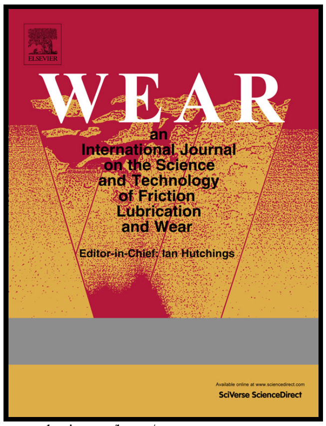

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Influence of Microstructure on Galling Resistance of Cold-Work Tool Steels with Different Chemical Compositions when Sliding against Ultra-High-Strength Steel Sheets under Dry Condition

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Abstract
The objective of this study was to determine the influence of a microstructure on the galling resistance of three variations of D2-grade steels that are used for the stamping of ultra-high-strength steel (UHSS) sheets. Standard D2 steel and two other types of D2-grade steel, having different microstructures, were used as the pins in a pin-on-flat galling test, and a dual-phase 980 (DP 980) sheet was used as the counterface. The friction coefficient was monitored as a function of the sliding distance, and the critical sliding distance for the onset of severe galling was indicated by the transition to a high and unstable friction coefficient. The best galling resistance was observed for the steel that contained a large amount of relatively small secondary carbides, whereas the worst galling resistance was obtained for standard D2 steel, which contained a large amount of coarse primary carbides. The test data also indicated that the galling resistance of the cold-worked tool steels was influenced by the type, size, and distribution of the carbides rather than simply by the total amount of carbides. Furthermore, it was inferred that the galling resistance of cold-worked tool steels could be improved by larger amounts of secondary carbides, smaller mean free paths between secondary carbides, and smaller mean diameters of both primary and secondary carbides.

Keyword
Cold-work tool steel; Galling resistance; Primary carbides; Secondary carbides; Ultra-high-strength steel sheet; Stamping

1. Introduction

Ultra-high-strength steel (UHSS) sheets have been widely used to manufacture lightweight and rigid automotive panels and structures because of the increasing demand for improvement of fuel consumption and reduction of CO_2 emissions, as well as the enhancement of passenger safety. However, cold-work tool steels that is used in the stamping of UHSS sheets undergo severe surface damage because of the high contact pressure at the interface between the sheet and the tool. This surface damage of the stamping tool is strongly related to adhesive wear, generally referred to as galling, a phenomenon in which sheet material is transferred to and accumulated on the tool surface [1–7]. Therefore, tool surface failure in the stamping process of UHSS sheets predominantly occurs as a result of galling [8,9].

The galling resistance of tool steels is greatly influenced by the tool material, surface engineering treatments, and characteristics of the lubricant used [6,8,9]. It is generally known that the application of hard coatings to the tool steel can be effective in decreasing galling [2,5,7,10]. Moreover, surface roughness and topography also influence the galling and wear characteristics of the tool steel. Therefore, polishing of the contact surface and reduction of the substrate roughness can improve the galling resistance of tool steels [8,9,11,12]. Great efforts have also been made to investigate the influence of the microstructures of the tool steel on the galling resistance. The galling resistance of powder metallurgy (PM) tool steels has been compared with that of the conventional cold-work tool steel, AISI D2 steel (hereafter abbreviated as D2 steel), in many previous studies [6,13–20]. It has been reported that, because of the low adhesion tendency of the counter material to carbides, the galling resistance of PM steels, which have small, distributed carbides, is better than that of D2 steel, which has large, elongated carbides. The studies also contended that the higher galling resistance of PM steels is due to the large amount of uniformly distributed carbides they contain.

However, in the automotive industry, D2 steel is more widely used as the stamping die tool material because of its the low manufacturing cost compared with PM steel. Therefore, to enhance the galling resistance during the stamping of UHSS sheets, current automobile manufacturers require an improved variation of D2 steel. To achieve this, verification is first needed regarding whether the influence of type, size, amount, and distribution of carbides on the galling resistance, which has been reported in previous studies [6,13–20] for PM steel, is applicable to D2 steel, especially when UHSS is used as the counterface. In general, the microstructure of D2