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Wear behavior of bio-inspired and technologically structured HVOF sprayed NiCrBSiFe coatings

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ABSTRACT

Surface modification by means of textured structures can largely enhance the tribological and wear behavior of components and tools under various environmental conditions. Continuous developments in machining processes, such as the micromilling technology, can be used to manufacture fine-scaled structures on hardened steel tool surfaces. Thus, the adjusted friction behavior, which can affect the tendency of a material to adhere to the surface, is compensated by the small number of contact points between the friction partner and the surface. Accordingly, anisotropic friction properties of such structures can lead to a locally different wear behavior.

In this study, a NiCrBSiFe self-fluxing alloy is thermally sprayed onto specimens made of AISI M2 high-speed steel (HSS). Technological and bionic surface structures were applied on thermally sprayed and laser remelted substrates. Based on ball-on-disk tests, the coefficient of friction was determined and compared for different high velocity oxy fuel (HVOF) sprayed NiCrBSiFe coatings and surface textures. These experiments show that functional structures can reduce the coefficient of friction. The bio-inspired surface shows a friction reduction of approximately 35% compared to the as-sprayed and polished sample, and a reduction of 25% when compared to the remelted and smoothened surface. Moreover, the analyzed surface conditions lead to a different wear behavior than the bio-inspired structure, which possesses areas with a reduced oxidational wear and less adhesion when compared to the other surface conditions.

1. Introduction

Nature has developed numerous processes and systems within the nano- as well as macro-scales over the course of the entire evolution. These biological surfaces serve as natural interfaces and provide plants, insects, and animals with the ability to adapt to their environment. Within the field of materials technology, these surfaces are reproduced based on specific design architectures that combine elements from topography (e.g. texture) and functional chemistry. The potential of their manifold functionalities and applications has already been discussed in many studies. Improved adhesion 1 [1,2,3], optical engineering [4,5] due to interaction of light with a multi-level surface architecture, anti-biofouling to prevent the growth of fouling organisms on surfaces by using nano-scaled textured skin effects [6,7], and superhydrophobicity provided by lotus leafs [8,9] or the wings of the *Morpho aega* butterfly [10,11,12] are well known examples found in natural biological systems that provide superior functional surface properties.

The modification of surfaces by applying technological structures has already been developed within the field of surface engineering. Numerous designs and architectures have been investigated, thus, contributing to the generation of a superior friction behavior and enhanced wear resistance [13–22].

With regard to bio-inspired, manufactured surfaces, the aim is to mimic the advanced functionalities of nature, in order to be able to produce advanced products or ensure an enhanced quality in the processing technology. Numerous manufacturing techniques have been utilized to adapt features that mimic the designs and structures found in nature to improve the adhesion [23,24] or to obtain an enhanced wear resistance against erosion [25,26]. Concerning surfaces for cutting tools and wear parts, nano-scaled textures with a serrated shark teeth-like architecture [27] were analyzed (e.g. cutting edges) and patented [29] in thin coating systems (e.g. PVD and CVD coatings) by Jiang et al. [28]. These features reduce the adhesion and thus facilitate sliding. Moreover, they improve the surface finish in machining.

Another means to improve the functionality of technological surfaces is the application of different coating systems using the physical vapor deposition (PVD) technology [30–34] or thermal spraying [34–38]. As opposed to thin coating systems such as PVD layers, thermally sprayed coatings possess an inhomogeneous microstructure [38]. Common

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Table 1
Spray parameter settings.

Kerosene flow	Oxygen flow	Hydrogen flow	Gun velocity	Track pitch	Powder feed rate	Spray distance	Overruns
18 l/h	800 l/min	100 l/min	0.5 m/s	5 mm	30 g/min	300 mm	20

thermally sprayed coating systems do neither provide a well-defined micro- to nano-scaled surface texture, nor the ability to apply micro- and nano-scaled textures by means of mechanical post-treatments as micro-sized pores in the coating can influence the manufacturing process itself. With respect to self-fluxing alloys as feedstock for thermal spraying processes, post-treatment processes (e.g. laser remelting) of deposited coatings can lead to a change in the microstructure. In this context, NiCrBSi coatings are widely used as self-fluxing alloys. Moreover, remelted NiCrBSiFe coatings on steel substrates can lead to enhanced mechanical properties, as both the precipitate growth [39] and low porosity [40] levels of the coating ensure an improved wear resistance as well as a good adhesion to the substrate due to metallurgical bonding [40,41].

Researchers investigated the mechanical properties and tribological behavior of NiCrBSi coatings, produced by laser or flame assisted remelting processes [39–45]. Miguel et al. investigated the tribological behavior of these coating systems, which were obtained by means of different thermal spray processes and post-heat treated procedures [42]. It was reported that the sprayed and fused coatings obtain the best sliding wear resistance. Garrido et al. discussed the tribological behavior of NiCrBSi coatings with textured surfaces, which were obtained by diode laser cladding and textured by a Nd-YAG laser [43]. In this study, different densities and distances between dimples were tested by obtaining their coefficient of friction. The results were compared to non-textured NiCrBSi coatings. It was revealed that surface texturing reduces the coefficient of friction. Moreover, it was reported that the textured versus the non-textured ratio significantly affects the tribological behavior. It has to be mentioned that the dimples were large with diameter sizes ranging between 500 to 930 μm.

Regarding the surface texturing, the use of laser assisted processes can lead to burr formations [46] and different local characteristics, which can be attributed to a heat-affected zone [47]. Thus, textured surfaces are realized most recently by means of micromilling [48], a process without these disadvantages [19]. Furthermore, the use of mechanical methods such as micromilling allows to produce a greater variety of biomimetic and technological structures.

Combining coating technologies with new surface structures, especially bio-inspired structures, has the potential to improve surface treatments and opens new fields of application. Investigations in the field of incremental forming, using structured tools that were machined by a micromilling process and coated by means of PVD, show the possibilities of such a combination [49,50].

In this study, a self-fluxing nickel-based alloy, used as feedstock is deposited on steel substrates, utilizing HVOF spraying and laser remelting, in order to smoothen and compact the microstructure of coatings. Technological and bionic structures are manufactured by means of a micromilling process onto the remelted layers. Subsequently, utilizing ball-on-disk tests, tribological investigations were carried out on the surfaces to analyze their wear behavior. Except laser assisted processes, no other method producing textured NiCrBSi coatings could be found in the literature. It is not yet known whether it is possible to treat NiCrBSiFe coatings with a post-processing by applying fine scaled textures (e.g. dimple size of less than 200 μm) by means of micromilling technology.

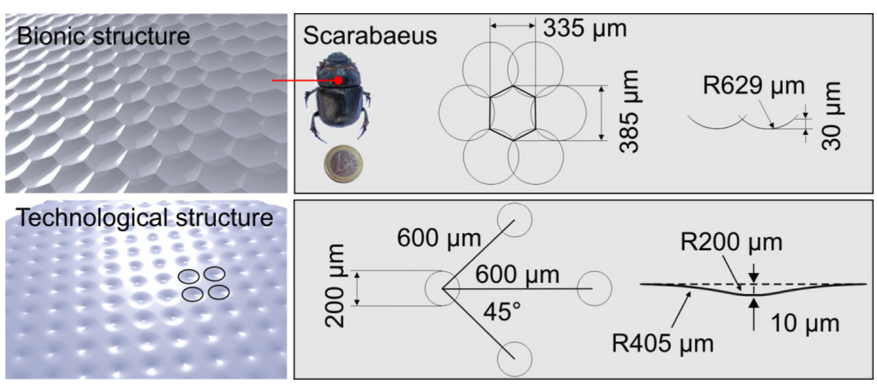
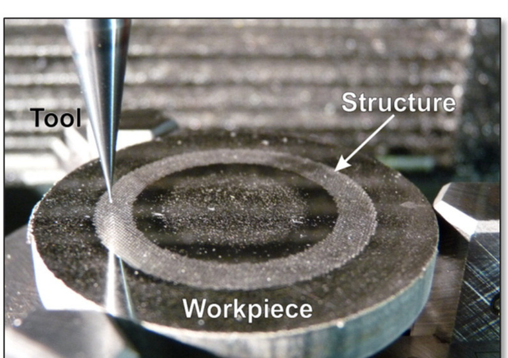


Fig. 1. CAD models of the investigated surface structures.



Workpiece	
Substrate:	AISI M2
Coating:	NiCrBSiFe
Tool	
Geometry:	Ball-end milling cutter, HC, d = 0.3 mm
Coating:	TiAlN
Micromilling process	
Strategy:	Down milling, dry
Feed per tooth:	f_z = 12 μm
Rotational speed:	n = 50,000 min^{-1}
Width of cut:	a_e = 5 – 10 μm
Depth of cut:	a_p = 0 – 15 μm

Fig. 2. Micromilling of the bio-inspired structure.