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Influence of work material proof stress and tool steel microstructure on galling initiation and critical contact pressure

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ABSTRACT

EN 1.4301 (austenitic), EN 1.4509 (ferritic), EN 1.4162 (duplex) and EN 1.4310 C1000 (metastable austenitic) stainless steels were tested in lubricated sliding against an ingot cast EN X153WCrMoV12 and powder metallurgy nitrogen alloyed Uddeholm Vancron 40 tool steels to reveal critical to galling contact pressure, P_{cr}. The calculated P_{cr} were higher for steels with higher strength. At $P > P_{cr}$, due to plastic flow of sheet material, the tool is damaged substantially and wear-induced matrix damage causes rapid galling initiation. At $P < P_{cr}$, galling was not observed. The powder metallurgy tool steel was more resistant to galling against all tested stainless steels. Better performance was associated with fine and homogeneously distributed hard phases preventing intensive wear of the tool steel matrix.

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1. Introduction

Transfer and accumulation of sheet material to the tool surface is a major problem in the sheet metal forming (SMF) industry. The problem is known as galling, which results in unstable friction and severe scratching of produced parts. Among other materials, stainless steels are popular materials due to high corrosion resistance, high strength and formability, but the tendency to galling limits the applicability of these steels. The ASTM definition of galling is known as a form of surface damage arising between sliding solids, distinguished by macroscopic, usually localized, roughening and creation of protrusions above the original surface. It often includes material transfer, or plastic flow, or both [1]. The ASTM definition describes galling as a macroscopic surface damage, but it does not consider that galling in SMF is a gradual process as shown in [2–5]. It has been shown that galling is influenced by several process parameters such as frictional heating due to lubricant failure, tool and sheet surface roughness, contact pressure and type of lubricant [5–8].

Additionally, galling is influenced by the sheet and tool mechanical properties and microstructure, and tribological performance is significantly changing if one material is substituted with the other one. Therefore, wear tests with different material combinations must be performed for understanding of galling and prediction of performance of materials in SMF operations. In such tests it is important that the initial contact situation is identical regardless of material types, and therefore calculated contact pressures are suitable values for evaluation of different tribopairs in equivalent contact situation.

In this paper, influence of tool steel microstructure distribution and size of hard phase, mechanical properties of the sheet materials on tribological performance of each tribopairs factors was analyzed and discussed in relation to critical to galling contact pressure.

2. Experimental part

2.1. Wear test

Wear tests were performed in a slider-on-flat-surface (SOFS) tribometer using a sliding speed of 0.5 m/s and normal loads from 50 N to 700 N. In the tribometer, a double-curved disc made of tool steel with 25 mm and 5 mm radii was pressed and slid against a lubricated stainless sheet surface. The disc was slid in one direction and at the end of the sheet the disc was lifted from the sheet surface and moved back to the point of origin. After a small shift of 1 mm perpendicular to the sliding direction, the disc sliding movement was reiterated against a fresh sheet surface, Fig. 1 [2]. In this study the maximum sliding distance was set to 200 m at which the tests were aborted.

Prior to wear tests, the sheets were washed with a degreasing agent and ethanol in several steps before 5 g/m^2 Castrol FST-8 lubricant was applied.

2.2. Finite element calculations

Contact pressures were calculated using a 3D finite element model with loading in the z-direction, Fig. 2. In the model, the tools were regarded as elastic and the sheets as elastic-plastic von

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Mises materials with strain hardening according to tensile test data supplied by the producer. The sheet and the tool were modeled with symmetry according to Fig. 2, and 10-node modified quadratic tetrahedron (C3D10M) elements with hourglass control and refined mesh in the contact area. Based on experimental data before the onset of galling, a coefficient of friction of 0.1 was used in the model.

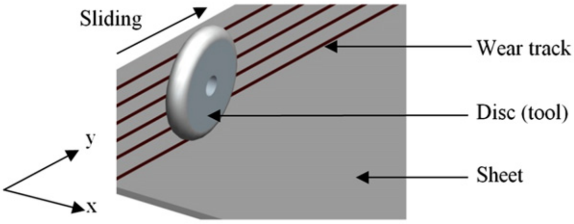

Fig. 1. Illustration of the SOFS tribometer.

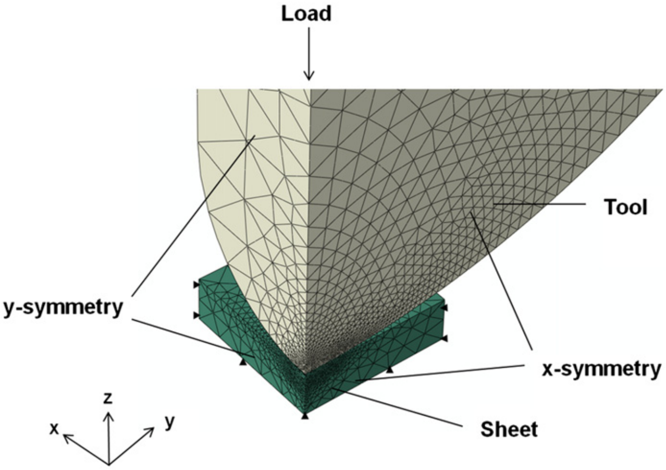

Fig. 2. Finite element model with quarter symmetry.

2.3. Materials

In this study the investigated tool materials were ingot cast (IC) EN X153WCrMoV12 and nitrogen alloyed powder metallurgy (PM) Uddeholm Vancron 40 tool steel, Fig. 3. The sheet materials were EN 1.4301 (austenitic), EN 1.4509 (ferritic), EN 1.4162 (duplex) and EN 1.4310 C1000 (metastable austenitic) stainless steels. Supplied data from the manufactures of the tested materials on chemical composition and mechanical properties of the tool and sheet steels are shown in Table 1.

The austenitic and the ferritic sheet materials had a 2B surface (annealed, pickled and skin passed), Fig. 4(a,b). The surface of the duplex and the metastable austenitic stainless steel sheets had a 2E (annealed, pickled and mechanical descaling by brushing) and a 2H (temper rolled) surface finish, respectively, Fig. 4(c,d).

To investigate surface roughness, microstructure and wear, tool and sheet surfaces were investigated in a GEMENI LEO 1530 FEG scanning electron microscope (SEM) and WYKO NT3300 optical profilometer, before and after wear tests.

3. Results

3.1. Friction behavior and wear mechanisms

Typical coefficient of friction data for the IC tool steel tested at 50 N and 200 N normal loads are presented in Fig. 5. At 200 N load, three stages of friction were observed within the test range. In order to correlate wear mechanisms to changes in friction, additional interrupted tests in each stage were done. In stage I, a thin layer of adhered sheet material to the tool surface and sheet surface flattening was observed in SEM, Fig. 6(a,d), though the coefficient of friction was stable. After 100 m sliding, the gradual increase of friction indicated transition to stage II. In stage two, sheet material fragments adhered locally to the tool surface, which were observed as microscopic lumps, Fig. 6(b). In this stage, abrasive wear pattern was found on the sheet surface, Fig. 6(e). In stage III, the coefficient of friction was high and

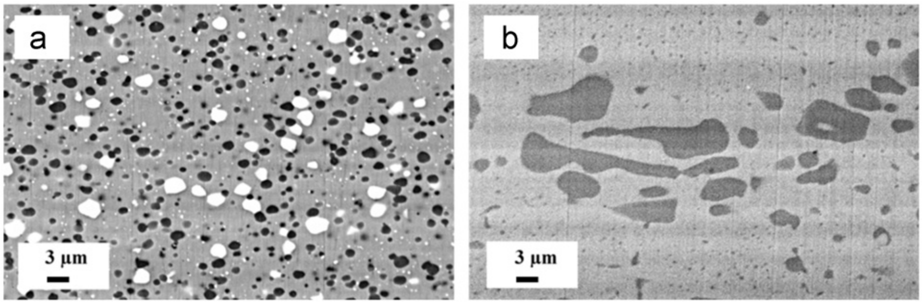

Fig. 3. Microstructure of the PM (a) and IC (b) tool steels.

Table 1
Chemical composition, structure, surface roughness and mechanical properties of the steel types.

Steel	Chemical composition [wt%]								Hard phase content [vol%]	Structure	$R_{p\ 0.2}$ [MPa]	Hardness	R_a [μm]
	C	Cr	Mo	W	N	V	Ni	Others					
PM	1.1	4.5	3.2	3.7	1.8	8.5	–	–	5% M_6C,14% M(C,N)	–	–	61HRC	0.05
IC	1.5	12	0.9	–	–	0.8	–	–	13% M_7C_3	–	–	60HRC	0.05
1.4301	0.04	18	–	–	–	–	8.1	–	–	Austenitic	300	$170 \pm 10HV_{0.05}$	0.2
1.4509	0.02	18	–	–	–	–	–	Nb Ti	–	Ferritic	360	$180 \pm 5HV_{0.05}$	0.2
1.4162	0.03	21.5	0.3	–	0.22	–	1.5	5 Mn	–	Duplex	600	$270 \pm 30HV_{0.05}$	0.3
1.4310 C1000	0.10	17	–	–	–	–	7	–	–	Metastable austenitic	900	$360 \pm 30HV_{0.05}$	0.4

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