

RESULTS OF A ROUND ROBIN ON ACCELERATED TESTING OF ABSORBER SURFACE DURABILITY

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ABSTRACT. From April '97 to June '97 a round robin test on accelerated life time testing of absorber coatings was performed by three different laboratories. This investigation was undertaken within a project of the working group 'Materials in Solar Thermal Collectors (MSTC)' of the International Energy Agency - Solar Heating and Cooling Programme (IEA – SHCP).

The tests were performed according to the standard proposal 'Solar Energy – Materials for Flat Plate Collectors – Qualification Test Procedures for Solar Absorber Surface Durability' [1], which was submitted to the secretariat of ISO TC 180 'Solar Energy' in February 1997. The proposal is based on a methodology for accelerated life-testing of solar absorber coatings developed within the framework of the former IEA SHCP Task X [2] and was refined by the IEA working group MSTC.

In all, five different absorber coatings were available for the round robin. Three of them are of the black chromium type (two on copper substrate one on stainless steel). One is a new sputter coating on stainless steel and another is a selective paint on an aluminium substrate.

The examination performed by all three laboratories are the check of the optical homogeneity followed by the tests of the resistance to thermal loads as well as to high humidity & condensation. The results of the different labs show very high agreement for all of the tests and for all of the coatings.

1. INTRODUCTION

In order to get an information about the stability of solar absorber surfaces, methods for accelerated life testing (ALT) have been established in the framework of the IEA Solar Heating and Cooling Programme Task X [2]. The continuation of this work, performed within the IEA Working Group 'Materials in Solar Thermal Collectors' (MSTC), was leading to a general test procedure for qualification of solar absorber surface durability which was sent to the secretariat of ISO TC 180 'Solar Energy' in February 1997 as standard proposal [1].

The procedure is applicable to absorbers for the intended use in single glazed flat plate solar collectors for domestic hot water production. It takes into account high

temperature degradation, degradation caused by the action of moisture or condensed water and degradation by atmospheric corrosion due to sulphur dioxide as an airborne pollutant. The design service life is assumed to be 25 years. This is the time period of exposure under service conditions, during which the degradation of the absorber surface is leading to a maximum loss in solar fraction of 5%.

Whereas passing all of the tests is equivalent to a qualification of the absorber coating - substrate combination for the use in a flat plate collector in DHW systems, failing a test is not a disqualification. As the procedure is basing on the assumption that degradation is caused by one single mechanism which is following the Arrhenius law, failing might be explained by a different path of degradation or by a combination of different mechanisms. Thus, a more comprehensive investigation about durability of the absorber surface is recommended in this case.

2. PARTICIPATING LABORATORIES AND TESTED COATINGS

The three participating test laboratories are very well experienced in durability assessment of solar absorber surfaces:

- SPF** Institut für Solartechnik Prüfung Forschung, HSR Hochschule Rapperswil, CH-8640 Rapperswil, Switzerland
- ISE** Fraunhofer - Institut für Solare Energiesysteme, D-79100 Freiburg, Germany
- SP** Swedish National Testing and Research Institute, S-501 15 Boras, Sweden

Two of the five participating absorber manufacturers are producing black chrome coatings since more than 20 years (F, G). The remaining three are either newcomers on the market (K, M) or have a new product (L, M). Two additional newcomers draw back their assent of participation shortly before starting the round robin.

Table 1: The five different coatings tested.

Label	manufacturer	Coating	substrate
F	Energie Solaire S.A., Switzerland	C2-80	stainless steel
G	MTI, USA	Solar-H-Foil	copper
K	ChromeCoat A/S, Denmark	ChromeCoat	copper
L	TeknoTerm Energi AB, Sweden	Sunstrip – Sputter	stainless steel
M	Nat. Inst. of Chemistry, Slovenia	selective paint	aluminium

3. TEST PROCEDURE

All tests performed were carried out according to the ISO standard proposal [1] with the exception of adhesion measurements. As the method is still in discussion, this measurements were conducted by one lab only. Furthermore, besides the optical homogeneity test, only high temperature and high humidity & condensation testing

was performed by all of the three laboratories. Therefore, atmospheric corrosion testing as well as adhesion measurements are not a subject of this publication, but can be found elsewhere [3].

To quantify the degree of degradation after a specific test, the performance criterion function PC is used. This function expresses the change in optical performance of the absorber surface caused by the test performed. It is defined as:

$$PC = -\Delta\alpha_s + 0.25 * \Delta\varepsilon, \text{ with}$$

$\Delta\alpha_s$ change in solar absorptance and $\Delta\varepsilon$ change in thermal emittance

In order to be qualified for testing, a set of 21 specimens (5 cm x 5 cm) of the candidate material have to meet the requirements for optical homogeneity, which are defined by the maximum standard deviation in determined values of the solar absorptance $\sigma_\alpha < 0.01$ and in determined values of the thermal emittance $\sigma_\varepsilon < 0.04$.

After passing the homogeneity control, high temperature and high humidity & condensation tests are performed. The way of testing (see figure 1) is the same for both stability criteria, even if the test conditions are different, of course.

In the following description of the test procedure, times and temperatures always

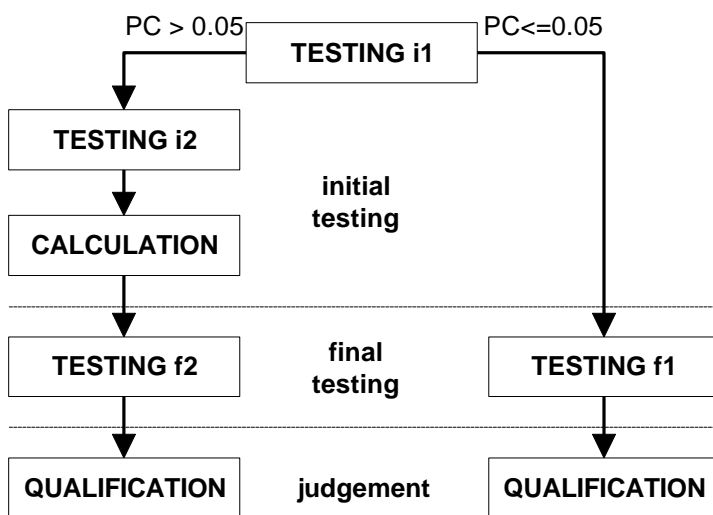


Figure 1: Flow chart of the test procedure

Always three samples of the candidate material are tested in parallel and the mean value of the PC function determines the continuation of the test.

The procedure starts with TESTING i1: 200 hours at 250°C (up to 600 hours with several interruptions to determine optical properties at 40°C). If the PC mean value of the three samples exceeds 0.05 TESTING i2 has to be performed at the same temperature but for a shorter time of exposure. From the PC values of TESTING i1 and TESTING i2 the activation energy can be found which should correspond to PC = 0.05. This activation energy determines the testing time for TESTING f2 at a temperature of 200°C (30°C). The coating is qualified if the PC value after TESTING f2 is smaller than 0.05.

If after TESTING i1 PC is smaller than 0.05, TESTING f1 has to be performed for 75 hours at 300°C (85 hours at 60°C). The coating is qualified if both, PC(i1) and PC(f1) are smaller than 0.01, or if PC(f1) > PC(i1) or if the difference of PC(i1) and PC(f1) is less than 0.01. The latter two can be combined to PC(f1) > PC(i1) – 0.01.

refer to high temperature testing. For humidity & condensation testing the values are enclosed in brackets. Furthermore, the testing temperature always refers to the temperature of the sample. This is important to notify, as in high humidity & condensation testing the sample is fixed onto a cooled holder at an angle of 45° and the ambient temperature is kept 5 K higher (at 95% relative humidity). Doing so, constant condensation on the surface of the sample is assured.

4. RESULTS AND DISCUSSION

4.1. Optical Homogeneity

The results of the homogeneity control are plotted in figure 2. The ordinate is divided up into two sections, reaching from 0.00 to 0.26 for thermal emittance and from 0.89 to 1.00 for solar absorptance. Besides the mean values with standard deviation the measured extreme values can be found in this diagram.

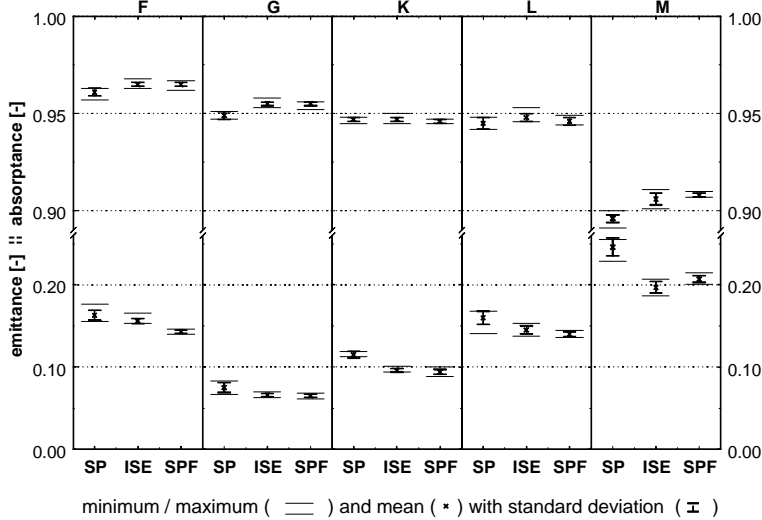


Figure 2: Optical properties of the coatings

between SP on the one hand and ISE and SPF on the other, are originated in the completely different method of measurement. However, as only changes in optical properties are used for the qualification tests, this is of minor importance.

4.2 Thermal stability

The course of high temperature testing is the same for all of the coatings and can be described with the right wing of the flow chart of figure 1. As after 200 hours at 250°C (TESTING i1) the PC values of the coatings still are smaller than 0.05, final testing has to be performed at 300°C for about 75 hours (TESTING f1).

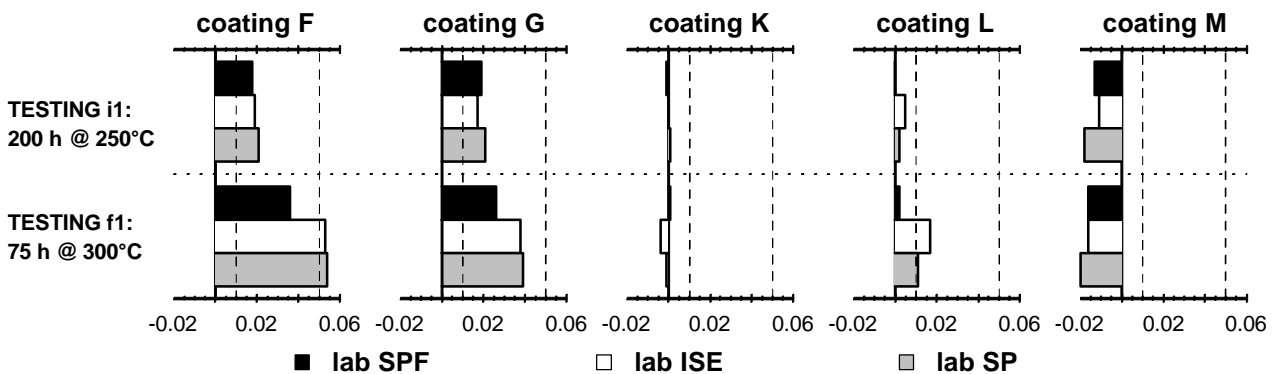


Figure 3: PC values of the coatings as reported from the different labs

Obviously, TESTING f1 is resulting in lower degradation at lab SPF than at the other laboratories. The reason for this was found to be a defective temperature control unit of the ventilating air furnace. The temperature was not kept at the required (300 ± 1) °C but it was fluctuating with an amplitude of ± 1.5 K around 298°C with a period of some hours. Repetition of the 300°C test with some new samples (after fixing the control unit) was leading to PC values which are in good accordance to the others.

Apart from this incident, all results are in very good agreement. Coatings F, G and L are qualified as $PC(f1) > PC(i1) - 0.01$. Due to the lower load during TESTING f1, lab SPF could judge coating L to be qualified as $PC(f1)$ and $PC(i1)$, both, are smaller than 0.01. Coatings K and M are qualified as after TESTING i1 and after TESTING f1 PC is less than 0.01.

However, it has to be mentioned, that TESTING f1 is superfluous if TESTING i1 is leading to $PC(i1) < 0.01$ (coatings K, L and M): in this case the coating is qualified either if $PC(f1) < 0.01$ or if $PC(f1) > PC(i1) - 0.01$. As $PC(i1)$ is less than 0.01 anyway, one of the two conditions always is true.

4.3 Stability to high humidity and condensation

Similar to high temperature testing, the course of the condensation test is the same for all coatings. It is described by the right wing of the float chart of figure 1.

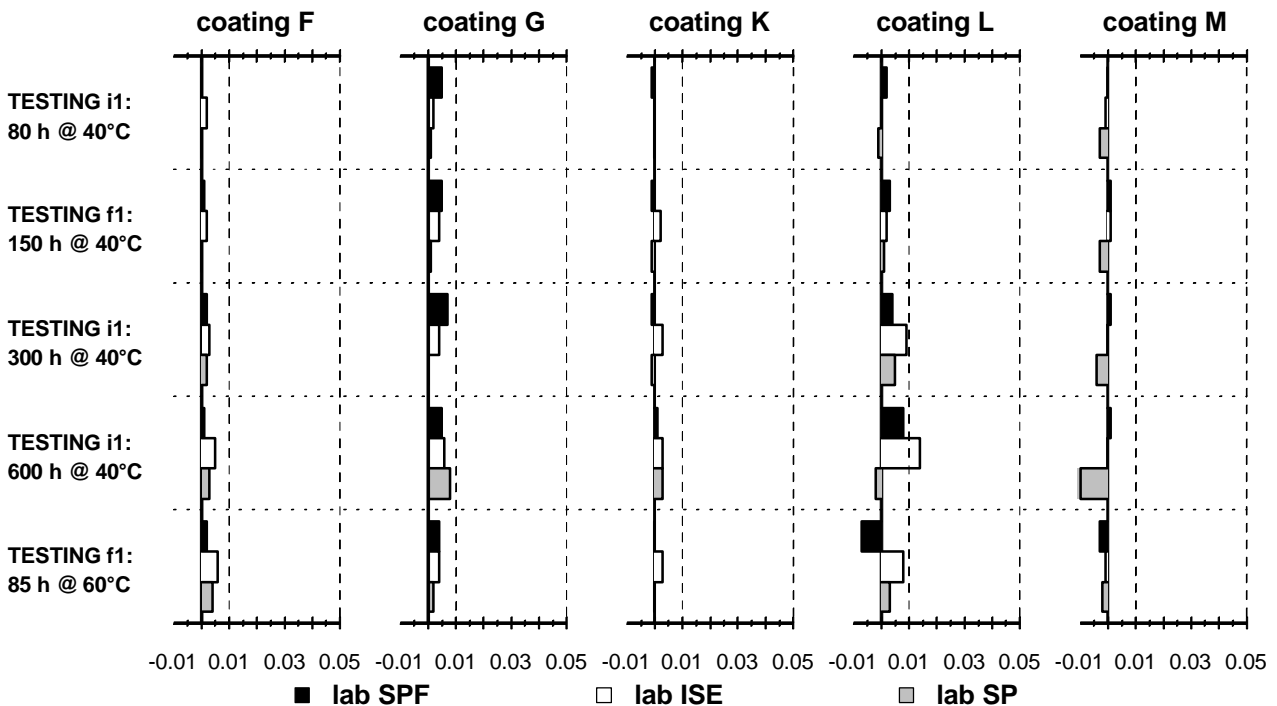


Figure 4: PC values of the coatings as reported from the different labs

Initial TESTING i1 is performed at 40°C sample temperature up to 600 hours with 3 interruptions for optical measurements after 80 hours, 150 hours and 300 hours, respectively. As after 600 hours PC still is less than 0.05, the procedure goes on with final TESTING f1 (85 hours at 60°C).

As can be seen from figure 4, all laboratories come to the same judging: qualified as $PC(f1) < 0.01$ and $PC(i1) < 0.01$. The PC values of the specific tests are

close together. An exception is the behaviour of coating L at lab ISE, which is qualified as $PC(f1) < PC(i1) - 0.01$. Obviously, degradation is a bit more pronounced in this case, which might be caused by a load slightly higher than the one of the other labs. The other coatings show the same tendency (apart from the 600 hours test at SP, see below). However, the measured changes in optical performance are too small to be a serious indication.

Furthermore, the $PC(i1)$ values after 600 hours of testing at 40°C of lab SP are a bit uncertain. Due to an error of the spectrophotometer, the absorptance had to be re-measured after the adhesion measurement. This is most probably the reason for the extraordinary low value for coating M.

Like already noticed at high temperature testing, final testing would have been superfluous for all of the coatings as the initial values of the performance criteria $PC(i1)$ are lower than 0.01.

5. CONCLUSION

The results of this round robin testing clearly show that the ISO proposal on accelerated life time testing for solar absorber coatings [1] is feasible and reproducible. Not only the main statements of qualification or non-qualification of the three laboratories are the same for all five coatings tested. Moreover, all three laboratories are measuring almost the same changes in optical properties after specific tests for the main part of the tests performed.

ACKNOWLEDGEMENTS

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