纳米 Al_2O_3 和 Fe_2O_3 填充尼龙 PA1010 的摩擦磨损行为

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摘要: 采用模具挤压成型方法制备了纳米 Al_2O_3 和 Fe_2O_3 填充 PA1010 尼龙复合材料, 采用MM-200 型摩擦磨损试验机考察了所制备的尼龙复合材料在干摩擦条件下同 45# 钢对摩时的摩擦磨损行为. 研究结果表明, 填充纳米 Al_2O_3 使得 PA1010 尼龙复合材料的摩擦系数增大, 而填充纳米 Fe_2O_3 使得摩擦系数降低; 纳米 Al_2O_3 和 Fe_2O_3 填充尼龙复合材料的耐磨性能优于尼龙; 当纳米填料的质量分数从 10% 提高到 20% 时, 纳米 Fe_2O_3 填充尼龙的磨损量增大, 纳米 Al_2O_3 填充尼龙的磨损量无明显变化, 2 种填料填充尼龙复合材料的摩擦系数变化不大. 纳米 Fe_2O_3 填充尼龙复合材料同 45# 钢对摩时主要呈现粘着磨损和轻微疲劳磨损特征, 而纳米 Al_2O_3 填充尼龙复合材料呈现脆性疲劳开裂特征. 纳米 Fe_2O_3 填充尼龙复合材料在偶件磨损表面形成的转移膜更加均匀和连续, 故其减摩抗磨性能优于纳米 Fe_2O_3 填充尼龙复合材料.

关键词: 金属氧化物; 纳米颗粒; 尼龙复合材料; 摩擦磨损性能
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尼龙作为常用的聚合物材料之一在摩擦学领域获得了广泛应用. 研究表明, 对尼龙进行纤维增强和颗粒填充改性处理可以显著改善其抗磨性能[1~4]. 随着纳米技术的发展, 纳米颗粒的摩擦学应用受到了广泛关注, 与此相适应, 关于各种金属、非金属及其氧化物纳米微粒填充尼龙复合材料摩擦磨损性能的研究取得了长足进展[5~8]. 本文作者制备了纳米 Al_2O_3 及 Fe_2O_3 填充尼龙 1010 复合材料, 考察了复合材料的摩擦磨损性能, 并探讨了其磨损机理, 期望为纳米微粒填充尼龙复合材料的摩擦学应用提供实验依据.

1 实验部分

所用原料包括 PA1010 粉末(密度 1.05 g/cm^3, 粒径< 175 μm)、纳米 Fe_2O_3 粉体(粒径 40~ 50 nm, 纯度> 99.3%)、纳米 Al_2O_3 粉体(粒径 60~ 70 nm, 纯度> 99.5%). 将 PA1010 粉末同纳米 Fe_2O_3 粉体或纳米 Al_2O_3 粉体进行机械共混后置于丙酮中超声混合 20 min, 然后在 110 ℃下烘干. 将烘干粉料置于 WZM-I 微型注塑机中加热熔融并搅拌均匀, 然后注入预热的模具中螺旋挤压成型, 打开模具自然冷却, 即得到尺寸为 20 mm × 10 mm × 6 mm 的填充尼龙 1010 复合材料试块. 将尼龙复合材料试块工作表面用砂纸打磨至表面粗糙度 R_a= 0.52~ 0.70 μm, 然后用丙酮清洗, 晾干待用.

采用MM-200 型摩擦磨损试验机评价填充尼龙 1010 复合材料的摩擦磨损性能, 偶件为 45# 钢试环(表面粗糙度 R_a= 0.29 μm, 硬度 40~ 45HRC). 试验条件为试环滑动速度 0.43 m/s、室温、载荷 150 N、试验时间 120 min、相对湿度 45%~ 60%. 摩擦力由试验机上的标尺读得, 用感量为 0.1 mg 的电子分析天平称量测定复合材料试块的磨损质量损失.

2 结果与分析

2.1 摩擦磨损性能

图 1 示出了 PA1010 及分别含 10% 和 20% 纳米 Al_2O_3 或 Fe_2O_3 的 PA1010 复合材料的摩擦系数随试验时间变化的关系曲线. 可以看出, 尼龙及其填充复合材料的初始摩擦系数均较低, 随着试验时间的延长, 摩擦系数逐渐升高并达到相对稳定值. 2 种填充尼龙复合材料均在摩擦约 40 min 后达到稳定摩擦状

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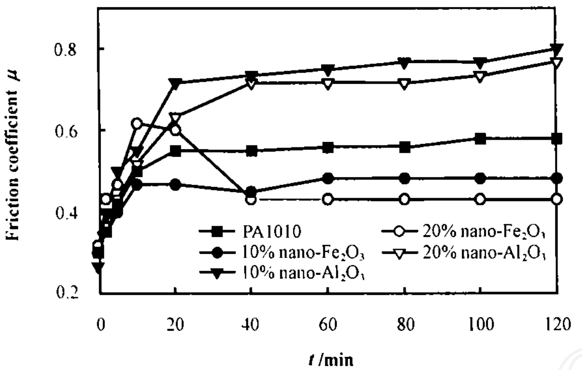


Fig 1 Friction coefficients *vs* sliding duration for PA 1010 and its filled composites against AISI-1045 steel

图 1 纳米 Al_2O_3 及 Fe_2O_3 填充 PA 1010 尼龙复合材料同 45# 钢对摩时的摩擦系数随滑动时间变化的关系曲线

态 总体而言, 填充纳米 Al_2O_3 使得摩擦系数明显增大, 摩擦系数最大可达 0. 8, 而填充纳米 Fe_2O_3 使得摩擦系数明显降低, 但纳米 Al_2O_3 和 Fe_2O_3 含量变化对摩擦系数的影响不大

图 2 对比示出了 PA 1010 以及纳米 Al_2O_3 和

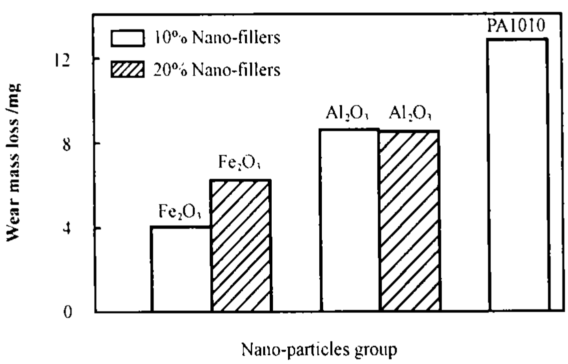


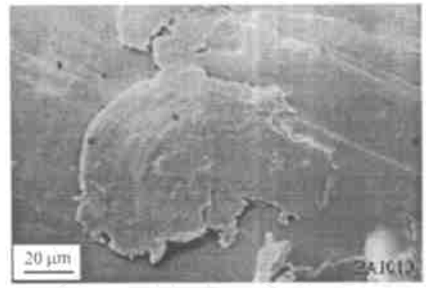
Fig 2 Wear mass losses of PA 1010 and its filled composites sliding against AISI-1045 steel

图 2 纳米 Al_2O_3 及 Fe_2O_3 填充尼龙复合材料的磨损质量损失对比

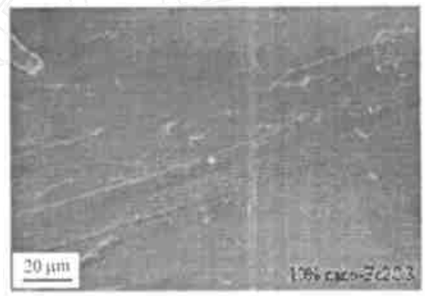
Fe_2O_3 填充 PA 1010 复合材料的磨损质量损失 可以看出, 2 种纳米金属氧化物作为填料均能显著改善尼龙 PA 1010 的抗磨性能, 且纳米 Fe_2O_3 的抗磨效果优于纳米 Al_2O_3. 与此同时, 纳米 Fe_2O_3 含量较低(10%)的填充尼龙复合材料的抗磨性能较优, 而纳米 Al_2O_3 含量变化对复合材料抗磨性能无影响

2 2 磨损表面分析

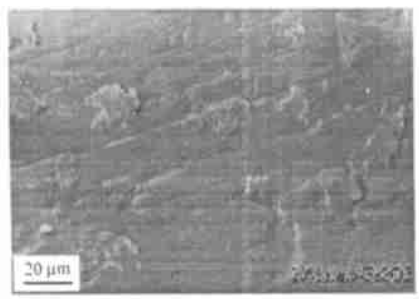
图 3 示出了尼龙及其填充复合材料磨损表面形貌 SEM 照片. 可以看出, 纯尼龙磨损表面存在犁沟划痕和明显的粘着剥落迹象[见图 3(a)], 在本文试验条件下纯尼龙主要发生粘着磨损和磨粒磨损; 纳米



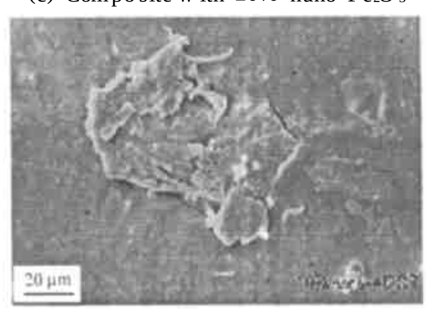
(a) Pure PA 1010



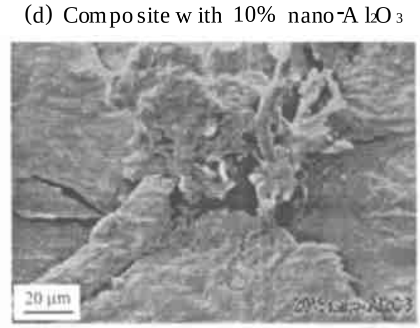
(b) Composite with 10% nano-Fe_2O_3



(c) Composite with 20% nano-Fe_2O_3



(d) Composite with 10% nano-Al_2O_3



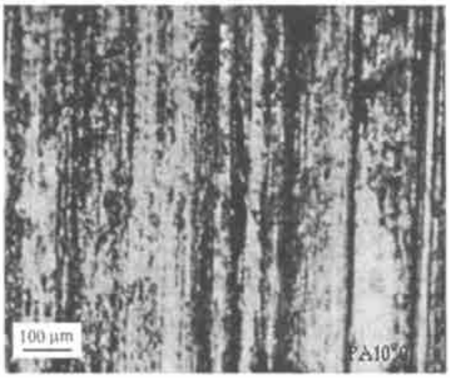
(e) Composite with 20% nano-Al_2O_3

Fig 3 SEM pictures of worn surfaces of PA 1010 composites sliding against AISI-1045 steel

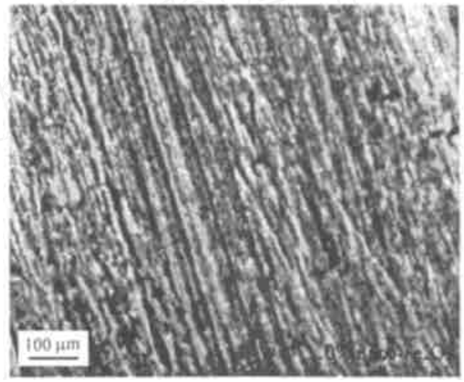
图 3 纳米 Al_2O_3 及 Fe_2O_3 填充尼龙复合材料磨损表面形貌 SEM 照片

Fe_2O_3 填充尼龙磨损表面形貌较为平整, 划痕和粘着显著减轻[见图 3(b)], 估计这是由于纳米 Fe_2O_3 填料同尼龙基体的结合强度较高所致. 而纳米 Al_2O_3 填充尼龙磨损表面呈现明显的塑性变形和表层剥落开裂迹象[见图 3(c)], 我们推测这同纳米 Al_2O_3 填料导致尼龙基体脆性增大有关. 与此同时, 不同纳米填料含量的填充尼龙复合材料磨损表面形貌呈现出一定的差异. 总体而言, 填料含量越高, 复合材料的塑性变形和粘着越严重[见图 3(d 和 e)]. 纳米微粒填充尼龙复合材料的摩擦磨损性能和磨损机理同其纳米填料含量相关.

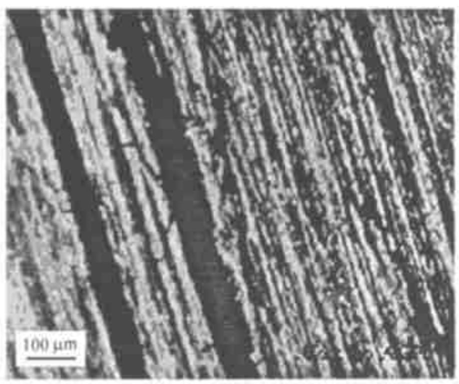
图 4 示出了分别同尼龙及纳米 Al_2O_3 或 Fe_2O_3 填



(a) Pure PA 1010



(b) Composite with 10% nano-Fe_2O_3



(c) Composite with 10% nano-Al_2O_3

Fig 4　Optical micrographs of worn steel surfaces sliding against PA 1010 and its filled composites (475×)

图 4　偶件磨损表面形貌光学显微照片 (×475)

充尼龙对摩的偶件钢环磨损表面形貌光学显微照片, 其中黑色区域对应于尼龙转移膜覆盖区域, 灰白色区域对应于未被转移膜覆盖区域. 可以看出, 纯尼龙及纳米填充尼龙复合材料均可向偶件钢环磨损表面转移并形成转移膜, 但其转移膜性质存在差异. 纯尼龙转移膜呈现条状分布[图 4(a)], 纳米 Fe_2O_3 填充尼龙的转移膜分布面积较大[图 4(b)], 纳米 Al_2O_3 填充尼龙的转移膜以宽深沟纹出现[图 4(c)]. 由此推断, 纳米 Fe_2O_3 和纳米 Al_2O_3 填充尼龙的减磨效果与转移膜的形态有关.

3　结论

a.　纳米 Fe_2O_3 作为填料可以明显改善 PA 1010 尼龙的抗磨性能, 并在一定程度上降低其摩擦系数; 纳米 Al_2O_3 作为填料亦可以明显改善 PA 1010 尼龙的抗磨性能, 但使得摩擦系数增大.

b.　纳米 Fe_2O_3 填充 PA 1010 尼龙复合材料的抗磨性能优于纳米 Al_2O_3 填充 PA 1010 尼龙复合材料, 这是由于纳米 Fe_2O_3 同尼龙基体的结合良好而纳米 Al_2O_3 导致复合材料脆性增加所致.

c.　纳米 Fe_2O_3 填料可以显著减轻尼龙同钢对摩时的粘着磨损和磨粒磨损, 而纳米 Al_2O_3 填充尼龙同钢对摩时呈现明显的塑性变形和表层剥落开裂迹象, 且填料含量越高, 相应复合材料的塑性变形和粘着越严重.

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Tribological Behaviors of Polyamide 1010 Composites Filled with Nanoscale Al_2O_3 and Fe_2O_3 Particulates

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Abstract: The polyamide 1010 composites filled with nanoscale Al_2O_3 and Fe_2O_3 particulates were prepared by extrusion moulding. The friction and wear behaviors of the resulting composites sliding against AISI-1045 steel were investigated on an MM-200 test rig in a ring-on-block configuration. The morphologies of the worn surfaces of the polymer matrix and the filled composites were observed on a scanning electron microscope, while those of the counterpart steel rings were observed on an optical microscope. It was found that both the nanoscale Al_2O_3 and Fe_2O_3 particulates as the fillers contributed to greatly increasing the wear resistance of the polyamide 1010. The nanoscale Al_2O_3 caused an increase in the friction coefficient, while Fe_2O_3 particulates as the filler led to decreasing of the friction coefficient. Moreover, the friction and wear behaviors of the filled composites were almost independent on the mass fraction of the nanoscale Al_2O_3, but the one with a relatively smaller content of Fe_2O_3 particulates had better friction-reducing ability and wear resistance than that containing a higher content of the Fe_2O_3 particulates. The nylon composites filled with nanoscale Fe_2O_3 were characterized by adhesion and mild abrasion, while the ones filled with nanoscale Al_2O_3 by brittle fracture and severe plastic deformation. This was related to the different actions of the nanoscale Fe_2O_3 and Al_2O_3 fillers and to the differences in the features of the corresponding transfer films on the counterpart steel rings.

Key words: metallic oxides; nanoscale particulates; nylon composites; friction and wear behavior

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