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EFFECT OF PLATE SURFACE FINISH ON ANTI-ICING ENDURANCE TIME

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EFFECT OF PLATE SURFACE FINISH ON ANTI-ICING ENDURANCE TIME

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Un sommaire français se trouve avant la table des matières.

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16. Abstract

Under contract to the Transportation Development Centre of Transport Canada, the Anti-Icing Materials International Laboratory (AMIL) undertook a study to evaluate the effect of test plate surface finish on anti-icing endurance times of SAE Type I and Type IV de/anti-icing fluids. The objective of these tests was to determine whether the roughness of the test plates had a significant effect on the protection time of the fluids.

Five aluminum surface finishes were studied: a mirror polished surface with an average roughness (Ra) between 0.2 and 0.8 μm, a plate scratched with grooves along the long axis with an Ra of 1.3 μm, a plate scratched with grooves along the short axis with an Ra of 2.6 μm, a weathered (oxidized) aircraft aluminum plate with an Ra of 0.54 μm and the painted flipside of this plate. Five fluids were studied: two SAE Type I deicing fluids, one propylene glycol-based fluid, one ethylene glycol-based fluid, and one military specification deicing fluid. The test method used was the Water Spray Endurance Test (WSET) of Annex A of AMS1424 and AMS1428.

Although there were no large or consistent differences in anti-icing times, ice formed earlier on the rougher plates. However, ice progressed faster along the smoother surfaces. Furthermore, there was more variation in the results on the rougher plates. A surface roughness of 0.5 μm or less was selected not only to ensure repeatability of the test results, but also because it is representative of an aircraft surface.

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16. Résumé

Dans le cadre d'un marché avec le Centre de développement des transports de Transports Canada, le Laboratoire international des matériaux antigivre (LIMA) a entrepris une étude pour évaluer l'effet de l'état de surface de la plaque d'essai sur la durée d'efficacité (ou endurance) de liquides de dégivrage/antigivre de type I et de type IV de la SAE. Ces essais avaient pour objectif de déterminer dans quelle mesure la rugosité des plaques d'essai influe sur la durée de la protection assurée par les liquides.

Cinq états de surfaces en aluminium ont été étudiés : une surface au poli «miroir» offrant une rugosité moyenne (Ra) de 0,2 à 0,8 µm, une plaque présentant des éraflures longitudinales (Ra = 1,3 µm), une plaque présentant des éraflures transversales (Ra = 2,6 µm) une plaque d'aluminium d'aéronef abîmée par les intempéries (oxydée) (Ra = 0,54 µm) et l'autre face de cette dernière plaque, revêtue de peinture. Cinq liquides ont été étudiés : deux liquides de dégivrage de type I de la SAE, un liquide à base de propylène glycol, un liquide à base d'éthylène glycol, et un liquide de dégivrage de spécification militaire. La méthode d'essai utilisée était le test d'endurance au jet d'eau (WSET, pour *Water Spray Endurance Test*) exposé à l'annexe A des normes AMS1424 et AMS1428.

Aucun écart important ou uniforme n'a été constaté dans les durées d'efficacité des liquides, mais le givre avait tendance à apparaître plus tôt sur les plaques rugueuses. Toutefois, il progressait plus rapidement sur les surfaces lisses que sur les surfaces rugueuses. De plus, plus la surface était rugueuse, plus les résultats étaient variables. Une rugosité de surface de 0,5 µm ou moins a été choisie, non seulement pour assurer la répétabilité des résultats d'essais, mais aussi parce qu'une telle rugosité est représentative d'une surface d'aéronef.

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SUMMARY

Under contract to the Transportation Development Centre of Transport Canada, the Anti-Icing Materials International Laboratory (AMIL) undertook a study to evaluate the effect of test plate surface finish on anti-icing endurance times of SAE Type I and Type IV de/anti-icing fluids. The objective of these tests was to determine whether the roughness of the test plates had a significant effect on the protection time of the fluids.

Five aluminum surface finishes were studied: a mirror polished surface with an average roughness (Ra) between 0.2 and 0.8 µm, a plate scratched with grooves along the long axis with an Ra of 1.3 µm, a plate scratched with grooves along the short axis with an Ra of 2.6 µm, a weathered (oxidized) aircraft aluminum plate with an Ra of 0.54 µm, and the painted flipside of this plate. Five fluids were studied: two SAE Type I deicing fluids, one propylene glycol-based fluid, one ethylene glycol-based fluid, and one military specification deicing fluid. The test method used was the Water Spray Endurance Test (WSET) of Annex A of AMS1424 and AMS1428.

Although there were no large or consistent differences in anti-icing times, ice formed earlier on the rougher plates. However, ice progressed faster along the smoother surfaces. Furthermore, there was more variation in the results on the rougher plates. A surface roughness of 0.5 µm or less was selected not only to ensure repeatability of the test results, but also because it is representative of an aircraft surface.

SOMMAIRE

Dans le cadre d'un marché avec le Centre de développement des transports de Transports Canada, le Laboratoire international des matériaux antigivre (LIMA) a entrepris une étude pour évaluer l'effet de l'état de surface de la plaque d'essai sur la durée d'efficacité (ou endurance) de liquides de dégivrage/antigivre de type I et de type IV de la SAE. Ces essais avaient pour objectif de déterminer dans quelle mesure la rugosité des plaques d'essai influe sur la durée de la protection assurée par les liquides.

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LIST OF SYMBOLS

FIE	First Ice Event: period of elapsed time for first ice crystal to reach the 25 mm line (minutes and seconds)
MIL	Military fluid MIL-A8243D
MIT	Mean Icing Time: period of elapsed time to have a mean ice front at the 25 mm line (minutes and seconds)
P_a	Air pressure of the spraying nozzle (kPa)
P_w	Water pressure of the spraying nozzle (kPa)
Ra	Average roughness
Rh	Relative humidity (%)
T_a	Temperature of the cold room (°C)
T_p	Temperature of the plates on the refrigerated units (°C)
TI-EG	Type I fluid, ethylene glycol-based
TI-PG	Type I fluid, propylene glycol-based
TIV-EG	Type IV fluid, ethylene glycol-based
TIV-PG	Type IV fluid, propylene glycol-based
WFR	Water Flow Rate from the nozzle (mL/min)
WSET	Water Spray Endurance Test

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1. INTRODUCTION

De/anti-icing fluids are commonly used during the winter to remove and prevent aircraft contamination created by frozen deposits on the wing while the aircraft is on the ground. The fluids are able to protect the aircraft for a time period that depends on environmental conditions such as the nature of the precipitation, the outside air temperature and the precipitation intensity.

The Transportation Development Centre of Transport Canada continues to support research and related efforts directed toward the improvement of aircraft deicing methods and practices. One such effort is the standardization of Anti-icing Endurance Time (AET) testing to produce Holdover Time (HOT) guidelines for de/anti-icing fluids. This task has largely been carried out through the combined efforts of the SAE G-12 Holdover Time and Fluids subcommittees, and has led to the adaptation of the concept of an Aerospace Standard, AS5485 [1] that is currently in draft form. The AET tests consist of evaluating the time that a fluid can protect an aluminum flat plate from a prescribed amount of freezing contamination under various conditions of freezing precipitation. One of the issues needing resolution in order to adopt this standard is the determination of the condition of the test plate surface on which the fluids should be tested.

1.1 Objective

The objective of this study was to determine the effect of the aluminum test plate surface finish on the protection time of anti-icing fluids by comparing AETs on different surfaces. Fluid comparisons were not part of this study.

1.2 Background

Until now, the tests run to produce the HOT tables have had no requirement regarding the surface finish. For standard tests, some requirement must be in place to ensure reproducible tests.

For a fluid to be qualified, it is currently tested using the Water Spray Endurance Test (WSET) as part of AMS 1424 or AMS 1428 [2]. These tests are run on mirror polished plates with an average roughness (Ra) of 0.1 to 0.2 µm to test the ability of the candidate fluid to wet the surface. The question arose in the SAE groups as to whether the AET tests should be run on these mirror polished plates to confirm wettability on a presumably worst case plate, or whether they should be run on rougher test plates more representative of real airplane surfaces.

2. TEST DESCRIPTION

2.1 Test Method

The test selected to investigate the surface effects was the Water Spray Endurance Test (WSET) in accordance with Annex A of AMS 1424 and AMS 1428 [2]. This test was chosen because it is a normalized test whose procedure is well documented and because AMIL has ten years' experience running the test according to specification.

2.1.1 Water Spray Endurance Test

This test is designed to simulate freezing fog exposure of an aircraft when the temperature is below 0°C. During a WSET, a 10 cm x 30 cm aluminum plate is coated with a film of the candidate fluid. The plate is positioned with a downward slope of 10° and cooled to -5°C. It is then subjected to supercooled droplets at a prescribed average icing intensity of 5.0 ± 0.2 g/dm²/h. The WSET set-up used is shown in Figure 1. The water spray is generated by a nozzle centred on a support at a height of 130 cm and oscillating at ± 30° at 3 cycles per minute. Experimental parameters and specifications are detailed in Table 1 and the droplet diameter distribution is shown in Figure 3.

Fluid performance in a WSET is evaluated from visual observations of the ice front position. Parameters measured during the test are:

1. Anti-icing endurance, WSET time or ***First Ice Event*** (FIE), which corresponds to the period when the ice front first reaches the line at 25 mm from the top of the plate; and
2. ***Mean Ice Time*** (MIT), which corresponds to the icing time required to have an average 25 mm length of ice deposit on top of the test plate.

2.1.2 Calibration

By AMS 1424 and AMS 1428 requirement, the icing rate during WSET is 5.0 ± 0.2 g/dm²/h. To provide several simultaneous measurements, the refrigerated support accommodates six 10 cm x 30 cm plates. The support consists of a refrigerated unit as shown in Figure 1. The variation in icing intensity as a function of the plate position is evaluated using calibration tests performed prior to standard tests. These calibration tests correspond to standard tests without fluid. The mass of ice accumulated on each plate is measured after 30 minutes to evaluate the distribution of the ice on the 10 cm x 30 cm test plates. Eighteen smaller ice catch plates, 10 cm x 10 cm, are used to cover the entire support area. Figure 2 shows the position of the small plates on the refrigerated support.

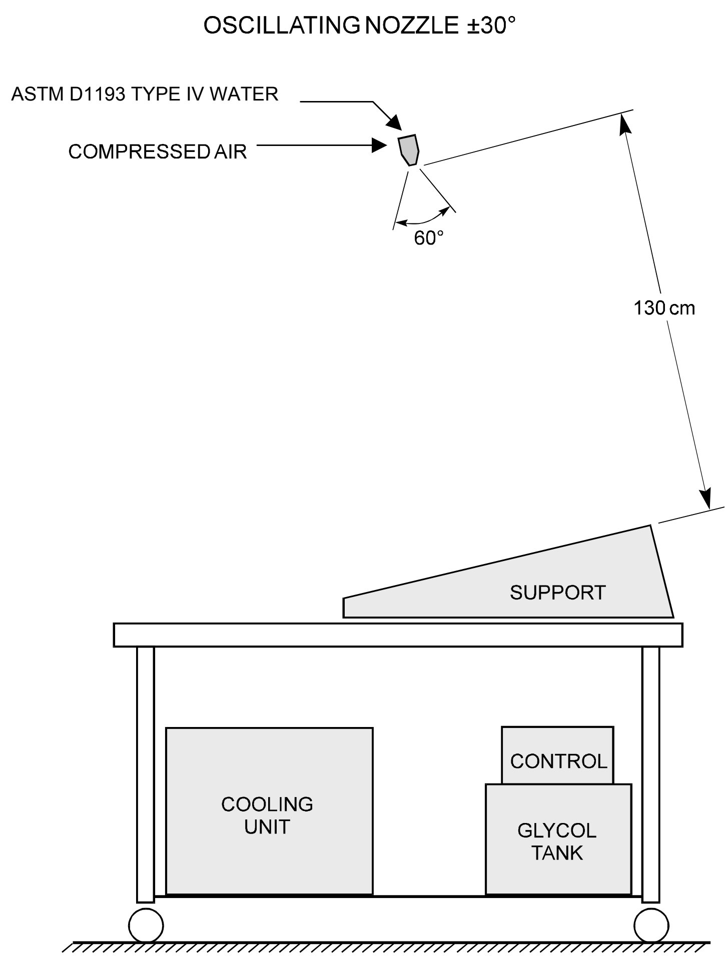

Figure 1 - WSET Experimental Set-up

1P1	2P1	3P1	4P1	5P1	6P1
1P2	2P2	3P2	4P2	5P2	6P2
1P3	2P3	3P3	4P3	5P3	6P3
P 1	**P 2**	**P 3**	**P 4**	**P 5**	**P 6**

Figure 2 - Small Plate Position on Support

Table 1 - Measured Experimental Test Parameters

PARAMETER	SETTING
Air Pressure (P_a)	270 kPa
Air Temperature (T_a)	-5.0 ± 0.3°C
Droplet size distribution	50% between 15 μm and 35 μm
Droplet volume average	20 ± 5 μm
Icing intensity	5.0 ± 0.2 g/dm²/h
Plate material	Al alloy 2024
Roughness of the surface finish	Ra < 0.2 μm
Support Temperature (T_p)	-5.0 ± 0.5°C
Water conductivity	85 ± 5 μScm
Water Flow Rate (WFR)	62 mL/min
Water pH level	6.8 ± 0.2
Water Pressure (P_w)	190 kPa

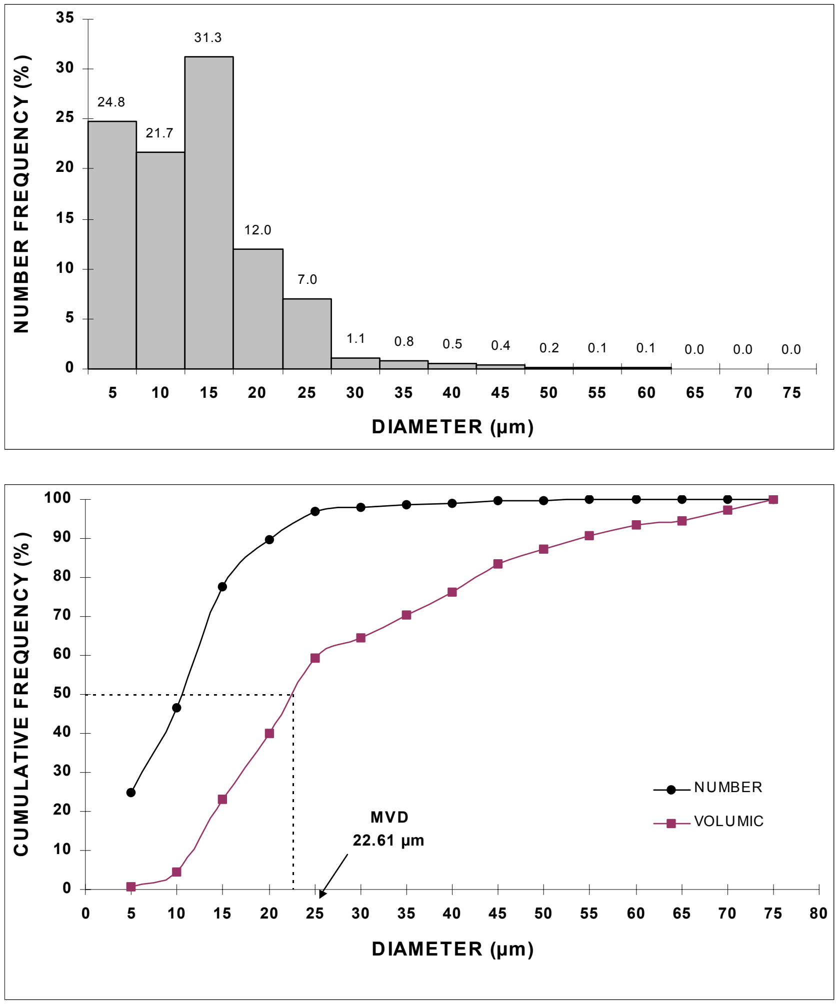

Figure 3 - Droplet Diameter Distribution in WSET

2.1.3 Modification to the Water Spray Endurance Time Test

The WSET, according to Annex A of AMS 1424 and 1428 [2], specifies one fluid per test run. To accelerate testing, the set-up was modified to accommodate two fluids per test run. Normally one fluid is tested on three plates intercalated with the ice catch plates as shown in Figure 4.

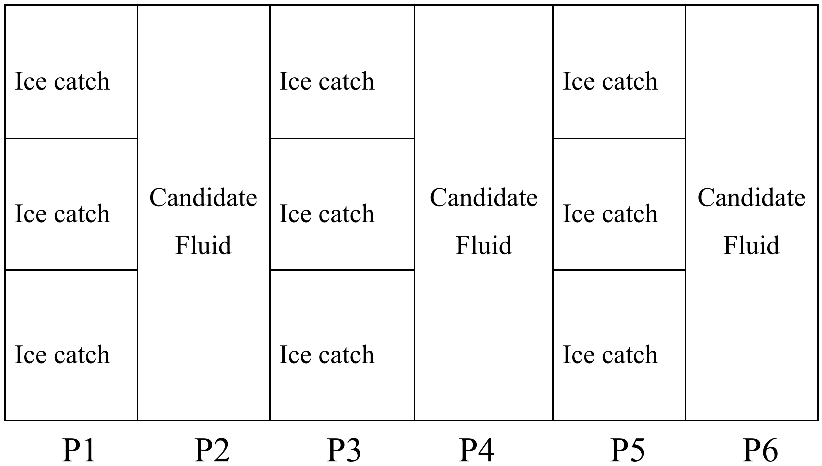

Figure 4 - Usual WSET Test Plate Set-up

However, for some of the tests in this study the test set-up shown in Figure 5 was used. This allowed for two fluids per test run, while still providing replicas of tests.

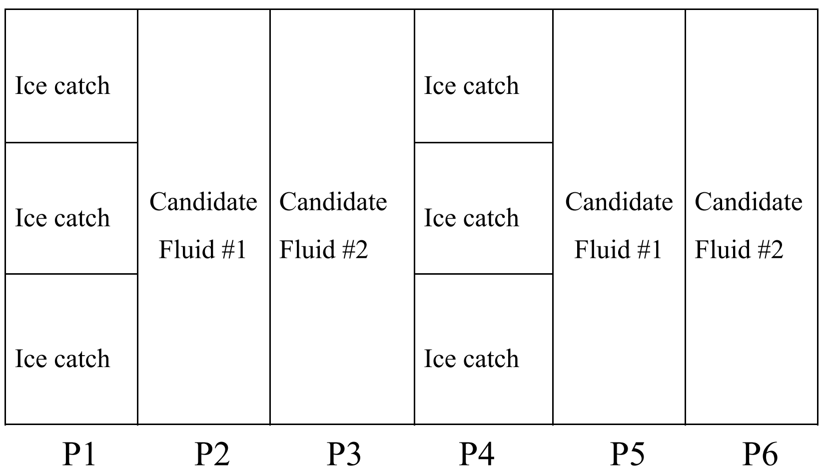

Figure 5 - Plate Set-up for Comparison Tests of Type IV over Type I

2.2 Test Plates

Since the object of this test was to compare the effect of surface finish, five different test plate surface finishes were studied during the WSET tests:

1) The normally used standard polished plates required by AMS 1424 and 1428 [2], which have been polished to an average roughness (Ra) of 0.2 µm.

2) Plates polished with grooves made along the long axis, to obtain a texture similar to brushed steel (Figure 6a).
3) Plates polished with grooves made along the short axis, again to obtain a texture similar to brushed steel (Figure 6b).
4) Plates made of weathered (oxidized) aircraft aluminum, provided by Anthony Manzo of Air Canada.
5) The flipside of the aircraft aluminum plate, which was painted.

a) b)

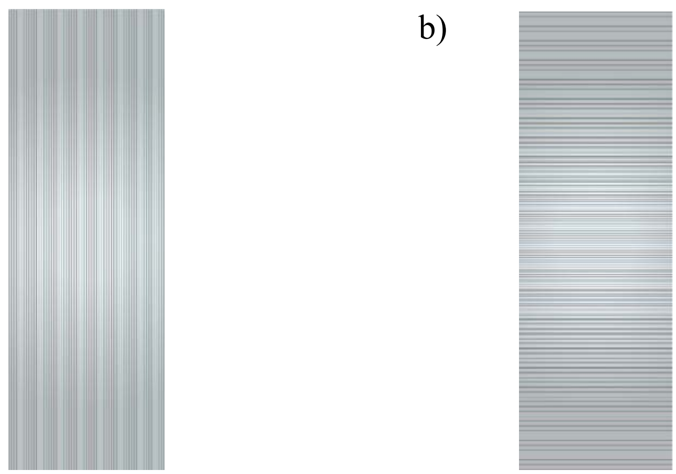

Figure 6 - Plates Polished with Grooves (a) Along the Long Axis (b) Along the Short Axis

2.2.1 Roughness Measurement of the Test Plates

Since the objective of this study was to compare anti-icing times on different surfaces, the roughness of the surfaces was measured.

2.2.1.1 Surface Profile

The roughness of the studied surfaces was measured using a surface profilometer. The roughness is expressed in terms of its Ra, which is defined as the arithmetic mean of the profile deviation according to ISO 4287 [3].

2.2.1.2 Apparatus

- Main unit: UBM company, type: 2025, No = 92 M001
- Software: UBSOFT, version 1.9

The apparatus used was a profilometer, which uses a laser coupled with an optical lens system that eliminates all physical contact with the studied surface. It detects optical changes induced by the varying distance between the source and the surface trace in two or three dimensions. Different factors of roughness were calculated from the surface profile, including the Ra.

2.3 Fluids

Originally, four fluids were selected for the test set: two Type IV anti-icing fluids (one propylene glycol-based and one ethylene glycol-based) and two Type I fluids (again, one propylene glycol-based and one ethylene glycol-based). Both Type IVs were tested in neat form (undiluted). The Type I propylene glycol-based fluid was tested in a 50/50 concentration (diluted with hard water) and the ethylene glycol-based fluid was tested neat (in its concentrate form). The hard water used for dilution purposes was prepared as per AMS 1424 [2].

Table 2 - Fluid Identification

Type of Glycol	Fluid Type Dilution (fluid/water)	AMIL Label	Recep. Date	Reference
Propylene Glycol	Type IV neat	C317	99-03-03	TIV-PG
Ethylene Glycol	Type IV neat	C709	00-03-24	TIV-EG
Propylene Glycol	Type I 50/50	C612	00-01-05	TI-PG
Ethylene Glycol	Type I neat	C293	99-02-01	TI-EG
Propylene Glycol	MIL-A-8243D 50/50	M030	00-03-13	50/50MIL

The purpose of the study was to compare the surface finishes of the plates and not the fluids. Therefore, since all the fluids were certified fluids, the Type I fluids had WSET times in excess of 3 minutes on polished plates, and the Type IVs had WSET times of longer than 80 minutes. They all adequately wet polished plates to pass the test. If these fluids can wet a polished plate (and this is considered a worst case) they will also probably wet an unpolished plate. Therefore, another fluid was added to the test set: a 50/50 dilution of the military fluid MIL-A8243D. This fluid did not pass the WSET since it does not adequately wet the polished test plate surface. This fluid was added to the test set to see whether a rougher test surface would improve its time since it may be an easier surface to wet. This could lead to an unacceptable fluid appearing acceptable, or comparable to, a certified fluid.

3. TEST RESULTS

3.1 Test Presentation

Fluid sample identification is presented in Table 2 and the identification of the tests is presented in Table 4. All the fluids were sheared within two hours of the beginning of the test – the Type I's at 7500 rpm for 10 minutes and the Type IVs at 3500 rpm for 5 minutes, using the Brookfield counter rotator as specified in AMS 1424 and 1428 [2]. Air and plate temperatures for individual tests are shown in Appendix A.

3.2 Calibration

Calibration tests, as defined in section 2.4, were performed prior to standard tests. The results are presented in Table 3. According to the specification, the system is considered adequately calibrated if the icing intensity is within the prescribed margin of 5 ± 0.2 g/dm²/h for the WSET for each small plate. Accordingly, in the WSET calibration data presented in Table 3, all icing intensities are equal to 5 g/dm²/h within a range of ± 0.2 g/dm²/h.

3.3 Water Spray Endurance Test

FIE (First Icing Event) and MIT (Mean Icing Time) values, as defined in section 2.3, are listed for each test run in Table 5 through 9 with identification of the plate positions and the mass of ice collected on the blank plates. Standard WSET is considered acceptable if the average icing intensity for each blank plate is equal to 5.0 g/dm²/h within a range of ± 0.2 g/dm²/h. This is validated as shown in Table 5 through 9.

Table 3 - Calibration Test Results (g/dm²/h)

TEST	PLATE	P 1	P 2	P 3	P 4	P 5	P 6	OVERALL AVERAGE
WSC-2015	1	5.14	5.12	5.10	5.08	4.92	4.92	
99-09-20	2	5.08	5.10	5.06	5.08	5.04	4.96	
30 minutes	3	4.92	4.92	4.94	4.90	4.88	4.88	
	Average							5.00

Table 4 - Climatic Chamber Test Identification

NUMBER	DATE	FLUID	TEST PLATE
WSC2015	99-09-20	Calibration 30 minutes	N/A
WS1873	99-03-16	C317	Polished
WS1875	99-03-17	C317	Polished
WS2412	00-03-03	C317	Scratched long and short axes
WS2494	00-07-10	C317	Oxidized and painted
WS2427	00-05-11	C709	Polished
WS2426	00-05-10	C709	Polished
WS2513	00-07-19	C709	Scratched long and short axis
WS2516	00-07-20	C709	Oxidized and painted
WS2296	00-01-12	C612	Polished
WS2418	00-05-15	C612	Scratched short and long axis and polished
WS2413	00-05-03	C612	Scratched long and short axis
WS2495	00-07-10	C612	Oxidized and painted
WS2739	01-04-03	C293	Polished
WS2514	00-07-20	C293	Scratched long and short axis
WS2515	00-07-20	C293	Oxidized and painted
WS2394	00-04-06	M030	Polished
WS2478	00-07-05	M030	Scratched long and short axis
WS2478	00-07-05	M030	Oxidized and painted

3.4 Water Spray Endurance Test Results

For each fluid, three to four test sessions were required to test all five surface finishes. The results for each fluid are presented in Tables 5 through 9.

Table 5 – Type IV-PG

FLUID LABEL	TEST CODE	DATE y-m-d	ICE DATA		FLUID DATA			
			Plate	Intensity g/dm²/h	Plate #	Plate finish	FIE min	MIT min
C317	WS1873	99-03-16	P1	5.08 ± 0.07	P2	Polished	95	100
			P3	5.08 ± 0.08	P4	Polished	98	104
			P5	5.04 ± 0.08	P6	Polished	97	103
	WS1875	99-03-17	P2	5.01 ± 0.09	P1	Polished	97	106
			P4	5.01 ± 0.10	P3	Polished	102	107
			P6	5.05 ± 0.07	P5	Polished	105	108
	WS2412	00-03-03	P1	5.11 ± 0.04	P2	Short axis	94	95
					P3	Long axis	93	99
			P4	5.08 ± 0.04	P5	Short axis	92	95
					P6	Long axis	92	94
	WS2494	00-07-10	P1	5.07 ± 0.01	P2	Painted	86	87
					P3	Oxidized	83	87
			P4	5.06 ± 0.05	P5	Painted	54	65
					P6	Oxidized	83	87

Table 6 – Type IV-EG

FLUID LABEL	TEST CODE	DATE y-m-d	ICE DATA		FLUID DATA			
			Plate	Intensity g/dm²/h	Plate #	Plate finish	FIE min	MIT min
C709	WS2427	00-05-11	P1	5.08 ± 0.03	P1	Polished	122	>126
			P3	4.98 ± 0.03	P4	Polished	125	>126
			P5	4.93 ± 0.05	P6	Polished	122	>126
	WS2426	00-05-10	P2	4.87 ± 0.03	P1	Polished	125	>126
			P4	4.86 ± 0.02	P3	Polished	122	>126
			P6	4.89 ± 0.04	P5	Polished	123	>126
	WS2513	00-07-19	P1	5.01 ± 0.02	P2	Short axis	95	>96
					P3	Long axis	93	>96
			P4	5.08 ± 0.03	P4	Short axis	94	>96
					P5	Long axis	96	>96
	WS2516	00-07-20	P1	5.07 ± 0.06	P2	Oxidized	114	>120
					P4	Painted	107	>120
			P4	5.07 ± 0.11	P5	Oxidized	109	>120
					P6	Painted	118	>120

Table 7 – Type I-PG, 50/50 dilution

FLUID LABEL	TEST CODE	DATE y-m-d	ICE DATA		FLUID DATA			
			Plate	Intensity g/dm²/h	Plate #	Plate finish	FIE Min:sec	MIT min
C612	WS2296	00-01-12	P1	4.91 ± 0.03	P1	Polished	5:00	6:15
			P3	4.95 ± 0.07	P4	Polished	5:15	6:20
			P5	4.95 ± 0.08	P6	Polished	5:20	6:20
	WS2418	00-05-15	P3	5.04 ± 0.06	P1	Short axis	3:15	5:50
					P3	Polished	3:40	5:55
			P6	5.07 ± 0.11	P4	Long axis	4:20	5:50
					P5	Polished	4:10	5:30
	WS2413	00-05-03	P1	5.01 ± 0.05	P2	Short axis	2:30	4:25
					P3	Long axis	2:30	4:05
			P4	5.05 ± 0.07	P4	Short axis	2:30	3:55
					P5	Long axis	2:30	3:30
	WS2495	00-07-10	P1	4.94 ± 0.02	P2	Painted	3:30	6:00
					P4	Oxidized	2:30	6:00
			P4	4.93 ± 0.03	P5	Painted	2:30	6:00
					P6	Oxidized	2:30	6:00

Table 8 – Type I-EG, neat

FLUID LABEL	TEST CODE	DATE y-m-d	ICE DATA		FLUID DATA			
			Plate	Intensity g/dm²/h	Plate #	Plate finish	FIE Min:sec	MIT min
C612	WS2739	01-04-03	P2	5.01 ± 0.07	P1	Polished	6:55	8:10
			P4	5.09 ± 0.03	P4	Polished	7:30	7:30
			P6	5.11 ± 0.02	P6	Polished	7:10	7:10
	WS2514	00-07-20	P1	5.01 ± 0.07	P1	Long axis	3:50	7:50
					P3	Short axis	5:45	7:50
			P4	5.03 ± 0.03	P4	Long axis	6:10	7:50
					P5	Short axis	6:20	7:50
	WS2515	00-07-20	P1	4.97 ± 0.04	P2	Oxidized	6:50	7:20
					P3	Painted	6:00	7:10
			P4	5.07 ± 0.07	P4	Oxidized	6:55	7:20
					P5	Painted	6:30	7:30

Table 9 - MIL, 50/50 dilution

FLUID LABEL	TEST CODE	DATE y-m-d	ICE DATA		FLUID DATA			
			Plate	Intensity g/dm²/h	Plate		FIE Min:sec	MIT min
					#	finish		
M030	WS2394	00-04-06	P1	4.99 ± 0.09	P2	Polished	2:05	2:10
			P4	4.91 ± 0.05	P5	Polished	2:05	2:10
	WS2488	00-07-05	P1	4.91 ± 0.03	P2	Short axis	1:25	4:00
					P3	Long axis	2:30	4:00
			P4	4.91 ± 0.03	P5	Short axis	1:25	4:00
					P6	Long axis	2:30	4:00
	WS2478	00-07-05	P1	4.93 ± 0.07	P2	Painted	2:50	2:50
					P3	Oxidized	2:30	2:30
			P4	4.98 ± 0.05	P4	Painted	2:45	2:45
					P5	Oxidized	2:30	2:30

3.5 Test Plate Roughness

The roughness of certain surfaces was measured using a profilometer as described in section 2.2.1.1. The results are summarized in Table 10.

Table 10 - Surface Roughness

Test plate	Ra (μm)	Ra (μm)	Ra (μm)	avg
Polished plate - new	0.21	0.25	0.18	0.21
Polished plate - after 2 years	0.97	0.72	0.58	0.76
Aircraft plate (oxidized)	0.55	0.54	0.54	0.54
Scratched - long axis	1.19	1.19	1.56	1.31
Scratched – short axis	3.02	1.82	3.02	2.62

For each test plate, three 1 mm profiles were measured at three different places on the test plate. The test plates examined were the two scratched plates, the aircraft aluminum, and two polished plates (one a freshly polished plate that had not yet been used for testing, and the other a well-used test plate after two years of use). The table shows that polished test plates used in this test had an average roughness (Ra) between 0.21 and 0.76 μm; the scratched plates had an Ra of 1.3 (long-axis) and 2.6 (short-axis); and the aircraft aluminum had an average roughness between the polished and scratched plates. Note that the surface profile measures a 1 mm length and therefore occasional deep scratches in the plates were not taken into consideration.

4. COMPARISONS

4.1 Type I Propylene Glycol

A summary of the WSET results of the propylene glycol-based fluid on the different test surfaces is presented in Table 11. This table summarizes both the First Icing Event (FIE), also known as the WSET time, which is the time that the first ice crystal from the downward moving ice front reaches a line drawn 25 mm from the top of the plate, and the Mean Icing Time (MIT), which is the time at which the average ice front reaches the 25 mm line. When the FIE is the result of edges or spikes in the ice front reaching the 25 mm line long before the average front, the results may appear unnecessarily short or inconsistent. Therefore, for comparison, both the FIE and MIT are reported. The standard deviation is compared as well, since a test surface that provides repeatable results, or low standard deviation, would be most desirable for normalized tests.

Table 11 - Comparison of WSET Times of Type I PG on the Different Surface Finishes

Fluid	Test Plate	WSET (FIE)	std dev	MIT	Std dev
TI-PG	Polished	04:41	00:44	05:53	00:04
	Scratched - long axis	03:07	01:04	04:28	01:13
	Scratched - short axis	02:45	00:26	04:43	01:00
	Oxidized	02:30	0	06:00	0
	Painted	02:30	0	06:00	0

Table 11 shows that for the Type I propylene glycol-based fluid, the FIE time is longest on the standard WSET polished plates, and shortest on the oxidized and painted plates. The most variation is seen on the plates scratched along the long axis. For the MIT, the polished, oxidized and painted plates have the longest times, with the most variation seen on both scratched plates.

4.2 Type I Ethylene Glycol

A comparison of the WSET times for the ethylene glycol-based Type I fluid is presented in Table 12. The table shows that the longest FIE times were observed on the polished and oxidized plates, while the shortest times were found on both scratched plates, which also showed the most variation. In general, the MITs are the same for all fluids. However, slightly longer MITs were observed on both the scratched plates. The short FIE and long MIT seen on the scratched plates is the result of ice prematurely forming along the edges of the test plates, reducing the FIE with respect to the MITs.

Table 12 - Comparison of WSET Times of Type I EG on the Different Surface Finishes

Fluid	Test Plate	WSET (FIE)	std dev	MIT	std dev
TI-EG	Polished	07:11	00:17	07:36	00:30
	Scratched - long axis	06:10	01:39	07:50	00:00
	Scratched - short axis	06:02	00:24	07:50	00:00
	Oxidized	06:52	00:03	07:20	00:00
	Painted	06:15	00:21	07:20	00:14

4.3 MIL Fluid

A summary of the results of the Military fluid is presented in Table 13. The table shows that in all cases the FIE time is inferior to the minimum 3 minutes for an SAE Type I fluid. This shows that the fluid is uncertifiable, regardless of the test surface. The standard deviation in all cases is zero, implying the same measured value for each test: this may be due, in part, to the fact that only two test plates were tested for all conditions.

Table 13 - Comparison of WSET Times of the MIL Fluid on the Different Surface Finishes

Fluid	Test Plate	WSET (FIE)	std dev	MIT	std dev
50/50 MIL	Polished	2:05	0	2:10	0
	Scratched – long axis	2:30	0	4:00	0
	Scratched – short axis	2:15	0	4:00	0
	Oxidized	2:30	0	2:30	0
	Painted	2:45	0	2:40	0

Table 13 shows that the FIE is relatively the same for all test surfaces. For the MIT, the scratched plates have the longest time. As with the Type I EG, this is the result of a failure along the edges of the scratched plates.

4.4 Type IV Ethylene Glycol

A summary of the WSET results of the ethylene glycol-based Type IV fluid is presented in Table 14. The table shows that the longest FIE times were observed on the polished plates, while the shortest were seen on the scratched plates. The most variation, as expressed by the high standard deviation, was seen on the oxidized and painted plates. All the tests were stopped shortly after the FIE was reached and consequently the MIT was not measured.

Table 14 - Comparison of WSET Times of Type IV EG on the Different Surface Finishes

Fluid	Test Plate	WSET (FIE)	Std dev	MIT
TIV-EG	Polished	123:10	1:28	>126
	Scratched - long axis	94:30	2:07	>96
	Scratched - short axis	94:30	0:43	>96
	Oxidized	111:30	3:32	>120
	Painted	112:30	7:47	>120

4.5 Type IV Propylene Glycol

A summary of the WSET results on the different surfaces for the propylene glycol-based Type IV fluid is presented in Table 15. The table shows that the longest FIE times were observed on the polished plates, and the shortest times on the oxidized and painted plates. The most variation was seen in the FIE results on the painted plate, which had a large variation in results.

Table 15 - Comparison of WSET Times of Type IV PG on the Different Surface Finishes

Fluid	Test Plate	WSET (FIE)	Std dev	MIT	Std dev
TIV-PG	Polished	96:40	1:32	104:40	0:57
	Scratched - long axis	92:30	0:42	96:30	3:32
	Scratched – short axis	93:00	1:25	97:00	2:50
	Oxidized	83:00	0	87:00	0
	Painted	70:10	22:38	76:00	15:33

The polished plate had the longest MITs, while the painted plate had the shortest. As with the FIE, the standard deviation was the highest on the painted plate.

5. DISCUSSION AND COMPARISONS

Table 16 summarizes the results of all fluids on all five surfaces by comparing the longest and shortest WSET times for each test surface. The table shows that for most fluids the longest FIE times were seen on the polished plates now used for the WSET, which have the lowest roughness. The scratched plates usually had the longest MITs and the highest roughness.

Table 16 - Comparison of the Different Fluids on the Different Surfaces

	FIE-longest	FIE-shortest	MIT-longest	MIT-shortest
TI-PG	Polished	Oxidized, painted	Same	Same
TI-EG	Polished	Scratched	Scratched	Oxidized, painted
50/50 MIL	Same	Same	Scratched	Polished
TIV-PG	Polished, scratched	Oxidized, painted	Polished, scratched	Oxidized, painted
TIV-EG	Polished	Scratched	N/A	N/A

In all cases, no noticeable difference was seen between the two scratched plates. There was little or no difference in the WSET times regardless of whether the scratched plates were in the direction of the gravitational fluid flow (scratched along the long axis) or against it (scratched along the short axis). This suggests that the scratches neither hinder nor accelerate the accumulation of frozen contamination on the plate. However, in general the scratched plates showed the most variation in WSET times, which renders them the least effective for providing a reproducible test.

The standard polished plates have the longest FIE times. This is probably due to the fact that having no scratch marks allows for the fluid to evenly descend the plate, allowing for no additional nucleation sites.

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6. CONCLUSIONS AND RECOMMENDATIONS

Although there were no large or consistent differences in anti-icing times, it was on the rougher plates that the ice first appeared. However, the smoother surfaces were covered with ice more quickly. Also, there was more variation in the results with the rougher plates.

Therefore, an average surface roughness of 0.5 µm or less would be most desirable in a test plate, since this would provide the most repeatable results, while being approximely the same roughness as an aircraft wing.

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7. REFERENCES

[1] 24 March 2000 Draft of Aerospace Standard 5485. Endurance Time Testing For Aircraft Deicing/Anti-icing Fluids SAE Type I, II, III, and IV.

[2] Aerospace Material Specifications De/Anti-icing Fluid Aircraft, AMS 1424C Newtonian SAE Type I (November, 1999) and AMS 1428C Non Newtonian pseudo-plastic SAE Type II, Type III and Type IV (October, 1998).

[3] ISO 4287, 1997 – Geometrical Product Specifications (GPS) – Surface Texture: Profile Method: Terms, definitions and surface texture parameters.

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APPENDIX A

TEST DATA SHEETS
WITH AIR AND PLATE TEMPERATURE RECORDING

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TEST: WSC-2015 DATE: 99-09-20 DURATION: 30 minutes

Height	P1	P2	P3	P4	P5	P6
0 mm – 25 mm – 100 mm	I: 5.14 g/dm²h	I: 5.12 g/dm²h	I: 5.10 g/dm²h	I: 5.08 g/dm²h	I: 4.92 g/dm²h	I: 4.92 g/dm²h
100 mm – 150 mm – 200 mm	I: 5.08 g/dm²h	I: 5.10 g/dm²h	I: 5.06 g/dm²h	I: 5.08 g/dm²h	I: 5.04 g/dm²h	I: 4.96 g/dm²h
200 mm – 300 mm	I: 4.92 g/dm²h	I: 4.92 g/dm²h	I: 4.94 g/dm²h	I: 4.90 g/dm²h	I: 4.88 g/dm²h	I: 4.88 g/dm²h
	I_{av}:5.05 σ:0.09	I_{av}:5.05 σ:0.09	I_{av}:5.03 σ:0.07	I_{av}:5.02 σ:0.08	I_{av}:4.95 σ:0.07	I_{av}:4.92 σ:0.03

T_a: -4.9±0.0°C T_p: -5.0± 0.2°C Rh: 61.5 ±2.3% Ave. Icing Int.: 5.00±0.09 g/dm²h

Comments:

TEST: WS1873 **DATE:** 99-03-16 **DURATION:** 105 minutes

	P1	P2	P3	P4	P5	P6
0 mm		Beg: 50 min		Beg: 50 min		Beg: 49 min
0–25 mm	I: 5.03 g/dm^{2}h	FIE: 95 min	I: 5.05 g/dm^{2}h	FIE: 98 min	I: 5.00 g/dm^{2}h	FIE: 97 min
25–100 mm		MIT: 100 min		MIT: 104 min		MIT: 103 min
100–150 mm	I: 5.18 g/dm^{2}h	fluid: C317	I: 5.19 g/dm^{2}h	fluid: C317	I: 5.15 g/dm^{2}h	fluid: C317
150–200 mm		plate: polished		plate: polished		plate: polished
200–300 mm	I: 5.04 g/dm^{2}h	PIL: n.m.	I: 5.01 g/dm^{2}h	PIL: n.m.	I: 4.98 g/dm^{2}h	PIL: n.m.
	I_{av}: 5.08 σ: 0.07		I_{av}: 5.08 σ: 0.08		I_{av}: 5.04 σ: 0.08	

T_a: -5.0±0.0°C T_p: -5.2±0.3°C Rh: ±% Ave. Icing Int.: 5.07±0.08g/dm²/h

DELAY between shearing and test : 35 minutes

Comments: TIV-PG

TEST: WS1875 **DATE:** 99-03-17 **DURATION:** 108 minutes

	P1	P2	P3	P4	P5	P6
0 mm	Beg: n.m.		Beg: n.m.		Beg: n.m.	
25 mm	FIE: 97 min		FIE: 102 min		FIE: 105 min	
	MIT: 106 min	I: 5.02 g/dm²h	MIT: 107 min	I: 4.94 g/dm²h	MIT: 108 min	I: 4.97 g/dm²h
100 mm	fluid: C317		fluid: C317		fluid: C317	
150 mm	plate: polished	I: 5.12 g/dm²h	plate: polished	I: 5.15 g/dm²h	plate: polished	I: 5.13 g/dm²h
200 mm		I: 4.90 g/dm²h		I: 4.95 g/dm²h		I: 5.05 g/dm²h
300 mm	PIL: n.m.		PIL: n.m.		PIL: n.m.	
		I_{av}: 5.01 σ: 0.09		I_{av}: 5.01 σ: 0.10		I_{av}: 5.05 σ: 0.07

T_a: -5.0±0.0°C T_p: -5.0±0.0°C Rh: 64.1±3.1% Ave. Icing Int.: 5.03±0.09 g/dm²/h

DELAY between shearing and test : 60 minutes

Comments: TIV-PG

TEST: WS2412 **DATE:** 00-03-03 **DURATION:** 100 minutes

Depth	P1	P2	P3	P4	P5	P6
0 mm		Beg:	Beg:		Beg:	Beg:
25 mm	I: 5.05 g/dm^2h	FIE: 94min MIT: 95min	FIE: 93min MIT: 99min	I: 5.02 g/dm^2h	FIE: 92min MIT: 95min	FIE: 92min MIT: 94min
100 mm – 150 mm	I: 5.14 g/dm^2h	fluid: C317	fluid: C317	I: 5.10 g/dm^2h	fluid: C317	fluid: C317
150 mm – 200 mm		plate: scratched short axis	plate: scratched long axis		plate: scratched short axis	plate: scratched long axis
200 mm – 300 mm	I: 5.14 g/dm^2h			I: 5.12 g/dm^2h		
300 mm		LIE:	LIE:		LIE:	LIE:
	I_{av}: 5.11 σ: 0.04			I_{av}: 5.08 σ: 0.04		

T_a: -5.0±0.1°C T_p: -5.0±0.1°C Rh: 65.4±2.8% Ave. Icing Int.: 5.10±0.05 $g/dm^2/h$

DELAY between shearing and test : 20min

Comments: TIV-PG

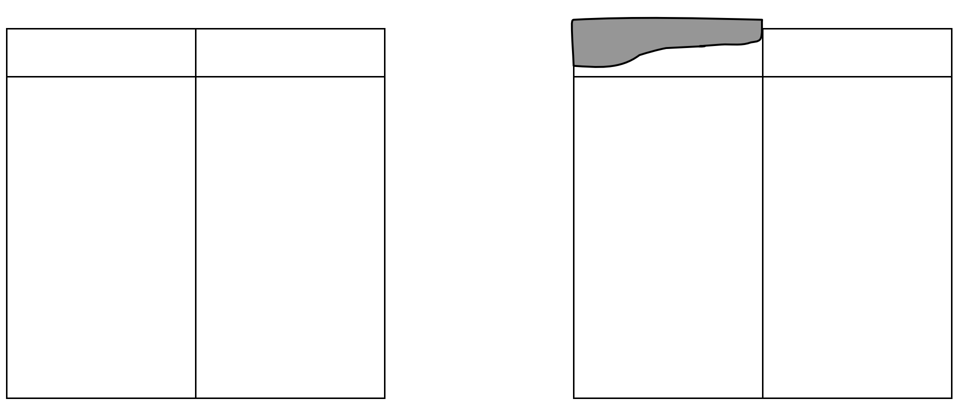
TEST: WS2494 **DATE:** 00-07-10 **DURATION:** 90 minutes

	P1	P2	P3	P4	P5	P6
0 mm		Beg:	Beg:		Beg:	Beg:
25 mm	I: 5.05 g/dm²h	FIE: 86min	FIE: 83min	I: 5.00 g/dm²h	FIE: 54min	FIE: 83min
		MIT: 87min	MIT: 87min		MIT: 65min	MIT: 87min
100 mm		fluid: C317	fluid: C317		fluid: C317	fluid: C317
150 mm	I: 5.07 g/dm²h	plate: painted	plate: oxidized	I: 5.06 g/dm²h	plate: painted	plate: oxidized
200 mm	I: 5.08 g/dm²h			I: 5.11 g/dm²h		
300 mm		LIE:	LIE:		LIE:	LIE:
	I_{av}: 5.07 σ: 0.01			I_{av}: 5.06 σ: 0.05		

T_a: ±°C T_p: ±°C Rh: ±% Ave. Icing Int.: ±g/dm²/h

DELAY between shearing and test :

Comments: TI- PG



TEST: WS2427 **DATE:** 00-05-11 **DURATION:** 126 minutes

	P1	P2	P3	P4	P5	P6
		Beg: n.m.		Beg: n.m.		Beg: n.m.
0 mm – 25 mm	I: 5.03 g/dm^2h	FIE: 122 min	I: 4.94 g/dm^2h	FIE: 125 min	I: 4.88 g/dm^2h	FIE: 122 min
25 mm – 100 mm		MIT: > 126 min		MIT: > 126 min		MIT: > 126 min
100 mm – 150 mm	I: 5.09 g/dm^2h	Fluid: C709	I: 5.01 g/dm^2h	Fluid: C709	I: 4.92 g/dm^2h	Fluid: C709
150 mm – 200 mm		Plate: polished		Plate: polished		Plate: polished
200 mm – 300 mm	I: 5.11 g/dm^2h	PIL: n.m.	I: 5.00 g/dm^2h	PIL: n.m.	I: 5.00 g/dm^2h	PIL: n.m.
	I_{av}: 5.08 σ: 0.03		I_{av}: 4.98 σ: 0.03		I_{av}: 4.93 σ: 0.05	

T_a: -5.0±0.0°C T_p: -5.0±0.1°C Rh: 66.1±3.2% Ave. Icing Int.: 5.00±0.07 $g/dm^2/h$

DELAY between shearing and test : 50 minutes

Comments: TIV-EG

TEST: WS2426 **DATE:** 00-05-10 **DURATION:** 126 minutes

	P1	P2	P3	P4	P5	P6
0 mm	Beg: n.m.		Beg: n.m.		Beg: n.m.	
25 mm	FIE: 125 min		FIE: 122 min		FIE: 123 min	
	MIT: > 126 min	I: 4.84 g/dm²h	MIT: > 126 min	I: 4.86 g/dm²h	MIT: > 126 min	I: 4.84 g/dm²h
100 mm	Fluid: C709		Fluid: C709		Fluid: C709	
150 mm	Plate: polished	I: 4.90 g/dm²h	Plate: polished	I: 4.88 g/dm²h	Plate: polished	I: 4.90 g/dm²h
200 mm		I: 4.88 g/dm²h		I: 4.84 g/dm²h		I: 4.93 g/dm²h
300 mm	PIL: n.m.		PIL: n.m.		PIL: n.m.	
		I_{av}: 4.87 σ: 0.03		I_{av}: 4.86 σ: 0.02		I_{av}: 4.89 σ: 0.04

T_a: -5.0±0.0°C T_p: -5.0±0.1°C Rh: 64.4±3.6% Ave. Icing Int.: 4.87±0.03 g/dm²/h

DELAY between shearing and test : 95 minutes

Comments: TIV-EG

TEST: WS2513 **DATE:** 00-07-19 **DURATION:** 96 minutes

Position	P1	P2	P3	P4	P5	P6
0 mm		Beg:	Beg:		Beg:	Beg:
25 mm		FIE: 95min	FIE: 93min		FIE: 94min	FIE: 96min
	I: 4.98 g/dm²h	MIT: > 96 min	MIT: > 96 min	I: 5.03 g/dm²h	MIT: > 96 min	MIT: > 96 min
100 mm	I: 5.03 g/dm²h	fluid: C709	fluid: C709	I: 5.09 g/dm²h	fluid: C709	fluid: C709
150 mm		plate: scratched short axis	plate: scratched long axis		plate: scratched short axis	plate: scratched long axis
200 mm	I: 5.03 g/dm²h			I: 5.11 g/dm²h		
300 mm		LIE:	LIE:		LIE:	LIE:
	I_{av}: 5.01 σ: 0.02			I_{av}: 5.08 σ: 0.03		

T_a: -5.0 ± 0.1°C T_p: -5.0 ± 0.1°C Rh: 64.9 ± 2.0% Ave. Icing Int.: 5.05 ± 0.04 g/dm²/h

DELAY between shearing and test :

Comments: TIV-EG

- failure as peaks

TEST: WS2516 **DATE:** 00-07-20 **DURATION:** 120 minutes

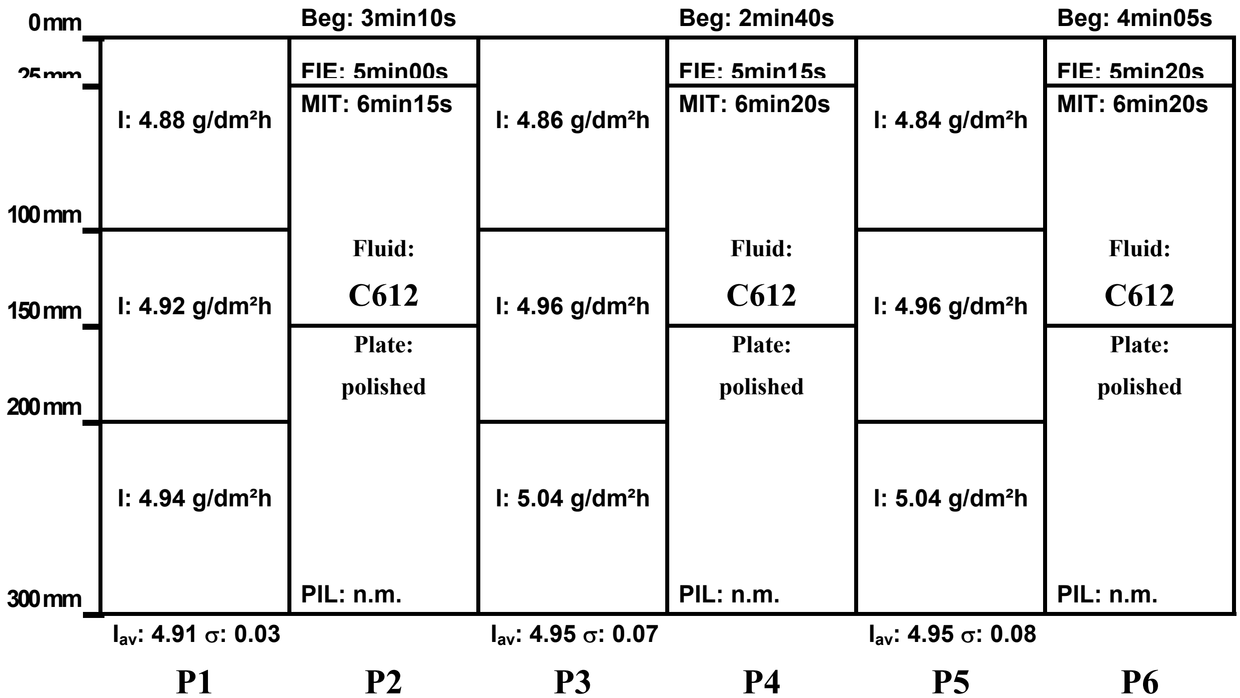
	P1	P2	P3	P4	P5	P6
0 mm		Beg:	Beg:		Beg:	Beg:
25 mm	I: 4.98 g/dm²h	FIE: 114min	FIE: 107min	I: 4.92 g/dm²h	FIE: 109min	FIE: 118min
100 mm		MIT: >120min	MIT: >120min		MIT: >120min	MIT: >120min
150 mm	I: 5.09 g/dm²h	fluid: C709	fluid: C709	I: 5.12 g/dm²h	fluid: C709	fluid: C709
200 mm		plate: oxidized	plate: painted		plate: oxidized	plate: painted
300 mm	I: 5.13 g/dm²h	LIE:	LIE:	I: 5.17 g/dm²h	LIE:	LIE:
	I_{av}: 5.07 σ: 0.06			I_{av}: 5.07 σ: 0.11		

T_a: -5.0 ± 0.0°C T_p: -5.0 ± 0.1°C Rh: 65.7 ± 2.2% Ave. Icing Int.: 5.07 ± 0.09 g/dm²/h

DELAY between shearing and test :

Comments: TIV-EG

TEST: WS2296 **DATE:** 00-01-12 **DURATION:** 30 minutes



T_a: -5.0±0.0°C T_p: -5.0±0.1°C Rh: 60.1±2.2% Ave. Icing Int.: 4.94±0.07 g/dm²/h

DELAY between shearing and test : 50 minutes

Comments: TI-PG

TEST: WS2418 **DATE:** 00-05-15 **DURATION:** 30 minutes

	P1	P2	P3	P4	P5	P6
0 mm	Beg:	Beg:		Beg:	Beg:	
25 mm	FIE: 3min15s	FIE: 3min40s		FIE: 4min20s	FIE: 4min10s	
	MIT: 5min50s	MIT: 5min55s	I: 4.96 g/dm^2h	MIT: 5min50s	MIT: 5min30s	I: 4.92 g/dm^2h
100 mm	Fuid: C612	Fluid: C612	I: 5.06 g/dm^2h	Fluid: C612	Fluid: C612	I: 5.12 g/dm^2h
150 mm	Plate: scratched short axis	Plate: polished		Plate: scratched long axis	Plate: polished	
200 mm			I: 5.10 g/dm^2h			I: 5.16 g/dm^2h
300 mm	LIE: 11min	LIE: 11min		LIE: 11min	LIE: 11min	
			I_{av}: 5.04 σ: 0.06			I_{av}: 5.07 σ: 0.11

T_a: -5.0 ± 0.1°C T_p: -4.9 ± 0.1 °C Rh: 60.4 ± 2.8 % Ave. Icing Int.: 5.05 ± 0.09 $g/dm^2/h$

DELAY between shearing and test : 30min

Comments: TI-PG

TEST: WS2413 **DATE:** 00-05-03 **DURATION:** 30 minutes

	P1	P2	P3	P4	P5	P6
0 mm		Beg:	Beg:		Beg:	Beg:
25 mm	I: 4.96 g/dm^2h	FIE: 2min30s MIT: 4min25s	FIE: 2min30s MIT: 4min05s	I: 4.96 g/dm^2h	FIE: 2min30s MIT: 3min55s	FIE: 2min30s MIT: 3min30s
100 mm	I: 5.08 g/dm^2h	Fluid: C612	Fluid: C612	I: 5.06 g/dm^2h	Fluid: C612	Fluid: C612
150 mm		plate: scratched short axis	plate: scratched long axis		plate: scratched short axis	plate: scratched long axis
200 mm	I: 4.98 g/dm^2h			I: 5.12 g/dm^2h		
300 mm		LIE:	LIE:		LIE:	LIE:
	I_{av}: 5.01 σ: 0.05			I_{av}: 5.05 σ: 0.07		

T_a: -5.0 ± 0.0 °C T_p: -4.9 ± 0.0 °C Rh: ± % Ave. Icing Int.: 5.02 ± 0.06 $g/dm^2/h$

DELAY between shearing and test : 30 min

Comments: TI-PG

TEST: WS2495 **DATE:** 00-07-10 **DURATION:** 30 minutes

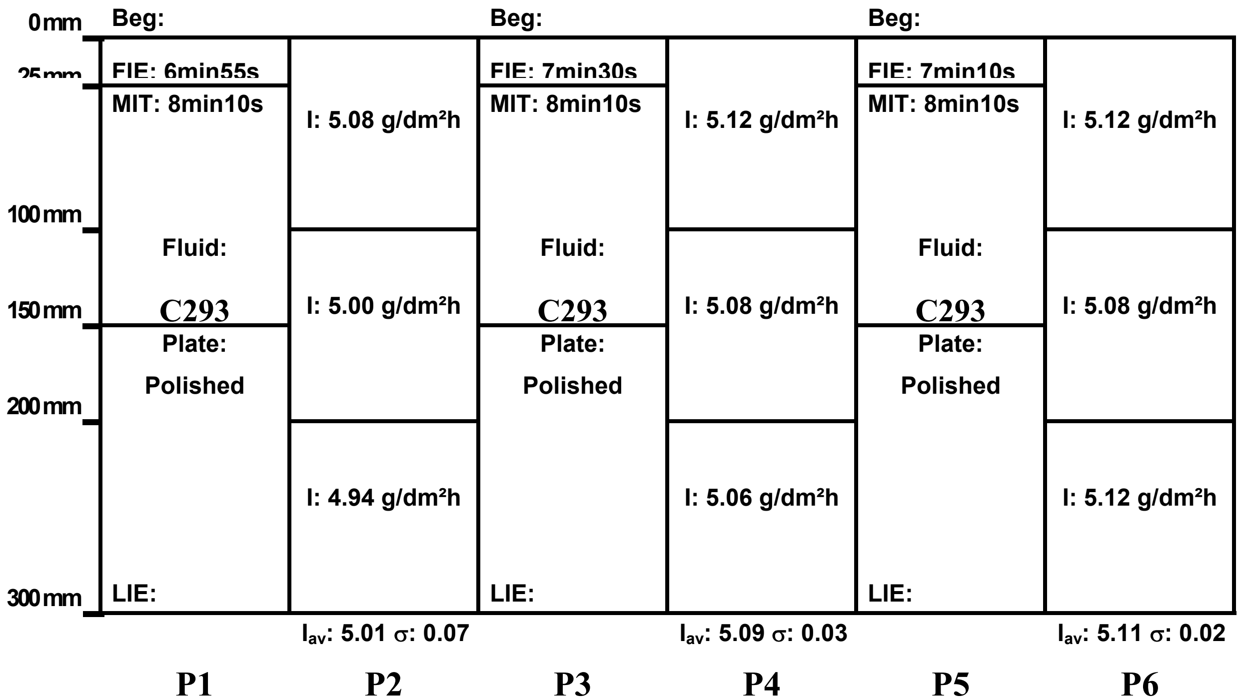
Position	P1	P2	P3	P4	P5	P6
0 mm		Beg:	Beg:		Beg:	Beg:
25 mm		FIE: 2min30s	FIE: 2min30s		FIE: 2min30s	FIE: 2min30s
25–100 mm	I: 4.92 g/dm²h	MIT: 6min00s	MIT: 6min00s	I: 4.90 g/dm²h	MIT:6min00s	MIT: 6min00s
100–150 mm		Fluid: C612	Fluid: C612		Fluid: C612	Fluid: C612
150–200 mm	I: 4.96 g/dm²h	Plate: painted	Plate: oxidized	I: 4.94 g/dm²h	Plate: painted	Plate: oxidized
200–300 mm	I: 4.94 g/dm²h			I: 4.96 g/dm²h		
300 mm		LIE:	LIE:		LIE:	LIE:
	I_{av}: 4.94 σ: 0.02			I_{av}: 4.93 σ: 0.03		

T_a: -5.0 ± 0.1 °C T_p: -5.0 ± 0.1 °C Rh: 62.4 ± 2.5 % Ave. Icing Int.: 4.94 ± 0.02 g/dm²/h

DELAY between shearing and test : 20min

Comments: TI-PG

TEST: WS2739 **DATE:** 01-04-03 **DURATION:** 30 minutes



T_a: -5.0 ±0.1°C T_p: -5.0 ±0.1°C Rh: 62.5 ±2.0% Ave. Icing Int.: 5.07 ± 0.06 g/dm²/h

DELAY between shearing and test : 70 min

Comments: TI-EG

TEST: WS2514 **DATE:** 00-07-20 **DURATION:** 30 minutes

	P1	P2	P3	P4	P5	P6
0 mm		Beg:	Beg:		Beg:	Beg:
25 mm		FIE: 3min50s	FIE: 5min45s		FIE: 6min10s	FIE: 6min20s
25–100 mm	I: 4.92 g/dm^2h	MIT: 7min50s	MIT: 7min50s	I: 4.98 g/dm^2h	MIT: 7min50s	MIT: 7min50s
100–150 mm	I: 5.04 g/dm^2h	Fluid: C293	Fluid: C293	I: 5.04 g/dm^2h	Fluid: C293	Fluid: C293
150–200 mm		Plate: scratched long axis	Plate: scratched long axis		Plate: scratched long axis	Plate: scratched long axis
200–300 mm	I: 5.08 g/dm^2h	LIE:	LIE:	I: 5.06 g/dm^2h	LIE:	LIE:
	I_{av}: 5.01 σ: 0.07			I_{av}: 5.03 σ: 0.03		

T_a: -5.0 ± 0.0 °C T_p: -5.0 ± 0.1 °C Rh: 59.8 ± 3.8 % Ave. Icing Int.: 5.02 ± 0.05 $g/dm^2/h$

DELAY between shearing and test : EG-TI neat

Comments: TI-EG

TEST: WS2515 **DATE:** 00-07-20 **DURATION:** 30 minutes

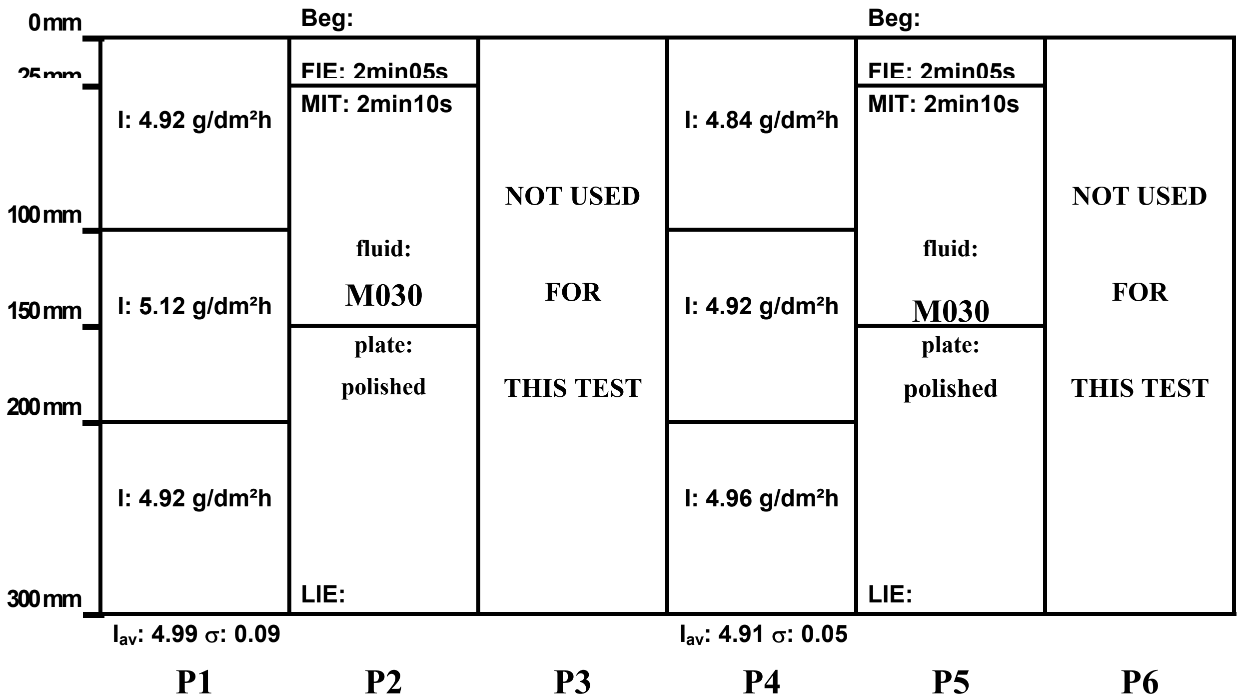
	P1	P2	P3	P4	P5	P6
0 mm		Beg:	Beg:		Beg:	Beg:
25 mm		FIE: 6min50s	FIE: 6min00s		FIE: 6min55s	FIE: 6min30s
	I: 4.96 g/dm^2h	MIT: 7min20s	MIT: 7min10s	I: 4.98 g/dm^2h	MIT: 7min20s	MIT: 7min30s
100 mm		fluid:	fluid:		fluid:	fluid:
150 mm	I: 5.02 g/dm^2h	C293	C293	I: 5.08 g/dm^2h	C293	C293
		plate: oxidized	plate: painted		plate: oxidized	plate: painted
200 mm						
	I: 4.92 g/dm^2h			I: 5.16 g/dm^2h		
300 mm		LIE:	LIE:		LIE:	LIE:
	I_{av}: 4.97 σ: 0.04			I_{av}: 5.07 σ: 0.07		

T_a: -5.0 ± 0.0 °C T_p: -4.9 ± 0.0 °C Rh: 64.3 ± 1.1 % Ave. Icing Int.: 5.02 ± 0.08 $g/dm^2/h$

DELAY between shearing and test :

Comments: TI-EG

TEST: WS2394 **DATE:** 00-04-06 **DURATION:** 30 minutes



T_a: -4.9 ±0.2°C T_p: -4.9 ±0.1°C Rh: 59.9 ±3.5% Ave. Icing Int.: 4.95 ±0.09 g/dm²/h

DELAY between shearing and test : 30min

Comments: mil fluid

TEST: WS2488 **DATE:** 00-07-05 **DURATION:** 30 minutes

Position	P1	P2	P3	P4	P5	P6
0 mm		Beg:	Beg:		Beg:	Beg:
0–25 mm	I: 4.92 g/dm²h	FIE: 1min25s	FIE: 2min30s	I: 4.88 g/dm²h	FIE: 1min25s	FIE: 2min30s
25–150 mm		MIT: 4min00s fluid: M030	MIT: 4min00s fluid: M030		MIT: 4min00 fluid: M030	MIT: 4min00s fluid: M030
100–200 mm	I: 4.94 g/dm²h			I: 4.92 g/dm²h		
150–300 mm		plate: scratched short axis	plate: scratched long axis		plate: scratched short axis	plate: scratched long axis
200–300 mm	I: 4.88 g/dm²h			I: 4.94 g/dm²h		
300 mm		LIE:	LIE:		LIE:	LIE:
	I_{av}: 4.91 σ: 0.03			I_{av}: 4.91 σ: 0.03		

T_a: -5.0 ± 0.0 °C T_p: -5.0 ± 0.1 °C Rh: 61.9 ± 2.8 % Ave. Icing Int.: 4.91 ± 0.02 g/dm²/h

DELAY between shearing and test : 30min

Comments: mil fluid

TEST: WS2478 **DATE:** 00-07-05 **DURATION:** 30 minutes

	P1	P2	P3	P4	P5	P6
0 mm		Beg:	Beg:		Beg:	Beg:
25 mm		FIE: 2min50s	FIE:2min30s		FIE: 2min45s	FIE: 2min30s
	I: 4.92 g/dm^2h	MIT: 2min50s	MIT: 2min30s	I: 4.92 g/dm^2h	MIT: 2min45s	MIT: 2min30s
100 mm		fluid: M030	fluid: M030		fluid: M030	fluid: M030
150 mm	I: 5.02 g/dm^2h	plate: painted	plate: oxidized	I: 5.04 g/dm^2h	plate: painted	plate: oxidized
200 mm	I: 4.84 g/dm^2h			I: 4.98 g/dm^2h		
300 mm		LIE:	LIE:		LIE:	LIE:
	I_{av}: 4.93 σ: 0.07			I_{av}: 4.98 σ: 0.05		

T_a: -5.0 ± 0.0 °C T_p: -4.9 ± 0.0 °C Rh: 64.2 ± 1.5 % Ave. Icing Int.: 4.95 ± 0.07 $g/dm^2/h$

DELAY between shearing and test : 75min

Comments: Mil fluid