# Durability of artificial grass after accelerated aging

## LimeGreen Play and LimeGreen Landscape product

Report SGS INTRON B.V.

| | |
|---|---|
| Status: | Final report |
| Date: | 12 May 2023 |
| Document number: | A137310/R20231205 |

WHEN YOU NEED TO BE SURE

# Colophon

Customer:
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Offer:
A137310/O20221353

Date:
3 May 2022

Purchase order:
Opdrachtbevestiging

Date:
28 juni 2022

Order taker:
SGS INTRON B.V.

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Date:
12 May 2023

Reason of change:

## Disclaimer

# Contents

# Summary

LimeGreen Holding B.V. is a producer of artificial grass and its key value is ONE-DNA. ONE-DNA means that its products are produced from a single type of polymer: polyethylene (PE).
In most common artificial grass systems multiple polymers are used in the final product e.g. also a latex backing.
In addition to a single polymer composition, the durability of the artificial grass products is also an issue for the circularity of the product. For best circularity properties the polymer properties would remain unchanged in aging. To get information about long-term the durability of the artificial grass products, accelerated weathering tests can be performed. LimeGreen has commissioned SGS as an independent testing and certification institute to test the single polymer composition of the LimeGreen products Play and Landscape for durability.

## Goal

Determine effect of aging on two types of the LimeGreen products Play and Landscape for durability by testing of the properties at start and after accelerated adding by weathering and UV-radiation for 2500 and 5000 hours. With the results information were obtained about the long-term stability of the products. 2500 hours of aging based on the tested weathering condition, corresponds to approx. 10 years outdoor exposure. Since the service lifetime of the LimeGreen products Play and Landscape is 10 years, the results of the accelerated aging of 2500 hours (corresponding to 10 years outdoor exhibition) durability of the products can be assessed. The 5000 hours of aging corresponds to approx. 25 years of outdoor exposure.

## Executed work

The influence on the LimeGreen products Play and Landscape by accelerated aging is tested after weathering (by UV-radiation, increasing temperature and water spraying) at fixed time-intervals. The test was performed after 2500 hours and 5000 hours and the product properties were compared to the properties at start of the original product.
After each interval a piece of the product was cut out of the original sample for testing. The remaining sample was being tested for the additional aging time. The properties of the fibres: length, diameter and colour were analysed. The specimens of both LimeGreen products (mix of backing and fibres) were analysed for Melt Flow Index (MFI) and Differential Scanning Calorimetry (DSC) for polymer assessment.

## Conclusion

For the tested properties of the LimeGreen type Play and Landscape, only a small change in Melt Mass-Flow Rate (MFR) is observed.

The regular service lifetime of LimeGreen products is 10 years. Based on this service-life time only small decrease in Melt Mass-Flow Index will be present in both products after 10 years of outside exposure. For all other tested properties, no significant change is observed

Effect of aging on fibre and polymer properties of the LimeGreen products

| Property | LimeGreen | |
|---|---|---|
| | Play | Landscape |
| Fibre | | |
| Length | ✓ | ✓ |
| Thickness | ✓ | ✓ |
| Colour | ✓ | ✓ |
| Polymer | | |
| Melt Mass-Flow Rate (MFR) | ! | ! |
| Melting Temperature | ✓ | ✓ |
| Enthalpy of Melt and Crystallization | ✓ | ✓ |

# 1. Preface

LimeGreen Holding B.V. is a producer of artificial grass and its key value is ONE-DNA. ONE-DNA means that its products are produced from a single type of polymer: polyethylene (PE).
In most common artificial grass systems multiple polymers are used in the final product e.g. also a latex backing.
The key difference here becomes prominent in the end-of-life procedure. The only way to maintain high molecular weight and strong characteristics is to separate different polymers at this stage. When polymer blends are mechanically recirculated, they enter a lower value stream.
Limegreen envisions its products to be reused in high value applications and is enabling this via ONE-DNA. This process of maintaining high value is in concurrence with the EU sustainability strategy for 2030 and other EU sustainability goals.
In addition to a single polymer composition, the durability of the artificial grass products is also an issue for the circularity of the product. For best circularity properties the polymer properties would remain unchanged in aging. To get information about long-term durability of the artificial grass products, accelerated weathering tests can be performed.
LimeGreen has commissioned SGS as an independent testing and certification institute to test the single polymer composition of the LimeGreen products Landscape and Play for durability.
Since there are no specific test methods for assessment for artificial grass for playgrounds and landscape on durability, the test methods were chosen that resemble the aging and the qualification of the properties best. For aging the European test method EN 1297 (Method for artificial aging by long term exposure to the combination of UV radiation, elevated temperature and water) was used. For quantification of the properties of the fibers the Fifa Test method 25[1] is used.

# 2. Products specification

The samples of artificial grass delivered by LimeGreen for durability testing were:

- LimeGreen Play
- LimeGreen Landscape

The LimeGreen Play consists of only one type of fiber for every lurch. The fiber is fibrillated and has one green color (RAL nr. 6025).

*Picture 1. Build-up of the artificial grass fibers LimeGreen Play*

[1] FIFA Programme for Football Turf, Test Manual I – test methods, October 2015 edition v3.4 01.02.2022

One lurch of the LimeGreen Landscape grass is build-up of a cluster of 20 fibers, all monofilaments per lurch. The 20 fibers of each lurch consist of 6 different types of fiber. Varying in color and shape.


*Picture 2. Build-up of the artificial grass fibers LimeGreen Landscape*

The composition of one lurch is listed in the table below:

| Number of fibres per lurch | Colour | Shape | RAL-code |
|---|---|---|---|
| 3 | Highly light green | slightly curled | 6017 |
| 3 | Light green | straight | 6011 |
| 3 | Moderately green | straight | 6025 |
| 3 | Dark green | slightly curled | 6002 |
| 4 | Moderately green | curled | 6025 |
| 4 | Brown | curled | 8001 |

# 3. Test conditions

For weathering of artificial grass, no harmonised standards are present to give information on the long-term behaviour of the product. However, there are harmonised standards for artificial ageing for flexible sheets for waterproofing. This testing is used for bitumen, plastic, and rubber sheet products.
In the test method (EN 1297) the product is exposed for long term to the combination of UV radiation, elevated temperature, and water.
The test method was used to determine the durability of the two types of artificial LimeGreen grass products.

From the original delivered LimeGreen grass products test specimens were cut to fit in the racks in the test chamber.
The test specimens were exposed to the aging cycles in the table below.

| Exposure cycle | Specificatiën |
|---|---|
| | |
| UV-radiation | Fluorescent UV lights of type I (340 nm) or UV light combination with average UV-irradiation on the specimen surface of 45 ± 5 W/m$^2$ in wavelength range λ ≥ 300 nm (EN ISO 4892-3) |
| Water | Demi water with a maximum conductivity of 500µS/m, 25 ± 5 °C. |
| Spray mechanism | Spray nozzles with a flow rate of 10 ± 3 l/min and per m$^2$ of specimen surface |
| Duration | 360 min consisting of 300 min dry period followed by 60 min spray period. During the wet period the light source is turned off. |
| Temperature | During the dry period the temperature in the test chamber is 60 ± 3 °C, this temperature must be reached within 30 min. in the dry period. During the spray period the temperature is switched off. |
| Number of cycles | 5 each of 1000 hours |
| Total UV exposure | 5000 u, equals approx. 800 MJ/m$^2$ UV radiation load. |

After 2.5 cycles (T=1; 2,500 hours) and after 5 cycles (T=2; 5,000 hours) the following properties of the fibers were rated against the original LimeGreen grass product without exposure (T=0; 0 hours):

- Colour change.
- Change in fibre thickness.
- Change in fibre length.

A part of the complete test specimen was analyzed for changes in Melt Mass Flow Rate (MFR) and melting enthalpy by Differential Scanning Calorimetry (DSC).

# 4. Results

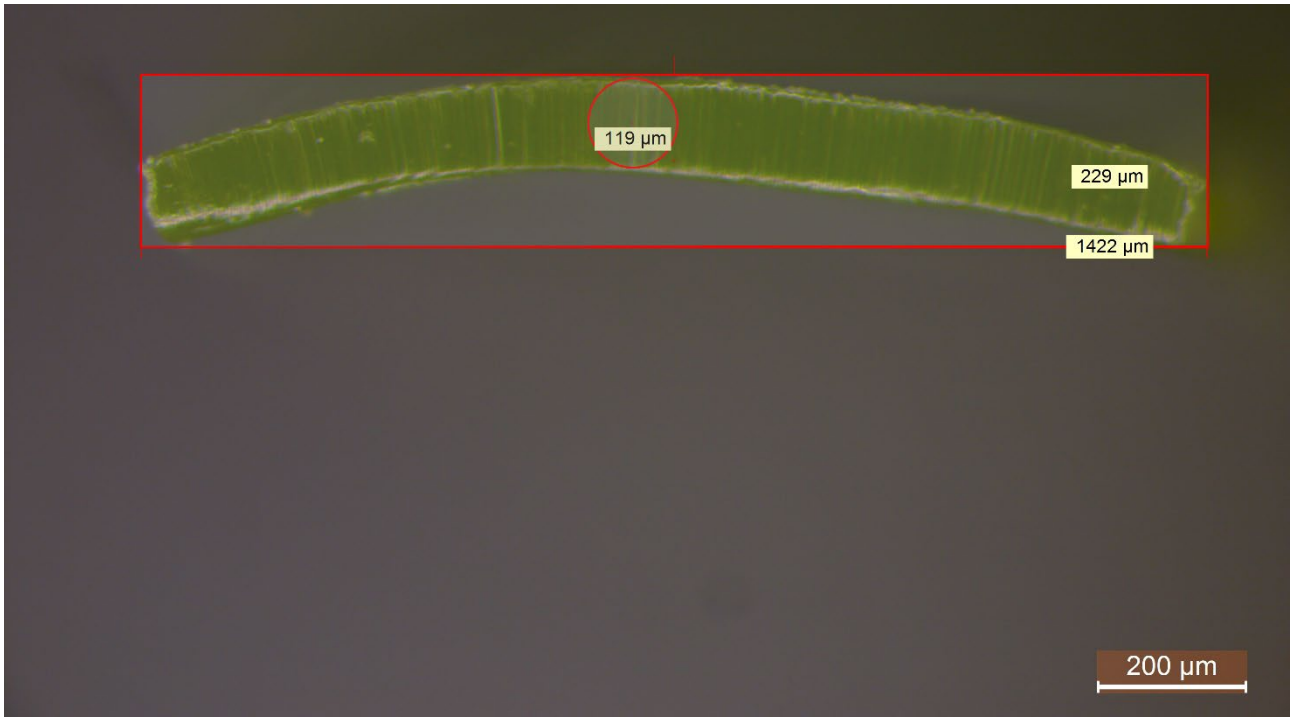
To get information about possible change in fibre properties the length and thickness were measured at:

- T=0 (0 hours of exposure),
- T=1 (2500 hours of exposure)
- T=2 (5000 hours of exposure.

## 4.1. Dimensions and color of the fibers before and after accelerated aging

### 4.1.1 LimeGreen Play

The dimensions length and thickness of the fibres of the LimeGreen Play type were measured according to the picture below:




*Picture 3. Artificial grass fiber LimeGreen Play at T=0*

The characteristics of the measurement of this fibre is:

- Thickness in the middle (cross=-section/diameter): 119 µm.
- Overall thickness: 229 µm.
- Total length: 1422 µm.

In table 1 the test results of the characteristics of the LimeGreen Play fibre is presented.
All measurements were done in three-fold.

Table 1: Results of the fibre characteristics of LimeGreen Play before and after aging

| | Property | | |
|---|---|---|---|
| Exposure | Thickness (µm) | Overall thickness (µm) | Total length (µm) |
| 0 hours (T=0) | 119 | 229 | 1422 |
| | 126 | 185 | 1420 |
| | 127 | 219 | 1407 |
| Average | 124 | 211 | 1416 |
| 2500 hours (T=1) | 110 | 138 | 1339 |
| | 105 | 155 | 1409 |
| | 108 | 158 | 1298 |
| Average | 108 | 150 | 1349 |
| 5000 hours (T=2) | 109 | 254 | 1425 |
| | 102 | 163 | 1191 |
| | 102 | 170 | 1265 |
| Average | 104 | 196 | 1294 |
| Change (%) | 16 | 29 | 9 |

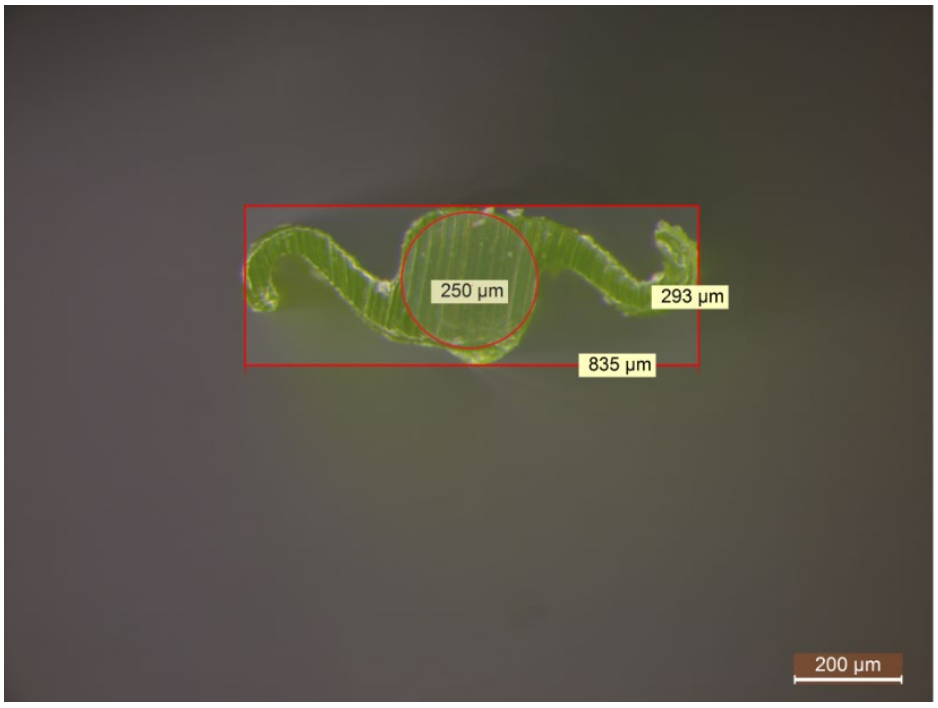
The largest change is observed for the overall thickness of the fibre. The deviation of the measurement for this property is higher than the measured difference.

We conclude that no significant change in this fibre property was observed after 5000 hours of exposure.

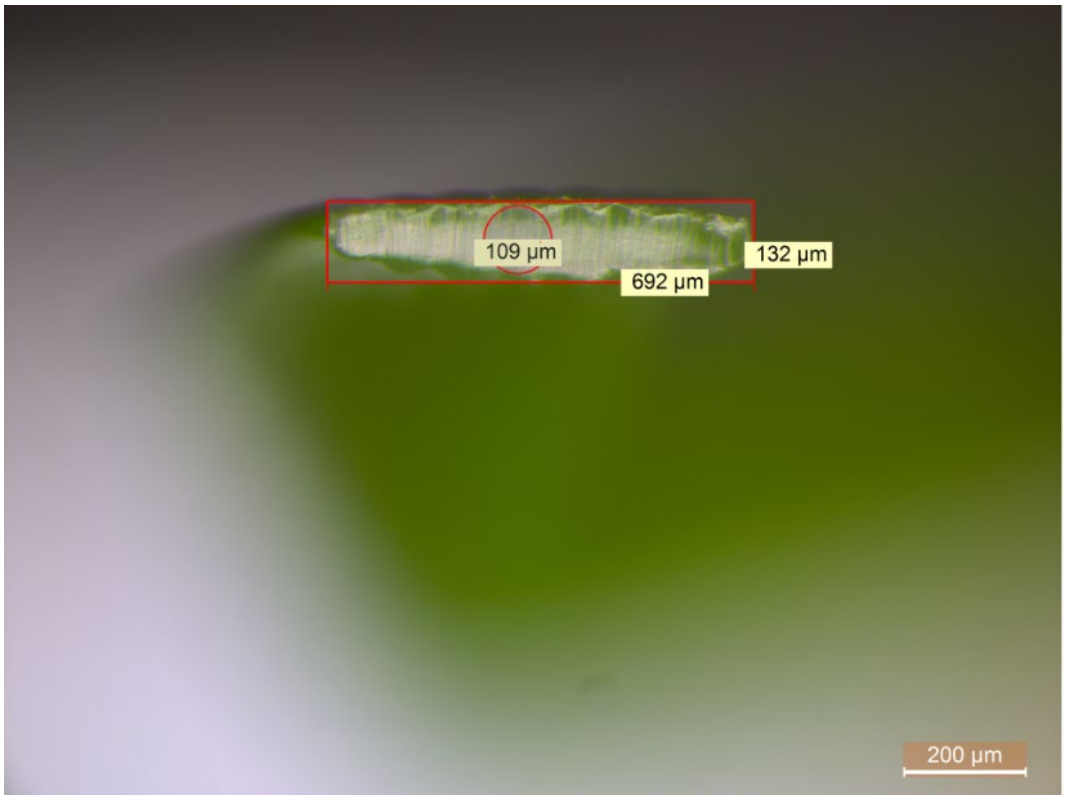
### 4.1.2 LimeGreen Landscape

Since the LimeGreen Landscape product consists of different numbers and types of fibres per lurch, the measurements was adjusted to the fibre type.
In the following pictures the way of measurement I shown.


*Picture 4: Highly light green, slightly curled, RAL nr.6017*

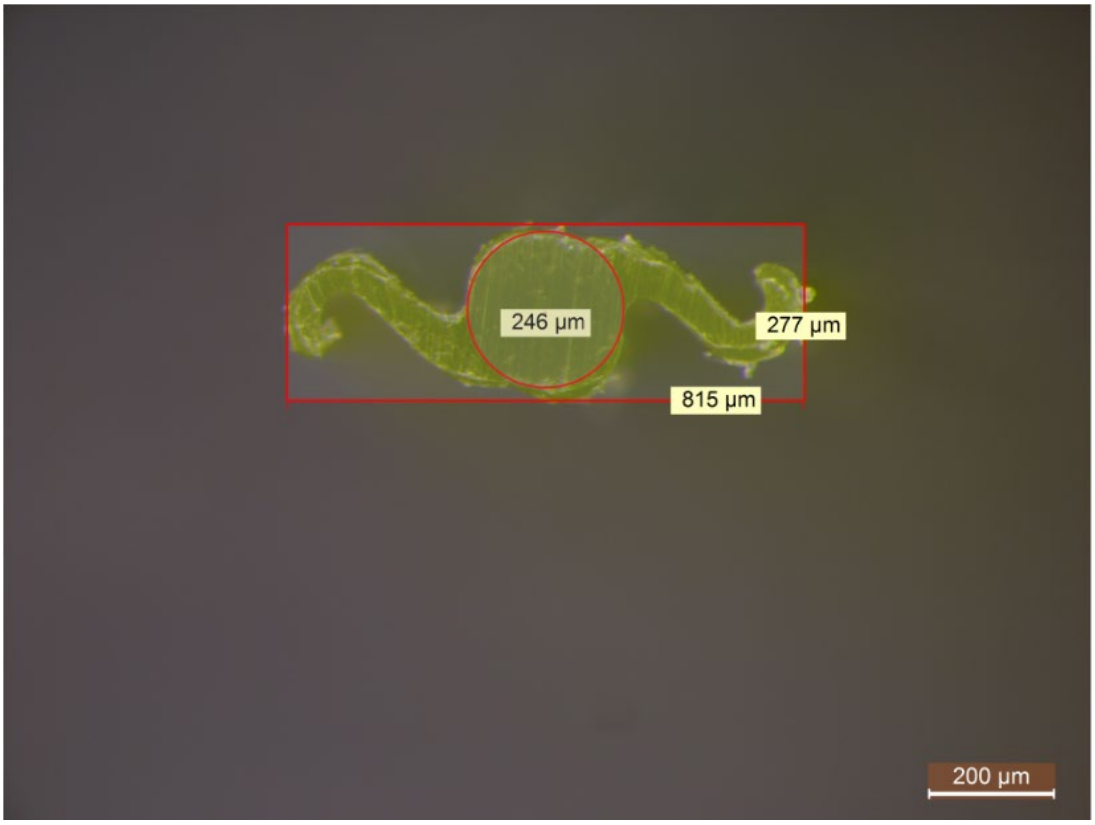



*Picture 5: Light green, straight, RAL nr.6011*

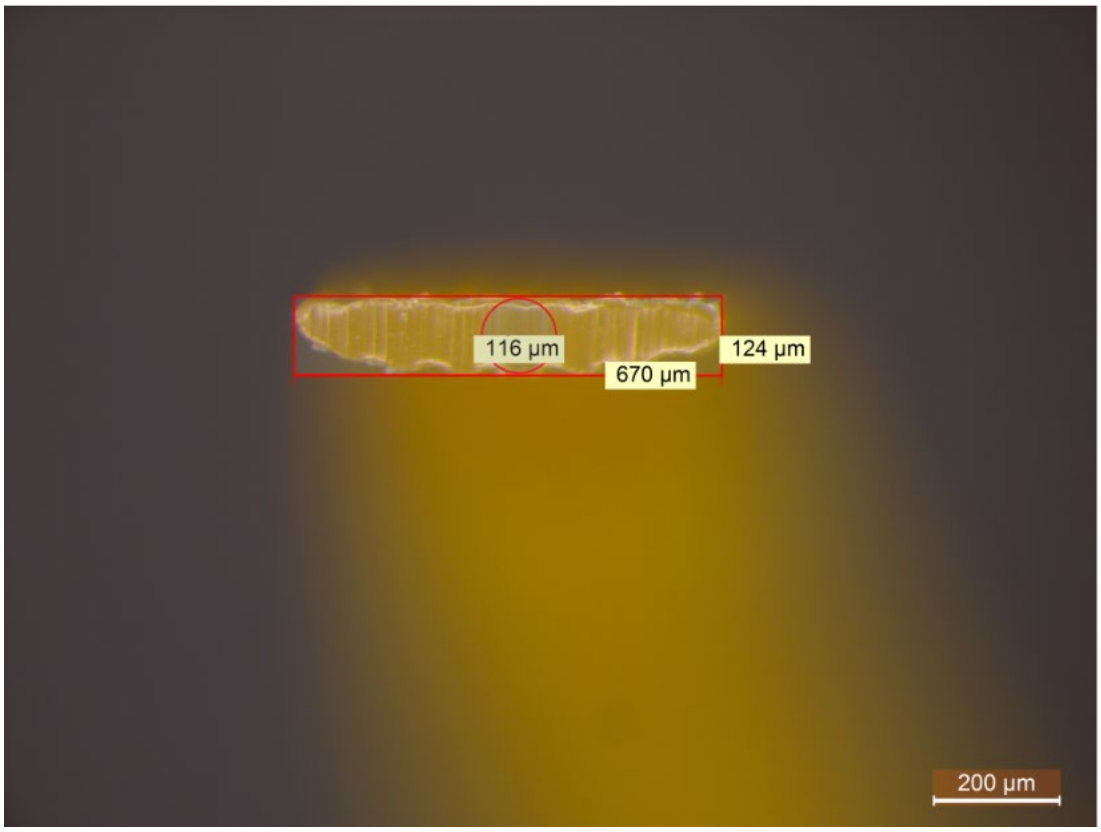



*Picture 6: Moderate green, straight, RAL nr.6025*


*Picture 7: Dark green, slightly curled, RAL nr.6002*




*Picture 8: Moderate green, curled, RAL nr.6025*




*Picture 9: Brown, curled, RAL nr.8001*

Table 2a: Results of the fibre characteristics of the LimeGreen Landscape product before and after aging

| | Fibre type | | | Fibre type | | | Fibre type | | |
|---|---|---|---|---|---|---|---|---|---|
| | 3-fibre monofilament Darkgreen light curl | | | 3-fibre monofilament moderate green straight | | | 4-fibre monofilament moderate green curled | | |
| | Property | | | Property | | | Property | | |
| Exposure | Thickness (µm) | Overall thickness (µm) | Total length (µm) | Thickness (µm) | Overall thickness (µm) | Total length (µm) | Thickness (µm) | Overall thickness (µm) | Total length (µm) |
| 0 hours (T=0) | 146 | 169 | 734 | 250 | 293 | 835 | 109 | 132 | 692 |
| Colour (RAL nr.) | 6002 | | | 6025 | | | 6026 | | |
| 2500 hours (T=1) | 165 | 175 | 773 | 269 | 295 | 870 | 128 | 138 | 642 |
| Colour (RAL nr.) | 6002 | | | 6025 | | | 6025 | | |
| 5000 hours (T=2) | 164 | 166 | 750 | 267 | 285 | 891 | 110 | 122 | 695 |
| Colour (RAL nr.) | 6002 | | | 6025 | | | 6025 | | |
| Greatest change (%) | 12 | 5 | 5 | 7 | 3 | 6 | 15 | 12 | 8 |

Table 2b: Results of the fibre characteristics of the LimeGreen Landscape product before and after aging

| | Fibre type | | | Fibre type | | | Fibre type | | |
|---|---|---|---|---|---|---|---|---|---|
| | 3-fibre monofilament highly light green lightly curled | | | 3-fibre monofilament light green straight | | | 4-fibre monofilament moderate brown curled | | |
| | Property | | | Property | | | Property | | |
| Exposure | Thickness (µm) | Overall thickness (µm) | Total length (µm) | Thickness (µm) | Overall thickness (µm) | Total length (µm) | Thickness (µm) | Overall thickness (µm) | Total length (µm) |
| 0 hours (T=0) | 157 | 172 | 739 | 246 | 277 | 815 | 116 | 124 | 670 |
| Colour (RAL nr.) | 6017 | | | 6011 | | | 8001 | | |
| 2500 hours (T=1) | 156 | 181 | 785 | 258 | 272 | 897 | 126 | 133 | 680 |
| Colour (RAL nr.) | 6018 | | | 6011 | | | 8001 | | |
| 5000 hours (T=2) | 155 | 179 | 780 | 247 | 258 | 987 | 122 | 138 | 634 |
| Colour (RAL nr.) | 6018 | | | 6011 | | | 8001 | | |
| Greatest change (%) | 1 | 5 | 6 | 5 | 7 | 17 | 8 | 10 | 7 |

Based on the data in table 2 **no significant change** in fibre properties and colour is observed after 5000 hours of exposure.

## 4.2. Polymer properties after aging

The Melt Mass-Flow Rate (MFR) is a method to assess the molecular weight of polymeric materials. The chain scission reactions, one of the most important outcomes of degradation, produce smaller polymer molecules. During the aging of the polymer, a cross-linking reaction would lead to a decrease in the MFR value, while chain scission reaction would result in an increase of the MFR value.

### 4.2.1 Impact of aging on Melt Mass-Flow Rate (MFR)

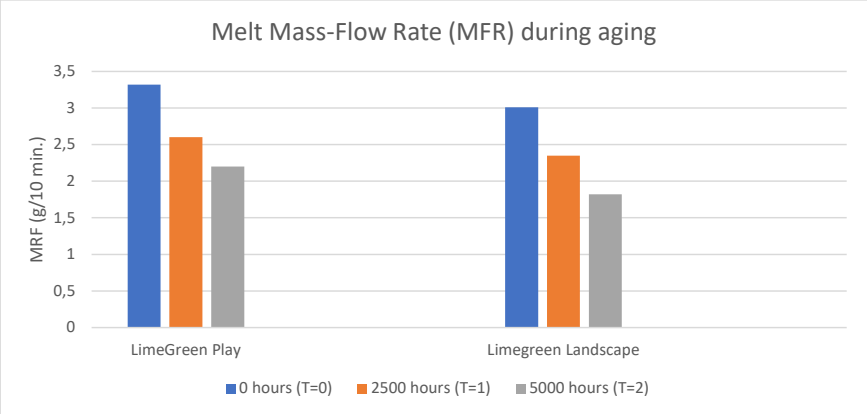
The melt flow index of a polymer gives an indication of viscosity of the melt and **behaviour** during production eg. extrusion, or fiber spinning. Where this value is correlated to zero-shear viscosity it furthermore gives indication of chain length and contamination and thus the quality of the feedstock. Melt flow index was measured conform ISO 1133-1 with a load of 2.16kg at 190°C, table **4**.

Table 4: Results of change in Melt Mass-Flow Rate (MFR) after aging

| | Melt Mass-Flow Rate (MFR) (g/10 min.) | | | Decrease (%) | |
|---|---|---|---|---|---|
| | 0 hours (T=0) | 2500 hours (T=1) | 5000 hours (T=2) | 2500 hours (T=1) | 5000 hours (T=2) |
| LimeGreen Play | 3,32 | 2,60 | 2,20 | 22 | 34 |
| Limegreen Landscape | 3,01 | 2,35 | 1,82 | 22 | 40 |

Both Lime Green products show a slight decrease in Melt Mass-Flow Rate (MFR) after 2500 hours aging. The decrease of the Melt Mass-Flow Rate (MFR) after 5000 hours aging of the LimeGreen products is considerable.
The LimeGreen Landscape product has at start a lower MFR than the LimeGreen Play product. The LimeGreen Landscape polymer has slightly more cross-linked polymers than the LimeGreen Play polymer, based on the curled fibres used in the LimeGreen Landscape product.

Chart 1: Influence of aging on Melt Mass-Flow Rate (MFR).




The regular service life time of LimeGreen products is 10 years. Based on this service-life time only slight decrease in Melt Mass-Flow Index will be present in both products after 10 years of outside exposure.

### 4.2.2 Impact of aging on heat to polymer by Differential Scanning Calorimetry (DSC)

In differential scanning calorimetry energy is transfused into the sample in the form of heat. In phase transitions the sample has a threshold of energy required to enter the next phase. This event is measured, and a correlation to the phase-transition temperature is found. Furthermore, during the melt of the polymer the crystallinity of the sample can be calculated from the phase-transition enthalpy. Polyethylene of high crystallinity has higher tensile strength, impact strength, has higher barrier properties, is less ductile and more thermally stable.
The glass-transition temperature of polyethylene is negative and cannot be measured with conventional DSC. The following parameters were measured:

- Melting temperature (Tm) in degrees Celsius in the first and second heating cycles.
- Enthalpy of the melt (ΔH) in joules per gram in the first and second heating cycles
- Enthalpy of crystallization (ΔH) in joules per gram.

The results of the DSC analyses on melting temperature (Tm) are presented in the table 5.
The results of the DSC analyses on enthalpy of the melt (ΔH) and the enthalpy of crystallization (ΔH) are presented in the table 6.

Table 5: Differential Scanning Calorimetry (DSC) of the melting temperature after aging of the LimeGreen products

| | Differential Scanning Calorimetry (DSC) Melting Temperature | | | | | |
|---|---|---|---|---|---|---|
| Product type | 0 hours (T=0) | | 2500 hours (T=1) | | 5000 hours (T=2) | |
| | Tm [°C] 1st | Tm [°C] 2nd | Tm [°C] 1st | Tm [°C] 2nd | Tm [°C] 1st | Tm [°C] 2nd |
| LimeGreen Play | 120,7 | 121,6 | 121,2 | 121,8 | 120,0 | 121,2 |
| Limegreen Landscape | 118,9 | 111,5 / 121,6 | 113,1 / 126,4 | 110,6 / 125,9 | 114,7 | 111,5 / 122,0 |

No significant change in melting temperatures is observed for the LimeGreen products after aging. For the LimeGreen Landscape type 2 melting temperatures are observed in the 2nd heating. The two different melting temperatures refer to the straight and curled fibres in the LimeGreen Landscape product.

Table 6: Differential Scanning Calorimetry (DSC) of on enthalpy of the melt and crystallization after aging of the LimeGreen products

| | Differential Scanning Calorimetry (DSC) Enthalpy of the melt and crystallization | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Product type | 0 hours (T0) | | | 2500 hours (T=1) | | | 5000 hours (T=2) | | |
| | ΔH [J/g] 1st | ΔH [J/g] 2nd | ΔH [J/g] crystall | ΔH [J/g] 1st | ΔH [J/g] 1st | ΔH [J/g] crystall | ΔH [J/g] 1st | ΔH [J/g] 1st | ΔH [J/g] crystall |
| LimeGreen Play | 136,6 | 130,4 | 124,9 | 121,2 | 121,8 | 128,0 | 151,8 | 135,9 | 131,3 |
| Limegreen Landscape | 113,2 | 108,4 | 104,8 | 121,7 | 116,4 | 113,9 | 114,7 | 115,2 | 109,4 |

For the LimeGreen Play product a small increase in enthalpy of the melt and crystallization after aging is observed.

# 5. Conclusions

No significant change in fibre property is observed after 5000 hours of exposure.

Both LimeGreen products show a slight decrease in Melt Flow Index (MFI) after aging during 5000 hours. The Melt Mass-Flow Rate (MFR) of the LimeGreen Landscape product is at start lower than the LimeGreen Play product. The LimeGreen Landscape polymer has slightly more cross-linked polymers than the LimeGreen Play polymer
For both LimeGreen products a decrease in MFR is observed after aging for 5000 hours. The decrease shows that some cross-linking reactions occur at the aging.
No significant change in melting temperature is observed for the LimeGreen products after aging.

For the LimeGreen Landscape type 2 melting temperatures are observed in the 2nd heating, due to the straight and curled fibres used.
For the LimeGreen Play product a small increase in enthalpy of the melt and crystallization after aging for 5000 hours is observed.

Effect of aging on fibre and polymer properties of the LimeGreen products

| Property | LimeGreen | |
|---|---|---|
| | Play | Landscape |
| Fibre | | |
| Length | ✓ | ✓ |
| Thickness | ✓ | ✓ |
| Colour | ✓ | ✓ |
| Polymer | | |
| Melt Mass-Flow Rate (MFR) | ! | ! |
| Melting Temperature | ✓ | ✓ |
| Enthalpy of Melt and Crystallization | ✓ | ✓ |

For the tested properties the LimeGreen type Play and Landscape, only a small change in Melt Mass-Flow Rate (MFR) is expected after the regular service lifetime of 10 years.

The regular service lifetime of LimeGreen products is 10 years. Based on this service lifetime only small decrease in Melt Mass-Flow Index will be present in both products after 10 years of outside exposure.
For all other tested properties, no significant change is observed

# Appendix 1. Report RE43685-A

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Koolwaterstofstraat 1
6161 RA Geleen
The Netherlands

Telephone: +31 (0)88 126 8888

www.intertek.com

# TEST REPORT – RE43685-A

## DSC AND MFR

**RECALL OF RESULTS MVR : LIMS NO. 23399733**

**SGS Intron BV**
Attn. Mr. Huub Creuwels
Dr. Nolenslaan 126
6130 PD Sittard
Netherlands

**DATE**
May 11, 2023

# RE43685-A

May 11, 2023

Dear Mr. Creuwels,

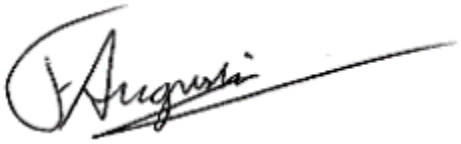
Hereby we present to you the results of the laboratory study, which was carried out in accordance with your request (SO43685). This report replaces the former report with no. RE43685. The report RE43685 is not valid. Revision; caused by a wrong calculation of MVR results of sample 22.3374-4

The general conditions of delivery for Intertek Polychemlab B.V., located in Geleen, the Netherlands, are applicable. These conditions are an integral part of all research carried out and the services and consultations provided; where appropriate, can be expanded upon by specific client agreement.

Samples of unknown origin can only be checked for plausibility to a limited extent. Results of the examination of these samples only relate to the samples as received by Intertek.
Intertek is not responsible for the data supplied by the client which may affect the validity of the analysis results.
Information on potential measurement uncertainty can be provided where requested.
Any opinions and/or interpretations in this report fall outside the scope of the ISO/IEC 17025 accreditation.

We trust that this information will meet your approval.

Yours sincerely,



Frank Augustin
Application Specialist

# 1 SAMPLES

The samples were packed in unsealed plastic bags and coded by the customer as displayed in table 1. The samples were also each coded by Intertek with a unique Intertek LIMS number.

**Table 1: Description of the samples of SO43685.**

| NO. | INTERTEK SAMPLE DESCRIPTION | CUSTOMER SAMPLE IDENTIFICATION | DATE RECEIVED | INTERTEK LIMS NUMBER |
|---|---|---|---|---|
| 1 | Piece of artificial grass | 22.3374-3 | 14-04-2023 | 23399732 |
| 2 | Piece of artificial grass | 22.3374-4 | 14-04-2023 | 23399733 |
| 3 | Piece of artificial grass | 22.3374-5 | 14-04-2023 | 23399734 |
| 4 | Piece of artificial grass | 22.3374-6 | 14-04-2023 | 23399735 |
| 5 | Piece of artificial grass | 22.3374-7 | 14-04-2023 | 23399736 |
| 6 | Piece of artificial grass | 22.3374-8 | 14-04-2023 | 23399737 |

# 2 METHODS AND HARDWARE

## DIFFERENTIAL SCANNING CALORIMETRY (DSC) – ISO 11357-3 (Q)

Equipment DSC 1 – 204428 – Mettler Toledo

| | |
|---|---|
| Type of DSC: | Heat-flux DSC |
| Auto sampler | <Auto sampler> |
| Crucible | Aluminium 40 µL <pin> |
| Purge gas | Nitrogen (≥ 99.997 vol%) |
| Purge gas flow | 50 ml/min |

Test conditions ISO11357-3:2018 Plastics – Differential scanning calorimetry (DSC) – Part 3: Determination of temperature and enthalpy of melting and crystallization

| | |
|---|---|
| Temperature range | 0°C to 210°C |
| Heating/cooling rate | 10°C/min |

Remarks –

# RE43685-A

May 11, 2023

## MELT MASS-FLOW RATE (MFR) – ISO 1133-1 (Q)

| | | |
|---|---|---|
| Equipment | A-flow extrusion plastometer of Zwick Roell | |
| Test conditions | ISO 1133-1:2011 Plastics – Determination of the melt mass-flow rate (MFR) and melt volume-flow rate (MVR) of thermoplastics – Part 1: Standard method | |
| | Method | A |
| | Temperature – Load | 190°C – 2.16 kg |
| Remarks | – | |

**(Q)** marked method is ISO 17025 (Dutch Accreditation Council RvA) accredited.

(RvA Registration number: L377: TESTING)

# RE43685-A

May 11, 2023

## 3 RESULTS

The summary of the results is displayed in table 2 till 7 (and the detailed results are available in the appendices).

**Table 2: Results sample 1.**

| | | |
|---|---|---|
| **NO.** | | 1 |
| **CUSTOMER SAMPLE DESCRIPTION** | | 22.3374-3 |
| **INTERTEK LIMS NUMBER** | | 23399732 |
| **DIFFERENTIAL SCANNING CALORIMETRY (DSC) – ISO 11357-3 (Q)** | | |
| PEAK CRYSTALLIZATION TEMPERATURE | °C | **71.5 / 113.2** |
| ENTHALPY OF CRYSTALLIZATION | J/g | 124.9 |
| PEAK MELTING TEMPERATURE 2ND HEATING CURVE | °C | **121.6** |
| ENTHALPY OF FUSION 2ND HEATING CURVE | J/g | 130.4 |
| PEAK MELTING TEMPERATURE 1ST HEATING CURVE | °C | **120.7** |
| ENTHALPY OF FUSION 1ST HEATING CURVE | J/g | 136.6 |
| DSC GRAPH | | APPENDIX I |
| TEST DATE | | 20-Apr-23 |
| REMARKS | | |
| **MELT MASS-FLOW RATE (MFR) – ISO 1133-1_A (Q)** | **190°C – 2.16kg** | |
| MELT VOLUME-FLOW RATE 1 | $cm^3$/10min | 4.29 |
| MELT VOLUME-FLOW RATE 2 | $cm^3$/10min | 4.29 |
| MELT VOLUME-FLOW RATE 3 | $cm^3$/10min | 4.30 |
| MELT VOLUME-FLOW RATE AVERAGE | $cm^3$/10min | **4.29** |
| MELT VOLUME-FLOW RATE STDEV | $cm^3$/10min | 0.01 |
| MELT MASS-FLOW RATE AVERAGE | g/10min | **3.32** |
| RAW DATA | | APPENDIX VII |
| TEST DATE | | 19-Apr-23 |
| REMARKS | | |

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**Table 3: Results sample 2.**

| | | |
|---|---|---|
| **NO.** | | 2 |
| **CUSTOMER SAMPLE DESCRIPTION** | | 22.3374-4 |
| **INTERTEK LIMS NUMBER** | | 23399733 |
| **DIFFERENTIAL SCANNING CALORIMETRY (DSC) – ISO 11357-3 (Q)** | | |
| PEAK CRYSTALLIZATION TEMPERATURE | °C | **68.7 / 113.2** |
| ENTHALPY OF CRYSTALLIZATION | J/g | 104.8 |
| PEAK MELTING TEMPERATURE 2ND HEATING CURVE | °C | **111.5 / 121.6** |
| ENTHALPY OF FUSION 2ND HEATING CURVE | J/g | 108.4 |
| PEAK MELTING TEMPERATURE 1ST HEATING CURVE | °C | **118.9** |
| ENTHALPY OF FUSION 1ST HEATING CURVE | J/g | 113.2 |
| DSC GRAPH | | APPENDIX II |
| TEST DATE | | 20-Apr-23 |
| REMARKS | | |
| **MELT MASS-FLOW RATE (MFR) – ISO 1133-1_A (Q)** | **190°C – 2.16kg** | |
| MELT VOLUME-FLOW RATE 1 | $cm^3$/10min | 3.91 |
| MELT VOLUME-FLOW RATE 2 | $cm^3$/10min | 3.87 |
| MELT VOLUME-FLOW RATE 3 | $cm^3$/10min | 3.90 |
| MELT VOLUME-FLOW RATE AVERAGE | $cm^3$/10min | **3.89** |
| MELT VOLUME-FLOW RATE STDEV | $cm^3$/10min | 0.02 |
| MELT MASS-FLOW RATE AVERAGE | g/10min | **3.01** |
| RAW DATA | | APPENDIX VII |
| TEST DATE | | 19-Apr-23 |
| REMARKS | | |

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**Table 4: Results sample 3.**

| | | |
|---|---|---|
| **NO.** | | 3 |
| **CUSTOMER SAMPLE DESCRIPTION** | | 22.3374-5 |
| **INTERTEK LIMS NUMBER** | | 23399734 |
| **DIFFERENTIAL SCANNING CALORIMETRY (DSC) – ISO 11357-3 (Q)** | | |
| PEAK CRYSTALLIZATION TEMPERATURE | °C | **72.0 / 113.2** |
| ENTHALPY OF CRYSTALLIZATION | J/g | 128.0 |
| PEAK MELTING TEMPERATURE 2ND HEATING CURVE | °C | **121.8** |
| ENTHALPY OF FUSION 2ND HEATING CURVE | J/g | 134.5 |
| PEAK MELTING TEMPERATURE 1ST HEATING CURVE | °C | **121.2** |
| ENTHALPY OF FUSION 1ST HEATING CURVE | J/g | 143.6 |
| DSC GRAPH | | APPENDIX III |
| TEST DATE | | 20-Apr-23 |
| REMARKS | | |
| **MELT MASS-FLOW RATE (MFR) – ISO 1133-1_A (Q)** | **190°C – 2.16kg** | |
| MELT VOLUME-FLOW RATE 1 | $cm^3$/10min | 3.35 |
| MELT VOLUME-FLOW RATE 2 | $cm^3$/10min | 3.36 |
| MELT VOLUME-FLOW RATE 3 | $cm^3$/10min | 3.39 |
| MELT VOLUME-FLOW RATE AVERAGE | $cm^3$/10min | **3.37** |
| MELT VOLUME-FLOW RATE STDEV | $cm^3$/10min | 0.02 |
| MELT MASS-FLOW RATE AVERAGE | g/10min | **2.60** |
| RAW DATA | | APPENDIX VII |
| TEST DATE | | 19-Apr-23 |
| REMARKS | | |

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**Table 5: Results sample 4.**

| | | |
|---|---|---|
| **NO.** | | 4 |
| **CUSTOMER SAMPLE DESCRIPTION** | | 22.3374-6 |
| **INTERTEK LIMS NUMBER** | | 23399735 |
| **DIFFERENTIAL SCANNING CALORIMETRY (DSC) – ISO 11357-3 (Q)** | | |
| PEAK CRYSTALLIZATION TEMPERATURE | °C | **68.0 / 103.5 / 113.8** |
| ENTHALPY OF CRYSTALLIZATION | J/g | 113.9 |
| PEAK MELTING TEMPERATURE 2ND HEATING CURVE | °C | **110.6 / 125.9** |
| ENTHALPY OF FUSION 2ND HEATING CURVE | J/g | 116.4 |
| PEAK MELTING TEMPERATURE 1ST HEATING CURVE | °C | **113.1 / 126.4** |
| ENTHALPY OF FUSION 1ST HEATING CURVE | J/g | 121.7 |
| DSC GRAPH | | APPENDIX IV |
| TEST DATE | | 20-Apr-23 |
| REMARKS | | |
| **MELT MASS-FLOW RATE (MFR) – ISO 1133-1_A (Q)** | **190°C – 2.16kg** | |
| MELT VOLUME-FLOW RATE 1 | $cm^3$/10min | 3.60 |
| MELT VOLUME-FLOW RATE 2 | $cm^3$/10min | 3.40 |
| MELT VOLUME-FLOW RATE 3 | $cm^3$/10min | 3.56 |
| MELT VOLUME-FLOW RATE AVERAGE | $cm^3$/10min | **3.52** |
| MELT VOLUME-FLOW RATE STDEV | $cm^3$/10min | 0.10 |
| MELT MASS-FLOW RATE AVERAGE | g/10min | **2.35** |
| RAW DATA | | APPENDIX VII |
| TEST DATE | | 19-Apr-23 |
| REMARKS | | |

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**Table 6: Results sample 5.**

| | | |
|---|---|---|
| **NO.** | | 5 |
| **CUSTOMER SAMPLE DESCRIPTION** | | 22.3374-7 |
| **INTERTEK LIMS NUMBER** | | 23399736 |
| **DIFFERENTIAL SCANNING CALORIMETRY (DSC) – ISO 11357-3 (Q)** | | |
| PEAK CRYSTALLIZATION TEMPERATURE | °C | **71.9 / 113.3** |
| ENTHALPY OF CRYSTALLIZATION | J/g | 131.3 |
| PEAK MELTING TEMPERATURE 2ND HEATING CURVE | °C | **121.2** |
| ENTHALPY OF FUSION 2ND HEATING CURVE | J/g | 135.9 |
| PEAK MELTING TEMPERATURE 1ST HEATING CURVE | °C | **120.0** |
| ENTHALPY OF FUSION 1ST HEATING CURVE | J/g | 151.8 |
| DSC GRAPH | | APPENDIX V |
| TEST DATE | | 20-Apr-23 |
| REMARKS | | |
| **MELT MASS-FLOW RATE (MFR) – ISO 1133-1_A (Q)** | **190°C – 2.16kg** | |
| MELT VOLUME-FLOW RATE 1 | $cm^3$/10min | 2.82 |
| MELT VOLUME-FLOW RATE 2 | $cm^3$/10min | 2.84 |
| MELT VOLUME-FLOW RATE 3 | $cm^3$/10min | 2.82 |
| MELT VOLUME-FLOW RATE AVERAGE | $cm^3$/10min | **2.83** |
| MELT VOLUME-FLOW RATE STDEV | $cm^3$/10min | 0.01 |
| MELT MASS-FLOW RATE AVERAGE | g/10min | **2.20** |
| RAW DATA | | APPENDIX VII |
| TEST DATE | | 19-Apr-23 |
| REMARKS | | |

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**Table 7: Results sample 6.**

| | | |
|---|---|---|
| **NO.** | | 6 |
| **CUSTOMER SAMPLE DESCRIPTION** | | 22.3374-8 |
| **INTERTEK LIMS NUMBER** | | 23399737 |
| **DIFFERENTIAL SCANNING CALORIMETRY (DSC) – ISO 11357-3 (Q)** | | |
| PEAK CRYSTALLIZATION TEMPERATURE | °C | **68.2 / 104.2 / 115.2** |
| ENTHALPY OF CRYSTALLIZATION | J/g | 109.4 |
| PEAK MELTING TEMPERATURE 2ND HEATING CURVE | °C | **111.5 / 122.0** |
| ENTHALPY OF FUSION 2ND HEATING CURVE | J/g | 115.2 |
| PEAK MELTING TEMPERATURE 1ST HEATING CURVE | °C | **114.7** |
| ENTHALPY OF FUSION 1ST HEATING CURVE | J/g | 122.4 |
| DSC GRAPH | | APPENDIX VI |
| TEST DATE | | 20-Apr-23 |
| REMARKS | | |
| **MELT MASS-FLOW RATE (MFR) – ISO 1133-1_A (Q)** | **190°C – 2.16kg** | |
| MELT VOLUME-FLOW RATE 1 | $cm^3$/10min | 2.41 |
| MELT VOLUME-FLOW RATE 2 | $cm^3$/10min | 2.30 |
| MELT VOLUME-FLOW RATE 3 | $cm^3$/10min | 2.39 |
| MELT VOLUME-FLOW RATE AVERAGE | $cm^3$/10min | **2.37** |
| MELT VOLUME-FLOW RATE STDEV | $cm^3$/10min | 0.06 |
| MELT MASS-FLOW RATE AVERAGE | g/10min | **1.82** |
| RAW DATA | | APPENDIX VII |
| TEST DATE | | 19-Apr-23 |
| REMARKS | | |

# APPENDIX I

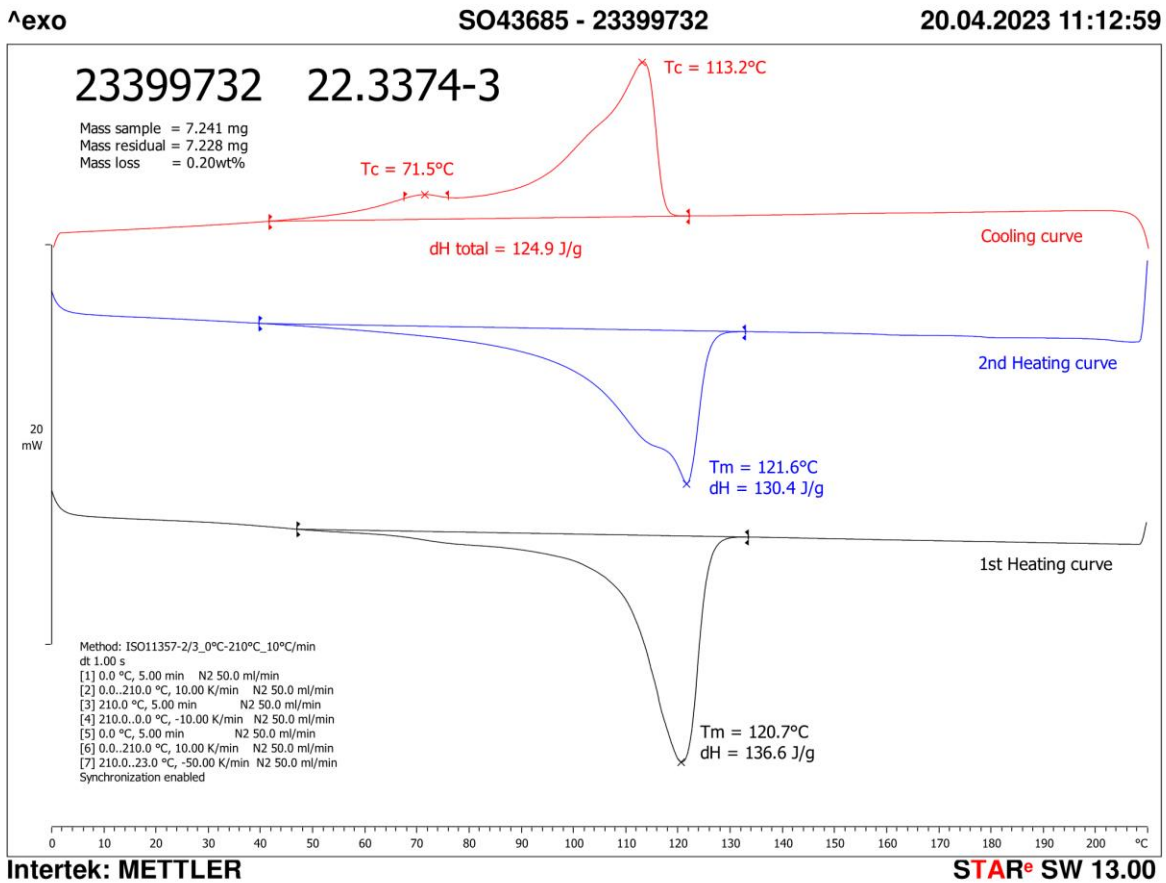


**Figure 1: DSC curves of sample "23399732 22.3374-3".**

# APPENDIX II

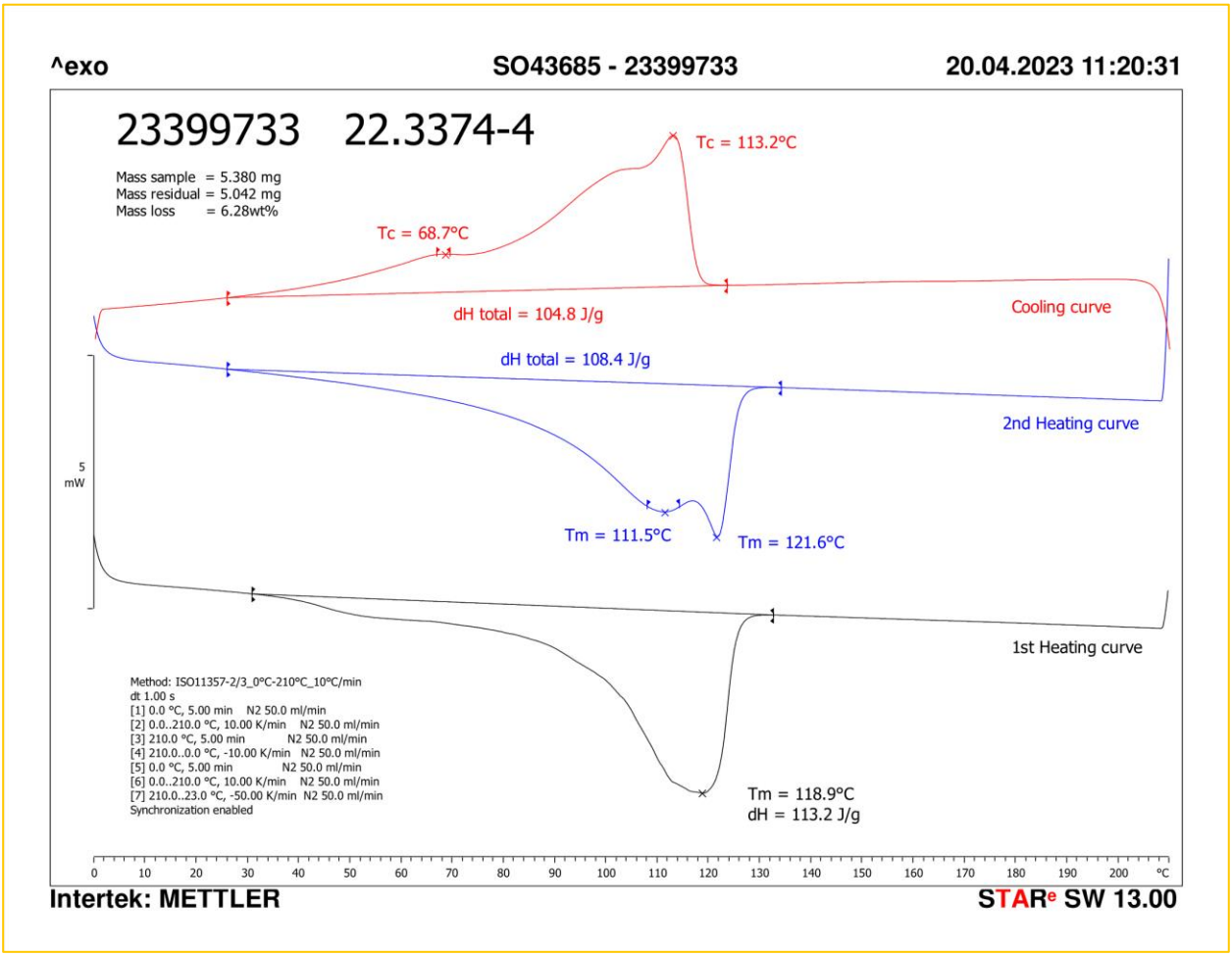


**Figure 2: DSC curves of sample "23399733 22.3374-4".**

# APPENDIX III

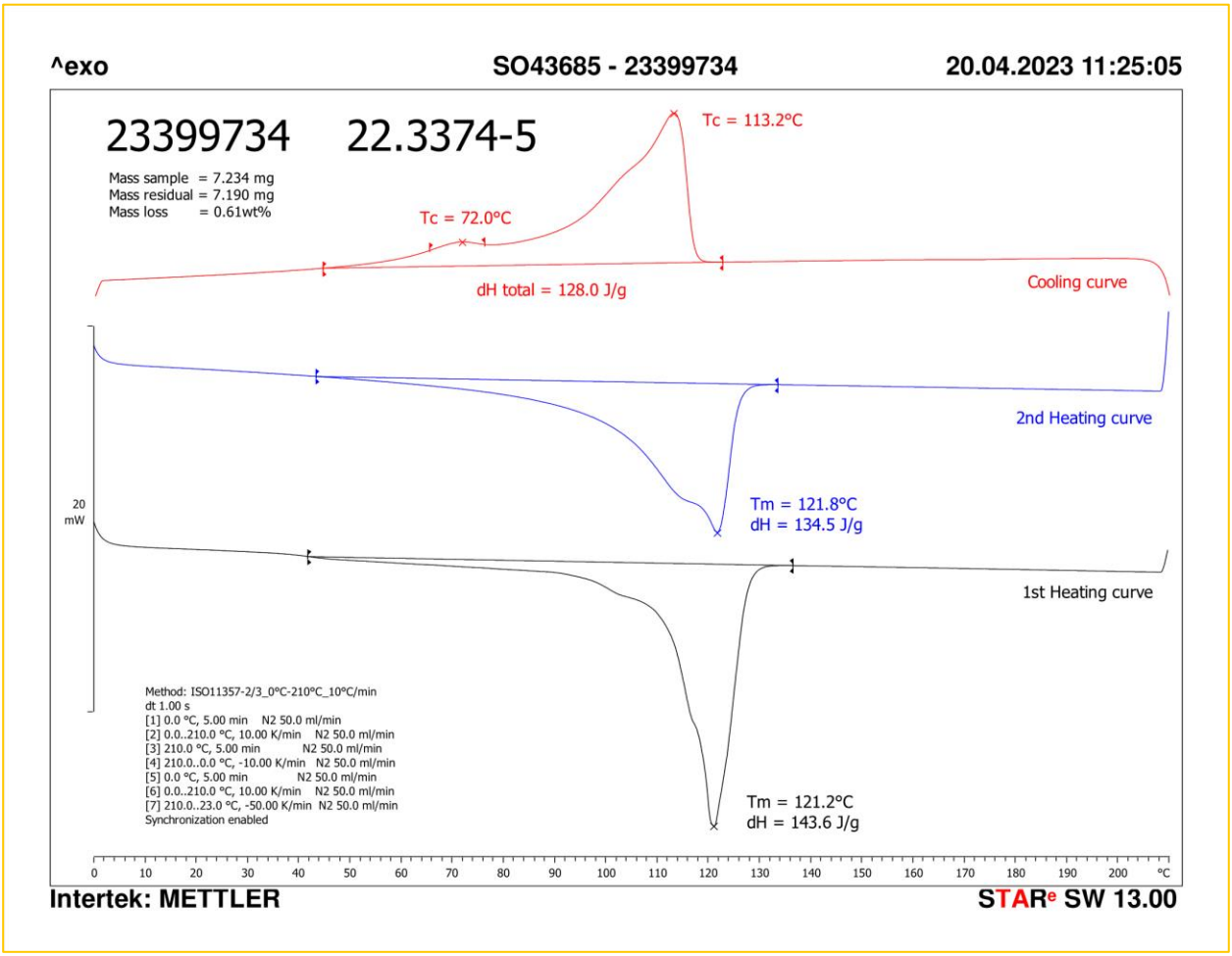


**Figure 3: DSC curves of sample "23399734 22.3374-5".**

# APPENDIX IV

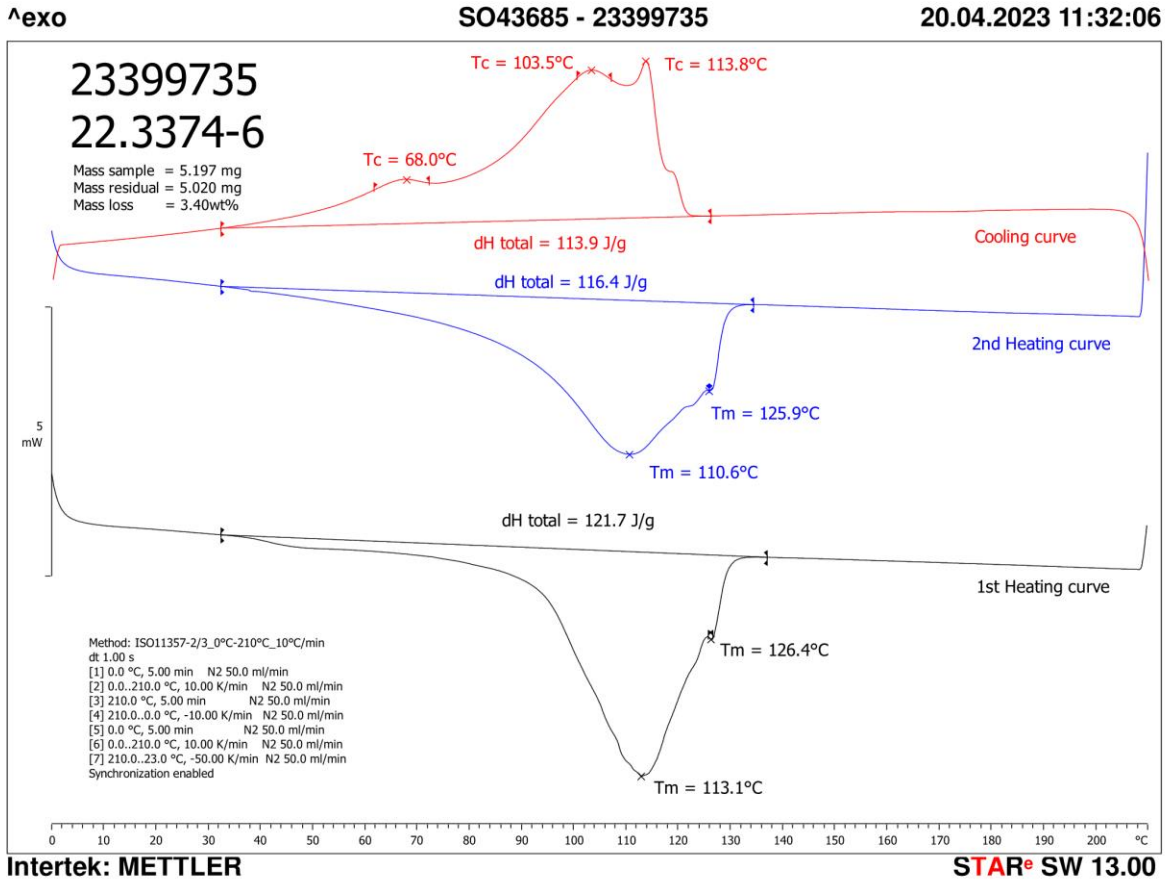


**Figure 4: DSC curves of sample "23399735 22.3374-6".**

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# APPENDIX V

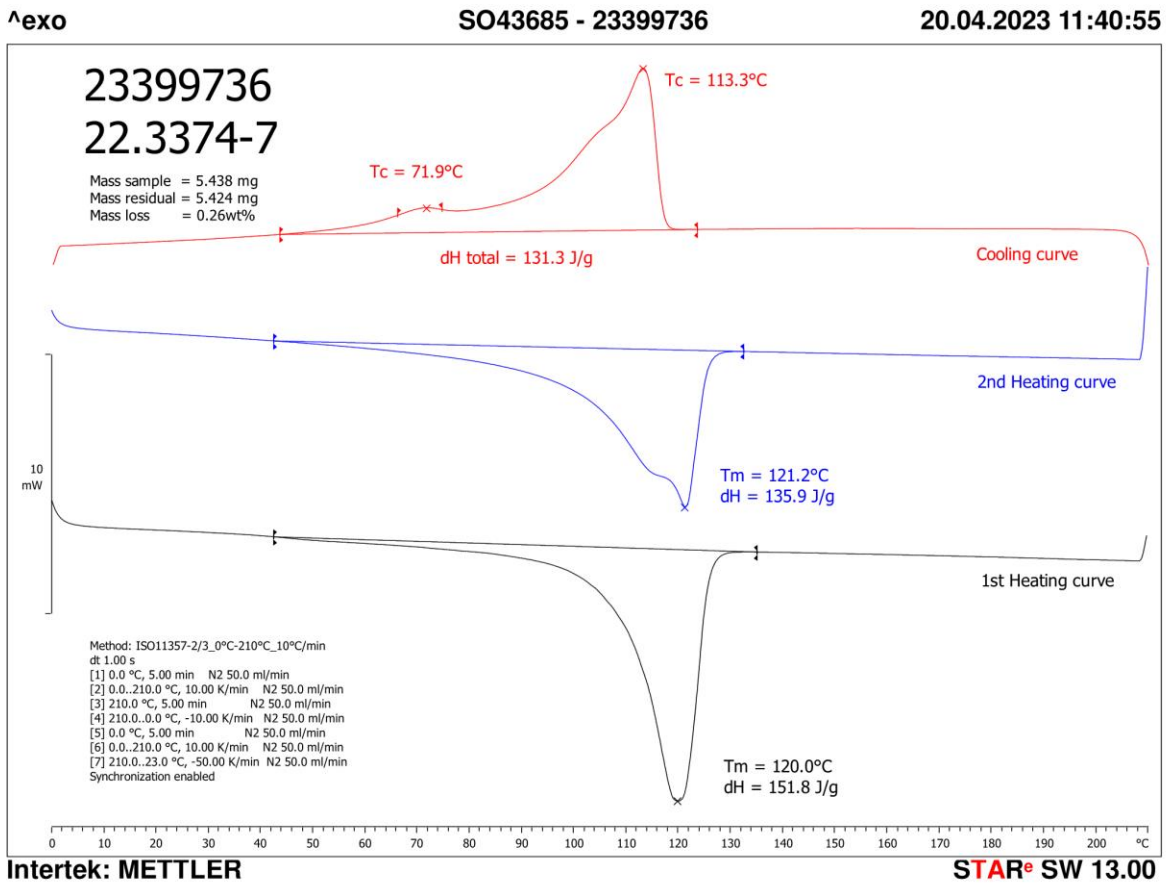


**Figure 5: DSC curves of sample "23399736 22.3374-7".**

# APPENDIX VI

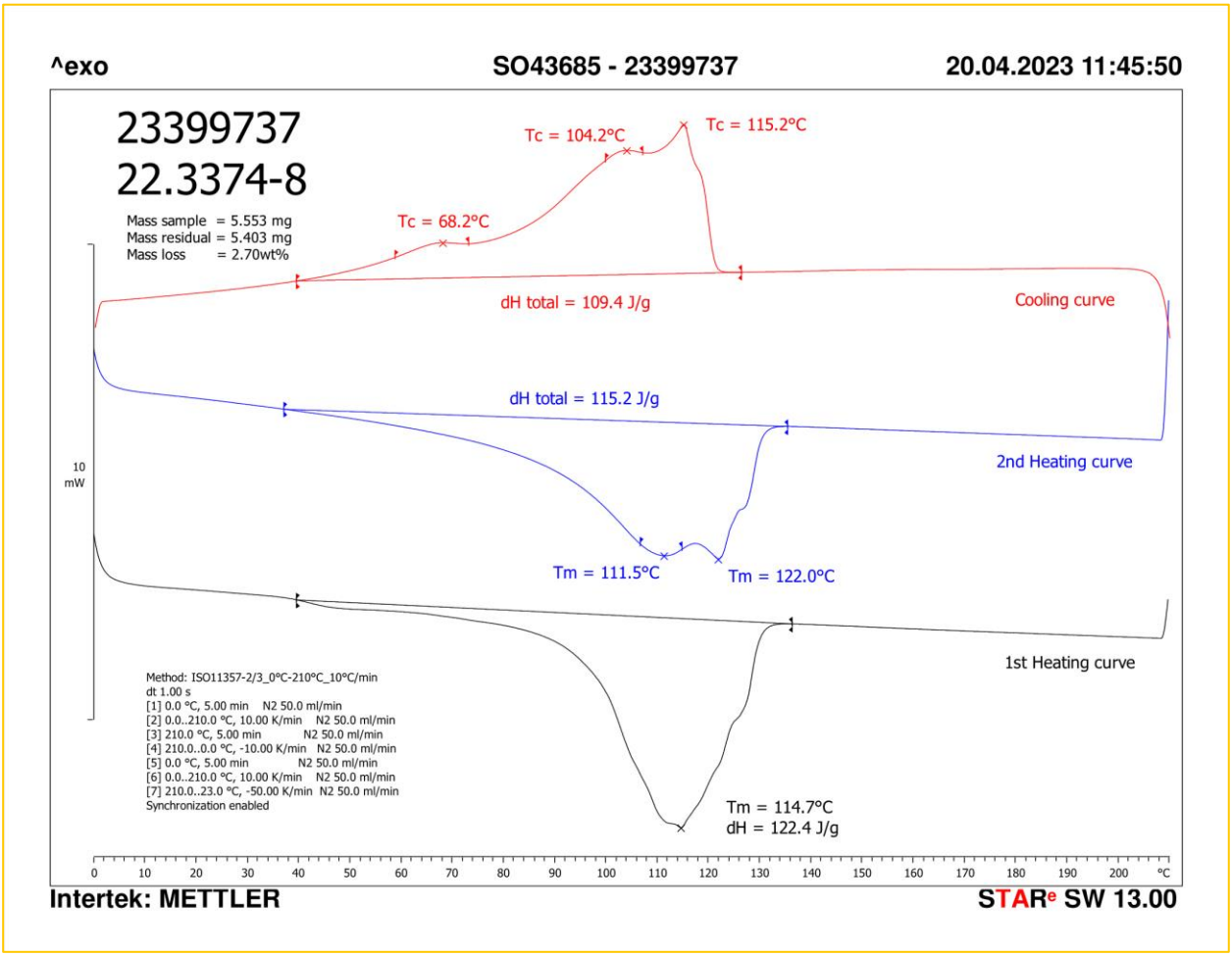


**Figure 6: DSC curves of sample "23399737 22.3374-8".**

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# APPENDIX VII

**Table 8: MFR raw data of the six samples of SO43685.**

**MELT MASS-FLOW RATE (MFR) – ISO 1133-1_A (Q)**

| NO. | CUSTOMER SAMPLE DESCRIPTION | INTERTEK LIMS NUMBER | TEMP - LOAD | TEST DATE | *t* *s* | MVR $cm^3/10\ min$ | $MVR_{ave}$ $cm^3/10\ min$ | *m* *g* | $MFR_{ave}$ *g/10 min* |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 22.3374-3 | 23399732 | 190°C – 2.16kg | 19-Apr-23 | 20 | 4.29 | 4.29 | 0.1106 | **3.32** |
| | | | | | | 4.29 | | 0.1105 | |
| | | | | | | 4.30 | | 0.1109 | |
| 2 | 22.3374-4 | 23399733 | 190°C – 2.16kg | 19-Apr-23 | 20 | 3.91 | 3.89 | 0.1010 | **3.01** |
| | | | | | | 3.87 | | 0.0998 | |
| | | | | | | 3.90 | | 0.1006 | |
| 3 | 22.3374-5 | 23399734 | 190°C – 2.16kg | 19-Apr-23 | 20 | 3.35 | 3.37 | 0.0853 | **2.60** |
| | | | | | | 3.36 | | 0.0868 | |
| | | | | | | 3.39 | | 0.0879 | |
| 4 | 22.3374-6 | 23399735 | 190°C – 2.16kg | 19-Apr-23 | 20 | 3.60 | 3.52 | 0.0798 | **2.35** |
| | | | | | | 3.40 | | 0.0758 | |
| | | | | | | 3.56 | | 0.0795 | |
| 5 | 22.3374-7 | 23399736 | 190°C – 2.16kg | 19-Apr-23 | 20 | 2.82 | 2.83 | 0.0729 | **2.20** |
| | | | | | | 2.84 | | 0.0739 | |
| | | | | | | 2.82 | | 0.0732 | |
| 6 | 22.3374-8 | 23399737 | 190°C – 2.16kg | 19-Apr-23 | 20 | 2.41 | 2.37 | 0.0623 | **1.82** |
| | | | | | | 2.30 | | 0.0578 | |
| | | | | | | 2.39 | | 0.0622 | |

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