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Study on the Tribological Properties of MC Nylon Composites Filled with Hydraulic Oil

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Abstract. Mechanical parts utilized in machinery, such as nylon slider and pulley, should have certain mechanical properties and good tribological properties, so that equipments' stability and smoothness can be assured. A kind of MC nylon (monomer cast nylon) composites filled with hydraulic oil was studied in this paper. The addition of hydraulic oil changed nylon's mechanical properties and tribological properties significantly, and improved the material's toughness and coefficient of friction. The composites have excellent strength, toughness and relatively low coefficient of friction when the content of the hydraulic oil is 4wt%.

1. Introduction

In the field of materials science, polymer materials, such as polyethylene (PE), polypropylene (PP) and nylon, have been used and researched commonly due to their good mechanical and processing characteristics [1-4]. Among the various polymers, nylon 6 (poly-amide) synthesized by anionic polymerization of caprolactam (CL) has been extensively investigated because of its high reaction rate, excellent strength, stiffness and wear-resistant properties.

At present, some parts on lots of machinery and equipments are made of nylon and other polymer materials. For example, the nylon slider, which is used to prevent the friction between telescopic booms, can improve the stability, and meanwhile support the pressure [5, 6]. Above all, nylon slider must have great mechanical properties, excellent friction and wear-resistant properties. On the commercial aspect, monomer casting nylons (MC nylon) can be directly produced from molten monomers (CL) in the mold, using sodium and diisocyanates as an activator and a chain initiator respectively [7]. Li Guolu et al. [3] studied the effect of the amounts of additives (catalysts, activators eg.) on mechanical properties, tribological properties of MC nylon. The article shows that MC nylon has excellent properties when the ratio of catalyst to activator is 0.002 to 0.003.

Pure MC nylon material has not met the requirements for machinery and equipment currently. Therefore MC nylon should be modified to improve its performance. Inorganic or organic fillers were added to improve the wear-resistant and self-lubrication properties of MC nylon, Zhang shihua et.al reported the trobological behavior of MC nylon composites filled with glass fiber and fly ash [8]. Nano calcium carbonate/graphite was used as reinforcing agents to modify MC nylon, which have improved the tribological properties of MC nylon significantly [9].

Hydraulic oil is an organic compound extracted from petroleum and contains alkanes, cyclic alkanes and other compounds. Nylon was a polymer of caprolactam. Both of them have good compatibility. In this article, a kind of hydraulic oil was added into MC nylon to improve the tribological properties of MC nylon. At the same time, the composite has great mechanical properties. This research can provide a reference for the study of the application of MC nylon.

2. Experiments

2.1. The reagents and the preparation process of MC nylon composites filled with hydraulic oil

The reagents materials are shown in table 1. MC nylons filled with hydraulic oil were synthesized by anionic polymerization of molten CL with hydraulic oil in the mold.

Table 1. Reagents.

Reagent	Name	Purity	Manufacturer
Monomer	Caprolactam C6H11NO (CL)	AR	Basf co., LTD
Catalyst	Sodium hydroxide NaOH	AR	Xuzhou kebao experiment instrument co., LTD
Activator	Toluene diisocyanate C9H6N2O2 (TDI)	AR	Chengdu aikeda chemical reagent co., LTD
Oil	Hydraulic oil	CP	Klueber Lubrication (Shanghai) Co., Ltd

CL was dried for 8~12h in drying oven before experiment. It was heated in a synthesis device under nitrogen environment at 85℃. Then the hydraulic oil was added. With continuous heating, sodium metal, and tolylene diisocyanate (TDI) were added. The mixture was stirred at (135±5)℃ and then was casted into a mold immediately which where temperature was maintained at 170℃.

2.2. The scheme of hydraulic oil filled MCnylon

The schemes of MC nylon filled with hydraulic oil is shown in table 2. The contents of hydraulic oil are from 2 wt%～8 wt%. The ratio of CL to NaOH to TDI is 1:0.003:0.002.

Table 2. The scheme of hydraulic oil filled MC nylon.

Number	1	2	3	4
The contents of hydraulic oil	0	2wt%	4wt%	8wt%

2.3. Properties of the MC nylon

- The morphology of MC nylon composites were tested by INSPECT S50 scanning electron microscopy (SEM) after the composites were covered with gold.
- The tensile strength, elongation, compression strength, bending strength and other mechanical properties were tested by ETM104C electronic universal testing machine. Five samples of each composite were tested.
- The friction tests were performed for 120min with a load of 200 N. The rotational speed was 200r/min. Three samples of each composite were tested.

3. Results and discussions

3.1. The morphology features of MC nylon filled with hydraulic oil

After MC nylon composites were fractured brittlely in liquid nitrogen, the morphology of samples was observed through a scanning electron microscope (SEM). MC nylon composites filled with eight different contents of hydraulic oil are shown in Fig. 1. All of them have no obvious defects. The oil in composites looks like a regular globe, and distributed uniformly. With the increase of the content of oil from 2wt% to 8wt%, the sizes of oil were shown in table 3. The longest diameter of oil is 3.394μm. That's because a reunion phenomenon of the oil appeared in the matrix, which led to the growth of oil with the increase of the content of oil. Also, the oil distribute unevenly. As shown in figure 1, the minimum size of oil droplets is 3.071μm, which demonstrate a denser and more uniform distribution than others, more oil can't took bigger size of droplets for the MC nylon, and that would be difficult to disperse.

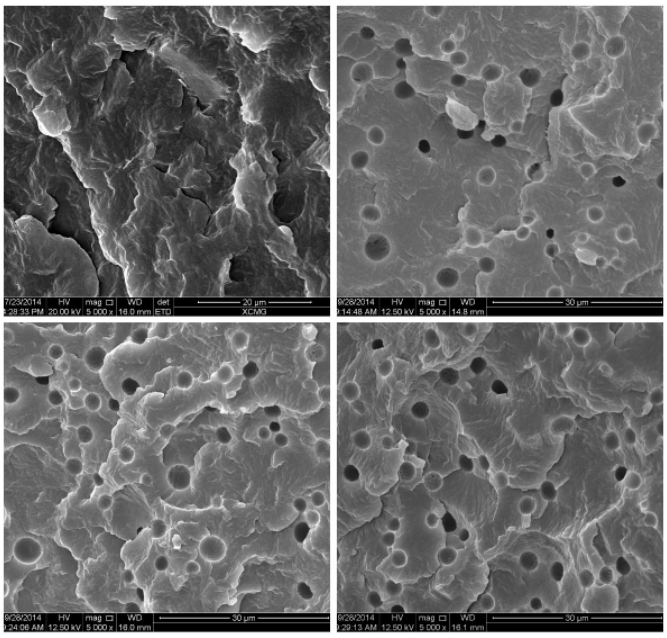

Figure 1. SEM morphology of MC nylon composites filled with different contents of hydraulic oil (a) 0; (b) 2wt%; (c) 4wt%; (d) 8wt%.

Table 3. The diameter of oil in MC nylon composites.

Number	**1**	**2**	**3**	**4**
The contents of hydraulic oil	0wt%	2wt%	4wt%	8wt%
The diameter of oil	0	3.226	3.394	3.071

3.2. Mechanical properties of MC nylon filled with hydraulic oil

The mechanical properties of MC nylon filled with hydraulic oil are illustrated in figure 2. With the increase of hydraulic oil's content from 0wt% to 8 wt%, the composites' tensile strength, bending strength, and compression strength fluctuate downward drastically: specifically, from 84.0MPa to 49.5MPa, from 113MPa to 71MPa, from 132MPa to 39MPa, respectively. Similarly, the composites' elongation increase from 53.0% to 75.0%, but with a remarkable decline to 20.0% when the hydraulic oil's content reaches 4wt% at last.

All hydraulic oil particles deform simultaneously during the deformation of the plastic, which lead to an increase of the composites' deformation. Meanwhile, the formation of liquid holes cause internal stress concentration. Consequently, both the resistance of plastic deformation and the tensile strength of composites go down. The hydraulic oil dispersed in the matrix can transfer deformation energy well, which can trigger silver craze, terminate the crack and increase the toughness when materials are damaged. However, uneven dispersion appears along with the increase of the hydraulic oil, which leads to local stress concentration, enhancement of interface effect, and uneven stress deformation. As a result, the composites become unstable, and the toughness decrease, while the brittleness increase. As shown in figure 2, when the oil content is 4wt%, the comprehensive mechanical properties of MC nylon reduce significantly.

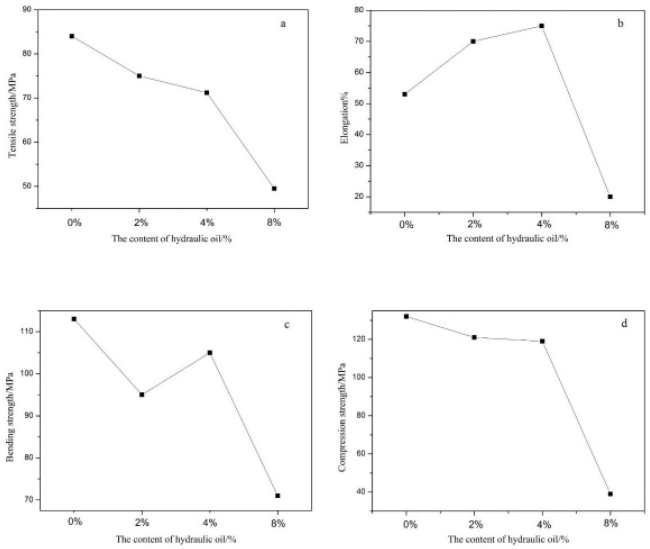

Figure 2. Mechanical properties of MC nylon composites filled with different contents of hydraulic oil (a) Tensile strength; (b) Elongation; (c) Bending strength; (d) Compression strength.

3.3. Tribological properties of MC nylon filled with hydraulic oil

The tribological properties of MC nylon filled with hydraulic oil are depicted in figure 3. The tribological properties of MC nylon improve significantly by the addition of hydraulic oil, i.e. the coefficient of friction decreases gradually with the increase of hydraulic oil content. The composites' coefficient of friction reduces to 0.16 when the hydraulic oil content is 8wt%, and the weight loss reduces to 2.4. The oil on the surface of composites overflows so that the matrix possess self-lubricating property while friction and wear are happening. As time goes, the amount of oil on the surface lessens. Then the oil inside overflows onto the surface gradually, which make it possible to self-lubricate with oil during the whole friction and wear period, and to reduce the coefficient of friction. Therefore, the lubrication enhances and the coefficients of friction of MC nylon composites filled with hydraulic oil are lower than that of pure MC nylon. At the beginning of friction, the weight losses of MC nylon composites are different due to the different contents of hydraulic oil there. After a period of time, nylon transfer film formed on the surface of the grinding ring. The weight loss of MC nylon was relatively low later. In general, the content of hydraulic oil has great influence on the wear weight loss.

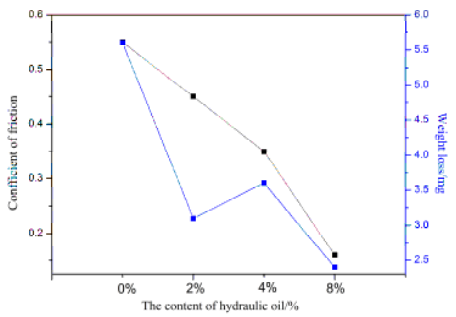

Figure 3. Tribological properties of MC nylon composites filled with different content of hydraulic oil.

5. Results

Within MC nylon filled with hydraulic oil, the oil distributed uniformly, and the size of the oil droplets increased with the raise of hydraulic oil's content.

The mechanical properties of MC nylon filled with hydraulic oil decreased obviously as a result of the addition of hydraulic oil. When the content of hydraulic oil was 4wt%, the mechanical properties of MC nylon reduced significantly.

The coefficient of friction of MC nylon filled with hydraulic oil reduced significantly attributed to the addition of hydraulic oil. The coefficient of friction of composites decreased gradually with the increase of the hydraulic oil.

MC nylon on heavy machinery must have excellent tribological properties as well as great mechanical properties (especially with good compression properties). To summarize, the MC nylon filled with hydraulic oil not only have great tensile strength and compression strength, but also has a lower coefficient of friction and wear weight loss when the content of oil is 4wt%

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