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Wear analysis of tools in cold forging: PVD versus CVD TiN coatings

M. Dubar*, A. Dubois, L. Dubar

Laboratoire d'Automatique, de Mécanique et d'informatique Industrielles et Humaines, UMR 8530, Université de Valenciennes et du Hainaut Cambrésis, F-59313 Valenciennes Cedex 9, France

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Abstract

This paper proposes a new approach to the degradation of cold forging tooling. First, a mechanical analysis of a given forming process is performed. Contact pressure, plastic strain, sliding velocity and temperatures are computed at tool–workpiece interface. These contact conditions are then simulated on a specific friction test. The friction test involved in this work is dedicated to the simulation of hot and cold metal forming tribology. It involves a contactor, which creates a given plastic strain along the sample surface under given contact pressure, sliding velocity and temperature. The main results of that friction test are the Coulomb's coefficient of friction, contactor and sample surface roughness, chemical composition of the third body. In order to study the industrial degradation of the tooling in laboratory conditions, samples come from actual workpiece and contactors come from actual tools at various stages of their lifetime.

This new approach is applied to quantify wear of PVD and CVD TiN coated AISI M2 tools used to form a screw head. Friction tests highlight the drift of the friction conditions at the contact interface due to tool surface deterioration. The results show that the CVD coating has to be used to improve the production of the screw head forging sequence.

Keywords: Cold forging; Wear; TiN coating; Friction

1. Introduction

The prediction of the drift of the tools towards failure is an important objective to guarantee good output from a cold forging process. The failure of a tool does not only require it to be replaced but it also stops production, causes rejection of the workpieces, and requires new adjustment of the machine. The replacement of tools planned according to a predictive maintenance program only affects less productivity than unexpected stops. However, in most cases the lifetime of the tool is not optimised, which means a loss of around 10% of the cost of the finished part [1,2].

Wear phenomenon is usually synonymous with loss of matter. The main actor of wear is the contact between the asperities present on a roughness profile. The removal of these asperities occurs according to various mechanisms such as abrasion, adhesion or fatigue contact, and depends on numerous parameters such as hardness of the surface, roughness, temperatures and lubrication [3]. Recent observations carried out on different tools either in cold or in hot forging, showed that all these wear mechanisms could be present at the same time on a single surface [4,5]. Moreover, classical tribotests, such as pin on disk or the four ball test, only represent a part of the observed damage on forging tools and does not represent the real contact conditions of the studied process. In order to be more representative of the process contact conditions, a new methodology based on a specific testing device has been proposed to analyze and integrate wear in the simulation of the industrial process [6].

In a first part, the methodology based on a specific friction test is presented. The upsetting–sliding test, friction test dedicated to metal forming tribology and developed at the LAMIH (Laboratory for Automation, Mechanical Engineering, Information Sciences and Human Machine Systems), allows the industrial contact conditions to be reproduced and studied in laboratory conditions. The identification

* Corresponding author. Tel.: +33 3 27511381; fax: +33 3 27511317.
E-mail address: mirentxu.dubar@univ-valenciennes.fr (M. Dubar).

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of representative and reliable friction parameters at the tool–workpiece interface relies on the adjustment of this friction test. The implementation of the friction parameters into the numerical model of the process allows the influence of wear on the process to be quantified in terms of the scatter in friction stresses, leading to seizure at the tool–workpiece interface.

In a second part, the methodology is applied to study wear of PVD and CVD TiN coated AISI M2 tool steels. The studied industrial process is the forging of an hexagonal screw head. Tool wear parameters are characterised in terms of friction coefficient variations and surface observations.

2. General strategy

2.1. Material data

Most of the time, a forming process involves a coated workpiece and a coated tool. The workpiece is coated to reduce friction, the tool to reduce wear. The rheological behaviour in the surface vicinity of a part is different from the one in core. The stress strain curves in core are identified by means of classical upsetting tests and specific methodology has been developed to identify the curves in the vicinity of the contact zone.

The methodology is based on an inverse procedure of identification, which involves an experimental part and a numerical one. The experimental part consists in Brinell indentation tests under increasing loads. The numerical part is the corresponding simulation of the experimental one. The coating is supposed to perfectly adhere to the substrate. The parameters of the behaviour law will be changed in order to make the numerical diameter converge towards the experimental one for each load case. The resulting behaviour law characterises the coating and its neighbouring substrate in a zone called the equivalent layer. Fig. 1 shows the two behaviour laws obtained with the AISI M2 tool steel (Table 1) coated with PVD TiN. The two curves converge one to another for a plastic strain around 0.1, which corresponds to the appearance of small cracks on the coating [7,8].

Similar curves are computed in the surface vicinity of the formed part.

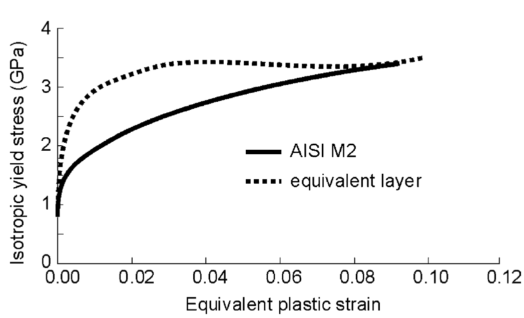

Fig. 1. Stress strain curves for the M2 PVD TiN coated steel.

Table 1
Chemical composition of AISI M2 steel

	AISI M2
C	0.8–0.87
Cr	3.5–4.5
W	5.7–6.7
Mo	4.6–5.3
V	1.7–2.2

The tribological data are a priori unknown. They are estimated to perform a first computation of the process, which leads to the knowledge of the contact conditions in terms of contact pressure and maximal equivalent plastic strain. The upsetting–sliding test is then involved to identify the friction parameters.

2.2. Upsetting–sliding test

The upsetting–sliding test (UST) is involved in this works to reproduce the contact conditions encountered at the tool–workpiece interface of cold forging process. A profiled sample represents the workpiece (in most cases a real workpiece part is used) and a contactor acts as the forging tool. The contactor is machined in a real tool by electroerosion so that the surface of the contactor that will come in contact with the sample is the working surface of the tool. Temperatures and lubrication of the process are also reproduced (the friction tests are operated with lubricants taken from the forging machine lubricant tank). During the test, the indenter moves up with a constant velocity towards the specimen. The indenter contacts the specimen and rubs against it, generating a locally deformed part. The forces, in both normal and tangential directions, are measured with special load sensors and recorded in a computer in order to calculate the Coulomb's friction coefficients (Fig. 2). In the case of a contactor with a cylindrical profile, the Coulomb's coefficient of friction is given by [9]:

$$\mu = \frac{\delta - p + q(F_t/F_n)}{q - (\delta - p)(F_t/F_n)}$$

where F_t and F_n are, respectively, the tangential and normal load on the contactor, p the penetration of the contactor into the sample, q the seating length of the contact zone and δ the height of the springback. UST results are completed with surface analysis (macro and micrographs, 3D surface measurements, hardness, chemical analysis of wear particles, etc.).

2.3. Methodology

The difficulty of the characterisation of wear phenomena mainly relies on two facts. First, it is almost impossible to analyse tool wear in situ (on industrial forging machine). So, observations and analysis have to be performed on laboratory devices. Second, tools may have to undergo several thousands of stroke before wear phenomenon may be observable. As it is impossible to perform so many tests in laboratory conditions,