# Aluminium moulds for polyurethane (PU) castings.

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## Abstract

Aluminium moulds are more and more commonly used in the industry for polyurethane (PU) casting. This is due to the fact that aluminium is easy to machine and because of the lower weight compared with other mould materials. The surface should be hard, wear resistant and have good non-stick properties to give the best solution for the PU casting industry.

Five different coatings were tested; hard anodizing, nickel teflon, plasma anodizing, PVD and a plasma coating. The different surface treatments were tested by hardness, wear resistance and adhesion to compare and see if one of the surface treatments would show a unique use for the PU casting purpose. Two different wear resistance methods were used in the tests, the Suga test (ISO 8251) and the Jet test (ISO 8252). The hardness was measured by Vickers hardness. The contact angle of the different coatings was measured and the surface tension was calculated by the Owen-Wendt-Rabel-Kaelble method.

## Introduction

Usually we look at the hardness and wear resistance of the hard coating but sometimes another factor should be kept in mind.

When using aluminium as mould material for PU casting the most important factor is the non-stick property of the surface.

The PU is pressed into the mould with a very high pressure which gives high requirements for the entrance channel according to wear but also to a surface which is ready to let go of the PU when the mould is opened.

Normally the mould is used with bare aluminium and a releasing agent. This is necessary to avoid destruction of the PU-part when the mould is opened. For every shot the realising agent must be sprayed into the mould. Spraying with this releasing agent pollutes the total production area, so everything is getting greasy.

The releasing agent must be applied as a thin and uniform layer to obtain the best non-stick property of the surface.

**What is a non-stick property**

For many purposes the aim of the surface is to meet another surface without the two surfaces are sticking together. These types of surfaces, which can handle this, are called non-stick surfaces. One of the most well-known non-stick surfaces is the Teflon (PTFE) surface on frying pans.

In the PU casting industry it is very important to have a surface where the PU parts are easily released without sticking to the surface. If the PU is still at the surface after the PU part is removed a cleaning process has to be done which gives an increase in the production time and PU waste.

To change the surface tension a releasing agent is used. The surface tension of different materials decides whether or not the two materials will stick together.

A materials surface tension decides whether or not a surface is non-stick. The non-stick effect can be described as the surface resistant to let anything stick to it. The effect of the non-stick property can be defined as a function of the surface energy of the solid.

Adhesion is the bindings between two different materials, which are in near contact through an interface[1].

By adhesion between a solid and a liquid will not only the surface energy of the solid have an influence but also the surface tension of the liquid.

One example is the drop of water on a surface of glass and a surface of Teflon. In this case will the drop of water continue to be a drop on the Teflon surface. Whereas the drop on the glass will be destroyed and wet the total surface. This is due to the much lower surface energy of Teflon (18mJ/m) compared Glass (250 mJ/m) and the surface energy of water (73 mJ/m), see figure 1.

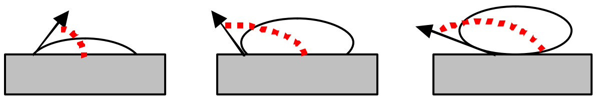

Figure 1, High surface energy compared to the water and low surface energy

These two examples give an idea of surface properties for wetting, the non-stick effect. The difference in wetting can be measured by the contact angle of the drop.

This contact angle is depended on the surface tension of the liquid and the surface energy of the solid.

When the contact angle is zero the critical surface energy of the solid is obtained. At this point will the surface energy of the solid be equal to the surface energy of the liquid (total wetting).

A liquid with a lower surface tension than the critical surface energy will wet the surface effectively, as told above.

### The five surface treatments

Different surface suppliers made the five surface treatments. The thickness of the layers is as subscribed from the supplier, see table 1.

The aluminium surfaces were sand blasted before surface treatment. The order for the suppliers was to make a non-stick and wear resistant surface.

Table 1, Layer thickness as stated by the supplier

| **Surface treatment no.** | **Layer thickness μm** |
|---|---|
| Plasma anodising | 40 |
| PVD | 2.4 |
| Plated Nickel Teflon | 10 - 20 |
| Hard anodizing with Teflon | 30 - 50 |
| Plasma coated | 60 |

## Results

### Surface roughness and contact angles

The surface roughnesses Ra and contact angles were measured before surface treatment. The results are based on five measurements on each sample, see table 2.

Table 2, Result of roughness measurements

| **Sample no.** | **$R_a$** | **Contact Angle** |
|---|---|---|
| 1 | 6.2 | 129.9° ± 3.7° |
| 2 | 6.2 | - |
| 3 | 9.2 | 135.6° ± 4.6° |

For the measurements on the bare aluminium milli-Q water were used. The liquid was supplied with a flow of 10 µl/min. The contact angle was measured on both sides of the drop. Figure 2 shows a drop on sample 1.

Figure 2, Drop on sample 1

The contact angles were measured with milli-Q water and hexadecane on all the surface treatments. Table 3 shows the results. The values are an average of 3-5 measurements on each sample.

The relatively large variation of the contact angles with water can be due to a variation in the homogeneity of the surface or a matter of a surface contamination.

When the needle is removed from a drop that has been laid on the surface, the drop would normally remain on the surface. For the Nickel Teflon treatment, however it is observed that when using water, the drop of water will let go of the surface and remain hanging on the tip of the needle.

Table 3, contact angles using of milli-Q water and hexadecane on surface treated samples

| Surface treatment | Contact angle/water | Contact angle/hexadecane |
|---|---|---|
| Plasma anodising - polished | 124.9° ± 5.9° | 32.1° ± 1.0° |
| Plasma anodising - unpolished | 28.7° ± 3.6° | * |
| PVD | 37.3° ± 7.2° | * |
| Plated Nickel Teflon | 153.3° ± 1.1° | 17.5° ± 2.5° |
| Hard anodising with Teflon | 124.5° ± 5.5° | 59.4° ± 2.8° |
| Plasma coated | 99.0° ± 3.6° | 46.9° ± 4.3° |

*: a contact angle could not be found, as the liquid soaked the surface totally. The contact angle is assumed to be < 10°.

Table 4, Surface energies of the surface treatment. Results are stated in mJ/m

| Surface treatment | Polar contribution | Dispersive contribution | Total surface energy |
|---|---|---|---|
| Plasma anodising - polished | 0 | 24 | 24 |
| Plasma anodising | 38 | 27 | 65 |
| PVD | 33 | 27 | 60 |
| Plated Nickel Teflon | 0 | 26 | 26 |
| Hard anodising with Teflon | 0 | 16 | 16 |
| Plasma coated | 2 | 20 | 22 |

*: the stated surface energies are calculated from a contact angle for hexadecane of 10°. It can be shown that surface energies changes only minimally (< 1 mJ/m) by calculation done with lesser contact angles than 10°.

In table 4 the calculation of the total surface energy is seen, as well as the polar and dispersive contribution to the surface energy.

**Wear resistance**

The wear resistance of the five surface treatments was measured by the Suga test (ISO 8251) and the Jet test (ISO 8252).

Table 5, Wear resistance of the five surface treatment

| Surface treatment | Wear (Suga) Cycles/µm | Wear (Jet) Mean specific abrasion resistance |
|---|---|---|
| Plasma anodising - polished | 105 | 2.34 |
| PVD | - | 31.25 |
| Plated Nickel Teflon | - | 25 |
| Hard anodising with Teflon | 55/104 | 15 |
| Plasma coated | - | 88 |

The ISO 8251 is a reciprocating test, which is a wear test especially designed for abrasive wear measurements on anodised aluminium. The tested surface is reciprocating over a wheel covered by an abrasive strip. The abrasive wheel turns 1/400 rotation for each reciprocal movement. The wheel is pressed against the test surface by a spring load. A load of 4.9 N (500g) is used, according to the ISO standard, no. 8251.

The tested part of the surface is 12 mm wide by 30 mm long and the diameter of the abrasive wheel is 50 millimetres. The test sample makes 40 reciprocal movements (cycles) per minute, giving a test time of 10 minutes per 400 wear cycles. After this the abrasive tape on the wheel is changed. The abrasive wear tape is silicon carbide, mesh 320.

The wear W is presented as the number of wear cycles needed to remove 1 µm of the coating. In all tests the number of cycles was 1200.

The thickness of the oxide layer was measured by a Fisher Isoscope MP3 Instrument.

It was impossible to measure the wear of three of the surface treatments, the PVD coating, the Nickel Teflon and the plasma coating.

The reason for not getting any results with the PVD coating could be due to the thickness, which was only 2 - 3 µm. The roughness (or grain size) of the abrasive wear tape used in this test would be able to go through the layer. By doing this the abrasive tape will get hold of the aluminium matrix and hereby given no informations about the wear resistance of the PVD layer.

The same could be due to the Nickel Teflon layer but only more tests with different layer thickness could explain this.

The plasma coating consists of various phases with a top layer like rubber. When this rubber surface layer is removed and it will be that due to the roughness of the abrasive tape a soft layer is found.

The two different values of the hard anodic coating show how much the quality of an anodic coating can vary. The two samples are processed at the same supplier. The lowest wear (55) was found on the samples that were sand blasted. The high one (104) on a machined part made afterward to use for production.

The ISO 8252 is designed to blast a small area of the oxide layer with silicon carbide particles. The delivery of abrasive was consistent at 28 g/min.

The 20 µm standard test specimen as described in Annex C was penetrated in 32 seconds. This gives the abrasive jet factor as 6.25 microns/s

The end point for each of the samples is quite different, and two tests were carried out on each sample.

The mean specific abrasion resistance has been calculated on the basis of time.

The higher the mean specific abrasion resistance is, the more abrasion resistant is the surface. The mean specific abrasion resistance of the standard panel will be 10, so, plasma anodising, PVD and Nickel Teflon are softer than the standard panel, and hard anodising and plasma coating is harder.

The reason for the very different results comparing to the ISO 8251 should be found in the two different test methods.

ISO 8251 is measuring the layer from outside to the inside whereas ISO 8252 measures right through the coating.

This could be the explanation for the variations in wear of the plasma anodising, which consist of different phases through the layer. The change in structure will give different wear through the layer.

The very high mean specific abrasion resistance of the plasma coating is probably due to the rubberlike surface. When the abrasive flow is meeting the surface it will be thrown back as with rubber.

### Microhardness

The microhardness was measured as Vickers Hardness with a load of 10 g on a cross section.

Table 6, Hardness measure with micro Vickers

| Surface treatment | HV 0.01 |
|---|---|
| Plasma anodising - polished | 450 |
| PVD | ≈ 3400 |
| Plated Nickel Teflon | 594 |
| Hard anodising with Teflon | 900 |
| Plasma coated | 280 / 875 |

The microhardness of the PVD coating is taken from the data sheet for this coating due to the problems with the very low thickness.

The two different values of the plasma coated hardness are due to the surface with various phases.

## Conclusions

The contact angle is the angle that a drop of liquid on a surface creates with the surface it self. The contact angle is an expression of the interaction between the surface and the used liquid. Measurements of the contact angle therefore provide an indication of the chemical characteristics of the surface.

Most often water is used for measurements. Water is a polar liquid that more easily will tend to wet a polar surface (hydrofil) than a nonpolar (hydrophobic) surface. Hence the nonpolar surface will typically get a larger contact angle with water than the polar surfaces. It must however be mentioned that the contact angle is also affected by the roughness of the surface.

As seen in table 2, the raw aluminium surface is very nonpolar (hydrophobic), a big contact angle with water (129.9° and 135.6°) has been measured. These two values are coherent with the values of the contact angles measured on the three surface treatments, plasma anodising, Nickel Teflon and hard anodising. Unfortunately measurements with hexadecane were not made on the untreated aluminium surface without release agent, which could have helped the understanding of the release effect.

The contact angles measured with water on plasma anodised/polished and the hard anodic coating are almost identical. These two surface treatments showed very different behaviour during test in the production line. Turning to the contact angles when using hexadecane, they show values, which differ. Here again the roughness of the surfaces should be taken into account. The polished surface is much more smooth than the hard anodic coating.

The surface energy of pure Teflon is 18 mJ/m. Looking at table 4, it shows that surface energies of the two surface treatments PVD and Nickel Teflon are higher than for the rest. Tests in the production line showed that the hard anodic coating and the plasma coating had the best non-stick properties of the five.

The wear resistance according to the ISO 8251 is in the area of earlier measurements[2]. The results from the Jet test are difficult to compare with the ISO 8251. More tests with the two methods should be done before comparing the results.

In table 8 the five coatings are listed with their ability according to non-stick, wear and hardness.

The wear in the PU mould will be horizontal, so the wear resistance measured by ISO 8251 is probably telling more about the production situation than 8252. Though the PVD coating would probably withstand the wear from the PU, which has not the same wear particles as the wear tape used in the Suga test.

Table 7, Hardness measure with micro Vickers

| Surface treatment | Non-stick | Wear | Hardness |
|---|---|---|---|
| Plasma anodising - polished | Failed | Good | Good |
| PVD | Poor | Good | Good |
| Plated Nickel Teflon | Poor | Good | Good |
| Hard anodising with Teflon | Good | Poor/Good | Good |
| Plasma coated | Excellent | Excellent* | Good |

* as long as the rubberlike coating is found on the surface

Looking at the non-stick surface is seemed like the hard anodic coating and the plasma coated surface had the best properties.

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The microhardness measurements was performed at HaustrupBodycote, Peter Gundel, www.haustrupbodycote.dk

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