POLYURETHANE COATINGS IN MEANS OF TRANSPORT

Powłoki poliuretanowe w środkach transportu

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A b s t r a c t: Polyurethane coatings are becoming increasingly popular, particularly due to their numerous beneficial properties. They are resistant to environmental weather conditions and other impacts associated with operation and time, including mechanical loads. The article is an introduction to investigations on the use of such paints in aircraft constructions to protect aircraft coatings. It presents the subject of polyurethane paints and their main types. It also describes what actions should be taken before starting the coating process, mainly the polyurethane one, also including many other types of coatings. Apart from the characteristics of surface cleaning methods, the authors list the types of impurities and the main types of surfaces on which coatings are applied. The selected areas of industry, in which polyurethane coatings are used, have also been presented. A very important feature of coatings is their adhesion to applied surfaces. This feature has also been analysed, describing the main methods of checking adhesion. The basic mechanical and thermo-physical properties of the coating as a cast material are determined in the experimental studies. A polyurethane coating, commercially known as Rangers 2K, has been used for the research.
K e y w o r d s: polyurethane coating, mechanical strength, tribological properties

S t r e s z c z e n i e: Powłoki poliuretanowe stają się coraz bardziej popularne, głównie za sprawą wielu korzystnych właściwości. Są odporne na środowiskowe warunki atmosferyczne oraz inne oddziaływania związane z użytkowaniem oraz upływem czasu, między innymi na obciążenia mechaniczne. Artykuł stanowi wstęp do badań nad zastosowaniem tego typu farb w konstrukcjach lotniczych do zabezpieczenia pokryć statków powietrznych. Zaprezentowano czym są farby poliuretanowe oraz jakie są ich główne rodzaje. Opisano również jakie czynności powinno podjąć się przed rozpoczęciem procesu nakładania powłoki, gównie poliuretanowej, lecz także wielu innych rodzajów. Oprócz charakterystyki metod oczyszczania powierzchni, wyszczególniono także rodzaje zanieczyszczeń oraz główne typy powierzchni, na które nakłada się powłoki. Przedstawiono także wybrane obszary przemysłu, w których powłoki poliuretanowe znajdują zastosowanie. Bardzo ważną cechą powłok jest ich przyczepność do nakładanych powierzchni i tą właściwość również poddano analizie, opisując także główne metody sprawdzenia adhezji. W badaniach eksperymentalnych określono podstawowe właściwości mechaniczne i termofizyczne powłoki w postaci materiału odlewanego. Do badań wykorzystano powłokę poliuretanową o handlowej nazwie Rangers 2K.
S ł o w a k l u c z o w e: powłoka poliuretanowa, właściwości mechaniczne, parametry trybologiczne

Introduction

Polyurethane paints were invented in 1937. At present, they are gaining popularity [4] mainly in shipbuilding, construction and mechanical industry. This is because these paints have very good properties. First of all, they are characterized by a high abrasion resistance [2, 6, 12, 21] and very good adhesion [6, 13, 18]. Moreover, they are flexible [13, 18, 19] and have good chemical resistance [9, 13, 19]. Additionally, polyurethane paint is resistant to corrosion [12], many external factors, i.e. mainly weather conditions [6, 9, 13] water and UV radiation. It is also worth mentioning that coatings of this type of paint can be applied at low temperatures [19] (with a minimum temperature of -5°C), so taking into account Poland's current climate, it is possible to use the paint practically throughout the whole year, which definitely distinguishes polyurethane paints from other types of coatings. They are made of a mixture of resins or only one polyester, polyether, acrylic, and also special hardeners, depending on their type. Owing to the latter component, this type of paint is resistant to external factors as well as colour change [5].

Painting with a polyurethane paint is not difficult, although the surface which is to be painted needs to be properly prepared beforehand [20]. Additionally, one should be aware that a special care must be taken when preparing the surface for painting and applying coatings since the paint may produce toxic chemical compounds [2, 9], which are usually caused by hardeners used for curing a polymer coating. The cured polyurethane paint coating no longer releases any harmful substances. Therefore, the paints can be used in many industries, including the food industry, although they cannot come into a direct contact with food [1].

Types of polyurethane paints

It is possible to distinguish two types of polyurethane paints [3, 11]:

- one-component;
- two-component.

One of the types of a polyurethane paint is a one-component polyurethane paint which is only made up of resin. It is easier to use than two-component paint. It is cured most often under the influence of moisture in the environment.

It is relatively easy to use and has usually excellent adhesion and hardness. It can be used as protection against rain, variable temperatures and frost. Due to its good adhesion, this type of a polyurethane paint is also suitable for more demanding surfaces. One-component paint is ready for use immediately after opening the container in which it is stored, as opposed to a two-component type, which must be mixed prior to its use [15].

The second type is a two-component polyurethane paint, which consists of two parts: resin and hardener. It is more difficult to use than its one-component counterpart because before the use, both components must be thoroughly mixed in proper proportions and used as soon as possible [15]. This type of paint is characterised by a high flexibility of the coating and equally high resistance to various factors as in the case of one-component paint. The two-component paint is often used as a protective coating for cars, aircraft, mechanisms and high-quality furniture [7]. This type of polyurethane paint is applied by means of a special roller, brush or spraying equipment [19]. The process of application is usually repeated two or three times with an interval.

It should also be remembered that both types can produce toxic chemicals. For this reason, before applying the paint, it is necessary to wear appropriate protective clothing and be particularly careful when painting.

Surface preparation for the application of coatings

Before applying the coating to any surface, in the first place it is necessary to properly prepare the surface. Firstly, it is essential to select an appropriate painting kit. The selection should take into account experimental research as well as a technical and economic analysis, which should include the following factors:

- an environmental corrosive impact on the paint coat,
- dimensions, shape of the surface to be painted and its type,
- expectations and ensured durability of the paint coat,
- characteristics of paint coatings (physico-chemical properties),
- technology of surface preparation for painting,
- methodology of paint application (layer thickness, drying/hardening time, method of application, required equipment, etc.),
- a period required for making coatings, taking into account environmental conditions (humidity, temperature, precipitation),
- dependence of durability and strength of coatings as a function of expenditures and an assumed service life,
- environmental and fire protection requirements.

After selecting the right painting kit, the surface to be coated should be inspected so as to determine all impurities and classify them properly. Depending on the impurity type, a proper method of its removal should be chosen. In the case of steel products, one of the most common types of impurities is rust, i.e. a product of steel oxidation, in the form of the released iron oxides forming layers of variable thickness and in various morphological forms, poorly adhered to the ground [17]. Another common dust is the one which is produced by all industry branches. However, it cannot gather on the surface due to different weather conditions. Due to dusts, moisture remains on a given surface. Mill scale (metal elements) can also be found on a great deal of surfaces. It results from gaseous corrosion, which is formed by a layer of metal oxides on the surface of heated metal objects as a result of their contact with air. Leaving the scorch mill may cause e.g.: detachment of metal sheets and consequently of a paint coating, emergence of a corrosive cell [8]. If the surface to be coated (metals and non-metals) is at the point where fats, greases and oils are present, greasy spots may appear, being the reason for a lack of adhesion. As it was already mentioned, dusts cause moisture to persist, which is also one of the contaminants depositing on surfaces. It usually occurs due to fog or other precipitation and can form undercoat corrosion. Two types of impurities can also be distinguished as ionic pollution. These are salts - invisible to the naked eye, water-soluble salts such as chlorides, sulphates and nitrates, which, similarly to dust, retain moisture and additionally increase corrosion.

However, the type of impurity is not the only criterion of choosing the surface preparation. It depends on several other factors, such as:

- type of material from which the element is made,
- dimensions and shape of the object surface,
- type of surface,
- surface condition and impurity area,
- aggressiveness of the corrosive environment.

Surface cleaning usually consists of two main stages. The first one is a preliminary removal of loose and ionic impurities. Next, it is necessary to proceed to proper cleaning, during which corrosion, and an old coating is removed and appropriate roughness is given. Greasy and dusty surfaces should be sprayed with water under high pressure. The areas in which ionic contamination may occur should be rinsed with a corrosion inhibitor dissolved in clean water.

In general, there are several methods of surface preparation for the application of coatings. A common method is a mechanical method. This includes brushing, grinding, hammering, scraping, stream-abrasive treatment and fire treatment. Another popular method of surface cleaning is a manual-mechanical method, i.e. grinding, hammering and brushing, however with both manual and mechanical tools. These methods prove effective e.g. in removing rust or scale. However, the most optimal method of preparing the surface for coating is stream-abrasive treatment, which involves applying an abrasive onto a coating by means of compressed air. There are several types of such cleaning:

- with open or closed circulation of the abrasive medium,
- dry or wet,
- depending on air pressure.

Preparation of the coating by stream-abrasive treatment is characterised by the number of factors that need to be determined:

- size, type and structure of the abrasive medium,
- angle of incidence of an abrasive stream and the distance of the nozzle from the work surface,
- compressed air pressure,
- type and shape of the nozzle dosing an abrasive.

Another main method of surface preparation is physico-chemical cleaning, which is carried out by means of alkaline, acid and steam-water washing and solvent degreasing. This method of cleaning can remove dust and sand, ion and rust impurities, as well as residues from mechanical treatment.

The last of the most important cleaning methods is spraying with aqueous solutions. It does not cause undercoat corrosion, yet afterwards it is recommended to wash the surface again with clean water.

An important issue prior to applying a coating onto a surface is a classification of the type of surface to be painted, as there may be other methods of surface preparation depending on it.

The most frequently covered type of surface is steel. The impurities of this kind are as follows: rust, oils, greases, iron dust and filings. A proper way to remove such substances is to wash the surface with water under high pressure. Washing and degreasing the surface prior to cleaning may be conducted manually or mechanically using steam, water with a detergent, organic solvents, emulsions and alkaline and acidic agents. The method of spraying aqueous solutions with biodegradable detergents is particularly recommended, for economic and ecological reasons [16].

Another frequently painted material is galvanised sheet metal. Due to poor adhesion of the paint coating, it may be difficult to apply the coating to galvanised sheet metal. However, there are several cleaning methods that will work well with this type of surface. This includes washing the surface with an ammonia solution, brushing with suitable brushes and using e.g. a solution of Emulsion RN - 1.

Non-ferrous metals, similarly to galvanised sheet metal, are not a favourable surface for coatings. It can be cleaned, among others, with a conversion coating produced by chemical or electrochemical methods. In this way, it is possible to enhance greater resistance to corrosion as well as improving surface adhesion.

Another very popular type of surface, i.e. a plastic surface, is also worth mentioning. This type has relatively low adhesion; therefore, coating usually proves to be quite a difficult task. Such a surface should be previously matted and degreased. Plastics exercise excellent resistance to chemicals, thus damage to such surfaces will not take place. As this type of a surface has a low adhesion, measures can be taken to improve this property. A correct way may be to roughen the plastic with P240, P360 or P600 abrasive paper. Obviously, the surface prepared in this way must be cleaned with an antistatic cloth. Another possibility is to treat the surface with petroleum ether.

Use of polyurethane coatings

Polyurethane coatings are used in a lot of types of industry, mainly in construction and mechanical engineering. However, there are some more specific areas where such coatings are extremely useful, for example floors. There are many types of flooring that can be covered with polyurethane. Industrial floors and those found in commercial centres are the most common ones. Polyurethane floors are used in bowling alleys to make them look shiny and well-polished. Due to its durability, polyurethane is also found on the floors of hangars and garages.

Another type of industry in which polyurethane coatings are used is the aircraft manufacturing industry. Such special polyurethane coatings are frequently designed for aviation applications. They are also used by many companies manufacturing aircraft and helicopters. Polyurethane coatings, apart from protecting aircraft components, also help to save fuel by reducing air resistance. It should also be noted that polyurethane paints is not the most popular polyurethane used in aircraft - these are foams, used in various applications including sandwich structures.

Polyurethane coatings can help protect valuable industrial equipment from various types of external damage that can often occur in this working environment. In addition, polyurethanes also improve performance of a machine; therefore it can operate for an extended period of time.

Apart from the air industry, another transport industry which exploits polyurethanes is the maritime industry. Polyurethane coatings are used to protect sea hulls from corrosion and adverse weather conditions. They are used in all categories of boats and vessels, with different sizes and applications. Additionally, they are used to secure and seal diving equipment.

Transmission infrastructure is another area where polyurethane coatings are used. This permanent coating is used to protect gas and oil pipelines. Many of them run underwater. Due to the fact that polyurethanes can withstand high pressure and harsh conditions, they are an ideal choice. They can also be used in other pipeline categories.

One of the most frequently coated polyurethane materials is steel. Therefore, roofs made of this material are ideal for the application of polyurethane coating. Polyurethane can give a roof a longer life rather than the acrylic base product. Extending the life of an industrial roof is a big saving on costly repairs. For this reason, it is the right choice for any project manager who cares about the economic, long-term features of the structure.

Another application of polyurethane coatings, worth mentioning, is the production of wind turbines. Coatings are used on blades and turbine bases. Polyurethane is a commonly used coating in this category as it can increase the energy efficiency of a turbine. Besides, it provides the right protection.

Adhesion of coatings

Each coating is characterized by adhesion depending on numerous factors. Two phenomena must occur - adhesion and cohesion if this property is to remain on a proper level. Adhesion is the joining together of surface layers of physical bodies or phases [10], while cohesion denotes resistance of physical bodies, which undergo separation. Its measure is the work needed to separate a specific body into parts, divided by the surface area resulting from this separation [14]. An adhesion test is performed to check that the coating has got the required adhesion and that it will adhere properly to the surface. There are several types of tests to measure the adhesion of paints and coatings to the surface, such as the cross-cut test, the scraping test, the pull-off test, etc.

In the scraping test, the adhesion of organic coatings is measured after their application to smooth, flat surfaces of surfaces. This is helpful in giving relative ratings for many coated panels, showing significant differences in adhesion. The tested materials are applied in uniform thickness on flat panels, mainly on metal sheets. Once the materials have dried, adhesion is determined by pressing the panels under a rounded stylus, which is loaded with increasing masses until the coating is removed from the ground surface.

The adhesion of a coating or of several coated samples of any paint product is measured by evaluating the minimum tensile stress needed to tear off or remove the coating perpendicular to the ground. Unlike other methods, the pull-off method maximises tensile stress, thus the findings may not be comparable with other results. The test consists of securing the loads (trolleys) perpendicularly to the surface of the coating with an adhesive. The test apparatus is then attached to the load handling device. Next it is levelled off so as to apply the voltage perpendicularly to the test surface. The applied force gradually increases and is monitored until the coating has been removed or a predetermined value has been reached.

The cross-cut test is a method of determining the resistance of paints and coatings to being separated from the ground, using a tool to cut out a coating pattern at the right angle, penetrating to the ground itself. Using this method, it is possible to perform a quick positive/negative test. When testing a multilayer system, one can determine resistance to separation of individual layers against one another. There are two methods described in the ASTM norm.

The A ASTM D 3359 test method

The cut X is made through the coating to the ground, with a cemented carbide tool. A self-adhesive tape is applied to the incision. The tape is smoothed in place with an elastic band in the incision area. The tape is removed by quickly pulling it back as close as possible to 180°. The adhesion is assessed on a scale from 0 to 5.

The test method B ASTM D 3359

The cross pattern is made through a coating to the ground. The torn off coating parts are removed by soft brushing. The pressure-sensitive tape is applied to the grid cut. Next, everything is performed in the same way as in the previous method. The adhesion is also assessed on a 0-5 scale.

Research methodology

A set of samples made by casting from the examined material was prepared in order to conduct experimental testing of basic properties of polyurethane paints.

The properties were estimated on the basis of the following:

- stretching test,
- compression test
- tribological tests,
- investigations of softening temperature.

In the first stage, moulds made of MM922 silicone were cast for samples to be tested:

- bone-shaped samples for tensile strength tests with the dimensions shown in the figure (Fig. 1),
- cylindrical test pieces for compression testing, at a diameter of 12.2 mm and a height of approximately 17 mm,
- samples for determining the softening temperature, sized 15x15 mm and 4 mm in thickness,
- tribological test specimens sized 80x10 mm and 4 mm in thickness.

The components were then put together in proportions recommended by the manufacturer (3:1 in volume), thoroughly mixed and placed in a vacuum chamber for degassing. The prepared mixture was cast into moulds and left to harden for 24 hours. Later it was removed from the moulds. The mixture excess was removed and the surfaces were sanded to make them even. Consequently the authors prepared: 5 samples for tensile and compression testing, 10 samples for tribological testing, 6 samples for Vicat softening temperature testing.

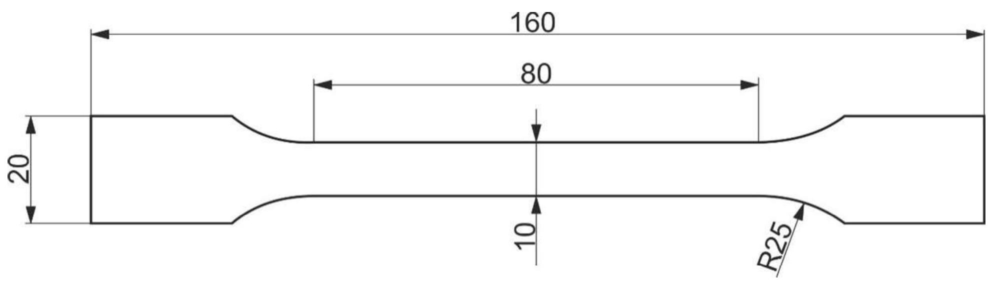

Fig.1. Dimensions of sample for tensile strength tests

Research results

The tensile and compressive strength tests were carried out using a Zwick/Roell 5kW testing machine. The tests of tensile strength were conducted in accordance with the conditions of PN-EN ISO 527 standard. The speed of the traverse movement equalled 2 mm/min. The findings of the tests are presented in Fig. 2. The average tensile strength of the test material is 1.97 ± 0.53 MPa, whereas the value of Young's modulus is 14.8 ± 1.28 MPa. The observation of failure makes it possible to conclude that the destruction of the examined samples occurred in the non-defective areas, so the results can be considered reliable.

The average strain of the samples during their destruction equals approximately 17.5 %.

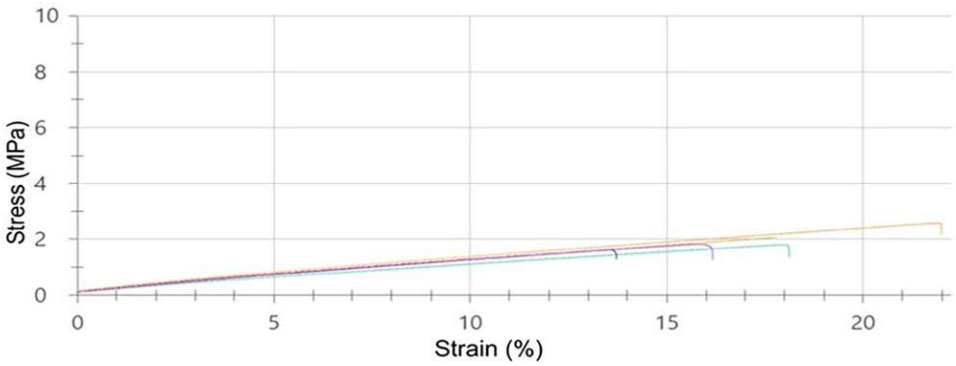

Fig. 2. Chart of material tensile strength

The compressive strength tests were conducted in accordance with the standard of PN-EN ISO 604:2006. The speed of the traverse movement equalled 2 mm/min.

The results of the testing for compressive strength have been presented in Fig. 3. The value of compressive strength is 46.5 MPa, whereas the value of Young's modulus is 10.1 ± 0.45 MPa. The sample destruction during its compression occurred along the height with deformations above 65%.

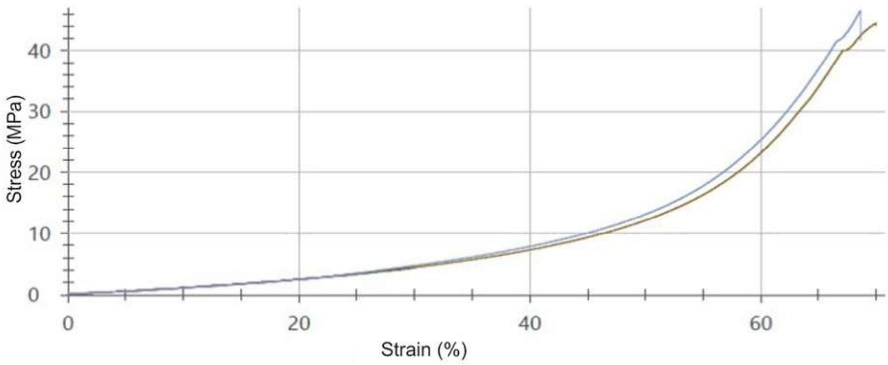

Fig.3. Chart of compressive strength test

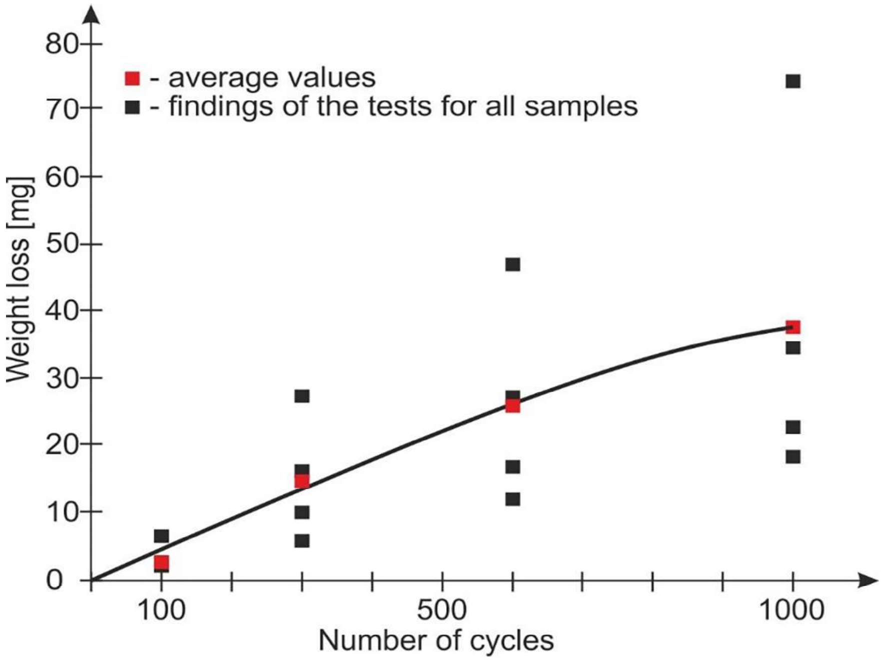

Fig. 4. Loss of sample mass during the abrasion test

The tribological examination was conducted using the Taber Linear Abraser tribometer and Mettler Toledo XSE205 laboratory balance. During the examination, the authors recorded a mass loss of the sample, which was subjected to abrasive wear with the head load of 1,850 grams. The mass loss was recorded after 100, 300, 600 and 1,000 cycles. The findings of the tests are presented in Fig. 4.

An analysis of the results in Fig. 4 shows an almost linear loss of mass as a function of the number of abrasion cycles. A significant scattering of results is characteristic for the test.

Determining the softening temperature of the polyurethane paint was carried out on a laboratory stand HDT and Vicat - Instron HV6X, on which 6 test samples were placed simultaneously. The samples were thermostated in oil at 25°C for 5 minutes and then heated at 120K/hour in (VST) in accordance with EN ISO 306 standard. The penetration measurement of the indenter loaded with a force of 10 N was conducted until a 1 mm material penetration was obtained (Fig. 5). When analysing the results of the softening temperature determination tests, it was noted that in the temperature range 52 - 55°C, most of the samples started to react to the acting force of the indenter (only two samples started to react under different temperature conditions - one at a much lower temperature around 35°C and the other at a much higher temperature around 70°C), however only approximately 0.7-0.9 mm of the penetration was obtained. This might have been caused by the surface and viscosity forces of the paint material. Thus, in subsequent experiments, much larger and thicker samples will be prepared for experimental testing.

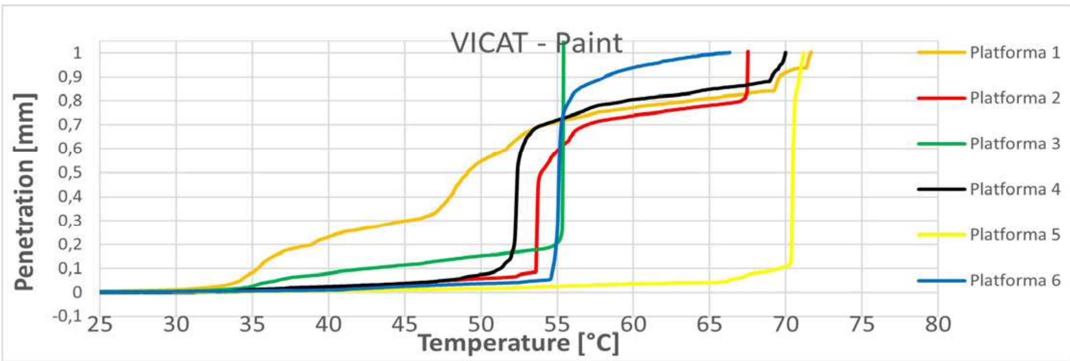

Fig. 5. Penetration of the indenter into the tested material during heating - determination of paint softening temperature

Conclusions

1. During the sample preparation, it is essential to use methods which will enable removing air bubbles from the mixture.
2. The values of the coefficient of longitudinal elasticity determined in the compression and tensile test have different values, despite the same traverse movement speed in both tests.
3. The nature of the tensile and compressive curves indicates a high similarity of the internal structure of the specimens obtained by degassing the mixture of components.
4. The obtained results of mass loss tests after the process of surface abrasion of the material show a linear change of this parameter as a function of the number of abrasion cycles. Yet, at the same time, they are burdened with a large scatter of the obtained experimental results.
5. The softening temperature of the material appears to be around 52 - 55°C.

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