# Aluminium Rolling Lubrication

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## Introduction

Lubrication is an essential part of all aluminium fabricating operations, either directly through the metal working processes, or indirectly to lubricate machinery. One of the most important ways of converting aluminium from cast slab/ingot into a usable industrial form is by rolling. The rolling process makes it possible to reduce an ingot of metal, weighing up to 20 tonnes and measuring 2 m x 8 m x 600 mm thick, to plate gauges (typically 250 mm to 6 mm), sheet gauges (typically 6 mm to 250 µm) and, ultimately, foil gauges (typically 250 µm to 6 µm) (1).

In many parts of the industrialised world, approximately 50% of all aluminium alloys used is in the form of flat rolled product and over the last 35 years major changes have taken place in rolling lubricant development and understanding. It is now accepted that the rolling lubricant not only influences mill productivity, but also significantly affects the quality of metal produced. The range of processes involved in the rolling of aluminium and the types of lubricant used are presented in Table 1.

| Process | Lubricant | Temperature (°C) | Gauge Range (mm) |
|---|---|---|---|
| Hot Rolling | Oil-in-water Emulsion | 270 - 560 | 2 - 600 |
| Cold Rolling | Oil-based / Water-based | Ambient - 170 | 0.15 - 6 |
| Foil Rolling | Oil-based / Water-based | Ambient - 140 | 0.005 - 0.6 |

*Table 1 - Aluminium rolling process lubricants*

For all types of aluminium rolling the role of the lubricant is threefold: to prevent direct contact between the roll and aluminium surfaces, to extract the heat generated by friction and deformation and to take away fines and debris from the roll bite area to the filter.

The load bearing capacity, cooling efficiency and ability to provide a clean annealed product must be considered when formulating a rolling lubricant and, in addition, it is essential to ensure chemical stability to minimise changes during use.

Lubricant performance depends on a balance of properties between the base stock and additive components. Correct selection of lubricant components, in terms of both their rheological properties and compositional features, has a significant impact on performance. Rolling additives are critical to the provision of optimum frictional characteristics, preventing problems of skidding or roll bite refusals that can occur with excessively low friction or poor surface quality that may arise with excessively high friction (2).

## Hot Rolling

The hot rolling of aluminium occurs over a wide temperature range (Table 1) and lubrication and thermal control of the work rolls is achieved by the use of oil-in-water emulsions (suspensions of oil droplets in a continuous water phase), which are sprayed onto the rolls in controlled patterns (Figure 1). Spraying the emulsion onto the rolls also removes any loose debris from the roll bite area, enabling it to be transported to the filter where it is removed.

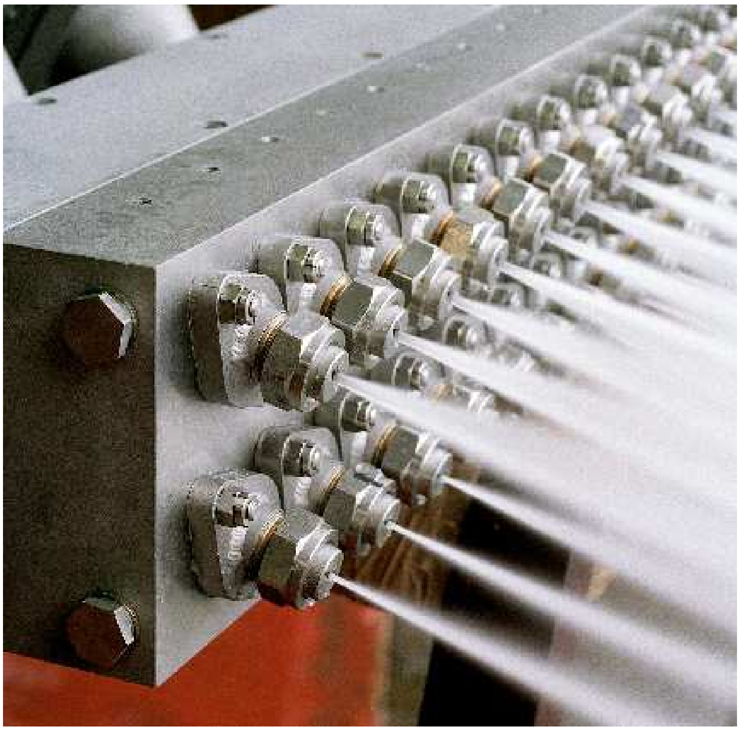

*Figure 1 - Hot rolling mill coolant sprays (Courtesy of Lechler Ltd.)*

Emulsions are complex mixtures of components and most commercial blends remain proprietary. In general, however, hot rolling lubricant formulations contain a base oil component (paraffinic, naphthenic, mineral or synthetic) into which are blended a range of additives including lubricity improvers, antioxidants, emulsifiers and wetting agents. Additionally, the formulation may also contain corrosion inhibitors, biocides and coupling agents that help provide stability during storage and assist the emulsification process.

Emulsifiers stabilise the surface of the oil droplets towards the water phase. The two most common types of emulsifier used in hot rolling are anionic and non-ionic in nature. Anionic emulsifiers are principally metal or alkanolamine soaps (the reaction product of an organic acid and a metal or alkanolamine). Non-ionic emulsifiers are ethylene oxide condensation reaction products where the length of the polymerised ethylene oxide chain determines the degree of water solubility (increasing chain length increases water solubility) and, ultimately, the amount of oil separated at the roll bite.

The additives are polar in nature, a feature that facilitates physical/chemical bonding onto the roll or roll-coated surface, providing load bearing and protecting the freshly generated aluminium surface. Commonly used additives are organic acids and esters. Even modest amounts of highly-reactive organic acids in formulations can have a dramatic effect on the surface quality of the rolled sheet; however they generate metal soaps during use which can influence emulsion stability(3).

Esters, being less reactive, are relatively stable in the emulsion and are now extensively used in commercial "acid-free" formulations(4). In general, the greater the polarity of the additive, the stronger the bonding force, providing more effective lubrication. Some formulations may contain extreme pressure additives which react directly with the surface of the roll and help minimise surface defects caused by localised welding of the aluminium to the steel roll.

Consistent lubricant performance must be established and maintained to ensure effective cooling and protection of the freshly generated surface whilst minimising roll wear and avoiding slippage and refusals (Figure 2).

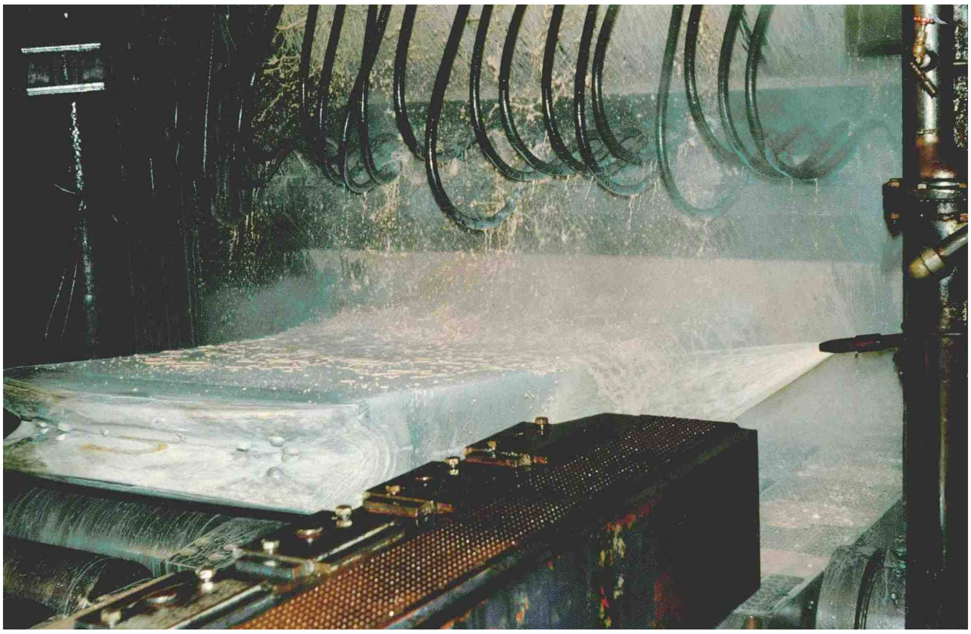

*Figure 2 - View of typical hot rolling mill showing lubricant application*

## Cold & Foil Rolling

Cold and foil rolling operations are carried out predominantly in the presence of hydrocarbon-based lubricants, although some mill systems can accommodate water-based lubricants. The base oil is the major component of the system, accounting for more than 90% of the total lubricant volume. The base oil functions as a solvent for the rolling additives, as a roll-cooling medium and also provides a hydrodynamic lubricant film. Its viscosity has a significant effect on the quantity of lubricant entering the roll bite and hence the control of the rolling operation. A typical cold rolling mill lubrication system is shown in Figure 3.

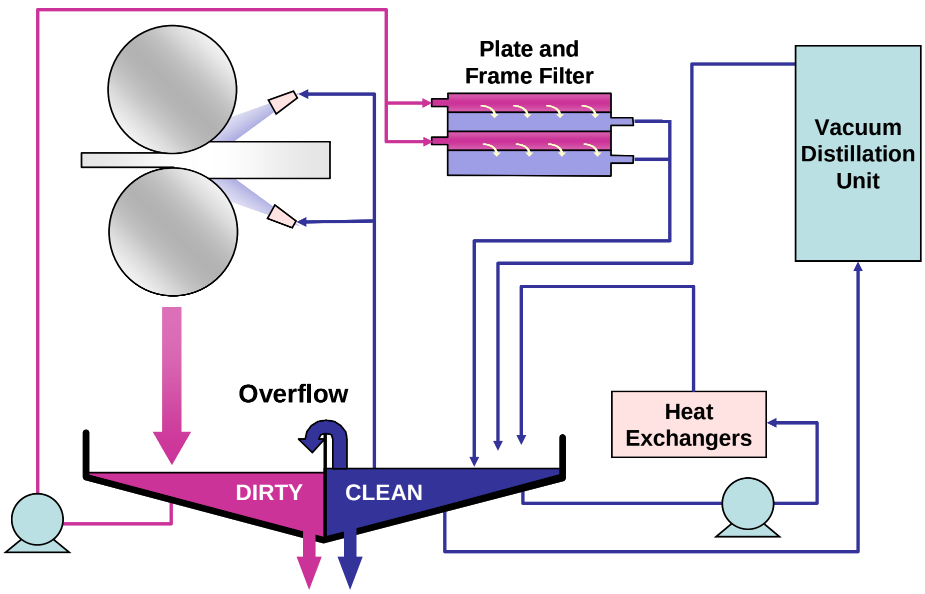


*Figure 3 - Schematic diagram of cold mill lubrication system*

Traditional cold rolling lubricants comprise a base oil, load bearing additives and possibly anti-oxidants and wetting/antifoaming agents. The base oil must have a suitable viscosity for the rolling conditions on the mill and evaporate cleanly, thereby avoiding staining during annealing of the rolled sheet in an air atmosphere. Load bearing additives must also not produce staining during annealing, whilst still providing the required level of load bearing capacity and frictional control[(5)].

Base oils should have a narrow boiling range, minimising both evaporation during use and the risk of staining during annealing of the rolled strip. During refining de-aromatisation and hydrogenation processes help to ensure compliance with several American Food and Drug Administration standards: these process steps also have the advantageous effect of increasing flash point and reducing odour in use.

Load bearing additives are organic compounds which contain a functional polar group e.g. acids, alcohols, esters or amines. The presence of these polar groups causes the molecules to be attracted and adsorbed onto the metal surfaces. The adsorption process is greatly enhanced when the aluminium undergoes deformation, as the freshly-formed aluminium surface is much more reactive than the normal surface that is covered in an air-formed aluminium oxide film. Typically, load-bearing additives are used at relatively low concentration levels.

## Water-Based Cold Rolling

While oil-based lubricants have been used for cold rolling for many years, it is acknowledged that water has significantly greater heat transfer properties, providing increased cooling of rolls[1]. In addition, water has several other advantages compared to oil including lower cost, non-flammability and reduced hydrocarbon emissions. However, the use of water also has several disadvantages, including an increased risk of surface staining, generation of metallic fines, and noise from the operation of containment systems. A larger lubricant system volume and more elaborate filtration systems are required and there is a reduced tolerance to process variations.

Mills which do operate water-based lubrication systems use a combination of surface active components in the formulation, coupled with complex containment/shielding systems which incorporate a combination of air wipes, vacuum removal and screens to eliminate water staining. A typical example of a commercial shielding system is depicted in Figure 4. Problems of water/strip contact increase as mills become wider and rolling speeds increase.

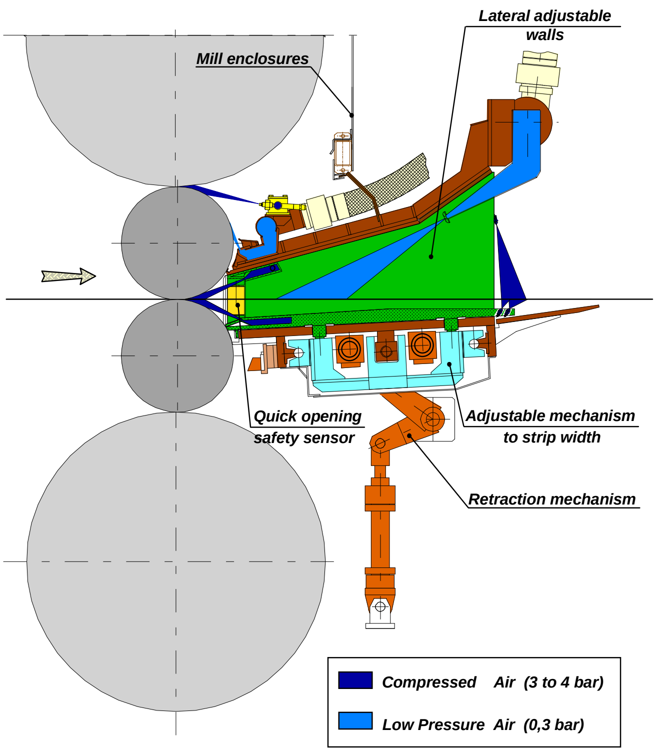


*Figure 4 - Schematic diagram of water-based cold mill shielding system (Courtesy of Kvaerner Metals)*

Water-based lubricant formulations include emulsions of oil-based formulations, solutions in which the load bearing additives are water soluble at room temperature but insoluble at roll bite temperatures and systems where the lubrication and cooling functions are separated by applying oil-based lubricant on the entry side of the mill and cooling water on the exit side of the mill[6].

Although a number of oil-in-water emulsions have been used in the cold rolling of aluminium, their formulations have largely been similar to those used for hot rolling and have suffered from surface staining issues. The use of polyoxyalkylene-based fluids has been significant in the development of lubricant solutions as they possess negative coefficients of solubility in water with temperature, influencing strongly their thermal separation under rolling conditions. In particular, the combination of polyoxyalkylene modified alkanolamines and phosphate esters which also reduce surface staining have evolved and have been commercialised[7,8].

## Lubricant Maintenance

During use rolling lubricants can become modified and contaminated in a number of ways:

- The more volatile components are lost through evaporation during rolling, increasing the flash point, viscosity and initial boiling point.
- Frictional wear introduces both aluminium and iron debris into the lubricant system.
- Some load bearing additives can chemically react with roll and product surfaces to form metal soaps.
- Exposure to increased temperature and pressure, combined with air, increases the possibility of oxidation and/or polymerisation of the lubricant components.
- Other lubricants used on the mill (bearing oil, hydraulic oil, etc.) can contaminate the rolling fluid, causing increased viscosity, changes to frictional characteristics and generating surface staining.

Changes must be carefully monitored and controlled to ensure consistent lubricant performance is maintained. Some of the main parameters that require measurement for the different types of lubricant are shown in Table 2.

| Monitoring Parameters | | |
|---|---|---|
| Hot Rolling Emulsions | | Oil-based Cold Rolling |
| Oil Concentration | Emulsifier Level | Additive Level |
| Oil Phase Viscosity | pH | Soap Level |
| Additive Level | Tramp Oil | Viscosity |
| Soap Level | Bacteria | Ash Level |
| Emulsion Droplet Size | Biocide Level | Gum / Heavy Ends |

*Table 2 - Rolling lubricant monitoring parameters*

A rolling mill lubrication system is designed to ensure that an adequate volume of clean lubricant is supplied to the mill at the required temperature, pressure and flow rate. The flow must be such that there is always an excess of clean lubricant available for supply to the mill. As a result, the filtration system must treat a greater volume of lubricant than is supplied to the mill and there should be a constant overflow from the clean to dirty side of the lubricant tank. In addition, lubricant must be pumped from the clean tank to heat exchangers to control temperature. Oil-based lubricants used for cold and foil rolling can be passed through a vacuum distillation unit for removal of contaminants, e.g. hydraulic, bearing and gearbox lubricants.

## Environmental Control

Cold and foil mills using oil-based lubricants are fitted with oil recovery systems to reduce the amount of lubricant lost from the mill to the environment via the mill exhaust system. Several types of recovery systems are available, including Venturi scrubbers (wet), electrostatic precipitators, fibreglass filters, activated charcoal filters and counter-flow oil washing systems. The most efficient and widely used recovery system is the counter-flow oil washing process but it has high capital cost, is expensive to operate and must run at high efficiency to be cost effective.

Spraying oil based lubricants at high velocity against the hot rolls of the mill generates oil vapour and a fog of fine droplets. Consequently, the operation of cold and foil rolling mills is always accompanied by the risk of fire. It is therefore essential both to provide fully adequate fire control equipment and to ensure that all operating personnel are trained in its use. A high capacity fume exhaust system plays a major part in preventing the build-up of potentially dangerous oil-air mixtures. Mill fire fighting equipment usually comprises carbon dioxide stored under pressure in gas bottles or at low pressure in bulk storage systems. Some mills have both high and low pressure systems installed.

A major advantage of using carbon dioxide to extinguish mill fires is that it does not interfere with the subsequent operation of the mill or contaminate the lubricant. As a result, once the fire has been extinguished, the carbon dioxide replenished and the fire fighting equipment reactivated then any mechanical problem on the mill (possibly the cause of the fire) can be corrected and rolling recommenced.

## Summary

The three main functions of a lubricant in aluminium rolling are to prevent direct contact between the rolls and aluminium surface, remove the heat generated by friction and deformation and to transport fines and debris away from the roll bite area to the filter.

The majority of hot rolling mills are lubricated and cooled by oil-in-water emulsions, whilst the majority of cold and foil rolling mills are lubricated and cooled by oil-based lubricants.

In hot rolling the major component of the emulsion is water, with less than 10% oil phase, whereas in cold and foil rolling the base oil is the major component, accounting for more than 90% of the total lubricant volume.

In all types of rolling lubricant the base oil functions as a solvent for the additive components which, in turn, provide load bearing capacity and control friction in the roll bite.

Finally, during use the lubricants must be adequately monitored and maintained to ensure their optimum performance.

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