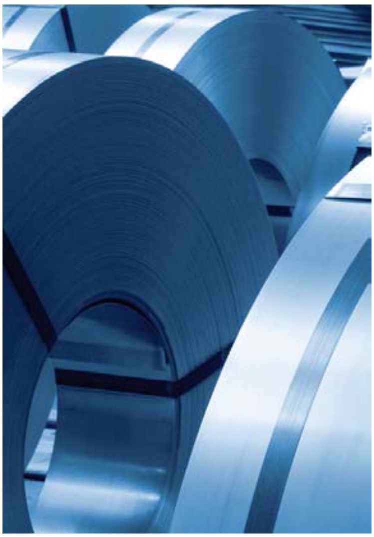
Zero-defect-strategy in the cold rolling industry

Edition 2019



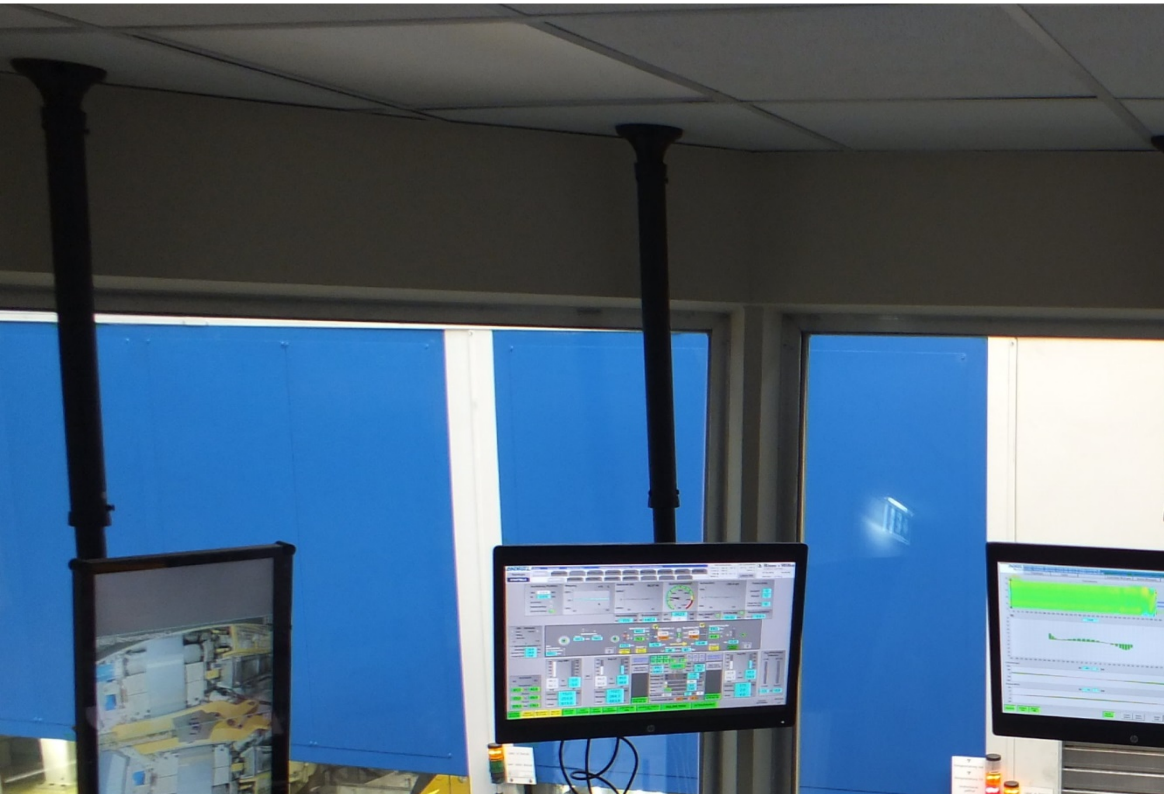
Possibilities and limitations of defect avoidance and defect detection in the production of cold-rolled steel strip

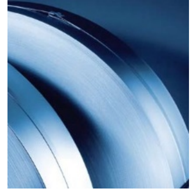
CIELFFA

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

FVK

Fachvereinigung Kaltwalzwerke e.V.





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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 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 a high product quality and reproducibility.

Due to continuous process improvements in the cold rolling industry and the upstream steel production processes, it has been possible to reduce defects to a minimum. However 100% defect-free products cannot be guaranteed when considering the entire process chain.

The aim of this brochure is to explain the causes and possibilities for avoiding and detecting residual defects. Moreover it points out the existence of the residual risk of defects in semifinished products of steel such as cold rolled steel strip.

Cold rolling mill: Quarto reversing cold rolling plant

This risk of defects must be taken into account in the framework of a continuous 0-defect strategy when establishing the material testings for the subsequent production stages of the cold rolled steel strip processor (e.g. punching, forming, quenching and tempering) depending on 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 EN ISO 9000:2015 „Quality management systems. Fundamentals and vocabulary“, Arts. 3.6.9 and 3.6.10.
In EN ISO 10021:2007 „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 and are no 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 processes 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

CR mill: H_2-high-convection batch annealing furnace

- Use of online 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

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

Steel plant: Oxygen converter

4. TYPICAL DEFECTS AND DISCONTINUITIES

Despite major progress in technology certain defects and discontinuities cannot be completely avoided. 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 occur as a result of inclusions directly under the surface (partly in linear form). Such inclusions are considerable stretched by subsequent deformation and tear open or are rolled over.

  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 mainly done by using aluminium.

The resulting deoxidization product Al_2O_3 - aluminium oxide - has a relatively high melting point and passes instantaneously into a solid state in the molten steel bath.
Depending on 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 with the slag. However a part may pass into the casting strand, for example because of turbulences 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 so-called cutting burrs at the cutting edges. 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 on the entire surface of the slabs during cooling. These cracks will be rolled over 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 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. Online 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.

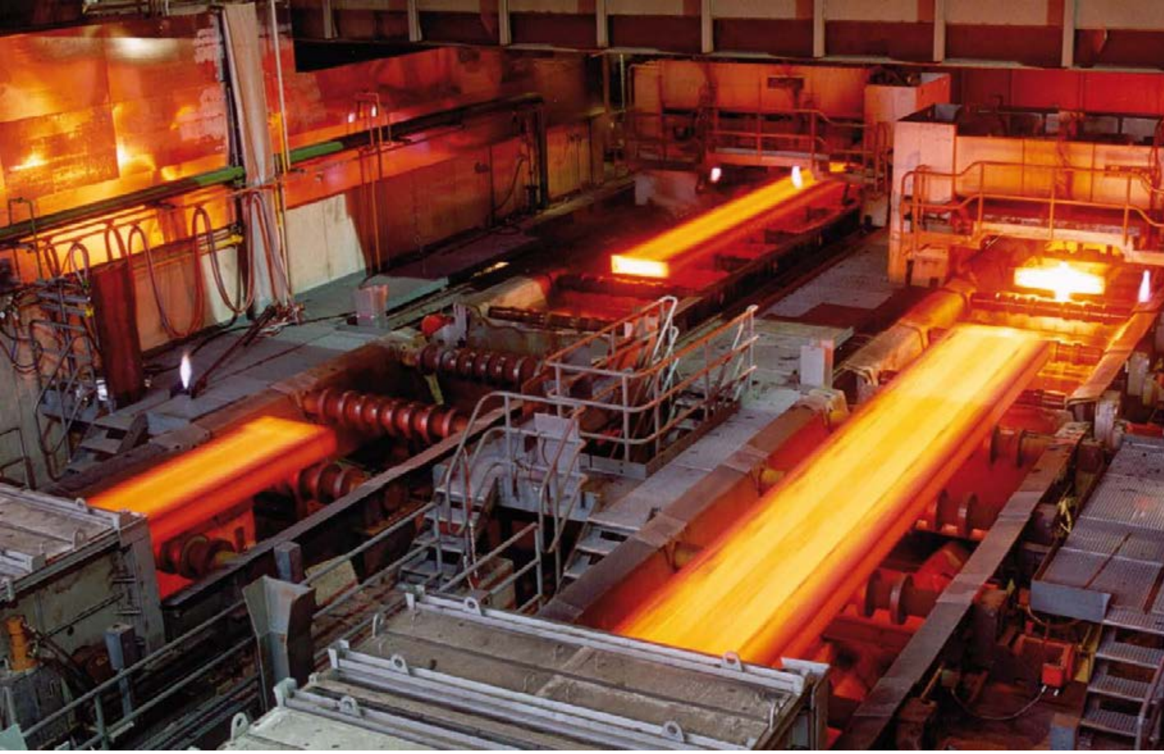
- **Prevention**
  - Limitation of the scatter of melting metallurgy and casting parameters
  - Structural measures on tundish, submerged tubes and casting system
  - Hot charging of slabs in the case of crack-susceptible grades

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 according to the state of the art or only with extremely high 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. They 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 therefore tend to rise. However, a certain proportion remains in the melt and shows a 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 pickled later. Hydrogen may expand so that visible bubbles may occur on the surface.



Steel plant: Slab continuous casting plant

- Detection

  At present it is not possible to conduct continuous nondestructive inspections 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 testing. Conclusions are drawn on the basis of the inspections 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 during the transport from the steel plant to the hot rolling mill and during passage through the preheating furnace leading 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, which 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 hot rolled strip subsequently rolled from this is called scale. The scale occurs in the form of scale tracks and scale pores.

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

One of the possible causes for scale that has not been removed and has been rolled in are clogged nozzles in the high-pressure descaling, which lead to track-like defects. In addition changes in the friction conditions in the roll gap, wear of the rollers and thermal and mechanical load on the rollers can result in scale particles which 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 requirements

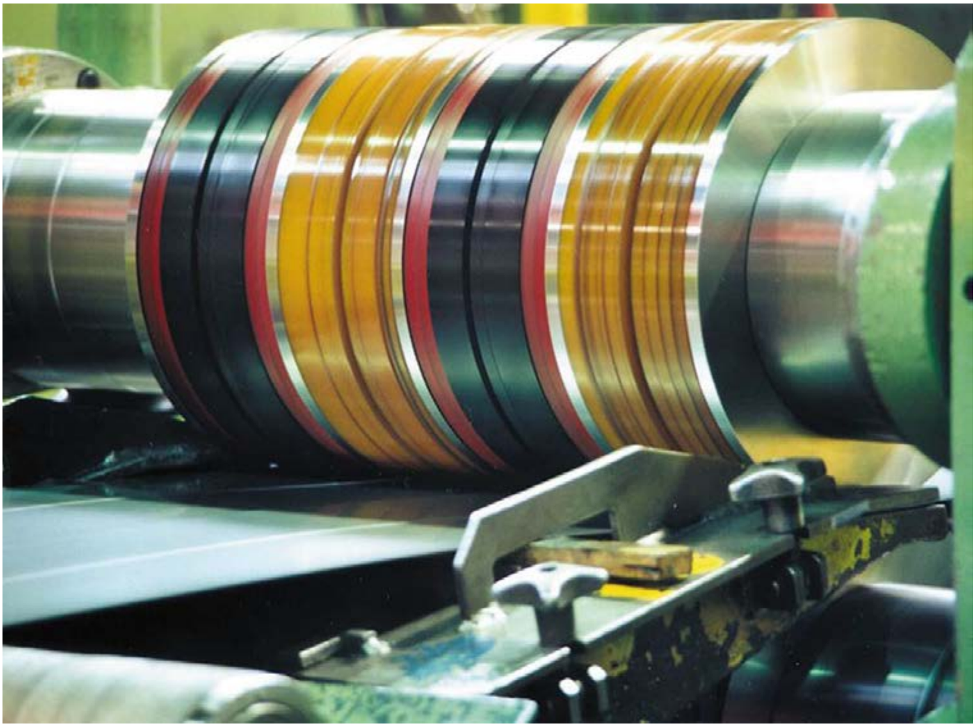
4.2.3 Abrasions, grooves and scratches

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 occur 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 areas will scale and can be rolled over 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 pimples

Indentations are depressions on the strip which often occur periodically. They are caused by foreign bodies on rolls or rollers. Pimples are periodical “high spots” caused by small cavities in the work roll surface.

- **Detection**

  In the inspection of the beginnings and ends of strips periodic indentations and pimples can be seen with the naked eye. Due to the high machine speeds, it is not possible or very difficult to detect non-periodic defects with the naked eye.

  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
  - Surface defect inspection of the rolls with eddy current or ultrasonic testing

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 - and, which frequently run in direction of rolling and are open or closed.
Cold-rolling abrasions can occur in nearly all stages of processing from cold rolling to processing at the customer. These abrasions are open after their occurence, but they can be rolled over in the course of further processing. There are various reasons for such cases of often accidental surface damage. In particular cold-rolling abrasions can often arise by scraping past sharp corners or edges of hard objects and machine parts or because of firmly adhering, hard dirt particles in guides and strip presses. In addition they can be 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 when the strip is running, it is not possible or very difficult to detect non-periodic defects with the naked eye.

- **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 COLD-ROLLED STRIP PRODUCTION

defects / discontinuities	steel mill		hot rolling mill		cold rolling mill	
(place arising)	detection	residual risk	detection	residual risk	detection	residual risk
nonmetallic inclusions (SM)	random samples	x	random samples	x	random samples	x
shells (SM)	slab / ingot inspection	x	visual and with SIS[1)]	x	visual and with SIS[1)]	x
abrasions (HRM)			visual and with SIS[1)]	x	visual, with SIS[1)] and ends inspection	x
scabs (HRM)			visual and with SIS[1)]	x	visual and with SIS[1)]	x
scale defects (HRM)			visual and with SIS[1)]	x	visual, with SIS[1)] and ends inspection	x
roll imprints / indentations (CRM)					visual, with SIS[1)] and ends inspection	x
scratches / grooves (CRM)					visual, with SIS[1)] and ends inspection	x

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

Despite all inspections during the steel production, a residual risk remains, which can only be excluded by a 100% inspection of the parts after processing or finishing.

Steel plant: Slab stock

Steel plant: Modern blast furnace

6. APPLICABILITY AND LIMITATIONS OF AUTOMATIC SURFACE INSPECTION SYSTEMS

The technical state of the art can be summarised as follows:

6.1 Benefits of the use of surface inspection systems (SIS)

- Surface inspection systems make it possible to continuously inspect the strip surfaces

- Surface inspection systems provide a 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).

- SIS show deviations from the target grey value, no measured defect depth values. 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). The accuracy of the systems is limited.

- Only previously classified surface defects are detected.

- Strip vibrations and irregularities in flatness can only be accepted to a limited extent, which means that the successful inspection of cut, narrow strips is not appropriate.

- Major oil or emulsion aerosols considerably impair the optical systems, which renders use in high-performance rolling installations questionable or even improbable.

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

6.3 Conclusion

Due to 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 in common use.

7. SUMMARY

The present article presents the major types of defects in the production of cold-rolled steel strip as well as the processes where they can 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 inspection methods available according to the state of the art in production processes to improve the process and exclude defective parts cannot reliably detect all defects. However they substantially reduce the risk of defects.

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

NOTE:

"At the recommendation of the European cold rolling association CIELFFA, the first edition of this brochure was prepared by a German working group. The preparation was preceded by numerous discussions in the Technical Committees of the CIELFFA and the German cold rolling association Fachvereinigung Kaltwalzwerke e.V.. The respective edition represents the state of knowledge of the entire European cold rolling industry.“

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Photos of the steel plants: „Stahl-Zentrum“ and steel plants mentioned above
Photos of the cold rolling mills - Member plants of the CIELFFA

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