Rockwell adhesion test - Approach to standard modernization

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Abstract

Automatization of industry processes and analyses has been successfully applied in many different areas using varying methods. The basis for these industrial analyses is defined by global or country specific standards and often development of automated solutions works towards streamlining processes currently done heuristically. Lately, image classification, as one of the automatization development areas, has turned to machine learning in search for solutions. Though approaches that involve neural networks often result in high accuracy predictions, their complexity makes feature hard to understand and ultimately reproduce. To this end, we introduce a pipeline for the design, implementation and evaluation of a hand-crafted feature set used for the parameterization of two thin film coating adhesion classification standards. The method mimics the current expert classification process, and is developed in collaboration with domain experts. Implementation of an automated classification process was used for verification and integration testing.

1. Introduction

Coating adhesion is one of the most important parameters for evaluating the quality and functional reliability of thin-films for tribological purposes. The Rockwell indentation test, standardized in DIN 4856 [DIN18] and ISO 26443 [ISO08], is an established test method in industry and research for determining coating adhesion. A hardness indentation according to Rockwell C is performed on the coated component. Currently, any damage to the coating around the indentation imprint (further referred to as imprint) is qualitatively assessed by an expert and classified into adhesion classes according to the visual impression. For this purpose, comparative images are used, which schematically show typical crack and delamination patterns in various forms (Figure 1). In this work we present a method, which aims to support domain experts in the classification process and enable finer class resolution. For the purpose of successful development, transfer of knowledge and integration into the industrial environment, a set of requirements was identified and used as development guidelines further on.

2. Requirements

Given that the DIN and ISO classification is currently done manually, a need for enhancement has been recognised. A set of features that shift classification from a trained subjective opinion to a streamlined quantitative analysis must be developed. The analysis should serve as a guideline for the development of future adhesion classification standards. To be acceptable to industry experts, assuming that image segmentation of both cracks and delamination is available, the analysis must satisfy the following requirements:

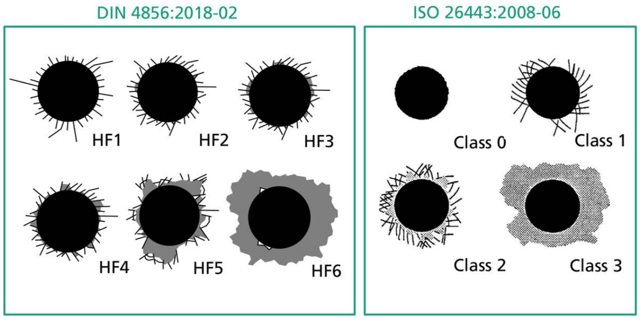


Figure 1: *DIN 4856: 2018-02 and ISO 26442: 2008-06 coating adhesion classification guidelines*

- Be intuitive
- Be quantitative
- Increase class resolution
- Be robust
- Be reproducible

3. Method

Guided by the requirements provided in Section 2, a workflow was developed for adhesion classification in a higher resolution based on intuitive, understandable and quantifiable features. The workflow is consisted of 1) separate delamination and cracking segmentation, 2) development and computation of delamination and cracking features and 3) training a DIN and ISO adhesion class regressor based on the data-set's per class feature value distribution. For a new sample, the first and second step are computed and an ad-

DOI: 10.2312/eurp.20201121

hesion class predicted based on the feature values. It is important to note that, though two segmentation methods are implemented in the workflow, feature values are not dependant on the segmentation method. The result of the workflow can be seen in Figure 3.

Delamination segmentation and feature calculation was performed using image processing software ToolIP [Fra19]. The crack U-Net semantic segmentation model and random forest regression was developed and trained using Keras Machine Learning API [C*15] for python 3.5, together with a TensorFlow backend [AAB*15] and Scikit-learn [PVG*11] respectively.

3.1. Feature Design

Discussing the classification thought process with adhesion classification experts gave guidelines on which specific properties are used to evaluate borderline conditions between classes. Sample characteristics such as the 1) general level of delamination, 2) distance of delamination from the central imprint, 3) distribution of delamination around the imprint and 4) presence of coating cracks are typically observed by experts and used to determine sample class.

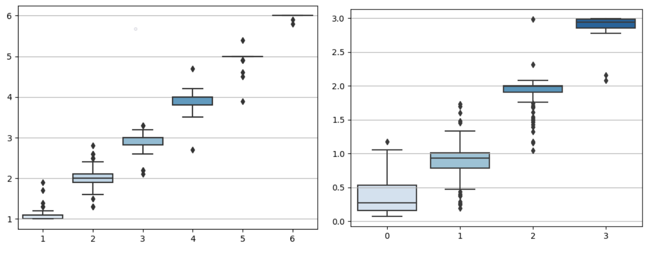
This insight was integrated into feature design and resulted with either a single feature describing a specific property or a group of features describing certain aspects of the same property. To this end, features are grouped to describe the extent, morphological characteristics and specific patterns of delamination and cracking. This resulted in the development of 6 delamination features and 3 cracking features.

4. Results and Discussion

As can be seen from Table 1, the method provides promising results. The obtained accuracy for DIN standard was 88.216% and 88.321% for ISO standard. More importantly, since ground truth is being compared to regression results, MSE metric is better suited for comparison. DIN regression results had MSE value of 0.167 and ISO had 0.161. The regressed class values indicate close correspondence with the ground truth for both DIN and ISO classified samples, with low MSE values. Deviations in DIN classes 1 and 4 visible in Figure 2a, can be explained by the characteristics of the classification guidelines (Figure 1). If observed carefully, one can notice that the difference between classes 1 and 2, and, 3 and 4 is much smaller than between the other classes. Therefore, determining class feature value intervals is made more difficult. The results behave accordingly. The deviation of the ISO class 0 (Figure 2b) is caused because the presented method is designed to identify delamination and cracking, and class 0 requires the complete absence of both. The results presented here are part of an ongoing project and are expected to change with the planned refinement of features and the addition of a delamination segmentation neural network due to high variation in sample texture.

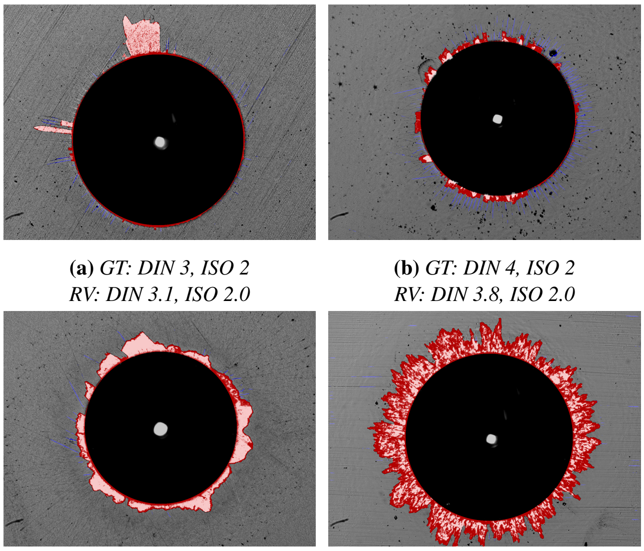
Measure	DIN	ISO
Accuracy	88.216	88.321
MAE	0.207	0.203
MPE	-5.569	-5.184
MSE	0.167	0.161
RMSE	0.408	0.401

Table 1: *Evaluation measures*



(a) *DIN* **(b)** *ISO*

Figure 2: *DIN and ISO expert classification (x-axis) compared to regression results (y-axis).*



(a) *GT: DIN 3, ISO 2 RV: DIN 3.1, ISO 2.0*
(b) *GT: DIN 4, ISO 2 RV: DIN 3.8, ISO 2.0*
(c) *GT: DIN 5, ISO 3 RV: DIN 5.0, ISO 3.0*
(d) *GT: DIN 6, ISO 3 RV: DIN 5.8, ISO 3.0*

Figure 3: *Segmentation and DIN and ISO classification results, with ground truth (GT) values displayed alongside regressed value (RV).*

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