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Effect of SiO_2 and PTFE additives on dry sliding of NiP electroless coating

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ABSTRACT

The aim of the present work is to study the effect of silicon dioxide and polytetrafluoroethylene (PTFE) additives on NiP coating performance under dry (unlubricated) conditions in unidirectional and reciprocating sliding modes in Ball-on-Flat configuration. Yttria-stabilized zirconia and chrome steel balls were used as counterbodies. Microstructural examination of specimens was conducted by a SEM with EDS. It was found that in contact with steel ball both additives were beneficial, while addition of SiO_2 particles was detrimental for contact against ceramic ball. The highest improvement of tribological performance was obtained for NiP coated samples having PTFE or mixed additives.

1. Introduction

Nickel–based coatings are widely used in mechanical engineering, electronics and chemical industry because of their hardness, corrosion and wear resistance. Their stable coefficients of friction (COF) in vacuum and air as well as high electrical conductivity make them promising for various applications in many sectors of industry such as transport (air, sea and land), energy generation, and manufacturing [1–7].

The challenge arises to development of nanostructured coatings that benefit from the unique physical and tribological properties of functional layers and nanoparticles incorporated into their structures. Significant improvement in tribological characteristics of NiP coatings can be reached by introducing self lubricating agent. Nowadays, a successful application of fluopolymer nanofillers such as polytetrafluorethylen (PTFE), perfluoroalkoxy (PFA), fluorinated ethylene propylene (FEP) and ethylene tetrafluoroethylene (ETFE) for reduction wear losses and increase durability of the final product is of a great interest for industry. These fillers are found to increase plasticity of Ni-based matrix and prevent crystallisation of the coating at counterbodies contact spots where the flash temperature caused by frictional heating increases to a great extent.

Electroless (chemical) deposition allows obtaining coatings of uniform thickness of any irregularly shaped surfaces made of either metallic or non-metallic materials. A process of deposition is based on oxidation–reduction reaction, when reducer is oxidised by $H_2PO_4^-$ and Ni_2^+ ions are precipitated onto substrate surface [8,9]. Generally there is a linear relationship between a holding time (in bath) and a final coating thickness [9]. Co-plating of phosphorus (P) results in formation of nickel phosphide (NiP and Ni_3P) enabling sufficient increase in hardness of a coating (up to 1000 HV) during heat treatment [10–12].

One of the current trends is a process of chemical co-deposition of nickel added by hard (ceramic) particles such as SiC, B_4C, Cr_2C_3, WC, BN, Si_3N_4, Al_2O_3, ZrO_2, TiO_2, $K_2Ti_6O_{13}$, CeO_2, SiO_2, diamond [5,6,13–18] and carbon nanotubes; or solid lubricants such as PTFE, MoS_2, WS_2, graphite [4,5,19–25], etc. Incorporation of suitable additives results in increasing hardness and wear resistance as well as decreasing coefficient of friction of the coatings that allows service in dry conditions without additional lubricant. By co-depositing the PTFE particles, the hydrophobic coating with excellent anti-sticking performance, and lubricating ability can be obtained. According to authors knowledge the NiP coatings added by combined PTFE and SiO_2 particles have not been studied yet. It is supposed that silicon dioxide particles impede dislocation movement and act as barriers to retard the plastic deformation of ductile Ni–P matrix and hence increase the microhardness while PTFE reduces the COF and increase a load bearing capacity.

The aim of the present work is to study the effect of silicon dioxide and polytetrafluoroethylene (PTFE) additives on NiP coating performance under dry sliding conditions in unidirectional and reciprocating mode in Ball-on-Flat configuration. The scanning method for the evaluation of the critical forces was applied to improve the differentiation among coatings.

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2. Materials and methods

2.1. Materials

Composite NiP-based coatings with additions of SiO_2 and/or PTFE were deposited using electroless nickel bath containing nanosized (5–20 nm) silicon dioxide (SiO_2) particles (GOST 14922) at pH 4.6 ± 0.4 and temperature 90–95 °C during 1 h. Phosphorus content in the NiP coating was 10 wt%. The coatings (Fig. 1) were deposited onto a mild carbon steel substrate (S235J2G3, EN10025). Concentration of SiO_2 particles in the solution was held on the level of 1.5 and 3.0 wt% that resulted in the concentration of silicon dioxide in the coating equal to 4.5 and 7.0 vol% respectively that is lower than reported in Ref. [26]. The amount of the silicon dioxide was confirmed by EDS analysis of polished samples.

In general, electroless co-deposition processes of second phase particles take place at low temperature and the chemical interaction is not favoured between the particles and the matrix. The particles are only physically entrapped into the Ni–P matrix. Therefore heat treatment of these coatings is necessary to promote high hardness and improve wear resistance. Coatings have been heat treated at 400 °C for 1 h [26,27]. Low-molecular fine-dispersed PTFE particles (size of a single particle was not exceeding 7 μm) were sprayed onto the base coating and melted at 340 °C during 1 h. Thickness of the PTFE layer was non-uniform: it was larger at the place of initial position of the PTFE cluster and less between them (Fig. 1c and d). Coatings compositions and their thicknesses are given in Table 1. The specimens were prepared in size of 5 mm × 15 mm × 30 mm. The coatings were tested as received without any surface modification. The

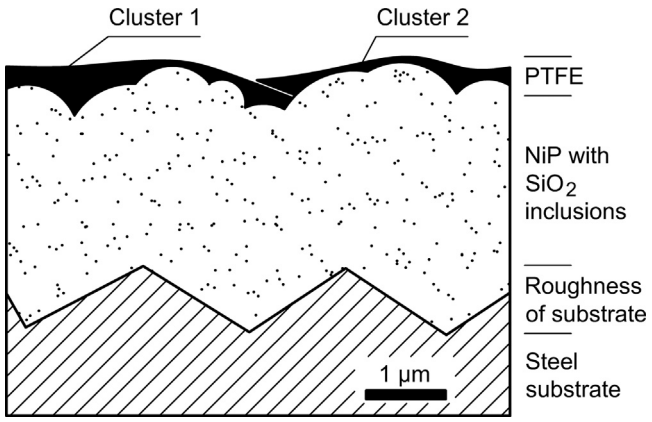

Fig. 2. Schematic representation of NiP coating with SiO_2 and PTFE (cross section).

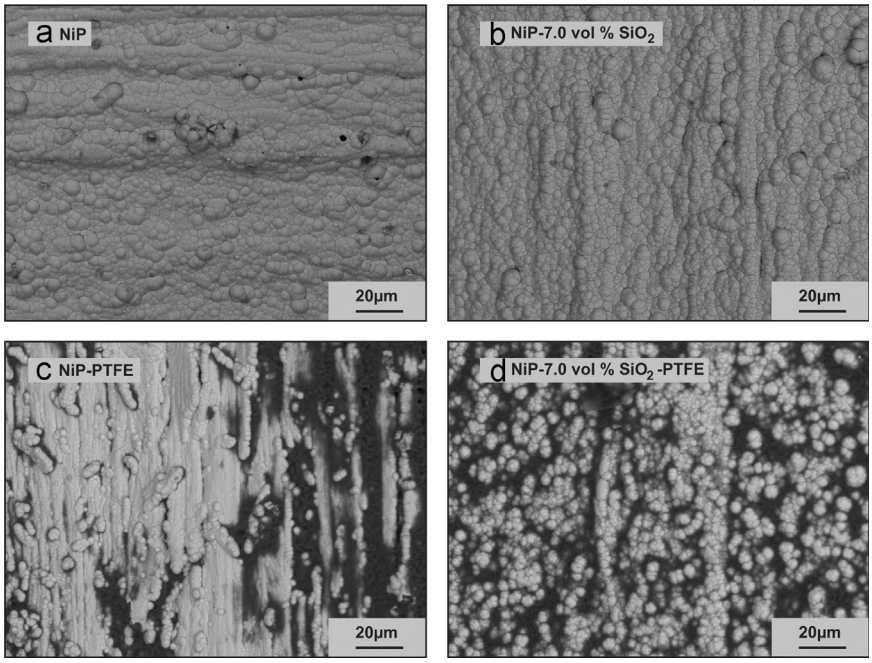

Fig. 1. SEM images of surfaces of as-deposited coatings.

Table 1
Properties of the coatings studied.

Coating	Thickness (μm)	Microhardness ($HV_{0.05}$)	Roughness parameters (μm)		
			R_a	R_{max}	R_z
NiP	6.0 ± 1.8	812 ± 125	1.5 ± 0.2	12.6 ± 1.2	10.5 ± 1.3
NiP–4.5 vol% SiO_2	5.0 ± 0.7	849 ± 204	1.5 ± 0.2	13.0 ± 2.8	10.7 ± 1.4
NiP–7.0 vol% SiO_2	6.6 ± 0.3	946 ± 345	1.2 ± 0.1	10.9 ± 1.1	8.8 ± 1.4
NiP–PTFE	4.7 ± 0.8	543 ± 63	1.4 ± 0.2	13.4 ± 3.0	11.1 ± 1.4
NiP–4.5 vol% SiO_2–PTFE	5.7 ± 0.1	50 ± 148	1.4 ± 0.3	15.7 ± 5.8	10.3 ± 3.1
NiP–7.0 vol% SiO_2–PTFE	3.7 ± 0.1	593 ± 139	1.6 ± 0.2	13.2 ± 5.5	10.6 ± 2.5
Steel substrate (S235J2G3)	–	232 ± 12	1.2 ± 0.1	9.8 ± 1.0	8.3 ± 1.4