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Effect of organoclay loading on the sliding wear behavior of Polyamide 6 nanocomposites

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ABSTRACT

Nylon based nanocomposites exhibit improved mechanical properties than pristine Nylon. The effect of organoclay loading was investigated on the sliding wear behaviour. Polymer nanocomposites with 1, 3 and 5% organoclay were prepared by melt intercalation technique. Nylon nanocomposite with 5% clay exhibits superior friction and wear properties than pristine Nylon, I and 3% clay loaded nanocomposites. Increase in the degree of crystallinity of Nylon nanocomposites and formation of uniform tenacious transfer film by nanocomposite on the counterface contribute to the improved wear performance of nanocomposites.

Keywords: Polymer clay nanocompsoties, Nylon, sliding wear, mechanisms

1. INTRODUCTION

Polymer clay nanocomposites (PCN) are materials that have been given much attention recently and represent an emerging class of specialty plastic materials [1]. As nano scale dispersion of the clay layers is achieved in the polymer matrix, reinforcement efficiency is realized at low loading levels (<5%). Nanolevel dispersion in polymer matrix was reported to improve the tensile properties, barrier properties, solvent intake resistance, thermal stability and flame retardancy [2, 3] .In many engineering applications the performance of the polymer parts depends on the wear resistance of the material. The improvement in the mechanical properties such as strength and modulus of base polymer / composite affects the tribo behavior of the composite. Sliding friction and wear behaviour of few nanocomposites was reported [4-6]. Low nanometer silicon nitride filled epoxy composites were found to exhibit significantly improved tribological performance and mechanical properties at low filler content [4]. The nano sized SiO2 filled PEEK showed considerably lower wear rate and coefficient of friction than neat PEEK [5]. The wear resistance of nano sized ZnO filled PTFE increased while the coefficient of friction remained the same due to prevention of destruction of the PTFE banded structure during the friction process by nanometer ZnO [6].

Nylon 6 being a most common engineering thermoplastic is used in many tribological applications. This work aims to study the effect of organoclay loading on the sliding friction and wear characteristics of Nylon clay nanocomposites.

2. Experimental details

Nylon nanocomposites containing 1,3 and 5% (all mentioned in wt %) organoclay in Nylon 6 matrix were prepared by melt intercalation technique. X-ray diffraction (XRD) analysis of the nanocomposite indicated the presence of intercalated and exfoliated clay monolayers. Detailed discussion on preparation and characterization of nanocomposites are described elsewhere [7]. The test samples in the form of cylindrical pins were injection molded. Dry sliding friction and wear tests were conducted using a pin-on-disk tribometer at different normal loads varyingfrom 30N to 60N and at a constant sliding speed of

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0.4 m/s. The counterface disk was made up of stainless steel (AISI 314). The friction force was measured using a load cell. The temperature rise in the disk was measured using an IR temperate sensor. A personal computer based data acquisition system was used to continuously acquire and store friction force and wear track temperature. The wear loss is quantified from the mass loss during sliding. The worn-out surfaces were analyzed using scanning electron microscope (SEM).

3. Results and discussion

Table 1 shows the tensile properties of Nylon and Nylon nanocomposites. Addition of clay increases the modulus drastically and tensile strength with a reduction in the ductility. Fig 1 shows the effect of clay loading on the coefficient of friction variation during sliding of Nylon and Nylon nanocomposites. As the clay loading increases, the coefficient of friction reduces. Nylon nanocomposite with 5% clay loading exhibits the lowest coefficient of friction compared with the pristine and Nanocomposite with 1 and 3% clay loading. It is also noted that the coefficient of friction increases linearly with the clay loading as seen in Fig 1.

The effect of normal load on the coefficient of friction of Nylon and nanocomposites are shown in the Fig 2 (a-d). The coefficient of friction increases with the normal load due to the changes in the real area of contact. The skin formed on the surface of pin due to injection molding tends to alter the friction behaviour of the Nylon and nanocomposites. The skin formed on the surface due to injection molding has different composition than the bulk [8,9] hence it is harder than the inner core. Table 2 shows the variation in the durometer hardness (shore D) measured on the skin and inner core. The skin affects the break-in behavior (Fig. 2). As the load increases, the sliding distance to attain the break-in decreases. For pristine Nylon at the load of 60 N, the break-in occurs immediately indicting the normal load was sufficient to disrupt the skin. The skin of Nylon nanocomposites is harder and higher load is required to disrupt the skin.

Fig 3 shows the temperature rise of the disk due to frictional heating at a normal load of 60 N. Due to the high coefficient of the friction of the pristine Nylon the heat generated in the disk is higher. With the increase in the clay content the rise in the temperature decreases and for Nylon nanocomposites with 5% clay the rise in the temperature is only ~ 5K. Similar results were also observed at all other loads investigated. Fig 4 shows the effect of clay loading on specific wear rate of Nylon nanocomposites. The clay addition is effective in reducing the specific wear rate. Nylon nanocomposite with 5% clay loading is more wear resistant than other materials tested at all loads. The specific wear rate decreases with clay addition almost linearly. The effect of normal load on the wear is clearly evident from the Fig 4, as the load increases the wear also increases since it is directly proportional to the normal load.

Nylon 6 nanocomposite with 1 to 5% clay exhibited a lower coefficient of friction and specific wear rate than pristine Nylon 6 at all test conditions investigated. This behavior may be attributed to higher degree crystallinity of Nanocomposites. Crystalline structures have higher density than amorphous structures due to the highly ordered packing. More energy is required to damage the orderly packed crystalline material than for disrupting the loosely packed amorphous materials [10] .The XRD data of nanocomposites containing variable amounts of clay (0, I, 3 and 5%) is shown in Fig 5. Pristine Nylon has diffraction peaks at 20.4° and 23.9°, which are of α-type crystalline form Nylon. Nylon nanocomposites with clay contents of I, 3 and 5%) shows a characteristic sharp peak at 21.2°, which results from γ-type crystalline structure of Nylon. This transition has occurred du6 to high temperature treatment that Nylon has undergone during melt processing. Increase in the temperature as for Nylon γ-phase grows stronger while α-phase weakens. The effect of the clay addition is apparent as the crystallinity increases. All nanocomposites show a sharp peak indicating more crystallinity than Nylon.

As the clay particles are dispersed in nano level in Nylon 6 matrix and also due to the high specific surface area of the nanoparticles the interfacial adhesion between matrix and nanoparticle is high and contributes to the improved tribological behavior. Due to the presence of nanolevel filler, which has the same size as the segments of the surrounding polymer chains, the material removal of nanocomposites is mild and also aids in the formation of uniform tenacious transfer layer [5]. This is evident from the Figs. 6a and b of the transfer layer formed on the counterface. Fig. 6a shows the incoherent transfer layer formed on the counterface during sliding of Nylon 6 pins. SEM images (Fig 7a and b) of the worn pins indicate the adhesive wear mechanism involved during sliding process.

4 Conclusions

The effect of the organoclay loading on the sliding friction and wear behaviour was studied and the following conclusions were drawn-

- The organoclay loading effectively reduces the coefficient of friction and wear and the reduction is almost linear with the clay loading
- The formation of skin on the surface of pin affects the frictional properties of Nylon and nanocomposites. Addition of organoclay affects the properties of skin as it increases the hardness of the skin.
- Formation of uniform tenacious transfer layer by Nylon 6 nanocomposite on the counterface contributes to the reduction in coefficient of friction and specific wear rate.
- Increase in the degree of crystallinity of the Nanocomposites and the presence of nanolevel filler of same size of the polymer causes a reduction in friction and wear of nanocomposites
- Nylon nanocomposites with 5% clay loading not only exhibited superior mechanical properties but also enhanced tribological properties.

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Organoclay content (wt %)	Tensile modulus (MPa)	Tensile strength (MPa)	Elongation at break (%)
0	145	45	384
1	166	44	266
3	207	47	203
5	315	51	95

Table 1. Tensile properties of Nylon and Nanocomposites.

	Hardness (Shore D) of the Pin	
	At molded surface	At cut surface
Nylon 6	72	68
Nylon 6 + 1% Clay	74	69
Nylon 6 + 1% Clay	75	69
Nylon 6 + 5% Clay	75	70

Table 2 : Hardness (Shore D) of the pins

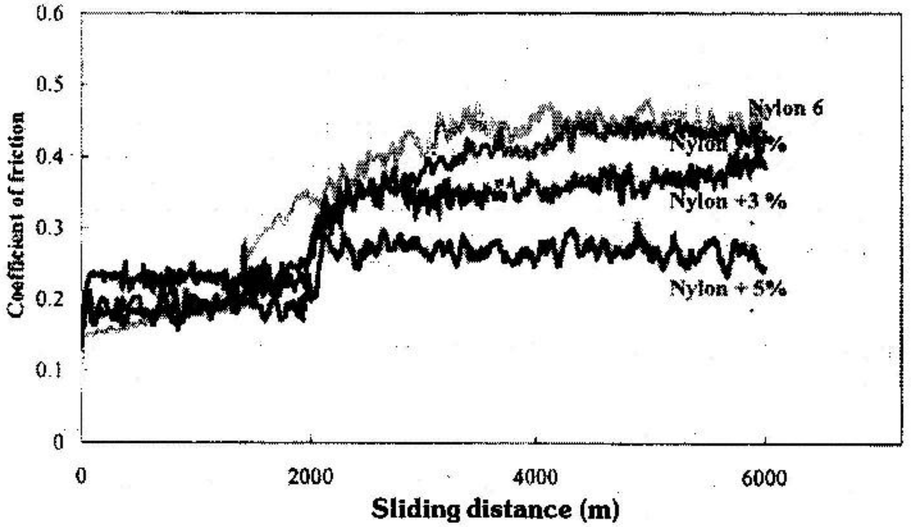

Fig 1 : Effect of wt percent of clay of Nylon on coefficient of friction

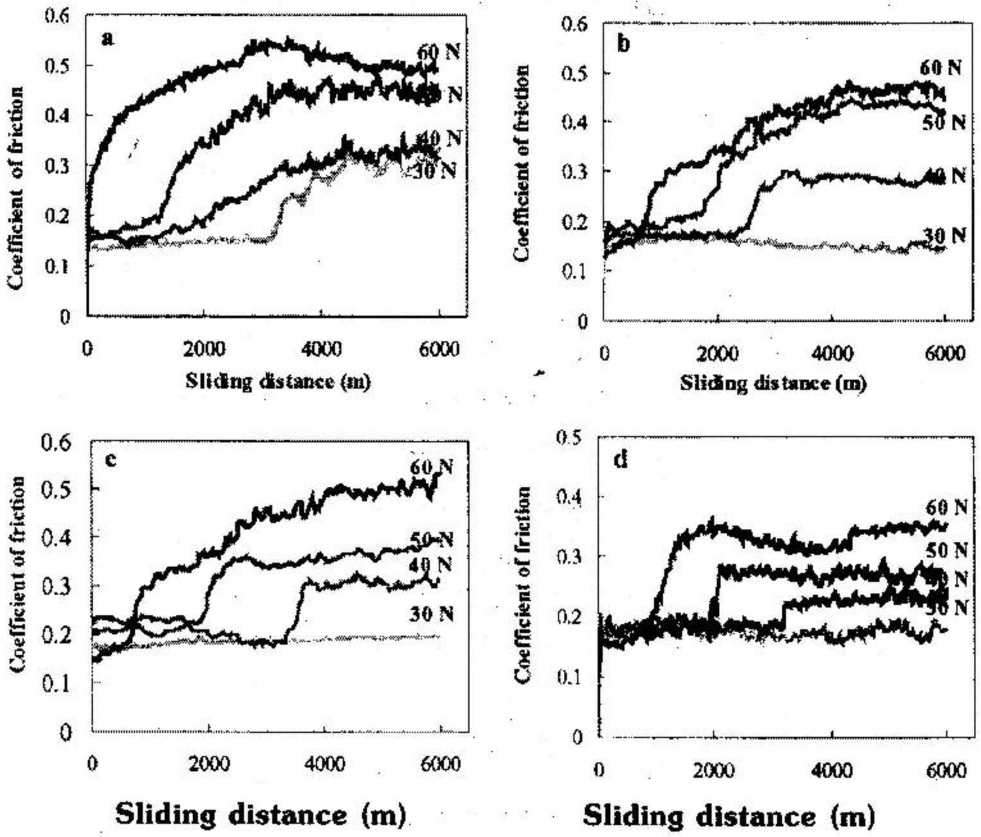

Fig 2 : Effect of normal load on coefficient of friction of Nylon and nanocomposites
a) Nylon 6 b) Nylong + 1% organoclay c) Nylon + 3% organoclay and d) Nylon + 5% organoclay

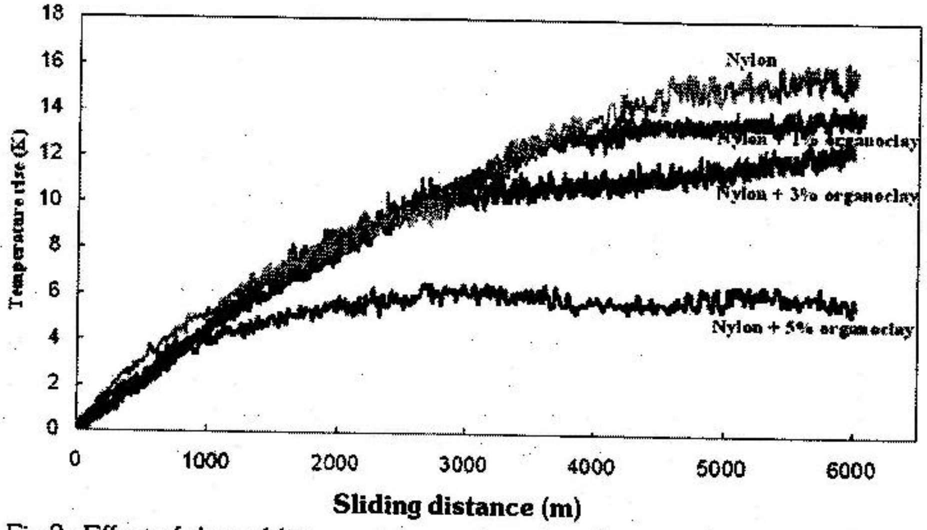

Fig 3 : Effect of clay addition on temperature rise of mating disc during sliding

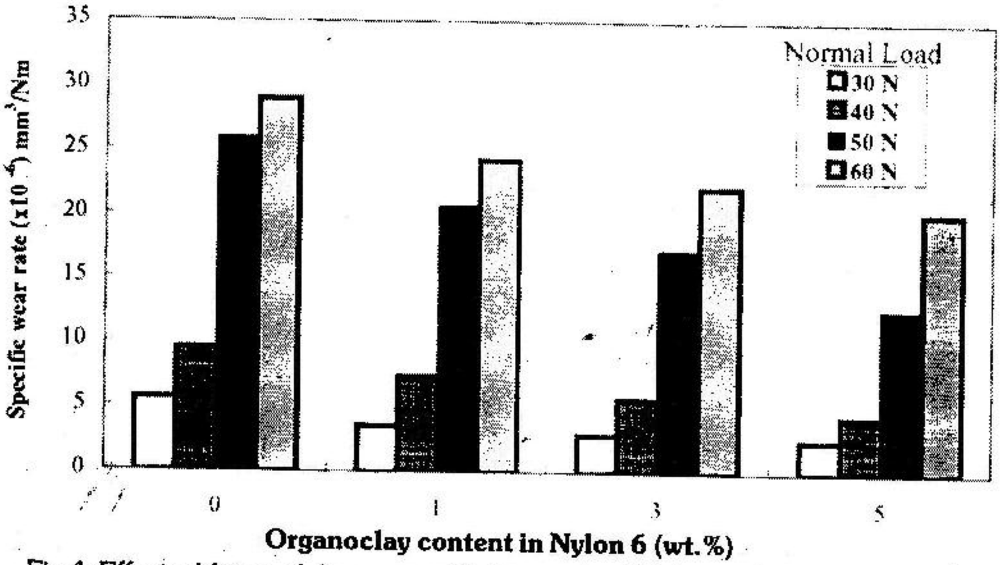

Fig 4: Effect addition of clay on specific wear rate of Nylon and Nanocomposites

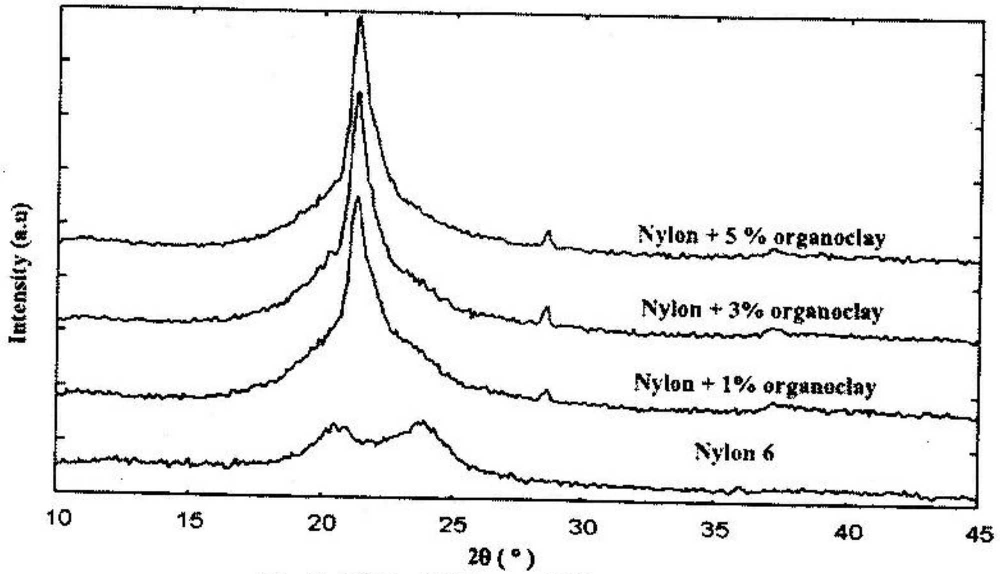

Fig 5 : XRD of Nylon and Nanocomposites

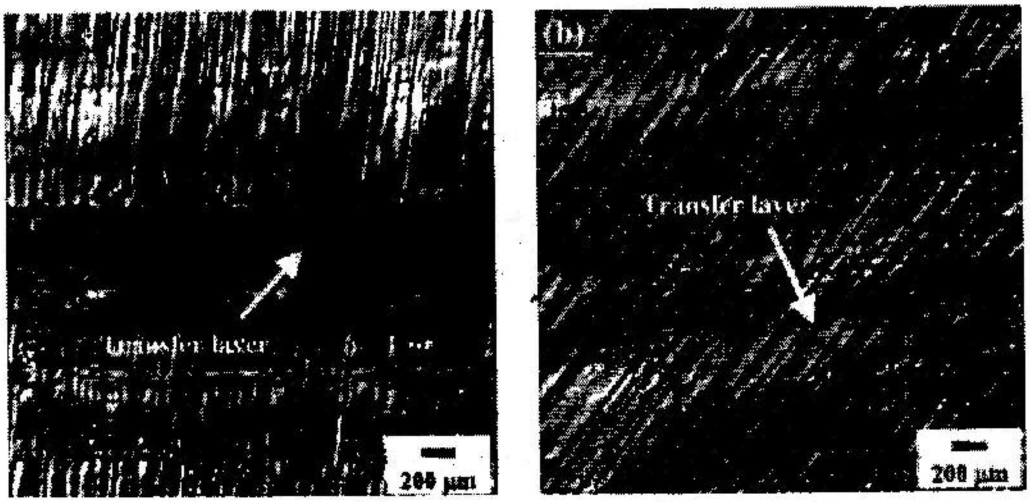

Fig 6 : Transfer layer formed on the counterface disc after sliding at normal load 50 N and speed 0.4m/s of a) Nylon 6 and b) Nylong 6+5% clay.

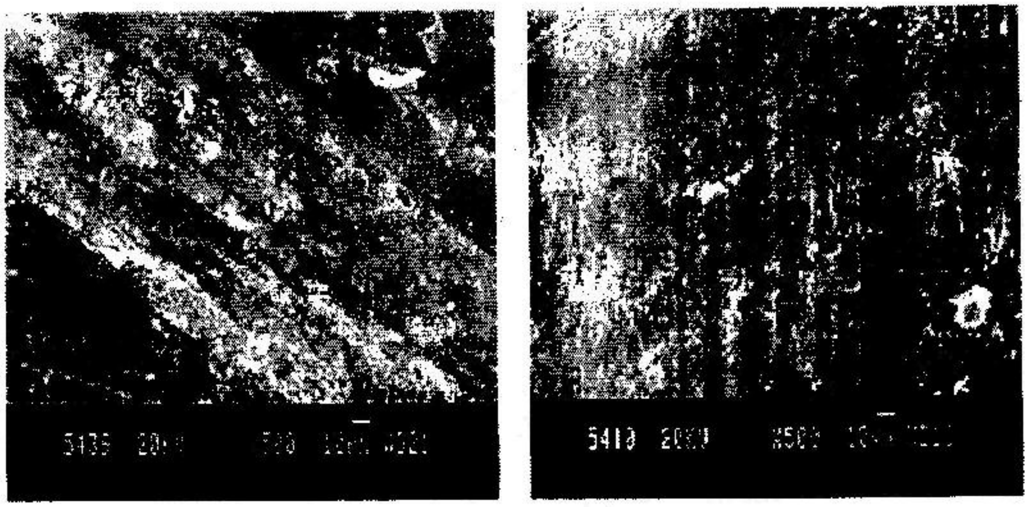

Fig 7 : SEM image of worn surface of the pin of a) Nylon 6 and b) Nylong 6 + 5% clay. (Normal Load = 50N, Speed = 0.4 m/s)