06/16/10

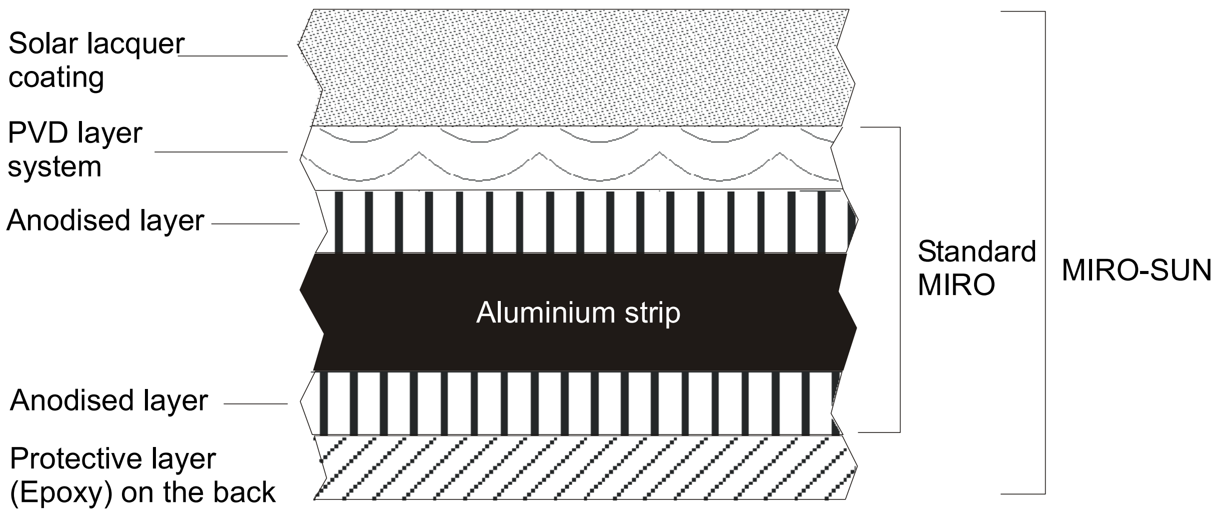
MIRO-SUN®

All products of the MIRO® family are provided with a PVD layer system, guaranteeing a 95 % total reflection. The use of these qualities is limited to lighting fixtures which are designed for indoor use. If you want to develop products for outdoor use the product must have corrosion protection. We provide this corrosion protection with a lacquer. Tests and experiences in the past came to the result that the corrosion protection is best with an anorganic lacquer, a so called “solar lacquer”.

The main fields of application for this new product are parabolic trough solar collectors and flat reflectors to be used in photovoltaic solar systems. The applications are not only systems which redirect daylight, but also applications which need light to generate energy from solar thermal applications or photovoltaic systems. We describe the properties of our product MIRO-SUN® and the results of several accelerated ageing tests on it. The intention is to proof MIRO-SUN® being a suitable product for reflecting light applications for outdoor use.

1 Structure of MIRO-SUN®

MIRO® quality for outdoor application:



Two types of MIRO-SUN® for outdoor use are available - namely MIRO-SUN® weatherproof reflective 90 and MIRO-SUN® PV weatherproof reflective 90. As standard both have a raw aluminum back-side. Both materials are also available with a lacquer on the back-side. These are named MIRO-SUN® backside lacquered 90 and MIRO-SUN® PV backside lacquered 90.

2 Spectral Sensitivity

The PVD-coating is applied to achieve a maximum total light reflection. At the same time it is important that despite varying angles of incidence which might vary from 0° to approximately 80°, a neutral colour should be exhibited. For this reason the MIRO® layer system is not a true ¼ wave layer system, and not even centred at a 0° angle of incidence, at a reference wavelength of 550 nm, as the basis data might suggest.

In order to meet the required spectral and angle parameters, it is essential to centralise the wavelength curve between 480 to 500 nm, in other words, to concentrate on the shorter wavelengths. In view of these basic parameters, the maximum light reflection is not achieved at an angle of incidence around 10°, but at 40° and above. MIRO® which is “Light” optimised for outdoor use, taking this into consideration, is called MIRO-SUN®.

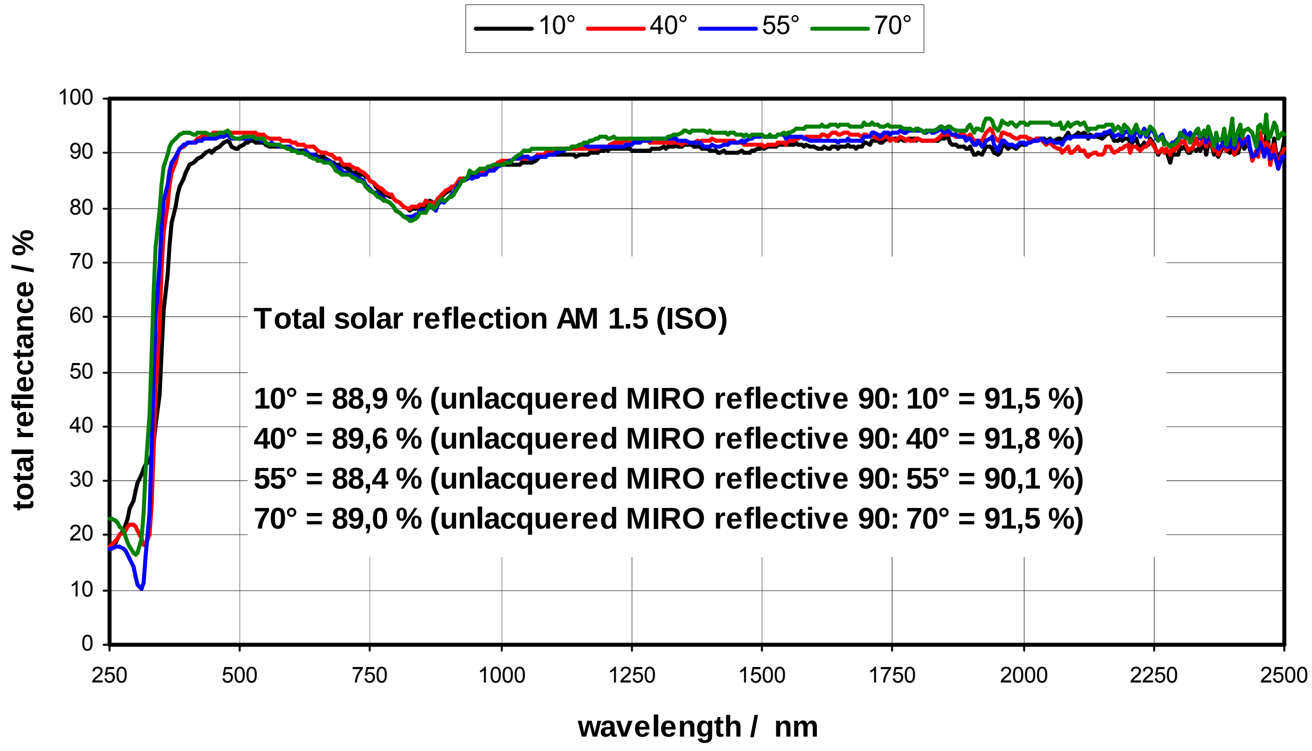
For the solar reflection efficiency, where wavelengths between 300 nm and 2500 nm weighted to the AM1.5 spectrum need to be considered, the absorption area of aluminium around 800 nm needs to be taken into account. Not only with anodised aluminium, but also with multi-layer coated aluminium is this “dip” in reflectivity unavoidable. For use where only the visible light spectrum plays a part, this absorption area is of no consequence since it lies outside the visible light wavelengths which are between 380 nm and 780 nm.

The situation is completely different for use with photovoltaic systems, where silicon is used as a base (sometimes doped with other elements) for the cells. Silicon has its maximum spectral photo sensitivity around 800 nm. For this application, the absorption area of aluminium, for use as reflectors made of either anodised or MIRO material is a serious drawback. This problem could be overcome by using MIRO-Silver®. However, this solution is not realistic since MIRO-Silver® is not suitable for outdoor use at the moment. However, a better solution to the problem of the absorption area of aluminium around 800 nm is to use “spectrally shifted” MIRO® material which can be coated with the solar lacquer for outdoor use. This will be called MIRO-SUN® PV.

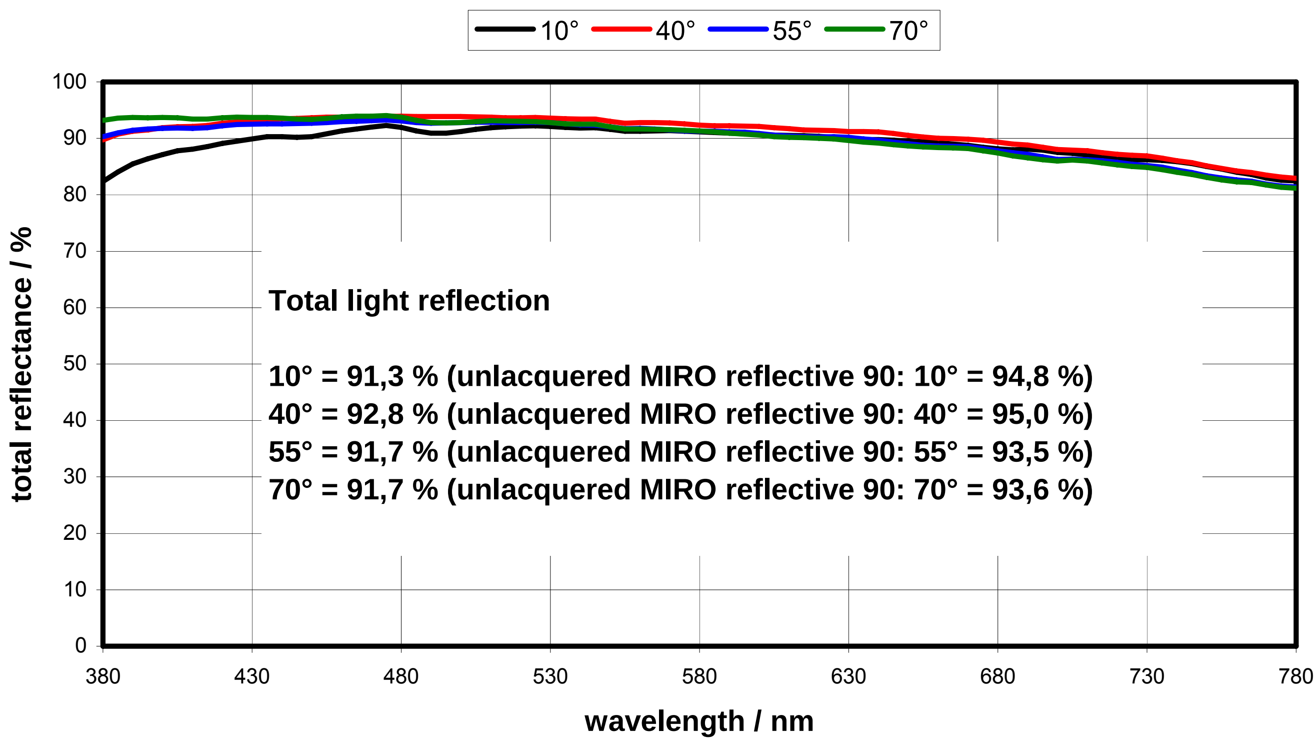
2.1 MIRO-SUN®

The corrosion protected aluminium reflector materials MIRO-SUN® backside lacquered 90 or MIRO-SUN® weatherproof reflective 90 are envisaged for the parabolic solar reflectors and the CPC mirrors (CPC = Compound Parabolic Concentrators), developed from the vacuum tube collectors, where these grades show their high reflection values in the solar light field (300 nm - 2500 nm) as well as in the visible light field. The total reflection figures for these two qualities is shown in the following diagram, each for different angles of incidence (10°, 40°, 55°, 70°).

Total spectral reflectance of MIRO-SUN in the solar region



Total spectral reflectance of MIRO-SUN in the visible range

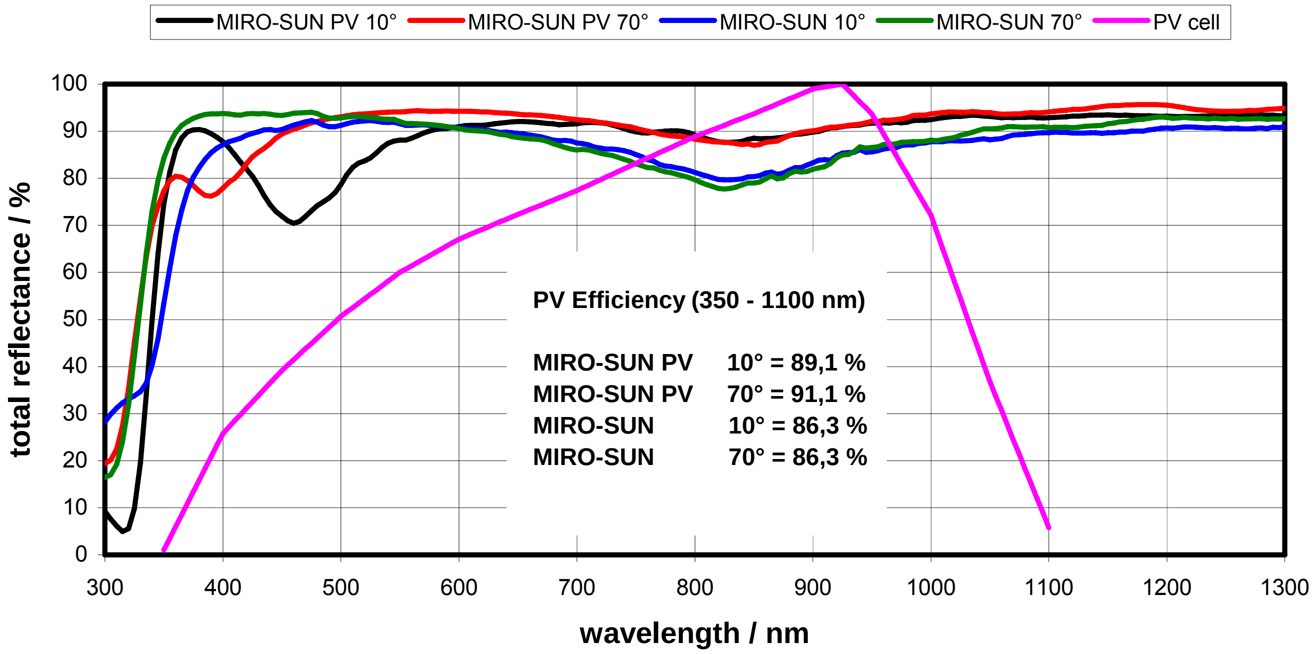


2.2 MIRO-SUN® PV for Photovoltaic Applications

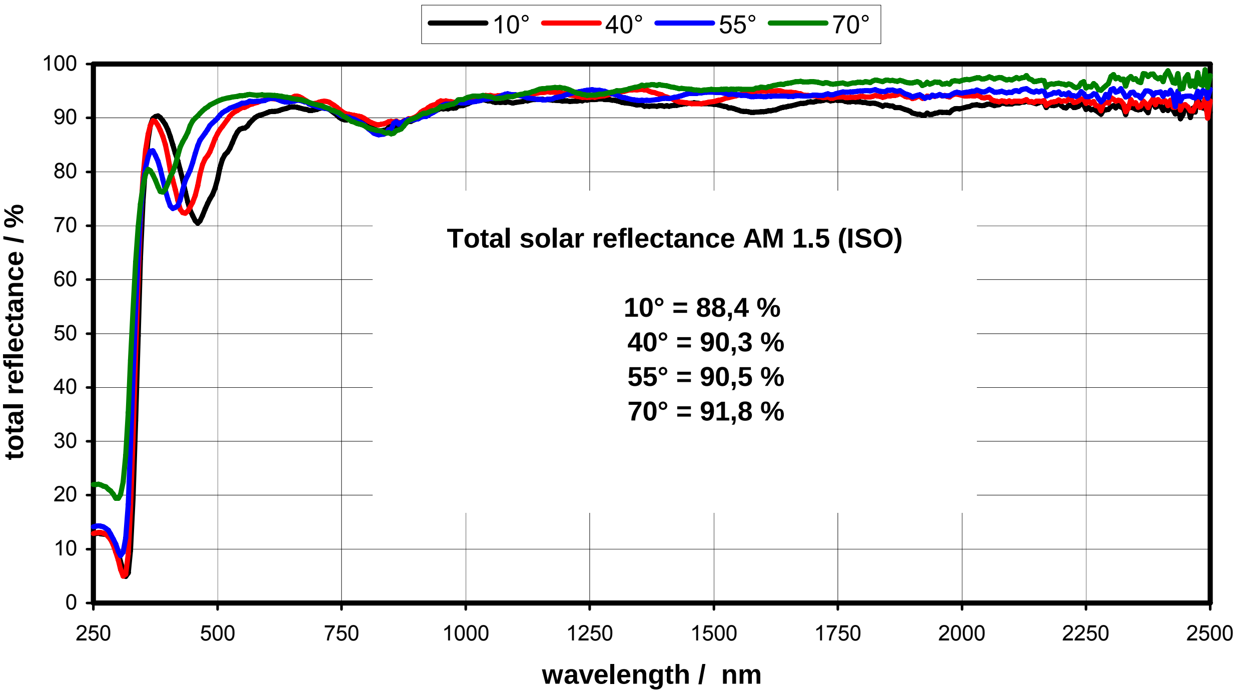
While for visible light applications in general, the spectral reflection needs to have its maximum centralised around 550 nm (500 nm for MIRO®), but for photovoltaic (PV) applications the relative sensitivity of the cells themselves needs to play a part. For Silicon based cells, the maximum sensitivity lies between 750 nm and 950 nm and it is this which needs to be considered. This is the case with the MIRO® variation MIRO-SUN® PV. The diagrams showing the relationship of reflection against wavelength in both, the solar light field (300 nm - 2500 nm) as well as in the visible light field, each for different angles of incidence (10°, 40°, 55°, 70°) follow.

The reflection diagram for MIRO-SUN® PV at angles of incidence of 10° and 70° is shown immediately below, offering a comparison with that of MIRO-SUN® and also showing a typical photo sensitivity of a Si cell against wavelength. The calculated PV efficiency of the lacquered material lies between 89% and 91%, depending upon the angle of incident light.

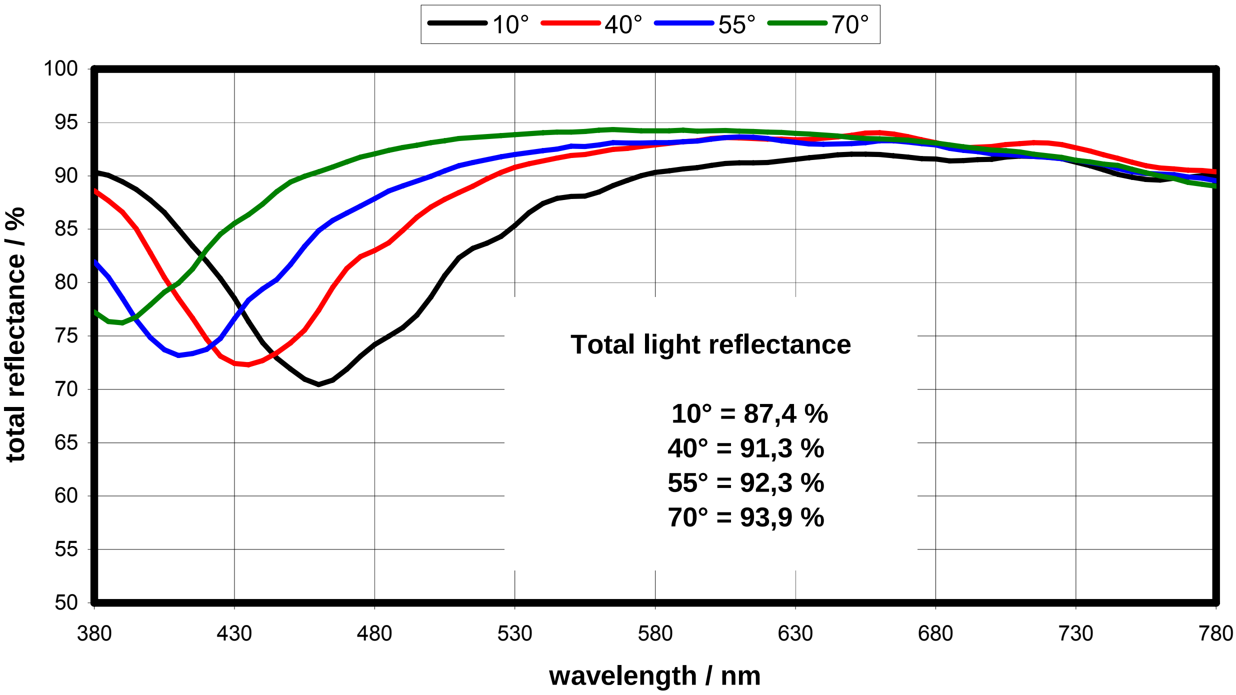
Total spectral reflectance of lacquered MIRO for PV Application MIRO-SUN PV and MIRO-SUN at different angles of incidence



Total spectral reflectance of lacquered MIRO for PV Application
MIRO-SUN PV in the solar region



Total spectral reflectance of lacquered MIRO for PV Application
MIRO-SUN PV in the visible range



3 Optical Values

MIRO-SUN® has the following optical values:

Measurement	Measurement Method	Value
Total Light Reflection / 8°	DIN 5036-3 (U-Kugel)	≥ 93,5 %
Diffuse Light Reflection / 8°	DIN 5036-3 (U-Kugel)	≤ 10,0 %
Total Light reflection / 30°	ASTM E-1651 (TR-2)	≥ 93,0 %
Brightness at 30° incident angle parallel to the rolling direction, light acceptance angle < 2°	ASTM E-430 (Hunter Dorigon)	≥ 87,0 %
Brightness at 30° incident angle across the rolling direction, light acceptance angle < 2°	ASTM E-430 (Hunter Dorigon)	≥ 85,0 %
Brightness at 20° incident angle, light acceptance angle 10°	ISO 7668 (Dr. Lange)	≥ 88,0 %
Brightness at 60° incident angle, light acceptance angle 10°	ISO 7668 (Dr. Lange)	≥ 88,0 %
Total Spectral Light Reflection	DIN 5033 (Minolta)	≥ 93,5 %
Solar Light reflection (10°)	AM 1.5 ISO	≥ 88,5 %

4 Accelerated ageing tests

4.1 Abrasion Test

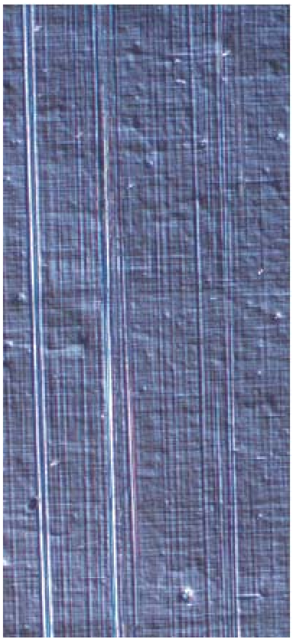
4.1.1 Test Method

The procedure of the abrasion test followed DIN 58 196 T5. Initially the samples were wiped with a felt cloth (diameter 10 mm) with a set force of 4.5 N. it was initially wiped ten times back and forth. Once the sample had passed this test well or showed very little signs of abrasion, the wiping process was continued, now with 20, 50 or 100 wipes.

4.1.2 Results

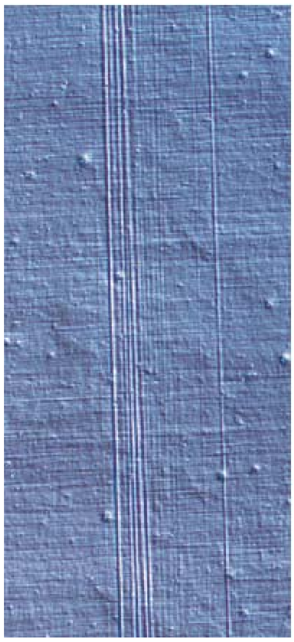
The sample MIRO-SUN® showed excellent abrasion resistance as documented in the photos below. They show the surfaces of MIRO-SUN® in comparison to MIRO® with conventional lacquer, unlacquered MIRO® 4270 GP and anodised 4270G after 100 wipes.

MIRO-SUN



MIRO with conventional lacquer

MIRO 4270GP



Anodized 4270G

The pictures above clearly show (microscope, light from above, bright field) that the sample of MIRO-SUN® shows no damage after the abrasion test, while at the same time MIRO® with conventional lacquer and MIRO® 4270 GP clearly show some abrasion marks. The sample of anodised aluminium 4270G, which is shown as a reference sample, also shows abrasion marks. For the users of MIRO-SUN® this result means that they can clean the surface with a cloth or other tissue without fear of damaging the highly reflective surface. This is a significant advantage for MIRO-SUN®.

4.2 ΔT-Test

4.2.1 Test Method

The test is described in DIN 50 928, chapter 9.5. Circular samples with a diameter of 118 mm were fixed in a special holder under tension. With the help of a pump, the front side (good side) was covered in 42 °C warm water, and the back side with 35 °C water. The test vessel is shown below. The test was carried out for 168 hours. Following this, the sample was visually inspected to see if the lacquer adhesion to the sample was damaged or not. Additionally, Tesa tape was applied to a cross-cut grid and then removed to see if any of the lacquer squares were removed together with the tape removal.

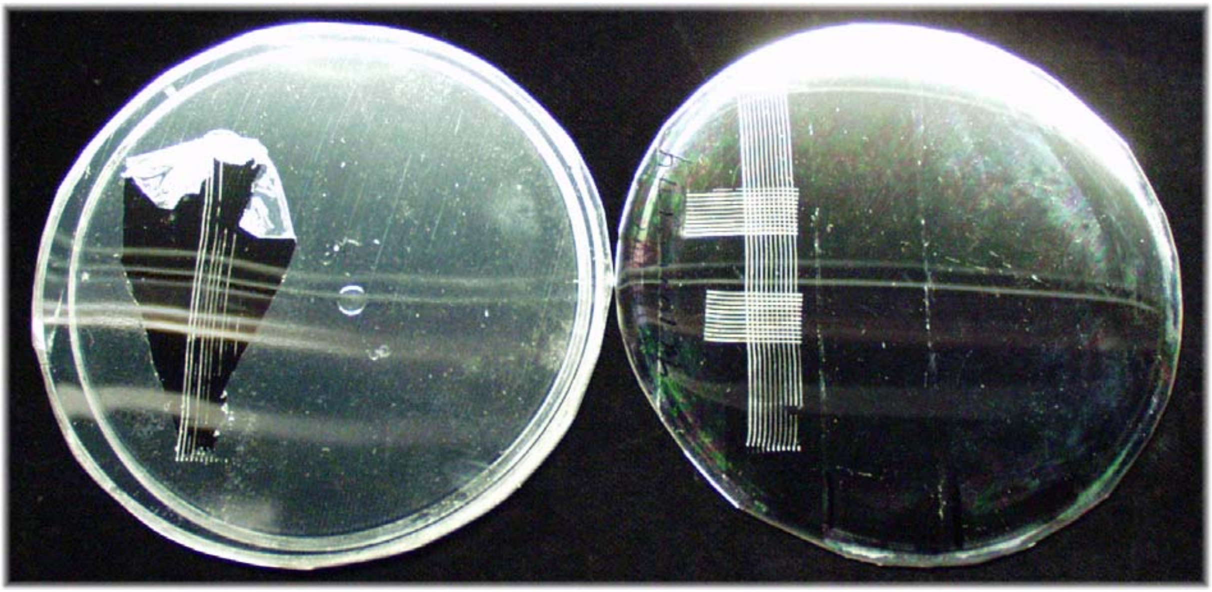
ΔT-Test Vessel:

With this test the following effects could be examined: if the lacquer is pervious to water, then water will diffuse through the layer of lacquer and condense on the cold surface. There it might propagate further and cause further areas of the lacquer to delaminate. Experience has shown that highly reflective surfaces heat up through solar radiation while at the same time the back side of the metal remains cold. In this context the ΔT-Test is very important to asses how the material will behave in practice.

4.2.2 Results

MIRO-SUN® passed the test in all respects, i.e. the lacquer did not delaminate, not even with Tesa film removal, nor Tesa film removal on the cross-cut grid. These results could not be achieved in the case of MIRO® with conventional lacquer which showed lacquer delamination after these tests. On the picture below you see two samples which underwent the ΔT-Test. The sample on the left is MIRO® with conventional lacquer, which did not pass the test, while MIRO-SUN® exhibited very good adhesion qualities.

Sample after ΔT-Test: left: MIRO® with conventional lacquer, right: MIRO-SUN®



The sample on the left shows that the lacquer appears milky and the adhesion test has led to area delamination of the lacquer. At the same time MIRO-SUN®, pictured on the right, shows absolutely no sign of damage. This again confirms the considerable improvement of this product.

4.3 Resistance to Boiling Water

4.3.1 Test Method

A further adhesion test is the heat resistance test; the test followed the guidelines issued by GSB (The German Quality Association for the Piecework Coating of Aluminium Components). In this case, the adhesion of the lacquer was tested in a humid environment. This test is a very sound quick test, where the simulated conditions are much more intense in comparison to the actual situation in practice. If the sample passes this test, very good adhesion characteristics can be testified. Planar samples sized 100mm x 100mm are kept in desalinated water which has been dyed red with a special colour for 8 hours at a temperature of 98 °C. Then the heat is turned off and the water slowly cools down to room temperature. The samples remain in the water during the 16-hour cool-down period; then heat is again reapplied and the samples remain in the liquid for a further 8 hours at 98 °C. This cycle is repeated a third time so that the sample remains in the water for a total of 72 hours, out of which for 24 hours the temperature is at 98 °C.

After above mentioned test procedure, a cross-cut grid is cut into all the samples. Then Tesa tape is applied to the cross-cut grid and in areas without the cross-cut grid. Large scale removal of tape in these areas is assessed, as well as in those areas where the Tesa adhesion test had been done. Removal of lacquer in those areas of the cross-cut grid is assessed on a scale of G1-G5. G0 means that the lacquer is still intact / no removal of lacquer could be observed. The porosity is analysed in those samples were the lacquer has been dyed red. A very dark red discoloration means a high degree of porosity while a pale red discoloration indicates low porosity. No discoloration is generally the aim.

4.3.2 Results

MIRO-SUN® passed the heat test without defects. Lacquer delamination is not observed. Even after the Tesa film removal from the cross-cut grid, the lacquer as well as the MIRO® layer system is intact. This test reveals the shortcomings of MIRO® with conventional lacquer, which have been be remedied through changes in the production process of MIRO-SUN®. The picture below demonstrates the differences in the two products. On the left is MIRO® with conventional lacquer where the lacquer had been dyed red during the course of the experiment. Removal of the lacquer with the Tesa film is clear to see, both where the cross-cut grid is, and of the undamaged surface. At the same time MIRO-SUN® shows no sign of discoloration nor of lacquer delamination.

Apart from the exceptional bonding characteristics it has become obvious that even after a 72 hour bath in the red colour the lacquer shows no signs of red discoloration. This indicates that the lacquer is not porous and does not absorb the red dye.

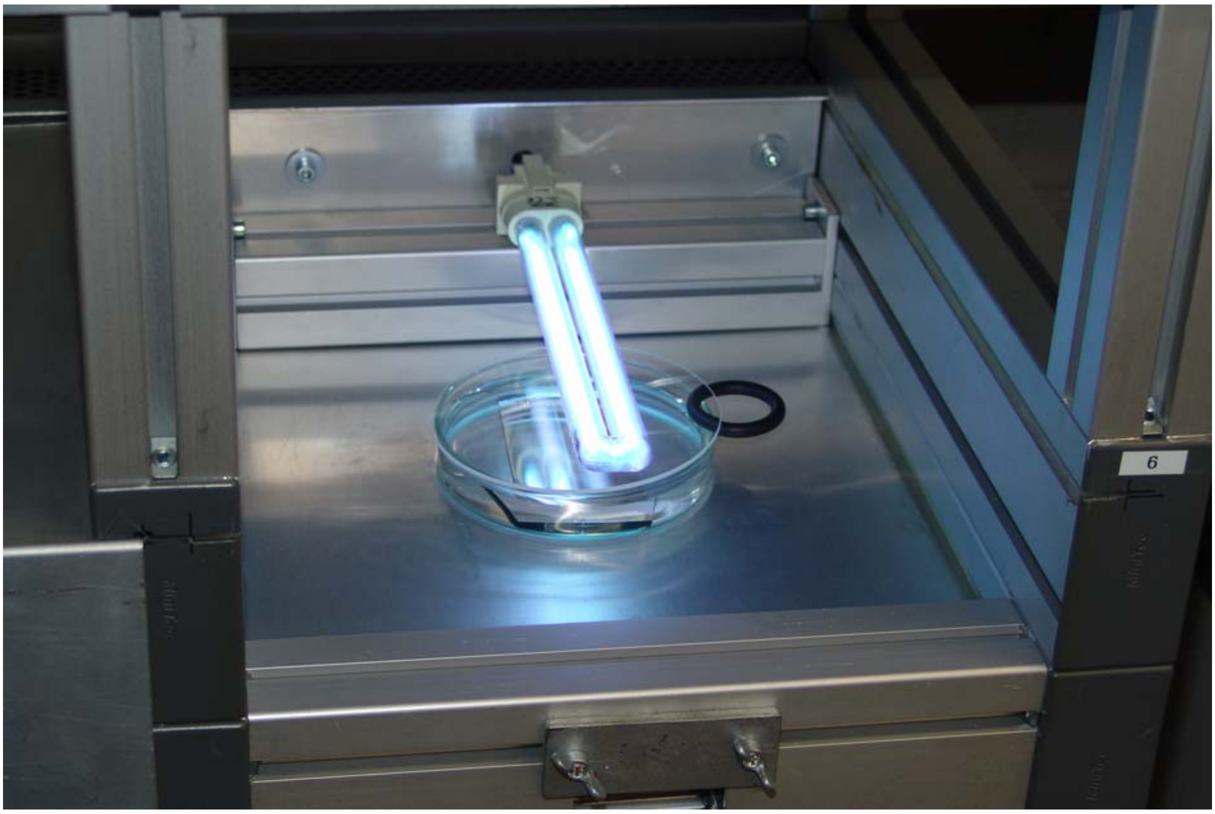
4.4 UV-C Test in desalinated water

4.4.1 Test Method

It is the purpose of this study to assess the stress of lacquered surfaces under UV-light and, at the same time in a humid environment. It is based on the assumption that TiO_2 tends to show photo catalytic behaviour which could lead to delamination of the lacquer.

Samples of size 50 mm x 90 mm are placed in desalinated water in a Petri dish and exposed to UV-C radiation (wavelength 254 nm) for 24 hours. The sample is placed at a 50 mm distance from the UV light source and the light intensity is set at 5.5 mW/cm^2. During the irradiation the Petri dish is covered with a Suprasil glass cover because of its good UV-C transmission. In order to avoid condensation on the Suprasil glass cover during the test phase, the cover is not laid flat but slanted with the help of a rubber ring. The samples are measured before and after exposure with the Minolta system. The spectral total light reflection ((Y) illuminated with the D65 light source), as well as the b* values are measured.

UV-C test in desalinated water:



Finally the samples are tested for delamination using the cross-cut test. Two strips of Tesa tape are applied, one across the cross cut grid and a second one on a virgin area. Both Tesa strips are immediately removed and stuck to a transparent overhead projector foil. The tests are assessed as with 4.2 and 4.3 where complete surface delamination might occur or whether only small squares from the cross cut grid delaminate.

4.4.2 Results

The MIRO-SUN® shows no damage or delamination with the UVC test in desalinated water contrary to that of MIRO® with conventional lacquer.

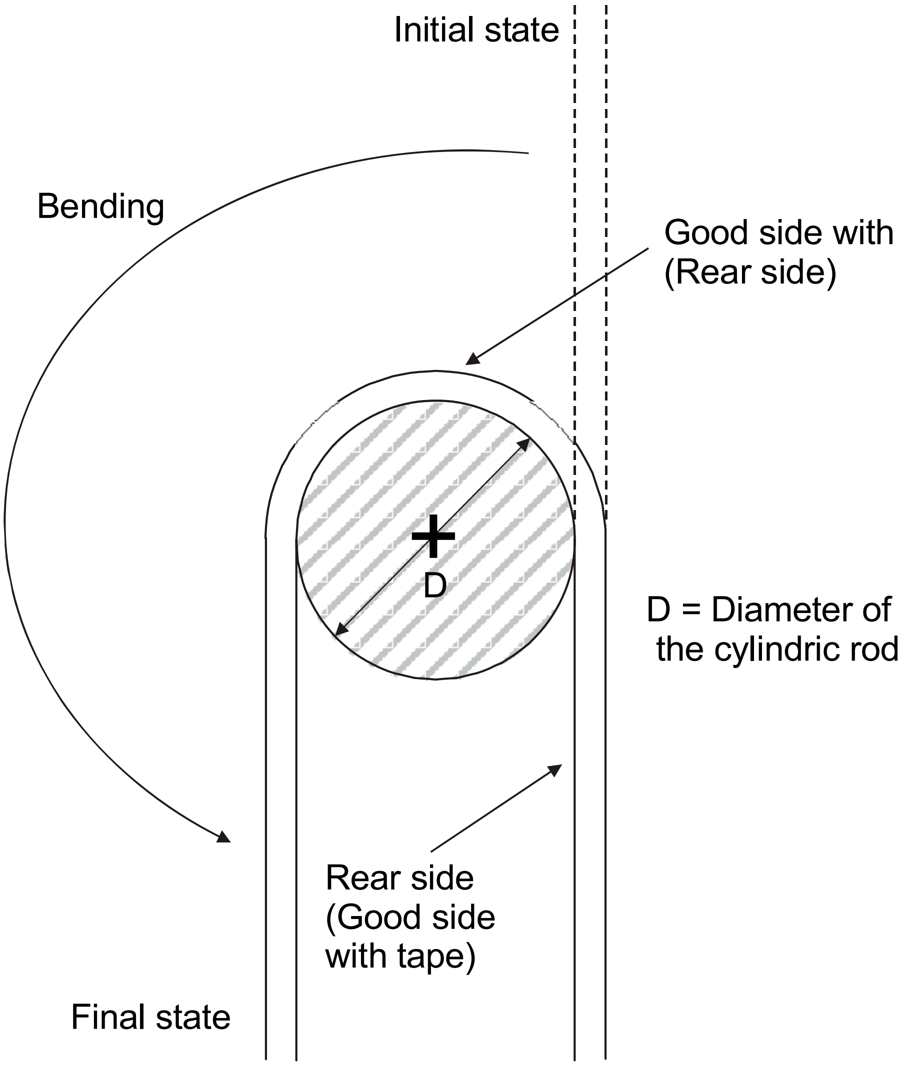
4.5 Bend test

4.5.1 Test Method

The bending test is carried out in accordance with DIN EN ISO 1519 and tests the adhesiveness of the lacquer in the area of the bend. The background for this test is that MIRO-SUN® is envisaged for solar applications and is likely to be formed in a roll-former which it must withstand.

A sticky tape is applied to the samples, which have a maximum width of 60 mm, and are stored for a minimum time of 24 hours. The tape used is one which is utilised as protective tape for our normal product. The samples are then bent around a cylindrical rod of varying diameter. With the good side on the outside of the bend around a 2 mm rod, the surface is put in tension. Additionally the material is bent around rods of 6 mm and 14 mm diameter, with the good side on the inside of the bend, and in this way, the good side surface is put under pressure. The tape is then removed and archived on a transparent overhead projector foil. Here it is checked to see whether any delamination has occurred. Additionally an electrical current tester is used to see if there is any current transmission through the lacquer in the formed areas. If this is the case, this indicates that at these points, the lacquer has been damaged. The principle of the bend test is shown in the following picture.

Bending of the good side on tension (pressure)



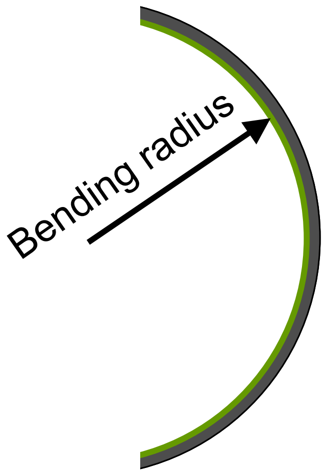
4.5.2 Results

Since the lacquer for MIRO-SUN® is very hard, only bending with the good side outside with an inside diameter of curvature of 2 mm and with the good side inside with a diameter of 14 mm can be withstood whereas with a smaller diameter of curvature of 6 mm (good side inside) occasionally damage to the lacquer layer is to be observed. The final users of the material can therefore bend the material good side outside without worry, whereas bending with the good side inside needs to have a minimum diameter of inside curvature of approximately 14 mm.

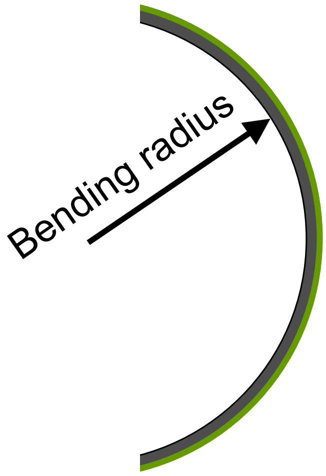
4.6 Lacquer Limit During Forming With MIRO-SUN®

4.6.1 Test Method

The quality side of MIRO-SUN® (material thickness 0.5 mm) was tested for compressive and tensile load on different bending radii.



Reflective surface inwards = compressive load



Reflective surface outwards = tensile load

4.6.2 Results

The test results show, that MIRO-SUN® (material thickness 0.5 mm) can be bended to a minimum radius of 50 mm without cracks in the protective coating.

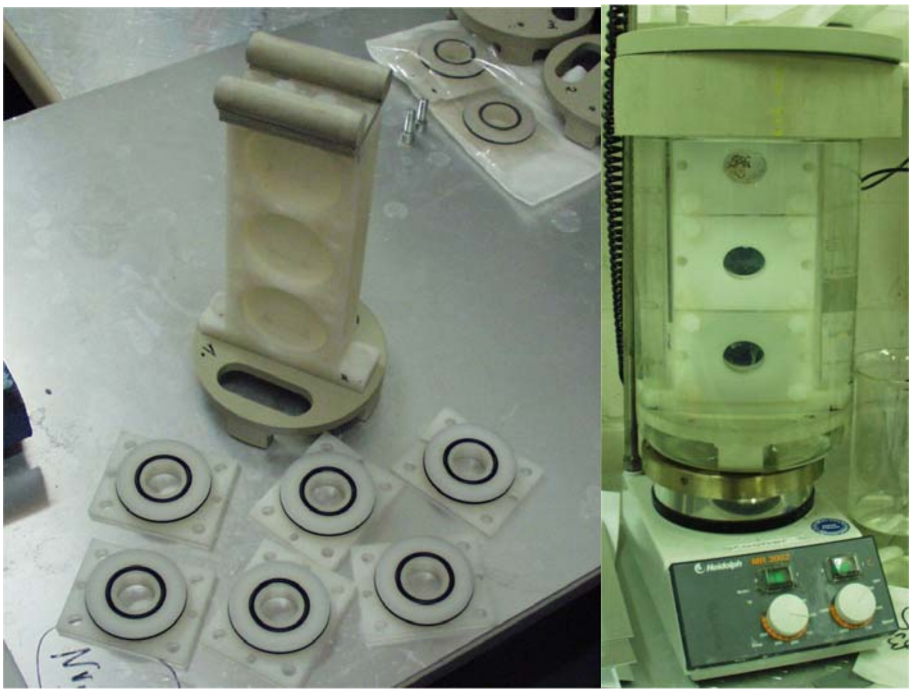
The approved bending radii for MIRO-SUN® (material thickness 0.5 mm) are bending radii ≥ 50 mm for compressive and tensile load.

4.7 Salt Test

4.7.1 Test method

The salt test was introduced to replace the Salt Spray Mist test done according to DIN 50 021. With the Salt Spray Mist test, the sample was tested in a mist of 5% NaCl, but this is replaced with immersion in a salt solution. Comparison tests have shown that the salt test has given virtually identical results to that of the Salt Spray Mist test carried out according to DIN 50 021.

The samples are immersed in a 1 mol/l solution of NaCl at a temperature of 40 °C for 168 hours, during which time the solution is constantly stirred. A special holder for the samples is used to guarantee only the front side of each sample is exposed to the solution. The back side and the edges are covered and not exposed to the corrosive solution. Sample of size 45 mm x 45 mm are tested in this manner. A circular area with a diameter of 25 mm is exposed for corrosion in the solution, equating to an area of 4.9 cm^2. The system is show below.



The samples are measured before and after exposure with the Minolta system and Ulbricht Integrating Sphere. Not only are the optical characteristics measured, but also a visual inspection of the surface is carried out to see if pit corrosion is the result of the immersion in the NaCl solution.

4.7.2 Results

MIRO-SUN® passed this test. The spectral total light reflection ((Y) illuminated with the D65 light source) shows a reduction on the average of 0.5% (occasionally with certain samples up to 1 %), and occasionally localised corrosion in the form of white dots on the surface.

4.8 Steam Test

4.8.1 Test Method

This test is done to mimic the Constant Climate Test done according to DIN 50 017, in a more simplified manner. Samples of size 100 mm x 100 mm are loaded vertically, exposed to steam above a 60°C water bath for 600 hours so that condensation can build and trickle off the sample surface. The samples are measured before and after exposure with the Minolta system and Ulbricht Integrating Sphere. Not only are the optical characteristics measured, but also a visual inspection of the surface is carried out.

4.8.2 Results

MIRO-SUN® passed this test without any damage whatsoever.

5 Summary

As can be seen in the many diagrams, the new MIRO-SUN® has optimal reflection rates in both the visible light spectrum, as well as the solar light spectrum. The good abrasion resistance, as well as corrosion resistance and resistance to delamination, point to a material which will stand the test of time in outdoor environments. At the state of the art there is no fixed formula to correlate accelerated ageing tests with actual time in an outdoor environment.

For the solar lacquer on anodised aluminium there exist already a 5 year experience. So you can assume that MIRO-SUN® is as good.

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