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Electrical performance of textured stainless steel under fretting

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ABSTRACT

Sliding between two couplings is the most common situation caused by dynamic solicitations, especially fretting. Preliminary studies suggest the relevance of contact compliance as well as the debris removable and agglomeration affinities.

The present work aims to analyse surface texturing influence, on the friction and electric conduction of AISI 304/301 stainless steel subjected to reciprocating fretting tests.

Textured surfaces present, most of the times, an increase in life expectancy of the electric connection. The ability to accommodate oxidize wear debris depends on the available open texture (hollow) volume and couplings contact size.

1. Introduction

Power supply connections of electric and electronic components often make use of austenitic stainless steel terminals when a good elastic behaviour is needed like spring contacts, high elastic modulus, but also battery contacts, particularly coin batteries.

Fretting wear is often associated with these types of contacts, either by the nature of small contact geometry or by work induced vibrations. This phenomenon is characterized by relative movement between two surfaces, typically in the range of microns, depending on the dimensions of the mated surfaces. The worn surface caused by this type of wear is similar to the contact interface geometry with directionality marks [1,2]. Tangential fretting, often associated to electric contacts, consists of a reciprocating linear relative movement of two mated surfaces, where the contact is maintained on a specific zone under displacement [3–5].

On the electric/electronic connector's performance subjected to fretting, the wear variation is not the most significant aspect but the electric resistance. The majority of published studies focus on the influence of coatings and surface treatments on electrical endurance of noble and non-noble metals with very good electrical conductivity [6–13]. Therefore, since the determination of electric resistance is directly related with interface contact materials, the fretting regime has an extremely important role in electric performance [6–8], whether in the preservation of coatings, maintaining a third-body-free interface, or expelling wear debris. Also, electric resistance can be predicted by the stabilized contact slip [7] and a resulting cycle span amplitude which allows a cross-comparison between different test rigs [6].

Electric current influence is usually a key parameter addressed by research on electric and electronic fretting [10,12], in part because there are limit working conditions but also due to the direct relation between electric resistance and current load considering the same power source, adding the known synergetic effects of dissipation mechanisms in electrical conductors [14].

On closed contact damage mechanisms as fretting, the creation of an oxide layer largely influences the contact performance, always depending of: temperature, atmospheric composition, and amount of available water as well as the contact parameters [15–19]. In this contact situation friction of the two surfaces resort on a plastic removal of particles through asperity contact, also increasing temperature to the point of rapid oxidation of the particles removed. For stainless steel, these oxides are mainly iron compounds because even with a high chromium content on the alloy the amount of iron in the composition is far greater and available for the immediately formed wear particle, a similar process as seen in [20]. The oxides that are expected to be found in a steel contact should be iron oxides (Fe_2O_3 and Fe_3O_4) [15] as found in a previous work [21], although the formation of these compounds is closely related with alloy elements and/or with surface modification techniques [15–17].

In an effort to modify friction, and consequent wear [22], surface wettability, [23], and surface morphology, [24], of selected surfaces, some authors started to apply texturization techniques. These are applied to a variety of applications but, for obvious reasons, fretting is a major field of interest. There are currently three technic groups to apply surface texture: chemical etching, mechanical plastic deformation and focused radiation emission.

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Chemical etching, commonly used to reveal alloy microstructures [25], consists of reacting process with partially or the entire surface composition which applies an uneven and random texture to the surface [24]. Commonly applied prior to deposition process to activate the surfaces, allowing an enriched adhesion of coatings, and with a wide range of texture wavelengths, micro and macro etching.

Mechanic deformation is the most common procedure to apply surface texture, most of the times as a secondary effect of the fabrication process, as seen in [26]. It can occur by material direct removal, as a milling method, or by mechanical conformation, similar to the one used in coin battery fabrication, with a range from micro to macro textures.

The focused radiation emission consists of a concentrated energy beam, as the most common is laser texturization in all its variations [22,23,27]. The major benefits of this technic are the precision and variable control [28], allowing texturization of complex or non-flat surfaces.

Most common applications are in the field of lubrication and surface adhesion. For lubrication purposes, the depressions work as a deposit of lubricant for limit or mixed regime with high localized pressure [27,29,30]. In the case of surface adhesion, the attention lies in the ability to alter surface wettability or energy [31], allowing an alternation of friction itself in the same contact.

Regarding the influence of texturization in electric performance, there is little work done, not counting some specific application *benchmarks*. Some authors, [32], studied the influence of depressions on the electric resistance of coated contacts. The oxide retention and friction coefficient reduction capabilities of these surfaces are addressed but only as a result of a specific type of texture.

The current work focus on analysing the influence of both positive and negative textures (dimples and hollows) on a standard sphere-on-flat surface contact subjected to reciprocating fretting, in common spring contact stainless steels, with special attention to the debris entrapment capabilities and multi-contact connections. Also, the main goal was to maintain a longer life for the electric connections (under a catastrophic failure of limitative impedance).

2. Materials, equipment and methods

2.1. Materials and specimens

Two stainless steel grades were used as specimen materials, selected especially for their similarity and thickness.

The spherical specimens used in the study were all made from AISI 304 stainless steel 0.5 mm sheet, whose standard chemical composition and hardness (measured by micro hardness tester) are shown in Table 1. The material selection was due to the similarity with electric and electronic applications.

Fig. 1 displays the microstructure of the stainless steel etched with Methanolic Aqua Regia, typically the austenitic grain boundaries (dark lines) and some agglomeration of $M_{23}C_6$ carbides (dark spots), composed fundamentally of precipitates of alloying elements. The austenite's medium grain size is around 44.2 ± 7.4 µm.

Fig. 2 displays the microstructure of the textured sample, an AISI 301 stainless steel sheet with 0.1 mm. The austenitic grain boundaries (dark lines) and some agglomeration of $M_{23}C_6$ carbides (dark spots), etched with Methanolic Aqua Regia, are visible. The austenite's medium grain size is around 40.4 ± 4.9 µm, but in these case the grains present a more elongated geometry due to lamination ratio.

The standard chemical composition and hardness are presented in

Table 1
AISI 304 properties.

Chemical composition (%)[a]								Hardness
C	**Si**	**Mn**	**Ni**	**P**	**S**	**Cr**	**N**	**MPa**
0.07	1	2	8–10.5	0.045	0.015	17.5–19.5	0.11	1810

[a] Based on available standards.

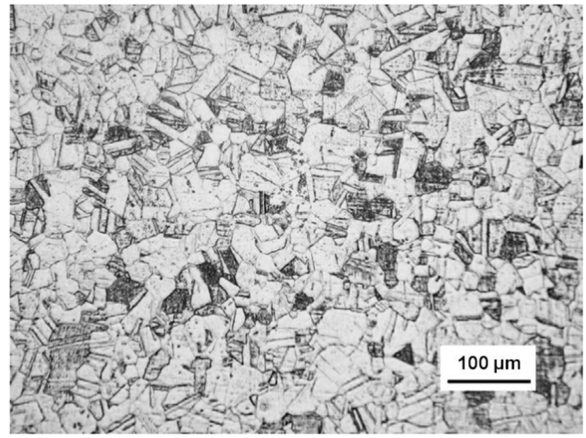

Fig. 1. AISI 304 microstructure (environmental).

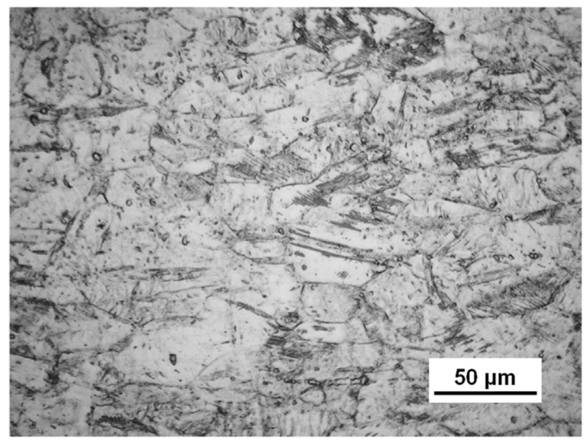

Fig. 2. AISI 301 microstructure (textured).

Table 2
AISI 301 properties.

Chemical composition (%)								Hardness
C	**Si**	**Mn**	**Ni**	**P**	**S**	**Cr**	**N**	**MPa**
0.15	1	2	6–8	0.045	0.03	16–18	0.1	4550

Table 3
Texturization indenters.

Indenter Type	Conical
Diameter (mm)	0.078
Tip angle	74°

Table 4
Texture characteristics.

Texture	Density (unit/mm^2)	Mean Height (µm)	Diameter (mm)
Dimples (positive)	6.25 11.11	5.7 ± 0.15	1.30 ± 0.19 (tip)
Hollows (negative)	6.25 11.11	5.5 ± 0.23	0.13 ± 0.01 (hole)