Zero-defect-strategy in the cold rolling industry

Possibilities and limitations of defect avoidance and defect detection in the production of cold-rolled steel strip

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COMITÉ INTERNATIONAL D'ÉTUDE DU LAMINAGE À FROID DU FEUILLARD D'ACIER

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1. INTRODUCTION AND OBJECTIVES

The cold rolling industry has developed over the past few decades into a modern supply sector. Precise geometrical and material properties are set in controlled production processes, and customers recognise and appreciate the resulting reliability and process capability.

The technological state of the sector and the continuing quality development of the raw material from modern steel plants ensure high product quality and reproducibility.

Thanks to continuous process improvements in the cold rolling industry and the upstream steel production processes, it has been possible to cut defects to minimum. But it is still not possible to guarantee 100% defect-free products if one considers the process chain as a whole.

The aim of this article is to highlight the causes and the possibilities for avoiding and detecting residual defects, and to point out the existence of this risk in semifinished products of steel such cold rolled steel strip.

Cold rolling mill: Quarto reversing cold rolling plant

The residual risk of defects must be taken into account within a continuous 0-defect strategy when establishing the examinations for the subsequent production stages of the cold rolled steel strip processor (e.g. punching, forming, quenching and tempering) as a function of the requirements for the end product.

2. TERMS AND DEFINITIONS

When discussing this subject it is very important to define precisely the individual terms used, since their meaning differs considerably.
In the relevant standards the terms nonconformities, defects and discontinuities are used, see DIN EN ISO 9000 „Quality management systems. Fundamentals and vocabulary", Arts. 3.6.2 and 3.6.3.
In DIN EN 10021 „General technical delivery requirements for steel products", Art. 7.4.1 reference is made to minor surface and internal discontinuities which may occur under normal manufacturing conditions shall not be a basis for rejection. The term discontinuities describes imperfections in the product which cannot be completely avoided and detected with the current state of the art.

In the following defects and discontinuities for the process chain in the production of cold-rolled steel strip are highlighted.

3. MAIN PROCESSES

Steel plant ➜ Hot rolling mill ➜ Cold rolling mill ➜ Cold rolled steel strip processor

The manufacturing process of this route has been developed and improved continuously over the past few years and decades. The main steps include:

- Computer-aided control of production conditions in the area of melting metallurgy
- Ladle metallurgy and vacuum treatment
- Mould level control and automated casting flux feed in the continuing casting installations
- Use of on-line instrumentation and control circuits in hot and cold rolling mills
- Use of automatic surface inspection systems in hot rolling mills and pickling lines
- Conversion to hydrogen high-convection technology in batch annealing furnaces

Cold rolling mill:
Hydrogen high-convection batch annealing furnace

This and other measures have led to a substantial reduction in the defect rates.

Steel plant: Qxygen converter

4. TYPICAL DEFECTS AND DISCONTINUITIES

Despite major progress in technology certain defects and discontinuities cannot be avoided completely. The main defects and discontinuities are explained as follows.

4.1 Steel plant defects and discontinuities

4.1.1 Shells

- Shells due to nonmetallic inclusions
  Shells can arise as a result of inclusions just under the surface (partly in linear form). Such inclusions are subject to considerable stretching by subsequent deformation and tear open or are overlapped.

  A typical way they occur is rooted in the deoxidization process of the steel plants.
  For the continuous casting process the steel must first be killed in the casting ladle, i.e. oxygen is removed. This is done mainly using aluminium.

  The resulting deoxidization product AL_2O_3 – aluminium oxide – has a relatively high melting point and passes instantaneously into the solid state in the molten steel bath.
  As a function of the temperature of the molten steel in the casting ladle, the particle size of the reaction product and its current position in relation to the surface, these specifically lighter particles rise and can be eliminated via the slag. A part may, however, pass into the casting strand because of turbulence, for example, in the tundish.

  Fluctuations in the bath level due to the clogging of the submerged nozzle or delays in changing the ladle may lead to slag being drawn into the strand, resulting in shell-like defects.
  In the case of bow type casting machines, the oxidic particles rising vertically out of the strand first encounter the strand shell located on the inside of the arc. This explains the asymmetrical distribution in relation to the slab thickness. The vertical casting machines often used have the advantage that the particles have more time to rise into the slag.

  Further slag-like surface defects may arise when casting flux, which is used as a sliding agent between the mould wall and the strand shell, is flowed over by the molten strand and gets under the surface.

- Shells due to slab damage
  After casting, the endless strand is cut transversely into individual slabs. This can lead to socalled cutting burrs at the cutting edges, and this happens to the same extent due to longitudinal slitting of slabs cast in multiple widths. If, despite the deburring, there remain minor residues on the slab, these can either result in shells on the rolled hot strip or drop off as early as the preheating furnace, thus causing damage to subsequent slabs.

  In the case of steels with high Carbon content and extremely high-strength micro-alloyed steels, edge cracks and longitudinal and transverse cracks can occur in the slabs over the surface during cooling, and these cracks will be lapped and cause shells.
  These steels are therefore frequently cooled slowly and are kept at a higher temperature until hot rolling (hot charging).

- Shells when casting steel ingots
  Specifically with ingot casting shells may also arise due to improper casting on and to inadequate feed of casting flux. Metal splashes caused by this may adhere to the inside wall of the mould and will only combine incompletely with the steel rising in the mould.

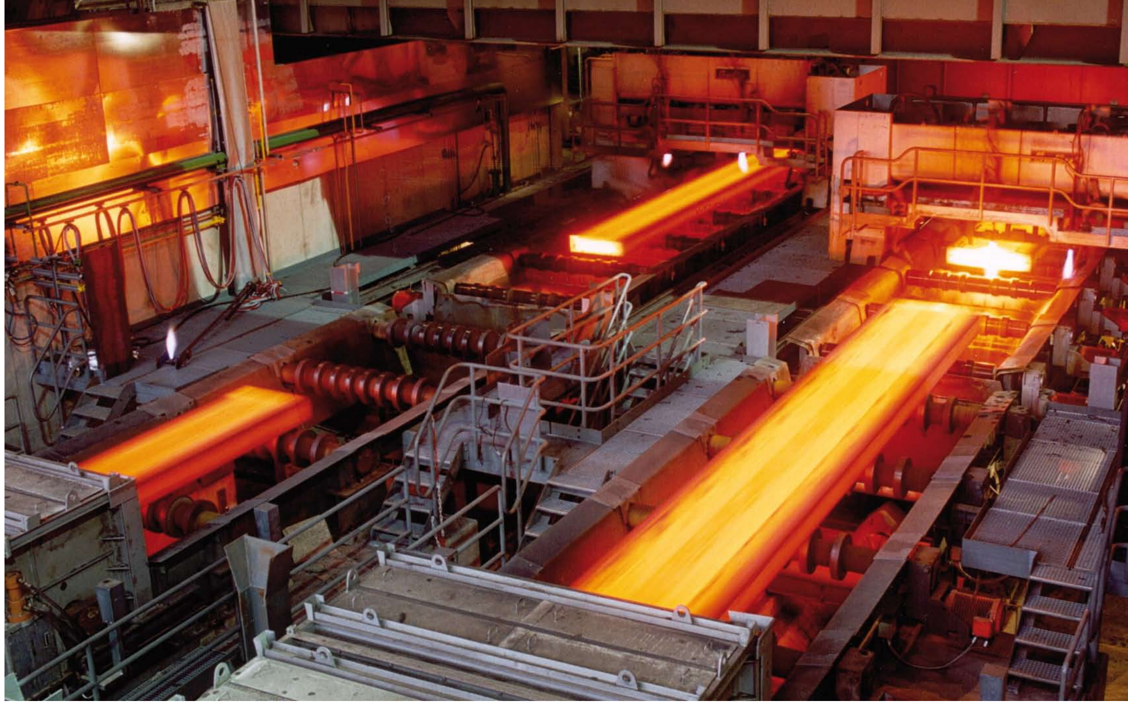
- **Detection**
  Shells can hardly be detected under the scale coating of the slabs or ingots. On-line instruments which work nondestructively are not available on continuous casting systems. Inspections and repairs, e.g. in the form of partial grinding or flame scarfing, are performed by hand or machine.
  Today automated defect prediction models based on recorded process data are available.

- **Prevention**
  · Limitation of the scatter of melting metallurgy and casting parameters
  · Structural measures on tundish, submerged tubes and casting system
  · Hot charging of slabs in the case of crack-susceptible grades

4.1.2 Nonmetallic inclusions

In any steel there is a bigger or smaller quantity of nonmetallic inclusions. Steel without such inclusions cannot be manufactured to the state of the art or only with extremely great effort (using special remelting processes). The quantity, composition and distribution are determined by numerous influencing factors, e.g. the chemical composition, the melting process, the deoxidization and the casting technology.
First a distinction must be drawn between exogenic and endogenic inclusions.
Particles form the furnace or ladle lining, from process slags (for example casting flux) and fragments form damaged submerged tubes and shroud tube are substantially bigger than compounds arising in the molten bath and are described as exogenic inclusions.
Endogenic nonmetallic inclusions such as sulphides, silicates, spinels and chromites arise as chemical compounds in steel.
In certain cases unfavourable chemical compositions – e.g. a high proportion of strongly segregating elements such as sulphur – cause eccentric segregations which can burst open during forming operations in subsequent production stages (cold-rolled strip).
Nonmetallic inclusions are always lighter than steel and endeavour to rise. A certain portion remains in the molten bath, however, and displays stochastic distribution. In the continuous caster these inclusions are frozen in the steel.

In order to ensure that the submerged nozzle between the tundish and the mould is free of AL_2O_3 deposits, argon is introduced during the casting operation. The argon is deposited on the inclusions and accelerates their rise. Too much argon can lead to argon bubbles in the steel. These can absorb atomic hydrogen when the steel is later pickled, and this will be expanded in subsequent heat treatments in such a way that visible bubbles can form on the material surface.



Steel plant: Slab continuous casting plant

- **Detection**
  It is at present not possible to conduct continuous nondestructive examinations to check for micro- and macro-inclusions on slabs or ingots and strips manufactured from these. To determine the degree of purity, random specimens are taken and subjected to a metallographic examination. Conclusions are drawn on the basis of the examinations for the whole batch. It must be considered, however, that it is not possible, given the present state of the art and recognised technical rules and standards, for the steel plants to guarantee inclusion-free melting in terms of the zero-defect strategy.

- **Prevention**
  · Limitation of the scatter of the melting metallurgy and casting parameters
  · Structural measures on distributor, submerged nozzle and casting installation
  · Slag detection systems
  · Special measures such as CaSi or vacuum treatment

4.2 Hot-rolling defects and discontinuities

4.2.1 Scabs

Scabs are material overlaps of differing form and extent which may be irregularly distributed over the surface of the rolled product and may only be

partially connected with the base metal. These defects can run in tracks or lines in rolling direction, and they partly run out in tips or tongues. They can occur on both sides over the whole width of the rolled product with differing intensity.
Slab damage may occur in the course of transport from the steel plant to the hot rolling mill and during passage through the preheating furnace, and will lead to scabs-like defects during hot rolling. In addition any damaged or jammed transport roller in the roller table may result in damage to the hot, and hence sensitive, pre-strip, and such damage will subsequently become conspicuous in the form of scabs.


Hot rolling mill: Multiple-stand finishing group

- **Detection**
  Automatic and/or visual inspection of the hot-rolled strip surface during hot rolling and pickling

- **Defects prevention**
  · Use of deburring machine
  · Regular examination of preheating furnace by means of control slabs
  · Regular inspection of roller table rollers

4.2.2 Scale, scale tracks, scale pits

On the way to cold-rolled strip the steel has numerous possibilities of receiving an oxide layer. The iron oxide layer formed by atmospheric oxygen on the continuous casting slab and the hotrolled strip subsequently rolled from this is called scale. Scale tracks and scale pores are the forms in which the scale occurs.

The scale formation is a function of time and temperature, taking account of the chemical composition, surface condition and ambient atmosphere. With the charging and heating up of the continuous casting slab in the reheating furnace scale arises in oxidizing atmosphere (primary scale) which is removed by spraying on water under high pressure prior to entry into the roughing mill. During thickness reduction at the roughing mill a layer of scale again forms (secondary scale) on the pre-strip, which is again removed prior to the finishing mill by means of high-pressure descaling. A third layer of scale (tertiary scale) forms during rolling in the finishing mill and with the coiling of the strip.

One of the possible causes for scale that has not been removed and has been rolled in is clogged nozzles in the high-pressure descaling, and this leads to track-like defects.
In addition changes in the friction conditions in the roll gap, wear in the rollers and thermal and mechanical load on the rollers can give rise to scale particles and these may be rolled into the surface.

- **Detection**
  Automatic and/or visual inspection of the hot-rolled strip surface during hot rolling and pickling

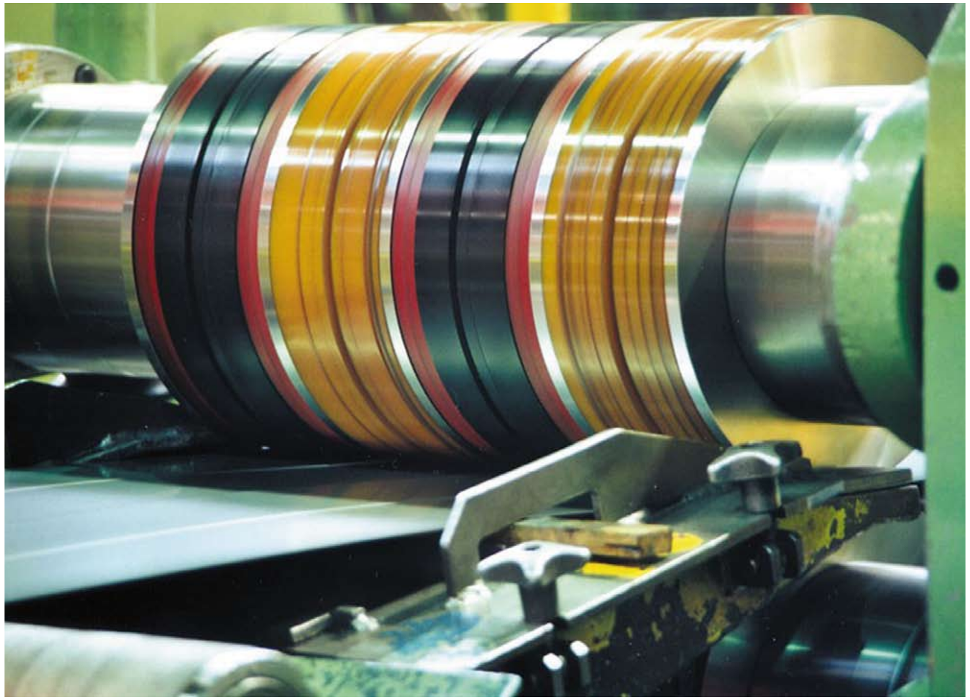
- **Prevention**
  · Precise setting of the high-pressure spraying system
  · Spray water optimization
  · Regular inspection of the nozzle and compliance with the maintenance intervals
  · Regular change of rolls according to wear behaviour
  · Exact compliance with temperature specifications

4.2.3 Abrasions, grooves and scratches

Abrasions, grooves and scratches are forms of mechanical damage of differing width, depth and length on the surface of the rolled product. They predominantly run longitudinally or transversely to the direction of rolling, can be slightly lapped, may contain scale or can also occur in the bare state.
These forms of damage arise as a consequence of relative movements between the rolled product and parts of the installation. Defects in longitudinal direction arise during transport of the rolled product or during coiling or uncoiling of the hot-rolled strip. Furthermore grooves and scratches may occur due to relative movements of individual windings in loosely wound coils. If the rolled product is damaged in hot condition, the damaged locations will scale and can be lapped in the subsequent passes, according to where they occur.

- **Detection**
  Automatic and/or visual inspection of the surface of the hot-rolled strip during hot rolling and pickling

- **Prevention**
  · Precautionary measures to avoid mechanical damage
  · Preventive maintenance



Cold rolling mill: Cold-rolled strip slitting line

4.3 Cold rolling defects and discontinuities

4.3.1 Indentations and impressions

Indentations or impressions are depressions on the strip which often occur periodically. They are caused by foreign bodies on rolls or rollers.

- **Detection**
  In the inspection of the beginnings and ends of strips periodic indentations or impressions can be seen with the naked eye. If they do not occur periodically, detection with the naked eye is not possible, or only with difficulty, given the high machine speeds.
  There is a residual risk in that foreign bodies may settle on rolls and rollers during the production of cold-rolled strip.

- **Prevention**
  · Preventive maintenance

4.3.2 Cold-rolled strip abrasions

Cold-rolled strip abrasions are grooves, scratches, grazes or tears of differing size which may arise before, during or after cold rolling, which frequently run in direction of rolling and are open or closed.
Cold-rolling abrasions can arise in nearly all stages of processing from cold rolling to processing at the customer. The cold-rolling abrasions are open after they arise, but they can be lapped in the course of further processing. The reasons for such cases of often accidental surface damage are various. In particular cold-rolling abrasions can often arise by scraping past sharp corners of edges on hard objects and machine parts or because of firmly adhering, hard dirt particles in guides and strip presses. In addition they can by caused by relative movements between loose windings or poor strip profiles.

- **Detection**
  In the inspection of the beginnings and ends of strips cold-rolled strip abrasions can be seen with the naked eye. If they occur as the strip is running, detection with the naked eye is not possible, or only with difficulty, given the high machine speeds.

- **Prevention**
  · Correct front tension
  · Good tying of coil
  · Avoidance of loose windings
  · Winding in of paper
  · Protection against tarnishing of plant components

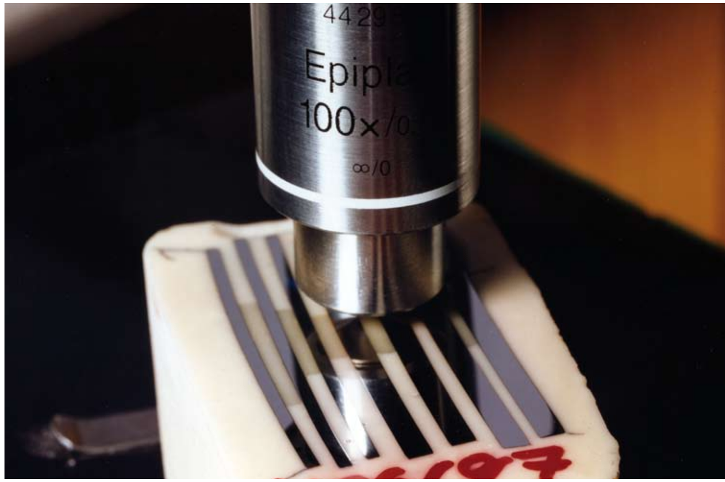
5. MATRIX – DETECTION AND RESIDUAL RISK OF DEFECTS / DISCONTINUITIES IN THE PRODUCTION OF COLD-ROLLED STRIP

defects / discontinuities	steel mill		hot rolling mill		cold rolling mill		costumer / consumer
(place arising)	detection	residual risk	detection	residual risk	detection	residual risk	detection
nonmetallic inclusions (SM)	random samples	x	random samples	x	random samples	x	100% inspection of the parts after forming
shells (SM)	slab / ingot inspection	x	visual and with SIS 1)	x	visual and with SIS 1)	x	100% inspection of the parts after forming
abrasions (HRM)			visual and with SIS 1)	x	visual, with SIS 1) and ends inspection	x	100% inspection of the parts after forming
scabs (HRM)			visual and with SIS 1)	x	visual and with SIS 1)	x	100% inspection of the parts after forming
scale defects (HRM)			visual and with SIS 1)	x	visual, with SIS 1) and ends inspection	x	100% inspection of the parts after forming
roll imprints / indentations (CRM)					visual, with SIS 1) and ends inspection	x	100% inspection of the parts after forming
scratches /grooves (CRM)					visual, with SIS 1) and ends inspection	x	100% inspection of the parts after forming

1) **SIS** = surface inspection systems:
restricted detection and classification accuracy must be noted

x = residual risk present.
The magnitude of the residual risk depends on:
material grade, process route, inspection effort, end use

Place arising:
SM = steel mill
HRM = hot rolling mill
CRM = cold rolling mill



Metallographic examination of nonmetallic inclusions

6. APPLICABILITY AND LIMITATIONS OF AUTOMATIC SURFACE INSPECTION SYSTEMS

In a joint project the Fachvereinigung Kaltwalzwerke e.V. arranged for an external study on the possibilities and limits of the use of automatic surface inspection systems in cold rolling mills. From a total number of 19 suppliers 10 systems were tested on the basis, among other things, of examinations of test samples with typical defects, and the results were evaluated in detail. The results of this study can be summarized as follows:

6.1 Benefits of the use of surface inspection systems

- Surface inspection systems make it possible to continuously inspect the strip surfaces
- Possibility of the objective assessment of strip surfaces
- Surface inspection systems provide an objective basis for assessing production processes.
  They make it possible to optimise the upstream working stages and to increase production reliability
- Defects which have been detected and classified can be used for the planning of the following process steps

6.2 Known limits

- Sophisticated defect detection imposes rigorous requirements regarding the installation situation (construction space, strip running, environment)
- The detection of different defect groups with different strip surfaces (bright, smooth, rough) demands differentiated equipment settings and cost-intensive additional equipment (lighting, camera angle, bright field/ dark field)
- Strip vibrations and irregularities in flatness can only be accepted with to a limited extent, which means that the successful inspection of cut, narrow strips is not possible
- Major oil or emulsion aerosols considerably impair the optical systems, which renders use in high-performance rolling installations questionable or even improbable
- Detection of defects on the test samples available did not yield a good result throughout with any of the suppliers

Cold rolling mill: Ready-to-despatch cold-rolled steel strip

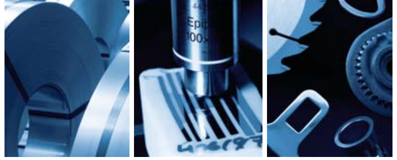
6.3 Conclusion

In view of the known limits the successful use of surface inspection systems in the production of cold-rolled strip is at present restricted to a few, specific applications.
In the production of parts, such systems are being used with increasing success

7. Summary

The present article presents the major defect possibilities in the production of cold-rolled steel strip as well as the place where they arise, causes, and the measures to detect and avoid them.
Although the processes in the steel plants, hot rolling mills and cold rolling mills are subject to continuous improvement, it is not 100% possible to exclude the possibility of residual defects.
The examinations available according to the state of the art in production processes to improve the process and exclude defect parts cannot reliably detect all defects, but they reduce the risk of defects substantially.

For the production of cold-rolled steel strip there remains a residual risk, which must be considered in the further processing as a function of the requirements for the end product.



NOTE:

At the instigation of the COMITÉ INTERNATIONAL D´ÉTUDE DU LAMINAGE Á FROID DU FEUILLARD D´ACIER CIELFFA a German working group took on the task of drawing up the present document. This was preceded by numerous discussions, primarily within the group of Technical Commissions of the CIELFFA such as the Fachvereinigung Kaltwalzwerke e.V. To this extent this paper represents the current state of discussion on the subject of a „Zero-defect strategy" in the European cold rolling industry as a whole.

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