Wear 328-329 (2015) 286–294

Contents lists available at ScienceDirect

Wear

journal homepage: www.elsevier.com/locate/wear

A study on galling initiation in friction coupling stretch bending with advanced high strength hot-dip galvanized sheet

Wurong Wang [a,*], Kai Wang [a], Yuzhang Zhao [a], Meng Hua [b], Xicheng Wei [a]

[a] School of Materials Science and Engineering, Shanghai University, Shanghai, China
[b] MBE Department, City University of Hong Kong, Hong Kong, China

ARTICLE INFO

Article history:
Received 15 December 2014
Received in revised form
22 February 2015
Accepted 24 February 2015
Available online 5 March 2015

Keywords:
Galling
Steel
Surface topography
Scratch testing

ABSTRACT

As a form of surface damage arising between sliding solids, galling has become a critical issue in the use of advanced high strength steel (AHSS) sheet and it will reduce tool life and lower part quality. To clarify the dynamic evolution of galling initiation and to identify its initiation quantitatively, this study was conducted to simulate the sliding of hot-dip galvanized AHSS sheet against cold-work DC53 die with the use of a self-developed sheet/strip tribo-tester. Such tester is capable to yield plastic deformation and stretch bending simultaneously. The test allowed the identification of galling initiation via analyzing the step response of recorded friction coefficient which was subsequently corroborated with the observation of surface morphology on die surface. The difference of sheet surface roughness in vertical direction (ΔR_y) was proposed as a quantitative index for the analysis and identification of galling initiation. Dynamic evolution of galling initiation was investigated with the help of SEM analyses on the surface of both slid sheet and die. Wear mechanisms affecting the friction behavior and galling initiation were subsequently suggested and discussed.

1. Introduction

Over the past few decades, the use of Advanced High Strength Steel (AHSS) in the automotive industry has been significantly increased because of its capability in improving crashworthiness and fuel economy. However, the major setbacks of AHSS from wide application are its limit of formability, high springback, and susceptibility in causing surface damage like galling. Galling is a form of severe adhesive wear normally involving with plastic flow of substrate and material transfer between mating surfaces [1]. It is distinguished and/or characterized with macroscopic localization of protrusions on the original surface, which subsequently causes further roughing and surface damage. In the forming of AHSS, it usually gives much higher contact pressure and temperature at the tool–workpiece interface than those in forming mild steel. Groche et al. [2] studied the wear behavior of tool materials in forming AHSS sheet metal by continuous measurements of the forces and temperatures of tool and sheet metal during forming stage. Their results revealed tool failure taking place in some regions exerted with highest loads and wear mechanism to be mere abrasion. Pereira et al. [3] examined the friction- and deformation-induced heating in the process of stamping AHSS steel and discovered that the temperature to be generated in normal ambient production conditions could be as high as 180 °C. All these are unfavorable to tribological performances of AHSS steel, and susceptibly leading to failure of commonly used lubricants which subsequently induces galling. The occurrence of galling can significantly reduce tool life, and generate unsatisfactory quality with scratched surface quality so as to increase the rejection rate of stamped parts.

Sheet metal forming with AHSS often suffers from wear, which is generally characterized by the material transfer from sheet to forming tool surface. Such mode of material transfer tends to cause scratching and unstable frictional behavior on the surface of sheets. There were a number of methods/approaches to be proposed for wear testing of AHSS steel sheet. Among them, Hummel and Partlow [4] compared the onset of galling by an ASTM button-on-block test (which is often referred as standard ASTM G98 [5]) and another non-ASTM button-on-cylinder test. Results from the two tests were basically agreeable qualitatively, but poor to be comparable quantitatively. Recognizing the existence of stress concentration in the ASTM G98, Hummel [6] designed a configuration of pilot testing to eliminate the non-uniform stress concentration. The configuration was basically consisted of two hollow cylindrical specimens concentrically aligned and loaded along their longitudinal axes. Such configuration provided contact surface in shape of an annulus with uniform stress distribution [7].

* Corresponding author. Tel.: +86 21 5633 1377; fax: +86 21 5633 1466.
E-mail address: wrwang@shu.edu.cn (W. Wang).

http://dx.doi.org/10.1016/j.wear.2015.02.058
0043-1648/

Its achievement of uniform stress distribution is mainly because [6]: (i) its well aligned setup provides uniform loading between the annularly contact surfaces; (ii) the recess neck of its alignment pin and the same outside diameter of the top and bottom hollow cylinders effectively release any possible entrapment of debris; and (iii) the small annularly interfacial contact area usually means difficult to capture debris within so as to give proper contact; etc. Although results from the button-on-block tests do not yield quantitative data suitably for detail design purposes, they can be used as references for rapidly ranking galling resistance of material pairs.

To simulate more closely the sliding in sheet metal forming experiments, Nine [8] developed a drawbead test method involving with successively bending and unbending of strip over two curved tools. Although the test method was originally designated for measuring the drawbead force, Hirasaka and Nishimura [9] extended the test technique to investigate the effect of surface micro-geometry of steel sheets on galling behavior. They also used the technique for measuring the associated friction coefficient. Kim et al. [10] performed a rectangular deep drawing and friction test for analyzing the friction characteristics of forming pre-coated metal sheets (PCMS). Their study indicated the achievement of low friction coefficients (μ=0.15–0.20) with the PCMS even in non-lubricated condition. It is anticipated that the coating film can play the role of lubrication effectively and subsequently diminishes the cause of galling. Gåård et al. [11] and Karlsson et al. [12] developed a slider-on-flat-surface (SOFS) tribometer with sliding tool surface consistently in contact with a fresh sheet surface. Use of the tribometer facilitates the exploration of galling resistance and wear mechanism of cold work tool materials to slide against carbon steel sheets [11] and against high strength stainless steel sheets [12]. Using twist compression test (TCT), Kim et al. [13] investigated galling behavior in forming AHSS and studied the coefficient of friction (COF) as a function of time with the use of various stamping lubricants. Stretching and/or bending deformation are the common deformation modes in forming sheet metals. However, the drawbead forming in [8–10] is generally associated with some specific sheet/strip forming processes. Their data are generally not applicable to the common deep drawing or stamping of sheet/strip. Furthermore, both SOFS [11,12] and TCT [13] testing methods normally do not involve with any bending deformation. As a result, data collected with the testing of both SOFS and TCT are not commonly feasible to apply directly to the processes of sheet metal forming.

Galvanized steel is considerably being used in AHSS automotive structural parts for minimizing or preventing corrosion [14]. Hot-dip galvanization is a process for coating a layer of zinc onto iron, steel or aluminum by immersing the metal in a molten zinc bath at a temperature of around 860 °F (460 °C). Analysis of cross-sectional micrographs of hot-dip galvanized steel sheet by Rooij and Schipper [15] suggested the galvanized steel consisting of (i) pure zinc (Zn) in a most-outer layer, and (ii) mixture of zinc and iron in different ratios in the other layers. As contents, hardness as well as strength of the zinc layer and steel substrate tended to cause different tribological and wear behaviors under stretched sliding condition, it would thus be more significant and meaningful to understand the galling initiation rather than other modes directly related to tribology.

Through study of metal transfer and galling in a number of metallic systems, Merchant et al. [16] came to a conclusion that adhesive wear is the main wear mechanism of galling to cause sheet material transfer. Karlsson and Gåård et al. [11] summarized that the galling process was gradually developed in many stages and its final stage was often characterized with coarse scratching on the slid sheets and lumps of adhered material on the surface of forming tools. Although there are many different initiation mechanisms been propounded, these mechanisms are closely related to the combination of one, some or all of the effects of adhesion, surface defects, microstructure, efficiency of lubrication, and temperature [17–20]. With the increasing use of galvanized AHSS sheet in automotive industry, exploring and understanding the different aspects of galling like friction behavior, dynamic evolution and wear mechanism under friction coupling plastic bending deformation are certainly beneficial to proper design and application of the sheet.

The present study aims to capture and quantify the onset of galling when an AHSS DP590 galvanized sheet slides against a cold-work DC53 die tool under the coupling effect of friction and plastic bending deformation. The study was carried out with a self-developed tribo-tester specifically for evaluating the tribological characteristics under mixed and/or boundary lubrication.

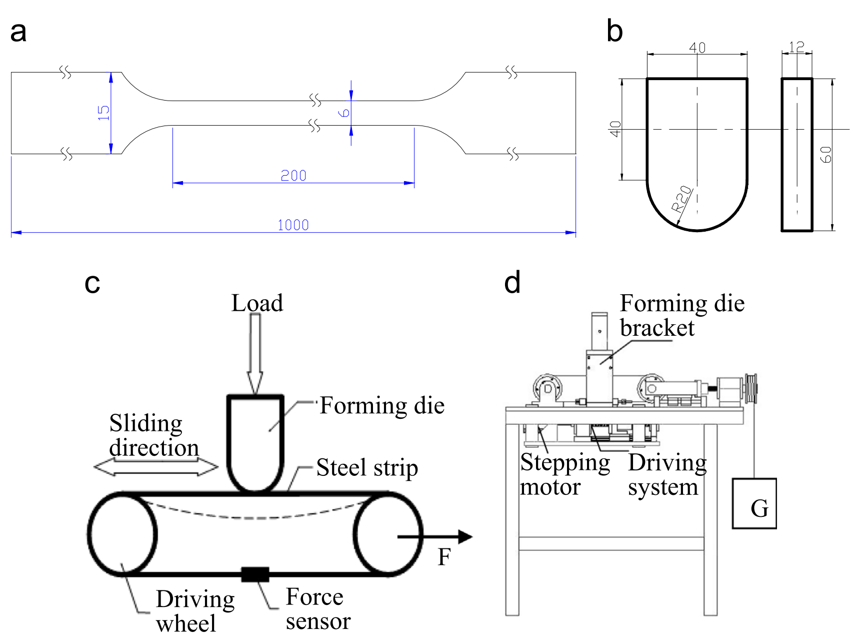

Fig. 1. Schematic illustration of friction test coupling deformation (a) sample; (b) DC53 steel sliding block; (c) schematic diagram for friction coupling ending deformation; (d) experimental set-up.