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Application of nanoclay lubricants for lowering wear of tools for steel meshing - A case study

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Abstract. The tools that are employed for industrial woven steel wire mesh processing suffer significant wear, particularly those employed for bending the steel wire at the beginning of the process due to the high forces that are required. Lubricants are employed for the purpose of reducing friction between the tool and the steel wire in these types of processes, hence reducing tool wear. Nanoparticle additives have been investigated for improving the tribological performance of lubricants; due to their small size they may fill surface valleys reducing surface roughness, act as nanobearing limiting metal-metal contact, amongst others. Particularly, nanoclay nanoparticles, such as montmorillonite (MMT), have been proposed as nanoadditives for tribological applications due to being naturally occurring, environmentally friendly, and low-cost. In our work, MMT clay nanoparticles were dispersed by homogenization and ultrasonication in a water-based synthetic lubricant with varying concentrations (0.01, 0.05, and 0.10 wt.%). The wear preventive tribological properties of the prepared nanolubricants were characterized experimentally with a T-02 four-ball tribostester according to ASTM D4172. The wear scar diameters of the three lower steel balls of the four-ball tribopair were measured with an Alicona EdgeMaster optical measurement system. In our laboratory experiments wear scar diameter was reduced by 19% with a MMT clay nanoparticle concentration of only 0.01 wt.%. Higher concentrations (0.05 and 0.10 wt.%) resulted in lower improvements due to nanoparticle agglomeration in the lubricant. Finally, MMT clay nanolubricants were employed for the wire-bending process in a steel-meshing equipment with the nanoparticle concentration where the best tribological performance was found (0.01 wt.%). Tools were monitored for 120 h; tool wear was recorded by measuring the change in the wire-bending tool dimensions compared to the change obtained when the unfilled base lubricant was employed. For the first inch of the tool, where the highest force for bending the wire is required, tool wear in was lowered from 0.014 in to 0.006 in, representing an improvement of 57%. In average, the improvement on wear resistance for the tool was found to be 30%. The results found for this study demonstrate that MMT clay nanoparticle additives are able to improve wear resistance and extend tool life, resulting in considerable savings.

1. Introduction

Tooling employed for processing of metallic products commonly suffer wear due to the friction between the contacting surfaces reducing tool life and increasing the overall production costs [1]. Improved lubricants with nanoparticle additives have been explored for the purpose of increasing tool life by several researchers [2–5]. Most recently, special attention has been given to environmentally friendly or green nanoparticle additives for lubricants [6,7]. For example, halloysite nanotubes

(HNTs), a type of nanoclay, demonstrated a reduction wear mass loss and coefficient of friction compared to the base metal-working fluid [8]. Calcium carbonate ($CaCO_3$) nanoparticles were employed as additives in a poly-alpha-olefin in a study by Zhang et al. [6] demonstrating improvements in load-carrying capacity and provide anti-wear and friction reducing properties. Montmorillonite (MMT) clay is a naturally occurring layered phyllosilicate material that has been widely used as a reinforcement for composite materials [9–12] that have been proposed for biomedical applications [13,14] due to their good biocompatibility [15]. While their application for improving tribological properties of polymer matrices has been studied [16–18] their use as lubricant additives has not been studied in depth, to the best of the authors knowledge.

The focus of this study was to improve the lifetime of the tools employed for processing industrial woven wire mesh, particularly for those employed for bending steel wire that suffer high wear due to the high forces that are required. Laboratory tests were first performed on the nanolubricants with varying concentrations of MMT nanoparticles to determine the optimal nanoparticle weight percent for the highest tribological performance. Finally, tool wear was monitored by measuring the change in dimensions over a period of 120 h in a critical region of the tool with our MMT nanolubricants and the base lubricant.

2. Experimental details

MMT clay nanoparticles with a chemical formula of $H_2Al_2O_6Si$, layer thickness of ~ 1 nm, and lengths of 10 μm were obtained from Sigma-Aldrich. Nanoparticles were dispersed in a water-based synthetic lubricant in concentrations of 0.01, 0.05, and 0.10 wt.% through homogenization and ultrasonication. Tribological testing was performed in a T-02 four-ball tribotester according to ASTM D 4172 for determining the wear preventive characteristics of lubricating fluids [19]. In this test the three lower balls covered in lubricant are fixed and the upper ball rotates with the applied load of 392 N, velocity of 1200 rpm, and temperature of 75°C. The time of the test was reduced form 60 min to 45 min to avoid the evaporation of the lubricant due to the high water content. Balls were of an AISI 52100 steel; wear scar diameters (WSD) of the three lower balls were measured with an Alicona EdgeMaster optical measurement system after each test.

Finally, the concentration with the best tribological performance was selected from the laboratory tests to be used for the wire-bending process in a steel-meshing equipment, as shown in Figure 1b-c. Tool wear (Figure 1a) was monitored for a 120 h with the water-based lubricant and the MMT nanolubricant.

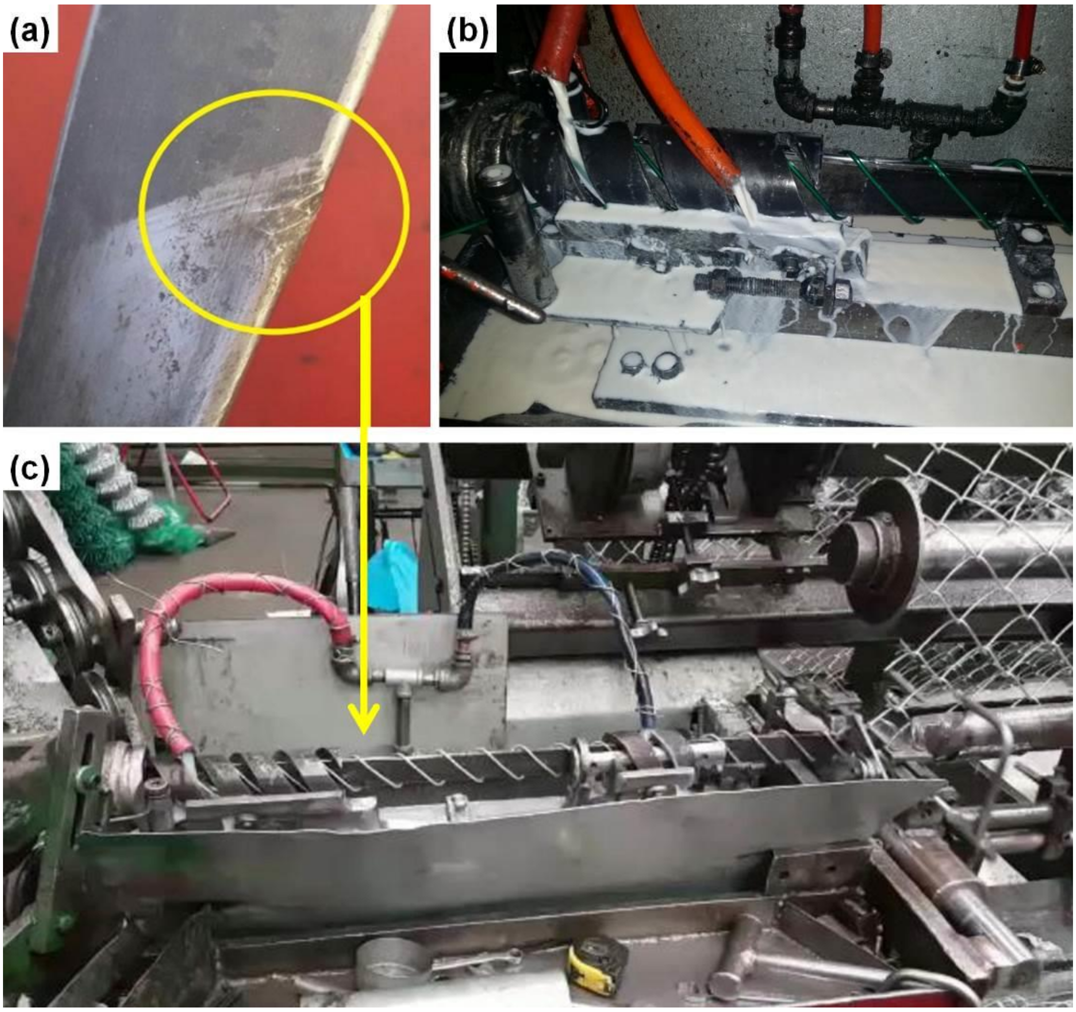

Figure 1. Wire-bending process in a steel-meshing equipment: (a) tool wear, (b) lubricant employed for the steel-meshing equipment, (c) tool employed for wire-bending, the first inches suffer the highest wear.

3. Results and discussions

Figure 2 shows the results of the tribological tests performed with the MMT nanolubricants. A significant decrease is observed at the very low concentration of 0.01 wt.% MMT, with a decrease in WSD of 19%. MMT clay is a layered nanomaterial, thus a tribological mechanism of exfoliation and possible tribofilm formation is proposed [20,21], as depicted in Figure 3. Higher nanoparticle concentrations increase wear likely due to re-agglomeration in the lubricant.

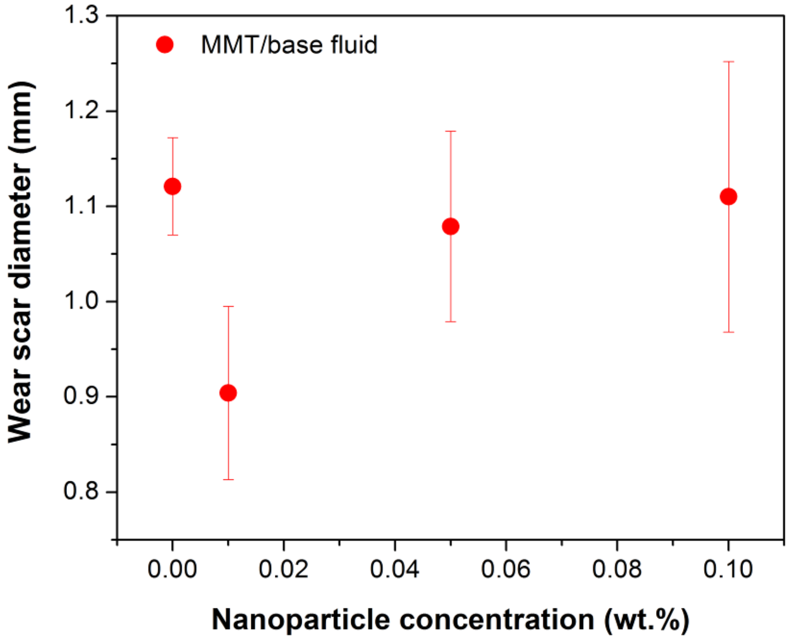

Figure 2. Wear scar diameter of steel balls covered in nanolubricants with varying MMT clay nanoparticle concentrations.

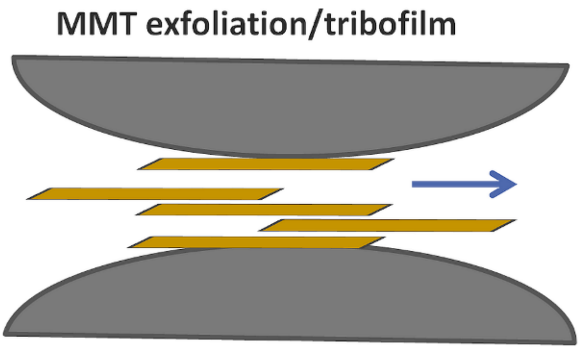

Figure 3. Proposed tribological mechanism of exfoliation and tribofilm formation for MMT clay nanoparticles.

Based on the results shown in Figure 2 nanolubricants with a concentration of 0.01 wt.% of MMT clay nanoparticles prepared by bath sonication were employed for the wire-bending process in a steel-meshing equipment (Figure 1c). Tool wear was monitored for 120h. Figure 4a indicates the critical region of the tool where the highest wear occurs due to the high forces needed for bending the steel wire (4 to 13 in). Figure 4b presents a photograph of the side the tools used with the base lubricant and with the 0.01 wt.% MMT nanolubricant. Higher wear is visible for the tool employed with the base lubricant without nanoparticle addition.

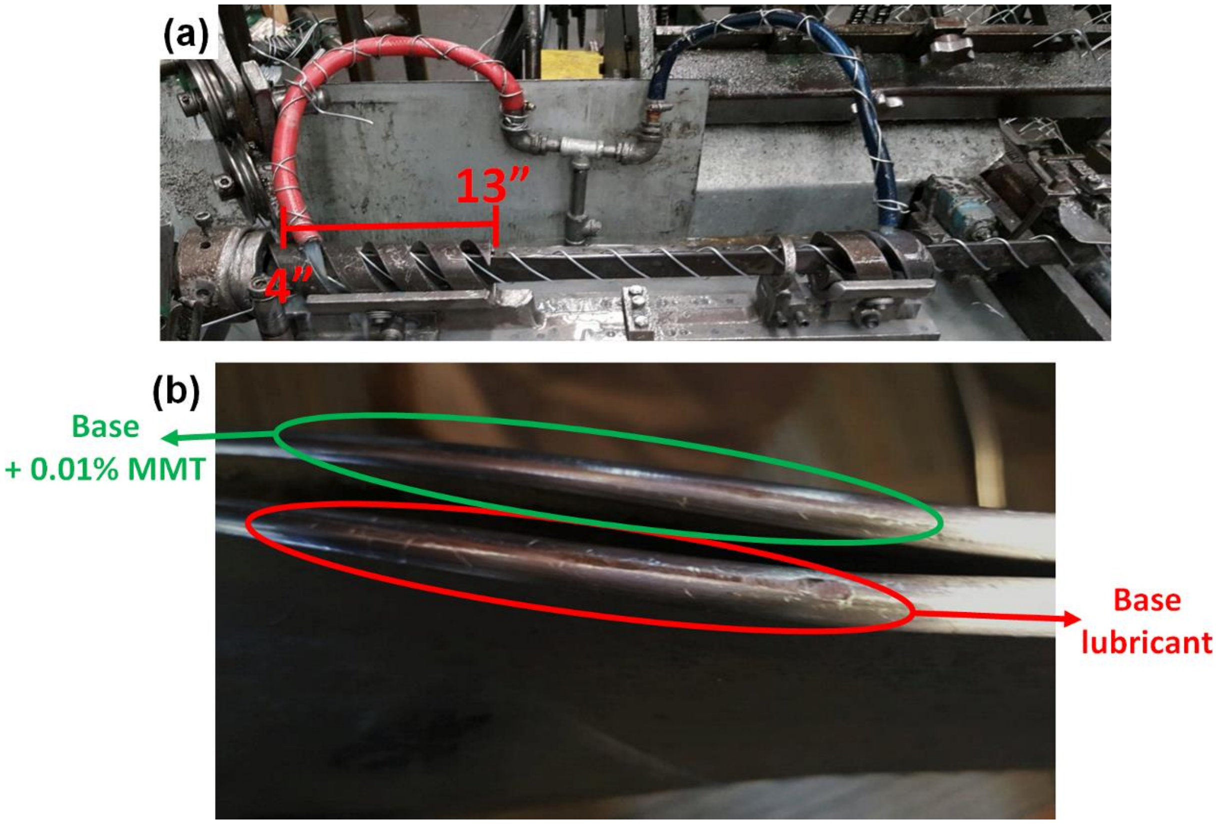

Figure 4. (a) Indicates the region of the tool that suffers the highest wear in the wire-bending process. (b) Photograph showing higher wear for the base lubricant, compared to the MMT nanolubricant.

As mentioned, tool wear was monitored for 120 h in tools employed in the wire-bending process with the base lubricant and the 0.01 wt.% MMT nanolubricant. Figure 5 shows a plot of the change in tool width (due to wear) along the critical distance ranging from 4 – 13 in when the base fluid and the nanolubricant were employed. From the image is evident that MMT nanoparticles are indeed able to limit metal-metal contact and possess good anti-wear properties. At inch 4 tool width for the MMT nanolubricant is only 0.006 in, compared to 0.014 with the base lubricant. This represents an enhancement on wear resistance of 57%. Overall, the average improvement on wear resistance along the critical area of the tool was 30%. This result indicates that MMT nanoparticles are good candidates as lubricant additives increasing wear resistance and extending tool life.

4. Conclusions

In this work, the anti-wear properties of MMT nanolubricants were characterized through a four-ball tribotest at varying concentrations. Nanolubricant prepared with the MMT weight percentage of nanoparticles with the best tribological results was then employed in a woven steel wire mesh process. Tool wear for the wire-bending part of the process was monitored for 120 h, showing an increase in wear resistance of 30% compare to the unfilled base lubricant. These results demonstrate that MMT nanoparticles may be used as anti-wear additives in lubricants employed in industrial processes extending tool life.

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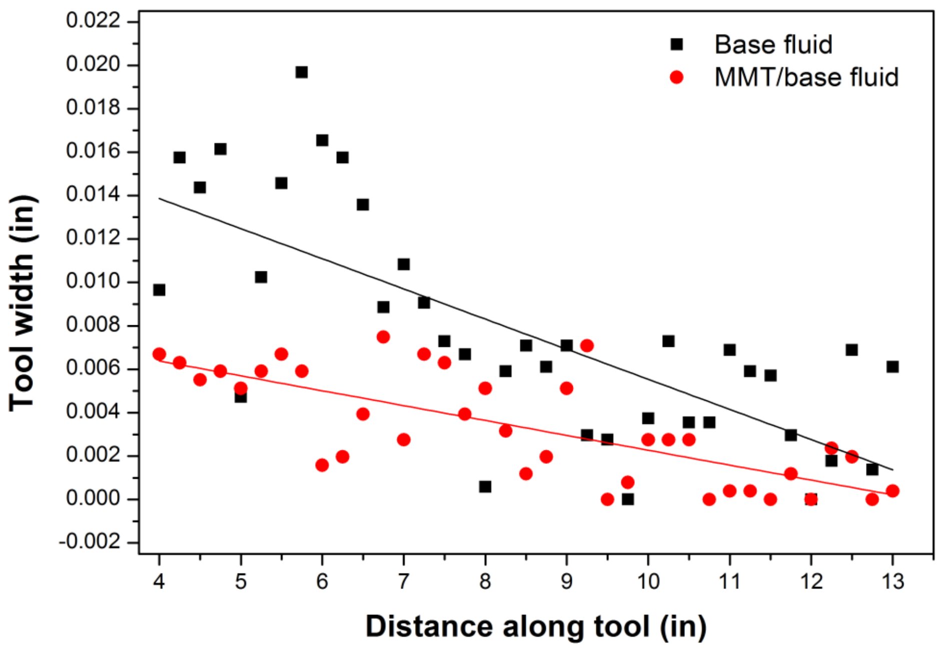

Figure 5. Change in tool dimension along the critical region (4-13 in) with the base fluid and the 0.01 wt.% MMT nanolubricant.

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