Solid lubrication ability and wear-resistance of thin $Ti_3C_2T_x$ coatings

Philipp G. Grützmacher [1)*], Carsten Gachot[1)], Sebastian Suarez[2)] and Andreas Rosenkranz[3)]

[1)] Department of Engineering Design and Product Development, TU Wien, Austria.
[2)] Department of Materials Science and Engineering, Saarland University, Germany.
[3)] Department for Chemical Engineering, Biotechnology and Materials, University of Chile, Chile.
*Corresponding author: philipp.gruetzmacher@tuwien.ac.at

Under harsh operation conditions like high temperatures or vacuum, common liquid lubricants reach their limits and focus turns to solid lubricants. Here, we introduce $Ti_3C_2T_x$ (MXene) nano-sheets as a new solid lubricant. MXenes were deposited as coatings (thickness of ~ 100 nm) on stainless steel substrates by drop casting. Using a ball-on-disc tribometer, their solid lubrication ability and long-term wear performance was studied. A remarkable reduction of both friction and wear was demonstrated, resulting from the formation of a tribo-layer/tribo-layer tribo-system.

Keywords: $Ti_3C_2T_x$ nano-sheets (MXenes), solid lubrication, wear resistance, tribo-film formation

1. Introduction

Commonly, liquid lubricants are introduced to the contact zone to separate both rubbing surfaces and reduce the resulting shear strength, thus minimizing friction and wear. However, under certain operation conditions, such as elevated temperatures or vacuum, the use of solid lubricants might be the better choice [1]. Often 2D layered materials are used for this purpose. Two of the most frequently investigated materials of this class are graphene and MoS_2. Although sometimes even showing superlubricious states, their main drawback is the low wear resistance under environmental conditions.
The recently discovered MXene nano-sheets, based upon early transition metal carbides/carbonitrides, can potentially overcome this short-coming due to their low-shear strength (easy-to-shear ability), enhanced intra- and inter-layer bonding characteristics and ability to form beneficial tribo-films [2], [3]. Here, we investigate the solid lubrication ability and long-term wear performance of thin MXene coatings applied to stainless steel (AISI 304) substrates.

2. Methods

MXene nano-sheets were synthesized from Ti_3AlC_2 powder by immersing the powder in hydrofluoric acid (40 %). The dispersion was then washed with deionized water and centrifuged to obtain multi-layer MXenes powder. To produce the MXene coatings, two drops with a volume of 500 µl each of a dispersion of MXenes in acetone (concentration of 0.04 mg/ml) were deposited onto a steel substrate heated to 150 °C. The tribological testing was performed on a ball-on-disc tribometer in linear reciprocating sliding mode using an Al_2O_3-ball (diameter of 6 mm) as counterbody. The parameters for the tribological tests are summarized in Table 1.

Table 1: Parameters tribological testing

Normal load [mN]	100
Linear speed [mm/s]	1
Stroke length [mm]	0.6
Temperature [°C]	22

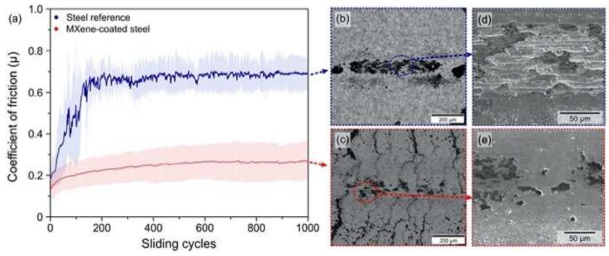

Figure 1: Tribological evaluation of the MXene coatings compared to an uncoated reference. (a) evolution of the COF. SEM micrographs of the worn surfaces for (b,d) the reference and (c,e) the MXene-coated sample.

3. Results and Discussion

The frictional behavior of the uncoated steel sample can be associated with a typical behavior for a dry, non-lubricated contact (Fig 1a). In contrast, the MXene-coated sample demonstrates a low and steady evolution of the COF without any pronounced running-in. Additionally, severe wear features can be found for the reference's wear track including abrasion, adhesion, and tribo-oxidation (Fig.1b,d). The MXene coating also helps to drastically reduce wear. Instead of wear features, signs of a beneficial tribo-layer can be found (Fig. 1c,e). We hypothesize that the accommodation of shear in the beneficial tribo-layer and its transfer to the counter-face leads to the formation of a tribo-layer/tribo-layer tribo-system thus avoiding direct contact between the steel substrate and the Al_2O_3-ball. This, in turn, protects the underlying steel substrate and results in low friction.

4. References

[1] T. W. Scharf and S. V. Prasad, "Solid lubricants: A review," *J. Mater. Sci.*, vol. 48, no. 2, pp. 511–531, 2013.

[2] B. Anasori, M. R. Lukatskaya, and Y. Gogotsi, "2D metal carbides and nitrides (MXenes) for energy storage," *Nat. Rev. Mater.*, vol. 2, no. 2, 2017.

[3] A. Rosenkranz *et al.*, "Multi-layer Ti3C2Tx-nanoparticles (MXenes) as solid lubricants – Role of surface terminations and intercalated water," *Appl. Surf. Sci.*, vol. 494, no. April, pp. 13–21, Nov. 2019.