

Operating performance of suction pads at low temperatures

carrying capacity of suction cups at minus temperatures

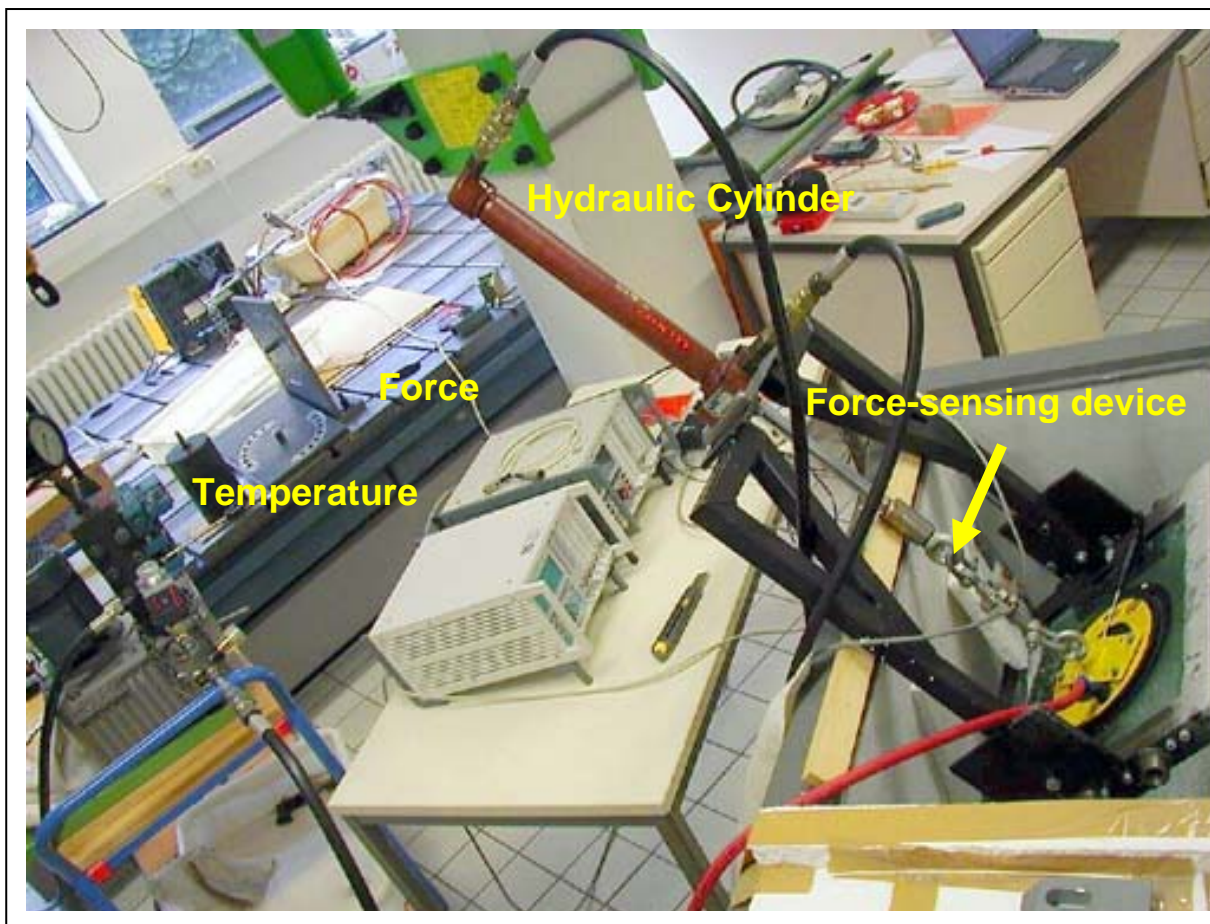
An investigation by the University for Applied Science in Kiel
(executed in the first six months of the year 2003)

conducted by Professor Dr.-Ing. Michael Klausner



Execution of the trial

The suction cups are put on a clean glass plate and connected to 0.6 bar partial vacuum, there is a Venturi jet with vacuum tank as partial vacuum supply. The entire test arrangement is shown on picture 1. The suction cups are weighted dynamically via a hydraulic cylinder, the tie force is acquired by a force-sensing device and registered by a measuring bridge. Read-off is the maximum value of the force. For the tension tests vertical to the glass the tension direction was arranged inclined in the deep freezer, the arising error of measurement from this remains smaller than 0.3%.



The photo shows the test arrangement for low temperature-measurement at suction cups.

At the measurements tensile direction parallel to the glass, the arrangement could be placed vertically. The tensile direction parallel to the glass is the type of burden during a vertical transport of the glass.

Execution of the trial

The suction cups as well as the tensile device were brought to the test temperature, all suction cups were held in the freezer in order to avoid a permanent cool down.

For the suction cup „not oil resistant“ (newer rubber mixture of the company Pannkoke) were six temperatures adjusted from -30.8°C to -5.5°C . The temperature was checked by two measuring points:

- ◆ directly on the suction cup
- ◆ by a quick reacting Pt100-feeler for the air temperature

For a steady temperature distribution a radial ventilator was in the freezer. However, with that it was only possible to influence the air temperature. The measuring device and suction cups reacted very lazily. The deep freezer was closed during the tension test as shown on the picture.



The photo shows the situation during the tension test, in front the temperature display for the measuring point on the suction cup.

Results

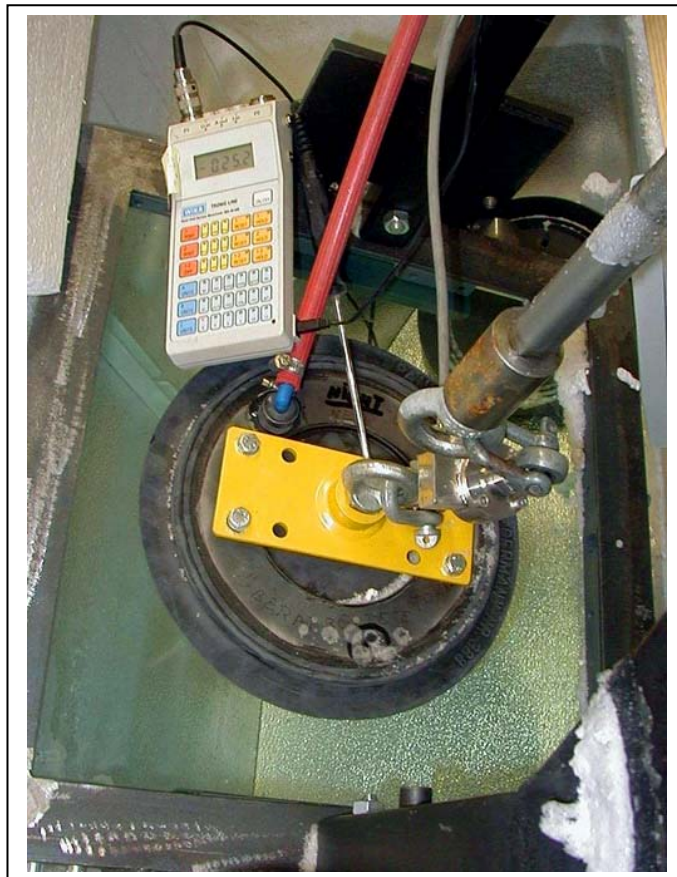
Suction cup „388-2003“

(new rubber mixture which is in use since the beginning of 2003 by Pannkoke)

The suction cup was flexible till -31.6°C and therefore able to secure an airtight lock also at clearly perceptible ice points. When tearing off it could be observed that the suction lip retracted strongly. The friction value of the rubber mixture on hoarfrost or ice is slightly under the value for the combination suction cup/dry glass.

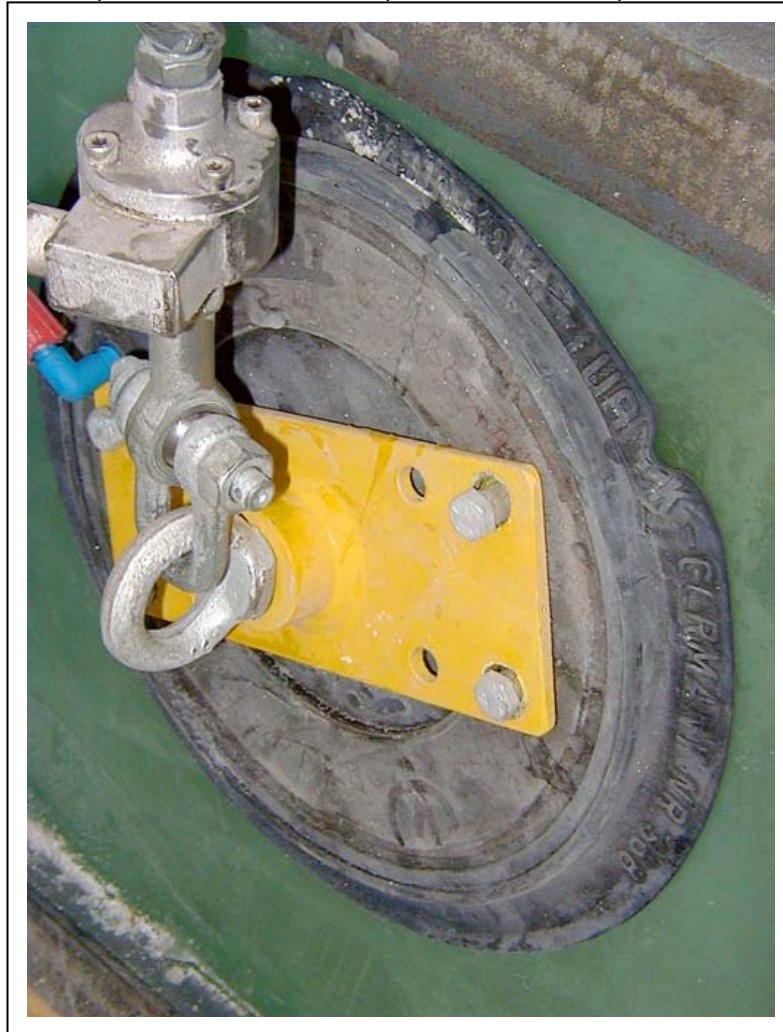
Nearly independent from the temperature, the tension force was 2800 N at tension vertical to the glass pane.

At tension parallel to the pane, there was a decrease detected of the tension force from 3119N at -10.9°C to 1185N at -29.8°C . The measurement values for parallel tension spread very much and depend on the surface (clean, dry, icy, hoarfrost) and tension speed. A maximum force of 1750 could be registered at slight hoarfrost. At low tension speed an increased force is observed.



The photo shows the suction cup „not-oil resistant“ arranged for burden vertical to the pane, temperature at second measurement series. Feeler for temperature checking under the holding plate.

The photo shows the suction cup "not oil-resistant" at parallel tension.



At the top the suction retracts lip with curling.

Suction cup „388-2000“

(rubber mixture which was used till the end of 2002 by Pannkoke)

The suction cup is only restrictedly operative at -11.4°C , under this not at all. The photo shows that the rubber lip is rigid at -30.8°C . The suction cup works above from -5.1°C .

The holding force vertical is 3400N, at parallel tension 3700N is measured.



The photo shows at -30.8°C the suction cup is stiff and not operative.

Suction cup „388-1998“

(rubber mixture which was used till the end of 2002 by Pannkoke)

The suction cup is restrictedly usable from -17.4°C , tension force vertical there 2100N. Well usable from -5.4°C , tension force increases to 3300N. At parallel tension an operativeness was determined at -10.8°C , the force is 3100N.

Suction cup „540“

The suction cup is restrictedly usable from -11.5°C , tension force vertical there 1300N. Well usable from -5.5°C , tension force stays at 1300N. At parallel tension an operativeness was determined at -11.5°C , the force is 1200N.

Remarkable is that the suction cup does not glide but via turning over the front edge tears off. That could be explained by the diameter in comparison to the high setting point of the tension force.

Remarks to the conclusion

Altogether a remarkable spreading of the measurement values was shown and it depends on the condition of the surface.

Measurement results

tension direction: vertical to the pane
 pressure: -0.6 bar
 medium tension speed: 3.6 mm/s

Suction cup: 388-2003

Temperature		Force [N]
before tension test [°C]	after tension test [°C]	
-31.6		2856.0
-31.1		2773.0
-30.1		2955.0
-30.6		2906.0
-30.6		2781.0
-30.8		2856.0
-30.8	average	2854.5

Suction cup: 388-2000

Temperature		Force [N]
before tension test [°C]	after tension test [°C]	
-30.8		1851
-30.8		1632
-29.9		1769
-29.6		1750
-30.3	average	1750.5
Suction cup stiff, suction only if it is pressed strongly.		

Temperature		Force [N]
before tension test [°C]	after tension test [°C]	
-24.5		2735.0
-25.2		2798.0
-26.3		2867.0
-26.0		2783.0
-25.5		2708.0
-26.0		2957.0
-25.6	average	2808.0

Temperature		Force [N]
before tension test [°C]	after tension test [°C]	
Suction cup stiff, suction only if it is pressed strongly.		

Temperature		Force [N]
before tension test [°C]	after tension test [°C]	
-19.9	-20.2	2962.0
-20.2	-20.6	2991.0
-20.2	-20.6	2971.0
-19.8	-19.6	2957.0
-19.2	-18.6	3190.0
-19.8	-20.7	2997.0
-19.9	average	3011.3

Temperature		Force [N]
before tension test [°C]	after tension test [°C]	
Suction cup stiff, suction only if it is pressed strongly.		

tension direction: vertical to the pane
 pressure: -0.6 bar
 medium tension speed: 3.6 mm/s

Suction cup: 388-2003

Temperature		Force
before tension test [°C]	after tension test [°C]	
-16.8	-16.8	2853.0
-16.6	-16.6	2804.0
-16.4	-16.3	2871.0
-16.2	-16.0	2863.0
-16.2	-16.4	2817.0
-16.5	-16.5	2817.0
-16.5	average	2837.5

Suction cup: 388-2000

Temperature		Force
before tension test [°C]	after tension test [°C]	
-16.9		4057
-16.4		3756
-15.3		3928
-16.2	average	3913.7

Suction cup stiff doesn't suction itself. It has to be pressed on strongly by hand.

Temperature		Force
before tension test [°C]	after tension test [°C]	
-11.2	-11.2	2967.0
-10.6	-10.4	2699.0
-11.2	-13.0	2719.0
-11.9	-11.4	3004.0
-11.7	-11.4	2961.0
-11.4	-11.4	2871.0
-11.3	average	2870.2

With island effects > 1 mm, after scraping the results were not better

Temperature		Force
before tension test [°C]	after tension test [°C]	
-11.6		3741
-11.2		3515
-11.3		3524
-11.9		3588
-11.2		3559
-11.4	average	3585.4

Suction cup is just a bit flexible, suction with slight pressure

Temperature		Force
before tension test [°C]	after tension test [°C]	
-6.1		2791.0
-5.4		2703.0
-4.6		2756.0
-5.0		2784.0
-6.3		2779.0
-5.6		2748.0
-5.5	average	2760.2
wiped		2802.0

Temperature		Force
before tension test [°C]	after tension test [°C]	
-5.9		3626
-5.4		3486
-4.7		3406
-5.3		3326
-5.0		3405
-4.5		3368
-5.1	average	3436.2

Suction cup suction on usefully

tension direction: vertical to the pane
 pressure: -0.6 bar
 medium tension speed: 3.6 mm/s

Suction cup: 388-1998

Temperature		Force
before tension test	after tension test	
[°C]	[°C]	[N]
Suction cup stiff, suctions only if it is pressed strongly.		

Temperature		Force
before tension test	after tension test	
[°C]	[°C]	[N]
Suction cup stiff, suctions only if it is pressed strongly.		

Temperature		Force
before tension test	after tension test	
[°C]	[°C]	[N]
-21		2830
-20.9		2995
-21.5		3213
-21.8		3516
-20.1		3665
-21.06	average	3243.8
Suction cup just a bit flexible, during the test it is increasingly softer. Pressed on by hand.		

Suction cup: 540

Temperature		Force
before tension test	after tension test	
[°C]	[°C]	[N]
Suction cup stiff, suctions only if it is pressed strongly.		

Temperature		Force
before tension test	after tension test	
[°C]	[°C]	[N]
-24.5	-24.5	1115
-25.5	-25.3	927
-26.3	-26.1	628
-25.4		
Suction cup stiff doesn't suction itself. It has to be pressed on strongly by hand.		

Temperature		Force
before tension test	after tension test	
[°C]	[°C]	[N]
-20.9	-20.2	1485
-19.5	-19.6	1767
-19.3	-17.4	1889
-19.4	-19.5	1868
-19.8	average	1752.3
Top value on iced-up pane, then scraped from ice; suction cup stiff, pressed on by hand.		

tension direction: vertical to the pane
 pressure: -0.6 bar
 medium tension speed: 3.6 mm/s

Suction cup: 388-1998

Temperature		Force
before tension test [°C]	after tension test [°C]	
-16.8		1959
-17.7		2281
-17.6		2282
-17.4	average	2174.0
Suction cup is just a bit flexible, suction with slight pressure		

Suction cup: 540

Temperature		Force
before tension test [°C]	after tension test [°C]	
-16.6	-16.4	1751
-17.6	-17.6	1853
-16.4	-16.1	1851
-16.9	average	1818.3
Suction cup stiff doesn't suction itself. It has to be pressed on strongly by hand.		

Temperature		Force
before tension test [°C]	after tension test [°C]	
-11.5		3172
-11.3	-11.1	3119
-11.7		2513
-11.6	-11.7	2103
-12.6		3677
-11.7	average	2916.8
At 3 and 4 pane slightly iced-up, suction process with strong pressure. At 5 pane rubbed? and waited for 3 minutes, suction process with slight pressure.		

Temperature		Force
before tension test [°C]	after tension test [°C]	
-11.2		1076
-11.2		1093
-12.9		1583
-12.0		1546
-11.0		1540
-10.9		1540
-11.5	average	1396.3
At value 3 suction cup and pane rubbed? slight pressure.		

Temperature		Force
before tension test [°C]	after tension test [°C]	
-6.3		3478
-5.7		3441
-5.1		3301
-4.6		3511
-5.4		3259
-5.1		3408
-5.4	average	3399.7
At value 4 suction cup wiped – suction cup suction well.		

Temperature		Force
before tension test [°C]	after tension test [°C]	
-5.1		1449
-5.8		1497
-5.8		1492
-5.3		1489
-5.3		821
-5.5	average	1349.6
At value 4 pane covered with thin ice, suction cup suction usefully		

tension direction: parallel to pane
 pressure: -0.6 bar
 medium tension speed: 3.6 mm/s

Suction cup: 388-2003

Temperature		Force
before tension test [°C]	after tension test [°C]	
	-12.3	2750.0
-11.8	-12.1	3016.0
-11.2	-11.5	3227.0
-11.0	11.2	3269.0
-11.0	-10.9	3208.0
-9.6	-10.4	3245.0
-10.9	average	3119.2

Suction cup: 388-2000

Temperature		Force
before tension test [°C]	after tension test [°C]	
	-10.5	2830
	-10.2	3487
	-10.2	3870
	-9.4	4048
	-9.5	4092
	-10.8	3982
-10.1	average	3718.2

Suction cup frozen stiff, suction only if pressed on strongly; becomes supple in course of test

Temperature		Force
before tension test [°C]	after tension test [°C]	
-29.9		902.0
-29.9	cleaned	1284.0
-29.7		1271.0
-29.5		1165.0
-29.6		1288.0
-30.1		1221.0
-29.8	average	1188.5

slow tension, 0.3 mm/sec, creep beginning 1970 N

thin hoarfrost effects friction increase:
 cleaned: 1067 N, then
 max. tension force after several stages:

Further suction cups at -29.8°C-medium no longer in working order