# Comparative analysis of protective coatings of car paints

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**Abstract**. The article presents the results of tribological tests aimed at evaluating the resistance of protective layers of car paints to abrasive wear using the ball-cratering method. Substance1 and substance2 was applied by spraying it on previously prepared (in accordance with car body paint practice) samples. The tests were carried out on unprotected samples and samples with several types of protection using ceramic-based substances, which were produced using nanotechnology. The experiment was planned using Taguchi methodology. First, preliminary tests were conducted in order to build a orthogonal array. Then, using an ETA function, the optimal parameters for the actual experiment were determined. The results of the experiment show that the fifth group of samples (coated with four layers of substance2 and one layer of substance1) produced the worst results. Using this type of protective layer makes the coating more susceptible to frictional wear than not using any type of protection.

## 1. Introduction

Cars, apart from their functional aspects, are a form of decoration. Therefore, their visual properties are significant. The durability of automotive coatings is still a huge issue both in the car industry and for producers of coatings. Scratches, abrasions or chippings deteriorate the car's appearance. One of the main causes of damage in the external coating is driving dirt roads, where the coating is hit with rocks or tree branches. Such situations are described as erosive coating wear [1, 2]. However, the car body is far more frequently damaged in the parking lot. The coating is in threatened with abrasions and hits [3]. The durability of the coating is also influenced by the climatic conditions in which the car is being used [4]. Biological factors that have a direct contact with the car body (tree sap, bird droppings, acidic rain) are also significant as they may cause discolouration or subsurface corrosion [5, 6].

There are many methods of improving the functional properties and durability of car body coatings. For example, research was conducted on the use of magnesium and its alloys in protective coatings, but the high susceptibility to corrosion greatly restricts their use in the automotive industry [7]. Coatings with aluminium based pigment were also used [8], but they did not demonstrate significant improvement in durability. Aluminium did, however, have a positive effect on temperature regulation inside the car (the coating reflected sunlight and the interior did not heat). The newest trend in the coating industry is the use of nanotechnology [9]. Coatings producers use this technology to develop sprays for automotive coatings. After these sprays harden, they provide an additional protective surface of the coating. This study tested the effectiveness of this type of protection.

## 2. Object of research

The study was conducted on 10 samples made of E295 steel, 1" (25.4 mm) in diameter and 10 mm thick [10] seen in figure 1.

**Figure 1.** Photograph of samples at each stage of preparation: a) cut and sanded samples b) samples with primer coating, c) samples with basecoat and clearcoat

The samples were numbered and covered with three coatings, in accordance with car body painting technology:
-     first layer: acrylic base paint (primer);
-     second layer: colour coat (the basecoat);
-     third layer: clearcoat.

Next, the samples were divided into five groups, with two samples in each group. Eight samples were then covered with two types of clear protective substances, whose molecular composition is mainly ceramics (further referred to as substance1 and substance2). The substances were applied in accordance with the producer's recommendations for various degrees of protection. The protective substances were produced by one of the global leaders in the industry.

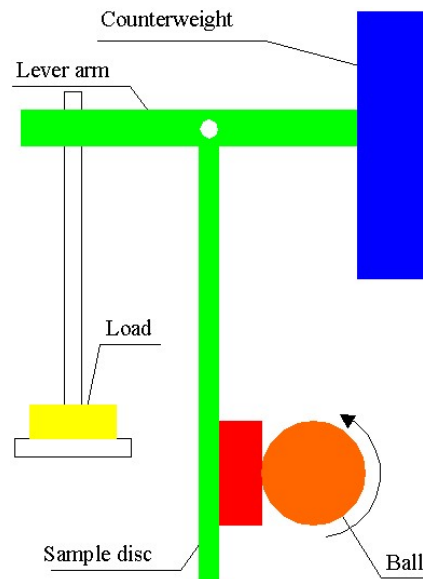**Table 1**. List of prepared samples

| Sample group | Sample no. | Applied coats |
|---|---|---|
| 1 | 1 | 3 coats |
| | 2 | 3 coats |
| 2 | 3 | 3 coats + one layer of substance1 |
| | 4 | 3 coats + one layer of substance1 |
| 3 | 5 | 3 coats + two layers of substance1 |
| | 6 | 3 coats + two layers of substance1 |
| 4 | 7 | 3 coats + one layer of substance2 |
| | 8 | 3 coats + one layer of substance2 |
| 5 | 9 | 3 coats + four layers of substance2 + one layer of substance1 |
| | 10 | 3 coats + four layers of substance2 + one layer of substance1 |

## 3. Research plan

The tests were conducted on a T-20 workstation (figure 2) used for abrasive testing using ball-cratering. The countersample was a 1 inch (25.4 mm) 17HNM steel ball (roundness: 0,0006mm, hardness: 60±2HRC) whose rotation creates friction against the study sample and causes it to wear (figure 3). Some researchers suggest using, for example, rubber balls and pressing the studied samples on both sides of the ball [11, 12], all while submerging the friction pair in an abrasive slurry [13]. However, in order to recreate real environment conditions, the tests were conducted in a traditional manner in accordance with the norm.

**Figure 2.** T-20 Abrasive Testing Machine workstation.



**Figure 3.** Coating abrasive wear testing set

Measurement of the crater created in the test allows the determination of $K_c$ (Coating abrasive wear rate factor). The norm describes two cases [10]:

1) for surfaces that were not worn during the test, $K_c$ is determined from the relation:

$$K_c = \pi \frac{b^4}{64 \cdot R \cdot S \cdot N}$$

(1)

where:

$b$ - diameter of coating crater;

$R$ - ball radius;

$S$ - sliding distance;

$N$ - load;

2) for surfaces that were worn during the test, $K_c$ is determined geometrically by drawing a diagram and determining the shift with regard to the "x" axis:

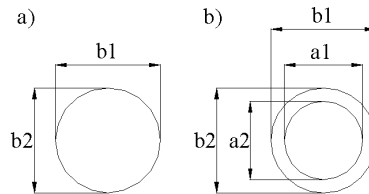$$\frac{S \cdot N}{V_c} = \frac{1}{K_S} \cdot \frac{V_S}{V_c} + \frac{1}{K_c}$$

(2)

v
$V_c$ - coat wear value;
$V_s$ - surface wear value;
$K_s$ - surface abrasive wear factor.

The diameter of the craters, both for worn and unworn coatings, is measured in two planes, and then its mean is determined (figure 4).



**Figure 4.** Crater diameter measurement: a) for unworn coatings; b) for worn coatings.

In order to get the best results, it is imperative to find the proper test parameters (ball rotation speed, load, and sliding distance) [2], which is a difficult and laborious task. After analysing various research planning methods [14-17], the final choice was Taguchi's method, which is frequently used in these types of testes [18-20]. It is also used in other disciplines such planning structure experiments, optimising burnishing processes, and in natural or engineering sciences [21-23].

The first step was the performance of preliminary tests. They are number of test with different, selected based on the researcher's experience, input parameters. The results of these tests allow to find the ranges of correct input parameters for which the dimensions of the craters are satisfactory (the preliminary parameters of the experiment will be set properly if the relative error of the crater diameters created in the preliminary tests do not exceed 0.01 [22, 24]). They are also used to create an orthogonal array (table 2).

Each of the nine tests was carried out five times. Following the "the less the better" rule, and using the obtained results, an ETA function was established, in accordance with the relation:

$$\eta = -10 \cdot \log_{10}\left[\left(\frac{1}{n}\right) \cdot \sum y_i^2\right]$$
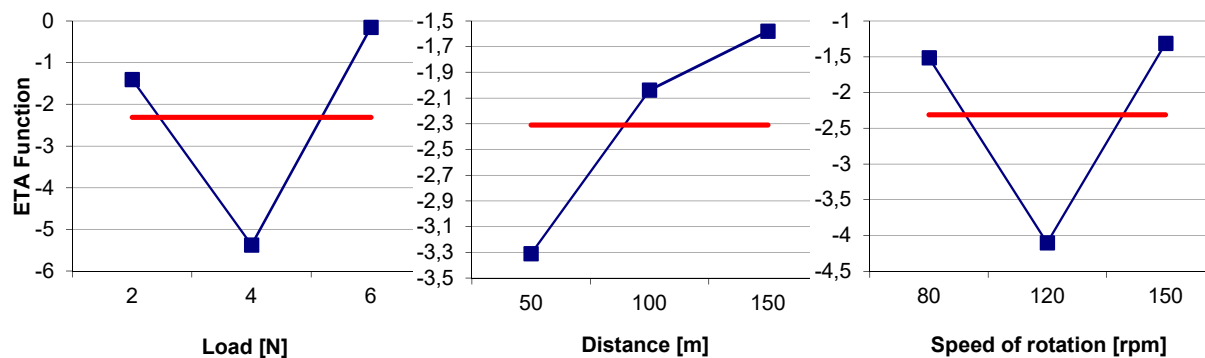
(3)

where:
$n$ - number of measurements;
$y_i$ - value of analysed parameter.

The value of the ETA function for each parameter is shown in figure 5.

After the obtained results of preliminary tests were analysed, it was possible to determine the optimal test parameters, which were the following:
- load: 6 N;
- sliding distance: 150 m;
- speed: 150 rpm.

**Figure 5.** ETA function diagram: red line - arithmetic mean of ETA Function for all the preliminary tests, blue line - ETA Function of each parameter level
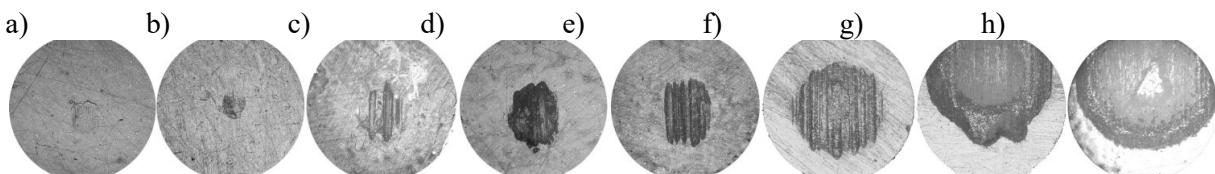
The main experiment involved the conduction of the test five times for each sample group while maintaining the set parameters.

**Table 2**. Orthogonal array in the Tageuchi method

| Experiment no. | Load [N] | Distance [m] | Speed of rotation [rpm] |
|---|---|---|---|
| 1 | 2 | 50 | 80 |
| 2 | 2 | 100 | 120 |
| 3 | 2 | 150 | 150 |
| 4 | 4 | 50 | 120 |
| 5 | 4 | 100 | 150 |
| 6 | 4 | 150 | 80 |
| 7 | 6 | 50 | 150 |
| 8 | 6 | 100 | 80 |
| 9 | 6 | 150 | 120 |

## 4. Results

Abrasive testing on the samples resulted in the creation of craters (figure 6). Some of the craters are very big and irregular (figure 6 g) and 6 h)), or very small, where the surface was only scratch and dense, not worn (figure 6 a) and 6 b)). This happened in preliminary tests. After defining test parameters, in actual experiment, craters were not perfectly round, but clearly the coating was worn (only coating, basecoat and clear coat wasn't worn), and size of crater is very similar for each sample group (figure 6 c) - 6 f), each picture is for different sample group). Their dimensions were measured in two planes in order to find the mean [10].



**Figure 6.** Example photographs of craters in samples due to abrasive wear, both in preliminary tests (a, b, g, h) and the actual experiment (c, d, e, f). Photographs taken with OLYMPUS BX51 camera, 10x zoom.

The dimension of the craters were measured using Brinell's magnifier and an OLYMPUS BX51M microscope and software. The microscope allowed to make the measurements on a live images of the

samples, using a method similar to Image Processing Techniques described in literature [25]. This technology decreases the measurement error.

After substituting the values to formulas (1) and (2), the $K_c$ values were determined for each sample group. All the test result presented in paper are the arithmetic mean. There is also given a standard deviation for each measurement calculated from the dependence:

$$s = \sqrt{\frac{1}{n-1} \cdot \sum_{i=1}^{n}(x_i - \bar{x})^2}$$

(4)

where:

s - standard deviation;

n – number of test;

$x_i$ – test result;

$\bar{x}$ - arithmetic mean for one sample.

The results of the calculations are presented in table 3.

Table 3. $K_c$ values determined for each sample group

| Sample group | Applied coats | Coat wear value $V_c$ [mm$^3$] | Abrasive wear speed of coating $K_c$ [10$^{-13}$m$^3$N$^{-1}$m$^{-1}$] |
|---|---|---|---|
| 1 | 3 coats | 0.1946±0,0011 | 175.13±0,09 |
| 2 | 3 coats + one layer of substance1 | 0.0054±0,0006 | 4.85±0,02 |
| 3 | 3 coats + two layers of substance1 | 0.0168±0,0005 | 15.16±,0,04 |
| 4 | 3 coats + one layer of substance2 | 0.1188±0,0008 | 106.96±0,08 |
| 5 | 3 coats + four layers of substance2 + one layer of substance1 | 0.3971±0,0116 | 357.38±2,11 |

The most likely cause of such large differences in the results for individual groups of samples is the poor adhesion between individual layers of the protective coating.

## 5. Conclusions

1.    As the paper presents, the ball-cratering method can be successfully used to study automotive protective coatings.

2.    The coatings were destroyed only as a result of the abrasion process.

3.    The best results of testing resistance to abrasive wear by ball-cratering (i.e., the lowest value of the $K_c$ factor) were observed in the second group of samples - using one layer of substance1 on the clearcoat.

4.    The worst results of testing resistance to abrasive wear by ball-cratering (i.e., the highest value of the $K_c$ factor) were observed in the fifth group of samples - using four layers of substance2 and one layer of substance1 on the clearcoat.

5.    Drastic increase of the $K_c$ factor in the fifth group of samples was caused by chipping off of the protective substance, which at some point started to act as an additional abrasive and greatly increased the wear rate.

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