Proceedings of Asia International Conference on Tribology 2018, pp. 251-252, September 2018

Investigation of galling mechanisms of 316L stainless steel using finite element method

G. Franz[1,*], K.E. Agode[1,2], S. Panier[1], T. Lesage[2], A. Jourani[2]

[1)] Laboratoire des Technologies Innovantes, EA 3899, Université de Picardie Jules Verne, IUT GMP, 80025 Amiens, France.
[2)] Laboratoire Roberval, UMR CNRS 7337, UTC, Centre de Recherche Royallieu, 60 203 Compiègne, France.

[*]Corresponding e-mail: gerald.franz@u-picardie.fr

Keywords: Galling; finite element modeling; 316 L austenitic Steel

ABSTRACT – Galling, defined as a severe kind of adhesive wear encountered when friction occurs between two sliding surfaces under sufficient load, is a complex multiscale and multi-physics phenomenon still not thoroughly understood. Its initiation and propagation is impacted by different factors related to microstructure, surface defects or chemical composition. Currently, a normalized galling test, denoted ASTM G-98, can be used to determine experimentally a threshold galling stress of material couples. A finite element modeling, using ABAQUS, of this tribological test is purposed in order to investigate the mechanisms appearing during galling of 316L stainless steel in particular.

1. INTRODUCTION

When two loaded mating surfaces slide with respect to each other, a form of surface damage, usually called galling, can be observed. Such a process occurs suddenly and evolves quickly, altering the surface integrity (material transfer, wear debris…) of the mechanical components, and consequently degrading their tribological properties. Galling can lead to disastrous consequences particularly in the agro-food, chemical and pharmaceutical industries (e.g. deposition of metal particles with carcinogenic elements (Cr, Ni…) on food or pharmaceutical products, atmospheric pollution by fine particles…), where austenitic stainless steels are commonly chosen for their relative ease of manufacture, high strength and stiffness, and excellent corrosion resistance. Unfortunately, these materials are also known for their poor resistance to galling [1].

A commonly used standardized test procedure for obtaining the relative ranking of galling resistance of material couples is the ASTM G-98 button-on-block test [2]. In this method, a constant compressive load is maintaining between two flat specimens. One cylindrical specimen with a flat end, called the button (or pin), is slowly rotated for one revolution on the other flat specimen held fixed, called the block. Galling is determined by unassisted visual inspection. A new galling test method, denoted ASTM G196-08, has been recently adopted as a new standard for galling measurement [3].

For a large part of works in the literature on the galling of stainless steels, conclusions relating on the influence of different factors on the severity of galling are limited to qualitative observations of the phenomena (e.g. impact of the nature of the materials, effect of the nature of the lubricant or the surface roughness, sensitivity to the type of surface treatment…). Little explanation is provided on the correlations between the adhesive wear resistance or galling threshold and the above-cited factors.

Due to its multi-physics aspects (thermal, chemical and mechanical) the wear process remains difficult to understand, as well as to simulate. The main objective of the present paper is to attempt to help of understanding of galling mechanisms of stainless steels using finite element modeling of the ASTM G-98 test.

2. GALLING RESISTANCE TEST – ASTM G98 BUTTON-ON-BLOCK TEST

The testing device, consisting of a standard tensile-compression machine, and specimens of the ASTM G-98 test are illustrated Figure 1. This galling test, which is a button-on-block test, is composed of two flat specimens maintained in compression each other while one of these specimens is rotated on only one full revolution, performed in 6 s in a single step. At the end of each test, both specimens are visually inspected. In the case where the specimens appear undamaged, the procedure is repeated with a higher load on untested specimens. Galling occurs if the contacting surfaces exhibit torn metal. The threshold galling is determined as the average between the highest non-galled test and the lowest galled test.

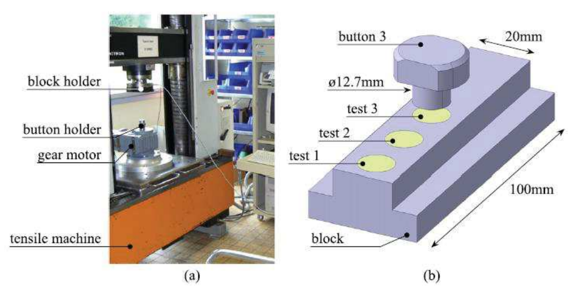

Figure 1 (a) Testing device and (b) specimen illustration with main dimensions, in reversed position [4].

3. FINITE ELEMENT MODELING

In a button-on-block system, a cylindrical pin with a flat end is sliding against a flat block, as described in the above section. The galling simulation is performed with the commercial software ABAQUS, for 316L stainless steel pairs. The pin and the block consist of the same elastic-plastic isotropic material (316L). The value of Young's modulus is 197 GPa and the Poisson's ratio is 0.3. In this model, the temperature effect is neglected because the standardized galling test is considered to be quasi-static due to its low rotation velocity (0.33π s^{-1}).

Since it is necessary to simulate the relative sliding motion between the pin and the block, the "finite sliding" formulation is chosen as allowing any arbitrary separation, rotation and sliding between the contacting surfaces. Furthermore, "surface to surface" contact discretization is used because it is well-known this kind of discretization improves accuracy of contact stresses. The overall finite element mesh is given Figure 2.

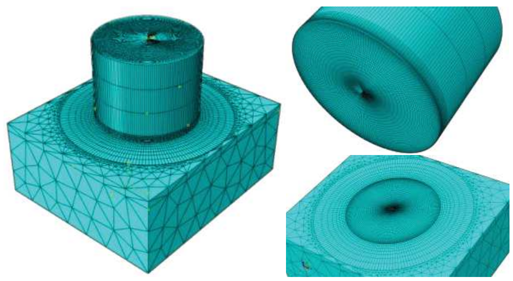

Figure 2 3D mesh of the ASTM G-98 configuration.

The main object of the purposed numerical modeling is first to reproduce the real pressure between the contacting surfaces and to determine the thickness of plastically affected regions. The pressure distribution between the pin and the disc is affected by the choice of the friction formulation. Friction modeling involves establishing relationship between the tangential contact force and the relative sliding speed. It is difficult to take into account the friction (adhesion-slip) because of the very great diversity of the behaviors. This leads to the formulation of several friction models. The first model, usually known as Coulomb or Amontons' laws, assumes that the friction force is proportional to the normal contact force. The coefficient of proportionality is called coefficient of friction and remains constant. These laws are not able to take into account the stick-slip phenomena. In order to cure this problem, several laws with variable coefficient of friction have been proposed. They based on the theory provided by Bowden et al. [5] and Tabor [6] and widely accepted. The friction coefficient can be expressed as the sum of an adhesive component, representing the formation and shearing of metallic junctions between the surface asperities, and a plowing component, depicting the plastic deformation of the softer surface by hard asperities.

4. RESULTS AND DISCUSSION

First, it is necessary to select the contact zone mesh sizes allowing reproducing accurately the contact pressure distribution between the pin and the block. Numerical simulations have been performed with different meshing for an elastic cylindrical flat button loaded in compression on an elastic block. The obtained results have been compared with the normalized contact pressure distribution $\frac{\sigma_z}{P_m}$ determined analytically [7] as a function of the contact radius a and the distance r from the centre of the button by:

$$\frac{\sigma_z}{P_m} = -\frac{a}{2\sqrt{a^2 - r^2}}, \qquad r \le a \tag{1}$$

For the chosen meshing, the comparison of the finite-element results with the analytical ones for the variation of normalized contact pressure is plotted Figure 3.

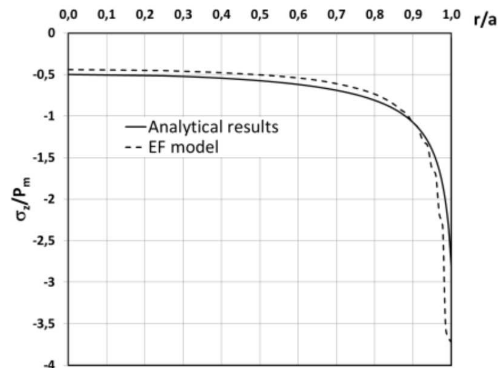

Figure 3 Normalized contact pressure distribution.

In order to validate the numerical model, the stress concentration will be then compared with experimental results of ASTM G-98 tests realized on 316L pairs. The thickness of plastically affected regions obtained numerically will be compared with SEM observations.

5. CONCLUSION

Quasi-static and sliding dry friction are frictional mechanisms studied since several decades but remain an open field of research due to the difficulty to correctly identify the contribution of numerous factors on the initiation and development of wear. The authors of the present article hope that the expected results with this numerical model will provide an additional contribution to the understanding of these complex mechanisms.

REFERENCES

[1] Anderson, A. E. (1992). ASM Handbook, Friction, Lubrification and Wear Technology. *Great Britain: ASM International*.

[2] ASTM G98-02. (2002). Standard test method for galling resistance of materials. *ASTM International.*

[3] ASTM G196-08. (2008). Standard test method for galling resistance of material couples. *ASTM International.*

[4] Hubert, C., Marteau, J., Deltombe, R., Chen, Y. M., & Bigerelle, M. (2014). Roughness characterization of the galling of metals. *Surface Topography: Metrology and Properties*, *2*(3), 034002.

[5] Bowden, F. P., Bowden, F. P., & Tabor, D. (2001). *The friction and lubrication of solids* (Vol. 1). Oxford university press.

[6] Tabor, D. (1964). *The friction and lubrication of solids*. Clarendon Press.

[7] Sneddon, I. N. (1946, February). Boussinesq's problem for a flat-ended cylinder. In *Mathematical Proceedings of the Cambridge Philosophical Society* (Vol. 42, No. 1, pp. 29-39). Cambridge University Press.