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DEVELOPMENT OF AN ACCELERATED POINT LOAD TEST FOR THE EVALUATION OF PIPES MADE OF PE 100-RC

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SHORT SUMMARY

This paper describes the work carried out by three research laboratories to develop an accelerated point load test. It describes the results of the conventional, non-accelerated point load test with Arkopal® N100 at 80 °C and 4 MPa and discusses the results of tests using alternative detergents. Despite the work of the three research laboratories, the failure behavior in the point load test proves to be very complex.

KEYWORDS

Point Load Test (PLT), Arkopal, Disponil, Dehyton, PE 100-RC

ABSTRACT

It has not been possible to derive an accelerated procedure for the Point Load Test (PLT) as a pipe test before now. Further research and testing were therefore needed to establish appropriate requirements for standards including EN 1555-1 to rule out uncertainty in the market. The PLT is a central product test for the user. The damage mechanism that arises in this test is close to real damage patterns observed in practice. This means there is a need for a reproducible and accelerated PLT as an application-related component test for the qualification of pipes made of PE 100-RC.

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This paper describes the work carried out by three research laboratories to develop an accelerated point load test. It explains that the results of the conventional, non-accelerated point load test with Arkopal® N100 at 80 °C and 4 MPa show little scatter within the results of each laboratory. Proposals to minimize the scatter have been drafted and incorporated into the latest version of the ISO test standard (ISO/CD 22102:2020).

Tests carried out with alternative detergents at 90 °C and 4 MPa on two PE 100 grades showed either a failure outside the point load range or no acceleration compared to Arkopal® N100. The point load test is intended to simulate a rock pressing into a pipe. Failure at the point load is therefore required to ensure that the correct failure mechanism has been investigated. Additional tests were therefore carried out at 80 °C and 4 MPa. These led to failure in the point load range for at least one chosen detergent (Disponil® LDBS 25).

Despite the work of the three research laboratories, the failure behavior in the point load test proves to be very complex. Further research activities could address the choice of detergent, especially in the context of the problematic availability of Arkopal® N100, and/or how to force the failure to appear in the point load range.

INTRODUCTION

When excavated soil is used as the embedding material, stone and rock indentations are likely to occur. A new, scratch-free polyethylene (PE) pipe may therefore be locally deformed. This may in turn lead to tensile stresses in the inner side of the pipe wall, which may eventually cause premature failure. PE 100-RC grades are specifically designed to have an increased resistance to Slow Crack Growth (SCG) and thus to withstand this failure behavior. The Point Load Test (PLT) was developed to test the resistance of pipes to point loads. The PLT was first described in a limited way in DIN PAS 1075:2019, which currently is withdrawn. The required failure time for PE 100-RC in the PLT (at 80 °C, 4 MPa and with Arkopal® N100 as the detergent) is one year (1).

Three international laboratories began redeveloping the test in 2014 to establish an open test method (2). However, it has not been possible to derive an accelerated procedure for the PLT before now (3, 4). Further research and testing were therefore necessary to establish appropriate requirements for standards including EN 1555-1 to rule out uncertainty in the market. The PLT is a central product test for the user. The damage mechanism that arises in this test is close to real damage patterns observed in practice (5, 6). This means there is a need for a reproducible and accelerated PLT as an application-related component test for the qualification of pipes made of PE 100-RC.

A DVGW project carried out by three laboratories and supported by various parties (see acknowledgments) aimed to develop an accelerated point load test (aPLT) and to identify minimum requirements for pipes made of PE 100-RC (7), i.e., a minimum service life to be achieved under specified test conditions. This paper summarizes the results of this project.

EXPERIMENTAL

The project had three main sub-objectives:

1. To determine the reproducibility of the PLT within a test laboratory and the comparability of the results of different test laboratories. Since the PLT as a creep rupture test is subject to a certain degree of scatter anyway, the additional influence of an external point load and a detergent solution circulating in the pipe must first be determined using the non-accelerated method, i.e., at 80 °C, 4 MPa and with Arkopal® N100 as the detergent.
2. To investigate the effectiveness of more aggressive detergents and an increase in temperature to allow an accelerated method to be developed and to establish a correlation with the conventional method, or to determine the acceleration factor of the test.
3. To validate the accelerated method for point load testing using pipes manufactured from commercial PE 100-RC materials and to derive corresponding minimum requirements for the PE 100-RC material class.

An overview of the PLT has previously been published (2, 8) and technical details are described in the international standard currently under development (ISO/CD 22102:2020). The equipment and method are summarized below. Figure 1 gives a schematic overview and shows a photo of the test setup at Kiwa Technology.

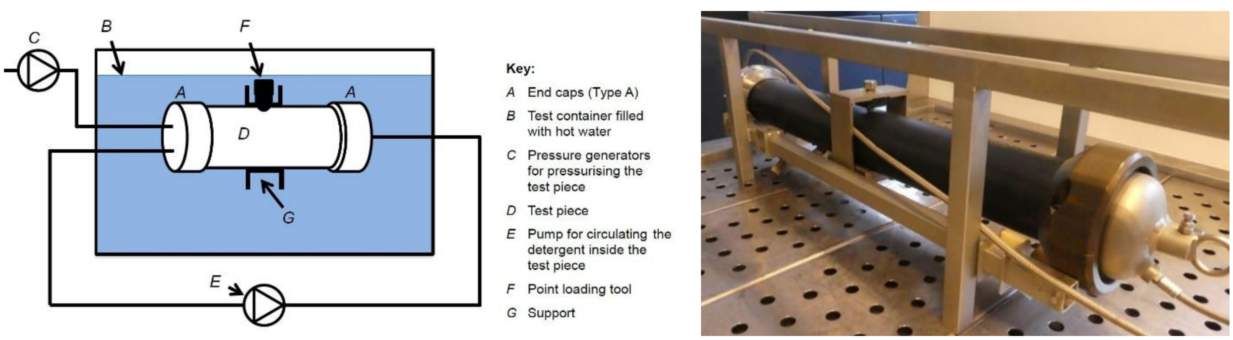

Figure 1. Left: Schematic overview of the point load test (PLT). Right: PE pipe deformed by a point load and filled with detergent solution, ready to be immersed in the water tank.

The PLT employs a normal water tank as used in the hydrostatic pressure test described in ISO 1167-1. The test pipe is supported or hung in the tank and pressurized using the pressurizing equipment.

The following additional equipment is required for the PLT:

- Circulation equipment: the test pipe is filled with a detergent solution, which must be circulated inside the pipe (*E* in figure 1).
- Point loading tool and support: the tool, which has a hemispherical tip, introduces a fixed displacement in the radial direction of the pipe (*F* and *G* in figure 1).

Newly manufactured pipes of two PE 100 grades (DN/OD 110 mm, SDR 11) were kindly provided by the member companies of the PE100+ Association. The two grades were coded as:

- PE 2019-266
- PE 2019-268

PE 100-RC pipes (DN/OD 110 mm, SDR 11) were also investigated. The two grades were coded as:

- PE 100-RC type 1
- PE 100-RC type 2

RESULTS – REPRODUCIBILITY AND COMPARABILITY OF THE CONVENTIONAL POINT LOAD TEST

Each of the three laboratories tested multiple pipes using the conventional, non-accelerated point load test. The test was based on ISO/NP 22102:2019. The following test parameters were used:

- Temperature: 80 °C
- Hoop stress: 4 MPa
- Detergent solution: Arkopal® N100 in demi-water
- Indentation depth: 8% (8.8 mm for the DN/OD 110 mm pipes)

The results of the tests were published in an earlier paper (8). The observed failure mechanism was found to be the same across all laboratories, with slow crack growth confirmed next to the point load. Moreover, the scatter within the results of each laboratory was found to be very good. The scatter between the laboratories was normal for a hydrostatic pressure test. For example, the failure times were in the same order of magnitude as those of a round robin with the Notch Pipe Test (NPT) in accordance with ISO 13479:2009 as performed in 2014 (9).

Nevertheless, the results and procedure were extensively discussed between various experts, including the members of ISO/TC 138/SC 5/WG 20. This resulted in an in-depth analysis of the differences between the three laboratories performing the conventional, non-accelerated point load test and a suggested improvement to the document ISO/NP 22102:2019. This eventually resulted in a new version of the PLT standard: ISO/CD 22102:2020.

Please note that no changes were made to the test equipment and procedure (besides detergent and temperature) when performing tests with another detergent (see next section). Changing test details at this stage would have confused the results when comparing failure times.

RESULTS – DEVELOPMENT OF AN ACCELERATED PLT

The following test program was carried out to determine an appropriate detergent and temperature for the accelerated version of the point load test:

- Lab 1: 4 MPa | 80 °C | 2% lauramine oxide (6.67% Dehyton® PL)
  + 3% lauryl ether sulfate (5% Genapol® LRO paste)

- Lab 1: 4 MPa | 90 °C | 2% lauramine oxide (6.67% Dehyton® PL) + 3% lauryl ether sulfate (5% Genapol® LRO paste)
- Lab 2: 4 MPa | 90 °C | 2% lauramine oxide (6.67% Dehyton® PL)
- Lab 3: 4 MPa | 80 °C | 2% benzenesulfonic acid (8% Disponil® LDBS 25)
- Lab 3: 4 MPa | 90 °C | 2% benzenesulfonic acid (8% Disponil® LDBS 25)

The results for PE 2019-266 and PE 2019-268 are shown graphically in figure 2 and figure 3 respectively. Although a good acceleration was found in the tests for both materials at 90 °C for Dehyton® PL + Genapol® LRO (lab 1) and for Disponil® LDBS 25 (lab 3), this did not result in failure at the point load. The fractures outside the point load location showed a craze-like structure (figure 4 and figure 5). This is evidence of a slow crack growth failure mechanism arising due to the combination of temperature, hoop stress and detergent for the two PE 100 materials. No crack forming was observed around the point load area in either material tested at lab 1, nor in the PE 2019-266 tested at lab 3. The only observed instance of crack forming at the point load was in the PE 2019-268 tested with Disponil® LDBS 25 at lab 3, although it did not lead to leakage (figure 6). However, as the point load test is intended to simulate a rock pressing into a pipe (10), failure at the point load is required to ensure that the correct failure mechanism has been investigated.

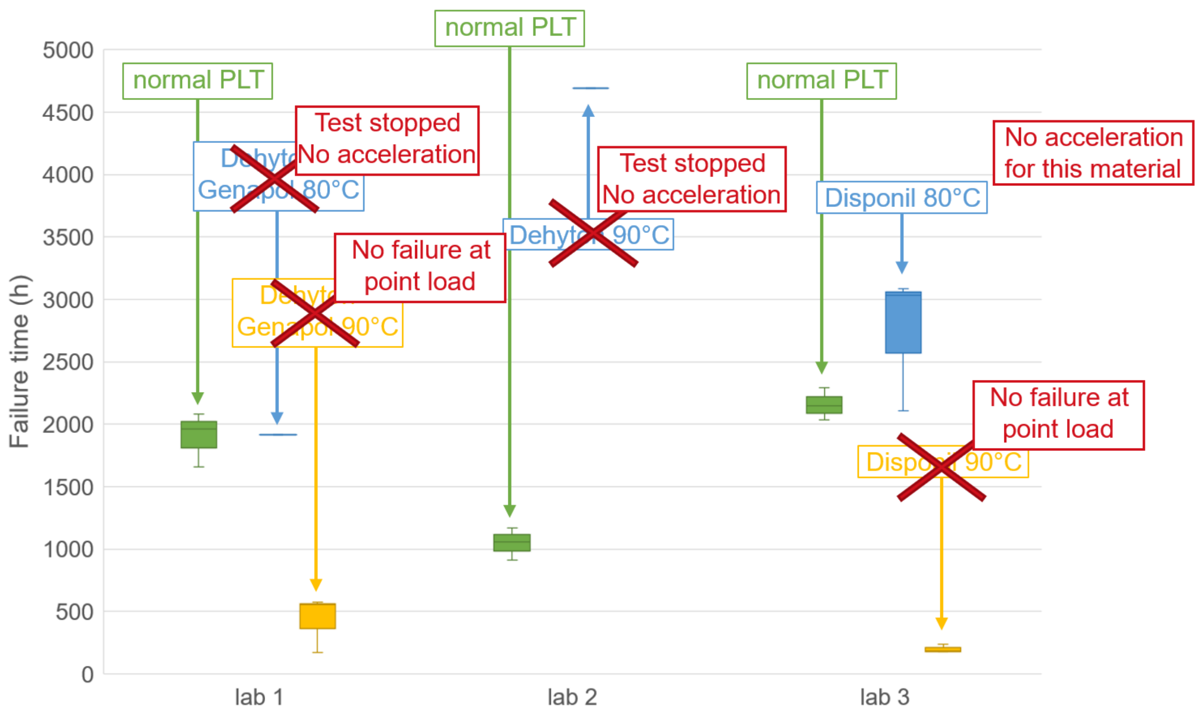

Figure 2. Comparison between the conventional, non-accelerated point load test (normal PLT) and the point load tests with accelerating parameters for material PE 2019-266.

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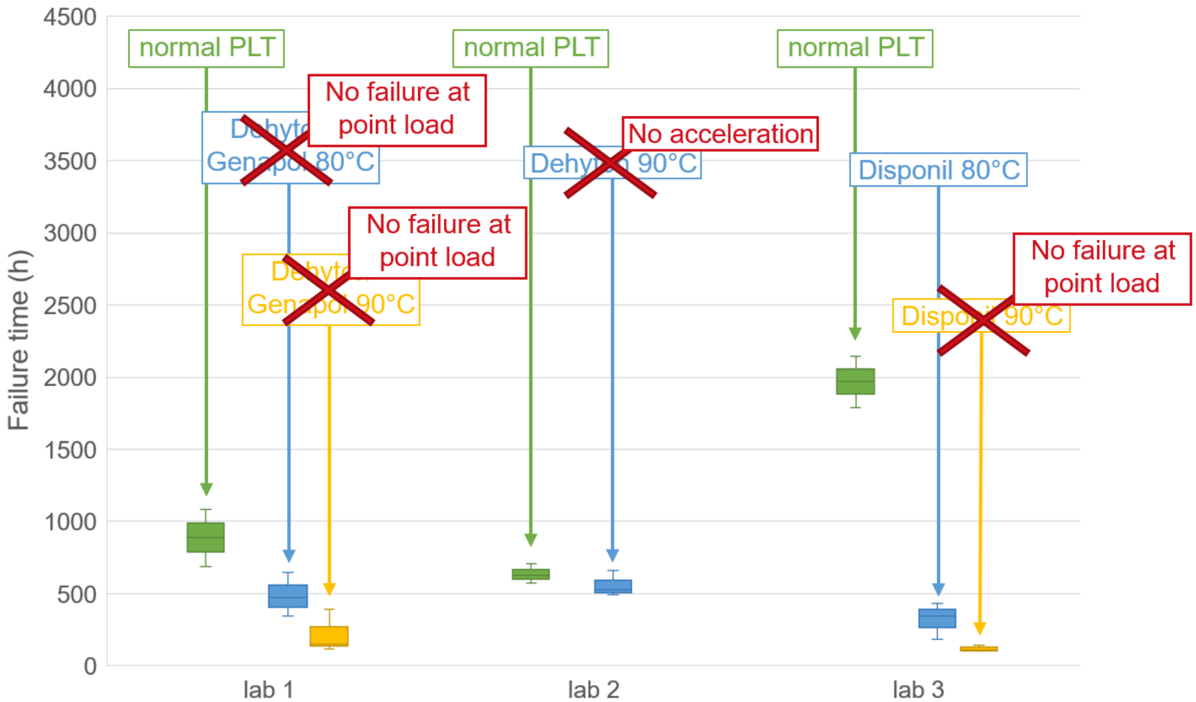

Figure 3. Comparison between the conventional, non-accelerated point load test (normal PLT) and the point load tests with accelerating parameters for material PE 2019-268.

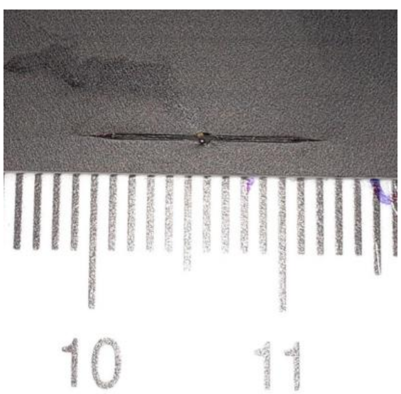

Figure 4. Failure outside the point load range at the inner pipe wall of PE 2019-268 as tested in Lab 1 with Dehyton® PL + Genapol® LRO at 90 °C and 4 MPa.

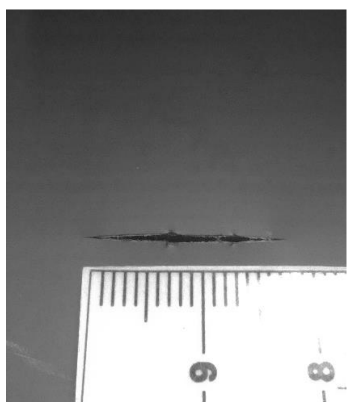

Figure 5. Failure outside the point load range at the inner pipe wall of PE 2019-268 as tested in Lab 3 with Disponil® LDBS 25 at 90 °C and 4 MPa.

Figure 6. Inner pipe wall at the point load location of PE 2019-268 as tested in Lab 3 with Disponil® LDBS 25 at 90 °C and 4 MPa.

Lab 2 found no acceleration for either material (there was still no failure within 4692 h for PE 2019-266) at 90 °C with Dehyton® PL alone. The previous project already determined that performing the point load test at 80 °C with Dehyton® PL would not lead to acceleration (3).

The tests at 80 °C with Dehyton® PL + Genapol® LRO at lab 1 resulted in either no failure within 1915 h to 2500 h (PE 2019-266, see figure 7) or a failure outside the point load area (PE 2019-268, see figure 8). Nevertheless, the tests did result in growing crazes at the point load in one of the three PE 2019-268 pipes (but none for PE 2019-266), as shown in figure 9.

Only the tests at 80 °C with Disponil® LDBS 25 at lab 3 resulted in failure in the point load range with a good acceleration for material PE 2019-268. In this case, the acceleration factor was found to be 6. This means that a failure time of 1 year in the conventional, non-accelerated point load test at 80 °C using Arkopal® N100, which is required for PE 100-RC grades, would correspond to a failure time of only 2 months (1460 h) in the accelerated point load test at 80 °C using Disponil® LDBS 25.

Based on these results, lab 1 and lab 2 purchased a new, fresh container with Disponil® LDBS 25 EVO for testing PE 2019-268 at 80 °C and 4 MPa. table 1 combines these results with the previously shown results of lab 3 (see figure 3). The failure times for lab 1 and lab 2 were even longer than with Arkopal® N100. This means that no acceleration was found. In fact, lab 2 had the longest failure time with Disponil® LDBS 25 EVO with failure in the point load range, while it had the shortest failure time of the three labs in the conventional point load test using Arkopal® N100 at 80 °C.

It is important to note that the manufacturer (BASF) changed the formulation slightly and now sells it as Disponil® LDBS 25 EVO rather than Disponil® LDBS 25. This means it is impossible to judge conclusively whether a lack of reproducibility (which may be caused by differences that arose because the test setup responded differently to a new detergent), or the slightly adjusted formulation of the detergent was the cause of the observed deviation between the results of the different laboratories. However, the results do show that the accelerated point load test proves to be very complex, because the results appear to be sensitive to small changes in the detergent and/or equipment.

Figure 7. Inner pipe wall at the point load location of PE 2019-266 as tested in Lab 1 with Dehyton® PL + Genapol® LRO at 80 °C and 4 MPa.

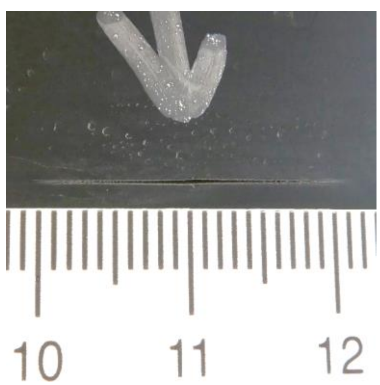

Figure 8. Failure outside the point load range at the inner pipe wall of PE 2019-268 as tested in Lab 1 with Dehyton® PL + Genapol® LRO at 80 °C and 4 MPa.

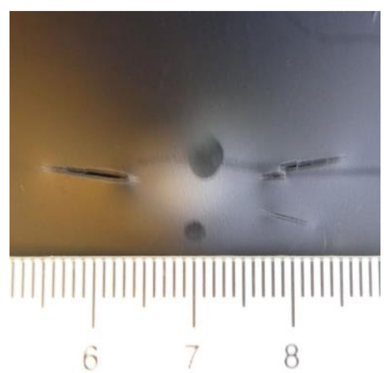

Figure 9. Inner pipe wall at the point load location of PE 2019-268 as tested in Lab 1 with Dehyton® PL + Genapol® LRO at 80 °C and 4 MPa.

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Table 1. Test results for one PE 100 grade (PE 2019-268) by three laboratories using Disponil® LDBS 25 and Disponil® LDBS 25 EVO at 80 °C for the accelerated point load test.

	Lab 1 Disponil® LDBS 25 EVO 80 °C (h)	Lab 2 Disponil® LDBS 25 EVO 80 °C (h)	Lab 3 Disponil® LDBS 25 80 °C (h)
PE 2019-268	2307**	1189	184
	1015**	3714	346
	2653**	1190	434
Average	1992**	2031	321
St. Dev.	863**	1458	127

*** Failed outside the point load area.*

RESULTS – VALIDATION OF THE METHOD ON PE 100-RC PIPES

For the sake of completeness, lab 3 tested two PE 100-RC pipe grades with Disponil® LDBS 25 at 80 °C and 4 MPa based on the results for PE 2019-268. Three tests were carried out to verify that failure would not occur within 2 months (1460 hours). It was found that:

- PE 100-RC type 1 has a failure time >5410 hours
- PE 100-RC type 2 has a failure time >4570 hours

It was indeed the case that none of the three pipes of either PE 100-RC type failed within the observation time. All pipes were cut in half after stopping the PLT.

For the PE 100-RC type 1 pipe (figure 10), only the deformation caused by the point load is visible. For the PE 100-RC type 2 pipe (figure 11), multiple craze initiation can be observed. A growing crack was even found in two cases, which justifies testing the desired failure mechanism of slow crack growth. The required minimum time to failure of 1460 h was clearly exceeded in both cases.

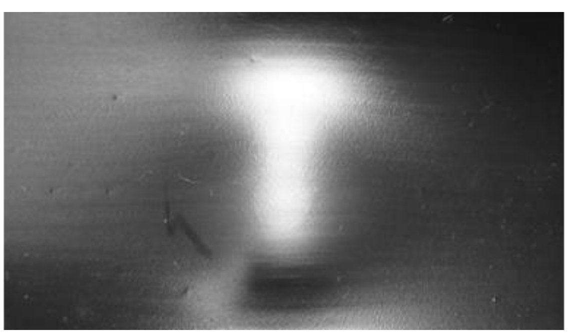

Figure 10. Inner pipe wall at point load locations of one PE 100-RC type 1 pipe as tested in Lab 3.

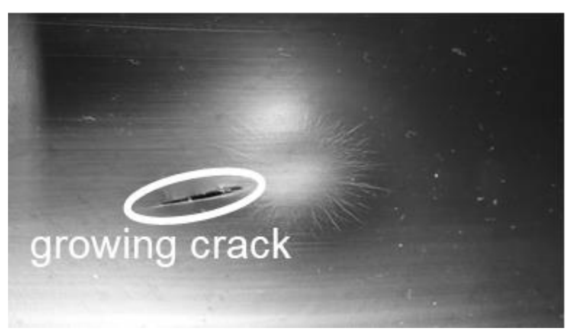

Figure 11. Inner pipe wall at point load locations of one PE 100-RC type 2 pipe as tested in Lab 3.

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CONCLUSIONS

The point load test (PLT) closely mimics real damage patterns in practice by simulating a rock pressing into a pipe. The aim of the project was to develop an accelerated point load test (aPLT) and to derive minimum requirements for pipes made of PE 100-RC, i.e., a minimum service life to be achieved under specified test conditions.

The first objective was therefore to determine the reproducibility of the conventional, non-accelerated point load test with Arkopal® N100 at 80 °C and 4 MPa. The results for two different PE 100 grades (PE 2019-266 and PE 2019-268) show little scatter within each laboratory. Differences between the three laboratories are in the order of magnitude that would be expected for comparable tests such as the creep rupture internal pressure test. Proposals to minimize the scatter have been drafted and incorporated into the latest version of the ISO test standard, which is currently under development (ISO/CD 22102:2020).

Following on from the first objective, the second objective was to develop an accelerated version of the point load test. Alternative detergents were investigated in accordance with the experimental plan originally envisioned: 2% lauramine oxide (6.67% Dehyton® PL) in lab 2, a mixture of 2% lauramine oxide (6.67% Dehyton® PL) and 3% lauryl ether sulfate (5% Genapol® LRO paste) in lab 1, and 2% benzenesulfonic acid (8% Disponil® LDBS 25) in lab 3. However, tests carried out on the two different PE 100 grades at 90 °C revealed problems, i.e., a lack of acceleration (Dehyton® PL) and failure appearing outside the point load range (for Disponil® LDBS 25 and Dehyton® PL + Genapol® LRO). Additional tests were carried out at 80 °C for the latter two to shift the failure to the point load range. Failure at the point load is crucial to ensure that the correct failure mechanism has been simulated. An acceleration factor of 6 compared to conventional point load testing was found for material PE 2019-268. No acceleration was found for PE 2019-266, however. Moreover, no acceleration was found using Disponil® LDBS 25 EVO in the other research laboratories (lab 1 and lab 2). It was not possible to definitively rule out that this was due to the small difference in the detergent, detergent batch variations or limited reproducibility (which may be caused by differences that arose because the test setup responded differently to the new detergent).

Taking the former results into account, the test setup in lab 3, which resulted in an acceleration factor of 6 for PE 2019-268, was used to investigate two different PE 100-RC grades to achieve the third objective. The required minimum time to failure (1460 h = 8760 h / 6) derived from the one-year (8760 h) criterion in conventional point load tests was clearly exceeded for both materials.

Despite the work of the three research laboratories, the failure behavior in the point load test proves to be very complex. A higher temperature (90 °C) appears to be unsuitable due to the increased probability of failure outside the point load range. Aside from the choice of lower temperatures (e.g., 80 °C), which usually leads to increased testing times, a reduction in the wall thickness in the point load range may also be a solution. Further activities should also address the choice of appropriate detergents, especially in the context of the problematic availability of Arkopal® N100. Coordination with similar activities for other standards would make sense in this regard. This should take account of the fact that any acceleration factor between conventional and accelerated point load tests should apply to all PE-HD materials of interest.

CONVERSION

80 °C = 176 °F
90 °C = 194 °F
4 MPa = 580 psi
110 mm ≈ 4"

ACKNOWLEDGMENTS

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