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A comparison study of sliding friction behavior between two high strength DP590 steel sheets against heat treated DC53 punch: Hot-dip galvanized sheet versus cold rolled bare sheet

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

[a] *School of Materials Science and Engineering, Shanghai University, Shanghai 200072, China*
[b] *MBE, City University of Hong Kong, 83 Tat Chee Avenue, Kowloon Tong, Hong Kong, China*

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ABSTRACT

Sliding friction tests were performed to compare the friction behaviors of hot-dip galvanized dual phase sheet (GA-DP590) and cold rolled bare sheet (BARE-DP590). The tests were undertaken with sheet specimens slid against heat treated DC53 punch mounted in a self-developed Tribo-tester to simulate the sliding between the sheets and the forming tool. Results show that the friction coefficients of GA-DP590 sheet are higher than those of BARE-DP590 sheet. The coefficient values of both sheets generally decrease with increasing of the loading, the punch stroke and the sliding speed. However, the frictional coefficients of GA-DP590 can be clearly classified into three stages. SEM observations on the slid sheets were performed to facilitate the understanding of the mechanisms affecting the friction behavior.

1. Introduction

Galvanized steel sheets have been developed and produced to stave the sheets off corrosion as a result of their exposure to other metals in the presence of an electrolyte, or to oxygen, or to water. The three major kinds of galvanized steel sheets widely used in industries are: hot-dip galvanized steel, electro galvanized steel, and aluminum coated Zn plate. As hot-dip galvanized steel is relatively cheap and ease-to-use in rolled steel coils, it is prevailed to use by many engineering industries. Most engineering steel workpieces are likely to be formed by sheet-metal-forming (SMF) process. Consequently, relative sliding between workpiece and forming tools usually induce friction and wear in the interface of sheet materials and die steel during forming. As the use of high strength steel (HSS) sheets and advanced HSS (AHSS) sheets have been greatly increased, forming of these stronger steel sheets usually is thus unavoidable and usually requires harder tool and larger tonnage press. This often results in serious damage of the galvanized Zn layer and defects on the surface of these workpieces. Hence, it leads to higher scrape rate and production cost. Transfer and accumulation of sheet material to tool surfaces by adherence effect and building-up of Zn powders on the die can be classified as galling wear. Events as such lead to surface defect on the workpiece and die life shortening. Surface defects so created recursively further affect friction and wear behavior of the sheets. Consequently, understanding the effect of galvanized Zn layer on the friction behavior between galvanized sheet materials and die tools is certainly important in improving quality of the formed parts, prolonging tool life, reducing scrap rate and production cost (as a result of optimizing the forming process).

Although many aspects of wear occurring in the forming of AHSS have been studied in literature, phenomena of galling may vary with the effective geometry and the dimensions of the mating components. Subsequently, the operational life of die and quality of product are also influenced [1]. To evaluate the galling and wear of sheet materials, techniques of ball scratching [2] and pin-on-disk [3] are normally used. Other techniques are also available in literature. Typically, Kim et al. [4] evaluated the performance of galvanized coatings and lubricants by a method of twist compression test (TCT). The method enabled the determination of the critical interface pressure and temperature that initiate galling or powdering in the process of forming galvanized AHSS. Bay et al. [5] also developed a laboratory testing technique for studying lubricant performance under different operational conditions of various sheet forming processes. The setback of these two test methods is that they do not reflect the actual stamping conditions in SMF processes and do not consider the situation of plastic deformation of sheet material. Hou et al. [6] investigated galling behaviors in SMF by drawing 400 specimens for every experiment. Although their test was undertaken in near real industrial operational conditions, their repetitive drawing tests exhausted a large amount of material and a great deal of experimental time, hence very expensive and time consuming.

* Correspondence to: Room 607, Rixin Building, No. 149 Yanchang Road, Shanghai 200072, China. Tel.: +86 21 5633 1377; fax: +86 21 5633 1466.
E-mail address: wrwang@shu.edu.cn (W. Wang).

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Study of Eriksson and Olsson [7] suggested when galvanized steel sheet was coated with CrC/C, CrN, and (Ti,Al)N, respectively, by physical-vapor-deposition (PVD), the material pick-up: (i) was increasing in order of CrC/C, CrN, and (Ti, Al)N if sheet was in contact with hot or cold rolled steel; and (ii) became significantly lower for the CrC/C or the (Ti,Al)N coating, as compared with the CrN coating, if sheet was in contact also with galvanized counterpart. Studies also showed that surface treatment of tool by PVD [8,9] or by carbon coatings [10] could also improve performance by suitably suppressing the occurrence of galling. Unfortunately, the size and cost problem prevents a majority of forming tools in automotive industry from coating. Knowledge of tribological characteristics in forming galvanized steel sheets is crucial in optimizing the relevant production processes and in facilitating the manufacturing of good quality products. Finite element analysis, in additional to experimental studies, thus also becomes an effective tool for predicting friction and galling in sliding condition [11].

The existence of galvanized Zn layer modifies the sheet friction mechanism. Study of Michal and Paik [12] found that mechanical properties like Young's module, yield strength and tensile strength of galvanized sheet were different from those of its bare base counterpart. Such difference results in dissimilarity of surface friction and formability between them. In situ scanning electron microscopy (SEM) analysis by Song and Sloof [13] facilitated the characterization of failure behavior of hot-dip galvanized Zn coatings on dual phase steels. They discovered that the propagation of microcracks along the Zn grain boundaries during tensile deformation prompted to form crack networks. Bellhouse and Mertens [14] also discovered that the intrinsic microstructure and the failure of the adhesion of coating to steel substrate were also the governing factors determining the crack behavior of Zn coating on the galvanized steel sheets. Large thermal mismatch between the Zn coating and steel substrate tends to induce microcracks at Zn grain boundaries during solidification. As a result, the crack density in Zn layer and the subsequent delamination of the Zn layer under loading are significantly affected [15]. However, understanding the influence of galvanized Zn layer on wear characteristics and surface defect generation in sliding contact of sheets and forming tools is still rather lacking.

This paper compares the friction behaviors of hot-dip galvanized DP590 (GA-DP590) sheets and cold rolled bare DP590 (BARE-DP590) sheets slid against DC53 punches. The comparisons were performed by coupling sliding friction with external loading to yield tensile deformation using a self-developed Tribo-tester. Analysis of the recorded friction coefficient permitted the effect of sliding speed, punch stroke, and tensile loading on friction behaviors to be studied. Scanning electron microscopy was also used to reveal the evolution of spalling, wear mechanism, and the effect of Zn layer on the frictional surface of DP590 steel sheets.

2. The experiment

2.1. The Tribo-tester

A patent pending Tribo-tester (Fig. 1) was designed and built to simulate the sliding friction between sheet/strip and the nose of punch in deep drawing process. Labels 1 to 13 in Fig. 1 represent the corresponding parts constituting the tester, while the remaining numbers specify the dimension of the relevant components in mm. Output from the sensing components were input to a computer data logging system. The complete tester was consisted of two subassemblies: (i) specimen mounting and deformation subassembly; and (ii) subassembly of driving and sliding mechanism. Referring to Fig. 1, the subassembly (i) was consisted of parts labeled by numbers 1 to 7 and 13, while the subassembly (ii) was composed of parts labeled by numbers 8 to 12. Alignment of the subassembly (i) with subassembly (ii) was properly ensured before the conduction of any test.

Prior to testing, a prepared sheet–strip specimen (Label 4) was wrapped over the pulleys (Labels 3 and 7). The pulleys were mounted in the respectively supporting frame with roller bearings so as to eliminate/minimize possible friction between supporting frames and pulleys. The specimen was connected by a connecting rod (Label 6) which had force sensor for detecting frictional force. The force sensor was well calibrated under tensile loading condition with accuracy in range of 0.5–0.1% of the applied loads. The circular half steel disk at the bottom of punch (forming tool – Label 5) simulated a deep drawing punch and acted as a friction mating pin. This half steel disk was connected to a rigidly mounted bracket by an adjustable block. The block was meant to release down or to retrieve up the circular half disk along a vertical plane so as to deform plastically the sheet–strip specimen, and yet to provide a means for varying sliding friction between the interface of specimen and tool. The mounting of the block allowed adjusting the depth of punch stroke within an accuracy of 0.25 mm. Test was performed with a weight (label "G") being applied on the hanger fastened to a chain round over an eccentric wheel (Label 1). The applied weight served to provide deformation loading to the sheet–strip specimen through the pulling action of the shift-able pulley bracket (Label 2) in front of the front pulley (Label 3). Suitably setting of the distance of the circular half disk on the punch and the weight G, the amount of plastic deformation of a test specimen was subsequently accomplished. During testing, the step motor (Label 8) drove to rotate the ball screw (Label 12) and subsequently to slide the linear bearing slide (Label 10) and the connecting and mounting workpiece (Label 9). The connecting and mounting workpiece was connected to the connecting rod with force sensor (Label 6). Its linear motion drove the sheet/strip specimen to slide relatively to the surface of the circular half disk under the punch. A computer data logging system was pre-programed to control the

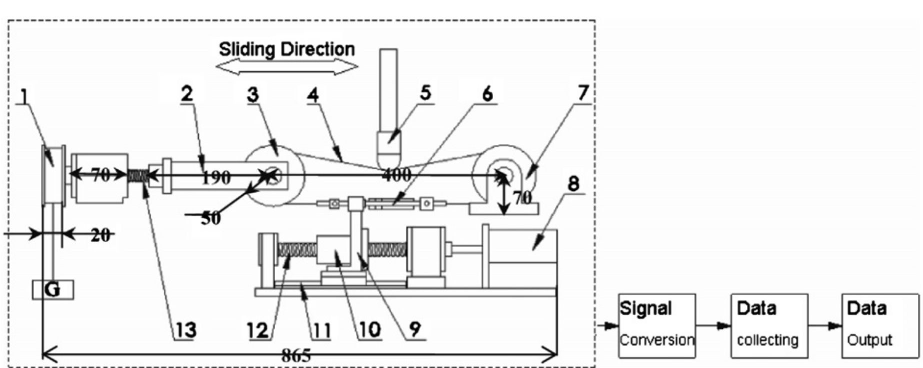

Fig. 1. Schematic of the developed Tribo-tester. 1: eccentric wheel; 2: shiftable pulley bracket; 3: shiftable pulley; 4: sheet/strip metal (Test specimen); 5: punch (forming tool); 6: connecting rod with force sensor; 7: static pulley; 8: stepping motor; 9: connecting and mounting workpiece; 10: slider; 11: linear bearing slide; 12: ball screw; 13: load screw drive.