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Tribological behavior of high thermal conductivity steels for hot stamping tools

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ABSTRACT

To improve the performances of new hot stamping processes for automotive industry, as well as to overcome their numerous drawbacks-such as oxidation, dies wear, severe thermal and mechanical cycles-new dies materials are being developed to obtain shorter heating and cooling cycles as well as improved strength and service-life.

The paper investigates the tribological behavior of two new high thermal conductivity steel grades, by applying thermo-mechanical cyclic loads in the temperature range 600–800 °C. The results show that a material microstructure characterized by agglomerates of Mo allows better performances than the case of finer elements of Mo homogeneously distributed in the metal matrix, with reduced friction and abrasion wear more relevant at the lowest testing temperatures.

1. Introduction

Nowadays, hot stamping is the most important technology for the production of structural parts of the car body-in-white, with the perspective that even more parts of the vehicles will be manufactured using such process. Among the advantages of using forming processes at elevated temperatures we can recall: (i) the shorter process chain, especially in the case of direct hot stamping, (ii) the increase of mechanical properties just after the deformation process and without the need of additional heat treatments, (iii) the reduction of the total weight of the vehicles thanks to thinner components maintaining the frame stiffness, (iv) the absence of lubricants that are often hazardous for the environment and require costly cleaning operations [1]. Conversely, engineers and process designers have to face quite a few critic drawbacks represented by the intensive energy consumption due to the material heating and the cooling [2], as well as the severe thermal and mechanical conditions at interface between the high temperature metal sheet and the cooled dies, which determine critical issues concerning the service-life of the equipment and tools [3,4]. Tools lubrication is generally avoided to preserve the surface quality of the final component, with particular regards to the paintability and weldability [5]. Consequently, the high shear stress that interests the interfaces in the forming process is accompanied by inefficient heat dissipation in the in-dies quenching due to the absence of the lubricant cooling action, with consequences on the Heat Transfer Coefficient (HTC), surface hardness, wear rate, etc.

Contributions in scientific and technical literature can be divided into the following groups:

1. *Industrial investigations*, in which friction and wear rate phenomena are evaluated through industrial tests carried out during the stamping of pre-series in industrial plants;
2. *Laboratory investigations* that aim at reproducing the tribological conditions typical of hot stamping with simplified conventional tests, or modified according to specific requirements.

Most of the latter focus on the tribological behavior of the material in dry conditions, where only the metal sheet coatings, used to prevent the metal oxidation in furnace, are helpful in the reduction of friction at elevated temperatures [6,7,8,9,20]. A novel testing procedure to replicate in a laboratory test the cyclic thermo-mechanical conditions typical of the stamping die during its service life was first introduced by the Authors in [14]. It was applied to the investigation of the performances of conventional X38CrMoV5-1 alloyed tool steels with AlSi coated [14] and Zn coated [15,16] 22MnB5 sheets finding that the Zn coating may represent an alternative to the traditional AlSi, even if it suffers at the highest temperatures typical of hot stamping. The phenomena at the dies counterpart interfaces are investigated mostly in the first group [10], but the use of materials and coatings are not linked to the local temperatures and to heat transfer. It was observed that the major damage is often represented by material

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transfer, resulting from the adhesion of the sheet metal-coating particles during the sliding at elevated temperatures, while abrasive wear appears as a minor phenomenon [3].

Being the deformation mostly completed near the austenite range [11], the heat transfer at the interface is the most important parameter to be taken into account for the quenching stage. Some Authors proved the importance of the metal sheet topography and anti-oxidation coatings on the heat transfer coefficient and pointed out that the thermo-physical properties (i.e. thermal conductivity, specific heat capacity) are the primary influencing factors on the HTC [12]. Regarding the tool materials, only few examples of pre-industrial developments are reported in [13], where steel grades are specifically developed to provide elevated hardness and HTC at high temperatures. Unfortunately, common materials actually used to manufacture dies and tools are not designed for such purposes yet, and start to be a critical limit to speed up the processes.

The present paper focuses on the investigation of new steel grades specifically developed for hot stamping applications, with high surface hardness and elevated heat transfer coefficient values to ensure the maximum heat exchange rate in the quenching phase. The two grades investigated differ for the dispersion of the molybdenum in the metal matrix. A novel High Temperature Tribological testing procedure was applied to investigate the tribological conditions of the dies material with thermo-mechanical cyclic loads, characterized by normal surface pressures in the range of a few tens of MPa and temperatures from 600 °C up to 800 °C.

2. Industrial process

The thermo-mechanical sequence of the operations that can be realized in hot stamping allows obtaining high mechanical properties for a wide range of parts geometries, with reduced level of stamping loads. During the process, the blank material, which presents a ferritic-pearlitic microstructure in the as-received conditions, is heated in a furnace above the austenitization temperature (approximately above 950 °C). After a soaking time of 180–360 s, long enough to assure the fully austenitization, the blank is rapidly transferred to the forming press, where it is formed and quenched at a cooling rate higher than 30 °C/s [17]. Thanks to the high temperatures, the average forming loads are significantly reduced, and the normal pressure at the interface between the blank and the dies results [18] in the range between 5 and 15 MPa under the blank holder and with peaks of about 200 MPa in the most critical forming sections [19]. According to the industrial experience, the average normal pressure is in the range of few tens of MPa for large portions of the forming dies. At the end of the cycle, the formed component presents a fully martensitic microstructure, with strength levels above 1500 MPa and still acceptable ductility.

3. Materials

3.1. Sheet metal

The material used in the investigations is the commercially available boron steel USIBOR1500P™, specifically designed for hot stamping applications, which consists in 22MnB5 metal sheets covered with an Al–Si hot-dip galvanized coating in order to prevent the oxidation during the heating and forming at elevated temperature. The sheets present an average thickness of 1.5 (±0.1) mm, and the nominal chemical composition is reported in Table 1.

The average coating thickness of the provided batch has significant scattering in the thickness of the AlSi coating that was measured through Scanning Electron Microscope (SEM) observations to be equal to 25(±10) μm. Fig. 1a shows the SEM cross section of the blank coating at room temperature in the as-delivered condition, with the typical layered structure already described in [7]. According to the images of Fig. 1b acquired by the SEM and 3D profiler (c), the coating surface is characterized by small valleys, with a maximum depth around 3(±0.2) μm, see Fig. 1d. The average surface roughness measurement is of S_a=1.295(±0.095) μm.

3.2. Tool steels

The investigated tool steel is commercially available with the name of High Thermal Conductivity Steel (HTCS®), provided in two grades named HTCS1 and HTCS3 [13]. Such steels, specifically designed for hot stamping processes, present a thermal

Table 1
Nominal chemical composition of the USIBOR1500P™ (wt%).

C	Mn	Si	Cr	Ti	B
0.21–0.25	1.1–1.4	0.15–0.35	0.15–0.30	0.02–0.05	0.03–0.005

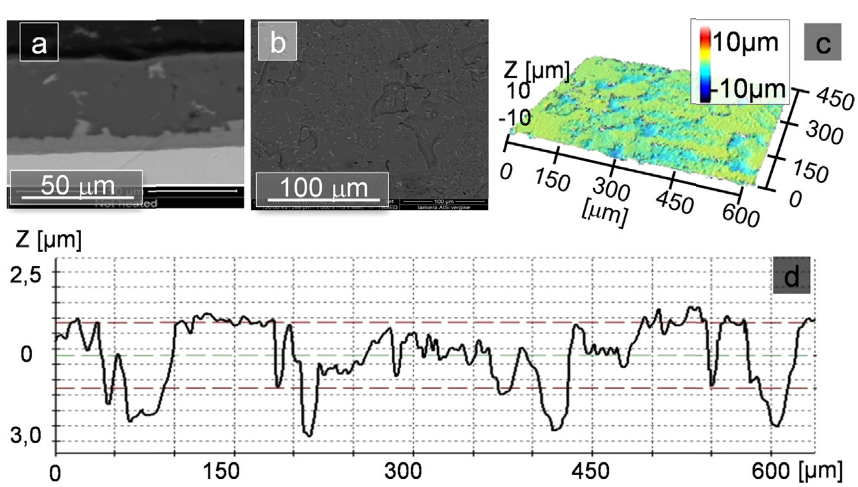

Fig. 1. 22MnB5 coating in the as-delivered condition: (a) AlSi thickness measured at room temperature and (b) surface topography observed with the SEM and (c) 3D profiler. (d) Metal sheet profile measured along the rolling direction.