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Wear onset in hot stamping of aluminium alloys sheets

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ABSTRACT

In the last two decades, severe regulations on fuel consumption, gas emissions and product recyclability have driven the attention of the automotive industry to the use of high-strength aluminium alloys to manufacture lightweight structural parts of the car body-in-white. To overcome the low formability and springback when these alloys are formed at room temperature, new high temperature forming processes have been developed with a critical impact on the lubrication policies, dies materials, and wear resistance.

The paper presents experimental investigations on the tribological performances of solid lubricants for the AA6016 aluminium alloy, by reproducing the different thermal conditions at the blank-die interface typical of the hot stamping process. A novel spraying apparatus was developed to apply the lubricants on the metal blank and capable of accurate control of the deposition parameters (i.e. temperature, pressure, film thickness) and quantity of the depositions. The performances of lubricants based on graphite, molybdenum-disulphide and boron-nitride were investigated, in terms of frictional and wear behaviour, by means of a novel strip drawing apparatus in the temperature range 300–400 °C and normal contact pressures up to 15 MPa. The surface characteristics of the metal sheets at the wear onset were analysed by means of optical profilometry, scanning electron microscopy and energy-dispersive X-ray spectroscopy. The results showed that the wear onset was primarily due to a loss of adhesion of the lubricants, and it was delayed when using graphite-based lubricants. It was found that at increasing the process temperature both the friction coefficient and the material adhesion increased, while the higher the sliding speed and pressure, the lower the friction coefficient. In particular, the influence of the pressure was found to be larger than the one of the sliding speed.

1. Introduction

Severe national and international regulations in terms of environment and energy consumption are forcing the automotive industry to work for a continuous improvement of the engines performances as well as for the decrease of the vehicles weight. Being unchanged the stiffness-to-weight ratio requirements, the latter has led to explore the applicability of new materials for the car-body-in-white, not limiting the choice to steels, but also introducing lightweight alloys such as aluminium, magnesium and titanium [1]. Recent analyses have estimated that, by using such alloys in substitution of the most commonly used steels, a mass reduction per vehicle equal to 120 kg can be obtained saving 982 million litres of fuel per year: in the case of 10 million cars with an annual mileage of 15,000 km, this results in a 2.3 million tons reduction in the CO_2 emissions into the atmosphere [2].

The AA5xxx and AA6xxx aluminium alloys have proved to be among the best candidates for such applications thanks to their mechanical (high strength-to-mass ratio) and chemical properties (good corrosion resistance and weldability) [3]. However, when formed at room temperature as in conventional sheet metal forming processes, they suffer of poor formability and significant springback, especially with complex shape part. A substantial increase of their formability [4] and, at the same time, a springback drastic reduction can be achieved using hot stamping processes, where the metal sheets undergo plastic deformation at elevated temperatures [5]. In these applications, friction and wear are recognized to be critical aspects due to the abrasive characteristics of the aluminium alloys and their tendency to adhere to the dies [6]. Furthermore, friction and wear in hot stamping processes are known to be influenced by several factors, both physical, such as the tool geometry and surface conditions, and process-dependent, such as the sliding velocity, temperature and contact pressure [7]. Therefore, the assumption of a constant friction coefficient is not representative of the real interface conditions in hot forming operations, and more accurate investigations of the local events at the blank-die interface are mandatory to support all the steps of the process design and optimization [8,9].

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In this paper, the friction behaviour at elevated temperatures of the commercial AA6016 aluminium alloy was investigated when using different solid lubricants and process parameters, reproducing the thermal conditions at the blank-die interface as in hot forming processes. The paper is organized into three parts. After a brief description of the reference industrial case, the materials object of the investigation are described. The second part deals with the description of the laboratory tests and experimental plans. Finally, the results of the experiments are discussed.

2. Reference industrial case

The reference industrial process is the hot stamping of the AA6016 aluminium alloy for automotive applications and, specifically, structural parts of the car body-in-white. During a typical hot stamping process, the blank is first heated up to 550 °C in an electric or gas furnace for 1800 s in order to obtain the full dissolution of the alloying elements. After the blank is transferred to the cold dies in about 10 s, the dies are closed in about 4 s using a ram speed that can range from 5 up to 50 mm/s, to keep the blank temperature in the range 300–450 °C, and then held for 15 s to ensure the sheet quenching. Typical applied pressures are in the range of 10–15 MPa with sliding velocities in the range of 5–30 mm/s [10]. Finally, the part is age hardened to obtain the T6 state at 120 °C for 24 h [11,12]. In each stamping cycle, the sheet is lubricated with lubricants devoted to hot forming processes [13], with the aim at reducing the sliding resistance and possible defects on the part due to the dies wear.

3. Materials

3.1. Sheet metal

The sheet metal object of investigation is the AA6016 aluminium alloy provided in 1.5 (±0.1) mm thick sheets. The alloy nominal chemical composition is reported in Table 1. The average surface roughness *Sa* of the as-delivered sheets was measured through the 3D surface profilometer Sensofar Plu Neox^{TM} and found equal to 1.043 (±0.032) μm (see Fig. 1).

3.2. Tool steel

The tool steel grade is the EN X38CrMoV5-1 alloyed steel, commercially available with the name of Böhler W300 (nominal chemical composition reported in Table 2). The tool steel was hardened through a thermal treatment consisting in a heating stage up to 1040 °C followed by oil quenching and subsequent annealing at 750 °C to obtain a surface hardness of 51.0(±1.5) HRC. The tools used in the experiments were machined using the same parameters of the reference industrial process, to obtain a final surface roughness *Sa* equal to 0.479(±0.019) μm and the surface topography shown in Fig. 2.

Table 1
Nominal chemical composition of the AA6016 alloy (wt%).

Chemical compositions in wt%					
Si	Fe	Cu	Mn	Mg	Al
1.10	0.28	0.069	0.058	0.39	Balance

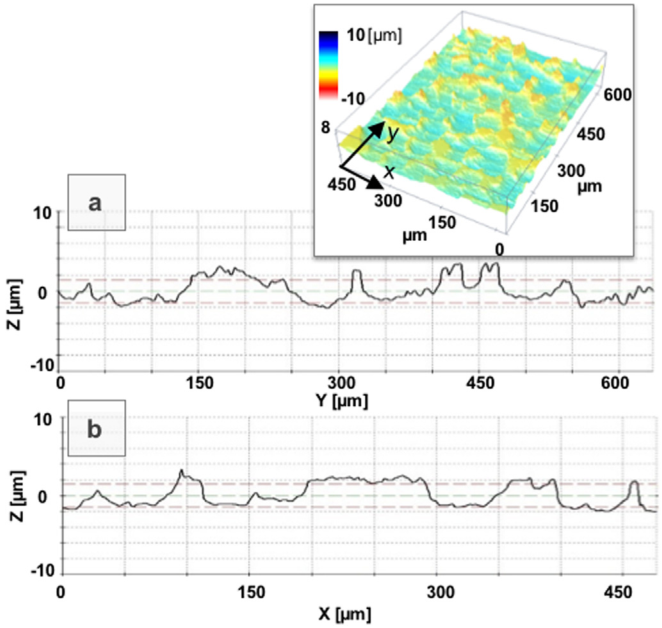

Fig. 1. Surface topography *Sa* of the as-delivered AA6016 sheets with detail of the roughness *Ra* in the *x* and *y* directions.

Table 2
Nominal chemical composition of the EN X38CrMoV5-1 steel (wt%).

Chemical compositions in wt%								
C	Si	Mn	P	S	Cr	Mo	Ni	V
0.39	0.97	0.43	0.015	0.006	5.01	1.14	0.21	0.35

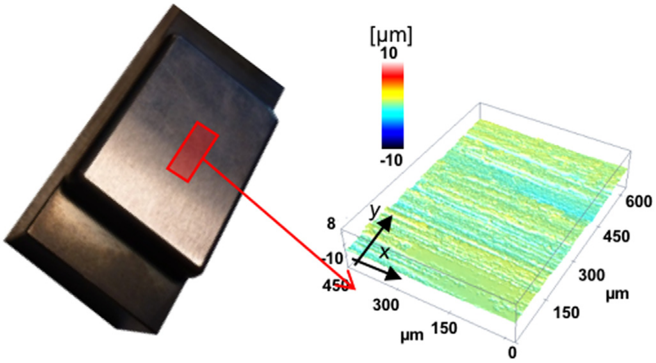

Fig. 2. Surface topography of the EN X38CrMoV5-1 die after the heat treatment and machining.

3.3. Lubricants

According to the industrial practice, the three following solid lubricants were selected for sake of comparison:

1. *Pulve BND 60A*®, based on a combination of boron-nitride aerosols, which results in a resistant paint thanks to the polymerization activated by the contact with the air. This lubricant is typically used to obtain surfaces that are anti-adherent, refractory and insulating at high temperatures, both at ambient atmosphere and in vacuum [15]. On the contrary, due to the sensitivity of the boron-nitride to humidity, it is not indicated for wet surfaces at room temperature. The average thickness of the coating after deposition was measured equal to 24(±5) μm while the surface roughness *Sa* was equal to 0.801(±0.117) μm.