HD SCAN – ULTRASOUND SCANS SLAB QUALITY *

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Abstract
Producers of cast products are in duty to their customers to document the inner quality of the product. The ultrasound measuring is a widely known and well-established technique for non-destructive analysis of the inside of a material used in medicine and many other fields. In the steel industry, ultrasound testing is already used to evaluate the internal quality of as-rolled material.
The ultrasound measurement technique of HD scan for the evaluation of internal quality defects in the cast product sample is environmental friendly and needs a less surface processing in comparison to the etching procedure. The clean and safe technology offers three-dimensional views into the sample, providing higher representative information for a better quality evaluation.
The quality evaluation is done automatically and based on clear statistical rules.
The ultrasound quality evaluation system offers reliable and objective quality results fully independent of etching parameters and subjective quality operator impressions. The hitherto existing etching method may be completely replaced or the number of etching tests will significantly be reduced.
Keywords: Ultrasound measuring; cast products; inner quality.

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1 INTRODUCTION

For over 40 years now the internal quality of cast products in steel plants has been evaluated using a variety of macro-etching techniques.
Quality assurance is a key issue in every production plant today. In casting plants macro-etching is used to verify the internal quality of a cast product. Macro-etching includes three steps: sample preparation, etching, and evaluation of the result. Sample preparation is the most time-consuming part of the process. Samples (lateral or longitudinal) are cut from a slab, scarfed and ground in order to achieve a high surface quality. The sample is then etched with an acid solution that is chosen on the basis of the steel grade and plant operating practice. The etching procedures are very elaborate, and some of them required the use of hot acids that are hazardous to health. The disposal of hazardous substances (acids) is also rather cost-intensive.

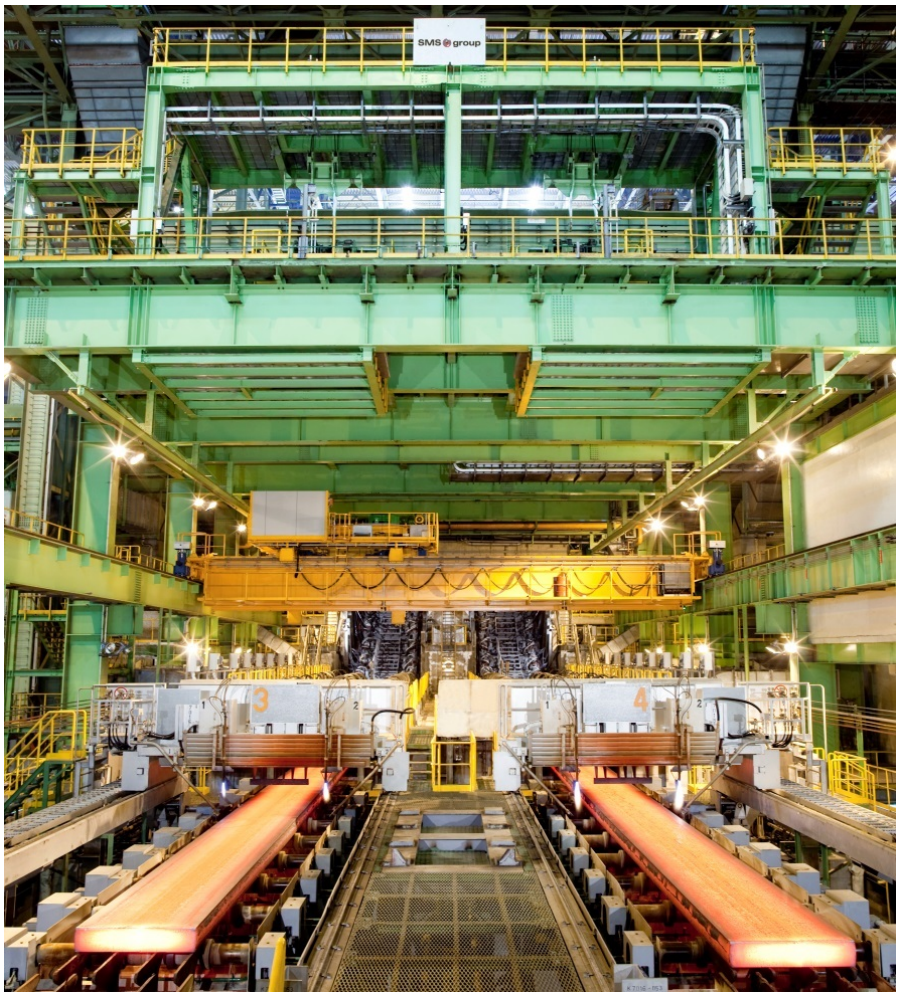

Figure 1. With HD scan the quality of the slabs is checked quickly and easily.

Therefore not every steel plant has an etching facility, and some plants have the etching process conducted in an external laboratory, in spite of the associated losses in terms of time and know-how. The choice of etching technique is made on the basis of in-house plant regulations or customer requirements. The most well-known technique is etching using hydrochloric (HCl) acid with a temperature of 70 °C, where the carbon segregation, in particular, is highlighted. However, this technique poses health-related risks due to the formation of hydrochloric acid fumes. Some

laboratories etch with an ammonium persulfate solution (NH4S2O8 + H2O) at room temperature to identify the phosphorus segregation instead. [1-2]
The quickest and most popular method is sulfur printing (Baumann) with H2SO4, which emphasizes the sulfur segregation [3]. Sulfur printing requires a high sulfur content in the steel (over 50 to 100 ppm) and the use of photographic paper, production of which has virtually ceased worldwide. All etching procedures require well-defined reproducible sample preparation and etching, as the result is influenced by etching conditions such as acid concentration, temperature, time, etc.
Therefore, obtaining an objective quality evaluation with macro-etching techniques is a huge challenge given the afore-mentioned difficulties.

After the etching process, segregations that are sensitive to the etching acid together with internal defects become visible on the polished sample surface. A picture of the etched sample is taken with a camera and a scale bar is used for subsequent sizing of the defects. During the evaluation procedure a picture of the etched sample is analyzed by an expert, who assesses the quality of the sample and thus of the whole cast. The segregation assessment is typically done by comparing it with a few “standard” pictures and is usually divided into five quality classes. The evaluation of profiles and cracks is more complex and involves the actual measurement of geometrical deviations and therefore the crack length, distance from the edge, etc. Consequently, macro-etching is a very laborious procedure and its evaluation is both subjective and time-consuming.

2 NEW FINDINGS WITH ULTRASOUND

In order to overcome the difficulties posed by macro-etching, SMS group developed a basic new approach to the internal quality evaluation of cast metals. A wide variety of customer samples from all over the world has been tested using HD scan. These included longitudinal and transversal samples of slabs, billets, beam blanks, cast strip, as well as different rolled materials of numerous steel grades and other metals. The tasks ranged from a mere comparison of the HD scan and macro-etching results to problems that could not be solved using traditional approaches. It was shown that HD scan produced reliable results in terms of quality assurance and the optimization of the casting process and development of new products.

HD scan is based on an ultrasound examination of slab samples. It features hardware with control and evaluation software. The hardware is an immersion tank in which the samples are placed, including the scanner system, ultrasound sensors, and the electronic unit. Significantly less effort and time are required for the sample preparation, as with macro-etching a “rough ground” or “as scarfed” sample surface quality is sufficient for HD scan analysis.
Scanning of the sample is done by the control software. Scanning parameter optimization was a key component of HD scan development and is a prerequisite for accurate automatic evaluation.

2.1 The software manages the complete analysis

HD scan evaluation software combines the in-house expertise of the SMS group cast material specialist and the experience gained in the final period of product development. It starts with the A (raw signal), B (sample narrow side in scanning

direction), C (“bird’s eye”) and D (sample narrow side across scanning direction) views that are typical for ultrasound evaluation, with an added three-dimensional view of the sample and its flaws. All of these views can be represented at once or layer by layer with the correct geometrical proportions or stretched, in different color-scales, thereby giving the operator a comprehensive tool for investigating sample defects. There are also some special evaluation tools that were specifically developed for cast product analysis. These tools include automatic evaluation based on implemented statistical rules, as well as manual correction options in cases where sample-specific evaluation/information needs to be applied.

One of the advantages of HD scan is the multiple layer evaluation. Whereas with macro-etching a randomly chosen sample layer is viewed as being a representative evaluation of the entire cast product quality, with HD scan a sample volume is analyzed, and not just one layer. This sample volume can be divided into over two hundred individual layers, and this can be used as a more representative quality evaluation. Normally a sum of several layers, for example within a thickness area of 1 mm, is examined in order to ensure reliable product quality assessment results.
The special HD scan tools created for cast product evaluation are described in detail below and relate to the relevant internal quality parameters of cast products.

2.2 Evaluation tool: Segregation analysis

Segregation analysis is a key component in the internal quality control of cast products. While micro-segregation is a normal process that does not cause any loss of quality, the formation of macro-segregations which are intensified by casting parameters should be kept within set limits. Evaluation and quantification is the central issue of HD scan.
Various testing methods can be used to detect and classify macro-segregation distribution in steel [4]. Different evaluation techniques are therefore used accordingly. By analyzing the chemical composition of segregations, parameters such as concentration increase and location are used to derive quantities for the objective characterization of macro-segregation. However, methods used to measure the chemical composition are typically time-consuming and are often limited by sample size. Therefore in cases where particular importance is attached to the chemical composition of segregations, it is recommended that such methods are used in addition to a “large-scale” technique: macro-etching or ultrasound evaluation [4].

As mentioned before, macro-etching was the technique chosen for routine analysis in most steel plants, therefore subjective evaluations are applied. Slab samples are typically given a segregation class that corresponds to a visual assessment of the size and distribution of segregations at the etched sample surface. With macro-etching the evaluation is performed subjectively by an expert, who typically compares the sample picture with five standard pictures of 1-5 segregation classes. For some applications and customers, however, this rough division into five classes is insufficient, not to mention the differences in expert opinion that arise from time to time as a result of the subjective evaluation. Consequently, several automation-based approaches evaluating the internal quality have already been applied for macro-etching pictures. The main obstacles here are picture quality (resolution, shades, sharpness, etc.) and automatic gage (scale bar) determination.

Using HD scan the segregation analysis is performed fully automatically. The system detects internal flaws with a diameter of 0.5 mm and a spacing greater than or equal to 0.5 mm. The choice of ultrasound head and frequency has been optimized for the automatic classification of centerline segregation. Other ultrasound heads and frequencies may be used to identify other internal flaws (e.g. fine cracks). The segregations and flaws provide higher ultrasound signal amplitudes due to the reflection of ultrasound waves on internal material boundaries (substances with varying acoustic impedance). HD scan software detects the position of flaws with ultrasound values that are higher compared to material without flaws. The flaws are then automatically highlighted and sized (Figure 2). The higher density of the flaws in the middle section of the sample is used to determine the metallurgical middle of the product cross section. It is common knowledge that the metallurgical middle ("segregation line") does not necessarily correspond to the geometrical middle of the product/sample. Flaws located at a defined distance in relation to both sides of the metallurgical middle ("segregation zone") are used for segregation class evaluation.

Two concepts based on various parameters that describe the segregation size and its distribution are provided. The first involves grading a sample in one of five segregation classes, due to the size and number of segregations presented. This procedure is similar to the expert assessment using the macro-etching method, however it is objective as the evaluation is automatic. The grading, therefore, is performed with clear rules, i.e., there is no machine learning function. With the second concept the segregation parameters are correlated with a segregation class in an equation using rational numbers. This evaluation method was developed at SMS group based on the results of various samples analyzed and is recommended for a more accurate and clear comparison of internal product qualities. Both evaluation concepts use a verified system of classification [5-6], which runs automatically with standard values implemented in the software.

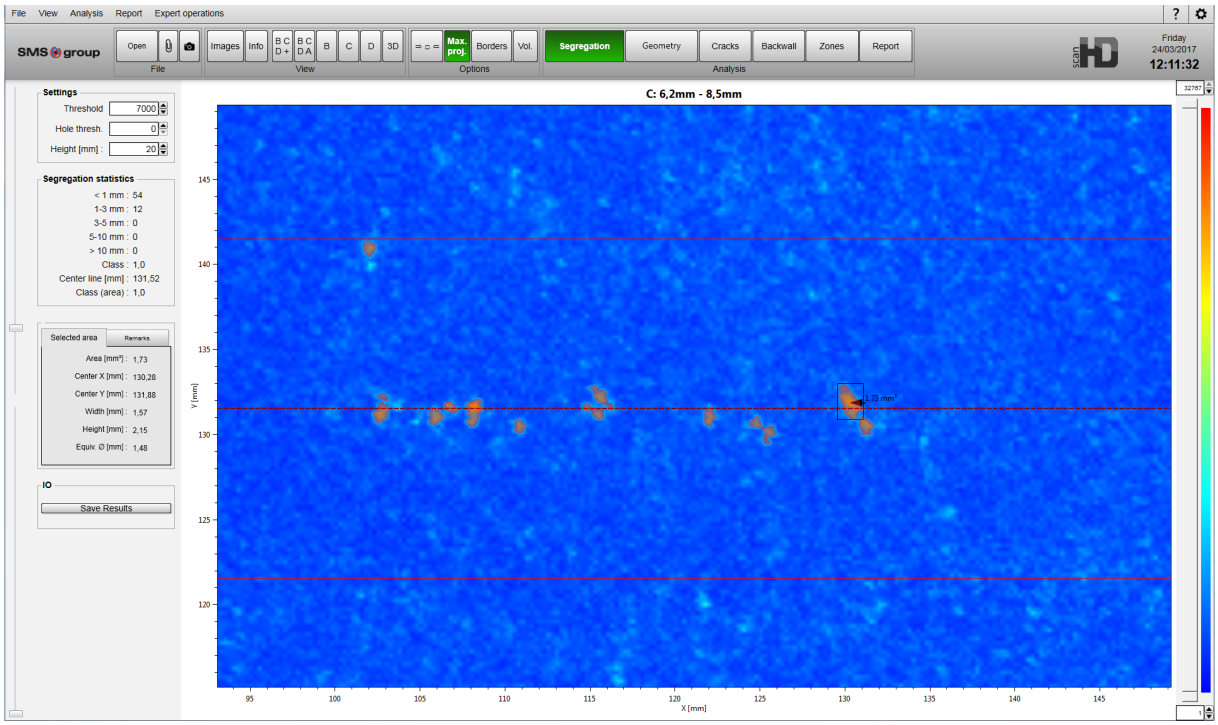

Figure 2. Example of the segregation analysis in HD scan Software

2.3 Evaluation tool: Crack analysis

In the event of cracks appearing in cast products, it is important to clarify their size and position, in order to help identify their cause and any consequences they may have on further material processing, as well as any countermeasures that need to be taken to prevent them in future. A quality expert normally evaluates a macro-etching photo manually using a ruler, and records the results in a report. This procedure can take hours.

With HD scan crack analysis is accomplished in less than a minute (Figure 3). The crack length and position (distance to cast edges) are evaluated automatically. Furthermore, cracks can be divided into several types: midway, subsurface, transversal, triple-point, etc.

Similar to the segregation analysis, this feature is based on increased ultrasound signal amplitudes. However, in the case of cracks the accurate identification of crack profiles is hindered by the thin crack "body" and narrow edging at both ends. Frequently, singular points of increased ultrasound intensity do not form a continuous line showing the crack, rather there are interruptions and steps. The same crack structure can be seen on a real polished sample surface. Nevertheless, in practical applications the crack length is estimated, regardless of such discontinuities. HD scan software, therefore, also estimates crack parameters based on the total individual indications corresponding to one crack.

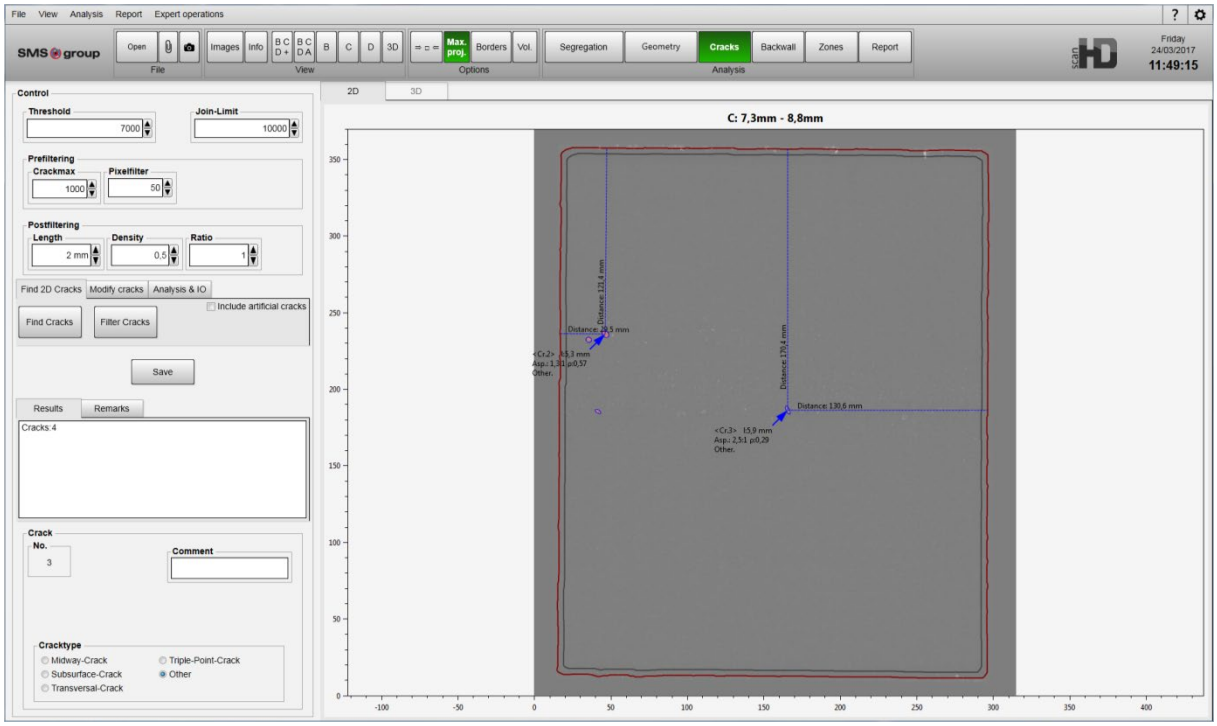

Figure 3. Example of the crack analysis in HD scan Software

2.4 Evaluation tool: Geometry analysis

The geometry of a cast product is not an internal quality parameter; its parallel evaluation is often provided by macro-etching samples. Measurements are mostly performed with a ruler on the sample itself, or the profile of the sample is transferred to a scale paper. Deviations from the target geometry are manually evaluated and

reported. With HD scan software the profile of an analyzed sample is automatically identified. Various geometrical parameters, including bulging, eccentricity, trapezoid form, etc. and others are determined subsequently. The geometry analysis rules were developed at SMS group on the basis of customer requirements. With billet products, for example, one of the key geometrical parameters is the diagonal ratio, which is also presented within HD scan software.
The estimated sample profile is also used to eliminate edge distortion with ultrasound measurements, caused by careless sample treatment (burrs, premorse edges, etc.), which could lead to evaluation mistakes.
The results of the geometry analysis are used to assess the casting process quality and optimize the casting parameters like e.g. the taper settings after recognition of an excessive narrow side bulge.

2.5 Add-on features

In addition to the features mentioned above, the following add-on options are implemented in HD scan software:
Macrostructure evaluation – this offers an analysis of the macrostructure and therefore the effects of casting parameters such as soft reduction, electro-magnetic stirring, etc.
The database is designed for supplementary data, including process parameters, material composition, and external pictures (i.e. macro-etching photos). Therefore HD scan not only ensures direct digitization of the measurement data, but also links it to the process data, providing quick and reliable process optimization. So that it meets the requirements for the digitization of the plants.
A special tool created in HD scan software enables the loading of macro-etching pictures and their scaling and evaluation using the same evaluation rules as those for ultrasound data (Figure 4). As a result, an objective evaluation of macro-etching data and their comparison with ultrasound results can also be carried out.

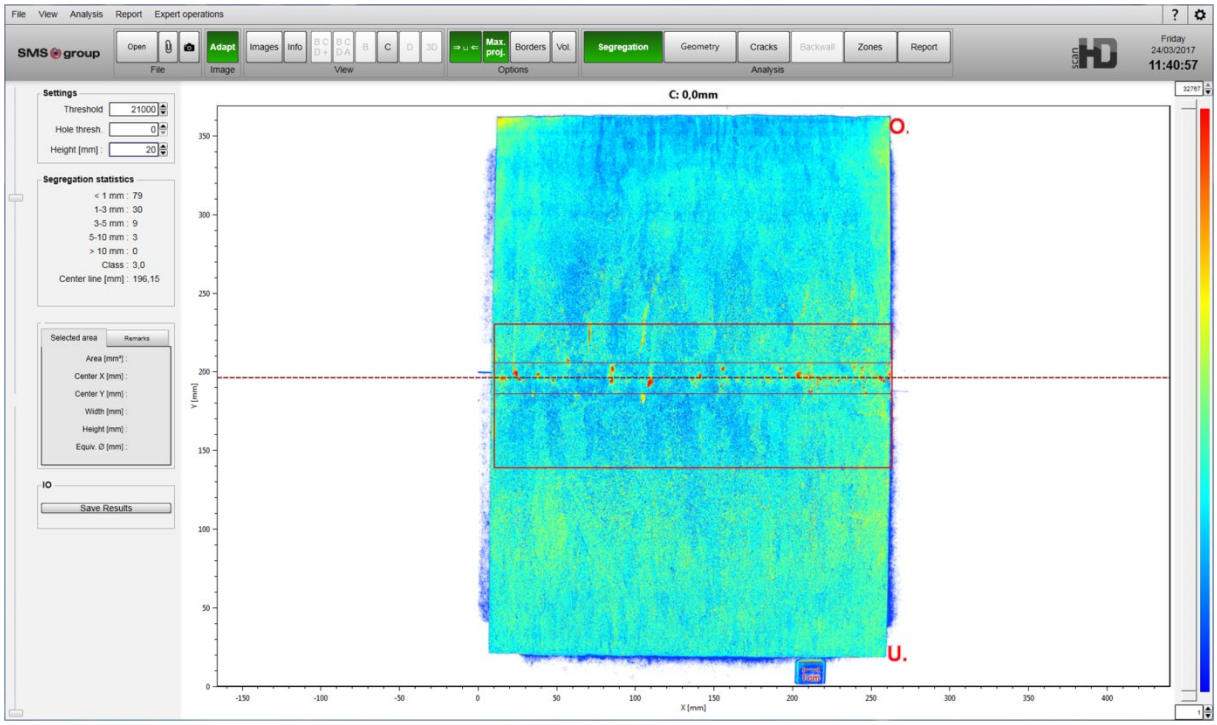

Figure 4. Automatic evaluation of macro etching photos with HD scan software

The automatic report creation function allows all the evaluation results to be documented in line with the customer's needs.

2.6 Classification and benchmark

The method of subjectively classifying samples using a picture catalogue cannot be used to compare the quality of products across all manufacturers. With its evaluation software HD scan offers far better comparability of products. As a result, manufacturers of premium products will be able to strengthen and expand their market position.
A clear system of classification is also important for downstream process stages. HD scan offers an independent, automated and objective quality evaluation and is therefore ideal for providing clear proof of performance.
There is a wide variety of test methods for evaluating the internal quality of cast products. The article "Quantitative Methods for Evaluation of Centerline Segregation", published in 2016 by the AIST [4], compared these different methods. It looked at nine criteria, which were each given a rating of one (poor) to three (good). Classical ultrasound methods are also included in this comparison. However, if HD scan, which is specially optimized for segregation classification in cast samples, is added and evaluated across all the criteria mentioned, then it is the test method of choice for the classification of centerline segregation without chemical composition being essential criterion.

Figure 5. Easy to use

HD scan is also easy to use (Figure 5). The operator loads the samples - with no prior knowledge of the test method - into the immersion tank. Once the loading process has been confirmed, the test procedure is performed fully automatically
The section of the sample to be analyzed can be chosen at random. With other test methods the term section always implies a two-dimensional surface. With HD scan, however, section implies volume information on the sample. HD scan gathers measurement data over a depth of 6 mm. To achieve the same result using the

macro-etching technique, for example, the sample would need to be ground and etched 200 times.
Increasing quality demands call for reproducible and objective product evaluation. This can be achieved using HD scan which is specially designed for automatic product classification.
The volume of data required is large due to high information density. The compression algorithms developed specifically for this purpose reduce the amount of data to a minimum. The time used to apply the compression can be parametrized. This means the raw data can be evaluated and stored one year after the scan and then the results are only shown. This ensures long-term archiving with a low volume of data. Given the system's functions and the results it produces, its purchase price is relatively low.

3 CONCLUSION

Who is able to recognize nowadays whether a photo has been retouched? Does it show the truth? Can eyes that cannot see flaws in a slab be trusted? How does one differentiate between a subjective and objective evaluation? With HD scan these questions are no longer relevant, as the analysis of the samples produces an objective quality evaluation. Alongside the positive effects - HD scan poses no health-related risks whatsoever - and the fact that it is easy and safe to operate; this is undoubtedly the most convincing argument for using it.

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