WHITE PAPER

De-Risking New Rolling Fluid Technology in Aluminum Hot Mills

BY YAO LU, GROUP LEADER - CENTER OF INNOVATION
AND BAS SMEULDERS, SENIOR RESEARCH SCIENTIST

Introduction

Achieving successful aluminum hot rolling operations and excellent quality strip surface relies critically on effective lubrication, cooling, and cleanliness during the rolling process. To achieve these objectives, a continuous supply of recirculating emulsion is applied, serving multiple functions simultaneously: facilitating work roll cooling, enabling precise camber control, and ensuring optimal lubrication as well as mill stand and strip cleanliness.

When developing, testing and trialing new fluid technologies, recognizing the diversity in industrial mill configurations is imperative. Variables like lubricant application method, wiper assemblies, and work roll brushes can differ significantly, so good lubricant performance and high strip surface quality must be proven under the specific process conditions, before shipping for field trials.

This white paper presents the unique and rigorous approach used by Quaker Houghton for developing advanced aluminum hot rolling fluids (Fig. 1). In this study we measure and compare the performance of new, non-soap technology QH EVEROLL™ A 5000 against traditional soap-based and existing soap-free chemistries. Using in-house laboratory evaluation techniques and validating the outcomes through process-tailored pilot mill trials, we ensure excellent rolling fluid performance – thereby de-risking implementation of new technologies at rolling mills.

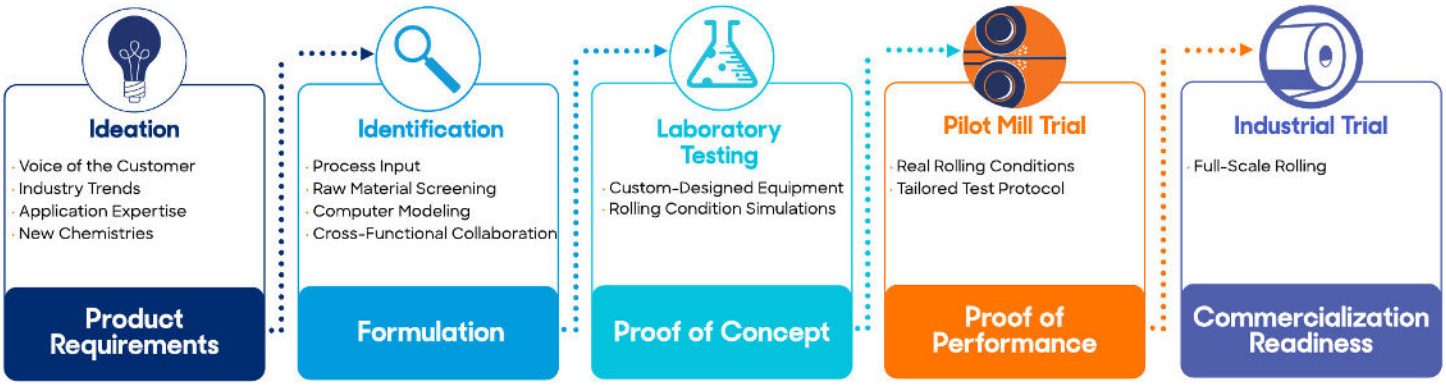


Fig. 1: Our unique approach to innovation includes validation of lab results through pilot mill trials, providing proof of performance and de-risking implementation of new technologies.

Quaker Houghton
Forward Together

©2025 Quaker Houghton. All rights reserved.

V001.25.01.EN.GL

De-Risking New Rolling Fluid Technology in Aluminum Hot Mills

BY YAO LU, GROUP LEADER - CENTER OF INNOVATION AND BAS SMEULDERS, SR RESEARCH SCIENTIST

Lubrication Mechanisms

Lubricity is a key process parameter in aluminum hot rolling. Under lubrication may result in metal sticking to the work rolls, aluminum oxide pick up, and excessive roll coating — ultimately impacting strip surface quality. Over lubrication can cause slip and slab refusal. There are several lubrication mechanisms to consider:

Film formation leads to a degree of separation between work roll and strip, reducing the friction. Film formation is often driven by the base oil viscosity but may also involve adsorption of high molecular weight compounds or a temperature-induced phase change. When a film is formed, essential friction modifiers and other additives can transfer more efficiently to the contact.

Boundary friction is the friction between two surfaces that are (locally) in close contact. This friction is usually lowered by friction modifiers such as fatty acids or phosphorous compounds that adsorb onto the surface. Lubricated boundary friction also relies on adequate protection of the surfaces, without which metal-to-metal contact would occur, accompanied by high (local) friction.

Elastohydrodynamic friction occurs within the lubricant layer in the areas where work roll and strip are separated by a pressurized film. However, considering the very high temperatures in aluminum hot rolling, and the resulting low viscosities, this contribution is likely negligible.

Development of a work roll coating is a normal phenomenon in aluminum hot rolling. This coating consists of metallic aluminum fines and aluminum oxides in an organic matrix. Similar to the film formation mentioned above, this coating may also serve as a separating medium.

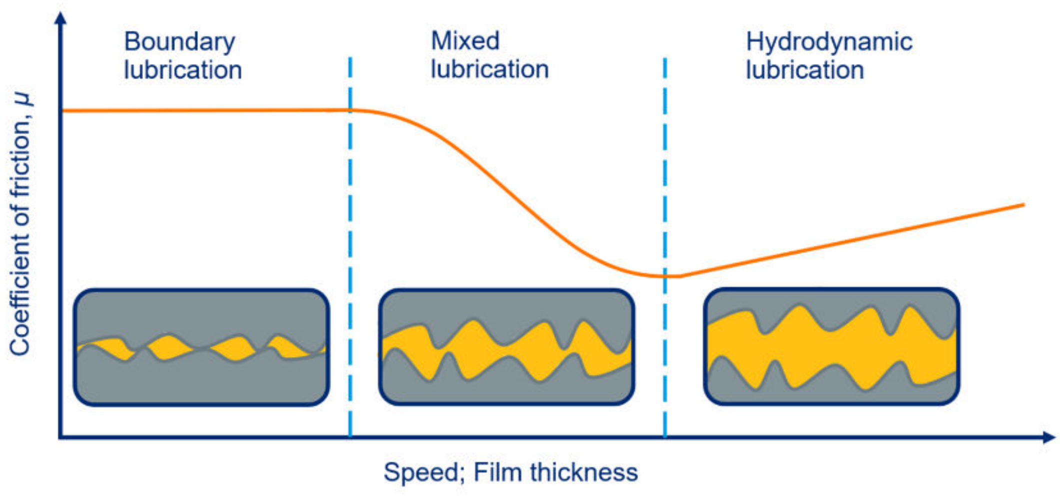


Fig. 2: Schematic Stribeck curve illustrating boundary, mixed and hydrodynamic lubrication mechanisms.

©2025 Quaker Houghton. All rights reserved.

De-Risking New Rolling Fluid Technology in Aluminum Hot Mills

BY YAO LU, GROUP LEADER - CENTER OF INNOVATION AND BAS SMEULDERS, SR RESEARCH SCIENTIST

Experimental Equipment

The key equipment and methods used for assessing emulsion performance in this study are outlined below.

The Mini Traction Machine (MTM) is a versatile ball-on-disc tribometer (Fig. 3), which can be used to assess lubrication in several lubrication regimes. Depending on specimen type, load, sum speed and sliding speed, an extensive range of well-defined tribological tests can be carried out. This way, we can measure Stribeck curves, carry out boundary tests (in severity ranging from very mild to very severe), and assess elastohydrodynamic (full-film) friction. Due to the independent control of both ball and disc speed, our self-developed roll bite mimicking tests can be carried out, which replicate the rolling process because both the rotating tool and moving aluminum 'specimen' frequently move out of contact, unlike a pin-on-disc test, for which the point of contact (usually on the tool) persists throughout the test.

Fig. 3: The Mini Traction Machine (MTM)

Ultra-thin film interferometer is used to quantify film formation of an emulsion. This instrument involves a rotating ball that is loaded onto a rotating glass disc while lubricant is applied. The thickness of the film that forms between the ball and disc is measured with an optical technique where a microscope is used to analyze the interference pattern that forms at the contact. The interference pattern is a measure of the film thickness. The film thickness can thus be measured as a function of rolling speed, while temperature and of course lubricant type are variables as well. Based on our decades of lubricant expertise, a robust proprietary film formation test method has been established.

Anodizing setup: The assessment of surface quality in the aluminum rolling process frequently involves anodizing, an electrochemical process used to rate hot or cold rolled strips. This method entails the controlled deposition of a thin aluminum oxide (Al_2O_3) layer on the aluminum strip surface through the passage of an electric current in an electrolytic bath.

To facilitate this process, an in-house anodizing setup was constructed, equipped with a one-liter vessel for the electrolyte (20wt% H_2SO_4), a transformer capable of delivering a direct current (DC) output using a potential of 12 volts, and a circulation system for maintaining a consistent bath temperature of 20°C. The aluminum strip functions as the anode while a piece of lead serves as the cathode. Precise control over two key parameters, time and current density, is crucial to achieving a desired Al_2O_3 layer thickness, ranging from 8-10 µm.

Before and after anodizing, the aluminum strip samples undergo a thorough cleaning procedure to eliminate any residual impurities. This involves washing with soap powder, followed by rinsing with

Quaker Houghton
Forward Together

©2025 Quaker Houghton. All rights reserved.

deionized water and finally, air blow off to ensure a clean surface for accurate evaluation. Following anodizing, the samples are visually evaluated in accordance with established industrial standards.

The Quaker Houghton Four-High Multi-Functional Reversing Mill

Located in Qingpu District, Shanghai, China, the Quaker Houghton Multi-Functional Reversing Mill was constructed between 2013 and 2014, and successfully commissioned and put into operation in 2016[1]. The mill is shown in Figure 4. Its innovative design integrates three distinct fluid systems: emulsion, cleaning, and direct application, offering flexibility in lubricant delivery for fulfilling multiple rolling applications.

Fig.4 The Quaker Houghton Four-High Multi-Functional Reversing Mill

The Pilot Mill's versatility is increased further by its capability of rolling both steel and aluminum alloys whether they are hard or soft, across a range of process settings. With an annealing furnace capable of reaching 600°C maximum, it can also be used for the aluminum hot rolling process. In tandem with our industry-leading laboratory facilities and rigorous protocols, our Pilot Mill facilitates a holistic approach for robust product development. Its comprehensive capability not only fulfills basic chemistry and mechanism studies and lab test method development, but also propels product technology optimization and fosters the development of innovative and next-generation technologies, aimed at addressing current and future customer needs.

©2025 Quaker Houghton. All rights reserved.

De-Risking New Rolling Fluid Technology in Aluminum Hot Mills

BY YAO LU, GROUP LEADER - CENTER OF INNOVATION AND BAS SMEULDERS, SR RESEARCH SCIENTIST

Hot Rolling Fluid Types

Both soap-based and soap-free rolling fluid technologies are widely used in the aluminum hot rolling industry. Soap-based products provide the highest level of lubricity and surface quality of rolled material, especially for hard alloys. This lubricity is achieved through the formation of metallic soaps generated from the reaction between oleic acid and metallic ions. However, these metallic soaps build up over time and can change or contaminate the emulsion if not carefully managed, making it unstable.

Soap-free products are easier to maintain and typically show lower oil consumption compared to soap-based chemistry. However, cleaning power and surface quality can be compromised by lower lubricity levels. Existing soap-free chemistries are also known to produce extremely fine aluminium particles that may deposit, often causing sludge buildup both at the mill and in the tanks (Fig. 5).

Fig. 5: Existing soap-free products are known to cause sludge buildup.

The new non-soap technology QH EVEROLL™ A 5000 employs phosphorous compounds as effective friction modifiers. Along with powerful dispersion agents, it keeps the benefits of both existing technologies while minimizing their shortcomings.

In this study, emulsions of the three different types of rolling oils were evaluated with a concentration of 4 wt% (referred to as Emulsion A, Emulsion B and Emulsion C) in the lab evaluation and on the pilot mill. Emulsion A was a traditional soap-based product, thus artificial aging was employed to simulate the generation of metallic soaps. Emulsion B, on the other hand, represented the novel non-soap technology, QH EVEROLL™ A 5000, designed to enhance mill cleanliness, while Emulsion C served as a common, existing soap-free benchmark.

Test Results

Lubricity and film formation assessment

To assess the lubricity of these emulsions, we used a MTM operating in ball-on-disc mode using a hard aluminum alloy substrate. This configuration is particularly suited for elucidating the intrinsic friction characteristics governed by molecular adsorption in the boundary lubrication regime. At 80°C, the coefficient of friction (CoF) measurements revealed that soap-based Emulsion A and novel non-soap Emulsion B exhibited comparable and superior performance compared to typical soap-free Emulsion C (Fig. 6(a)).

©2025 Quaker Houghton. All rights reserved.

De-Risking New Rolling Fluid Technology in Aluminum Hot Mills

BY YAO LU, GROUP LEADER - CENTER OF INNOVATION AND BAS SMEULDERS, SR RESEARCH SCIENTIST

Another crucial lubricant property is film formation. Aluminum hot rolling lubricant experiences thermal separation resulting from high strip temperatures, where film formation leads to a certain degree of separation between work roll and strip, reducing the amount of boundary contact and thus reducing the overall friction[2]. Film formation was evaluated with an ultra-thin film interferometer. Conducted at 4 wt% concentration and 80°C, the results indicated that the soap-based and novel non-soap emulsions significantly outperformed the typical soap-free emulsion in terms of film thickness, with a value that is twice as high at the higher speeds (Fig. 6(b)).

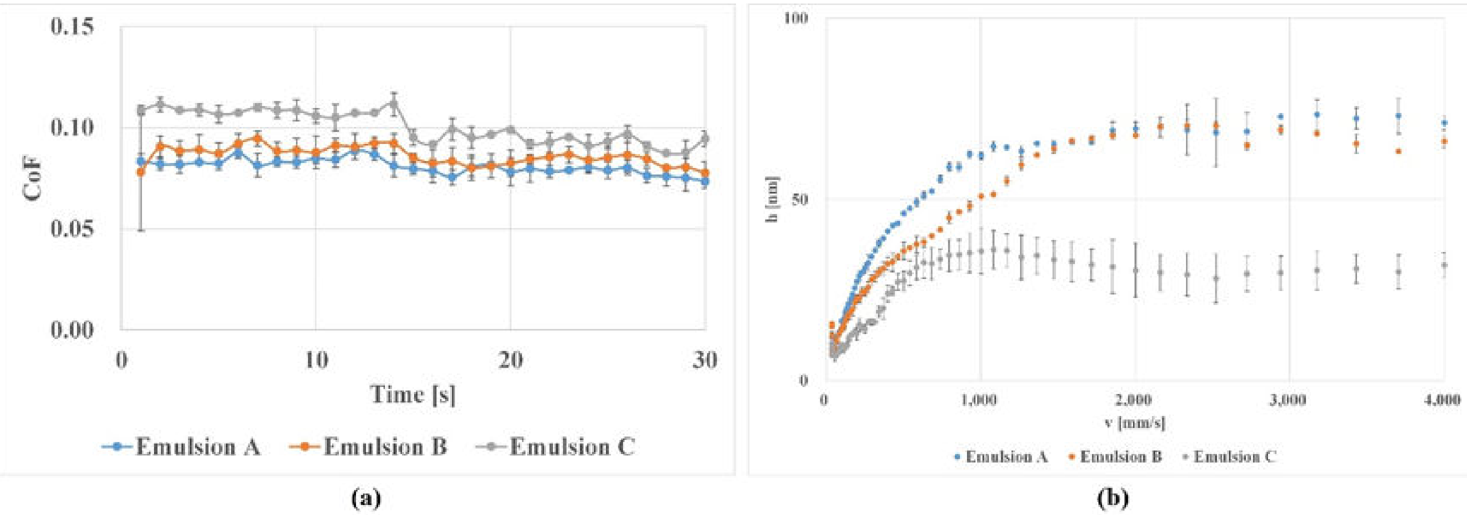


Fig.6 (a) boundary lubrication curves showing CoF vs. time and (b) film thickness vs. speed for the three emulsions: Emulsion A: traditional soap-based product, Emulsion B: novel non-soap technology, QH EVEROLL™ A 5000, Emulsion C: existing soap-free benchmark

Aluminum fines dispersing and dynamic surface tension properties of the three emulsions

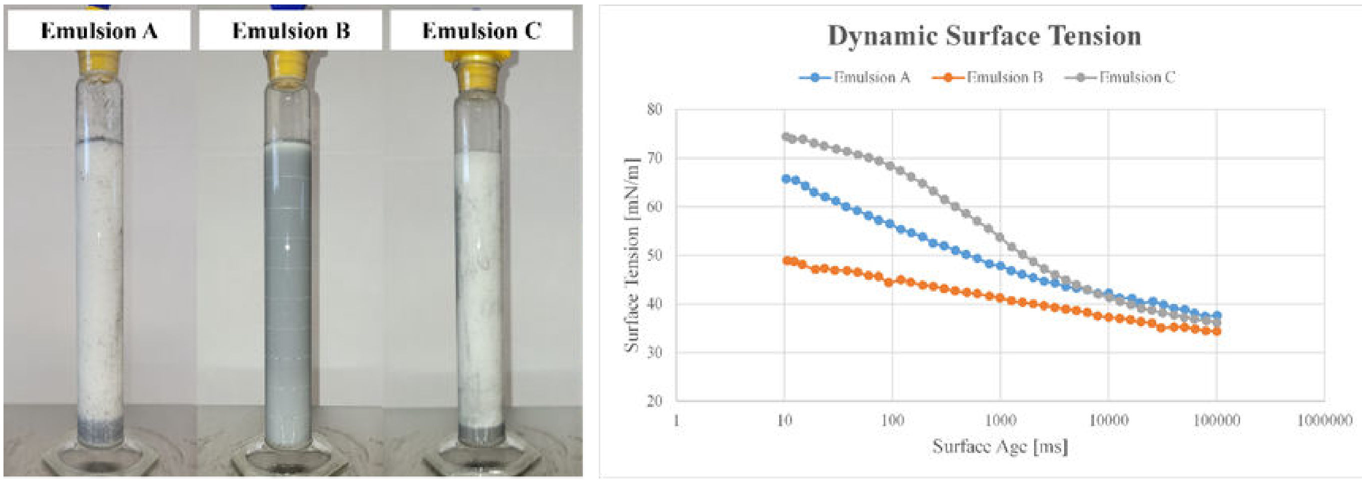
Aluminum fines dispersibility and wetting are crucial for aluminum strip and mill cleanliness. Aluminum fines dispersion is a mechanism governed by the adherence of air to the fines, mainly unwetted fines, which results in either floating (bad wetting) or sinking fines (clogging). In the lab, aluminum fines dispersibility, a performance-related emulsion parameter that describes the tendency of aluminum fines to remain finely dispersed within an emulsion under standardized conditions, was used to evaluate fines dispersion tendency in different emulsions. By adding an equivalent amount of spherical aluminum powder (3.0 to 4.5 μm in diameter) to 100 ml of each emulsion and assessing the dispersion tendency after rigorous shaking and one-minute settling, we found that novel non-soap Emulsion B demonstrated the best fines wetting and dispersibility (Fig. 7(a)). This superior wetting performance was further corroborated by dynamic surface tension measurements, with the lowest value for Emulsion B (Fig. 7(b)). Effective fines dispersibility and wetting also facilitate easy filtration, thereby mitigating deposition and sludge formation in industrial applications.

Quaker Houghton
Forward Together

©2025 Quaker Houghton. All rights reserved.

De-Risking New Rolling Fluid Technology in Aluminum Hot Mills

BY YAO LU, GROUP LEADER - CENTER OF INNOVATION AND BAS SMEULDERS, SR RESEARCH SCIENTIST



(a) (b)

Fig.7 (a) aluminum fine dispersion performance and (b) dynamic surface tension curves of the three emulsions: Emulsion A: traditional soap-based product, Emulsion B: novel non-soap technology, QH EVEROLL™ A 5000, Emulsion C: existing soap-free benchmark

Pilot mill trials

To validate the laboratory findings, pilot mill trials were carried out with the three emulsions under conditions tailored to mimic field emulsion parameters. Soap-based Emulsion A underwent artificial aging to mimic the break-in period, while novel non-soap Emulsion B and typical soap-free benchmark Emulsion C were evaluated in their freshly prepared states. Other crucial emulsion parameters for each of them on our Pilot Mill were: 1) Emulsion A: 4 wt%, emulsion temperature of 55 to 60°C, and a particle size range of 2.0 to 2.5 µm; 2) Emulsion B: 4 wt% in concentration, emulsion temperature of 50 to 55°C, and a particle size of 0.7 to 1.1 µm; 3) Emulsion C: 4 wt% in concentration, emulsion temperature of 50 to 55°C, and a particle size around 0.7 µm; Figure 8(a) displayed the roll force results when the rolling speed stabilized. In total three 5052 alloy coils were used for each emulsion evaluation under the same mill settings.

The initial strip thickness for each coil was around 4.0 mm and the start strip temperature was around 370°C. For Coil 1 and Coil 2, the reduction rate was 22.5% and the rolling speed was 80 mpm (meters per minute) for creating a layer of work roll coating by introducing more metal-to-metal contact. For Coil 3, the reduction rate was 20% with a rolling speed of 150 mpm. After rolling, the coil temperature decreased to 320-325°C. Rolled Coil 3 strip samples were gathered for anodizing and surface quality checking (Fig.8(c)). The work roll chock cleanliness was checked by wiping after rolling three coils (Fig.8(b)).

The trials revealed that soap-based Emulsion A yielded the lowest roll force, while typical soap-free Emulsion C exhibited the highest roll force, across all coils. Notably, the novel non-soap Emulsion B

©2025 Quaker Houghton. All rights reserved.

De-Risking New Rolling Fluid Technology in Aluminum Hot Mills

BY YAO LU, GROUP LEADER - CENTER OF INNOVATION AND BAS SMEULDERS, SR RESEARCH SCIENTIST

demonstrated superior mill cleanliness, as evidenced by work roll chock inspections. Fig.8(b) showed that anodized strip samples from Coil 3 rolled with Emulsion A and Emulsion C displayed relatively more dispersed black points or short stripes, albeit still rated as average in surface quality. In contrast, Emulsion B produced the best anodizing quality.

The consistency between laboratory and pilot mill results underscores the strong correlation between boundary lubrication, film formation, and roll force, as well as the alignment between aluminum fines dispersibility, dynamic surface tension, and mill cleanliness. Notably, the newly developed non-soap Emulsion B stood out in maintaining excellent mill cleanliness while

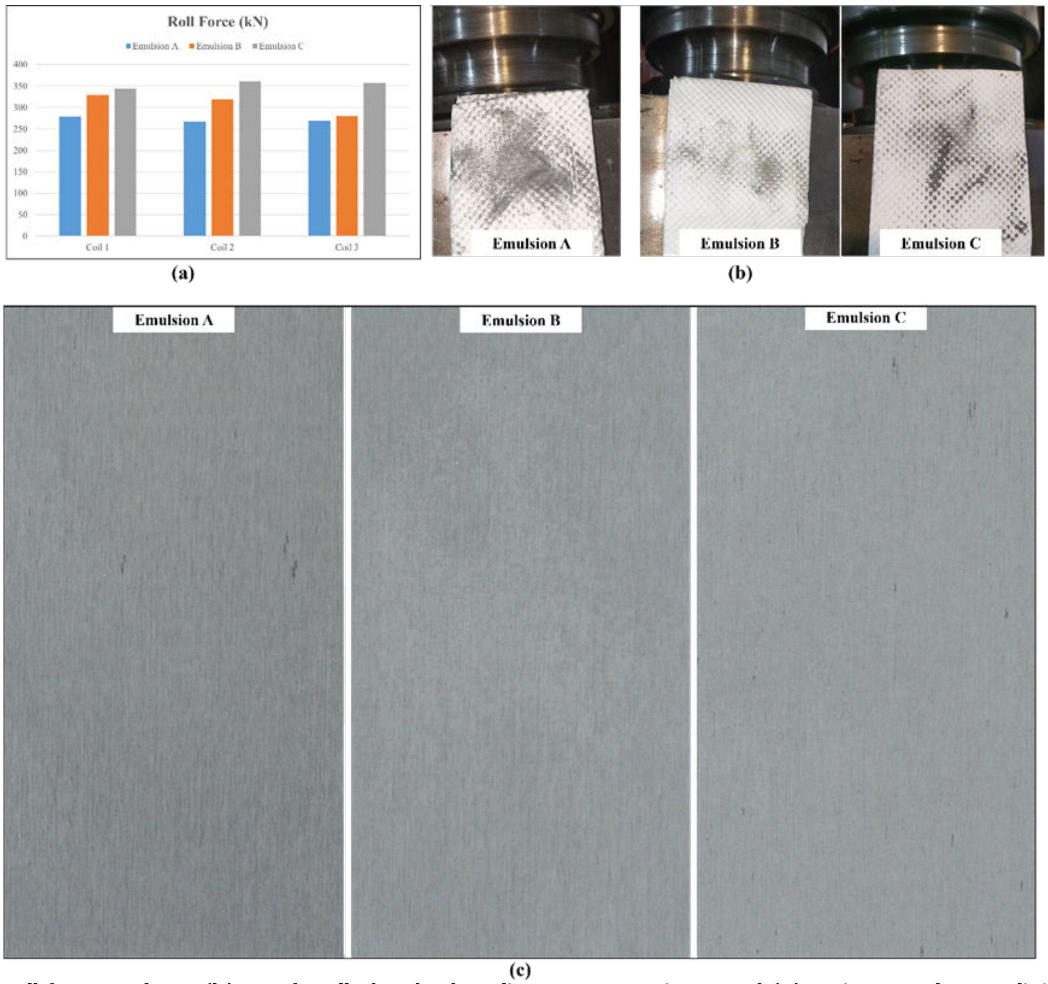


Fig.8 (a) roll force values, (b) work roll chock cleanliness comparison and (c) strip sample anodizing quality comparison between the three emulsions: Emulsion A: traditional soap-based product, Emulsion B: novel non-soap technology, QH EVEROLL™ A 5000, Emulsion C: existing soap-free benchmark

©2025 Quaker Houghton. All rights reserved.

simultaneously preserving lubricity and strip surface quality. This excellent performance was further validated on an industrial tandem mill.

Field Trial Proofing

All three types of rolling fluid were sequentially applied on an industrial tandem mill. Initially, typical soap-free Emulsion C was in use, however, it was subsequently replaced by soap-based Emulsion A due to excessive sludge formation and the customer's desire for enhanced lubricity. The switch to Emulsion A offered improvement, but in January 2024 novel non-soap Emulsion B was introduced with the goal of achieving excellent surface quality, improved cleanliness and minimal fluid maintenance. Since its commissioning, the novel non-soap fluid has excelled in terms of both surface quality and customer process optimization.

The novel non-soap technology demonstrates notable advantages in both performance and process efficiency, including its consistency in emulsion parameters, dramatically reducing the need for additional tank-side additives. Consequently, biweekly laboratory emulsion testing suffices, resulting in a streamlined workflow and reduced manpower requirements for on-site laboratory activities. Moreover, a remarkable 30% reduction in oil consumption, coupled with consistently outstanding surface quality across diverse alloy types, underscores the oil's superiority over previous lubricant technologies.

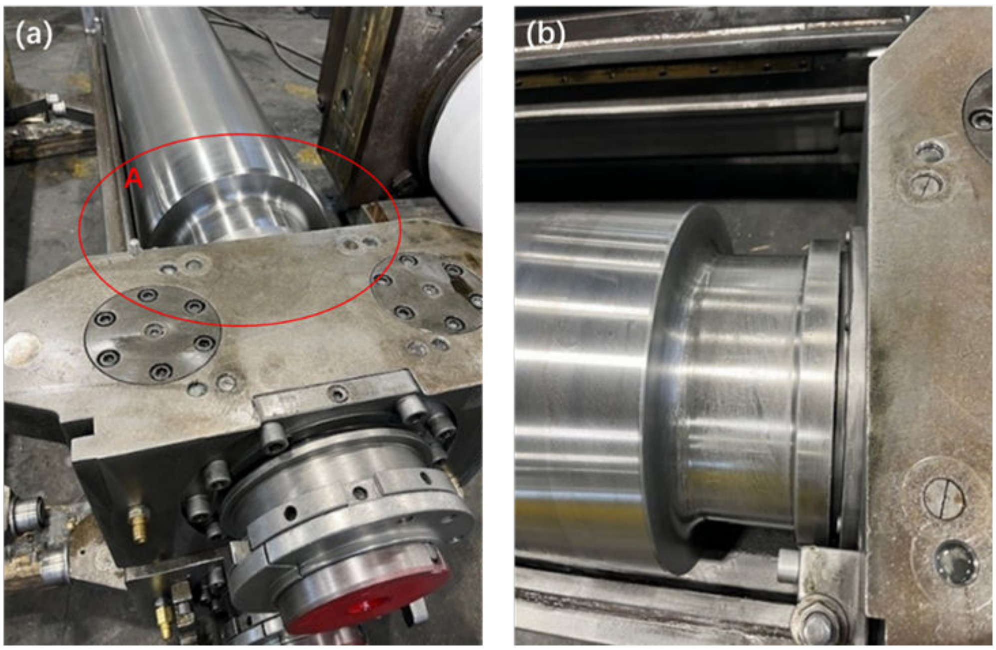


Fig.9 (a) work roll chock; (b) a closer look at area A in Picture (a).

©2025 Quaker Houghton. All rights reserved.

De-Risking New Rolling Fluid Technology in Aluminum Hot Mills

BY YAO LU, GROUP LEADER - CENTER OF INNOVATION AND BAS SMEULDERS, SR RESEARCH SCIENTIST

A noteworthy improvement is its exceptional dispersal of aluminum fines, which has significantly enhanced mill cleanliness. This improvement is particularly evident in the reduced accumulation of dirt on work roll chocks and adjacent mill equipment, as depicted in Fig. 9. This enhanced cleanliness not only facilitates maintenance but also contributes to the overall efficiency of the rolling process.

Conclusion

This white paper presents the unique and rigorous approach used by Quaker Houghton for developing advanced aluminum hot rolling fluids. Through comparing the performance of a new, non-soap technology QH EVEROLL™ A 5000 against traditional soap-based and existing soap-free chemistries in lab tests, pilot mill trials and industrial application we make the following conclusions:

The roll force is lubricant dependent, where soap-based chemistry performs slightly better than , both significantly outperforming Emulsion C, aligning well with boundary lubrication and film formation results in the laboratory.

The work roll cleanliness and aluminum fine dispersing and dynamic surface tension are also lubricant dependent, highlighting the excellence of Emulsion B compared to the other emulsions.

Further, the application on an industrial tandem mill has proven the excellence of Emulsion B in terms of mill cleanliness while simultaneously preserving lubricity and strip surface quality.

This study demonstrates that pilot mill trials and laboratory testing, especially boundary lubrication tests with MTM, film formation, aluminum fine dispersing and dynamic surface tension tests, are valuable tools for lubricant development as well as for risk-free introduction in industry.

Acknowledgements

The authors would like to thank Tom Oleksiak, Ben Stone, Pablo Bakermans, René Gabriel Liedtke, Kai Ye, Damon Zhu, and Wenbin Jiang for their assistance with laboratory testing, pilot mill trials, and field performance tracking; thank you to Wim Filemon and Peter De Bruyne for their helpful discussions.

References

[1] Yao Lu, J.B.A.F. Smeulders, The Quaker Houghton Multi-Functional Reversing Mill: Research on and for rolling, Millennium Steel, p. 86-90 (2024)

[2] J.B.A.F. Smeulders, Aspects of Boundary Lubrication in Advanced High-Strength Steel Rolling, Proceedings of the Iron & Steel Technology Conference, p. 865-877 (2022).

Quaker Houghton
Forward Together

©2025 Quaker Houghton. All rights reserved.