A technology overview of cold rolling lubrication

Cold rolling lubricants are essentially designed to cool and reduce friction. They also improve surface cleanliness and overall quality, enable rolling mill speeds to be increased, so improving productivity and lowering the total cost of operation.

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Parameters	Emulsion	Stabilised dispersion	Full dispersion
Concentration, %	4.0–7.0	1.5–4.0	2.0–4.0
Operating pH	>7.0	5.8-6.8	5.3-6.5
Particle Size, μm	<5.0	8-12	15-30
ESI	0.95	0.70	0.20
Tramp oil rejection	Fair to good	Excellent	Good
Oil plate out	Low to moderate	Moderate to high	High
Iron on strip	High	Low	Low
Agitation required	No	No	Yes

● **Table 1** ***Summary of the typical properties for a comparison of the three types of coolant delivery systems***

Customer demand for higher mill productivity over a diverse product mix continues to present challenges for lubricant formulators. As designers and engineers are being driven to find ways of creating new higher strength and lighter weight materials of construction, steel producers are engineering new metallurgies to meet the demands of the market. This has resulted in increased demands for lighter gauge and higher strength steels from the cold reduction process. New engineered materials, including plastics, have begun to directly compete against steel and, in turn, have created a strongly cost-conscious environment. The steel industry has responded with a series of consolidations and is now searching for efficiency gains to further improve its total cost of operation to re-establish a profitable foundation for the future.

D. A. Stuart Company has been one of the market leaders in cold-rolling lubricant technology throughout the past 30 years. Stuart continues to evaluate and develop innovative technologies to provide the steel industry with new means of addressing customer requirements while reducing total operating costs. This article will revisit the basics of lubrication and the diversity of formulation technology that has been developed over the past 30 years and discuss the implications for the cold rolling process.

There are four major considerations in the formulation of lubricants for the cold reduction of steel:

- Developing the best combination of friction-reducing chemistries
- Presenting the optimum amount of lubricant to the roll bite
- Creating the best burn-off of the remaining residues in subsequent heat treatment
- Providing the best economic position in relation to the total cost of the steel producers' operation

Lubricant role in cold reduction

The lubricant system has a dual function in cold reduction that can be summarised as follows:

- It provides a means of minimising heat build-up in the work rolls and strip through good lubrication and heat transfer (cooling) away from the roll bite
- It delivers a lubricant to the roll bite in a manner that provides sufficient lubrication to reduce the steel strip at acceptable speeds, control energy loads and produce satisfactory surface quality

These two functions are difficult to isolate and discuss separately since an effective lubricant system represents a balance between lubrication and cooling. However, to illustrate compromises that must be made in lubricant formulations. These two functions will be described separately.

Cooling function During cold reduction there are two sources of heat:

- Frictional heat generated at the roll bite by strip/work roll contact and work roll/back-up roll contact. The magnitude of this heat can be decreased with an effective lubricant film but cannot be eliminated
- Heat of deformation generated by the deformation of the grain structure and work hardening during cold reduction

Ideally, large volumes of water could provide the cooling effect required to dissipate this heat. However, although water is the ultimate coolant, it is an inadequate lubricant for today's high-speed mills and challenging product mix. Alternatively, lubricant systems consisting of oils and other additives are very effective in reducing frictional heat but have very poor heat transfer properties because they are insulating by nature. A balance between these two systems must be developed in order to maximise cooling and prevent or minimise poor strip shape, heat related roll failure, high strip re-coiling temperatures and limitation of mill speeds.

Lubricant function As steel strip is rolled, it elongates and changes speed in the roll bite relative to roll speed. During this process, the strip naturally tends to slide against roll surfaces, setting up a frictional condition. The resultant friction produces forces that try to retain the strip in the roll bite. This action results in pressure build-up that is typically measured as roll force and interstand tension.

According to all rolling theories the coefficient of friction (COF) existing at the roll bite is directly related to the roll force required for specific reductions. Theory demonstrates that the lower the COF, the lower the rolling force. Also, the greater the reduction that is required and achieved indicates a greater lubricant efficiency. Therefore, under a given set of circumstances, a poor lubricant will be the limiting factor in attaining the desired reduction. When the rolling force is reduced for a given reduction, other benefits are realised including better control of cross-sectional gauge, decreased roll wear and less heat generation in the roll bite. These contribute to maximum permissible speed, as well as gauge control and strip shape. It also leads to a reduction in mill power consumption.

There are several ways of taking advantage of chemistry to improve lubrication by reducing the COF. Historically, phosphorus and sulphur-bearing compounds are generally cost-effective ways of addressing this challenge. Also, high viscosity additives such as dimer acids, polymer chemistries and higher viscosity hydrocarbons can contribute to reducing friction.

Design and chemistry of the delivery system

Needs Rolling oils are designed for individual applications. These applications can vary from single stand reversing mills to three to six stand sheet or tinplate tandem mills, with either direct application or recirculation systems. Mill speeds can vary from 1,000 to 7,000ft/min (305–2130m/min). The product mix can vary from sheet and tinplate low carbon chemistries to high-strength low-alloy (HSLA), dual phase or silicon steels, as well as steels that are subsequently treated with various coatings (galvanised, aluminised or organic products). In addition, a wide variety of widths and gauge reductions must be considered. All of these factors play roles in the selection of the optimum lubricant formulation.

The delivery method For the lubricant to perform successfully, it must wet the strip surface or 'plate out' a uniform thickness and create a continuous film on both the strip surface and roll surface at the roll bite. The lubricity additives in the formulation now come into play. These additives serve as a film strengthener, imparting a thin, continuous, tough film that will not break down during rolling and yet will not inhibit heat transfer. This particular feature is of great significance in the harder-to-roll steel grades, which have historically required substantially higher oil concentrations in order to provide adequate lubrication. This typically creates a series of consequences, including heat build-up, because cooling is inhibited and potentially dirtier strip produced, due to a higher residue on the strip leaving the mill.

Often overlooked in this phase is the chemistry and consistency of the water that is mixed with the lubricant to produce the rolling solution. Sources of water vary significantly, ranging from local drinking water, well or river water, recycled service water, chemically softened water, or de-mineralised or reverse osmosis water. The key is to provide the lubricant formulator with the most consistent and predictable source of water. In addition, the source of the water will dictate the final pH of the rolling solution. This is critical in developing the proper delivery design. Over the years, formulators have become adept at building buffering systems in the formulations to assure a consistent and therefore predictable delivery of coolant to the roll bite.

As the strip leaves the roll bite and the used rolling solution returns to the system, the solution contains the debris generated in rolling (ie, iron fines, roll breakdown, and general dirt). This can be removed through magnetic separators, filtration or skimming. The debris is then undercut and floated off in a detergent-type of action by the coolant.

There are three basic delivery methods: emulsions, dispersions and a hybrid called a stabilised dispersion.

Emulsions These have been the major delivery method since oil and water were first combined to cold reduce sheet and tinplate products. Emulsions are normally produced by combining a significant amount of surfactant (1.5–5.0%) into the base lubricant package so that, when combined with water, the end result is a white solution (ie, homogenised milk) with little or no free oil breaking out. This feature enables emulsions to be suitable for any coolant design system.

Dispersions Here the surfactant or dispersant acts as a protective colloid on the surface of the oil particle, significantly decreasing or eliminating coalescence. Typically cationic surfactants are utilised for these dispersion systems where the degree of mechanical shear, dispersant type and level determine the distribution of oil particles in a dispersion. (A dispersion has a much narrower range of oil particle size than an emulsion.) A large particle sized dispersion remains uniformly dispersed with typical agitation levels. Visually upon standing, the dispersion rapidly splits an oil layer with virtually only a trace of oil left in the water phase. This oil layer is easily re-dispersed into solution and attains its original particle size distribution which greatly enhances the oil and uniformity of the oil film that is delivered at the roll bite.

With this uniformity of film, the concentration of oil in the coolant can generally be reduced leading to lower overall consumption and improved cooling because of the higher percentage of water going to the mill. Consistent oil film thickness also results in a predictable COF that allows for mill drafting practices to be optimised. The quick oil separation in the quiescent state indicates the potential for much easier waste treatment. Also, a dispersion rolling solution acts as a detergent and provides a similar cleansing action on the parts of the mill structure that it comes in contact with, leading to a much improved working environment.

Stabilised dispersions These represent a hybrid of emulsions and dispersions. Normally they are the delivery system of choice for coolant systems that are lacking in sufficient mechanical agitation to uniformly suspend a dispersion formulation. This system takes advantage of the combination of surfactants from both emulsions and dispersions. The resulting coolant has a smaller average particle size of oil droplet which creates a solution that needs very little, if any, mechanical agitation. Oil plate-out is very uniform but the volume of oil at the roll bite is less and therefore they can deliver most of the benefits of a full dispersion. *Table 1* summarises the typical properties for a comparison of these types of coolant.

Anneal burn off and formulation designs

Ultimately the resulting quality of the strip produced by cold reduction is the final measure of the efficiency of the process. Resulting surface cleanliness out of anneal or prior to coating are critical. At Stuart, thermogravimetric analysis (TGA) is used to measure the lubricant's contribution to surface cleanliness. In this evaluation the neat lubricant is volatilised in an oven over a cycle of temperatures that mimic an annealing cycle. During this cycle, the weight loss of the lubricant and the final remaining residue weight are evaluated between 20°C and 550°C. This provides a prediction of how the lubricant will perform during the annealing phase in mill processing. This protocol is used to evaluate individual formulation components as well as final formulations. Over the years, a number of different approaches to the construction of formulae have evolved as a result of utilising this technique.

The following four general types of technology for rolling lubrication have been developed:

- Conventional
- Semi-synthetic
- Highly synthetic
- Full synthetic

Conventional technology

The animal fat-based (oldest) technology is the traditional and lowest cost approach to rolling lubricant formulation. The primary building block is either tallow or choice white grease. The nature of this chemistry is complex and varies both seasonally and by the feed that the animals consume, as well as from variation in the processing phase that produces these oils. These fats can be diluted with hydrocarbon oil and augmented by additional lubricity additives to provide a specific level of lubrication. The selection of delivery method (emulsion, stabilised dispersion or full dispersion) dictates the way the residual lubricant is left on the surface after cold reduction. The nature of the chemistry of animal fats limits what can be achieved relative to strip cleanliness performance.

Semi-synthetic technology

This is the first step towards improving strip cleanliness by altering the chemistry of the base lubricant. By beginning to substitute synthetic esters and natural vegetable esters for a portion of the animal fat, this allows for an incremental improvement in strip cleanliness at a small increase in product cost.

Highly synthetic technology

The next step is to fully remove all animal fat, replace with synthetic esters and add oxidation inhibitors. This again raises the resulting strip cleanliness performance to a higher level and there is another incremental increase in the cost of the lubricant. Other benefits include a higher overall improvement in lubrication as well as the potential for extended solution batch life with proper solution maintenance.

Advanced synthetic technology

The maximum strip cleanliness performance can be achieved with this fully synthetic technology. All components within these formulations are derived from synthesis. The lubricant additives are synthetic esters – there are no 'natural' hydrocarbons – and if sulphur chemistry is used, it is also a synthetic

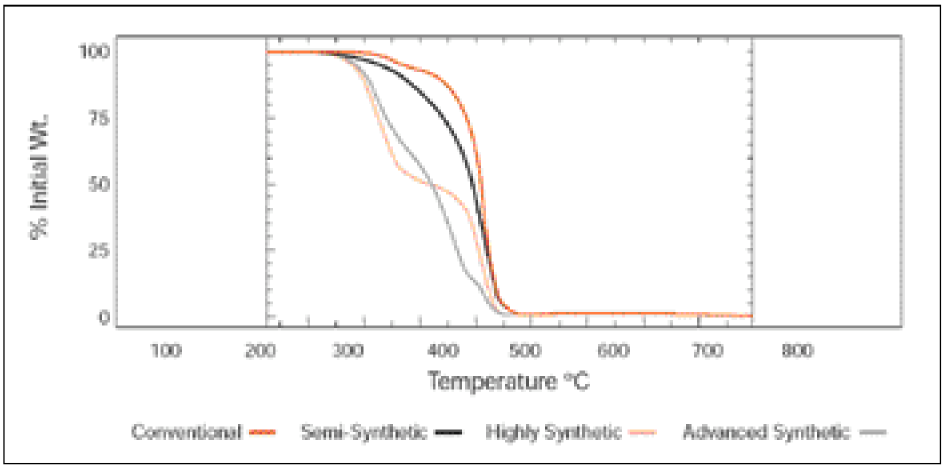

Figure1 ***Thermogravimetric analysis of rolling oils***

additive. The stability of the molecules in this chemistry, when utilised in a well-maintained system, offers an excellent total cost of operation performance, even with a higher cost per unit of product. *Figure 1* is a consolidated TGA presentation comparing the various formulation approaches.

Economics and total cost of operation

As formulators continue the technology evolution, it is understood that many criteria enter into the purchasing decisions that customers must make. Among those decisions are performance needs including improved surface cleanliness and overall quality, mill speeds, higher mill productivity, lower total cost of operation, and in some cases, just a lower price lubricant. Formulators continue to be driven by the market to apply chemistry to offer innovative ways of improving performance at a lower cost. The industry has, in fact, been very successful in accomplishing this, with the average price of rolling oil having decreased over the past 15 years, while overall mill productivity has increased.

Concluding remarks

This article has attempted to present an overview of the fundamentals of cold rolling lubrication and provide an appreciation of the complexity of the criteria that must be considered in the design and development of rolling oils. There are a wide variety of options available to the rolling oil consumer, supported by formulators with experience and understanding of not only the technological process, but also the needs of the industry.

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