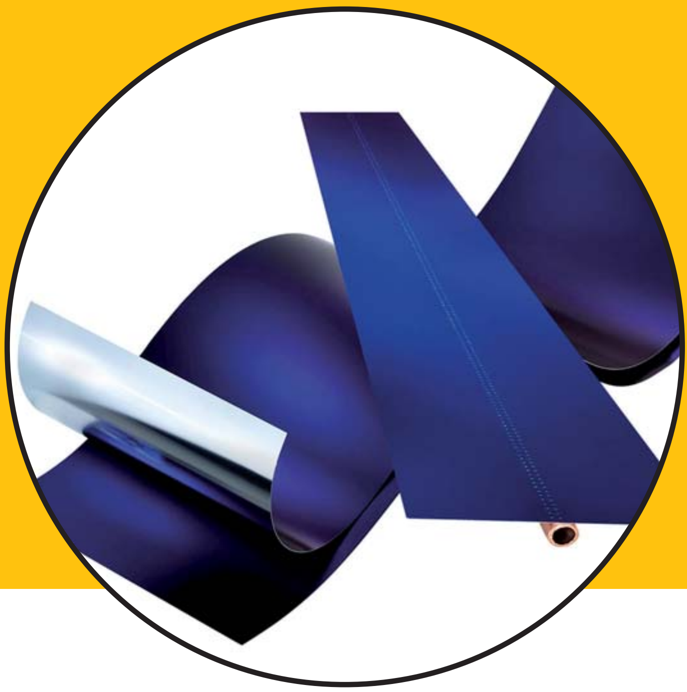

mirotherm® absorber fact book

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mirotherm® absorber fact book

Dear Reader,

In 1999, when ALANOD® set out to develop a highly selective absorber coating based on an aluminum substrate (what would eventually become known as mirotherm), few could have imagined that the same laser welded copper tube and aluminum absorber would be introduced as the "new industry standard" at the First Solar Thermal Industry Forum during Intersolar 2008 in Munich. But for ALANOD®, this was part of our vision all along, and is now an important milestone in our long-term strategy to bring the superior cost and handling advantages of aluminum absorber material to the wider solar market.
This important validation was only achieved through the use and advancement of laser welding technology in order to guarantee an end product that would last for more than twenty years in a flat plate collector system. The journey that began in 1999 has taken many different shapes and forms over the years, and has included many laser welding technology and customer achievements.

For example, in 2003 ALANOD's commitment to the creation and launch of innovative new products led to the founding of a new venture called SunLaser AG Switzerland. Through this collaboration, we co-developed the laser welded mirotherm absorber with the goal of designing a product that featured the industry's highest efficiency, durability and corrosion resistance standards. SunLaser AG won the prize for innovation at the 14th Solar Thermal Symposium in Bad Staffelstein in 2004, and as an OEM manufacturer has successfully sold laser welded mirotherm absorbers to more than 20 solar collector manufacturers. With its successful product introduction complete by 2006, the venture was eventually sold to one of its own customers.

Looking back, we are proud that almost all large European collector manufactures now have in-house production capabilities for manufacturing laser welded absorbers. We consider this as a victory in our goal to make the technology widely accepted and readily available. And with mirotherm now almost a decade old as a proven and reliable product, we at ALANOD® felt it was time to document the performance of laser welded absorber technology and to showcase its many applications.

This **mirotherm® absorber fact book** is filled with testimonials and examples from the solar thermal industry, and is intended to reinforce the quality and durability of aluminum laser welded solar thermal absorbers in our customers' own words. We hope this book can serve as a best practice resource for the industry as well as a tool that can instill confidence amongst distributors, installers, end consumer, and stakeholders in emerging markets that laser welded aluminum absorbers are a reliable industrial product for the growing global solar thermal market.

Ennepetal, 20.02.2009
Alanod-Solar GmbH & Co. KG

Ingo Beyer
CEO · Managing Director

ppa. Frank Schoonen
Sales Director

mirotherm® absorber fact book

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2.1

Test Report No. X111

Customer: Wagner & Co. Solartechnik GmbH – Long term load testing:
Laser welded Cu-Alu absorber thermal-shock test procedure (on arrangement).

Contents

1. Test setup

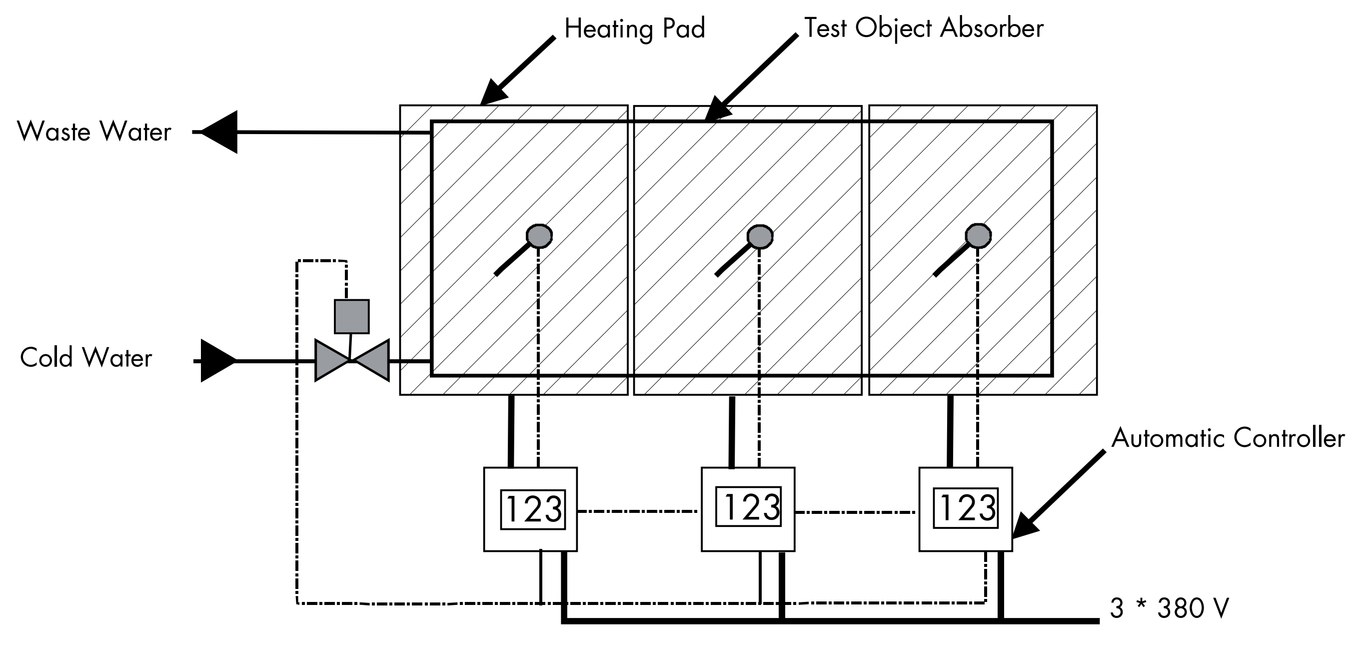


Figure 1: Test setup

1.1 Setup of test facility

The absorber was mounted freely on a horizontal mineral wool base. A heating blanket consisting of 3 synchronized heating zones was laid over the absorber, whereby each heated zone had a separate programmable temperature controller. Cold tap water controlled from a program by a solenoid valve was circulated through the absorber to induce thermal shocks.

1.2 Description of the test object

The solar absorber was delivered by the customer. It consists of a selective-coated aluminum sheet with a welded-on (laser welding) copper pipe circuit.

Absorber dimensions:	1100 mm x 1863 mm
Absorber thickness:	0.5 mm
Harp circuitry:	9 ascending pipes; separation approx. 115 mm
Pipe dimension, External diameter:	8 mm
Begin of the weld (Distance from absorber edge):	between 5.5 cm and 6.5 cm
Distance of most external pipe to absorber edge:	85 mm

1. Test setup

1.) High temperature cycles	
Event	Duration (approx. in minutes):
Heating to 200 - 220°C	10
Maintain maximum temperature	4 - 5
Cooling to approx. 20°C	10
Number of cycles	20
2.) Low temperature cycles	
Event	Duration (approx. in minutes):
Heating to >100°C	4
Maintain maximum temperature	<1
Cooling to < 60°C	2
Number of cycles	3000

1.3 Test conditions

The absorber was heated to the desired temperature as given by the customer after which cooling was provided via the cold tap water. This cycle of heating and cooling was repeated successively until the prescribed number of repetitions was reached. The investigations were divided into the following two categories.

1.4 Method

For the purpose of temperature logging and control a number of Pt100 sensors were fixed to the absorber (Fig. 3). The following figure shows the temperature profile (high temperature cycle) over the period of an hour. Clearly visible on each cycle approaching 100°C is the boiling of the stagnant water within the piping:

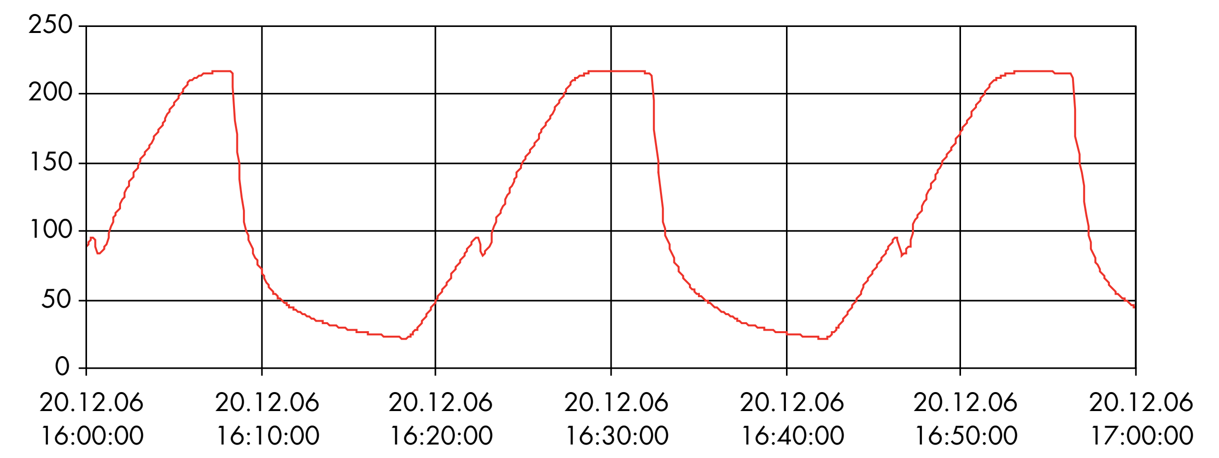


Figure 2: Temperature profile over time of high temperature cycle

1. Test setup

Measurement of the temperature at different points on the absorber shows a significant scattering. To homogenize the temperature over the whole absorber the waiting time on the upper temperature limit should be maintained for a number of minutes. In the case of the high temperature cycling modification was made accordingly to the test sequence and the subsequent programming. In order to keep the total testing time acceptable this measure was abandoned for the low temperature cycling. As is visible in Fig. 3 this scattering of measured temperatures of the absorber are evident yet within the tolerances specified (100°C ± 10°).

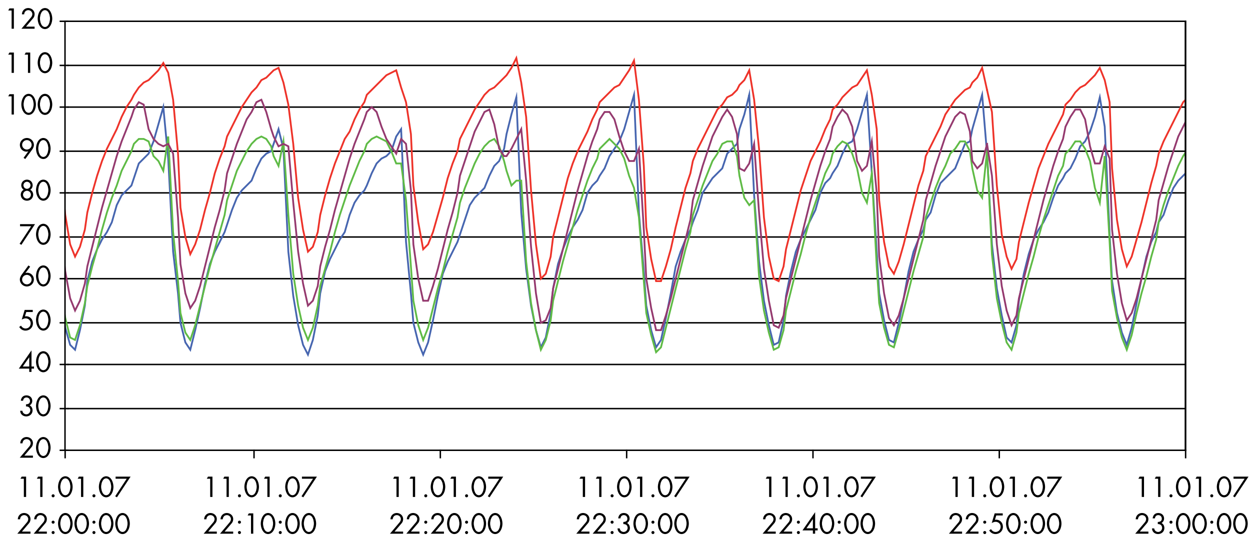


Figure 3: Temperature profile over time of low temperature cycle

Duration of complete test sequence:
20 High temperature cycles, each approx. 25 min: 500 minutes
3000 Low temperature cycles, each approx. 6.5 min: 19500 minutes
Total approx. 335 hours

2. Observations

The absorber was visually appraised following the first 20 high temperature cycles as well as each subsequent 1000 low temperature cycles.

2.1.1 Absorber before testing

On appraisal of the absorber before testing there were no noticeable problems. In particular all welded seams were judged to be in good condition.

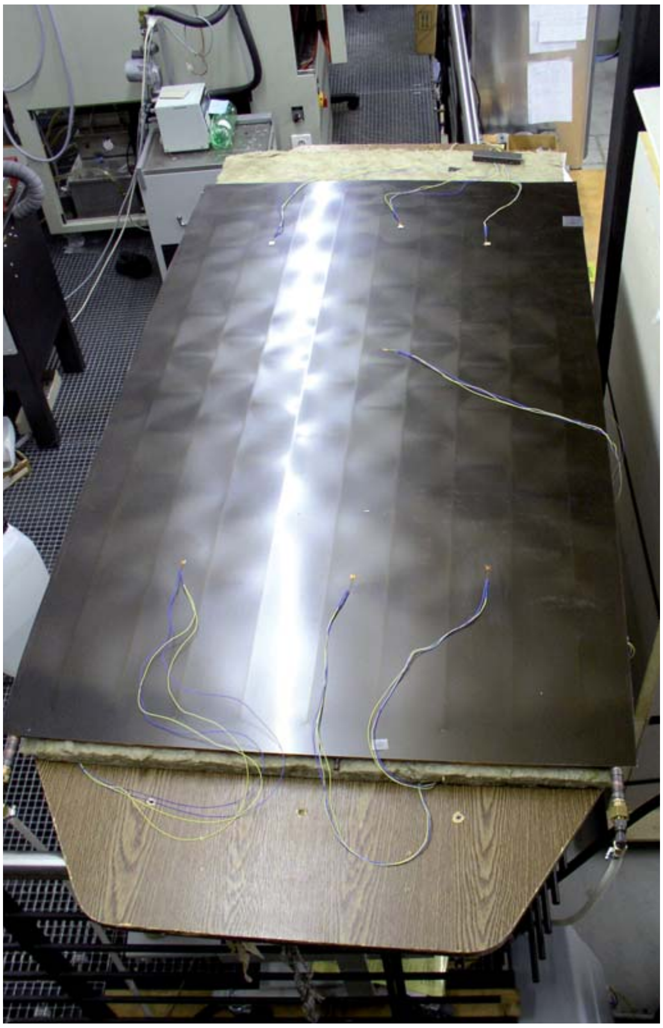


Figure 6: Absorber lying on insulation platform. Various positioned Pt100 sensors visible on absorber surface.

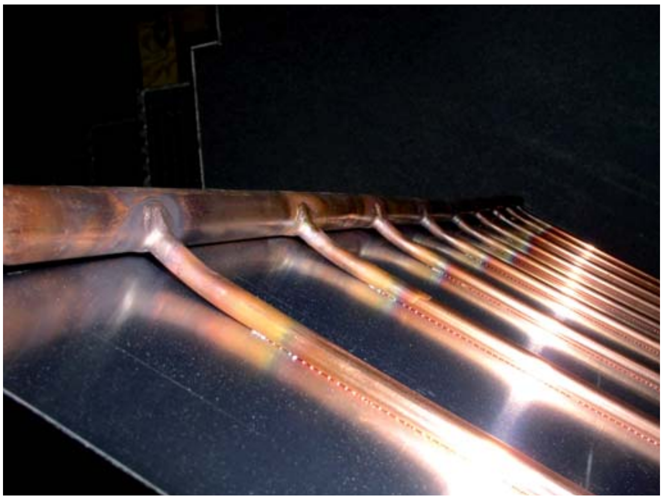


Figure 7: Rear side of absorber.

Figure 8: Mildly cranked copper pipe register.

2. Observations

2.1.2 Visual appraisal following 20 high temperature cycles

The absorber was visually inspected after 20 high temperature cycles. The crumpling of the aluminum sheet typical for Al-Cu absorbers as well as a dished curvature over the absorber is readily observed. As far as a visual inspection can reveal, all welded seams were found to be intact.

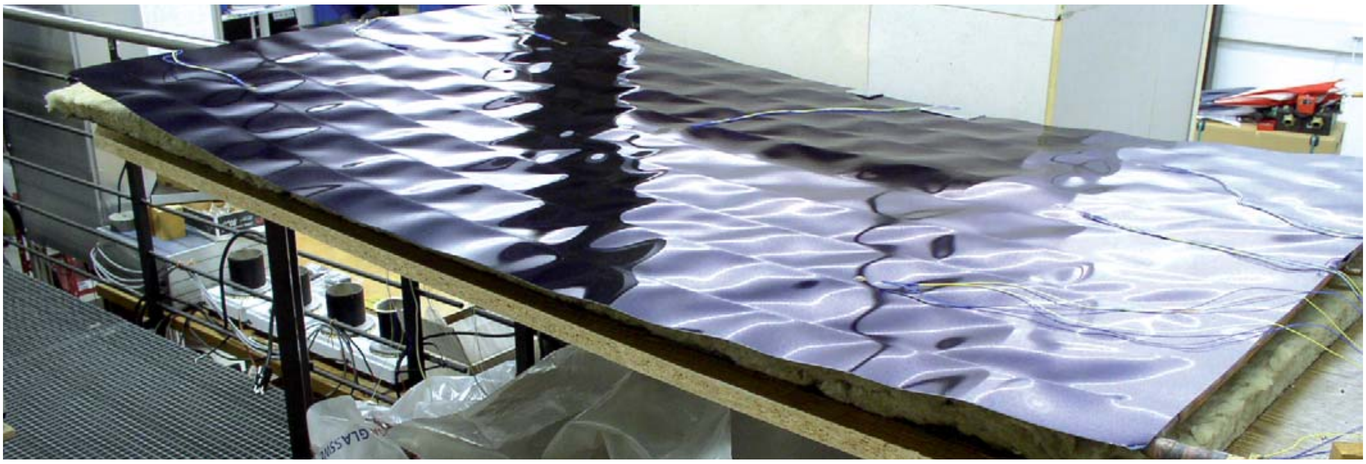
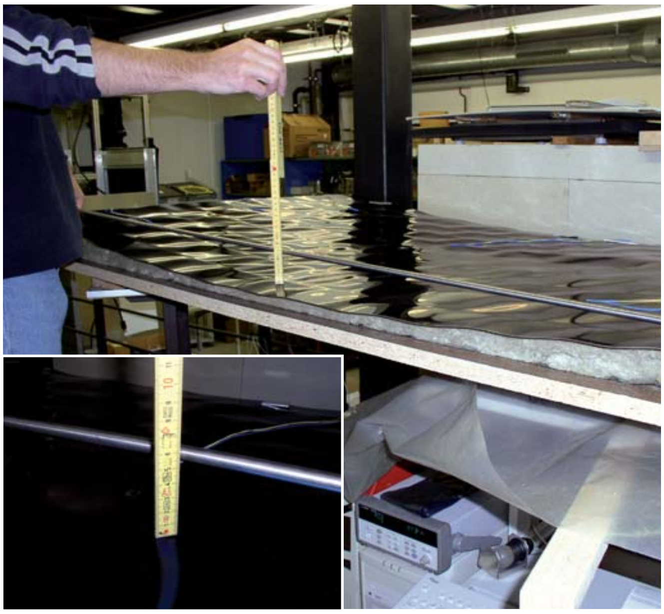


Figure 9: The typical crumpling pattern is visible already following the first few cycles.



Figures 10 & 11: Significant dished deformation led to an overall curvature with a depth in the range of 5 - 6 cm.

Figure 12: Backside of the absorber. All welded seams remain intact.

2. Observations

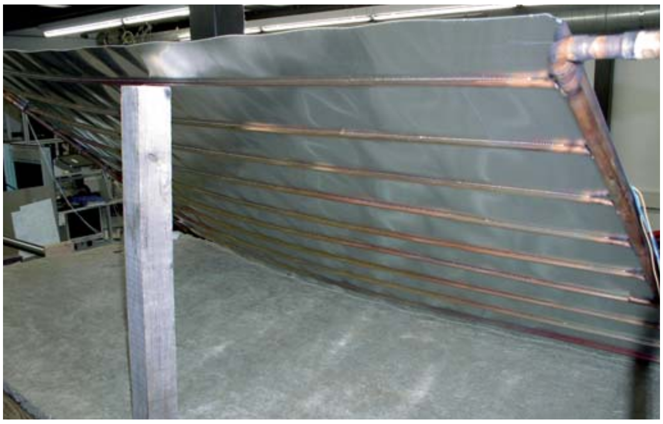


Figure 13: Backside of absorber following 1000th cycle.

Figure 14: Mild separation of one of the ascending pipes.

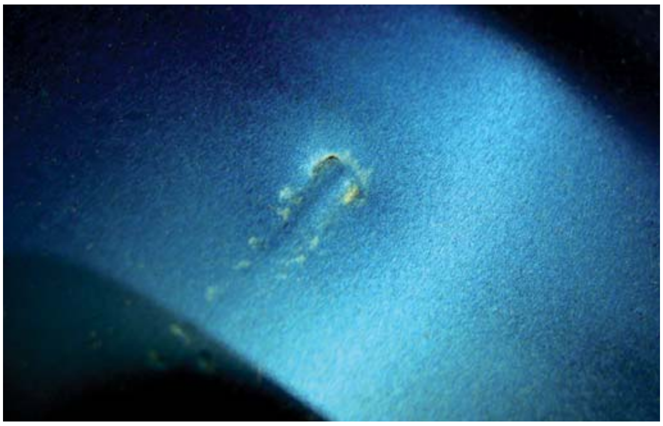


Figure 15: Mild damage of the absorber at the beginning of one of the welded seams.

2.1.3 Visual appraisal following 1000 low temperature cycles

A visual inspection was carried through following 1000 low temperature cycles. The welded seams appeared on (visual) inspection to be in order. On the end of one of the ascending pipes (Fig. 14) a mild delamination between aluminum sheet and copper pipe was apparent. Minor damage to the aluminum sheet was detected (Fig. 15) on closer inspection of the end of all welded seams. Given additional force or longer strain times these weaknesses could lead to larger scale flaws (crack-growth).

2.1.4 Visual appraisal following 2000 low temperature cycles

There were no additional observations diagnosed following the 2000th low temperature cycle.

2.1.5 Visual appraisal following 3000 low temperature cycles – end of testing

All of the above mentioned findings were found in the same state as was found following 1000 cycles:

Dished curvature:

As was observed with earlier experimentation, the crumpling of the aluminum sheet and the overall dished curvature resulting from the bimetallic thermal work stabilized within the first few cycles.

Welding:

The delamination of the welded seam on the ascension pipe as observed following 1000 cycles did not worsen within the subsequent test cycles. The weakening at the ends of the welded seams also appeared to have stabilized by the 1000th cycle.

3. Evaluation

The welding between aluminum sheet and copper piping on completion of the test cycles is largely intact. A minor delamination of one of the welded seams was appraised but on following inspection was found to have stabilized. The bi-metallic bending or curving of the absorber was found to be significant. This could lead to problems dependent on how the absorber is mounted in the collector housing. It is likely that the overall deformation of the absorber could result in a contact between the absorber and collector housing or covering.

Throughout the testing the absorber had significant freedom in which to move which need be considered when interpreting the observations made thereof. In particular to note is that succeeding the mounting of the absorber into a respective collector housing, this limitation to freedom of movement (in thermal expansion and contraction) could induce considerate stress within the absorber. This was not accounted for.
To discover and be able to comment on the overall durability of the absorber when exposed to a large number of temperature cycles a complete collector would need to be investigated.

Dr. Andreas Bohren
Head SPF Testing

Solartechnik
Prüfung
Forschung

2.2 Summary

SPF Summary Shocktests

In the development of process design and the proofing of associated products a number of temperature oscillation tests on varying aluminum-copper absorber configurations were carried out in the years 2002 to 2005. The experience gained has led to the following conclusions:

- The executed tests have shown that despite the unfavorable compatibility of the two materials aluminum-copper solar thermal absorbers pose a most suitable new development.

- Assuming the bond between aluminum sheet and copper pipe is consistently performed, these absorber types can endure significant temperature changes without serious damage.

- Warping of the absorber is unavoidable where the bond between aluminum and copper is rigid. As long as the collector is designed accordingly though a reduction in performance as a result of this can be hindered.

- All tests performed point out that the results are independent of whether sunlight, solar simulator or heating elements are used to heat the absorber.

Editor´s note:

In this test a new procedure for a more rigid start and end weld pattern was tested. The conclusion of the minor separation and damage of the absorber sheet was that if too much laser energy is induced into the welding seam the rigidity of the aluminium absorber sheet can be reduced. An adjustment of this start and end pattern has shown no damage anymore.

Shock Test

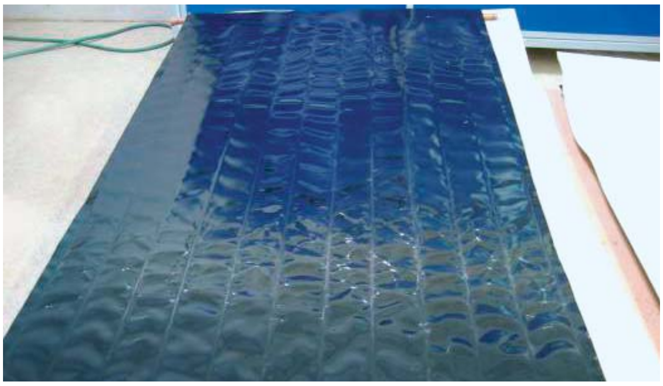
GreenOneTec GmbH & Co. KG absorber thermal-shock

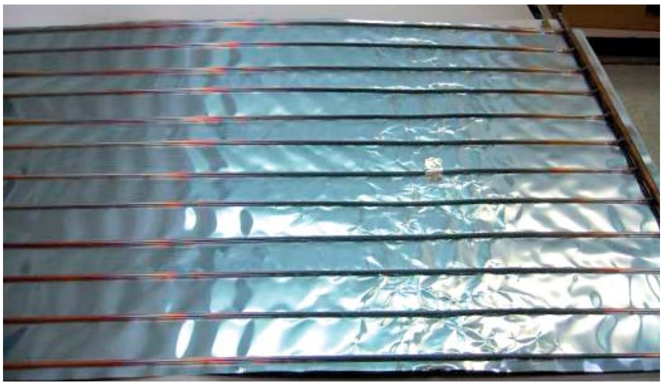
Test number: 08_015
Test result: Positive
Date: 26 February 2008
Test begin: Execution of a shock test with the aluminium absorber, which was then subjected to an internal pressure test.

Results: The test was completed after 500 cycles and an assessment carried out. With the exception of a few ripples and deformations in the sheet metal, no changes were found. The weld joints between the tube array and the absorber plate did not show any defects at all. The subsequent internal pressure test also did not produce any negative results.

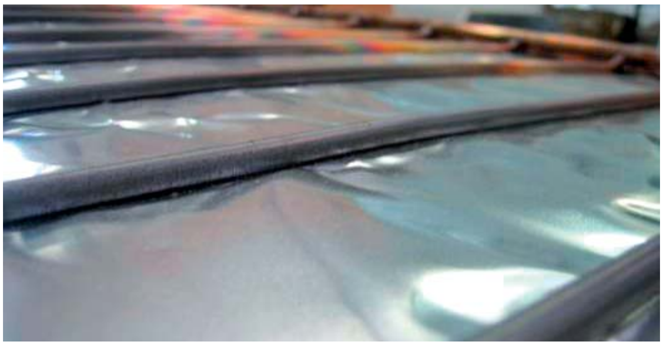
Test description and type of test: The absorber was mounted to the shock test stand and 500 shock cycles were carried out, whereby the absorber was heated above heating mats to 250 °C before having cold water fed through it (shock). The remaining water was blown out and the cycle repeated. This roughly corresponds to 25 years of operation with 20 downtimes per year. An internal pressure test with 30 bars was then carried out.

Results / Analysis of the shock test:





Images 1 and 2: Photo of the absorber after the shock test. Formation of ripples on the absorber plate.



Images 3 and 4: Close-up photos showing the ripples on the absorber plate.

With the exception of the ripples, no changes were found after the shock test.
The result of the subsequent internal pressure test with 30 bars was also positive.

alanod SOLAR

2.4 Alanod-Solar GmbH & Co. KG

Tensile Loading of fins after thermal shock

The mechanical strength of the laser-welded points between aluminium and copper both before and after thermal shock were tested under the following cyclical conditions:

- The fins were heated to 200°C and then shock cooled with tap water for 1 minute
- 20 cycles, 200 cycles and 2000 cycles were performed
- Each fin of length 1100 mm was then cut into pieces 50 mm long, and these pieces were tested.
- Fins with different copper tube diameters (8, 10 and 12 mm) were tested
- As a reference sample, one fin was not subjected to the temperature shock cycling, but tested.

The stability and integrity of the join was tested with equipment which could bring a definite tensile load (250N) perpendicular to the fin plane.
In this way, it could be established that no shear load was applied to the joint during the test. (The results are tabulated below.)

Result:

The integrity of the laser-welded joint is not affected in any way by thermal shock, even after 2000 cycles. It should also be noted that a fin with 50 mm length can support a load of at least 250N.

Tensile Load 250 N

Fin, Not Loaded		(Cu tube Ø 12 mm)	No Failure
Fin, Loaded,	20 Cycles	(Cu tube Ø 12 mm)	No Failure
Fin, Loaded,	20 Cycles	(Cu tube Ø 10 mm)	No Failure
Fin, Loaded,	20 Cycles	(Cu tube Ø 8 mm)	No Failure
Fin, Loaded,	200 Cycles	(Cu tube Ø 10 mm)	No Failure
Fin, Loaded,	2000 Cycles	(Cu tube Ø 8 mm)	No Failure

Editor´s note:

This test was performed in the beginning of Mirotherm absorber laser welding in 2002. The determined min. tensile load of 50N/cm has been improved meanwhile. Rigidity measurements of up to 200N/cm are common today.

Alanod-Solar GmbH & Co. KG

Thermal shock on a 2.5m^2 flat plate absorber and microscopy of the thermally shocked laser welded joint

The mechanical strength and integrity of the plate, laser-welded by the company Sunlaser AG was confirmed with the help of extreme thermal shock loading.

In this test, large absorber plates (2000 mm x 1250 mm) were laser-welded with a copper tube meander. The tube was connected to normal tap water and the absorber plate was heated using floodlighting with a total power input of 48 kW.

The absorber plate is heated with a constant energy input. The temperature of the plate is measured at its centre. As soon as the temperature of 200°C is reached at the measuring point, water is let into the tubing. The water flows in the tube for a time of 1 minute, and will result in a reduction in the temperature at the measuring point to approximately 100°C.

This heating / cooling cycle is repeated 20 times. Finally the laser-welded connection between the absorber plate and the copper tube is assessed for its integrity.

Result:
No failure of the laser-welded joint could be identified, nor any cracks in the weld were observed.

SPF Solartechnik Prüfung Forschung

3.1

Test Documentation

„Attachment and Deformation Behaviour of Laser-Welded Aluminium Sheet Copper Pipe Absorbers“

1. Goal

By means of cyclic temperature loading of complete collectors, the deformation behaviour of the absorber is studied. Absorber construction, geometry and attachment are carried out exactly as in planned production. Precise technical drawings (to be supplied upon delivery for testing) are the requirement for performing the test.

The goal of the test is not a judgement of the long-term behaviour of the attachment technique between tube and absorber sheet. For a robust characterisation of the attachment technique, a much higher number of test cycles is required.

The successful test should prevent later problems due to deformation of the collector absorber. In particular, increased heat losses due to a reduction in the distance between front plate and absorber or through the compression of the insulation material must be prevented. The test criteria (degree of deformation) are determined as follows.

2. Test procedure:

Energy source: Solar simulator with a homogeneity over the tested absorber area of ± 10 % and a minimum power of 800 W/m^2.
The following cycle is valid for a conventional flat-plate collector having a spectrally selective absorber with $\alpha_{AM1.5} > 0.9$, $\varepsilon_{373K} < 0.1$:
Heat the collector to >160°C, a temperature of >160°C must be maintained for at least 5 minutes. Subsequently cool the collector to < 60°C. Until 100°C the cooling rate must be > 20°C/min. The temperature of the collector must be kept under 60°C for at least 5 minutes.
Cycle duration is approximately 40 minutes.
This cycle is repeated 150 times. Total test duration approximately 4 days.

Note regarding cycle count:
The goal of the test is not a judgement of the long-term behaviour of the attachment technique between tube and absorber sheet. For a robust characterisation of the attachment technique, a much higher number of test cycles is required. The defined cycle count suffices for the assessment of the deformation behaviour of the absorber. Studies have shown that doubling the cycle count from 150 results in no significant change to the deformation behaviour.

Test Documentation

„Attachment and Deformation Behaviour of Laser-Welded Aluminium Sheet Copper Pipe Absorbers"

3. Judgement criteria:

Distance to glazing:
The distance between absorber and glazing must be defined in the information provided upon delivery of the collector for testing (planning basis of the collector). The implementation is verified by visual inspection. At the conclusion of the test, the distance to the front plate must not be reduced by more than 20 % over 98 % of the total absorber area. (Example: designed for 25 mm between absorber and front plate, minimum distance after the test over 98 % of the absorber area: 20 mm). A reduction of 50 % of the distance is tolerated over 2 % of the absorber area. This information is also noted in the test report. To judge the results, the absorber position after the test must be measured and reported at no less than 100 points (raster with approximately equal intervals in length and width). The measurement points are to be chosen such that the outermost points lye a maximum of 25 mm from the absorber edge.

Distance to rear side:
The distance between the absorber plate and the collector rear side must be defined in the information provided upon delivery of the collector for testing (planning basis of the collector). The implementation is verified by visual inspection. At the conclusion of the test, the distance to the rear side must not be reduced by more than 30 % over 90 % of the total absorber area. (Example: designed for distance of 60 mm to rear side, minimum distance after the test over 90 % of the absorber area: 40 mm). A reduction of 50 % is tolerated over 10 % of the absorber area. This information is also noted in the test report.

A possible deformation of the rear side as a result of the test is not considered. The calculation of the distance between absorber and rear side is based upon the position of the absorber (planning basis) at the time of delivery.

4. Cost:

The test consists of:
- Mounting and demounting of the test item including data acquisition
- Support during the test procedure
- Operation of the solar simulator
- Analysis of the collector after exposure
- Data reduction and judgement
- Report in German

Price available upon request

Institut SPF
Rapperswil, 11.01.2004

3.2

Test Report C670

Fixation and deformation of laser welded aluminium copper absorbers

Test procedure:

Key data for test of a conventional flat plate collector with selective coating with $\alpha_{AM1.5} > 0.9$, $\varepsilon_{373K} < 0.1$: Heating of the collector to >160°C, the temperature must exceed >160°C for at least 5 min. Cooling the collector to < 60°C. Down to 100°C the cooling rate must be > 20°C/min. The collector temperature must stay below 60°C for at least 5 min. The cycle is repeated 150 times. Total duration: approximately 4 days.
A detailed description of the test procedure „Fixation and deformation of laser welded aluminium copper absorbers“ is attached to this report.

Identification

- Collector C670/1

Manufacturer (Supplier):

- Frame: unknown, Absorber: SunLaser AG

Applicant:

- SunLaser AG

Delivery of test sample:

- 26.04.2004

Test execution:

- From 27.04.2004

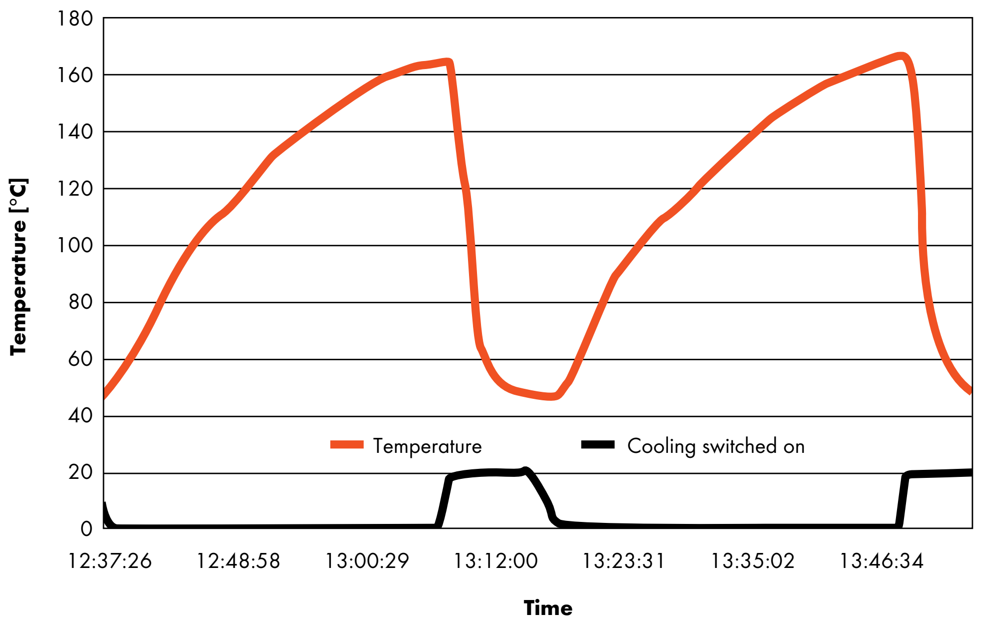
Absorber dimensions, Absorber construction:

- see sketch in addendum

Lay out design:

- Distance between glass bottom side and absorber surface: 20 mm
- Distance between absorber bottom side and back panel surface: 50 mm

Result: Figure 1: Typical test cycle:

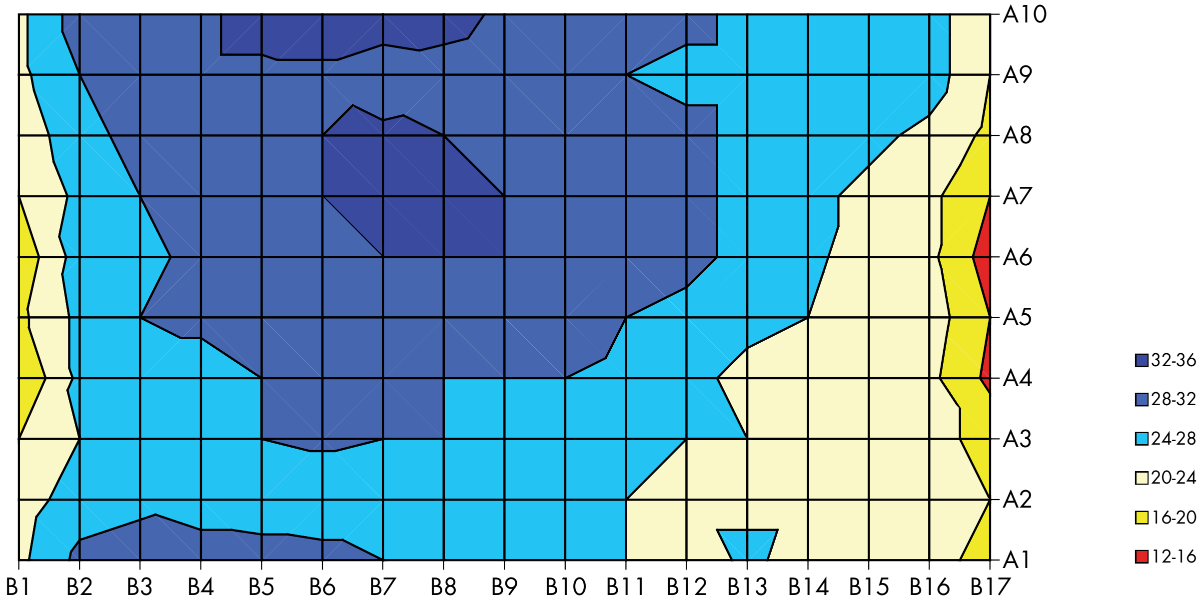


Test Report C670

Fixation and deformation of laser welded aluminium copper absorbers

Result: Figure 2: Position of absorber surface after test:

Distance between glass bottom side and absorber surface in mm.



Evaluation:

Distance to glass bottom after test (lay out design 20 mm):

Distance	≥ 16 mm (80% of 20 mm)	< 16 mm (80% of 20 mm)	< 10 mm (50% of 20 mm)
Fraction in %	99 %	1 %	0 %
Criteria	98 %	2 %	0 %
Evaluation	**Fulfilled**	**Fulfilled**	**Fulfilled**

Distance to glass bottom after test (lay out design 20 mm):

Distance	≥ 35 mm (70% of 50 mm)	< 35 mm (70% of 50 mm)	< 25 mm (50% of 50 mm)
Fraction in %	100 %	0 %	0 %
Criteria	90 %	10 %	0 %
Evaluation	**Fulfilled**	**Fulfilled**	**Fulfilled**

3.2

Test Report C670

Customer: SunLaser AG
Fixation and deformation of laser welded aluminium copper absorbers

After 150 cycles the deformation of the absorber stays inside the given limits to pass the test.

Note:
The absorber shows a remarkable deformation behaviour that was already observed in earlier tests: During the first temperature cycle the centre area of the absorber bends towards the glass. However, beginning with the second cycle, the deformation reverses and the absorber bends toward the back sheet. During the following cycles this deformation behaviour remains constant.

The hereby considered criteria comply with the basic principle that the permanent deformation must have no significant effect on the performance, or respectively the yield, of the collector. Experience shows that the distance between glass and absorber should be not less than 20 mm. Note that the criteria and limit values of 16 mm and 35 mm refer solely to the deformation of the absorber. However, the manufacturer must critically review the specific requirements, ancillary conditions and lay out designs for the planned deployment of the absorber.

Rapperswil, 18.05.2004

Bruno Füchslin
SPF Mess- und Kollektortechnik

Dr. Andreas Bohren
SPF Leiter Kollektoren

Addendum A:

Photos of test stand and collector after exposure

View of solar simulator

View of test setup

View of collector after exposure

View of absorber after exposure

3.2

Addendum B:

Absorber design (manufacturer details)

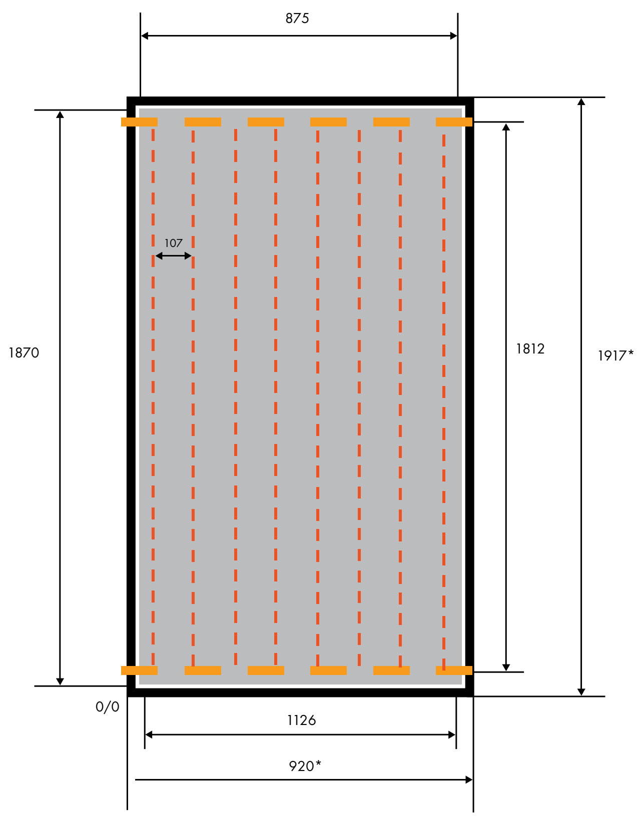
Absorber Substrat: mirotherm® 0.5 mm
Pipe grid: Copper F36 hard

0/0 Coordinates for distance measurement (see separate table)

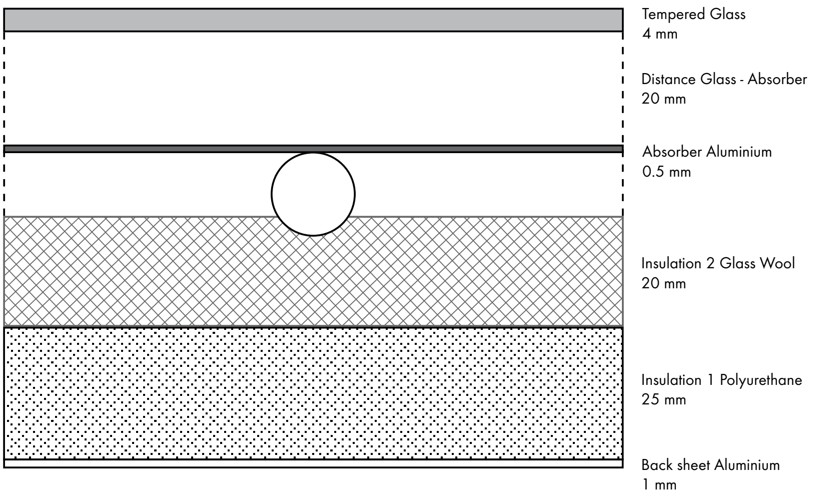
* Outer dimensions collector frame

Copper riser da =16 mm laserwelded on aluminum sheet

Copper header da = 25 mm not laserwelded



Vertical cut through collector



Solidness Tests

Vaillant GmbH & Co. KG
Absorber welding connection, Mechanical durability, Quality of the welding seem

1. Test conditions

- Test object - Original parts from Gelsenkirchen collector production
- Absorber – Alanod company - MT1300 mirotherm® type
- Sample length 50 mm
- Spot-welded absorber plate with copper tubing (copper tubing supplied by KME company)
- 3 tube grades available (W, T and K).

Number of test objects:	6 samples Determination of pull-off forces Micrograph to inspect the melt in the welding point
Test:	Tensile test in tensile testing machine Microscope examination
Number of cycles:	2
Time necessary:	8 h

2. Test results for pull-off test

The samples were visually inspected after each cycle.

The following table shows an overview of the tests.

Number of samples	Type	Test results	
1	K 1	Tensile force N 685	Average value Fmax = 658 N
2	K 2	Tensile force N 630	
3	T 1	Tensile force N 655	Average value Fmax = 652 N
4	T 2	Tensile force N 650	
5	W 1	Tensile force N 640	Average value Fmax = 540 N
6	W 2	Tensile force N 440	

Table 3: Test results

The following test targets were specified:

		Compressive force [N]
Test target	A: Very suitable	>=250 N
	B: Not suitable	< 250 N

The test was passed as test target A was achieved in every case (samples 1 - 6).
The weld joint is deemed to be mechanically very suitable.

4.1 Solidness Tests

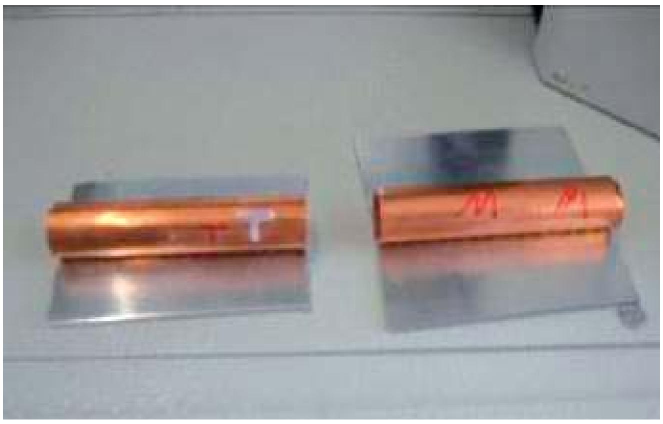
Vaillant GmbH & Co. KG
Absorber welding connection, Mechanical durability, Quality of the welding seem

3. Summary of pull-off test:

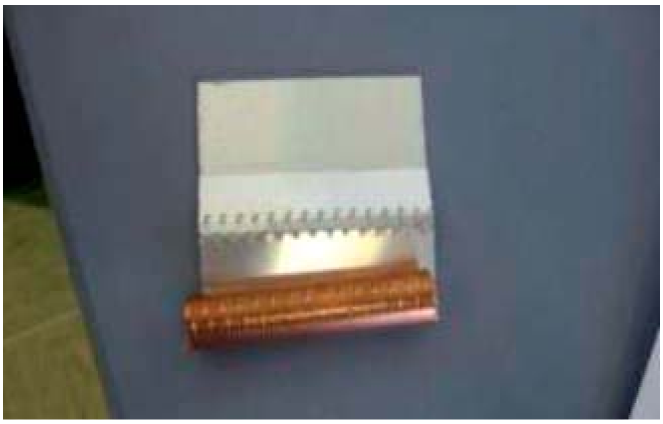
The following materials are to be employed when the MT1300 (Alanod) absorber plate is used with rear welding of copper tubing to a solar absorber:
Absorber plate – selectively coated mirotherm®
MT 1300 aluminium plate
Tubing – copper tubing of grades K,T,W

4. Photographs and diagrams:

Photograph 1: Test setup



Photograph 2: Welding sample – before test



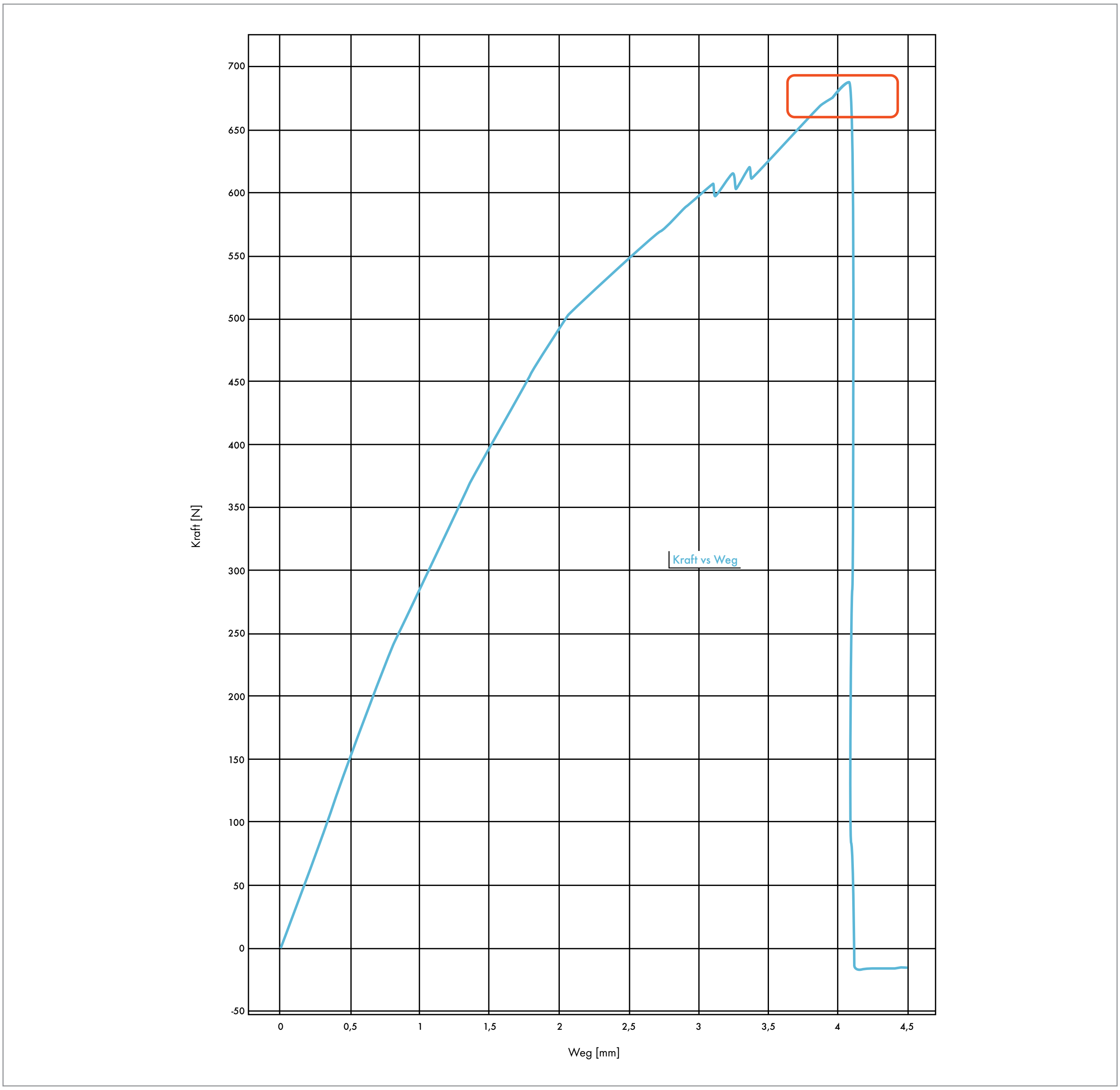
Photograph 3: Welding sample – after test

Solidness Tests

4.1

Vaillant GmbH & Co. KG
Absorber welding connection, Mechanical durability, Quality of the welding seem

4. Photographs and diagrams:



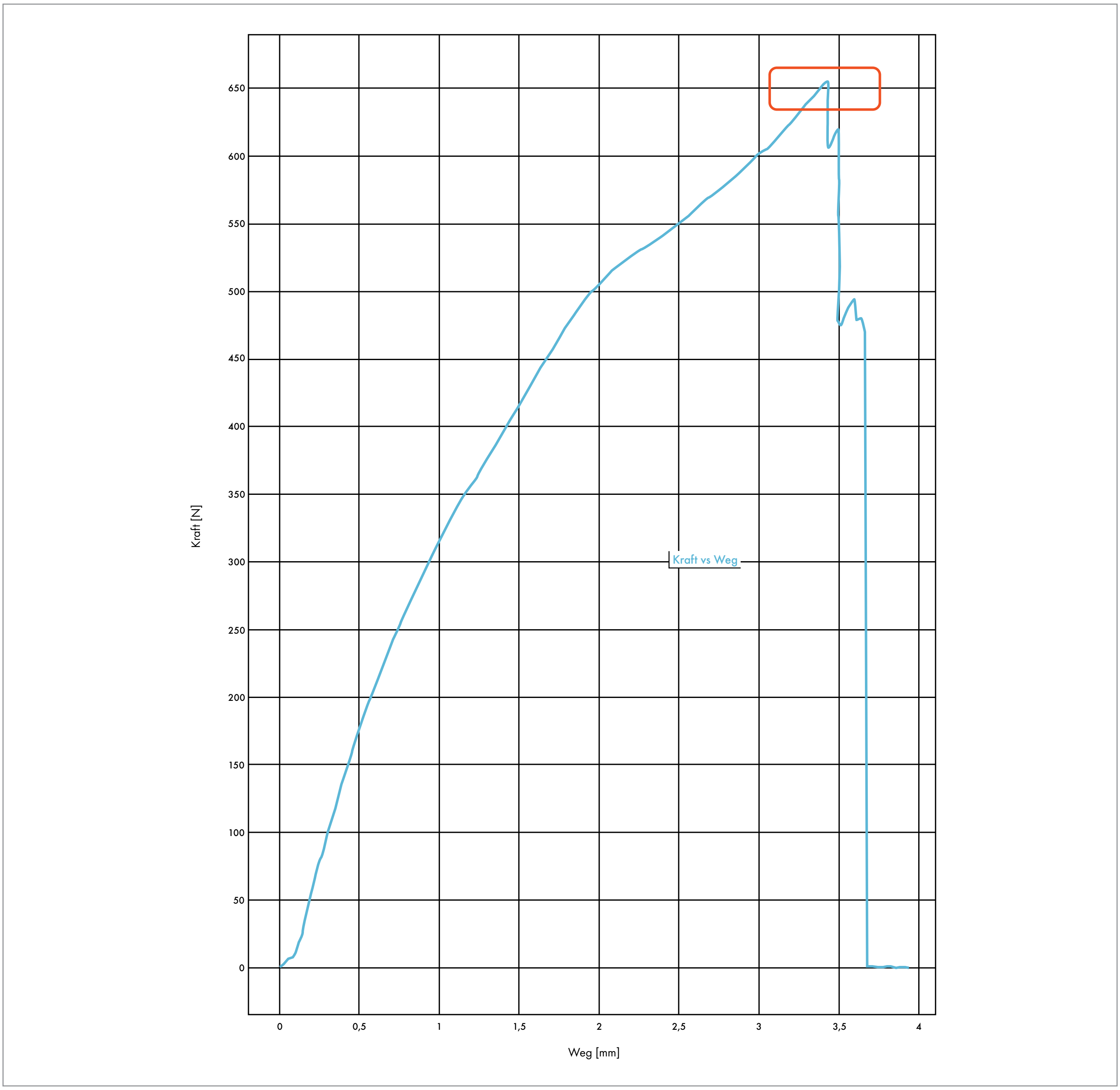
Abreißprobe Absorber Probe K

4.1

Solidness Tests

Vaillant GmbH & Co. KG
Absorber welding connection, Mechanical durability, Quality of the welding seem

4. Photographs and diagrams:

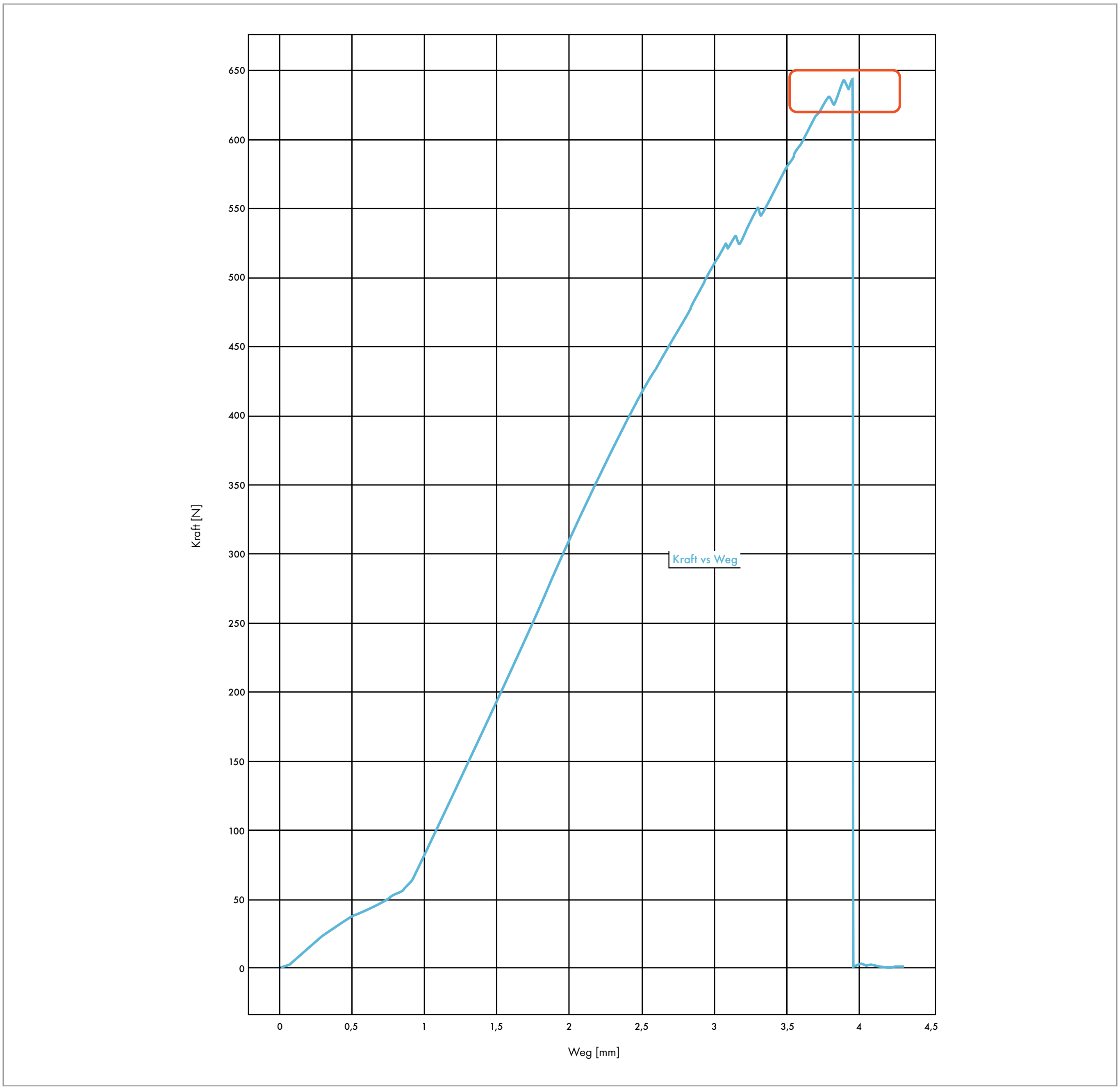


Abreißprobe Absorber Probe T

Solidness Tests

Vaillant GmbH & Co. KG
Absorber welding connection, Mechanical durability, Quality of the welding seem

4. Photographs and diagrams:

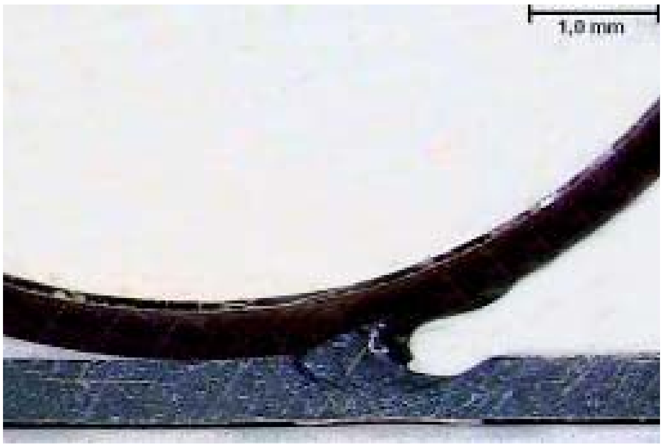


Abreißprobe Absorber Probe W

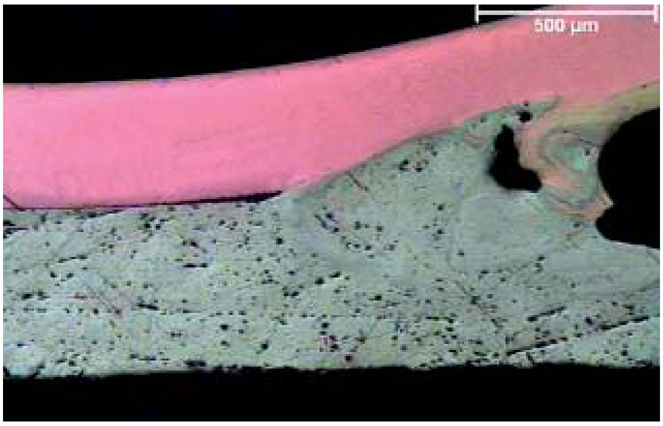
Solidness Tests

Vaillant GmbH & Co. KG
Absorber welding connection, Mechanical durability, Quality of the welding seem

Micrograph 1



Micrograph 2



Micrograph 3

5. Test results for micrograph sample

- The strength of such a welding joint is mainly due to the mechanical bonds in the melted areas.
- Metallographic examinations are thus not suitable for a comprehensive evaluation of such a joint.
- The weld is best investigated using mechanical tests such as the pull-off test.
- The extent of melting on the copper tubing and aluminium plate is up to half of the wall thickness of each material.
- The minimum weld-point diameter of approximately 1 mm is fulfilled.
- No melting/damage to each of the rear sides due to weld roots has occurred.
- 'Burning-through' of tubing or plate must be avoided and was avoided.
- A leakage test is a good test of the maximum pressure that can be withstood after the welding process.
- Heat transmission (f-factor) must be tested separately.

Overall result:

The test was passed. The welding joint was not problematic – both mechanically (pressure, force) and in terms of materials (melt, material) – and can be used for the planned application.

Corrosion tests:

OLS Wet Room DIN50017, Salt Mist ISO 9227

We confirm that two pieces of your sample of aluminium selective sheet laser welded to copper tube have been submitted to corrosion tests.

One has been put in the wet room DIN 50017 (40°C 100% humidity) for 240 hours : no damages, the other has been put in the salt mist test ISO 9227 (35°C 100% humidity 5% NaCl) for 240 hours: few damages of the selective coat , no corrosion problems on the copper aluminium junction

Eng Antonella Ferrara
Ols srl

Laser welding Test

Front side

Wet room Salt mix test

5.1

Corrosion tests:

OLS Wet Room DIN50017, Salt Mist ISO 9227

Laser welding Test

Reverse side

Wet room Salt mix test

> **Editor´s note:**
>
> It is obvious that such a harsh test will do damage to any selective coating. The important outcome of this test is that no galvanic corrosion occurred in between copper pipe and aluminium sheet.

Corrosion tests:

Vaillant GmbH & Co. KG
Continuous salt mist spray test at a Solar Thermal Collector

	FORSCHUNGS- UND TESTZENTRUM FÜR SOLARANLAGEN **Institut für Thermodynamik und Wärmetechnik** **Universität Stuttgart** Professor Dr. Dr.-Ing. habil. H. Müller-Steinhagen	in Kooperation mit

Sonderuntersuchung

Special Investigation

Kontinuierlicher Salzsprühnebeltest an einem Sonnenkollektor

Continuous Salt Mist Spray Test at a Solar Thermal Collector

Bericht Nr.: 07COR01

Report No.: 07COR01

Stuttgart, 3. Januar 2008

Stuttgart, January 3rd, 2008

Auftraggeber: *client:*	Vaillant GmbH Berghauser Straße 40 42859 Remscheid
Kollektortyp: *collector type:*	VFK 145 H

5.2 **Corrosion tests:**

Vaillant GmbH & Co. KG
Continuous salt mist spray test at a Solar Thermal Collector

4. Kontinuierlicher Salzsprühnebeltest
Continuous Salt Spray Mist Test

Beschreibung:

Es wurde ein kontinuierlicher Salzsprühnebeltest in Anlehnung an DIN EN 60068-2-11 (Prüfung Ka: Salznebel) mit folgenden Randbedingungen durchgeführt:

Description:

A continuous salt mist spray test based on DIN EN 60068-2-11 (test Ka: salt mist) was carried out with the following boundary conditions:

Anfangsmessungen *Initial measurements*	• Sichtkontrolle des Prüflings • fotografische Dokumentation des Prüflings • Prüfung Wärmeleistung • *visual inspection of test specimen* • *photographic documentation of test specimen* • *thermal performance test*
Prüfverfahren: Kontinuierlicher Salzsprühnebeltest *Test method:* *continuous salt spray mist test*	• Durchführung in Anlehnung an EN 60068-2-11, Prüfung Ka • keine Vorbehandlung des Prüflings • Konzentration der Salzlösung: 5 ± 1 % Massenanteile Salz und 95 % Massenanteile demineralisiertes Wasser • pH Wert der Lösung bei 35 ± 2 °C zwischen 6,5 und 7,2 • Temperatur der Prüfkammer: 35 ± 2 °C • *procedure based on EN 60068-2-11, test Ka* • *no pre-treatment of the test specimen* • *concentration of salt solution: 5 ± 1 % mass fraction salt and 95 % mass fraction demineralized water* • *pH value of the solution between 6,5 und 7,2 at 35 ± 2 °C* • *temperature of test chamber: 35 ± 2 °C*

Corrosion tests:

Vaillant GmbH & Co. KG
Continuous salt mist spray test at a Solar Thermal Collector

Anordnung des Prüflings während des Tests (siehe Bild 9) *Arrangement of test specimen during the test (see picture 9)*	• Neigung: 30° zur Horizontalen • *inclination: 30° to horizontal plane*
Beanspruchungsdauer *Duration of test*	• 96 Stunden (4 Tage): 2.11. - 5.11.2007 • *96 hours (4 days): 2.11. - 5.11.2007*
Nachbehandlung *Post treatment*	• Absprühen des Prüflings mit Wasser • Sichtkontrolle des Prüflings • Überprüfung der Wärmeleistung durch vereinfachte Leistungsprüfung bei zwei charakteristischen Temperaturen • test specimen was sprayed with water • visual inspection of test specimen • examination of thermal performance by means of simplified thermal performance test at two characteristic temperatures

Bild 9: Anordnung des Kollektors in der Prüfkammer
Picture 9: Set-up of collector in test chamber

5. Fotografische Dokumentation nach 96 h test
Photographic Documentation after 96 h Salt Spray Mist Test

Bild 10: Beschlag der Scheibe durch Kondensat im Inneren des Kollektors
Picture 10: Humidity on the glass due to condensate inside the collector

Vaillant

5.2 Corrosion tests:

Vaillant GmbH & Co. KG
Continuous salt mist spray test at a Solar Thermal Collector

6 Ergebnisse Prüfung Wärmeleistung nach 96 h Salzsprühnebeltest
Results Thermal Performance Test after 96 h Salt Spray Mist Test

Nach dem Salzsprühnebeltest wurde die Wärmeleistung des Kollektors durch eine vereinfachte thermische Leistungsprüfung bei zwei charakteristischen Betriebstemperaturen überprüft (07.11.2007).

After the salt spray mist test the thermal performance of the collector was examined by means of a simplified thermal performance test at two characteristic operation temperatures (07.11.2007).

Ergebnis ***Result***	Die Leistungsmessung ergab, dass die durch die Salzsprühnebeltest aufgetretenen Verfärbungen der selektiven Absorberschicht keinen signifikanten Einfluss auf die thermische Leistungsfähigkeit des Kollektors haben. *The thermal performance test showed that the discolorisation of the selective absorber coating occured due to the salt spray mist have no significant influence on the thermal efficiency of the collector.*

Ergebnis ***Result***	Absorber *Absorber*	• durch Salzbelastung keine Auswirkungen auf Verbindung Kupferrohr / Aluabsorber erkennbar (Bilder 21 und 22) • Salzablagerungen an Vorderseite des Absorbers, Verfärbung bleibend, weiße Salzkristalle können gelöst werden, es bleibt jedoch eine Verfärbung des Absorbers zurück (Bilder 24 bis 29) • *as a result of salt mist test no impact is visible on the connection between copper tube and alum absorber (pictures 21 and 22).* • *Salt deposits at the front side of the absorber - permanent discolouration - white salt crystals can be removed, however a permanent colouration at the absorber is remaining (picture 24 to 29)*

Corrosion tests:

Vaillant GmbH & Co. KG
Continuous salt mist spray test at a Solar Thermal Collector

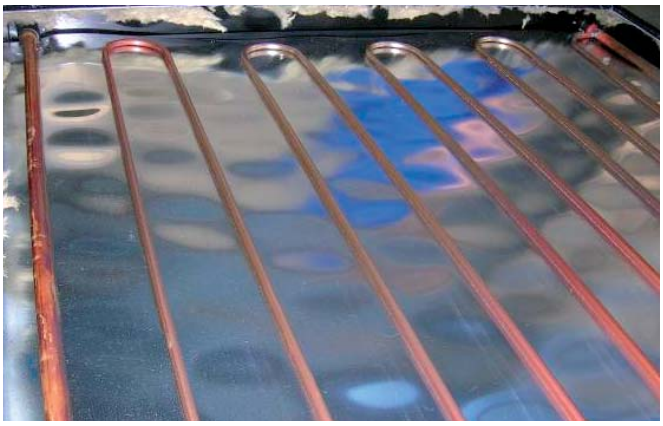


Bild 21: Verbindung Kupferrohre / Aluabsorber
Picture 21: Connection copper tubes / alu absorber

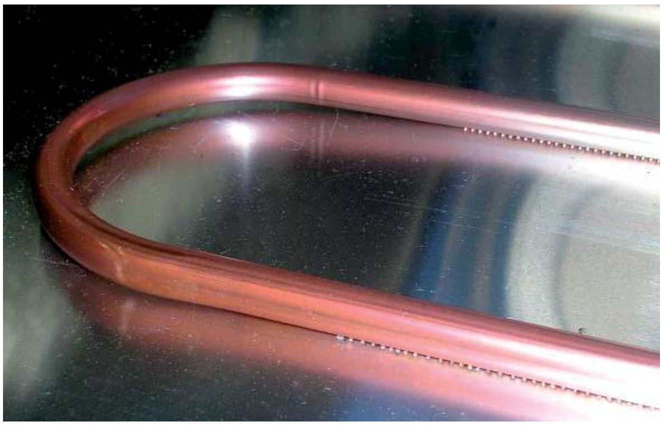


Bild 22: Absorber: Bogen Mäander
Picture 22: Absorber: Arch meander

Bild 24: Verfärbung Absorberbeschichtung
Picture 24: Discolouration absorber coating

Bild 25: Verfärbung Absorberbeschichtung
Picture 25: Discolouration absorber coating

Bild 26: Verfärbung Absorberbeschichtung
Picture 26: Discolouration absorber coating

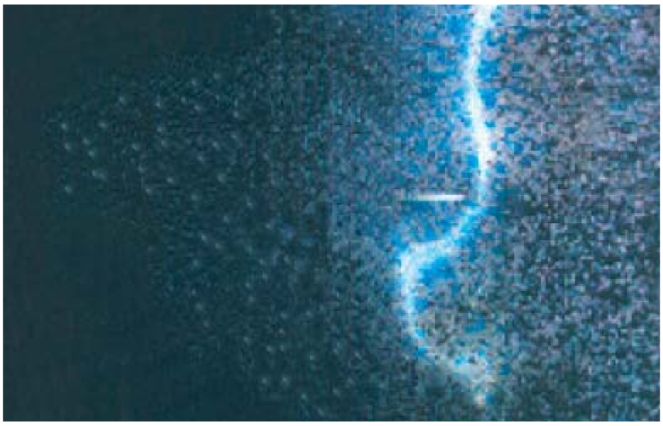


Bild 27: Verfärbung Absorberbeschichtung
Picture 27: Discolouration absorber coating

5.3 Alanod-Solar GmbH & Co. KG

Microscopy of the thermally shocked laserwelded joint

A sample piece was cut out of a thermally shocked absorber plate. This was then cut both along and across the join, and the resulting pieces set in resin. After sanding and polishing, a metallurgical examination under a microscope was undertaken.

Picture 3. shows the joint cut along the tube direction. It can be clearly seen that a good join between the aluminium plate and copper tube has been made.

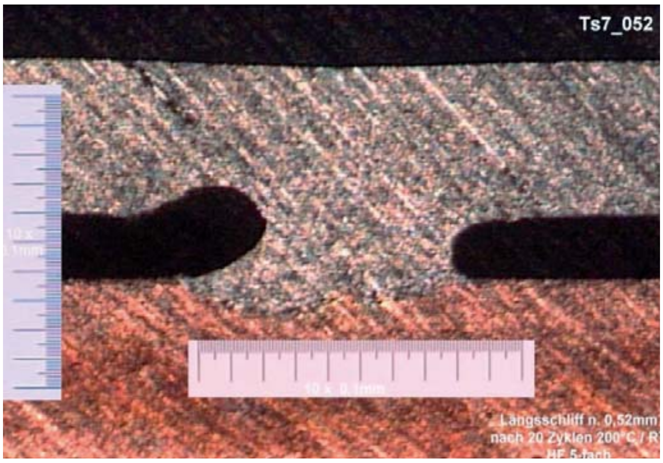
Result:

At the welding point and in the area of the welding point, no cracks or other changes can be seen after thermal shocking.

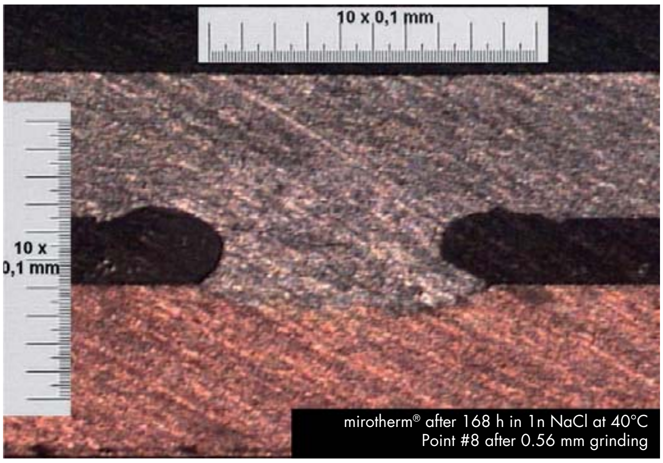
Microscopy examination of salt-water corroded fins

Discussions with customers show that there is a worry that galvanic corrosion might be a problem with aluminium and copper in contact, in this application. In order to answer this point, the laser-welded joint was tested using a salt water solution with concentration of 1 mole NaCl at 40°C. The piece was immersed in this solution for 168 hours (1 week).

As documentation, Picture 4., to the same magnification as Picture 3., along the joint (copper tube) axis is shown. This picture is after the 168 hour test has been carried out, and it is clear to see that absolutely no corrosion of either the copper tube to the aluminium around the joint has taken place.



Picture 3



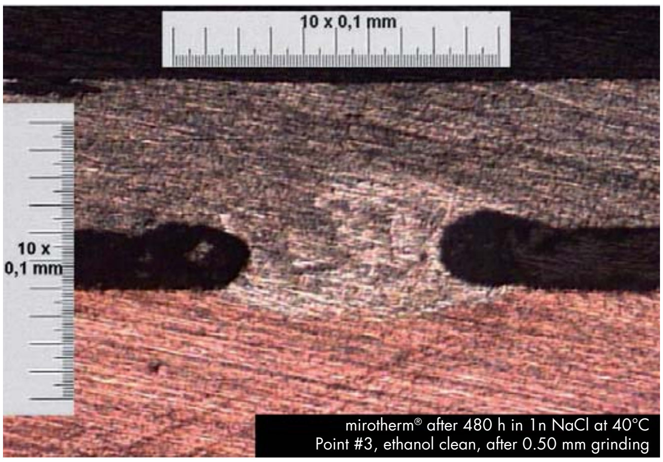
Picture 4

Alanod-Solar GmbH & Co. KG

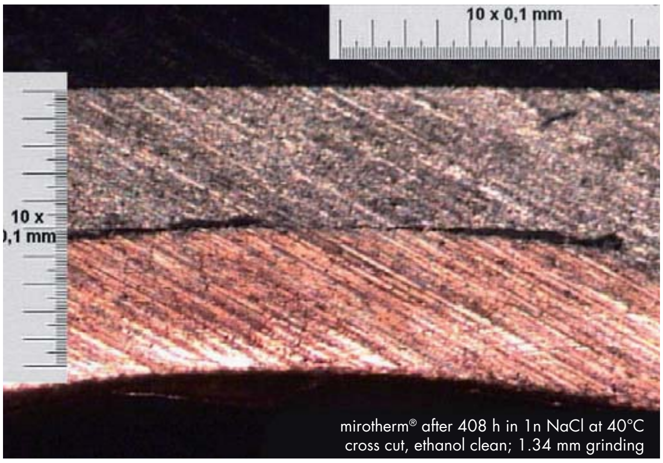
Microscopy of the thermally shocked laserwelded joint

Considering the results obtained after the 168 hour salt water test, we extended the immersion time to 408 hours, and carried out the same metallurgical examination. Picture 5. shows the result as does Picture 6, through the joint but across the tube axis. In the laser welded zone where also metal intermixingtakes place, there is no corrosion to be seen.

Result:
After immersion in salt-water for 408 hours, no galvanic corrosion can be detected at the laser-welded join between the aluminium absorber plate and a copper tube. This confirms the absolute integrity of the laser-welded joint between mirotherm® and a copper tube even after heavy corrosive load.



Picture 5



Picture 6

6.1 Outdoor Tests

Solvis GmbH & Co. KG
Outdoor Stagnation Test on the Atlantic Coast

Up until 2005, Solvis placed its trust in copper-copper absorbers and only used these absorbers. Because of the shortage of copper as a raw material on the world market and the above-average price rises caused by this, SOLVIS GmbH & Co. KG decided to use aluminium-copper absorbers from 2005 on.
Based on and backed up by long-term studies carried out beforehand (many in cooperation with various technical universities and research institutes) and by tests and field reports, Solvis now places its faith in the following cost-effective solution for absorbers:

„Coated aluminium plate with copper tubing"
The efficiency and quality offered by coated aluminium plates are at least equal to those of coated copper plates, and there is also a significant cost advantage.
The initial difficulties in processing and manufacturing using the two different raw materials combined have long since been overcome and mastered in everyday working and production procedures.
SOLVIS GmbH & Co. KG already has two laser-welding machines with a total annual capacity of around 350,000 m^2 for the production of copper-aluminium absorbers. A stable bond is created between the well-conducting copper tubing and the aluminium using modern laser technology. The quality of the selective coating is preserved, resulting in high-performance, cost-effective solar absorbers.

These absorbers consist of an aluminium plate coated with Mirotherm, with a laser-welded copper tube coil on the rear. This special laser-welding process leads to a wide, form-fitting contact area between plate and tube. The large concentration of welding points ensures strong, long-lasting bonding. Welding to the rear of the absorber avoids damage to the highly selective absorber coating. The entire upper surface of the absorber can thus absorb solar heat. The fact that a total of 370,000 m^2 of absorber surface area has been produced in two years shows that both technicians and end customers have faith in the new absorber technology.

Cala collector Portugal (2-year test) on the southwest coast of Portugal

This collector on the southwest coast of Portugal was out of service for two years and was exposed to the elements all that time. (Wind, sand, salty air and rain)

No signs of corrosion can be detected on the front or rear of the absorber, and the welding and contact points are also free of corrosion.
No loosening or separation of welding points is present, meaning that the copper-aluminium laser-welded joint is fully intact.

In 2006 and 2007, before series production began, appropriate high-temperature and low-temperature tests in accordance with the specifications of the SPF Institute in Rapperswil, Switzerland, were carried out on the absorbers. The absorbers were subjected to 20 high-temperature shock cycles and 2,000 low-temperature shock cycles.
The internal tests have been more stringent since November 2007: The absorbers are now subjected to so-called high-temperature shock tests 500 times. The absorber is heated to a temperature just above 200 °C and then immediately cooled down to 30 °C using cold water. This procedure is repeated 500 times.
The maximum loosening rate must not be greater than 4.5%.

2,000 further temperature cycle tests are carried out before approval for series production is given.

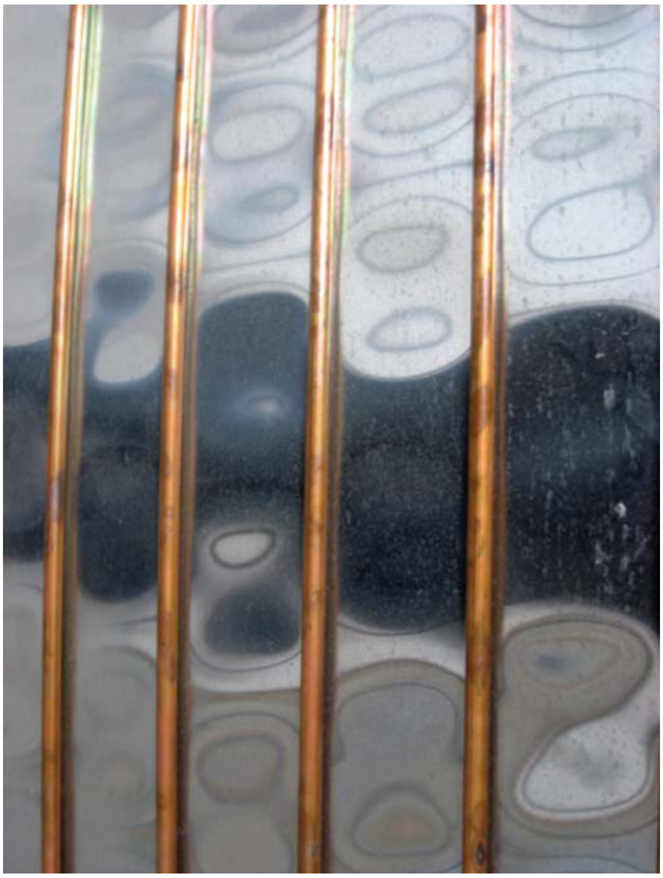
6.1

Outdoor Tests

Solvis GmbH & Co. KG
Outdoor Stagnation Test on the Atlantic Coast

Sample photographs Solvis Cala / southwest coast of Portugal

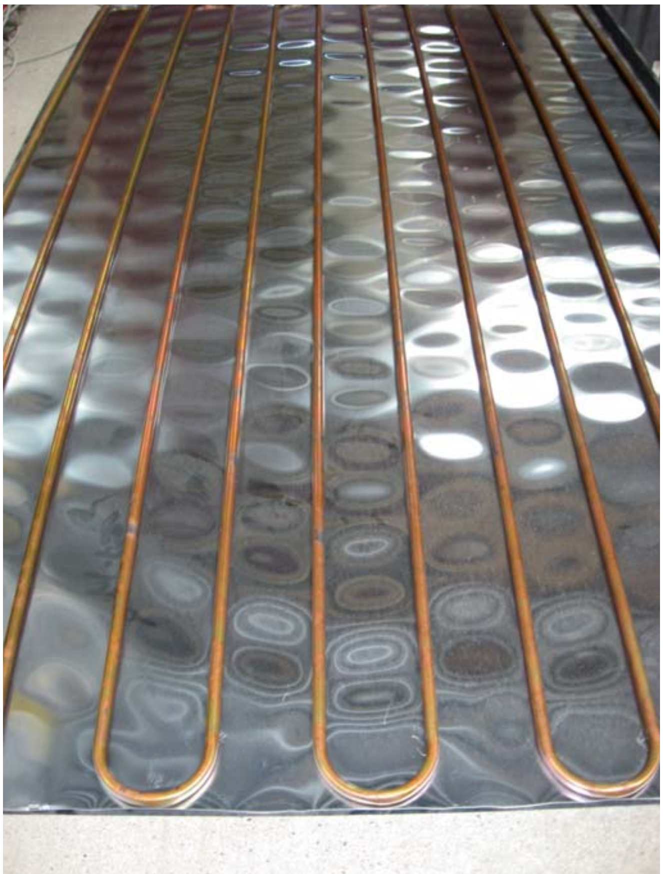
The photographs intentionally show the dirt which has accumulated. See also the collector housing.



SOLVIS

6.1 Outdoor Tests

Solvis GmbH & Co. KG
Outdoor Stagnation Test on the Atlantic Coast



mirotherm-afb/ E/ 04.09

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