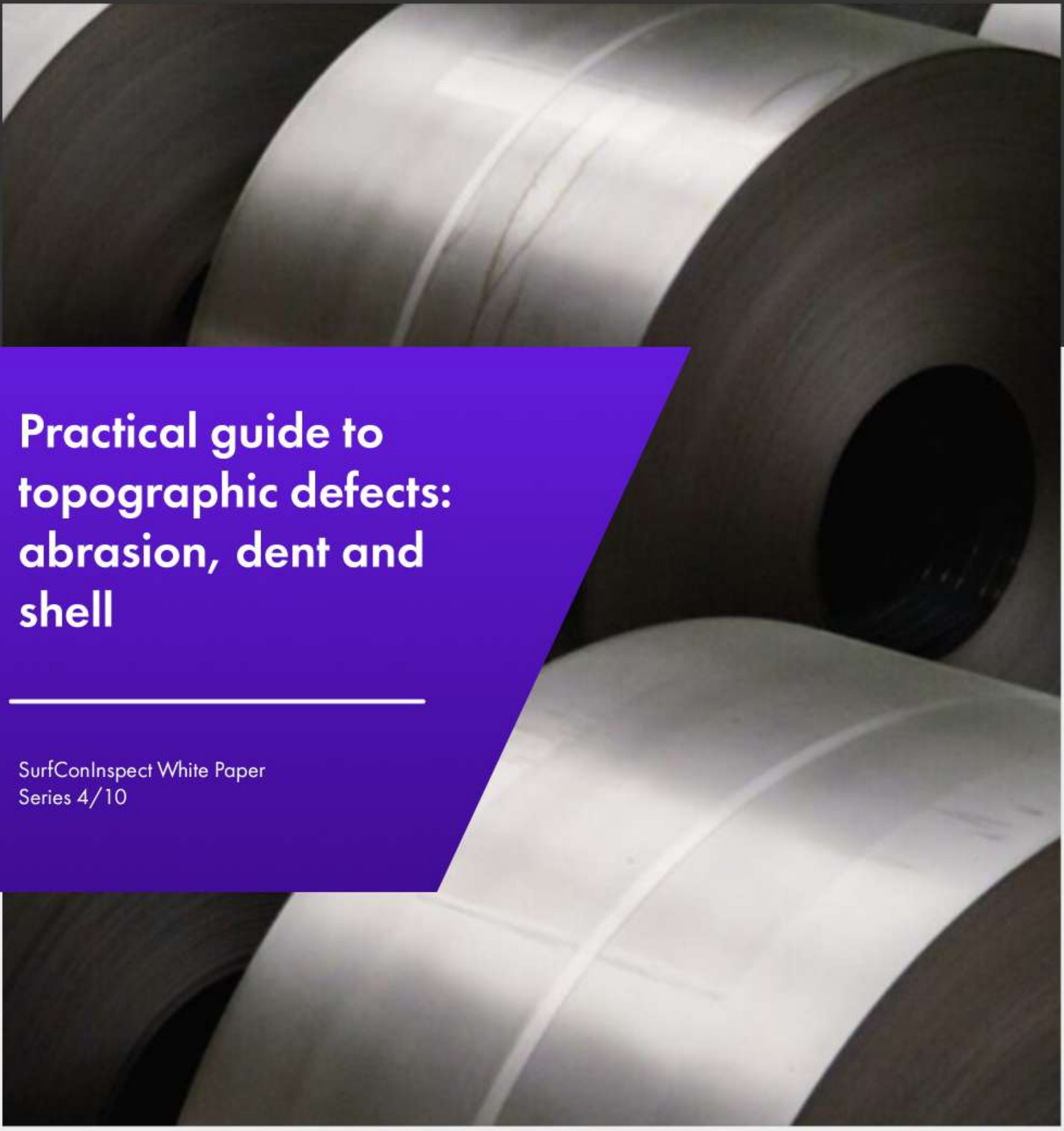
SURF CON INSPECT

WHITE PAPER



Practical guide to topographic defects: abrasion, dent and shell

SurfConInspect White Paper
Series 4/10

About Us

WHO WE ARE

SurfConInspect (SCI) is a European project funded by the Research Fund for Coal and Steel (RFCS). Our consortium brings together leading steel producers, research institutes, technology developers and innovation experts.

The partners combine industrial expertise, academic knowledge and advanced digital solutions to transform the way steel quality is controlled.

OUR MISSION

The steel industry faces increasing pressure to become more sustainable, efficient and competitive—key goals of the European Green Deal.
Our mission is to enable zero-defect manufacturing in flat steel production by:

- Detecting surface defects earlier and more accurately.
- Reducing waste and improving resource efficiency.
- Supporting operators with advanced visualization tools.
- Providing real-time control actions directly in production lines.

MAIN ACTIVITIES

- Industrial trials in tin-plate and automotive steel production.
- Development of AI-based inspection methods.
- Application of AR for real-time operator support.
- Creation of open datasets to enhance research and industrial collaboration.
- Dissemination of results to industry, research and society through events, publications and digital platforms.

EXPECTED RESULTS

- Zero-defect production through optimized inspection and control.
- Reduced waste and energy consumption, contributing to the
  European Green Deal.
- Higher competitiveness for European steel producers.
- Transferable technologies with potential applications beyond the steel sector.
- Improved working conditions, with operators supported by innovative visualization and decision-making tools.

Executive Summary

Flat steel production is a continuous sequence of process steps in which every stage of the manufacturing chain leaves a physical imprint on the material surface. In pickling-line inspection, topographic defects occupy a special category because they require in-depth visual inspection. Their industrial relevance does not lie primarily in how they look in a 2D image, but in how they are shaped in space: depth, elevation, lateral extension, profile sharpness and distance from the strip edge determine whether a defect is innocuous or whether it becomes a precursor of downstream rupture. This distinction is not theoretical. In the SurfConInspect industrial environment at Rasselstein, critical defects that were classified in 2D as "wet", "underpickled", or not detected at all became clearly interpretable once their three-dimensional structure was measured directly. That is precisely why the project adopted a full-width 3D inspection concept for the pickling line: not to add visual complexity, but to recover the one variable conventional inspection misses when risk is mechanical rather than optical—geometry.

This white paper examines three defect families that repeatedly emerge as operationally relevant in pickling-line conditions—abrasion, dent and shell—and treats them not as isolated image classes, but as process-significant geometries. Each of these defects originates in a different way, interacts differently with downstream deformation and requires a different decision logic at line level. Abrasions are typically linked to frictional contact and can evolve into perforation sequences; dents are compact depressions often associated with entrapped particles and can become hole initiators under rolling load; shells are metallurgically rooted discontinuities whose apparent mildness at pickling may conceal severe instability during later thickness reduction. Framed this way, the document is not merely a defect catalogue. It is a practical guide to interpreting three-dimensional defect behaviour in the context of real production decisions.

The guide addresses the morphology and formation mechanisms of each defect type, as well as the relationship between their measurable geometric attributes—depth, extension and profile shape—and the damage mechanisms they can activate during cold rolling, coating and forming operations. One of the strongest findings emerging from the project is that position matters almost as much as morphology. Analysis of 24 documented coil-break cases at Rasselstein showed that around 90% of the associated defects were located close to the strip edge, while 96% exhibited measurable height or depth information visible in the 3D channel. A defect of moderate depth in the strip centre and a defect with the same depth near the edge do not represent the same risk. Any serious inspection strategy for topographic defects must therefore treat edge proximity not as a secondary descriptor, but as an explicit severity variable in the decision model.

The analysis presented here is rooted in industrial evidence gathered in the SurfConInspect project from pickling-line operation under realistic production conditions. By the end of this guide, the reader should come away with more than a taxonomy of abrasion, dent and shell. The real objective is to establish a practical mental model of defect criticality in flat steel production: why topographic defects are governed by geometry, why edge proximity changes risk, why 2D ambiguity is structurally unavoidable in wet pickling conditions and why the combination of 3D sensing, trained classification and real-time quality supervision represents a decisive step toward zero-defect manufacturing. This is also the broader storyline of SurfConInspect itself: a move from reactive defect handling to quantified, in-coil decision support capable of improving yield, reducing waste and making surface quality control more reliable at industrial speed.

Topographic defects in flat steel production: an introduction

Topographic defects are surface irregularities whose defining characteristic is a measurable deviation from the nominal geometry of the strip surface. They have a three-dimensional structure that can be described quantitatively: a depth below the surrounding surface or an elevation above it, a lateral extension characterising their footprint and a profile shape that determines how they interact with mechanical forces. This geometrical definition sets them apart from the broader class of surface anomalies that affect the optical properties of the surface—its colour, reflectivity, or local texture—without implying any significant change in its physical shape.

The distinction is practically important because it directly determines which inspection approach is capable of detecting and characterising a given defect type. Conventional 2D systems remain valuable for many classes of optical surface anomalies, but they reach a structural limit when the decisive information is topography. In the pickling environment, this limitation is amplified by water films, changing reflectivity and acid-related surface effects leading to heavy background structures in 2D inspection setups. Under these conditions, a topographic defect can present itself as an optical artefact rather than as a mechanical hazard. The project documentation captures this failure mode clearly: relevant pickling defects that would have been dismissed in the 2D view as wet influence, underpickling, or background variation were recovered in the 3D channel because depth—not contrast—was the distinguishing feature. This is the conceptual step that makes the SurfConInspect approach significant: it reframes detection around the most discriminating physical attribute of the defect instead of attempting to infer severity from unstable visual surrogates.

In the pickling-line context, this limitation is compounded by the environmental conditions under which inspection must take place. Wet surfaces, acid residues and the optical effects introduced by water films all tend to alter the visual appearance of defects in ways that are unrelated to their geometric properties. As a result, the visual classification of topographic defects in pickling environments is inherently uncertain and this uncertainty has direct operational consequences: it leads either to the unnecessary rejection of material that could safely be processed, or to the uninhibited passage of critical defects toward downstream stages where the cost of failure is far higher.

The three defect types addressed in this guide—abrasion, dent and shell—represent the range of topographic anomalies most frequently associated with quality incidents in pickling-line environments. They differ from each other in their origin, their geometry and their typical behaviour under downstream processing, but they share a fundamental characteristic: all three are primarily defined by their three-dimensional structure and all three can cause failures in subsequent production stages if they are not identified and handled appropriately. A fourth property they share is that their risk to the downstream process is not proportional to their visual prominence. Some of the most operationally significant topographic defects are precisely those that are least visible in a standard two-dimensional image.

The steel strip surface as a production record

2D inspection systems analyze images captured by industrial cameras, typically supported by controlled illumination designed to enhance contrast and highlight surface features. In pickling-line environments, these systems operate with high-resolution line-scan cameras—often exceeding 4000 pixels with sampling rates in the order of tens of kHz—to ensure full coverage of the strip at production speed. This configuration makes them well suited to detecting variations in brightness, contrast, texture, and color, allowing reliable identification of stains, residual scale, scratches, and other visually distinct surface anomalies.

However, 2D systems fundamentally interpret the steel surface as a flat projection. All information is reduced to intensity variations in an image, meaning that the system captures how a defect appears, but not how it is shaped in three dimensions. This distinction becomes particularly relevant in pickling lines, where surface conditions—such as water films, reflections, and chemical residues—can significantly alter the visual appearance of defects without changing their physical geometry.

This limitation becomes critical when dealing with topographic defects. Industrial observations show that defects which are clearly critical from a mechanical perspective can appear ambiguous or even misleading in 2D images. For example, defects influenced by wet conditions may be incorrectly classified as "underpickled" or "wet" areas, while others may not be detected at all in the 2D channel despite having a pronounced geometric impact. In contrast, when the same areas are observed through a topographic representation, their depth profile becomes immediately evident, revealing their true severity.

Two defects may therefore appear very similar in a 2D image—sharing shape, size, and contrast—while having completely different depths. One may be a shallow surface irregularity with negligible impact, while the other may be a deep indentation capable of triggering defects in subsequent rolling processes. From the perspective of a 2D system, these cases are difficult to distinguish in a consistent and reliable way.

As a consequence, 2D inspection often struggles with ambiguous classification, where visually similar defects are assigned to the same category despite having different implications. It may also lead to systematic overestimation or underestimation of defect severity, depending on lighting conditions and surface state. This uncertainty translates into higher rates of false positives and false negatives, which directly affect production efficiency. In practice, this means either rejecting material that could be safely processed, or allowing critical defects to pass through undetected—both scenarios generating avoidable costs and operational risk in downstream processes.

Abrasion: formation, geometry and failure mode

Abrasion is best understood as a mechanically generated contact scar whose industrial relevance depends on profile complexity rather than on apparent size. In the Rasselstein 3D inspection results, abrasion appears not as a flat mark but as a structured defect with measurable relief. The project documentation describes examples in which profiling cuts reveal height differences on the order of 5 mm along the defect, despite a comparatively modest visual impression in the 2D image. That discrepancy is essential. Abrasions of this kind can act as initiators of hole or hole-sequence formation at the tandem line, particularly when local ridges and depressions create sharp stress gradients under rolling load. The practical implication is clear: an abrasion cannot be assessed by visibility alone. What matters is the measured shape of the

In practice, frictional contact can occur in a variety of ways: against the surface of a roller, against the edge of a guide, against another layer of the strip during coiling, or against particles trapped between the strip surface and a contact element. The common factor is relative motion between two surfaces under contact pressure sufficient to remove or displace surface material. The resulting feature is not a simple groove; it is a complex three-dimensional structure whose geometry reflects both the kinematics of the contact event and the mechanical properties of the strip material.

The geometry of an abrasion defect is characterised by its orientation, its length, its cross-sectional profile and the relationship between its central depression and the zones of displaced material on either side. In the most typical case, abrasion manifests as an elongated mark running approximately parallel to the rolling direction, with a length ranging from a few millimetres to several centimetres in severe cases. The cross-sectional profile is typically characterised by a central depression flanked, in some cases, by raised ridges of displaced material where the surface has been pushed outward rather than removed.

This combination of a central groove and peripheral ridges is particularly relevant to downstream processing. When the abraded strip passes through the rolls of a cold rolling mill, the raised ridges can act as stress concentrators, introducing localised pressure gradients that may exceed the yield strength of the material in that region. Even when displacement ridges are small in absolute terms—on the order of a few tens of micrometres—their presence can have measurable effects on thickness uniformity and, in more severe cases, can initiate surface cracks that propagate during subsequent rolling passes.

In a two-dimensional inspection image, an abrasion typically appears as a longitudinal mark with varying contrast. On a wet strip, where a water film modifies local reflectivity, the contrast of the abrasion can be reduced to the point where it becomes difficult to distinguish from background texture variations. Industrial observations confirm that this type of misclassification is common. Abrasions on wet strip surfaces are frequently logged as simple reflectivity variations rather than as the topographic defects they are—a misclassification that can have severe consequences at downstream stages. The three-dimensional profile, by contrast, presents the abrasion as a clearly defined negative feature whose severity can be quantified directly in terms of maximum depth, mean depth, cross-sectional area and peripheral ridge height.

Dent: formation, geometry and failure mode

Dent defects illustrate particularly well why sub-millimetre geometry can have mill-scale consequences. In the SurfConInspect material, a representative critical dent is described as an indentation of roughly 0.8 mm depth and 4–6 cm length, typically observed in the head section of the coil and only on the upper side, with a plausible origin in particles falling from the welding-machine area and being pressed into the strip. In visual terms, such a defect may appear minor. Mechanically, it is not. A compact depression with a sharp transition radius creates a local stress concentration that can evolve into holes during subsequent production. This makes dents a classic example of why 3D measurement changes the decision basis: once depth, extent and localisation are available numerically, the defect can be treated as a quantified failure precursor rather than as an ambiguous image event.

A dent is a localised depression typically produced by a hard particle being pressed into the material under compressive load. The particle may originate from scale fragments detached from the strip or from upstream equipment, metallic debris generated by wear of rolls or guides, or foreign matter introduced during handling. In each case, the fundamental mechanism is the same: the particle is caught between the strip and a contact surface—typically a roll—and the resulting compressive force displaces the strip material downward, creating a depression whose geometry reflects both the shape and size of the particle and the mechanical properties of the material at the moment of contact.

The physical reason for the severity of dents lies in the geometry of the depression itself. A dent is not simply a region where material has been removed: it is a region where surface continuity has been interrupted by a sharp geometric transition. The sides of the depression—the transition zone between the undisturbed surface and the deepest point of the feature—act as stress concentrators when the strip is subjected to tensile forces during rolling. At these locations, stress intensity is amplified relative to the surrounding material and if the amplification is sufficient, crack initiation can occur at the base of the feature. Once a crack has initiated at a dent, it may propagate during subsequent rolling passes, ultimately leading to strip rupture—the failure mode known in the industry as a coil break. The visual signature of a dent in a two-dimensional inspection image is often unremarkable. A small, compact feature with a mild contrast difference from the surrounding surface is what most two-dimensional systems detect and what most operators see on their monitoring screens. In some cases—particularly when the strip surface is wet or when the dent is shallow—the two-dimensional contrast may be insufficient for reliable detection or classification. Industrial data collected at pickling lines operating with concurrent 2D and 3D inspection shows that a substantial fraction of dents that subsequently caused coil breaks had not been reliably classified as critical by the two-dimensional system, precisely because their visual appearance did not differentiate them from non-critical surface events of similar shape and size. In three-dimensional data, by contrast, a dent is immediately recognisable as a localised minimum in the height map and its depth, lateral dimensions and boundary sharpness can all be measured directly—providing the numerical basis for a risk assessment grounded in the physical mechanisms of crack initiation.

Shell: formation, geometry and failure mode

Shell defects occupy a different category because they are often the visible consequence of upstream metallurgical history rather than of local line interaction. In the project evidence, shells are explicitly linked to primary material issues and are described as especially critical because their severity is not always expressed through a pronounced three-dimensional signature at pickling. Some shells or shell strips may become dramatically evident only after more than 90% thickness reduction at the tandem mill, where they emerge as break-outs or crack-like failures. This makes shell management strategically important. The pickling line cannot eliminate the root cause; it can only identify the precursor early enough to prevent avoidable downstream damage. For that reason, shell evaluation must combine geometric interpretation with process knowledge: shallow appearance is not an indicator of low risk, particularly when the defect reflects a partial separation or weak interface that becomes unstable under deformation.

The most common origin of shell defects is the presence of inclusions or segregations in the continuously cast slab. During solidification, non-metallic particles or localised compositional heterogeneities can become incorporated into the material at or near the surface of the slab. As the slab is subsequently rolled and thinned, these discontinuities are elongated and may evolve into shallow surface features that become detectable only after the overlying scale has been removed at the pickling stage. In this sense, a shell defect at the pickling line is the visible manifestation of an event that occurred several processing steps earlier in the production chain. This upstream origin makes prevention extremely difficult: by the time the defect is accessible for inspection, its fundamental cause is no longer addressable.

In two-dimensional inspection, shell defects present a wide range of visual appearances, from a subtle texture change barely distinguishable from the background to a more pronounced linear mark with moderate contrast. The challenge is that the visual appearance of a shell is not strongly correlated with its geometric severity. A shallow shell—one in which the surface separation is only a few micrometres deep—may be visually prominent if it has a rough, torn boundary. Conversely, a deeper shell with a smooth, gradual transition may be nearly invisible under standard brightfield illumination. This lack of correlation between visual prominence and geometric depth makes shell defects particularly difficult to classify reliably using imaging information alone.

In three-dimensional data, shell defects are characterised by their shallow depth profile and their relatively large lateral extent. Unlike dents, which are compact and deep, shells tend to be thin and wide—features that require high spatial resolution in the height measurement to be captured accurately, since the depth variation across the defect may be small even when the feature extends over a significant surface area. The risk associated with shell defects intensifies significantly during cold rolling, where the thickness reduction imposed on the strip can cause the partially separated layer to lift further from the bulk, creating a region of mechanical discontinuity that may propagate into a crack or, in more severe cases, a perforation. In practice, this means that the geometric characterisation of shell defects—even when their depth appears small relative to the strip thickness—provides valuable predictive information that cannot be obtained from visual inspection alone.

How geometry determines severity

The three defect types described in the preceding sections differ from one another in their origin, their shape and their typical dimensions, but they share a fundamental property: the relationship between their geometry and their risk to downstream processes is neither linear nor simple. This section addresses the physical principles that govern how geometric parameters translate into process risk and explains why quantitative measurement of defect geometry is indispensable for reliable quality assessment.

Depth is the indispensable starting point of any serious assessment of topographic defects, but it becomes meaningful only when interpreted together with the shape of the discontinuity it describes. A deeper defect generally perturbs the rolling stress field more strongly and is therefore more likely to initiate damage, yet industrial practice shows that maximum depth alone is not a sufficient predictor of severity. What matters just as much is the way the defect transitions into the surrounding material. A shallow, smooth depression and a sharp, steep-walled indentation of similar depth do not behave in the same way under load. This is why three-dimensional measurement changes the logic of classification: it allows defect evaluation to move from coarse visual labels toward physically interpretable descriptors such as depth, slope, base radius and boundary sharpness. It is not how visible the defect is that matters most, but how efficiently its geometry concentrates stress once the strip re-enters deformation.

From a mechanics perspective, the decisive issue is not the absolute amplitude of a defect, but the local stress concentration it creates. The ratio between depth and base radius captures this far better than depth alone because it reflects how abruptly the material profile is forced to change. A narrow, deep feature can generate a highly localised stress peak even when its footprint appears trivial in a 2D image. By contrast, a broader and smoother depression may distribute its effect over a wider area and remain process-tolerable. This is one of the most important conceptual shifts enabled by the SurfConInspect approach: three-dimensional data make it possible to work with risk indicators that are mechanically meaningful, rather than relying on image contrast or operator impression as a proxy for severity.

Lateral extent is the second half of the severity equation. Industrially, this explains a familiar paradox: defects that look small can still be dangerous. A narrow feature with sharp boundaries can create a crack-initiation condition that is disproportionately severe relative to its apparent size, while a wider feature of modest depth may be much less critical despite covering a larger visible area. This is particularly relevant in pickling-line environments, where optical appearance is already degraded by wet influences and reflectivity effects. Once geometry is measured directly, the defect can be understood for what it is mechanically, not for how it happens to look under a given illumination state. That distinction is central to any attempt at reliable in-coil intervention.

Position along the strip width is not a contextual extra; it is part of the defect itself from an operational standpoint. The Rasselstein evidence shows that around 90% of the documented coil-break-related defects were located close to the edge, which immediately turns edge distance into a first-order severity parameter rather than a descriptive afterthought. Edge zones are mechanically more sensitive during subsequent rolling, but they are also more challenging to inspect because the strip border is often rougher, locally folded, or more optically unstable than the central region. The implication for practitioners is clear: a defect tolerance criterion that ignores edge proximity is incomplete by design. The same nominal depth may be acceptable at the centre and unacceptable near the edge. That spatial asymmetry must be embedded directly into the inspection and decision logic.

The project evidence converges on a four-parameter view of criticality: depth, elevation or profile form, size and position relative to the strip edge. This is not a theoretical abstraction; it is the same combination Rasselstein identified when tracing downstream breaks back to topographic precursors. In a production setting, this means that severity cannot be reduced to a single threshold value. It must be expressed as a rule set or quality model that weighs geometry and location together. That requirement also appears in the SurfConInspect software logic, where measured defect data are converted into quality indices and then into quality events and actions. The real technical achievement is not merely detecting a defect in three dimensions, but transforming multi-parameter geometry into a decision that is fast enough and robust enough to be used live on the line.

Downstream Consequences: Cold Rolling, Coating and Coil Breaks

Downstream failure is where the importance of topographic inspection becomes economically undeniable. A coil break is not a marginal quality incident but a disruption event in a tightly coupled production chain. Once rupture occurs, the line must stop, the broken strip must be removed from the roll gap, the condition of the rolls and surrounding equipment must be assessed and only then can production restart. In modern flat steel operations, that sequence translates into lost availability, scrap, maintenance effort and heightened intervention risk for personnel. This is why the SurfConInspect logic consistently treats pickling-line inspection as an upstream control lever rather than as a passive monitoring function. The earlier the geometry is measured and interpreted correctly, the lower the probability that a mechanically unstable defect will escalate into a downstream production crisis.

A coil break is not simply a defect escaping inspection; it is an expensive interruption of an otherwise continuous process. Once rupture occurs at a tandem mill or another downstream line, the event typically triggers a full stop, manual removal of broken strip sections, inspection of the roll gap, possible roll or equipment checks and only then restart. The direct cost is measured not only in scrap, but in hours of lost line availability, maintenance burden and elevated safety exposure during intervention. That is why the project does not frame 3D inspection as a marginal quality enhancement. It treats it as a preventive control capability aimed at reducing avoidable downstream crises. In the SurfConInspect exploitation logic, this translates into a targeted 20% reduction of coil breaks through automated cutting control for heavy defects and into broader gains in yield, waste reduction and process reliability. The economic case for topographic defect management is therefore straightforward: better geometry upstream means fewer emergencies downstream.

The failure pathway is conceptually clear even if the exact threshold varies by defect class and product condition. At pickling, the defect exists as a local geometric discontinuity. At downstream rolling, that discontinuity is exposed to intense deformation, tensile stress and local pressure gradients. If the defect is sufficiently deep, sharp, or poorly positioned, the local amplification of stress may initiate a crack, destabilise a partially separated surface layer, or promote perforation. There is a traceable mechanics-based chain from measured topography to downstream risk—supported by the project evidence on abrasions, dents and shells, each through a different mode of instability.

For coating processes—electrolytic galvanising, hot-dip coating, or tinning—the primary risk associated with topographic defects is somewhat different. In these processes, the concern is not strip rupture but coating adhesion and uniformity. A dent or abrasion in the substrate surface can disrupt the deposition of the coating layer, creating a region where the coating is thinner, less adherent, or visually non-uniform. In applications where the coating serves both a functional and an aesthetic purpose, as in automotive-grade galvanised steel, even a small area of non-uniform coating can constitute grounds for a customer claim. The economic impact of such claims—including rework, transport and commercial penalties—typically exceeds the cost of the material itself.

Strip edge proximity as a criticality multiplier

Industrial analysis of coil break events at tandem cold rolling mills and continuous annealing lines consistently reveals a spatial pattern whose implications for inspection strategy are direct and significant: the overwhelming majority of defects responsible for strip ruptures are located close to the strip edges, typically within the outermost 100 to 200 millimetres of the strip width. Data collected across multiple production lines and over extended observation periods show that approximately 90% of coil break events can be traced to topographic defects in this near-edge zone, even though these zones represent a relatively small fraction of the total inspected strip area.

This concentration is not coincidental. It reflects the specific mechanical conditions to which the strip edges are subjected during rolling. In a rolling mill, the strip tension—the longitudinal tensile force applied upstream and downstream of the roll gap to control the strip path and dimensions—is not uniform across the width. Near the edges, where the material is less constrained by the surrounding strip body and where the cross-sectional area is smaller, the tensile stress level is generally higher than in the central region. This elevated edge tension means that any stress concentration introduced by a topographic defect is superimposed on a background stress level that is already more demanding than at the strip centre.

The consequence of this edge effect is that a defect of a given depth and profile sharpness presents a greater risk when it is located near the edge than when it is located in the central region. A dent with a depth of 0.5 mm in the central region of the strip might remain within acceptable limits—the local stress concentration, added to the moderate background stress at that location, might stay below the threshold for crack initiation. The same dent located 50 mm from the strip edge might be critical: the identical stress concentration, superimposed on the higher edge stress level, might exceed the threshold and initiate a crack that propagates during subsequent rolling passes. The defect itself has not changed; only its position has changed—and with it, the entire risk assessment.

For inspection systems, this edge-dependency of criticality creates a clear design priority: near-edge regions must be inspected with sensitivity at least equal to that applied to the rest of the strip and the intervention criteria applied to near-edge defects must reflect their systematically higher risk. In practice, this means that the geometric thresholds used to trigger quality events—automated cutting decisions, operator alerts, or reduced-speed signals—should be lower for near-edge defects than for equivalent defects at the strip centre. This spatial differentiation of risk can only be implemented systematically if the inspection system provides both reliable geometric information and precise positional information relative to the strip edge.

The spatial distribution of defects also has implications for the configuration of the detection system itself. Near-edge zones are often the most challenging for optical inspection systems, because the strip edges may be slightly folded, rough, or geometrically irregular due to the rolling process, creating a local background that is noisier and more variable than the central strip surface. Inspection systems designed to operate reliably in these zones—with sensor configurations providing full-width coverage including edge regions and with algorithms capable of separating genuine topographic defects from edge geometry artefacts—are therefore essential for addressing the dominant failure mode documented by industrial data.

From defect knowledge to inspection strategy

The picture of topographic defects developed in the preceding sections—their formation mechanisms, characteristic geometries, downstream failure modes and spatial distribution on the strip—points toward a concrete set of requirements for the inspection system responsible for detecting, characterising and classifying them. This section draws the connection between the defect knowledge developed in this guide and the practical design of an effective inspection strategy at the pickling line.

Once the discussion moves from defect description to inspection strategy, the first requirement is unavoidable: the system must measure depth directly. In pickling-line conditions, two-dimensional imaging simply does not provide a stable path to severity assessment for topographic defects. The project documentation makes this point repeatedly and from different angles. Critical defects may be misread as wet influence, underpickling, or not detected at all in 2D, whereas they become interpretable once their depth profile is available. This is not an incremental improvement in image quality; it is a change in the information basis of quality control. Depth measurement is what allows the defect to be assessed in the language of mechanics rather than optics. The ability to measure depth quantitatively, with sufficient precision to resolve the sub-millimetre variations that are mechanically decisive, is therefore not an enhancement to a two-dimensional inspection system—it is a qualitatively different capability that addresses a class of quality problems that two-dimensional imaging cannot solve.

A useful 3D system must not only measure height; it must do so with enough spatial fidelity to resolve the defect families that matter in production. Dents require accurate capture of compact sub-millimetre depressions. Abrasions require longitudinal continuity and profile variation over much larger distances. Shells require sensitivity to shallow but extended separations whose danger lies as much in their boundary behaviour as in their nominal depth. In the Rasselstein setup, this requirement is addressed through a laser-triangulation architecture with three cameras and line lasers per side, configured for full-width operation up to 1,500 mm in full production speed. These are not abstract instrumentation specifications; they reflect the scale and speed required by actual pickling-line operation.

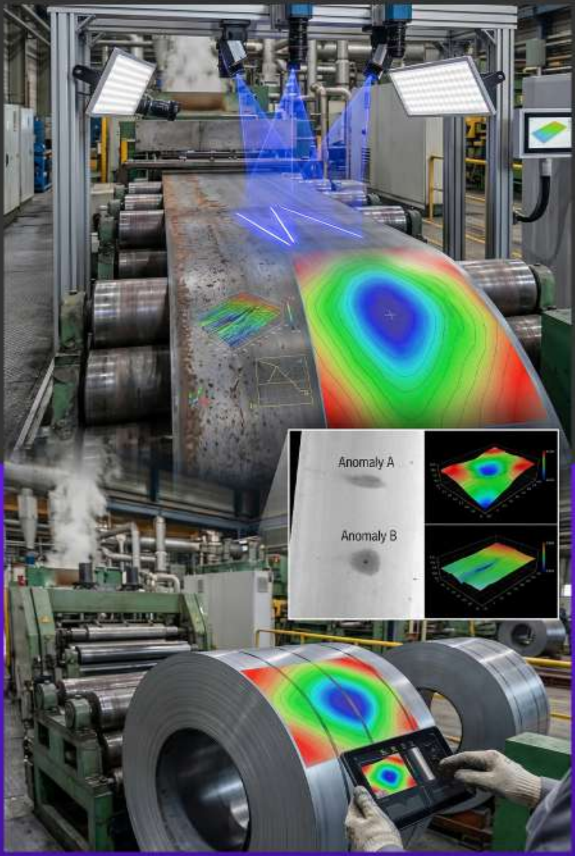
Pickling is not a benign optical environment. Water films, chemical residues, line vibration and long-term degradation of optical components all interfere with stable inspection. That is precisely why the transition from rule-based classification to more advanced trained approaches became necessary in the project: not because geometry was unhelpful, but because even 3D systems must cope with water contamination, weld artefacts, hole events and degraded laser information over time. The real advance of the project is not that it eliminates complexity, but that it creates a path to manage it: robust sensing, trained classification and post-classification logic that preserves sensitivity to critical defects while reducing false reassurance.

No inspection technology creates value by itself. Value emerges only when measurement is translated into timely action. In SurfConInspect, that translation is formalised through the SCI framework: Quality Processors turn clustered raw data into quality indices, the Online Quality Supervisor converts deteriorating quality signals into quality events and recommended actions and the entire cycle is designed to operate continuously in real time. The requirement that the control result be available within 10 seconds is especially important because it establishes the practical horizon of usability. For topographic defects, the true maturity of the system lies not only in sensing precision but in decision latency, workflow integration and operator-facing clarity. If a geometric assessment is technically correct but arrives too late, it has already failed industrially.

The most important strategic message of this guide is that sensing and judgement cannot be separated. A 3D system may provide highly accurate height data, but if the downstream decision model treats all defects as if depth were the only variable or ignores the stronger risk profile of edge-located events, the inspection chain remains incomplete. This is where the project's architecture is especially relevant: it is designed around the idea that data, quality modelling and control action belong to the same operational loop. For a producer, that loop is what turns measurement into fewer breaks, less scrap and more consistent quality decisions. For a reader of this white paper, it is the point at which defect knowledge becomes process strategy.

Conclusions

Abrasion, dent and shell are not simply representative examples of surface defects; together, they illustrate the broader industrial lesson of topographic defect management. Each class carries its own origin story and its own downstream failure logic, yet all three demonstrate the same underlying principle: mechanical relevance is encoded in geometry, not in appearance. Once that principle is accepted, several consequences follow. Inspection must prioritise direct height information. Classification must evolve beyond fixed descriptive labels. Quality supervision must account for edge-sensitive risk. And interventions must be generated quickly enough to matter in-coil rather than after the fact. This is the deeper contribution of the SurfConInspect work: not just a new sensor channel, but a more rigorous way of thinking about what makes a surface defect dangerous in flat steel production.



For steel producers, the practical conclusion is now difficult to avoid. If the objective is to reduce preventable downstream failures without inflating scrap through overreaction, then topographic defects must be measured quantitatively and interpreted within a real-time quality-control architecture. The technology is no longer speculative. At Rasselstein, the 3D installation has already been commissioned for full-width inspection, the defect population has been analysed against actual downstream events and the decision logic required for automated support has been formalised in the project requirements. What remains is not proof of relevance, but the disciplined industrialisation of that knowledge into thresholds, models and workflows that are robust enough for daily production.

The function of this white paper, then, is not merely descriptive. It provides the conceptual substrate for better inspection design, more informed operator decisions and more credible quality automation. By linking morphology to mechanics and mechanics to intervention, the guide helps close the gap between defect image, process consequence and operational response. That is the right register for a professional audience: not a catalogue of anomalies, but a framework for understanding how geometry, sensing and action must align if zero-defect ambitions are to become technically plausible on real production lines.

The project evidence converges on a clear strategic direction: quantitative topographic inspection, integrated with edge-aware decision logic and real-time quality supervision, represents the most defensible path toward reducing preventable downstream failures in flat steel production. The three defect families examined here—abrasion, dent and shell—are the practical starting point for that journey. They are also its most compelling argument. Each one, in its own way, demonstrates that the geometry of a defect is not an academic abstraction but an operational fact with direct consequences for yield, cost and safety. The inspection systems and decision frameworks described in this guide exist to make those facts actionable before the damage occurs.

FURTHER READING

- SurfConInspect Project Website
- Introductory resources on 3D surface inspection
- Related white papers in the SurfConInspect series

The Consortium

SurfConInspect unites a diverse group of partners:

- **Steel producers:** thyssenkrupp Rasselstein (RAS), Salzgitter Flachstahl (SZFG)
- **Research & Academia:** VDEh-Betriebsforschungsinstitut (BFI), Scuola Superiore Sant'Anna (SSSA), CETIC
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Together, we are shaping the future of **sustainable steel production**.

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