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Transfer film formation mechanism and tribochemistry evolution of a low-wear polyimide/mesoporous silica nanocomposite in dry sliding against bearing steel

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Abstract: The addition of a kind of mesoporous silica (MPS) can significantly reduce the wear rate of a thermoplastic polyimide (PI) by more than 90%, which is ascribed to the quick formation of high-quality transfer films induced by unique tribochemical reactions [1]. In-situ observation illustrated the morphology evolution of the transfer films. Further X-ray photoelectron spectroscopy on these transfer films revealed the variation of tribochemical reactions intensity while significant tribochemically induced polymer decomposition and reactions was detected by infrared spectroscopy. Intact and robust transfer films were formed by initial tribochemical adhesion of wear debris and its subsequent accumulation and expansion on the steel surface, which was ascribed to the combined effects of tribochemistry and reduced size and varied morphology of the wear debris.

Keywords: polymer matrix composites (PMCs); friction and wear; transfer film formation; tribochemistry; XPS; ATR-IR

1. Introduction

Polyimide (PI) is a very popular and widely used engineering plastic owing to its excellent thermostability, mechanical and chemical properties in industrial applications such as relative-movement devices [2-5]. In a dry sliding process against a metal, large PI wear debris or plates are easily sheared off because the rigidity of main chains and some are transferred on surfaces of metal counterpart, causing high friction and wear of pure PI. Such triobofilms are generally thick, lumpy and weakly bonded with metal pieces [1, 6]. The incorporation of different micro/nanofillers such as carbon fibers, glass fibers, aramid fibers, ceramics and solid lubricants has been reported to contribute to over 50% increase in the wear resistance of PI [7-9]. Pozdnyakov et al. [10, 11] revealed that C_{60} materials could significantly reduce the specific wear rate of PI/C_{60} composite coating. Nanofillers like carbon nanohorns [12], carbon nanotubes [13], nanosilias [14] improve tribological properties of PI nanocomposites with good reinforcing effect. Wang et al. [15-17] evaluated synergistic effects of organic fibers, solid lubricants and nanoparticles on tribological properties of corresponding PI composites. By this means, different PI composites can be designed by altering related specification, composition and contents of fillers to adapt various working conditions. Samyn et al. [18-20] worked on tribochemical variations of PI and PI composites at room and elevated temperatures to understand the relationship between associated tribochemical variations and tribological properties of PI composites. In-situ polymerization method was employed initially to enhance tribological properties of PI composites, but with contrary outcomes obtained, possibly induced by combined effects of approaches, reinforcing agents and interfacial design [21, 22]. Many reinforcing mechanisms [2, 6-13] were proposed to explain the reason for enhancing tribological properties of PI composites, consisting of the formation of high-quality triofilms, lubricity and preferential load bearing of fillers, as well as enhanced mechanical properties. Within diverse mechanisms, the improved quality of transfer films consistently gives rise to the improvement of tribological properties of PI composites.

It is well recognized by the research community that triofilms can make great contributions to control the

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