SIMPLE SCRATCH METHOD FOR INDUSTRY AND FOR TEACHING

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Abstract:

It's requested for many products to make a good aesthetic impression. This feeling cannot be permanent of course, but manufacturer takes care of a scratch-resistance coating, as surface appearance is one big part of this impression. The paper discusses new method for the scratch test, as an answer to the industry need for the technique that is quick, reliable and economically acceptable. Hence, new test stand was designed to improve existing methods for economical aspect especially. Construction of this instrument is described. Discussion of strong points is presented but also a list of weaknesses and all factors that were neglected is given.

To prove reliability of this test stand some experiments were carried out. All results were verified using a measurement system to inspect surface roughness and contour. Every scratch was evaluated with this system before the load application on the specimen (pre-scan). Then all scratches were measured at several cross-sections – one cross-section for each load.

New method was compared to the one described in ISO 19252 standard for determining the scratch properties of plastics under defined conditions. Also the instrument itself was compared to the advance scratch tester CETR-UMT. In the last section all planned modifications of this tester are described, considering adjustment to industry needs and flexibility for didactic use at technical schools and universities.

Keywords: Scratch Test Stand, Sclerometry

1. INTRODUCTION

The very first documented scratch tests were carried in the 1722 by Reaumur [1]. It means that this method is really old, because it was described a century before a popular Mohs scale, based on 10 minerals, was proposed for hardness of materials determination [2]. Since then numerous modified techniques have been developed. Some of them are very simple, like the one from ISO 19252 standard [3], but on the other hand there are also highly sophisticated instruments designed in compliance with ISO 14577 standard [4], where coating parameters are measured without any horizontal motion of the specimen in respect to the indenter position (pure hardness test). General idea remain the same, while scratch loads and speeds varies, different parameters are considered as a result (i.e. coefficients of friction change or visibility of the scratch track) and at least several specific scratch tips geometry applies (Vickers, Rockwell, cube corner, ball and many others) [5].

Considering most common methods scratch resistance, that corresponds to material hardness, can be defined as the ability of one material to abrade another [6]. Damage is the results of a complicated process. However, understanding this mechanism leads to the conclusion, that there are always two important factors common for every method – load and contact area [6]:

$$F_I = H_I \cdot A^I_{LB} \quad (1)$$

where F_I is the horizontal force applied to the specimen, H_I is the indentation hardness and A^I_{LB} is the projected load bearing area resisting the horizontal force.

Indentation mechanism differs from scratch mechanism but general formula that describes scratch hardness is the same [6]:

$$F_S = H_S \cdot A^S_{LB} \quad (2)$$

where F_S is the horizontal force applied to the specimen, H_S is the indentation hardness and A^S_{LB} is the projected load bearing area resisting the horizontal force.

The formula (2) is a base to emphasize the need to implement a new scratch method that can characterize scratch properties of varnishes at the microscale. It's based on the current state of art, fast and repeatable so it can be widely accepted for the quantification of coating properties. Custom-built test device is easy for operation, portable and free from operator influence, which leads to the reproducibility of experimental results. It can be called comparator because of the limited functionalities for test parameterisation. In more advanced instrument load is applied continuously, speed is constant or it's increasing during the test to keep acceleration constant, indenter position is adjustable to achieve correct attack angle and *in situ* data acquisition system, even including visual system for scratch visibility evaluation, are implemented. As the device was not developed for researches but for resistance test most of those parameters are neglected. Only the vertical load, which is a critical point for test capability on soft and hard materials, has to be adjustable. This method does not involve additional system to base coating study on acoustic emission signal. Also after-scratch verification method will not be included to get only quick information about the specimen.

2. SCRATCH METHOD AND MATERIALS

2.1 Test stand

Custom-build test stand (Fig. 1) consist of two main parts: slider (2) and indentation unit (3). There is a space for 110 mm long specimen on the top of this stage, which moves 100 mm in the horizontal direction. Velocity equal to scratch speed is determined by the gravity force acting on the dead weight located at the end of a flexible connection. Slider wheels and pulley are installed on low-friction bearings.

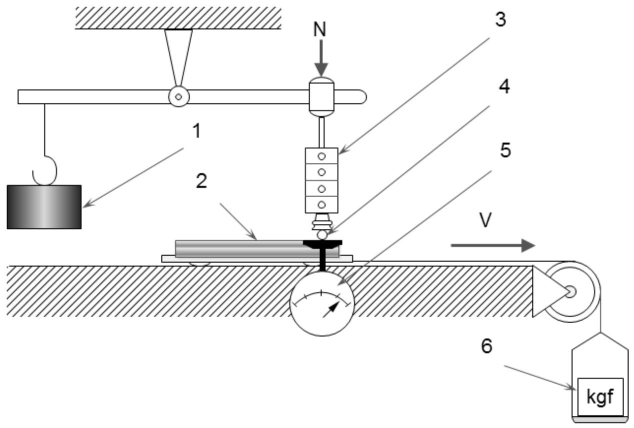

Fig. 1: Scratch test stand (1 – counter-balance, 2 – specimen on the stage, 3 – weights (normal load), 4 – indenter, 5 – dial gauge, 6 – weight (stage movement)

Indentation unit consist of the indenter (4), indenter holder and set of weights for vertical load application. There are also two auxiliary components. Counter balance (1) to achieve accurate loading without any influence from the load application unit and dial gauge for indentation depth measurement. Gauge tip is connected in a direct proximity to the indenter tip to allow position zeroing before the test (without any load applied) and to read depth accurately. Certified accuracy of this gauge is equal to 1,0 μm with resolution 0,2 μm.

2.2 Scratch test method

This method was developed to compare coatings without determination of numerous material parameters thus two principal assumption were made. First one in refer to resistance to penetration – resistance to penetration is taken as a material constant independent of the penetrating direction (vertical indentation or horizontal scratch). Second one in refer to friction – adhesive friction is treated as independent of the portion responsible for deformation. Both assumptions were verified [6] up to the 120° indenter angle which means that significant part of ball indenter is in touch with specimen coating.

Load necessary to carry scratch test increases with the tip radius [7]. Because of that it is better to determine widely available indenter first and then calculate necessary load. For lacquer based coatings there is no need to use very sharp indenter like Vickers diamond, because only a small load can be applied during the test. That makes scratch method hard to introduce for the industry. Bigger radius works also as an mechanical filter, that makes the system less sensitive to surface roughness.

Critical vertical load applied on the indenter was calculated from the formula [8], that describes correlation between the critical load of the scratch adhesion and the composite hardness based on the elastic–plastic deformation model of the coated material:

$$F_C = 2\pi \cdot R \cdot \gamma \cdot \delta_{cr} \cdot H_{cr} \quad (3)$$

where F_C is the critical horizontal force applied to the specimen, R is the indenter radius, δ_{cr} and H_{cr} are the scratch depth and the composite hardness and at the maximum load and γ is a dimensionless quantity equal to 0,7.

Assuming varnish hardness of 15 N/mm^2 (Martens hardness) to test with load in macro range radius of the indenter should be close to 1,0 mm. Under this condition device can be equipped with weights to cover 5 – 15 N range. For parameters determination with a small tip 0,5 N resolution is requested [9], but for qualification test 1,0 N resolution is sufficient. Starting from 5 N only 5 weights are necessary: 2 x 5 N, 2 x 2 N and 1 N.

3. VARNISH SCRATCHING EXPERIMENT

Eight samples of steel plates coated with varnish were taken from automotive industry. Type of coating wasn't changed during this experiment to avoid influence of material properties on the test stand capabilities. On the Fig. 2 general position of the indenter tip (2) during the test is presented with respect to base material (1) and coating (3).

First part of the test was oriented on coating material study. With FMP100 instrument that utilize magnetic-inductive method, coating thickness was measured. Accuracy of measurement is equal to 0,5 μm. Averaged thickness for each specimen are presented in Table 1. At

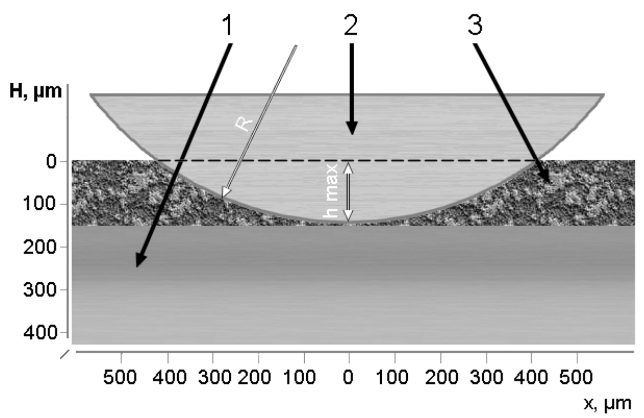

Fig. 2: Contact area during scratch-test (1 – base material, 2 - spherical indenter, 3 - coating

next stage flatness was tested with combined roughness and contour system T8000. Direction of the tip movement was perpendicular to planned scratch vector to ensure proper measurement of indentation depth H [10]. Significant flatness deviation can be read as a bigger depth H, leading to unexpected errors.

The most important part of this experiment is a series of scratch tests. There is an interesting technique described by Vencl [11] that requires scratch testing on coatings cross-sections. Hardness type test (with indenter perpendicular to the surface) is not the best to describe adhesive strength. However it won't be possible to determine crossing point between base material and coating with any simple test stand. Hence, specimen material moves in a horizontal direction under vertically placed indenter. Scratch velocity also influences results, however for the range from 10 mm/s to 50 mm/s values are almost comparable [12]. In the system without motorized stage only average speed can be calculated. To achieve speed of 30 mm/s set of experiments were carried with different weights causing stage movement. For the actual scratch tests weight wasn't changed so speed remains constant.

At next stage T8000 system was used to evaluate profile of the scratch. During every scratch pointer of dial gauge indicates maximum depth of the scratch. Profile measurement was necessary to verify whether this reading corresponds to the H max depth or maybe on to the indenter position. In case of a soft core under the coating influence of base material doesn't withstand high pressure from the indenter tip and compressed increases depth reading. This factor is always considered for standard hardness test – according to the Buckle's one-tenth rule indentation depth must be 10 times smaller than coating thickness [13]. However during the scratch test this rule doesn't have to be followed and real scratch depth has to be evaluated anyway. Hence, change of the indenter position during the scratch test was observed and finally compared with H max value measured with contour system.

The last stage of this experiment was carried with a professional scratch tester CETR-UMT 2. Servo-controlled carriage position with indenter holder applies load on the coating. Accuracy of measurement is equal to 1% of the reading at the full load range from 0,5 to 50,0 N. Resolution is equal to 50 mN, so it's 20 times better than in the custom-built device. Load profile simulates dead weight installed over the indenter tip and every test was carried with constant speed of 10 mm/s, the highest speed of the computer controlled x slider. This device is a sophisticated system capable to apply different loading profiles (including sine and trapezium profiles). With linear increase of load, resolution of friction measurement is increased in respect of similar test with constant load. This more accurate method allows verification of custom device. Unfortunately with custom-built stand load can't be changed during the test.

4. RESULTS AND DISCUSSION

Averaged results of tests carried on 8 specimens are presented in Table 1. On the Figure 3. graphic representation of results is plotted. Thickness of the coating is nearly the same indicating very stable painting process, typical for automotive industry. At the short trace of 1,0 mm measured flatness was not bigger than 5 µm, not affecting scratch test results. This pre-scan has proven that specimens were prepared properly.

In every scratch-test with load over 8 N dial gauge pointer stopped at ca. 150 µm. This value is close to the coating thickness which means, that indenter tip was sliding on the base material surface. For every softer coating 8 N load will not be high enough to perform such a deep scratch, however it can't be concluded from the resolution whether any value between 7,0 N and 8,0 N is not capable to achieve the same depth.

Real scratch depth was a little bit smaller than read from the custom-built device. Difference is equal to 4 – 5 µm and it's reproducible for every tested specimen. An example of the profile is presented on Figure 4. Because the system is not designed to study material parameters there is no reason to measure profile over the surface and the shape of the same profile right under the surface. This is a subject for another research work. Penetration depth measured with the profilometer proves repeatability of the indenter positioning device and stiffness of the stand. Results from bended indenter tip will be higher (deeper penetration), thus also

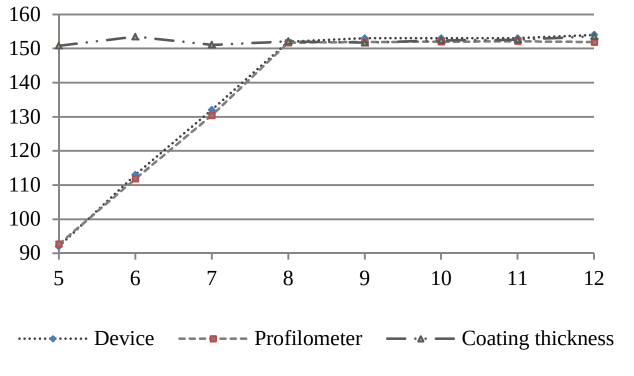

Fig. 3 Comparison of indentation depth measurement with respect to the coating thickness

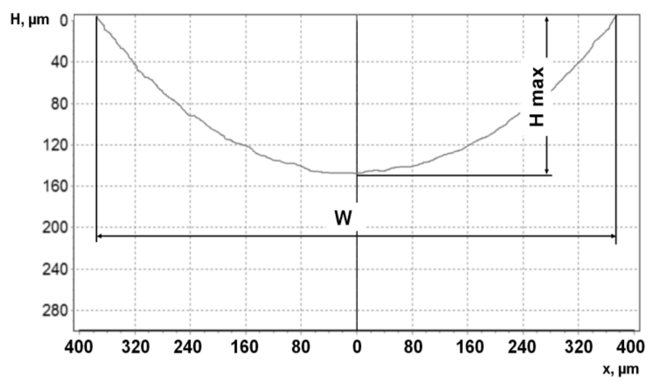

Fig. 3 Example of scratch profile

scratch-resistance will be considered as higher. This factor can be neglected if only comparative tests are conducted.

Table 1: Experimental results of scratch-resistance evaluation

Normal load F_S, N	Coating thickness, μm	Penetration depth H max, μm	
		Custom Device	Profilometer
5	150,8	92	88,9
6	153,5	113	108,8
7	151,1	132	128,5
8	152,1	152	147,2
9	151,7	153	147,9
10	152,4	153	148,0
11	152,6	153	147,8
12	153,6	154	148,3

4. CONCLUSION

From results of carried tests and from the analysis of those results several points of conclusion can be drawn:

- this simple scratch test method can't be used to determine material parameters, but accuracy of the indentation depth measurement is good enough to distinguish different varnishes on steel base;
- comparison between simple test stand and sophisticated computer based system points acceptable difference in scratch-resistance results, however it can be only neglected at industry level, not in material science;
- repeatability of results proves small influence of the operator and shows good reproducibility of custom-built test stand;
- better load resolution, that can be easily achieved, will improve ability to recognize proper coating
- further researches will be focused on speed increase, but first influence of carriage velocity must be investigated;
- requested surface flatness is the weakest point of custom-built test stand and there is no method to improve that at this stage of researches work;
- test stand is ready for comparative tests on varnishes in industry and it can be used by university students to observe basic idea of scratch-testing.

Further work is required to perform better accuracy of depth penetration reliability and to decrease influence of surface flatness. All popular sensors applied in more advanced systems are unfortunately not useful since it's requested to use data acquisition system. This improvement affects one of the very basic requirements – device must be simple and easy for operation. Current version is a good proposal for laboratories where students have their first contact with scratch testing. Load can be changed manually, so as specimen velocity and type of indenter to understand better complicated theory of scratching.

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