Journal of Achievements in Materials and Manufacturing Engineering
VOLUME 61
ISSUE 2
December
2013

Comparison of the tribological properties of flat steel products with heterogeneous organic coatings

J. Wiśniewska*, M. Bilewicz
Institute of Engineering Materials and Biomaterials, Silesian University of Technology, ul. Konarskiego 18a, 44-100 Gliwice, Poland
* Corresponding e-mail address: justyna.wisniewska@polsl.pl

Received 07.10.2013; published in revised form 01.12.2013

Properties

ABSTRACT

Purpose: Comparison of tribological properties of coated metal sheets.
Design/methodology/approach: Samples were subjected to the variety of tests such as: pencil hardness test, resistance to scratching, bending test (T-test), paint adhesion, determining optimal method of measurement of the coating thickness.
Findings: Polyurethane coatings are extremely hard and its strength exceeds strength of organic coating, but polyester coatings have proved to be superior in adhesion to the steel substrate. Micrometer method was found to be one of the best methods of measurement of the coating thickness.
Research limitations/implications: Galvanized and coated materials can be successfully implemented for application which are cost effective and will not create a financial burden in the future.
Practical implications: Wide range of application for industrial and household.
Originality/value: Optimal configuration of the coatings properties in order to create best technological solutions.
Keywords: Polymer; Organic protective coatings; Polyurethane; Tribological properties; Adhesion

Reference to this paper should be given in the following way:
J. Wiśniewska, M. Bilewicz, Comparison of the tribological properties of flat steel products with heterogeneous organic coatings, Journal of Achievements in Materials and Manufacturing Engineering 61/2 (2013) 315-320.

1. Introduction

Protective coatings are used for antiseptic and decorative purpose, but principally as a protecting layers of metallic materials . Through spreading the layers on prepared ground , there is formed a kind of barrier insulating the substrate of metal from the adverse external agents due to the formation of a thin layer with significant hardness and fine protective properties [1-5].

The most common type of coatings are polymer coatings. Its popularity mainly owes thanks to simplicity of processing. As the liquids polymers and polymer blends, including polymer nanocomposites, are easy to apply on surfaces with any shape, hey have a high hardness after drying, high corrosion resistance, low coefficient of friction, good leakproof, which not allow for penetration of impurities, and additionally polymers can be colored by addition of any dye [4-9]. Another possibility is to cover the metal sheets using worldwide known techniques such CVD or PVD, which are also very common techniques in automotive and aerospace industry. Their protective functions and durability, except their composition and morphology, are determined by such factors as the condition of surface of the substrate and structural defects. These two factors constitute

another important aspect applying to adhesion, whose strength determines the quality of the physicochemical properties of the manufactured coatings [10-14].

This article presents research of flat steel products with heterogeneous organic coatings basing on polyester or polyurethane spread continuously. In the research was compared the tribological properties of individual sheets divided into three groups according to the thickness of the protective coating , and their structure. Research was performed also in the am to demonstrate the various features and behavior of the protective layer under different conditions. The same type of testing is use to perform in quality control point at the mass scale production stage in manufacturing companies.

2. Experimental procedure

In the research has been analyzed samples, which due to their individual properties, was divided into three different categories. The classification and a brief description was shown in the following arrangement (Table 1).

Table 1.
Classification od tested steel sheets

Group	Thikness, µm	Characteristics
A	25	Organic polyester coating with matt and rugged surface
B	35	Organic polyester coating with matt and rugged surface
C	45	Organic polyurethane coating with matt and rugged surface

Prior to qualitative research, each sample has undergone appropriate treatment in order to prepare plates for testing. Preparation consisted in choosing the appropriate coated plates (without cracks, bumps, abrasions, etc.) and trimmed it with a cutter to the size required for the study. Microscopic investigations were preceded by adequate preparation involving them in selecting and collecting the appropriate sample, cutting on a cutter, mounting with in the thermoset resin, grinding, polishing and coating by gold (Fig. 1).

All tests were performed under constant humidity 50% and room temperature 20°C.

Totally four tests were performed, responsible for verifying such properties as the hardness of the coating, its resistance, adhesion and flexibility. In addition, measurements were made of the protective layer thickness of three different testing methods.

The first study involved the verification of the hardness of the coating using a set of pencils with different hardness of graphite. Before each measurement graphite has been properly sharpened to a height of 5-6 mm above the level of wood with a dull knife sharpener and then blunted using sandpaper of 400, so that graphite formed at right angle to the main axis of the pencil. The study consists of scratching movements by performing a 45° angle with a measurable force to not more than 7 mm at the same time not less than 6 mm. The measurements obtained by the three-shift sample of graphite, the scratch was less than or equal 3 mm (Fig. 2). Its designation is simultaneously the hardness of the coating.

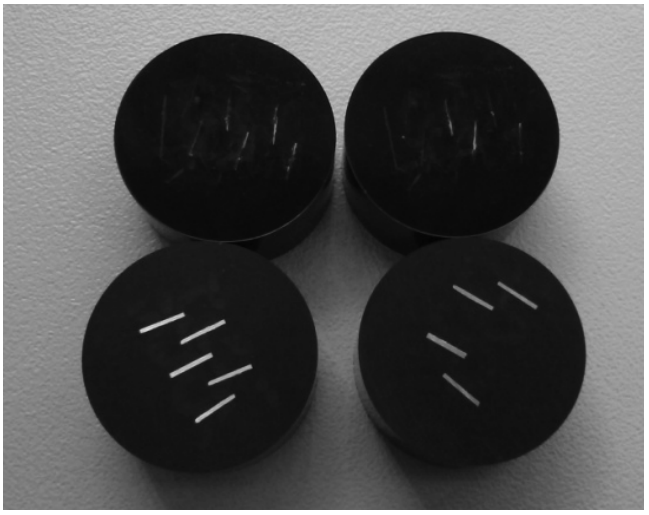

Fig. 1. Samples after mounting, partially sanded and polished

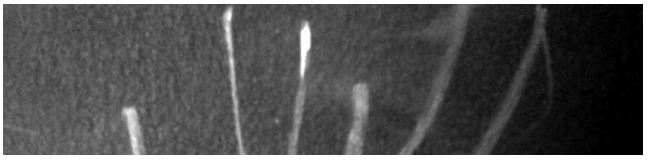

Fig. 2. The part of sample from the group B with visible scratches on the coating after pencil hardness test

Another study designed to control the resistance of the coating to external factors, is resistant to scratches. For this performance was used the Clemen test device, which imposes the same dimensions as the sheet metal samples, that is 75 x 150 mm. The test material was placed on the platform, and then, a series of scratches at different loadings of the scriber, sliding with reciprocating movement (Fig. 3). As in the previous study, it shall be terminated after triple scratching of coating. The load at which the scratch was leaving the mark was treated as result.

Adhesion test of the coating after stamping was made using the Erichsen stamping device. Through a series of cuts with a sharp scalpel and template prepared by a grid of parallel and perpendicular cuts in a set consisting of 25 squares with side equal to 1 mm. Sheets were purified from filings after the test, by brush with soft bristle, then lubricated with grease form the uncoated side, using a brush, in order to avoid rupture of the sample, and then placed in the device and extruded to a depth of 8 mm (Fig. 4). Carrying out a test using an adhesive tape with a width of 25 mm consisting in gluing it to the embossing and separating angle of 60° to the substrate over a period of 0.5 to 1 s, is compared to the table with resulting imprint according to the norm PN-EN ISO 2409:2007. Based on the description of the

appearance and the resulting fingerprint is determined class of coating adhesion.

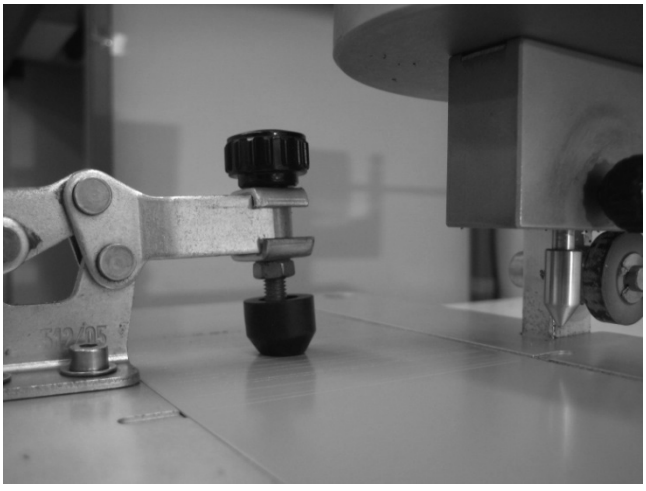

Fig. 3. Sample from A group under Clemen test

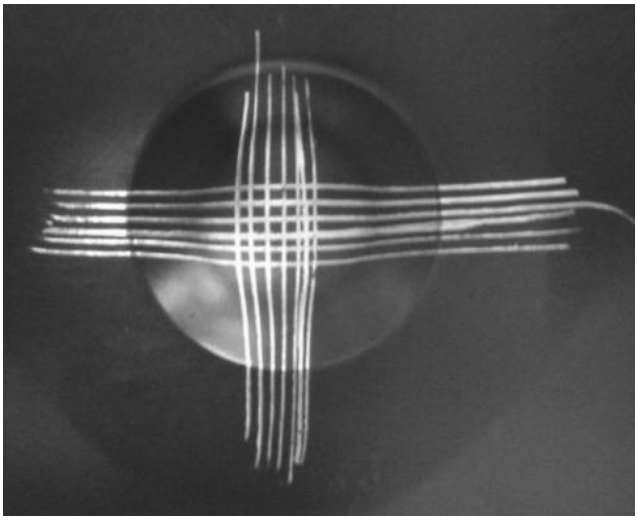

Fig. 4. Sample from A group after stamping on 8 mm

In order to analyze the flexibility of the outer protective layer, was performed test known as the sample underwent bending T. In the experiment, the devices, such as a magnifier of 10 - fold magnification, a vice and a set of brass inserts. By bending sheet metal at an angle of 180° in the direction of the coating, in no more than 2 seconds, but at the same time not less than one second, an analysis of the flexibility of coatings based on observations of the surface of a sample under a magnifying glass. Durability of paint was determined by the number of used inserts (each having a thickness of 0.5 mm) divided by two, at which a marked change was observed on the coating at a distance of not less than 10 mm from the edge of the sample.

A recent study on the thickness of the protective layer due to the already known parameters, aimed at selecting the most appropriate and the best measurement method by which one can obtain the most reliable results. A series of studies by three different and independent from each other methods. The first measurements took place with the help of a micrometer screw. Using cellulose wadding soaked in an organic solvent 2-butamon, soften layers constituting the protective coating, after which they were removed by scraping with a blunt knife until the appearance of the steel sheet.

Then compared with the measurements made with an accuracy of 1 micrometer Pm on the same part of the sample before and after removal of the coating. The resultant difference of measurements presented in microns, was the result of the test.

The last measurement was the analysis of microscopic image. Pictures taken at 100x magnification stereoscopic microscope ZEISS SteREO Discovery, were examined using the program to analyze microscopic images. Another advantage of this study was the ability to observe and identify the different layers of sheet metal section. Due to the nature of the tests performed and analyzing of non-transparent samples, although the viewing objects in the transmitted and reflected light, only the technique used research using reflected light. Example measurements made using this method is presented below (Figs. 5, 6).

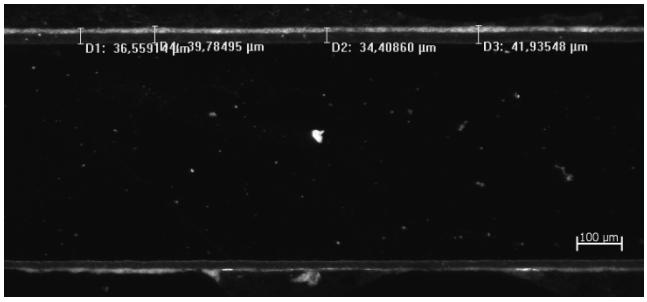

Fig. 5. Sample from group B; stereoscopic microscope, 100x

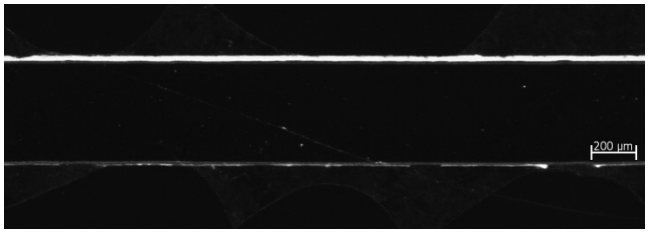

Fig. 6. Sample from group A; stereoscopic microscope, 100x

Another method of measurement was carried out using a tool called Phascope®, which uses measurements of eddy currents and magnetic fields. The test was effected by applying a probe apparatus to the head of the test surface in a series of measurements on ten randomly selected areas on the sample, which lead to the arithmetic average.

3. Discussion of experimental results

In studies of the strength of the coating using the pencil hardness test, the following results were obtained (Figs. 7, 8).

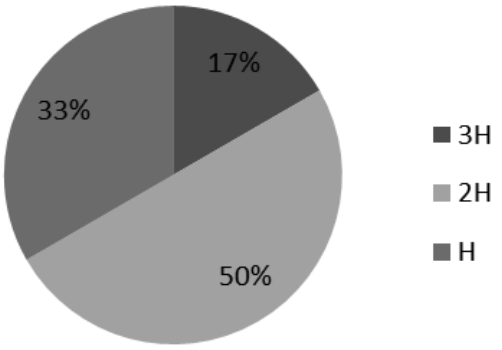

Fig. 7. Percentage contribution of occurrence of the coatings hardness

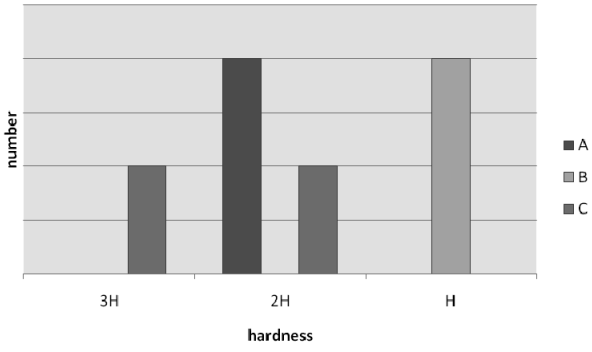

Fig. 8. The ratio of the results for the pencil hardness for each of the three product groups

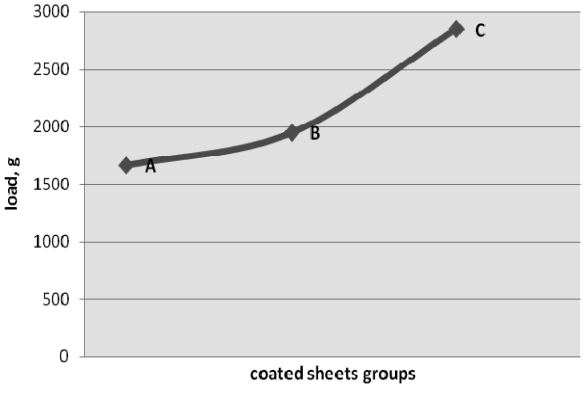

Fig. 9. Load at which was observed scratch of coatings for particular groups

Most often the result obtained was a hardness corresponding number of graphite 2H. Had it up to 50% of the samples. In direct relation to the treatment group, showed the greatest hardness of the samples from the group C, which is the maximum thickness of the polyurethane coating of 45 microns. They reached the result of who place themselves between the hardness of 2H and 3H graphite. The weakest but showed sheets of Group B with a polyester coating thickness of 35 microns. By scratching resistance test using a Clemen test, the results were averaged for each group (Fig. 9).

The diagram shows a clear upward trend relative to the thickness of the coating. What's more, revealing a definite advantage in the obtained results show polyurethane coatings from Group C, where the first scratch could be observed in some cases, as at 3000 g load, which leads to the conclusion that their strength is about 1.5 times greater than the coating polyester from groups A and B.

In the study of adhesion of paint using a grid cuts, the best results within the class of "0", received a group A of the thinnest coating thickness of 25 microns polyester. The sheets of this group, there was no coating departing and the edges were smooth cuts without chipping occurring. Slightly inferior results were given the other two groups, where some of the samples, classified in Class "1" and "2". Analyzing the results obtained by these groups of samples were observed on the surface of the paint go cross-cut, and the intersections of grid lines were chipping. A more detailed summary of the results obtained with the classes of adhesion of paint, is shown in the figure below (Fig. 10).

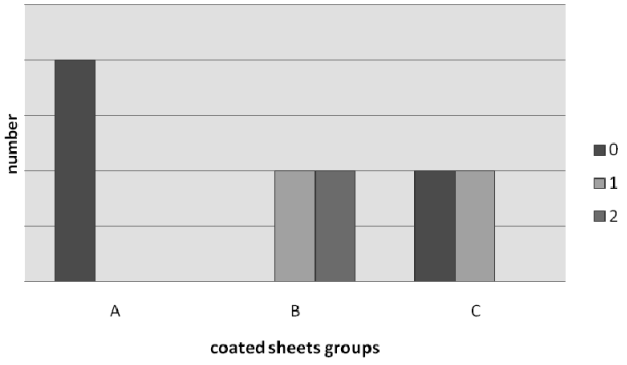

Fig. 10. Classes of paint adhesion after stamping, using a cross-cut sheets for each group

In the measurement of the flexibility of the coating using the bending test T of sheet, the results were obtained on the strength of the paint cracking and chipping paint, which were then averaged (Fig. 11).

All plates tested achieved similar final results, and therefore no apparent effect was observed thickness and morphological composition of the protective layer of the flexibility of the coating. Summary of the three methods of measuring coating thickness made using such devices as Phascope ®, micrometer screw and a stereoscopic microscope (Fig. 12).

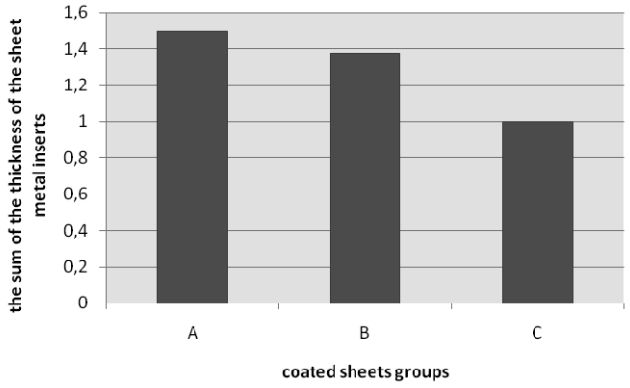

Fig. 11. Test results of the coating after bending flexibility in T test

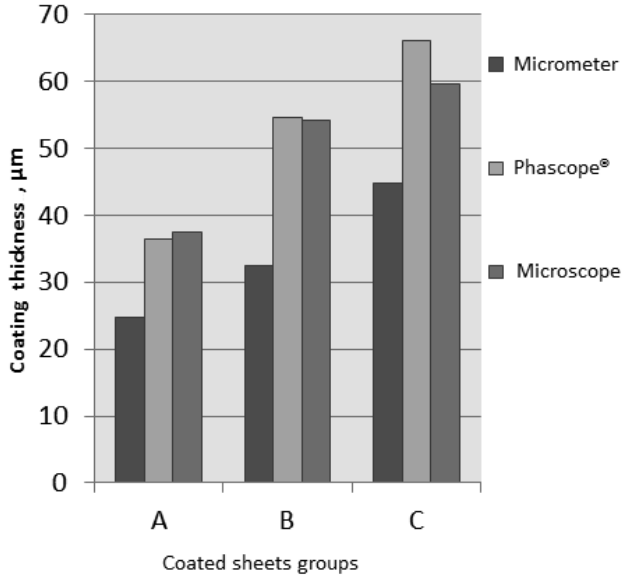

Fig. 12. Summary of three methods of thickness measuring

By observing the cross section of samples under a stereoscopic microscope ZEISS SteREO Discovery, found laminar structure of coatings. Analysis of the resulting graph, allows you to choose the optimal method of measurement. Despite the clear differences, reaching up to 20 microns, has been concluded by the study micrometer thick as the most accurate measurement. The results of these studies are the closest to the parameters set by the manufacturer. Their accuracy takes into account structural inequalities during measurements, which were held by limiting specific area on a sample of the anvil and spindle micrometer. The studies using the microscope and Phascope ®, the probe has a diameter of about 1 mm, it is not possible to take account of irregularities in the structure.

4. Conclusions

In the research was analyzed tribological properties of steel flat products with organic coating applied continuously. The coatings were tested for their thickness and morphological composition. Sheets divided into three groups , were tested for durability, traction and flexibility paint. Polyurethane coatings are extremely hard and its strength exceed strength of organic coating. This could be particularly observed in the Clemen test, where coating damage was occurring at a much greater load than in the case of the polyester coatings, which in turn, have proved to be superior in adhesion to the steel substrate . Moreover, the thinner the coating was examined , the better the results given in the context of this test.

There have been also verified the best method of measuring the thickness of which was measurement by micrometer screw. The key criterion for the accuracy of the results was the relatively large surface area measurement, including also structural inequalities of surface. For the tests used for the measurement point Phascope ® and a program for microscopic image analysis results accuracy probability is small even when a large number of measurements .

Implementation of the research described in this article, has allowed the identification of the best properties of different types of coatings, which will allow in the future to set optimal configuration in order to create best technological solutions.

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