology at elevated temperatures but could not correlated them with friction and wear. A more realistic experimental test rig was used by Wieland and Merklein [12] for investigating the influence of tool coating on adhesive wear during forming of Al–Si coated high-strength steel.

The aim of this work is to study the influence of the most relevant press hardening parameters on tool wear. To this end, a novel test rig is developed for performing close-to-reality simulations of the hot forming process on a laboratory scale. The design of the test rig provides a holistic consideration of the complete tribological system, taking into account all process parameters which influence tool wear. These parameters need to be considered in order to reproduce on lab the wear mechanisms observed in the industrial process. Additionally, the test rig allows evaluating the role of tool composition and mechanical properties on wear, as well as the role of sheet coatings. In the present work, we set the focus on evaluating the role of four selected process parameters on tool wear and drawing force using statistical methods. With the developed test rig, the influence of process parameters on the resulting drawing force and tool wear are evaluated using uncoated ultra-high strength steel while keeping constant tool composition.

2. Experimental methods

2.1. Materials

The press hardening process was investigated using uncoated blanks of commercially available 22MnB5 ultra-high strength boron steel. The nominal composition of the material is given in Table 1. The blanks were delivered in a ready-to-use condition and were cut into strips with the following dimensions (350 mm ± 0.5 mm × 50 mm ± 0.5 mm × 1.8 mm ± 0.1 mm). These blanks require a homogeneous three minutes austenitisation at 950 °C for an optimal martensitic transformation [3]. Following Naderi et al. [13], all used blanks were manufactured from the same coil in order to reduce material inhomogeneities and therefore, undesired scattering of material properties.

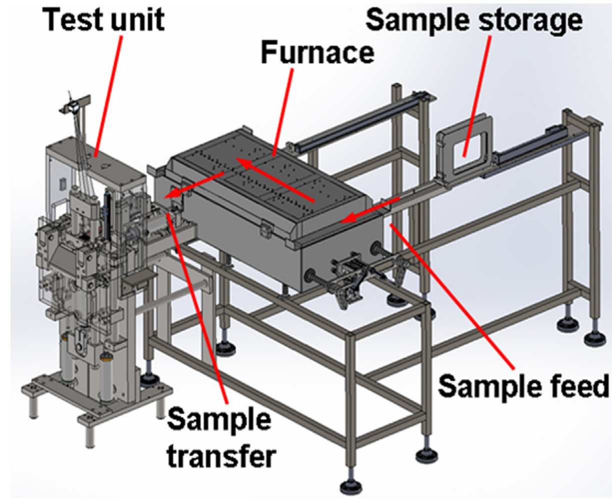

Fig. 1. Schematic of the hot forming test rig: the blanks from the sample storage are fed into the furnace and then transferred to the test unit.

The tool material is a hot work tool steel (high Cr-alloyed with Mo and V additives) with excellent high temperature wear resistance and high working hardness. Tempering temperature is in the range of 500–700 °C. This tool steel is recommended by the manufacturer for hot working applications, is applied industrially for full size press hardening tools and is selected for being representative for industry. The tool material and dimensions were kept constant throughout the experiments, so that the results obtained are valid for this material combination.

2.2. Hot forming test rig

A novel lab scale hot forming test rig (HFTR) was designed and constructed in order to reproduce the tribological conditions found in the industrial hot forming process. The main advantage besides having realistic contact conditions is that the input parameters are well-defined and can be controlled throughout the experiment, while simultaneously monitoring the system response. By these means, the influence of the process parameters on the tool wear mechanisms during hot forming can be analysed (Fig. 1).

The test rig is formed by a steel blank storage connected to a feeding system, which brings the testing blanks to a furnace, where blanks are heated before proceeding to the test forming unit. All displacements of the steel blanks within the test rig are done automatically by pneumatic cylinders. This automated operation ensures controllable and constant cycle times for every process step. The furnace of the HFTR allows heating-up steel blank samples up to 1000 °C in three adjustable heating zones. The transit time through the furnace can be varied according to the desired testing conditions. This feature allows investigating the influence of the holding time in the furnace on oxidation or for coated blanks on the morphology and topography of the oxide scales as done by Ghiotti et al. [14]. The furnace atmosphere is determined by the flow rate of protective gas, which can be selected in order to control scale formation. Within the present study, a mixture of forming gas (N_2 + 5% H_2) was used. An operation without protective atmosphere is also