

# SKIN-PASS ROLLING OF STEEL STRIP USING LIQUID NITROGEN<sup>1</sup>

Gian R. C. Silva <sup>2</sup>  
Élcio Fortes <sup>2</sup>  
G. Plicht <sup>3</sup>  
H. Schillak <sup>3</sup>  
H. Höfinghoff <sup>4</sup>  
T. Demski <sup>4</sup>

## Abstract

Using liquid nitrogen as a coolant in final or skin pass cold rolling can dramatically increase productivity by raising throughput, improving product quality and reducing rejects. Using liquid nitrogen as a cooling medium for the final pass in the cold rolling of metal strip can increase production rates dramatically, in some cases by up to 50%. The liquid nitrogen replaces conventional water-based cooling fluids in wet rolling, and it works with dry rolling too. In the case of steel strip, it eliminates product losses caused by rust spots, post cleaning and can increase the life of the working rolls. The new process, known as Air Products cool rolling technology, was developed jointly and is patented by metal strip manufacturer C.D. Wälzholz and industrial gas and technology supplier Air Products. It has been used successfully for eight years on carbon steel strip at C.D. Wälzholz's plants at Hagen, Germany and São Paulo, Brazil, where it has shown large cost savings and other benefits.

**Key words:** Skin pass; Liquid nitrogen; Industrial gas; Commercial technology.

## LAMINAÇÃO DE PASSE SUPERFICIAL OU FINAL DE CHAPAS DE AÇO UTILIZANDO-SE NITROGÊNIO LÍQUIDO

### Resumo

O uso do nitrogênio como meio de refrigeração durante o passe final da laminação a frio pode aumentar dramaticamente a produtividade, melhorando a qualidade do produto e reduzindo rejeitos. Utilizando-se o nitrogênio como um refrigerante moderado para o passe final na laminação a frio de chapa metálica pode aumentar a velocidade de produção significativamente, em alguns casos acima de 50%. O nitrogênio líquido substitui o fluido refrigerante convencional baseado em água na laminação, e também na laminação a seco. No caso de chapas de aço, o nitrogênio elimina as perdas de produto causado por manchas de ferrugem, etapas de pós-limpeza, e pode aumentar a vida útil de operação dos rolos de laminação. O processo inovador, reconhecido pela Air Products como tecnologia de laminação a frio, foi desenvolvido conjuntamente e patentado pelo fabricante de chapas metálicas C.D. Wälzholz e a Air Products fornecedora dos gases industriais e da tecnologia de suprimento. Isto tem sido utilizado com sucesso por oito anos em chapas de aço carbono na planta da C.D. Wälzholz em Hagen na Alemanha, e na Brasmetal em São Paulo no Brasil, onde ele tem demonstrado ampla redução de custos entre outros benefícios.

**Palavras-chave:** Laminação à frio de aços; Nitrogênio líquido; Gases industriais.

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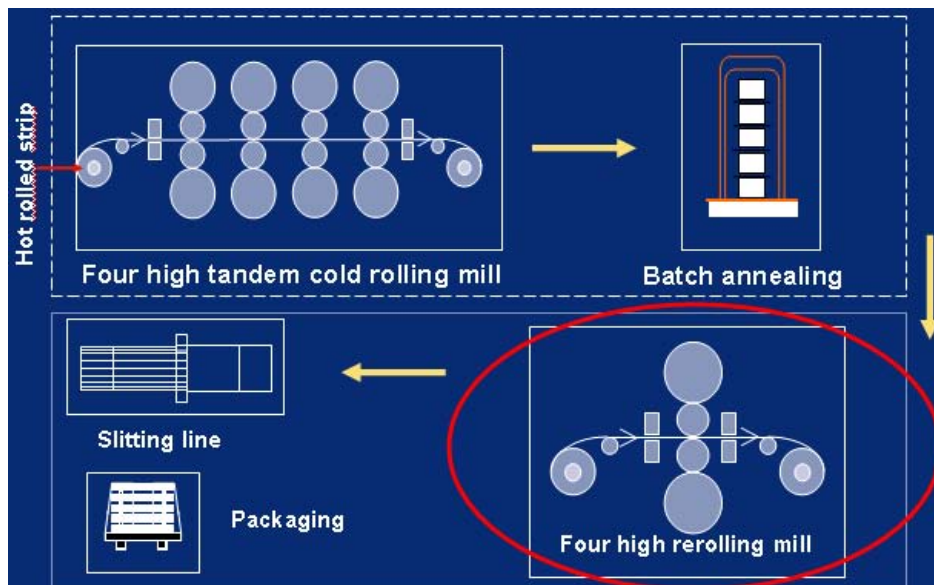
<sup>2</sup> *Master Engineer Metallurgical and Materials Science – Air Products Brasil, Brasil*

<sup>3</sup> *Metals Processing Specialist – Air Products GmbH, Germany*

<sup>4</sup> *C.D. Wälzholz, Germany*

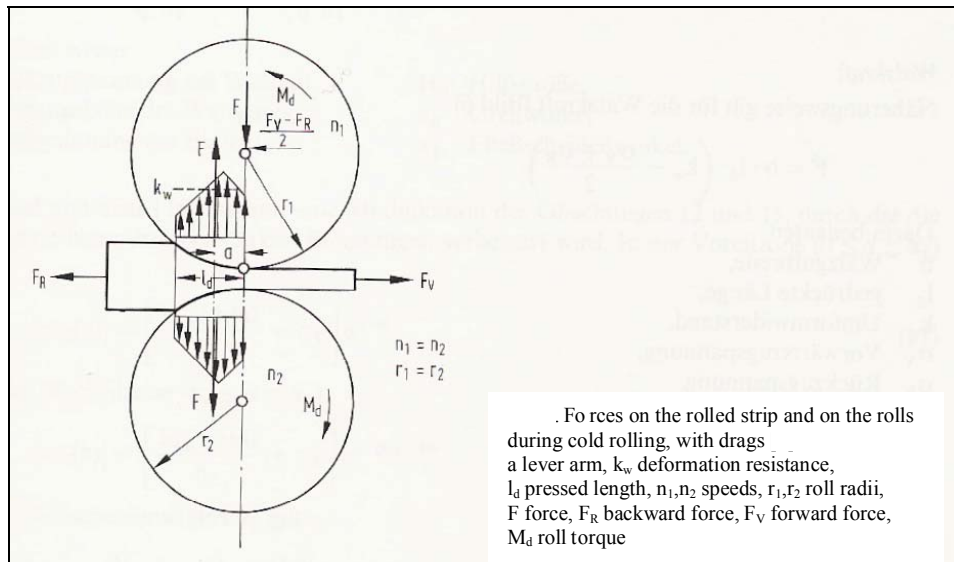
## 1 CONVENTIONAL COLD ROLLING AND ITS CHALLENGES

Cold rolling is a process that simultaneously deforms and strengthens metal. It is used as the final stage in the manufacture of metal strip, after hot rolling (Figure 1).



**Figure 1:** In the manufacture of strip stock, hot rolling is typically followed by cold rolling, annealing and a final low-reduction cold rolling stage

Hot rolling can achieve large dimensional changes in a single step, but gives poor dimensional control and surface finish. Because it is carried out at temperatures above the recrystallisation temperature, hot rolling does not increase the strength of the metal. Cold rolling, on the other hand, takes place without recrystallisation, so the material undergoes work hardening. As a result, the final cold rolling step after annealing can be used to fine-tune the mechanical properties of the strip, as well as yielding a product with a high-quality surface finish. In skin pass rolling, the final cold rolling process is used to process a strip surface with a defined surface roughness only. In this case a low very low reduction rate is used. Cold-rolled steel strip is typically used for motor vehicle bodies and domestic appliances. There are two types of final cold rolling: dry and wet. Dry rolling, as the name implies, takes place without the use of rolling fluids such as water-based emulsions or oil. The result is a high-quality bright surface finish, but at the cost of low line speed and short life of the working rolls. The problem with dry cold rolling is the large amount of heat generated in the roll gap by friction and plastic deformation of the metal (Figure 2).



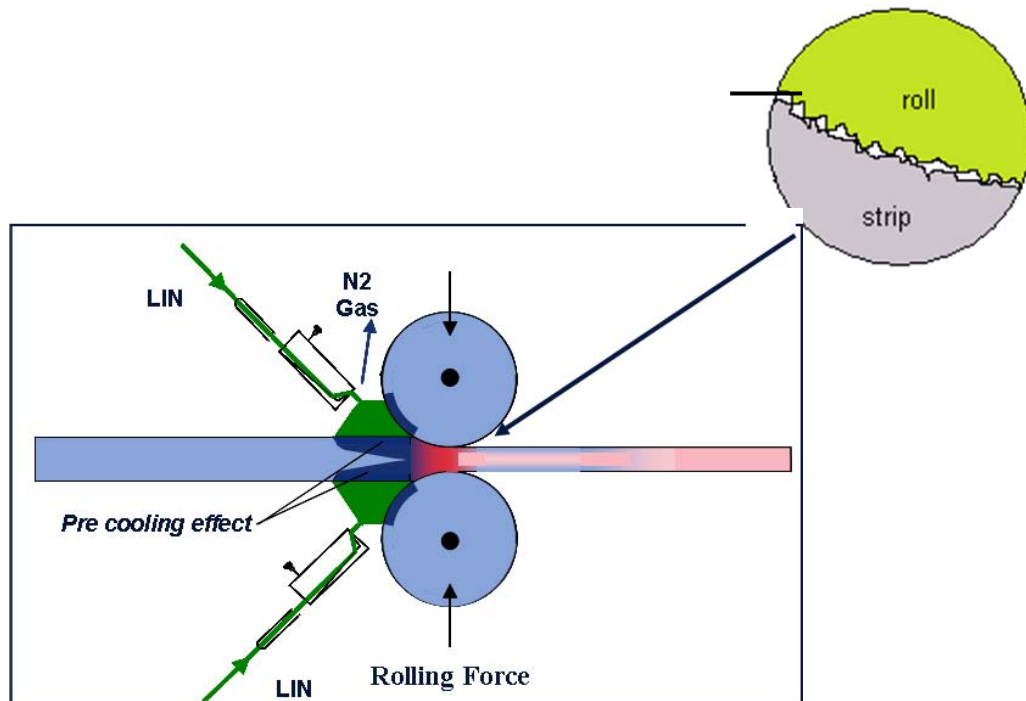
**Figure 2:** In dry rolling, friction and plastic deformation in the roll gap produce heat that slows production and can damage both the product and the rolls.<sup>(1)</sup>

Most of this heat is dissipated in the rolls and the product, and if the resulting temperature rise is too great, the metal surface of the strip or the working rolls can oxidise. Product that is damaged in this way has to be rejected, while damage to the rolls requires frequent reconditioning. In practice, strip producers run their rolling mills at the highest speeds possible before the product begins to tarnish. As a result, they need frequent roll changes, which in turn means high costs for downtime and regrinding the rolls. Frequently, the product also suffers heat damage; this can be a significant cost, particularly in the case of valuable materials such as copper or stainless steel. A technique known as minimum quantity lubrication is sometimes used to achieve higher reduction rates with lower roll forces and less friction. Since this does not provide cooling, however, it suffers from the same disadvantage of low productivity as conventional dry rolling. The obvious way to reduce friction and remove heat is to use a water-based cooling fluid, usually a water/oil emulsion. Wet rolling allows the line speed to be increased significantly, but brings some problems of its own. In most cases, the use of rolling fluids results in a dull surface compared to the bright finish found in dry rolling. Then there is the capital cost of the lubricant circuit, and the ongoing costs of monitoring and adjusting the emulsion composition. The biggest problem at C.D. Wälzholz, however, was rust spots on the strip surface. The downstream cleaning equipment was unable to remove all traces of emulsion, and the resulting residual moisture caused rust to develop during storage or transport to the customer. The resulting rejections were very costly.

## 2 LIQUID NITROGEN: A BETTER SOLUTION

Using liquid nitrogen, C.D. Wälzholz and Air Products have developed a new cooling technique that provides greater productivity than conventional dry rolling — and in some cases even wet rolling — without using aqueous emulsions. Liquid nitrogen is often used in industry as a special-purpose refrigerant. Its advantages include a large heat capacity, the ability to generate very low temperature if required, and the fact that it evaporates without leaving any moisture or residues. Nitrogen is also non-flammable, reducing the risk of fires and explosions, and can be discharged to the atmosphere in a safe and environment-friendly manner after use. The new Air

Products cool rolling technology (Figure 3) uses spray bars to distribute liquid nitrogen at temperatures between  $-170^{\circ}\text{C}$  and  $-196^{\circ}\text{C}$  (depending on the supply pressure) over the width of the metal strip as it enters the rolls.



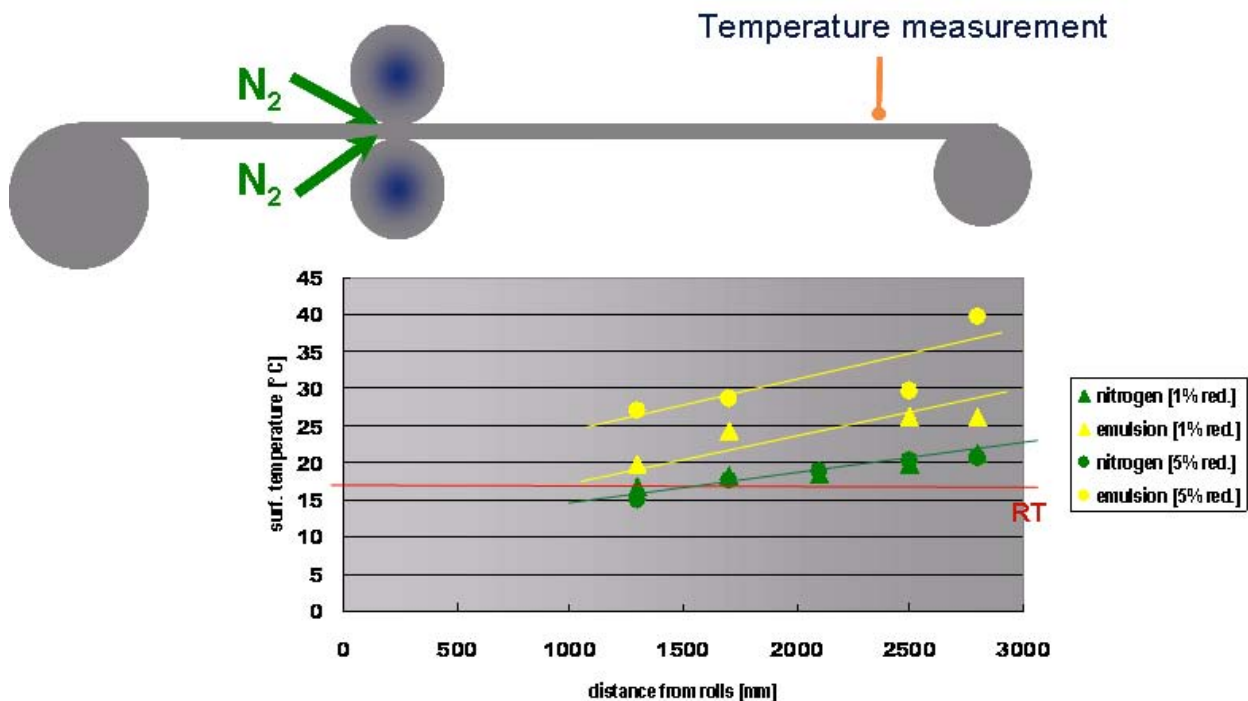
**Figure 3:** Liquid nitrogen sprays prevent oxidation during cold rolling through (a) pre-cooling the strip and roll surfaces, so as to reduce the temperature rise, and (b) keeping oxygen out of the work area

By pre-cooling the surfaces of the rolls and the strip, the use of liquid nitrogen reduces the peak temperature inside the roll bite, or alternatively allows the rolling speed to be increased without raising the peak temperature. Nitrogen also reduces oxidation by lowering the oxygen concentration in the contact area between the rolls and the strip. In wet rolling, conventional emulsions also work as lubricants, reducing the generation of heat by reducing friction. Liquid nitrogen, in contrast, has no lubricating effect; instead it removes frictional heat thanks to its very high heat capacity. Once its work is done, the liquid nitrogen evaporates, leaving no residue.

### 3 THE EFFECT ON THE ROLLING PROCESS

#### 3.1 Lower Temperatures

Cold rolling with nitrogen requires a nozzle system that can provide a homogeneous, non-pulsating jet of liquid nitrogen across the width of the strip. This ensures effective cooling without hot or cold spots that might spoil the flatness of the strip. It is also important to stop ice from building up on the nozzle, because any carryover of ice or water is bad for product quality. Air Products therefore developed an innovative and proprietary liquid nitrogen supply system, nozzle and shroud that ensures a uniform spray of nitrogen without ice formation. Once we had finished the design of the nozzle system, we carried out several tests on the rolling mill at C.D. Wälzholz to evaluate the reliability of the process and the technical benefits. The tests included a comparison of strip surface temperature between wet rolling and the use of liquid nitrogen. This was done with a typical low carbon steel at a rolling speed of 200 m/min and reduction rates of 1% and 5% (Figure 4).



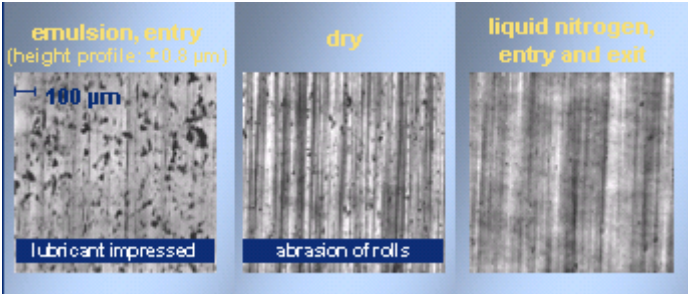
**Figure 4:** Temperature comparison between nitrogen and wet rolling. And the use of nitrogen reduces strip temperatures compared to conventional wet rolling

This measurement confirmed that nitrogen reduces the temperature of the strip surface during the rolling process. The typical temperature increase on the strip surface after rolling appears due to heat diffusion from the hotter core to the colder strip surface, caused by internal deformation heat. In cooperation with the rolling mill manufacturer SMS Demag, Air Products and C.D. Wälzholz carried out a research programme to understand how the final rolling process affects the quality of the finished strip surface and the life of the work rolls. Sections 3.2 and 3.3 below describe the results of this work.

### 3.2 Improved Surface Quality

We have increasingly come to appreciate the surface cleaning effect of the liquid nitrogen sprays in Air Products cool rolling technology. Magnified images (Figure 5) show the difference in surface appearance between wet rolled, dry rolled and liquid nitrogen rolled strip. Conventional wet rolling shows a significant number of surface defects from impressed lubricant and rolling debris. Dry rolling provides greatly improved surface quality, as expected, but even here we see some rolled-in particulate matter. Liquid nitrogen sprayed cold rolled strip, in contrast, shows an essentially clean surface. We attribute the cleaning effect of liquid nitrogen to different mechanisms, which together dislodge and blow away surface particles: one of them is the high-velocity impact of liquid nitrogen droplets, and this is followed by explosive expansion as the liquid nitrogen vaporises. When liquid nitrogen is sprayed into the roll bite, this cleaning effect probably takes place on the surfaces of both the strip and the rolls. Air Products is experimenting to optimize the position of the nitrogen sprays and take best advantage of the surface cleaning effect. The reduction in the number and size of impressed surface defects shown in the strip

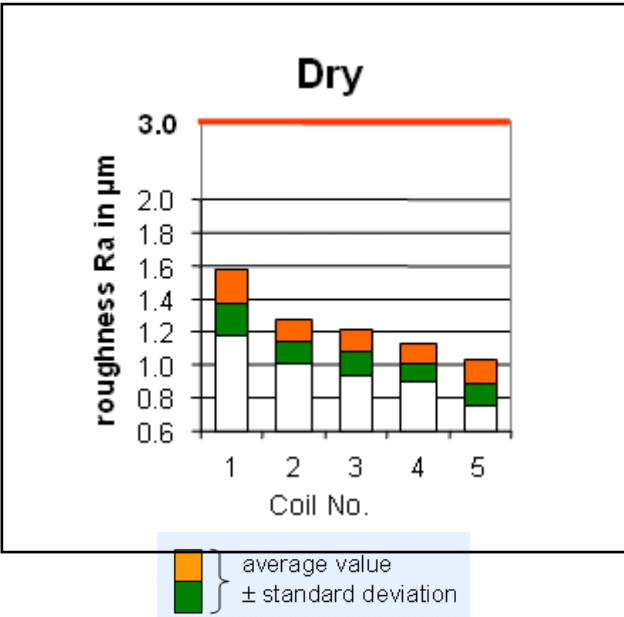
rolled with liquid nitrogen means a great improvement in strip surface quality. This clearly proves the cleaning effect of liquid nitrogen jets on metal surfaces.



**Figure 5:** Magnified images of wet rolled (left), dry rolled (centre) and liquid nitrogen rolled (right) strip

### 3.3 Longer Roll Life

Practical experience at C.D. Wälzholz showed that the use of liquid nitrogen as a cooling and cleaning agent extended the life of the work rolls compared to dry rolling. To more clearly understand this effect, we measured how fast the roll surface roughness changed for both dry rolling and rolling with liquid nitrogen. In both cases we started with a roll surface roughness ( $R_a$ ) of 3.0–3.3  $\mu\text{m}$ , and re-measured the roughness after each coil had been rolled. For dry rolling (Figure 6), the roll surface roughness decreased continuously as five coils were rolled. For the customer in question, the tolerable limit of roughness is 1  $\mu\text{m}$ , so the working rolls need to be replaced after every four coils.



**Figure 6:** With dry rolling, the working rolls have reached their minimum acceptable roughness (1  $\mu\text{m}$ ) and need replacement after four coils have been processed

With liquid nitrogen (Figure 7), the decrease in roll roughness after the first coil, and the rate of decrease after subsequent coils, was less. Roughness remained above 1.5  $\mu\text{m}$  even after 10 coils, so in this case the life of the working rolls is more than doubled.



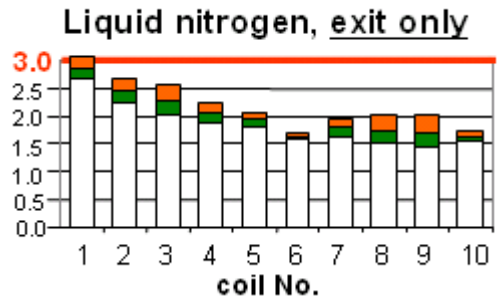


Figure 7: Liquid nitrogen extends the life of the working rolls to 10 coils or more

#### 4 ECONOMIC EVALUATION

The technical benefits of Air Products cool rolling technology are different for each cold rolling operation. To understand the commercial value of these benefits, the rolling mill operator has to analyse the overall production chain and the financial impact of the technical and administrative issues (Figure 8).

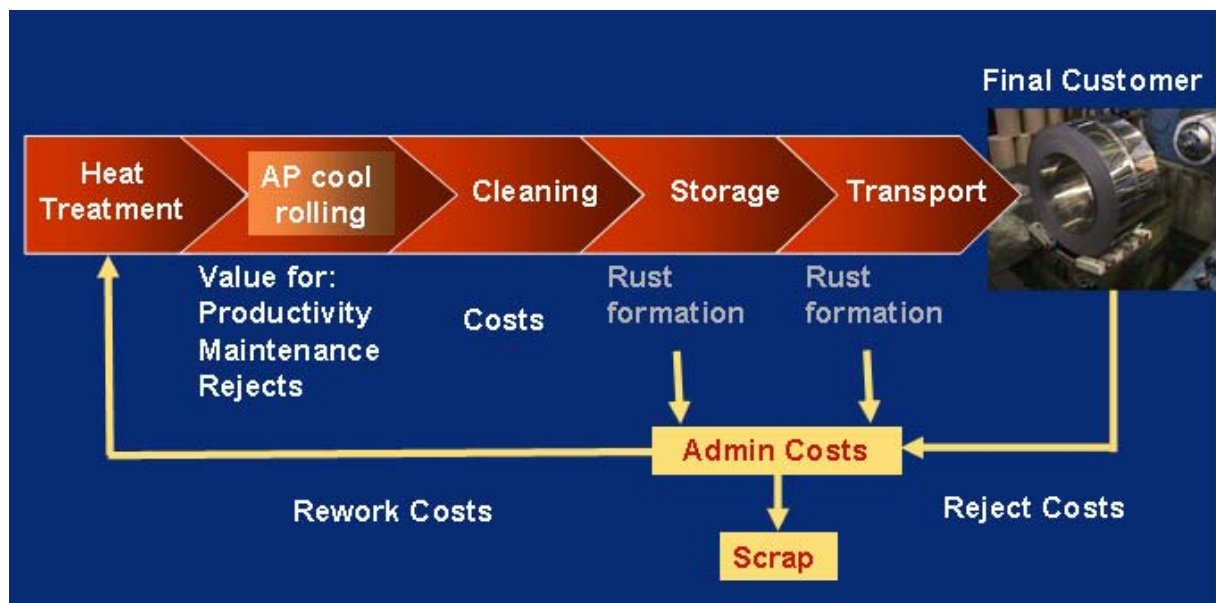


Figure 8: Evaluating the economics of productivity and quality issues in strip rolling

It is important to understand the reasons for, and rates of, product rejection, as well as the costs of rework and labour associated with resolving these issues. Table 1 summarises the general advantages of Air Products cool rolling technology. Not all of these, of course, will necessarily apply to every site. Analysing the specific cold rolling process and quantifying the financial benefits listed in Table 1, however, will enable operators to see clearly whether Air Products cool rolling technology could benefit them.

**Table 1:** Typical benefits from Air Products cool rolling technology

<b>Safety</b>	Eliminates fire and explosion hazards from oil-based emulsions
	Eliminates noxious oil vapour
	Eliminates emulsion residues in the work area, and associated slipping
<b>Capital expenditure</b>	Higher line speed, hence higher productivity, with little investment and no need to expand the plant
	No emulsion circuit needed
	Increased work roll life
	No downstream cleaning system needed
	No CO <sub>2</sub> extinguishing system needed
<b>Maintenance</b>	Emulsion monitoring no longer needed
	Less frequent roll changing and refurbishing
	No cleaning system or emulsion circuit to maintain
<b>Consumables</b>	No emulsions or additives to buy
	No filter preparation
	Lower electricity consumption
<b>Quality</b>	More consistent surface quality, and defect reduction due to surface cleaning
	More uniform roughness
	Fewer rejects due to rust
	Mirror-finish surfaces at higher line speed
	Possibility of expanding product range thanks to oil- and grease-free process

## 5 COUNTING THE BENEFITS

Using Air Products cool rolling technology on the final pass, C.D. Wälzholz was able to eliminate rejects caused by rust spotting, which had been a serious problem with emulsions. The use of nitrogen also guarantees an oil-free strip surface. As a result, the company was able to eliminate the post-cleaning step, which for technical reasons had limited the rolling speed. The result was a line speed increase of up to 200%, the maximum speed of which the current machinery is capable, giving big gains in overall productivity. Analysis according to the points listed in Table 1 shows that conversion to Air Products cool rolling technology reduced the costs of final-pass rolling by around 25%. This is a net saving, and takes into account all the operating costs of the Air Products cool rolling technology itself. Liquid nitrogen has also been used on a dry cold rolling line at C.D. Wälzholz. Again, it proved possible to increase the line speed by up to 200%, resulting in plant production increases of up to 50%.

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