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**Testing Report**

**Dated**

**8th November 2022**

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**Welltec testing report.**

# Test performed

The test conducted by the OU on the thermoplastic rings and the rubber squares provided by Welltec consisted of

1. Dimension testing
2. Hardness testing
3. High-temperature exposure testing
4. Thermal properties test

It should be noted that thermal properties test was only conducted on rubber square samples.

# Material used

## Thermoplastic Rings

The thermoplastic rings provided by Welltec are as follows

* D1867
* D1868
* D1869
* D1870
* D1872

Figure 1: Thermoplastic rings provided by the Welltec

## Rubber Square

Welltec also provided forty different types of rubber squares which were divided into four different types of material, as shown in Figure 2. These four materials have been classified as follows by the Welltec:

* 1799/03
* 1787/03
* 1782/03
* 1788TH

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Figure 2: Rubber squares provided by the Welltec

# Test and results

## Dimensions testing

The purpose of doing the dimension test was to make sure that the dimensions given on the labels are the same as the dimensions measured in the lab. Moreover, a dimension test was also performed each time after the samples was exposed to the high-temperature testing that will be discussed in the following section. A standard vernier caliper (Figure 3) was used for measuring OD, ID and wall thickness (WT) of the samples.

****

Figure 3: Vernier caliper used for dimension test

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Table 1: Comparison of the dimensions measured in the lab with the given labels provided by the Welltec**   |  |  |  |  |  |  |  | | --- | --- | --- | --- | --- | --- | --- | | Sample No. | Labeled | | | Measured in lab | | | |  | OD (mm) | ID (mm) | WT (mm) | OD (mm) | ID (mm) | WT (mm) | | D1867 (1) | 60 | 30 | 5 | 59.95 | 31.02 | 4.98 | | D1867 (2) | 60 | 30 | 5 | 59.98 | 31.03 | 4.97 | | D1868 (1) | 75 | 55 | 10 | 74.96 | 55.01 | 10 | | D1868 (2) | 75 | 55 | 10 | 74.97 | 55.02 | 10 | | D1869 (1) | 110 | 90 | 10 | 109.95 | 89.99 | 10 | | D1869 (2) | 110 | 90 | 10 | 109.96 | 89.98 | 10.01 | | D1870 (1) | 75 | 55 | 10 | 74.96 | 54.99 | 10.02 | | D1870 (2) | 75 | 55 | 10 | 74.97 | 55.01 | 10.01 | | D1872 (1) | 50 | 30 | 5 | 49.95 | 31.04 | 5.01 | | D1872 (2) | 50 | 30 | 5 | 49.97 | 31.01 | 5.03 | |

## Hardness testing

The purpose of doing the hardness test was to observe the difference in the hardness of the material after the samples have been exposed to high temperatures. For that reason, the hardness of the samples was noted before and after the exposure to high-temperature conditions. A durometer was used to determine the hardness of the thermoplastic rings and squares as shown in Figure 4.



Figure 4: Durometer used for hardness testing

The procedure consists of puncturing the sample with the help of a durometer in order to get the hardness value of the samples. This puncturing process is performed threetimes on each different sample. Before the start of the test, the screen must show the value of zero to confirm the device is calibrated (if not, the “zero” button must be pushed to recalibrate the device). Initial hardness values of thermoplastic rings and rubber squares are given in Tables 2 and 3 respectively.

Table 2: Initial hardness value of thermoplastic rings

|  |  |  |
| --- | --- | --- |
|  | Hardness Values |  |
| |  | | --- | | **Sample** | |  | **Average** |
| D1867 (ring 1) | **52 – 44 – 49** | **50** |
| D1867 ( ring 2) | **51.5 – 40.5 – 41.5** | **44.5** |
| |  | | --- | | **D1868 (1)** | | **54 – 53 – 56.5** | **54.5** |
| D1868 (2) | **46.5 – 49 – 43** | **46.16** |
| D1869 (1) | **54 – 58.5 – 49.5** | **54** |
| |  | | --- | | **D1869 (2)** | | **50 – 54 – 49.5** | **51.16** |
| D1870 (1) | **63.5 – 56.5 – 59.5** | **59.83** |
| D1870 (2) | **59 – 57.5 – 59.5** | **58.66** |
| |  | | --- | | **D1872 (1)** | | **53 – 52.5 – 61.5** | **55.66** |
| |  | | --- | | **D1872 (2)** | | **62 – 58 – 53.5** | **57.83** |

Table 3: Initial hardness value of rubber squares

|  |  |  |
| --- | --- | --- |
| Square number | Hardness measured (before oven) | Average |
| 1799/03 | 40 – 41 – 42 | 41 |
| 1787/03 | 42.5 – 40.5 – 40 | 41 |
| 1782/03 | 42.5 – 43 – 42.5 | 42.66 |
| 1788TH | 49 – 50 – 51 | 50 |

## High temperatures testing

### Thermoplastic rings

High-temperature conditions refer to placing one ring from each representative sample in the oven heated at high temperatures (475ºF – 650 ºF). Tests were conducted for seven cycles. Each cycle of the test consists of exposing the sample to high-temperature conditions for two weeks. After each cycle, the dimension and hardness of the samples were measured and compared with the labeled data provided by Welltec. Moreover, for better visualization of the temperature effects on the samples, pictures were captured from the microscope before and after the exposure to the high-temperature testing. The results of different test cycles on the thermoplastic rings are as follows:

#### First cycle

The first cycle test consisted of exposing the sample to 475 ºF for two weeks. The result after the first cycle is given in Tables 4 and 5, and in Figure 5.

Table 4: Dimension result of thermoplastic rings after the first cycle of exposure

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Sample after heated up / 475ºF | Labeled dimensions provided by Welltec | | | Dimensions after exposure to 475ºF for two weeks | | |
|  | OD (mm) | ID (mm) | WT (mm) | OD (mm) | ID (mm) | WT (mm) |
| D1867 | 60 | 30 | 5 | 59.99 | 31 | 5.01 |
| D1868 | 75 | 55 | 10 | 74.97 | 55.01 | 10 |
| D1869 | 110 | 90 | 10 | 109.96 | 90.01 | 10.02 |
| D1870 | 75 | 55 | 10 | 74.98 | 55.03 | 10 |
| D1872 | 50 | 30 | 5 | 50.02 | 31.02 | 5.01 |

Table 5: Hardness result of thermoplastic rings after the first cycle of exposure

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | |  | | --- | |  | |  |   Hardness Values |  |
| Sample after heated up / 475ºF |  | Average |
| D1867 | 62.5 – 58 – 60 | 60.16 |
| D1868 | 62 – 62 – 64 | 62.66 |
| D1869 | 64 – 65 – 64 | 64.33 |
| D1870 | 63 – 65 – 64 | 64 |
| D1872 | 64.5 – 63.5 – 63.5 | 63.83 |

|  |  |  |
| --- | --- | --- |
| **Sample No.** | **Pictures taken before exposure to the first cycle** | **Pictures taken after exposure to first cycle** |
| **D1867** | A picture containing loudspeaker  Description automatically generated | **A picture containing loudspeaker, electronics  Description automatically generated** |
| **D1868** | /var/folders/5z/pjcmx0m52bb7k_jz4mwznw080000gn/T/com.microsoft.Word/WebArchiveCopyPasteTempFiles/2Q== | /var/folders/5z/pjcmx0m52bb7k_jz4mwznw080000gn/T/com.microsoft.Word/WebArchiveCopyPasteTempFiles/Z |
| **D1869** | /var/folders/5z/pjcmx0m52bb7k_jz4mwznw080000gn/T/com.microsoft.Word/WebArchiveCopyPasteTempFiles/2Q== | /var/folders/5z/pjcmx0m52bb7k_jz4mwznw080000gn/T/com.microsoft.Word/WebArchiveCopyPasteTempFiles/Z |
| **D1870** |  | **A close up of a person's skin  Description automatically generated with low confidence** |
| **D1872** |  | **A close up of a microscope  Description automatically generated with low confidence** |

Figure 5: Picture of thermoplastic rings samples before and after exposure to the first cycle

#### Second cycle

The second cycle test consisted of placing the sample in the oven for two weeks at 475 ºF. The results of the second cycle test are given in the following tables and figure.

Table 6: Dimension result of thermoplastic rings after the second cycle of exposure

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Sample after heated up (second time) / 475ºF | Labeled dimension provided by Welltec | | | Dimension after exposure to 475ºF for two weeks | | |
|  | OD (mm) | ID (mm) | WT (mm) | OD (mm) | ID (mm) | WT (mm) |
| D1867 | 60 | 30 | 5 | 59.99 | 30.98 | 5 |
| D1868 | 75 | 55 | 10 | 74.97 | 55 | 10 |
| D1869 | 110 | 90 | 10 | 109.99 | 90.02 | 10.03 |
| D1870 | 75 | 55 | 10 | 74.96 | 54.98 | 10 |
| D1872 | 50 | 30 | 5 | 50 | 31.01 | 5.01 |

Table 7: Hardness results of thermoplastic rings after the second cycle of exposure

|  |  |  |
| --- | --- | --- |
|  | Hardness Values |  |
| Sample after heated up (second time) / 475ºF |  | Average |
| D1867 | 60.5 – 62 – 60 | 60.83 |
| D1868 | 64 – 62 – 61 | 62.33 |
| D1869 | 68.5 – 68 – 67.5 | 68 |
| D1870 | 63.5 – 65.5 – 65 | 64.66 |
| D1872 | 65 – 65 – 65.5 | 65.16 |

|  |  |  |
| --- | --- | --- |
| **Sample No.** | **Pictures taken before exposure to the first cycle** | **Pictures taken after exposure to the second cycle** |
| **D1867** | A picture containing loudspeaker  Description automatically generated | **A picture containing loudspeaker  Description automatically generated** |
| **D1868** | /var/folders/5z/pjcmx0m52bb7k_jz4mwznw080000gn/T/com.microsoft.Word/WebArchiveCopyPasteTempFiles/2Q== | A picture containing loudspeaker  Description automatically generated |
| **D1869** | /var/folders/5z/pjcmx0m52bb7k_jz4mwznw080000gn/T/com.microsoft.Word/WebArchiveCopyPasteTempFiles/2Q== | A picture containing loudspeaker  Description automatically generated |
| **D1870** |  |  |
| **D1872** |  | **A picture containing loudspeaker  Description automatically generated** |

Figure 6: Picture of thermoplastic rings samples before and after exposure to the second cycle

#### Third cyclec

For the third cycle testing, the samples were exposed to 575 ºF in the oven for two weeks.

Table 8: Dimension results of thermoplastic rings after the third cycle of exposure

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Sample after heated up (third time) / 575ºF | Labeled dimension provided by Welltec | | | Dimension after exposure to 575ºF for two weeks | | |
|  | OD  (mm) | ID (mm) | WT (mm) | OD (mm) | ID (mm) | WT (mm) |
| D1867 | 60 | 30 | 5 | 59.89 | 30.93 | 5.02 |
| D1868 | 75 | 55 | 10 | 74.75 | 54.9 | 9.98 |
| D1869 | 110 | 90 | 10 | 109.85 | 89.94 | 10 |
| D1870 | 75 | 55 | 10 | 74.77 | 54.85 | 9.97 |
| D1872 | 50 | 30 | 5 | 49.92 | 30.93 | 5.01 |

Table 9: Hardness results of thermoplastic rings after the third cycle of exposure

|  |  |  |
| --- | --- | --- |
|  | Hardness Values |  |
| Sample after heated up (third time) / 575ºF |  | Average |
| D1867 | 61.5 – 61 – 61 | 61.16 |
| D1868 | 63.5 – 62 – 62.5 | 62.66 |
| D1869 | 66.5 – 65.5 – 65.5 | 65.83 |
| D1870 | 64.5 – 63.5 – 65 | 64.33 |
| D872 | 64 – 64 – 64.5 | 64.16 |

|  |  |  |
| --- | --- | --- |
| **Sample No.** | **Pictures taken before exposure to the first cycle** | **Pictures taken after exposure to the third cycle** |
| **D1867** |  |  |
| **D1868** | /var/folders/5z/pjcmx0m52bb7k_jz4mwznw080000gn/T/com.microsoft.Word/WebArchiveCopyPasteTempFiles/2Q== |  |
| **D1869** | /var/folders/5z/pjcmx0m52bb7k_jz4mwznw080000gn/T/com.microsoft.Word/WebArchiveCopyPasteTempFiles/2Q== |  |
| **D1870** |  | **A close up of a person's skin  Description automatically generated with medium confidence** |
| **D1872** |  |  |

Figure 7: Picture of thermoplastic rings samples after exposure to the third cycle

#### Fourth cycle

Data collected after rings were placed at high temperature (**575 ºF**) in the oven for two weeks. Table 10, 11, and Figure 8 shows the result of the fourth cycle.

Table 10: Dimension result of thermoplastic rings after the fourth cycle of exposure

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Sample after heated up (fourth time) / 575ºF | Labeled dimension provided by Welltec | | | Dimension after exposure to 575ºF for two weeks | | |
|  | OD (mm) | ID (mm) | WT (mm) | OD (mm) | ID (mm) | WT (mm) |
| D1867 | 60 | 30 | 5 | 59.89 | 30.93 | 5.06 |
| D1868 | 75 | 55 | 10 | 74.76 | 54.88 | 9.99 |
| D1869 | 110 | 90 | 10 | 109.89 | 89.93 | 10 |
| D1870 | 75 | 55 | 10 | 74.65 | 54.83 | 9.98 |
| D1872 | 50 | 30 | 5 | 49.98 | 30.99 | 5 |

Table 11: Hardness result of thermoplastic rings after the fourth cycle of exposure

|  |  |  |
| --- | --- | --- |
|  | Hardness Values |  |
| Sample after heated up (fourth time) / 575ºF |  | **Average** |
| D1867 | 61– 62 – 60 | 61 |
| D1868 | 66 – 67 – 65.5 | 66.16 |
| D1869 | 66 – 65.5 – 67 | 66.16 |
| D1870 | 63 – 63 – 64 | 63.33 |
| D1872 | 62 – 64.5 – 64.5 | 63.66 |

|  |  |  |
| --- | --- | --- |
| **Sample No.** | **Pictures taken before exposure to the first cycle** | **Pictures taken after exposure to the fourth cycle** |
| **D1867** | A picture containing loudspeaker  Description automatically generated | **A picture containing loudspeaker  Description automatically generated** |
| **D1868** | /var/folders/5z/pjcmx0m52bb7k_jz4mwznw080000gn/T/com.microsoft.Word/WebArchiveCopyPasteTempFiles/2Q== | A picture containing loudspeaker  Description automatically generated |
| **D1869** | /var/folders/5z/pjcmx0m52bb7k_jz4mwznw080000gn/T/com.microsoft.Word/WebArchiveCopyPasteTempFiles/2Q== | A picture containing loudspeaker  Description automatically generated |
| **D1870** |  | **A close up of a skin  Description automatically generated with low confidence** |
| **D1872** |  | **A picture containing ground, loudspeaker  Description automatically generated** |

Figure 8: Picture of thermoplastic rings samples after exposure to the fourth cycle

#### Fifth cycle

In the fifth cycle, the temperature of the oven was further increased to 650 ºF. The results of the fifth cycle are given in the following tables and figure.

Table 12: Dimension result of thermoplastic rings after the fifth cycle of exposure

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Sample after heated up (fifth time) / 650ºF** | **Labeled dimension provided by Welltec** | | | **Dimension after exposure to 650ºF for two weeks** | | |
|  | OD (mm) | ID (mm) | WT (mm) | OD (mm) | ID (mm) | WT (mm) |
| D1867 | 60 | 30 | 5 | 59.82 | 30.9 | 5.02 |
| D1868 | 75 | 55 | 10 | 73.25 | 53.59 | 10.17 |
| D1869 | 110 | 90 | 10 | 109.84 | 89.77 | 10.03 |
| D1870 | 75 | 55 | 10 | 72.01 | 53.3 | 9.75 |
| D1872 | 50 | 30 | 5 | 50.85 | 31.71 | 5.2 |

Table 13: Hardness result of thermoplastic rings after the fifth cycle of exposure

|  |  |  |
| --- | --- | --- |
|  | Hardness Values |  |
| Sample after heated up (fifth time) / 650ºF |  | **Average** |
| D1867 | 64.5– 64.5 – 64.5 | 64.5 |
| D1868 | 61 – 62.5 – 60.5 | 61.33 |
| D1869 | 64.5 – 64.5 – 60 | 63 |
| D1870 | 59 – 58 – 57 | 58 |
| D1872 | 65.5 – 64 – 64.5 | 64.66 |

|  |  |  |
| --- | --- | --- |
| **Sample No.** | **Pictures taken before exposure to the first cycle** | **Pictures taken after exposure to fifth cycle** |
| **D1867** | A picture containing loudspeaker  Description automatically generated | **A picture containing loudspeaker  Description automatically generated** |
| **D1868** | /var/folders/5z/pjcmx0m52bb7k_jz4mwznw080000gn/T/com.microsoft.Word/WebArchiveCopyPasteTempFiles/2Q== | A picture containing background pattern  Description automatically generated |
| **D1869** | /var/folders/5z/pjcmx0m52bb7k_jz4mwznw080000gn/T/com.microsoft.Word/WebArchiveCopyPasteTempFiles/2Q== |  |
| **D1870** |  | **A picture containing helmet  Description automatically generated** |
| **D1872** |  | **A close up of a microscope  Description automatically generated with low confidence** |

Figure 9: Picture of thermoplastic rings samples after exposure to the fifth cycle

#### Sixth cycle

The sixth cycle consisted of the sample being placed at 475ºF in the oven for two weeks. The results are given in Tables 14 and 15, and Figure 10.

Table 14: Dimension result of thermoplastic rings after the sixth cycle of exposure

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Sample after heated up (sixth time) / 475ºF | Labeled dimension provided by Welltec | | | Dimension after exposure to 475ºF for two weeks | | |
|  | OD (mm) | ID (mm) | WT (mm) | OD (mm) | ID (mm) | WT (mm) |
| D1867 | 60 | 30 | 5 | 59.75 | 30.8 | 4.99 |
| D1868 | 75 | 55 | 10 | 73.2 | 53.4 | 10.13 |
| D1869 | 110 | 90 | 10 | 107.79 | 89.54 | 9.9 |
| D1870 | 75 | 55 | 10 | 71.85 | 52.85 | 9.67 |
| D1872 | 50 | 30 | 5 | 50.8 | 31.96 | 5.2 |

Table 15: Hardness result of thermoplastic rings after the sixth cycle of exposure

|  |  |  |
| --- | --- | --- |
|  | Hardness Values |  |
| Sample after heated up (sixth time) / 475ºF |  | Average |
| D1867 | 64.5– 64.5 – 65 | 64.66 |
| D1868 | 60.5 – 62.5 – 60.5 | 61.16 |
| D1869 | 62.5 – 64.5 – 61.5 | 62.83 |
| D1870 | 60 – 58 – 60.5 | 59.5 |
| D1872 | 65.5 – 65 – 66 | 65.5 |

|  |  |  |
| --- | --- | --- |
| **Sample No.** | **Pictures taken before exposure to the first cycle** | **Pictures taken after exposure to sixth cycle** |
| **D1867** | A picture containing loudspeaker  Description automatically generated | **A picture containing loudspeaker  Description automatically generated** |
| **D1868** | /var/folders/5z/pjcmx0m52bb7k_jz4mwznw080000gn/T/com.microsoft.Word/WebArchiveCopyPasteTempFiles/2Q== | A picture containing headdress, helmet  Description automatically generated |
| **D1869** | /var/folders/5z/pjcmx0m52bb7k_jz4mwznw080000gn/T/com.microsoft.Word/WebArchiveCopyPasteTempFiles/2Q== | **A picture containing close  Description automatically generated** |
| **D1870** |  | **A picture containing helmet, close  Description automatically generated** |
| **D1872** |  | **A picture containing close, silver  Description automatically generated** |

Figure 10: Picture of samples after the exposure to sixth cycle

#### Seventh Cycle

In this cycle the thermoplastic rings were exposed to 475°F again for two weeks and the measurements were made after the test that can be seen in Tables 16, 17 and Figure 11. After the exposure to the temperature test, it was found that the sample D1869 had different wall thickness in one of the points in the circumference.

Table 16: Dimension result of thermoplastic rings after the seventh cycle of exposure

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Sample after heated up (seventh time) / 475ºF | Labeled dimension provided by Welltec | | | Dimension after exposure to 475ºF for two weeks | | |
|  | OD (mm) | ID (mm) | WT (mm) | OD | ID | WT (mm) |
| D1867 | 60 | 30 | 5 | 59.66 | 30.8 | 4.99 |
| D1868 | 75 | 55 | 10 | 72.85 | 53.5 | 10.14 |
| D1869 | 110 | 90 | 10 | 108.31 | 88.35 | 9.94\* |
| D1870 | 75 | 55 | 10 | 71.71 | 52.85 | 9.66 |
| D1872 | 50 | 30 | 5 | 50.77 | 32.1 | 5.18 |

\* In addition to this value, there was a point on the ring that had a different wall thickness of 10.32mm

Table 17: Hardness result of thermoplastic rings after the seventh cycle of exposure

|  |  |  |
| --- | --- | --- |
| Sample after heated up (seventh time) / 475ºF | Hardness Values |  |
|  |  | Average |
| D1867 | 64.5– 64 – 65 | 64.5 |
| D1868 | 58 – 61 – 60 | 59.667 |
| D1869 | 65.5 – 65 – 64.5 | 65\* |
| D1870 | 61 – 58 – 60.5 | 59.833 |
| D1872 | 65.5 – 67 – 67 | 66.5 |

\* In addition to this value, zone of the ring that had a different wall thickness had a different hardness whose values were 56 – 55 – 59 having average of 56.667.

|  |  |  |
| --- | --- | --- |
| **Sample No.** | **Pictures taken before exposure to the first cycle** | **Pictures taken after exposure to seventh cycle** |
| **D1867** | A picture containing loudspeaker  Description automatically generated |  |
| **D1868** | /var/folders/5z/pjcmx0m52bb7k_jz4mwznw080000gn/T/com.microsoft.Word/WebArchiveCopyPasteTempFiles/2Q== |  |
| **D1869** | /var/folders/5z/pjcmx0m52bb7k_jz4mwznw080000gn/T/com.microsoft.Word/WebArchiveCopyPasteTempFiles/2Q== |  |
| **D1870** |  |  |
| **D1872** |  |  |

Figure 11: Picture of samples after the exposure to seventh cycle

#### Comparison of results of thermoplastic rings

In the following figures comparison of dimensional (OD, ID, and WT) and hardness result between the different cycle and initial condition of the thermoplastic rings are given

##### Dimensions

Figure 12: Dimensions comparison of sample D1867 when exposed to seven cycles of temperature testing

Figure 13: Dimensions comparison of sample D1868 when exposed to seven cycles of temperature testing

Figure 14: Dimensions comparison of sample D1869 when exposed to seven cycles of temperature testing

Figure 15: Dimensions comparison of sample D1870 when exposed to seven cycles of temperature testing

Figure 16: Dimensions comparison of sample D1872 when exposed to seven cycles of temperature testing

##### Hardness

In the following table and figures, hardness comparison of the samples when exposed to different temperature cycle is shown

Table 18: Legend description for Figures 17 to 20

|  |  |
| --- | --- |
| Material No. | Sample No |
| 1 | **D1867** |
| 2 | **D1868** |
| 3 | **D1869** |
| 4 | **D1870** |
| 5 | **D1872** |

Figure 17: Samples hardness after first and second cycle of exposure at 475°F

Figure 18: Samples hardness after third and fourth cycle of exposure at 575°F

Figure 19: Samples hardness after fifth cycle of exposure at 650°F

Figure 20: Samples hardness after sixth and seventh cycle of exposure at 475°F

Figure 21: Hardness comparison of sample D1867 when exposed to seven cycles of temperature testing

Figure 22: Hardness comparison of sample D1868 when exposed to seven cycles of temperature testing

Figure 23: Hardness comparison of sample D1869 when exposed to seven cycles of temperature testing

It must be noted that after the seventh cycle of exposure sample D1869 showed two different hardness because it had different wall thickness

Figure 24: Hardness comparison of sample D1870 when exposed to seven cycles of temperature testing

Figure 25: Hardness comparison of sample D1872 when exposed to seven cycles of temperature testing

#### Anomaly in the sample D1870

A special set of tests were done in the sample with D1870 because the sample had totally changed in color after seven cycles of testing. The ring was divided in eight sections (Figure 26), the wall thickness and hardness was measured and is shown in the following Figures.



Figure 26: Sample D1870 divided into eight sections

Table 19: Section measurements of sample D1870

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **D1870 BEFORE EXPOSURE TO HT** | | | | | **D1870 AFTER EXPOSURE TO HT IN SEVEN CYCLES** | | | | |
| Couple Sections | OD (mm) | ID (mm) | Section | WT (mm) | Couple Sections | OD (mm) | ID (mm) | Section | WT (mm) |
| AE | 74.95 | 54.95 | A | 9.99 | AE | 71.61 | 52.78 | A | 9.67 |
| BF | 74.96 | 54.96 | B | 10 | BF | 71.75 | 52.8 | B | 9.67 |
| CG | 74.97 | 55.02 | C | 9.99 | CG | 71.71 | 52.95 | C | 9.69 |
| DH | 74.99 | 55.03 | D | 9.99 | DH | 71.78 | 52.90 | D | 9.69 |
|  |  |  | E | 9.98 |  |  |  | E | 9.68 |
|  |  |  | F | 9.97 |  |  |  | F | 9.63 |
|  |  |  | G | 9.98 |  |  |  | G | 9.63 |
|  |  |  | H | 9.98 |  |  |  | H | 9.66 |

Figure 27:Dimesion measurement comparison of different sections of sample D1870

Figure 28: Hardness measurement comparison of different sections of sample D1870

#### Finding of thermoplastic rings

Following changes in the thermoplastic ring were observed after being exposed to high temperatures for seven-time:

* The hardness of the material increases during the different temperature cycle testing
* The color of the specimen changed, especially for D1870 the color was transformed from brown to white as shown in Figure 26
* The rings lose their shapes and shift from circle to oval. In that respect, sample 1869 showed a prominent change in the shape transformation
* The dimension of the samples was changed and shrunk to a few millimeters after multiple exposures to high-temperature conditions

### Rubber squares testing.

For the rubber squares, two cycle of temperature testing was conducted at 475°F. In which each cycle represents the exposure of rubber square samples for two weeks at the given temperature. After every cycle of exposure to high temperature, the hardness and dimension test was performed, and pictures were captured from the microscope.

#### First cycle

In this cycle, the rubber square samples were exposed to 475°F for the time period of two weeks. The results from this cycle are shown in Figure 30 and Table 20.

Table 20: Hardness results of rubber square sample after being exposed to 475F for two weeks

|  |  |  |  |
| --- | --- | --- | --- |
| Material No. | Square number | Hardness measured after oven (475 ºF) | Average |
| 1 | 1799/03 | 47.5 – 49 – 52 | 49.5 |
| 2 | 1787/03 | 56 – 57.5 – 55.5 | 56.33 |
| 3 | 1782/03 | 54.5 – 53 – 56 | 54.5 |
| 4 | 1788TH | 59.5 – 60 – 59.5 | 59.66 |

Figure 29: Hardness comparison of rubber square after being exposed to 475°F for two weeks

|  |  |  |
| --- | --- | --- |
| **Sample No.** | **Pictures taken before exposure to the first cycle** | **Pictures taken after exposure to first cycle** |
| **1799/03** | **A picture containing close  Description automatically generated** |  |
| **1787/03** |  |  |
| **1782/03** |  |  |
| **1788TH** |  | **A picture containing loudspeaker  Description automatically generated** |

Figure 30: Picture of rubber square samples after the exposure to first cycle

It is important to mention that after the first cycle, the material labeled as1782/03 suffered severe damage as shown in Figure 31.

A picture containing text

Description automatically generated

Figure 31: Severe damage to rubber square 1782/03

#### Second cycle

For the second cycle the rubber square samples were again exposed to 475°F after which the dimension and hardness test along with the pictures were taken and is represented in Tables 21, 22 and Figure 33. It was seen that sample 1782/03 which was already damaged during the first cycle was completely broken during the hardness test that was conducted after the second cycle (Figure 32).

A picture containing wooden, wood

Description automatically generated

Figure 32: Broken sample 1782/03

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Square number | Dimensions before exposure (room temperature) (mm) | WT (mm) | Dimensions after second exposure to 475 ºF (mm) | WT (mm) |
| 1799/03 | 49.65 x 49.49 | 6.3 | 49.02 x 48.81 | 6.02 |
| 1787/03 | 49.29 x 49.30 | 6.47 | 48.41 x 48.37 | 6.24 |
| 1782/03 | 49.29 x 49.44 | 6.4 | Sample was broken | |
| 1788TH | 49.83 x 49.84 | 6.31 | 49.45 x 49.55 | 5.96 |

Table 21:Dimession results of rubber square sample after being exposed to 475°F for two weeks in second cycle

Table 22: Hardness results of rubber square sample after being exposed to 475°F for two weeks in second cycle

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Square number | Hardness measured (before oven) | Average | Hardness measured after oven (475 ºF) | Average | Hardness measured after second time in oven (475 ºF) | Average |
| 1799/03 | 40 – 41 – 42 | 41 | 47.5 – 49 – 52 | 49.5 | 50.5 – 50 – 51 | 50.5 |
| 1787/03 | 42.5 – 40.5 – 40 | 41 | 56 – 57.5 – 55.5 | 56.33 | 57 – 57.5 – 55 | 56.5 |
| 1782/03 | 42.5 – 43 – 42.5 | 42.66 | 54.5 – 53 – 56 | 54.5 | Sample broken | |
| 1788TH | 49 – 50 – 51 | 50 | 59.5 – 60 – 59.5 | 59.66 | 62.5 – 62.5 – 62.5 | 62.5 |

|  |  |  |
| --- | --- | --- |
| **Sample No.** | **Pictures taken before exposure to the first cycle** | **Pictures taken after exposure to second cycle** |
| **1799/03** | **A picture containing close  Description automatically generated** | **A picture containing building material, stone  Description automatically generated** |
| **1787/03** | A picture containing text  Description automatically generated | A picture containing brick, stone  Description automatically generated |
| **1782/03** |  | **No microscopic picture taken (Sample Broken)** |
| **1788TH** | A close up of a grey surface  Description automatically generated with low confidence |  |

Figure 33: Picture of rubber square samples after the exposure to second cycle

#### Comparison of results of rubber square

In the following figures comparison of the rubber square before and after the exposure to temperature cycle is shown. It should be noted that the sample 1782/03 was broken during the hardness test, therefore, its reading will be missing in the figures 34, 35 and 36.

##### Dimensions

Figure 34:Comparison of wall thickness between before and after the exposure to second cycle

Figure 35: Comparison of rubber square perimeter between before and after the exposure to second cycle

##### Hardness

Figure 36: Comparison of rubber square hardness between before and after the exposure to first and second cycle

## Thermal properties

Thermal properties testing was performed on the rubber square samples with the help of Keithley 2400 meter with TPS-3 (Figure 37). The equipment has the capability to measure thermal conductivity, heat capacity, diffusivity, and effusivity. The measurement is taken in such a way that the sensor is place between the two same sample and the equipment is run. In the first set of tests the reading was taken on the samples that were not exposed to high temperature condition. Whereas for the second set of tests, one sample of rubber square from the representative same was taken after the second cycle exposure and the other sample was the one that was not exposed to the thermal loading. The results are shown in Table 23 and 24.

A picture containing text, indoor, wooden, worktable

Description automatically generatedA machine on the counter

Description automatically generated with low confidenceA picture containing text, table, indoor, wooden

Description automatically generatedA picture containing table, indoor, wall, wooden

Description automatically generated

Figure 37: Keithley 2400 meter with TPS-3 for the measurement of thermal properties

Table 23: Thermal properties of rubber square samples that were not exposed to high temperature condition

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Sample No.** | **Thermal conductivity (W/mK)** | **Diffusivity (mm2/s)** | **Heat Capacity (MJ/m3K)** | **Effusivity**  **(W√s/(m²K))** |
| **1799/03** | 0.380 | 0.271 | 1.403 | 730.092 |
| **1787/03** | 0.333 | 0.183 | 1.189 | 777.650 |
| **1782/03** | 0.366 | 0.221 | 1.815 | 803.49 |
| **1788TH** | 0.263 | 0.124 | 2.126 | 747.09 |

Table 24: Thermal properties of rubber square sample in which one sample was taken after second cycle test and the other one was not exposed to high temperature condition

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Sample No.** | **Thermal conductivity (W/mK)** | **Diffusivity (mm2/s)** | **Heat Capacity (MJ/m3K)** | **Effusivity**  **(W√s/(m²K))** |
| **1799/03** | 0.346 | 0.225 | 1.535 | 728.787 |
| **1787/03** | 0.318 | 0.170 | 1.880 | 773.315 |
| **1782/03** | The sample broke down after the second cycle exposure | | | |
| **1788TH** | 0.279 | 0.146 | 1.912 | 729.601 |

Figure 38: Comparison of thermal properties of initial and second cycle of rubber square

Figure 39: Comparison of effusivity of initial and second cycle of rubber square

It can be noted form the above figures that the thermal properties of rubber squares decreased after the exposure to second cycle.