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Influence of tool steel microstructure on friction and initial material transfer

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ABSTRACT

An investigation was conducted to study the influence of tool steel microstructure on initial material transfer and friction. Two different powder metallurgy tool steels and an ingot cast tool material were tested in dry sliding against 1.4301, 1.4162, Domex 355 MC and Domex 700 MC sheet materials. It was found that tool steel hard phase heights influence initial material transfer and friction. The coefficient of friction increased with decreasing tool steel hard phase heights at 50 N normal load and initial material transfer occurred around protruding hard phases. At higher load of 500 N the sheet material adhered to both the tool steel matrix and hard phases. Coefficient of friction decreased with increasing proof strength of the sheet material at 500 N normal load.

1. Introduction

Surface damage related to material transfer and adhesive wear in sheet metal forming (SMF) operations is known as galling. The ASTM standard G40 defines galling as "*A form of surface damage arising between sliding solids, distinguished by macroscopic, usually localized, roughening and creations of protrusion rising above the original surface; it often includes material transfer, or plastic flow, or both*" [1]. In SMF, galling results in high and unstable friction, scratching of produced parts and damage of the metal forming tool causing costly production stops due to replacement of the tool. Therefore, it is of high importance for the sheet metal forming industry to gain more knowledge about galling.

It has been shown that galling is a gradual process and is influenced by factors such as tool and sheet mechanical properties and surface roughness, type of lubricant, contact pressure and lubricant failure due to frictional heating [2–7]. Tool steel microstructure is another important factor influencing the galling resistance of the tool [2,5,8–13]. However, details of the very beginning stage of galling are not systematically investigated. Thus, tests focusing on the initial material transfer are important. It has been shown in studies of the early stage of galling under lubricated conditions [11,13] that material transfer already occurred after short sliding distances. Mechanisms of the very first transfer are not clear and influences of tool steel microstructure, phase composition and chemical composition have not been systematically investigated. Therefore, it is important to investigate the initiation of material transfer for several different material couples.

In the present study the influence of tool steel microstructure on initial material transfer and friction was studied. Three different tool steels were tested against four different sheet materials under dry sliding conditions in a slider-on-flat-surface (SOFS) tribometer using a single pass of sheet material over the tool steel surfaces. Tests were done under high- and low-load conditions to evaluate influence of contact situation on the beginning of sheet material transfer to the tool steel surface.

2. Experimental

2.1. Wear tests

Wear tests were performed in ambient air (24 °C, 30% relative humidity) under dry sliding condition in a slider-on-flat-surface (SOFS) tribometer, Fig. 1(a), using a sliding speed of 0.0025 m/s and normal loads of 50 N and 500 N. Changes in friction during wear testing were continuously logged by a computer through collection of signals from force gauges measuring normal force, F_1, and friction force F_2, Fig. 1(a). In the SOFS tribometer a disc was slid against a counterbody material. The disc was slid in one direction and at a predetermined sliding length the disc was lifted and moved back to the point of origin. After a small shift

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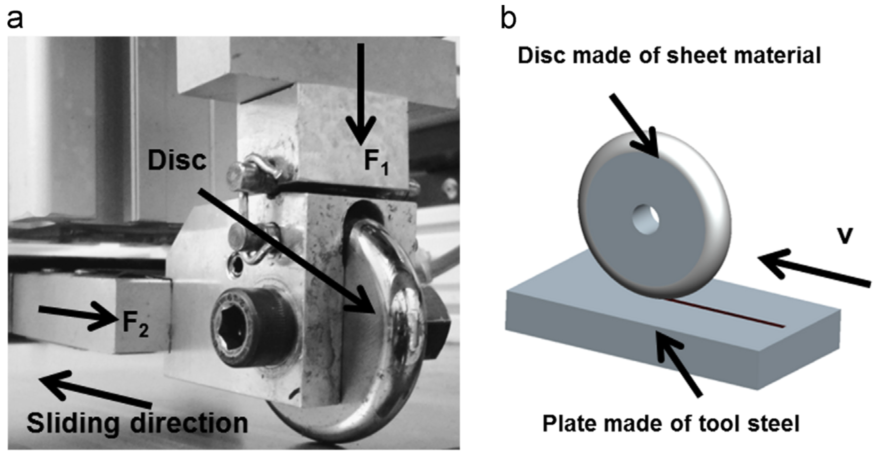

Fig. 1. Overview of the SOFS (a) displaying the disc fixed in a disc holder and force gauges F_1 and F_2. In the SOFS tests, discs made of sheet material were slid against plates made of tool steels (b).

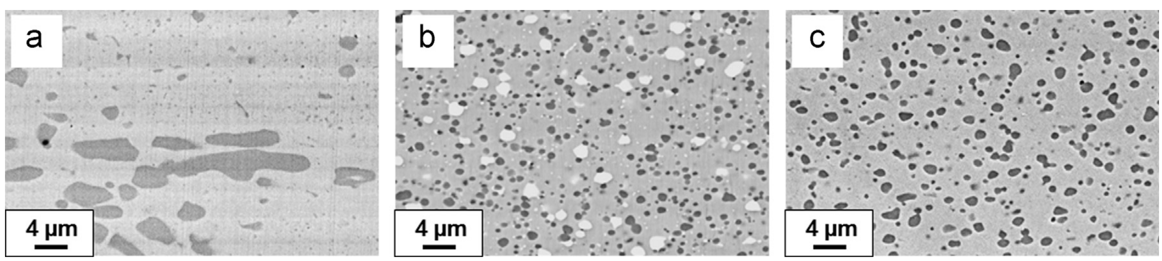

Fig. 2. Microstructure of the IC (a) steel comprising M_7C_3 carbides and the Vancron 40 steel (b) comprising M(C,N) carbonitrides and M_6C carbides. In (c) the microstructure of the PM2 tool steel containing MC carbides is shown.

perpendicular to the sliding direction the disc sliding movement might be reiterated against a fresh counterbody surface. The history of material transfer and wear was preserved on the surface of the counterbody. In the present study, the sheet material transfer to tool steel surface was in focus and, therefore, tool steels were chosen as counterbody. In the tests done in the present research, a double-curved disc made of sheet material with 25 mm and 5 mm radii was pressed and slid against plates made of tool steels with size of approximately $85 \times 45 \times 12$ mm^3, Fig. 1(b). The disc was slid in a single stroke against the tool steel plate and the stroke length was 75 mm. Test specimens were ultrasonically cleaned in ethanol prior to testing to ensure that no surface contaminants would affect the results.

2.2. Materials

The investigated tool materials were ingot cast (IC) EN X153WCrMoV12 tool steel and two different powder metallurgy (PM) steels: Uddeholm Vancron 40 and PM2, Fig. 2. The IC steel comprises M_7C_3 carbides with size of about 5–7 μm in diameter and 15–20 μm in length and the Vancron 40 steel contains M(C,N) carbonitrides and M_6C carbides with a diameter of approximately 1–2 μm. MC carbides with a diameter of about 1–2 μm were the hard phase in the PM2 material. Austenitizing temperatures of approximately 1050 °C and 1020 °C with holding time of 30 min and tempering at 525 °C for 2×2 h and 560 °C for 3×1 h were used to achieve the hardness of the IC and Vancron 40 tool steels, respectively. The austenitizing temperature for the PM2 steel was about 1020 °C with holding time of 30 min and tempering was performed at 525 °C for 2×2 h.

The sheet materials were austenitic (EN 1.4301) and duplex (EN 1.4162) stainless steels and two carbon steel sheet materials: Domex 355 MC (DX355) and Domex 700 MC (DX700). Data from the manufactures of the materials on chemical composition and mechanical properties are shown in Table 1. Independent of tool material type, the corresponding contact pressures to the normal loads used in the SOFS wear tests were approximately 0.83–0.85 GPa and 0.99–1.0 GPa at normal loads of 50 N and 500 N respectively in tests against the sheet materials EN 1.4301 and DX355. The corresponding contact pressures to 50 N and 500 N normal loads were 1.0–1.1 GPa and 1.5–1.7 GPa respectively in tests against the EN 1.4162 and DX700 sheet materials. Both the tool steels and sheet materials were delivered in as hardened condition.

Prior to wear tests, the test specimens were polished to approximately 0.05 μm (R_a) and subsequently cleaned in ethanol. The surface preparation of the discs made of sheet materials was performed manually using 500, 800 and 1000 mesh SiC papers for 4 min at each SiC paper mesh. Subsequently, polishing the discs to a mirror-like surface finish was performed using Struers MD-plus polishing disc and 3 μm diamond slurry for 4 min. The grinding and polishing of the tool steel plates were done automatically using Hermes EWK 500 mesh grinding disc for initial grinding of the plates at 150 N for 1 min. Subsequently, the tool steel plates were polished with Struers MD-Allegro polishing disc with 9 μm diamond slurry at 180 N for 5 min and MD-Plus with 3 μm at 140 N for 4.5 min. In the last surface preparation step of the tool steel plates a mirror-like surface was achieved by polishing the plates using Struers MD-Nap with 1 μm diamond slurry at 60 N for 1.5 min.

Surface roughness, height of hard phases and microstructure were investigated using a GEMENI LEO 1530 FEG scanning electron microscope (SEM) and a Innova atomic force microscope (AFM). Heights of the tool steel hard phases were measured using AFM.