# MAP® AQ PU1 AND MAP® AQ PUK: WATER-BORNE COATINGS AS ALTERNATIVES TO HIGH SPACE LEGACY PU1 AND PUK COATINGS

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**ABSTRACT**

To substitute PU1 and PUK coatings, MAP® AQ PU1 and MAP® AQ PUK coatings have been exposed to ageing tests in several industrial configurations.
For MAP® AQ PU1, E' and MAP® HpO11 primers were used on the most used substrates. Two curing conditions were used: (1) a minimum of 3 h at 23°C and 55% RH to allow the water to evaporate, then a minimum of 15 h at 70°C (FC), and (2) a minimum of 28 days at 23°C and 55% relative hygrometry (RT).

For MAP® AQ PUK, AM1109 and MAP® HpO11 primers were used on the most used substrates. The same two curing conditions as those used for MAP® AQ PU1 were tested.

Product characterization (outgassing, solar absorptance, emissivity, adhesion and electrical surface resistance) was performed at the initial state and after the ageing tests were compliant. These results and those issued from the initial qualifications of the products are summarized in this paper.

## 1. INTRODUCTION

Since its creation in 1986, MAP has developed numerous products for the space industry. Most of these products are coatings, adhesives, varnishes, or greases.
PU1 and PUK are black thermal control coatings for use on satellites. These two products are low outgassing polyurethane coatings. PU1 is an electrical insulant, whereas PUK is electrically conductive.
In an effort to propose green products, safer for humans and the environment, MAP® AQ PU1 and MAP® AQ PUK were developed some years ago [1-3] as a substitute for PU1, and PUK. MAP® AQ PU1 and MAP® AQ PUK are formulated without organic solvents that do not comply with new European environmental regulations (REACH).
As the PU1 and PUK have been used since the 1980s, numerous configurations (substrate + primer + coating) were qualified for space applications. The substrates are mainly metallic (Al alloys, Ti alloys, Invar, Stainless steel, etc.), but organic ones were also used (Kapton®, CFRP, etc.). Several adhesion primers were used, such as silane primers: E' [4] and PSX [5] or wash-primer: MAP® HpO11 [6]. Silane primers are used for the waterborne MAP® AQ PU1 and MAP® AQ PUK coatings: E' and AM1109 [7]. A delta-qualification was defined to propose an alternative to most PU1 and PUK configurations with equivalent curing conditions. The most used configurations were identified, and then a complete qualification was performed:

1. Damp heat test: 7 days at 50°C and 90% RH
2. Thermal cycling test in a vacuum: 35 cycles between -170°C and 130°C.

This paper first presents the properties of MAP® AQ PU1 and MAP® AQ PUK in their initial state. These properties are compared to those of PU1 and PUK. Secondly, the results after ageing tests are presented.

## 2. MATERIALS, PROCESSES AND TECHNIQUES

### 2.1. Materials and processes

MAP® AQ PU1 and MAP® AQ PUK are two-component waterborne coatings. For each product, the base is a mix of waterborne polyurethane, pigments and several additives, which give it its electrical, rheological, and mechanical properties. The hardener is composed of a mix of cross-linkers.

To obtain the final material, the base, and the hardener are mixed in the following weight proportions, respectively:

- MAP® AQ PU1: Base / Hardener: 91 / 9
- MAP® AQ PUK: Base / Hardener: 93 / 7

To get the proper viscosity, it is mandatory to dilute the mix using MAP® AQ thinner. Depending on the size and shape of the parts, the thinning ratio can be varied 10 ± 5%.

The mix is then applied using spray gun pulverization. For instance, a Kremlin S3 spraying gun [8] with an AM head and a No. 12 nozzle can be used with the following parameters (Table 1).

Table 1. Spray gun parameters

| Parameter | Value |
|---|---|
| Below output | 1.5 turns |
| Output | 3 turns |
| Pressure | 2.0 bar |
| Vector gas | Oil-free, compressed air |

Regarding the application conditions, the nominal values are listed hereunder in Table 2.

Table 2. Nominal application conditions

| Parameter | Nominal conditions |
|---|---|
| Temperature | 18°C ≤ T ≤ 25°C |
| Relative hygrometry | 40% ≤ RH[1] ≤ 60% |

To reach the final thickness, the following cross coating steps are proposed (Table 3).

The number of crossed coats depends upon the complexity, shape and size of the parts. Sufficient drying must be allowed between coats to achieve a flat appearance.

Table 3. Application parameters

| Coating | Thickness range (µm) | Cross coats |
|---|---|---|
| MAP® AQ PU1 | 40 - 80 | 1 mist coat +<br>2 to 3 crossed coats |
| MAP® AQ PUK | 40 - 90 | 2 to 4 |

Two standard curing processes are possible and correspond to:

(1) Minimum 3 h at 23°C and 55% RH to allow the water to evaporate, then 15h minimum at 70°C, referred to as the Fast-curing process hereafter (FC);

(2) 7 days minimum at 23°C and 55% relative hygrometry, referred to as RT for room temperature hereafter.

MAP® AQ PU1 has been qualified with E' primer [4]. E' primer is a silane-primer used on most industrial substrates, both metallic and composites.

MAP® AQ PUK has been qualified with AM1109 primer [7]. AM1109 primer is a silane-primer used on most industrial substrates, both metallic and composites.

The main characteristics of MAP® AQ PU1 [9] are listed in Table 4 and Table 5.

Table 4. Functional properties of MAP® AQ PU1 comapred to those of PU1

| Properties | MAP® AQ | PU1 |
|---|---|---|
| Solar absorptance | 0.95 ± 0.02 | 0.96 ± 0.02 |
| Infrared | 0.90 ± 0.03 | 0.88 ± 0.04 |
| RML (%) | 0.90 | 0.39 |
| CVCM (%) | 0.00 | 0.04 |

Table 5. General properties of MAP® AQ PU1 cured by the FC process

| Properties | MAP® AQ PU1 | PU1 |
|---|---|---|
| Typical thickness (µm) | 40 – 80 | 40 – 80 |
| Density | 1.21 ± 0.05 | 1.12 ± 0.05 |
| Solids content (%) | 45 ± 3 | 64 ± 3 |
| Viscosity (s) | 50 ± 10[2] | 47 ± 7[3] |
| V.O.C. ($g.L^{-1}$) | 27 | 521 |
| Theoretical consumption at 50 µm ($m^2.Kg^{-1}$) | 8.1 | 7.6 |
| Theoretical dry film weight ($g.m^{-2}.\mu m^{-1}$) | 1.14 | 1.4 |

The main characteristics of MAP® AQ PUK [10] are listed in Table 6 and Table 7.

[1] RH: Relative hygrometry
[2] Afnor cup 4 at 20°C (Base + Hardener + Thinner)
[3] Afnor cup 2.5 at 20°C (Base + Hardener + Thinner)

Table 6. Functional properties of MAP® AQ PUK compared to those of PUK

| **Properties** | **MAP® AQ PUK** | **PUK** |
|---|---|---|
| Solar absorptance | 0.95 ± 0.02 | 0.96 ± 0.02 |
| Infrared emittance | 0.88 ± 0.03 | 0.91 ± 0.03 |
| RML (%) | 0.72 | 0.56 |
| CVCM (%) | 0.00 | 0.00 |

Table 7. General properties of MAP® AQ PUK compared to those of PUK

| **Properties** | **MAP® AQ PUK** | **PUK** |
|---|---|---|
| Typical thickness | 40 – 90 | 40 – 80 |
| Density | 1.25 ± 0.05 | 1.00 ± |
| Solids content (%) | 47 ± 3% | 49 ± 3% |
| Viscosity (s) | 10 ± 2[4] | 15 ± 5[5] |
| V.O.C. ($g.L^{-1}$) | 58 | 566 |
| Theoretical consumption at 50 µm ($m^2.Kg^{-1}$) | 4.5 | 5.6 |
| Theoretical dry film weight ($g.m^{-2}.µm^{-1}$) | 1.87 | 1.23 |

To propose an alternative to the use of MAP® HpO11 primer qualified with PU1 and PUK, this primer has been tested with MAP® AQ PU1 and MAP® AQ PUK within the framework of this evaluation campaign.

### 2.2. Techniques

All the characteristics were measured in-house by MAP further to the following ISO standards, which are included in the reference section:

- Solar absorptance [11];
- Infrared emissivity [11];
- Electrical measurements [12];
- Adhesion [13] using Scapa 8705b tape [14].

For the ageing and the environmental tests, CNES also conducted some adhesion tests and electrical resistance measurements.

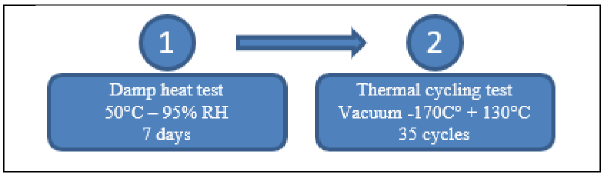
Outgassing rates were measured in accordance with standard ECSS-Q-ST-70-02C [15]. The measurements were taken at Airbus Toulouse and Elemca Toulouse.

### 2.3. Ageing tests

Ageing tests were carried out at the CNES facility. Ageing tests are composed of two cumulative steps [16]:

1) A damp heat test (DHT) was conducted at 50°C and 95% RH for 7 days;
2) Thermal cycling tests were performed under vacuum (VCT). 35 cycles were performed between -170°C and 130°C with a 10-minute plateau at high and low temperatures (gradient = 5°C/min).

Figure 1 - Schematic principle of cumulative ageing tests




Samples were composed of plates measuring 80 mm x 80 mm with a thickness of 2 mm (electrical surface resistance measurement) and plates measuring 40 mm x 40 mm x 2 mm.

## 3. RESULTS

MAP® AQPU1 and MAP® AQ PUK have been already qualified for space applications.

Additional tests were carried out within the scope of this study to validate the outgassing of additional systems and curing conditions.

For the ageing tests, the acceptance criteria were no degradation in adhesion, solar absorptance, infrared emissivity. For MAP® AQ PUK only, the electrical surface resistance must be under 1 x$10^5$ Ω/□.

### 3.1. OUTGASSING DATA

#### 3.1.1. MAP® AQ PU1

The outgassing properties were measured at the Elemca facility on an E' + MAP® AQ PU1 system that had been cured for 28 days at 23°C. The results are listed in Table 8 [17].

[4] Afnor cup 6 at 20°C (Base + Hardener + Thinner)

[5] Afnor cup 4 at 20°C (Base + Hardener + Thinner)

Table 8. Outgassing results for E' + MAP® AQ PU1 cured for 28 days at 23°C and 55% RH

| | TML (%) | RML (%) | CVCM (%) |
|---|---|---|---|
| E' + MAP® AQ PU1 | 0.63 | 0.36 | 0.00 |

For the MAP® HpO11 + MAP® AQ PU1 system cured by the fast-curing process, the outgassing properties were measured at the Airbus Toulouse facility. The results are listed in Table 9 [18].

Table 9. Outgassing results for MAP® HpO11 + MAP® AQ PU1 cured for 3h at 23°C + 15h at 70°C

| | TML (%) | RML (%) | CVCM (%) |
|---|---|---|---|
| MAP® HpO11 + MAP® AQ PU1 | 1.35 | 0.90 | 0.00 |

#### 3.1.2. **MAP AQ PUK**

The outgassing properties were measured at the Elemca facility on the AM1109 + MAP® AQ PUK system that had been cured for 28 days at 23°C. The results are listed in Table 10 [17].

Table 10. Outgassing results for AM1109 + MAP® AQ PUK cured for 28 days at 23°C and 55% RH

| | TML (%) | RML (%) | CVCM (%) |
|---|---|---|---|
| AM1109 + MAP® AQ PUK | 0.28 | 0.18 | 0.00 |

For the MAP® HpO11 + MAP® AQ PUK system cured by the fast-curing process, the outgassing properties were measured at the Airbus Toulouse facility. The results are listed in Table 11 [18].

Table 11. Outgassing results for MAP® HpO11 + MAP® AQ PUK cured for 3h at 23°C + 15h at 70°C

| | TML (%) | RML (%) | CVCM (%) |
|---|---|---|---|
| MAP® HpO11 + MAP® AQ PUK | 0.62 | 0.45 | 0.00 |

### 3.2. AGEING TESTS

Ageing tests were carried out at the CNES facility during two campaigns. The first test was dedicated to the samples cured by the fast-curing process (FC ), and the second was performed on the samples cured at ambient conditions (temperature and relative hygrometry).

#### 3.2.1. MAP® AQ PU1

The E' + MAP® AQ PU1 system, cured for a minimum of 3h at 23°C and 55% RH + 15h at 70°C, was applied on:

- Stainless steel 304L
- INVAR
- TA6V
- 2024-T3 Surtec 650
- 6061-T6 Au
- 6061-T6 Ag

All the tests (solar absorptance, infrared emissivity and adhesion) were compliant at the initial state and after ageing.

The MAP® HpO11 + MAP® AQ PU1 system, cured for a minimum of 3h at 23°C and 55% RH + 15h at 70°C, was applied on:

- 2024-T3
- 2024-T3 Alodine
- 6061-T6 Au
- 6061-T6 Ag
- 2024-T3 Surtec 650
- TA6V
- INVAR
- Cu a1
- Stainless steel 304L

All the characteristics (solar absorptance, infrared emissivity and adhesion) were compliant at the initial state and after ageing.
On copper (Cu a1), the use of a primer and no primer (neither E' nor MAP® HpO11) were testede prior to MAP® AQ PU1 application. All the characteristics (solar absorptance, infrared emissivity and adhesion) were compliant at the initial state and after ageing.

### 3.2.2. MAP® AQ PUK

The MAP® HpO11 + MAP® AQ PUK system, cured for a minimum of 3h at 23°C and 55% RH + 15h at 70°C, was applied on:

- 2017-T4
- 6061-T6 Au
- 6061-T6 Ag
- 6061-T6 Ni
- 2024-T3 Alodine
- 2024-T3 Surtec 650
- TA6V
- INVAR + Ag
- INVAR
- Stainless steel 304 L
- Cu a1

All the tests (solar absorptance, infrared emissivity and adhesion) were compliant at the initial state and after ageing.

On copper (Cu a1), the use of a primer and no primer (neither E' nor MAP® HpO11) were tested prior to MAP® AQ PUK application All the characteristics (solar absorptance, infrared emissivity and adhesion) were compliant at the initial state and after ageing.

The MAP® HpO11 + MAP® AQ PUK system, cured for a minimum of 3h at 23°C and 55% RH + 15h at 70°C, was applied on:

- 2017-T4
- 6061-T6 Au
- 6061-T6 Ag
- 6061-T6 Alodine
- 2024-T3 Surtec 650
- TA6V
- INVAR + Ag
- INVAR
- Stainless steel
- Cu a1
- CFRP
- 6061-T6 Ni

All the characteristics (solar absorptance, infrared emissivity and adhesion) were compliant at the initial state and after ageing.

On copper (Cu a1), no primer (neither E' nor MAP HpO11) was applied prior to MAP® AQ PU1. All the characteristics (solar absorptance, infrared emissivity and adhesion) were compliant at the initial state and after ageing.

Table 12. Characteristics of the E’ + MAP® AQ PU1 system, cured for a minimum of 3h at 23°C and 55% RH + 15h at 70°C [19]. Thickness of MAP® AQ PU1: 66 µm.

| Substrate | Initial state | | | After DH test | After DH test + VTC | | |
|---|---|---|---|---|---|---|---|
| | **Adhesion** | **$\alpha_S$** | **$\varepsilon_h$** | **Adhesion** | **Adhesion** | **$\alpha_S$** | **$\varepsilon_h$** |
| SS 304L* | 0/5 | 0.96 | 0.90 | 0/5 | 0/5 | 0.96 | 0.90 |
| INVAR | 0/5 | 0.96 | 0.90 | 0/5 | 0/5 | 0.96 | 0.90 |
| TA6V | 0/5 | 0.96 | 0.90 | 0/5 | 0/5 | 0.96 | 0.90 |
| 2024-T3 Surtec 650 | 0/5 | 0.96 | 0.90 | 0/5 | 0/5 | 0.96 | 0.90 |
| 6061-T6 Au | 0/5 | 0.96 | 0.90 | 0/5 | 0/5 | 0.96 | 0.90 |
| 6061-T6 Ag | 0/5 | 0.96 | 0.90 | 0/5 | 0/5 | 0.96 | 0.90 |

** Stainless steel 304L

Table 13. Characteristics of the MAP® HpO11 + MAP® AQ PU1 system, cured for a minimum of 3h at 23°C and 55% RH + 15h at 70°C [20, 21]. Thickness of MAP® HpO11: 7 µm. Thickness of MAP® AQ PU1: 61µm.

| Substrate | Initial state | | | After DH test | After DH test + VTC | | |
|---|---|---|---|---|---|---|---|
| | **Adhesion** | **$\alpha_S$** | **$\varepsilon_h$** | **Adhesion** | **Adhesion** | **$\alpha_S$** | **$\varepsilon_h$** |
| 2024-T3 | 0/5 | 0.96 | 0.90 | 0/5 | 0/5 | 0.96 | 0.90 |
| 2024-T3 Alodine | 0/5 | 0.96 | 0.90 | 0/5 | 0/5 | 0.96 | 0.90 |
| 6061-T6 Au | 0/5 | 0.96 | 0.90 | 0/5 | 0/5 | 0.96 | 0.90 |
| 6061-T6 Ag | 0/5 | 0.96 | 0.90 | 0/5 | 0/5 | 0.96 | 0.90 |
| 2024-T3 Surtec 650 | 0/5 | 0.96 | 0.90 | 0/5 | 0/5 | 0.96 | 0.90 |
| TA6V | 0/5 | 0.96 | 0.90 | 0/5 | 0/5 | 0.96 | 0.90 |
| INVAR | 0/5 | 0.96 | 0.90 | 0/5 | 0/5 | 0.96 | 0.90 |
| Cu a1 | 0/5 | 0.96 | 0.90 | 0/5 | 0/5 | 0.96 | 0.90 |
| SS 304L | 0/5 | 0.96 | 0.90 | 0/5 | 0/5 | 0.96 | 0.90 |
| Cu a1* | 0/5 | 0.96 | 0.90 | 0/5 | 0/5 | 0.96 | 0.90 |

*: without MAP HpO11 - ** Stainless steel 304L

Table 14. Characteristics of the E’ + MAP® AQ PU1 system, cured for 28 days at 23°C and 55% RH [22, 23]. Thickness of MAP® AQ PU1: 63 to 87 µm. *: without E’ - ** Stainless steel 304L.

| Substrate | Initial state | | | After DH test | After DH test + VTC | | |
|---|---|---|---|---|---|---|---|
| | **Adhesion** | **$\alpha_S$** | **$\varepsilon_h$** | **Substrate** | **Adhesion** | **$\alpha_S$** | **$\varepsilon_h$** |
| 2017-T4 | 0/5 | 0.96 | 0.90 | 0/5 | 0/5 | 0.96 | 0.90 |
| 6061-T6 Ag | 0/5 | 0.96 | 0.90 | 0/5 | 0/5 | 0.96 | 0.90 |
| SS 304L** | 0/5 | 0.96 | 0.90 | 0/5 | 0/5 | 0.96 | 0.90 |
| 6061-T6 Au | 0/5 | 0.96 | 0.90 | 0/5 | 0/5 | 0.96 | 0.90 |
| 6061-T6 Alodine | 0/5 | 0.96 | 0.90 | 0/5 | 0/5 | 0.96 | 0.90 |
| CFRP | 0/5 | 0.96 | 0.90 | 0/5 | 0/5 | 0.96 | 0.90 |
| Kapton® 50 µm | No degradation | 0.96 | 0.90 | No degradation | No degradation | 0.96 | 0.90 |
| INVAR | 0/5 | 0.96 | 0.90 | 0/5 | 0/5 | 0.96 | 0.90 |
| TA6V | 0/5 | 0.96 | 0.90 | 0/5 | 0/5 | 0.96 | 0.90 |
| 2024-T3 Surtec 650 | 0/5 | 0.96 | 0.90 | 0/5 | 0/5 | 0.96 | 0.90 |
| Cu a1* | 0/5 | 0.96 | 0.90 | 0/5 | 0/5 | 0.96 | 0.90 |

Table 15. Characteristics of the MAP® HpO11 + MAP® AQ PUK system, cured for a minimum of 3h at 23°C and 55% RH + 15h at 70°C [24, 25]. Thickness of MAP® HpO11: 6 µm. Thickness of MAP® AQ PUK: 70 to 76µm.

| **Substrate** | **Initial state** | | | | **After DH test** | | **After DH test + VTC** | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | **Adhesion** | **$\alpha_S$** | **$\varepsilon_h$** | **Rs (Ω/☐)** | **Adhesion** | **Rs (Ω/☐)** | **Adhesion** | **$\alpha_S$** | **$\varepsilon_h$** | **Rs (Ω/☐)** |
| 2017-T4 | 0/5 | 0.96 | 0.88 | 1350 | 0/5 | 9320 | 0/5 | 0.96 | 0.88 | 1350 |
| 6061-T6 Au | 0/5 | 0.96 | 0.87 | 3120 | 0/5 | 7640 | 0/5 | 0.96 | 0.88 | 2850 |
| 6061-T6 Ag | 0/5 | 0.96 | 0.87 | 1480 | 0/5 | 7040 | 0/5 | 0.96 | 0.88 | 2840 |
| 6061-T6 Ni | 0/5 | 0.96 | 0.88 | 2660 | 0/5 | 3450 | 0/5 | 0.96 | 0.88 | 1250 |
| 2024-T3 Alodine | 0/5 | 0.96 | 0.88 | 2060 | 0/5 | 4800 | 0/5 | 0.96 | 0.88 | 2690 |
| 2024-T3 Surtec 650 | 0/5 | 0.96 | 0.87 | 2310 | 0/5 | 11170 | 0/5 | 0.96 | 0.88 | 4430 |
| TA6V | 0/5 | 0.96 | 0.87 | 1940 | 0/5 | 8260 | 0/5 | 0.96 | 0.88 | 2540 |
| INVAR + Ag | 0/5 | 0.96 | 0.87 | 1240 | 0/5 | 2020 | 0/5 | 0.96 | 0.88 | 1330 |
| INVAR | 0/5 | 0.96 | 0.87 | 2720 | 0/5 | 9080 | 0/5 | 0.96 | 0.88 | 1880 |
| SS 304 L | 0/5 | 0.96 | 0.87 | 2970 | 0/5 | 8500 | 0/5 | 0.96 | 0.88 | 1910 |
| Cu a1 | 0/5 | 0.96 | 0.87 | 2540 | 0/5 | 4150 | 0/5 | 0.96 | 0.88 | 1520 |
| Cu a1* | 0/5 | 0.96 | 0.88 | 68 | 0/5 | 244 | 0/5 | 0.96 | 0.89 | 98 |

*: without MAP HpO11

Table 16. Characteristics of the AM1109 + MAP® AQ PUK system, cured for 28 days at 23°C and 55% RH [26, 27]. Thickness of MAP® AQ PUK: 58 to 76µm.

| | **Initial state** | | | | **After DH test** | | **After DH test + VTC** | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Substrate** | **Adhesion** | **$\alpha_S$** | **$\varepsilon_h$** | **Rs (Ω/☐)** | **Adhesion** | **Rs (Ω/☐)** | **Adhesion** | **$\alpha_S$** | **$\varepsilon_h$** | **Rs (Ω/☐)** |
| 2017-T4 | 0/5 | 0.96 | 0.88 | 78 | 0/5 | 388 | 0/5 | 0.96 | 0.88 | 202 |
| 6061-T6 Au | 0/5 | 0.96 | 0.88 | 43 | 0/5 | 88 | 0/5 | 0.96 | 0.88 | 59 |
| 6061-T6 Ag | 0/5 | 0.96 | 0.88 | 141 | 0/5 | 200 | 0/5 | 0.96 | 0.88 | 109 |
| 6061-T6 Alodine | 0/5 | 0.95 | 0.88 | 216 | 0/5 | 576 | 0/5 | 0.95 | 0.88 | 420 |
| 2024-T3 Surtec 650 | 0/5 | 0.96 | 0.88 | 88 | 0/5 | 665 | 0/5 | 0.96 | 0.88 | 359 |
| TA6V | 0/5 | 0.96 | 0.88 | 102 | 0/5 | 151 | 0/5 | 0.95 | 0.88 | 52 |
| INVAR + Ag | 0/5 | 0.96 | 0.88 | 50 | 0/5 | 107 | 0/5 | 0.96 | 0.88 | 83 |
| INVAR | 0/5 | 0.96 | 0.88 | 56 | 0/5 | 98 | 0/5 | 0.96 | 0.88 | 33 |
| SS 304L | 0/5 | 0.96 | 0.88 | 91 | 0/5 | 236 | 0/5 | 0.96 | 0.88 | 112 |
| Cu a1 | 0/5 | 0.96 | 0.88 | 180 | 0/5 | 548 | 0/5 | 0.96 | 0.88 | 187 |
| CFRP | 0/5 | 0.96 | 0.88 | 127 | 0/5 | 378 | 0/5 | 0.96 | 0.88 | 174 |
| 6061-T6 Ni | 0/5 | 0.96 | 0.88 | 66 | 0/5 | 578 | 0/5 | 0.96 | 0.88 | 251 |
| Cu a1* | 0/5 | 0.96 | 0.88 | 121 | 0/5 | 221 | 0/5 | 0.96 | 0.88 | 112 |

*: without AM 1109

### 3.3. QUALIFIED SYSTEMS

#### 3.3.1. MAP® AQ PU1

MAP® AQ PU1 has already been qualified for space applications [1]. Using the previous results from this evaluation and adding the results of this campaign, all the systems qualified are listed in the table below.

Table 17. MAP® AQ PU1 systems qualified with ambient temperature curing

| Substrate | Primer | Origin |
|---|---|---|
| **2017-T4** | E’ | This work |
| **Stainless steel** | E’ | This work |
| **INVAR** | E’ | This work |
| **2017-T4 Alodine** | E’ | This work |
| **CFRP** | E’ | This work |
| **Kapton** | E’ | This work |
| **TA6V** | E’ | This work |
| **Cua1** | - | This work |
| **TA6V** | E’ | This work |
| **2024-T3 Surtec 650** | E’ | This work |
| **6061-T6 Au** | E’ | This work |
| **6061-T6 Ag** | E’ | This work |

Table 18. MAP® AQ PU1 systems qualified with the fast-curing process

| Substrate | Primer | Origin |
|---|---|---|
| **2024-T3** | E' | Initial qualification |
| **CFRP** | E' | Initial qualification |
| **Kapton** | E' | Initial qualification |
| **Alodine** | E' | Initial qualification |
| **Surtec 650** | E' | Initial qualification |
| **2017-T4** | E’ | This work |
| **Stainless steel** | E' | This work |
| **INVAR** | E' | This work |
| **TA6V** | E' | This work |
| **2024-T3 Surtec 650** | E' | This work |
| **6061-T6 Au** | E' | This work |
| **6061-T6 Ag** | E' | This work |
| **2024-T3** | MAP HpO11 | This work |
| **2017-T4 Alodine** | MAP HpO11 | This work |
| **6061-T6 Au** | MAP HpO11 | This work |
| **6061-T6 Ag** | MAP HpO11 | This work |
| **2024-T3 Surtec 650** | MAP HpO11 | This work |
| **TA6V** | MAP HpO11 | This work |
| **INVAR** | MAP HpO11 | This work |
| **Copper** | - | This work |
| **Copper** | MAP HpO11 | This work |

#### 3.3.2. MAP® AQ PUK

MAP® AQ PUK has been already qualified for space applications [2]. Using the previous results from this evaluation and adding the results of this campaign, all the systems qualified are listed in the table below.

Table 19. MAP® AQ PUK systems qualified with ambient temperature curing

| Substrate | Primer | Origin |
|---|---|---|
| **2017-T4** | AM1109 | This work |
| **6061-T6 Au** | AM1109 | This work |
| **6061-T6 Ag** | AM1109 | This work |
| **6061-T6 Ni** | AM1109 | This work |
| **6061-T6 Alodine** | AM1109 | This work |
| **6061-T6 Surtec 650** | AM1109 | This work |
| **TA6V** | AM1109 | This work |
| **INVAR + Ag** | AM1109 | This work |
| **Invar** | AM1109 | This work |
| **Stainless steel** | AM1109 | This work |
| **Cu a1** | AM1109 | This work |
| **Cu a1** | - | This work |
| **CFRP** | AM1109 | This work |

Table 20. MAP® AQ PUK1 systems qualified with the fast-curing process

| Substrate | Primer | Origin |
|---|---|---|
| **2024-T3** | AM1109 | Initial qualification |
| **Alodine** | AM1109 | Initial qualification |
| **Surtec 650** | AM1109 | Initial qualification |
| **Al – Ag** | AM1109 | Initial qualification |
| **Al – Au** | AM1109 | Initial qualification |
| **INVAR** | AM1109 | Initial qualification |
| **TA6V** | AM1109 | Initial qualification |
| **2017-T4** | MAP HpO11 | This work |
| **6061-T6 Au** | MAP HpO11 | This work |
| **6061-T6 Ag** | MAP HpO11 | This work |
| **6061-T6 Ni** | MAP HpO11 | This work |
| **6061-T6 Alodine** | MAP HpO11 | This work |
| **6061-T6 Surtec 650** | MAP HpO11 | This work |
| **TA6V** | MAP HpO11 | This work |
| **INVAR + Ag** | MAP HpO11 | This work |
| **Invar** | MAP HpO11 | This work |
| **Passivated stainless steel X5Cr18-10** | MAP HpO11 | This work |
| **Cu a1** | - | This work |
| **Cu a1** | MAP HpO11 | This work |

## 4. CONCLUSION

In order to substitute PU1 and PUK coatings, MAP® AQ PU1 and MAP® AQ PUK coatings were exposed to ageing tests in several industrial configurations.
For MAP® AQ PU1, E' and MAP® HpO11 primers were used on the most commonly used substrates. Two curing conditions were used: (1) a minimum of 3h at 23°C and 55% RH to allow the water to evaporate, then for a minimum of 15h at 70°C (FC), and (2) for a minimum of 28 days at 23°C and 55% relative hygrometry (RT).

For MAP® AQ PUK, AM1109 and MAP® HpO11 primers were used on the most commonly used substrates. The same two curing conditions as those used for MAP® AQ PU1 were tested.

All the characterization (outgassing, solar absorptance, emissivity, adhesion and electrical surface resistance) carried out at the initial state and after ageing tests were compliant. These results and those obtained from the initial qualifications of the products are summarized in Tables 17 to 20.

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