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RESEARCH PROGRESS OF METAL-ORGANIC FRAMEWORKIN TRIBOLOGY

Hanglin LI[1,2], Xudong SUI[2], Pablo AYALA[3], Carsten GACHOT[2], Jiusheng LI[1,*]

[1]Shanghai Advanced Research Institute, Shanghai, China

[2]Research Unit Tribology E307-05, TU Wien, Vienna, Austria

[3]Institute of Materials Chemistry, TU Wien, Vienna, Austria

*Corresponding author: lijs@sari.ac.cn

Abstract: *Metal-organic frameworks (MOFs), as a type of nanoparticles, have attracted much attention due to their tunable structure and surface effects. In recent years, its application in tribology is gradually developing. In this work, the structure of MOFs is categorized according to the differences between secondary building units and the application of MOF in tribology is estimated. The development trend and research progress of MOF are summarized. The roles of MOFs in tribology system are categorized, in order to give a clear understanding of MOFs in tribological systems. A recently published work was presented to show the effect of environmental conditions on MOF solid lubrication. Finally, based on the above research progress, the research direction for the future is proposed.*

Keywords: *metal-organic framework, tribology, friction, solid lubrication, liquid additive.*

1. INTRODUCTION

Friction can cause about 23% of global energy losses annually due to friction and wear. To solve this problem, researchers are developing efficient lubricants to control friction, improve tribological performance, and prolong equipment service life. Nanoparticle is a kind of promising material due to their special size and surface effects. Metal-organic framework (MOF) particles have gained developing attention due to their structure in the fields of catalysis, adsorption, energy storage, and so on.

In tribology fields, MOFs combine the load-capacity performance of metal parts and the lubrication effect from organics. The structure or surface can be modified according to the situation. Han et al. [1] reviewed recent research progress of MOFs in tribology up to 2024. They summarized MOFs as an additive in lubricants, non-liquid environments, and super-lubrication. The review provides a quite good overview of MOFs in the field of tribology and further direction for creating new MOF materials. Based on previous work, the application fields of MOF are shown, and the development of the MOFs is reviewed. Then, the roles of the MOFs in tribology are more refined categorized. Besides, the study of MOF in solid lubrication is added. Finally, a recently discovered advanced insight of MOF in solid lubrication is reported.

2. RESEARCH PROGRESS IN TRIBOLOGY

2.1 Structure and applications of MOFs

MOFs are a novel class of reticular materials formed by coordinating inorganic metal-based parts with organic ligands. Between these metal parts, the connection is completed by coordination bonds via organic ligands. There is an academic term for the metal part, named secondary building unit (SBU). According to the SBUs, the structure of MOF can be categorized into three types, including 0D metal cluster, 1D metal rod, and 2D metal sheet (Figure 1).

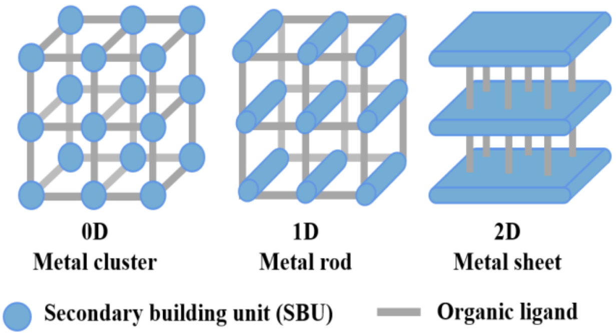

Figure 1. MOF structure categorized by SBUs

The connection between SBUs and ligands results in lots of pores, which makes MOFs large specific surface areas. Therefore, MOF is a celebrity in adsorption, separation, catalysis, energy storage, gas capture, and so on. By searching for MOF-related literatures on Web of Science based on keywords, the proportion of articles on each MOF application was estimated by the end of 2024, as shown in Figure 2. It is worth noting that the studies in tribology (<100) only account for a very small percentage of overall studies.

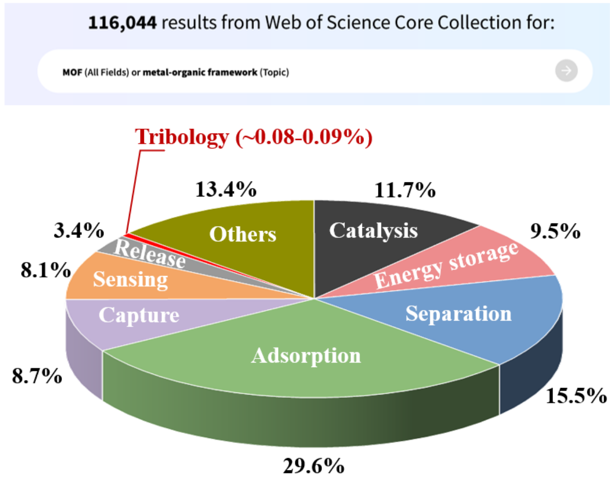

Figure 2. MOF applications in different fields (by 31/12/2024)

2.2 Research progress of MOFs in tribology

Although the studies on tribology are less, the developing trend is clear. As shown in Figure 3a, there are more and more articles focused on MOF in tribology. The blue arrow showed an obvious increasing trend. Among all kinds of family, zeolite imidazole framework (ZIF) family is popular since reported for the first time by Yaghi et al. [2]. In tribology, ZIF family is also widely studied, which showed a clear lead over other families (Figure 3b). Therefore, the study on MOFs in tribology is still in early stage, which also opens many directions and possibilities for future work.

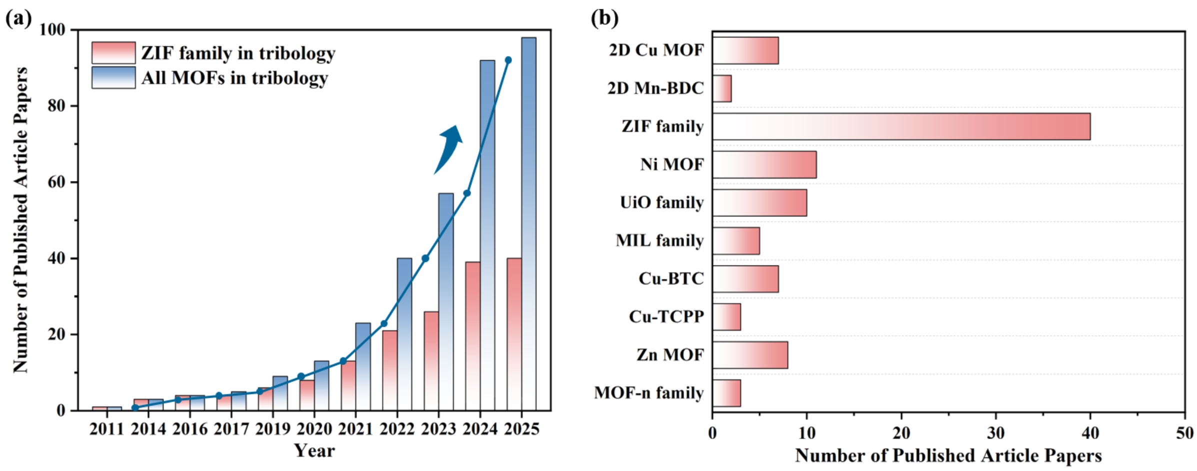

Figure 3. Developments of MOF in tribology: (a) the number of articles published annually on all kinds of MOFs and ZIF family, (b) the number of articles in tribology on various MOFs reported by the end of 2024

The roles of MOFs in tribology system are summarized in Figure 4. There is a pretty large part of MOF studies in tribology is about additive, especially in liquid lubrication. In the following, we only discuss macroscale tribology, which may accelerate the practical applications of MOFs. MOF particles are believed to have high mechanical strength, which can be applied to improve tribological performances of liquid. The relevant literatures have been reviewed in detail by Han et al. [1] and will not be repeated presented here.

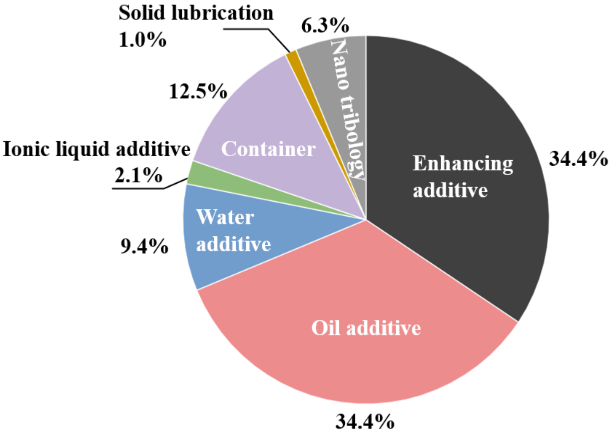

Figure 4. Roles of MOF in tribology (by 31/12/2024)

For tribology systems without liquid, the studies are mainly focused on the addition of MOFs in fiber, polymer matrix or hydrogel. Fei et al. [3] reported a new carbon fiber/phenolic composite with rigid-flexible hierarchical structure decorated by the MOFs. The tensile and interlaminar shear strength of composite carbon fiber were increased by MOFs. Cheng et al. [4] prepared a 2D Ni-Fe MOF/PVA composite hydrogel. Ni-Fe MOF improved the mechanical and friction-reducing performances, which showed a new additive direction. Another important role of MOFs is as a container. Due to the porous structure of MOF, it has strong adsorption of lubricating oil, so it can be used as a small container to keep oil and then prepare sliding partners. When the friction proceeds, the shear force destroys the structure and the oil is released to the interface, acting as a self-lubricating coating [5].

There is only one published work about solid lubrication of MOFs by the end of 2024. Eguchi et al. [6] reported the copper-based MOFs with different structures (0D, 2D, and 3D). The 2D MOF showed best friction-reduction with an average coefficient of friction (COF) of ≈ 0.2 under steel/filter paper. However, the lubrication failed after heating. The mechanism analysis indicated that the solvent (dimethylformamide, DMF) took part in the formation of MOF. High temperature destroyed the coordination, resulting in the transformation of structure.

Hydrolysis is always playing a negative role in MOFs. Recently, it was reported an advanced insight of MOF in solid lubrication. The positive role of moisture in MOF solid lubrication was first reported. Gachot et al. used a newly described Ti-based MOF (COK-47) powder in solid lubrication for the first time [7]. They found that under dry air, the lubrication failed. A series of characterization methods were used to confirm water catalyzed the decomposition of COK-47, a crucial step in forming the tribofilm. Moreover, the counterbody-independent property of COK-47 suggests a promising potential for solid lubrication applications. It also showed better performance than other commonly used MOFs (MIL-125, ZIF-8, ZIF-67) and 2D materials (MXenes, TMDs, rGO, BP).This study demonstrated the idea of utilizing MOF and water-assisted lubrication mechanisms. It provides new insights into MOF applications in tribology and highlights interdisciplinary contributions of mechanical engineering and chemistry.

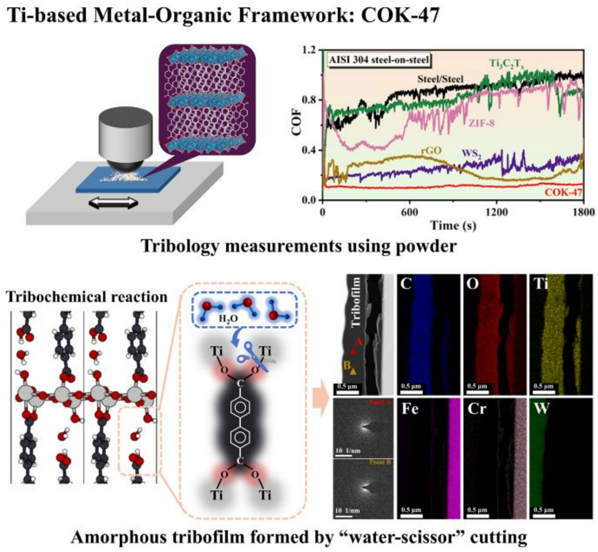

Figure 5. Tribological performance of COK-47 [7]

3. CONCLUSION

MOFs are emerging as promising materials in tribology due to their hybrid organic-inorganic structures, offering tunable porosity and functional versatility. Beyond the commonly studied MOF families, other structural types should be studied to expand tribological applications. Additionally, solid lubrication research is still in its preliminary stages, requiring a deeper understanding of how intrinsic structural features influence friction and wear properties. Environmental factors such as humidity, temperature, and oxidative conditions should also be considered to optimize MOF performance in practical tribological systems. Future efforts should aim at enhancing stability, diversifying applications, and improving environmental adaptability, paving the way for MOFs as high-performance lubricants.

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ORCID iDs

Hanglin LI 0009-0006-0955-6955
Xudong SUI 0000-0002-3910-3424
Pablo AYALA 0000-0002-2569-4438
Carsten GACHOT 0000-0001-6981-1563
Jiusheng LI 0000-0002-2651-5198

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