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THE REMAINING QUALITY OF THE PVC GAS GRID - RESULTS OF 10 YEARS OF ON-GOING RESEARCH

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SHORT SUMMARY
To prevent an enormous surge in the replacement costs of the Dutch PVC gas distribution grid a so-called Exit Assessment programme was started in 2004. This programme determines the actual quality of old excavated PVC-U and PVC-Hi pipes using a tensile-impact test at temperatures varying from -25°C to +47,5°C, whereby the brittle-ductile-transition-temperature is determined. With this research the average remaining quality of the Dutch PVC grid is determined. Also prioritizing pipe replacement becomes possible by distinguishing between pipe populations based on PVC-U types, diameter or installation year.

KEYWORDS
Polyvinyl Chloride (PVC)
Brittle-ductile-transition-temperature (T_{BD})
Remaining Quality Gas Grid
Prioritizing Replacement
Tensile-impact Test

ABSTRACT
This decade most of the PVC-U pipes used for the distribution of natural gas in the Netherlands will reach their initially specified lifespan of 50 years. To prevent an enormous surge in the replacement costs of these pipes, it is of increasing importance to determine the remaining material quality. Therefore a so-called Exit Assessment programme was started in 2004.

Field failure studies have shown that the lack of ductile behaviour during excavation damage is the most important reason for incidents involving PVC in the Netherlands. Therefore in this programme the quality of old excavated PVC-U and PVC-Hi pipes is determined using a tensile-impact test at temperatures varying from -25°C to +47,5°C, whereby the brittle-ductile-transition-temperature (T_{BD}) is determined.

With this research programme the average remaining quality of the Dutch PVC grid is determined. In this paper the relation between the diameter and the material properties are shown. Also the difference in the production quality of two PVC-U types in the early sixties of the last century is made visible. This knowledge gives the Dutch grid operators an opportunity to prioritize the replacement of old PVC-U pipes based on material quality instead of service time only.

Finally it is shown that through the years there has been a major improvement in the impact resistance of PVC. Well known of course are the improvements from PVC-U to PVC-Hi and latest PVC-O. However this research also shows that within

PVC-U itself the material quality has made a large improvement over the years, due to improvements in the production process of PVC-U.

INTRODUCTION

In the Netherlands, the distribution of natural gas takes place through approximately 77,500 km of PVC pipes, which make up over 60% of the Dutch distribution grid. Rigid PVC pipes (or PVC-U) account for 20,800 km, where impact modified PVC pipes (or PVC-Hi) account for 56,700 km [1]. Most of the PVC-U pipes were installed in the 1960s when the natural gas field at Slochteren, in the north of the Netherlands came in production. From the 1970s the transition was made to install more PVC-Hi. With the withdrawal of the Dutch test specification for PVC-U pipes in gas distribution, the usage of PVC-Hi became mandatory in 1974 [2]. PVC-Hi is still installed today for the distribution of gas.

To gain insight into the quality of the PVC pipes which are still in use today a so called Exit Assessment programme was started in 2004 [3]. This programme is supported and sponsored by Netbeheer Nederland and all Dutch Distribution System Operators (DSOs). In this Exit Assessment, the current quality of the existing Dutch PVC grid is determined by taking out samples from all over the Netherlands and testing those at Kiwa Technology. Trends and correlations are sought between the material quality and (topographic) data known at the DSOs. With those trends and correlations DSOs can prioritize their replacements better and prevent a replacement surge incurred by a predetermined lifetime prediction of exactly 50 years. In this paper the results are discussed which have been acquired with the improved tensile-impact test method.

EXPERIMENTAL SETUP

When trying to determine the remaining quality of a material it is important to look at its lifetime limiting failure mechanism. Field failure studies of fractured PVC gas pipes in the Netherlands have shown that a lack of ductile behaviour is the most important reason for incidents involving PVC pipes. Spontaneous failure hardly ever occurs in PVC pipes in the Dutch gas grid and most failures originate from third-party damage (i.e. caused by digging) [4]. If a PVC pipe fails, it is important that is does so with a ductile fracture, as brittle fractures result in larger gas outflows. Also repairing brittle fractures (e.g. when sawing) is more difficult and therefore slower. So brittle PVC pipes pose a greater safety risk, making embrittlement a limiting factor in the service life of PVC pipes. Therefore the ductility of the excavated pipes in the Exit Assessment programme is tested using a tensile-impact test.

Previously the ductility of the PVC pipes in the Exit Assessment programme were measured in accordance with ISO 13802 [5] at a degree of 5°C. This resulted in an average fracture energy at 5°C. Over time the experimental setup was improved by adding an extra cooling and heating device, see figure 1. Now the development of the fracture energy of PVC is measured between -25°C and +47,5°C. [6],[7]. This results in a so called brittle-ductile-transition-temperature (T_{BD}), see also figure 2.

Figure 1: Experimental setup: standard impact tester with added heating and cooling.

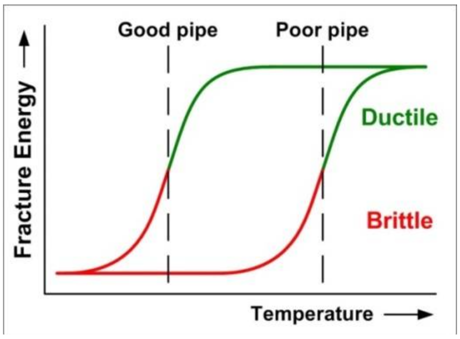

Figure 2: Schematic graph of the brittle-ductile-transition-temperature for a good and a poor quality PVC pipe.

This T_{BD} gives insight in the temperature at which a PVC pipe will break ductile or brittle as a result of for example excavation damage. This transition temperature can also be found by visually comparing the test bars of for example a good and a poor quality pipe, see figure 3A and 3B.

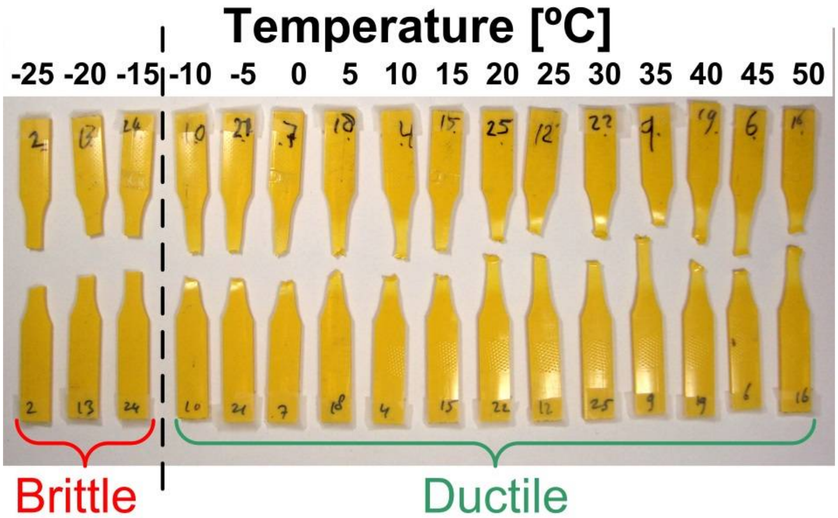

Figure 3A: test bars of a good quality pipe with a low T_{BD}.

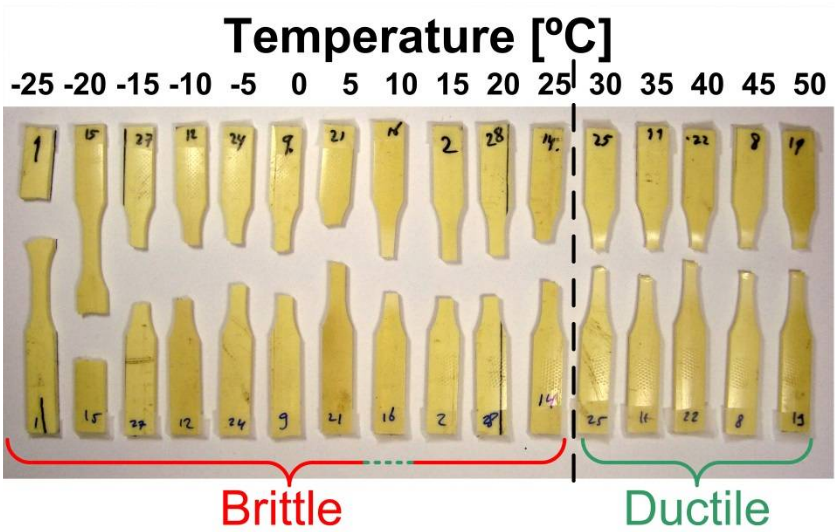

Figure 3B test bars of a poor quality pipe with a high T_{BD}.

From figure 3A and 3B it can be seen that left of the T_{BD} the test bars broke in a brittle way. On the right of the T_{BD} the test bars are broken in a ductile way. These ductile test bars show stress whitening and also a distorted fracture area. Furthermore elongation of the test bars is visible.

The result of measuring a PVC-U pipe with an average material quality is shown in figure 4. To determine the T_{BD} of a pipe, 30 test bars are tested at temperatures varying from -25°C to +47,5°C. The pipe shown in figure 2 has a T_{BD} of 8,75°C (solid vertical line). It can also be seen that the average fracture energy of the test bars in the brittle temperature range is 198,2 kJ/m² (dashed horizontal red line). The average fracture energy for the ductile temperature range is 599,9 kJ/m² (dashed horizontal green line). This means that pipes which break ductile also dissipate more energy before they break.

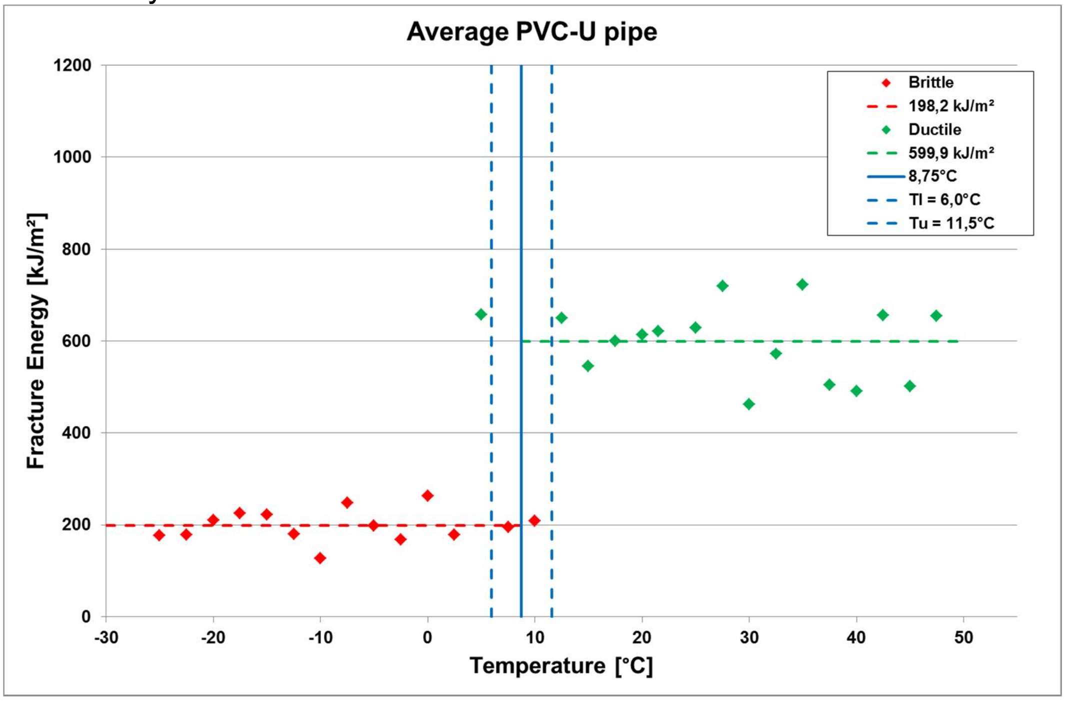

Figure 4: An average PVC-U pipe with a T_{BD} of 8,75°C.

DISCUSSED TRENDS IN THIS PAPER

For the Exit Assessment programme 103 pipes of both PVC-U and PVC-Hi have been tested with the improved test method so far. 100 of those follow the criteria of random selection and have been used for analysis. In this paper the trends as shown in figure 5 are discussed.

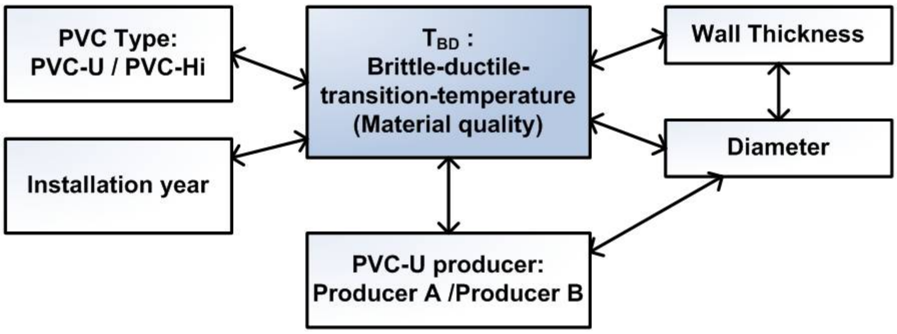

Figure 5: The trends discussed in this paper.

PVC-U AND PVC-HI

The experimentally obtained brittle-ductile-transition-temperatures of the 100 pipes are shown in figure 6, differentiated in PVC-U and PVC-Hi.

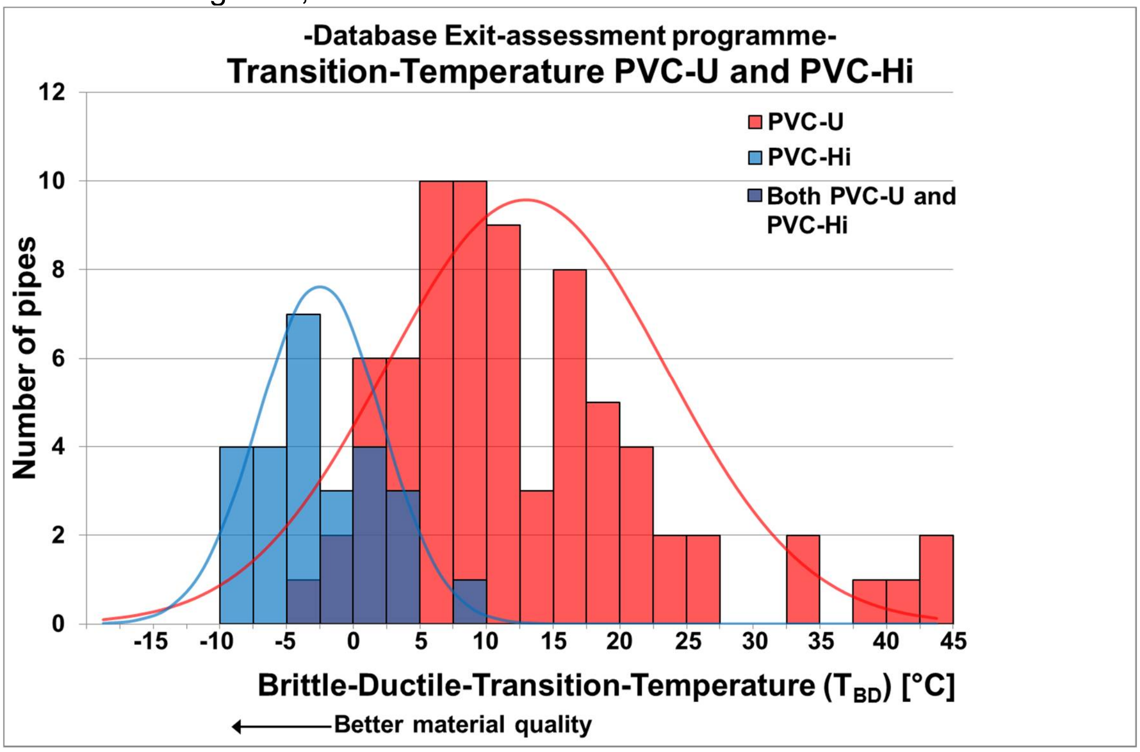

Figure 6: Histogram T_{BD} (brittle-ductile-transition-temperature) of PVC-U and PVC-Hi.

Of the analyzed pipes, PVC-Hi has an average T_{BD} of -2,5°C, with a standard deviation of 4,6°C. The average T_{BD} of PVC-U is 12,9°C with a standard deviation of 10,5°C. This confirms the more ductile behaviour of PVC-Hi, compared to PVC-U. It can also be seen that the best PVC-U pipes are as good as the average PVC-Hi pipes. At the moment more tests on PVC-U than on PVC-Hi have been performed, since the PVC-U programme started earlier. With more measurements on PVC-Hi in the future a more balanced picture will be seen.

DIAMETER AND WALL THICKNESS

To determine the possible relationship between the diameter and the T_{BD} figure 7 was created.

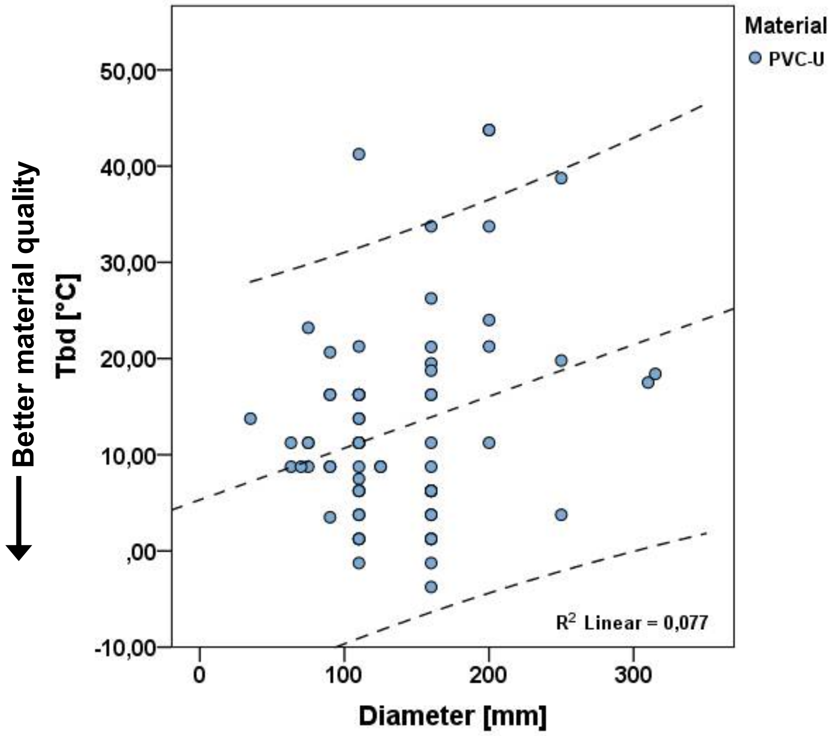

Figure 7: Trend between the brittle-ductile-transition-temperature (T_{BD}) and the diameter of old PVC-U pipes.

It can be seen that with larger diameters the T_{BD} seems to increase. It has to be noted that there is a large amount of scatter and also the linear R^2 is small. Further statistical correlation analysis however has shown that there is a significant positive correlation between the diameter and the T_{BD}. This is an indication that larger diameters of old PVC-U pipes[1] on average have less good material properties. Important to realize is that the larger diameters pipes often have thicker wall, see also figure 8.

It is probable that the on average poorer material quality of the old PVC-U pipes with larger diameters is connected to the thicker walls of those pipes. The higher T_{BD} can probably be led back to the production. Cooling of the inside of a thicker wall takes longer. Also the level of gelation during extrusion can vary between thick and thin walled pipes.

[1] For PVC-Hi there are not enough pipe samples available yet to perform the same analyses. With more PVC-Hi pipes tests in the future, the same analysis will be made.

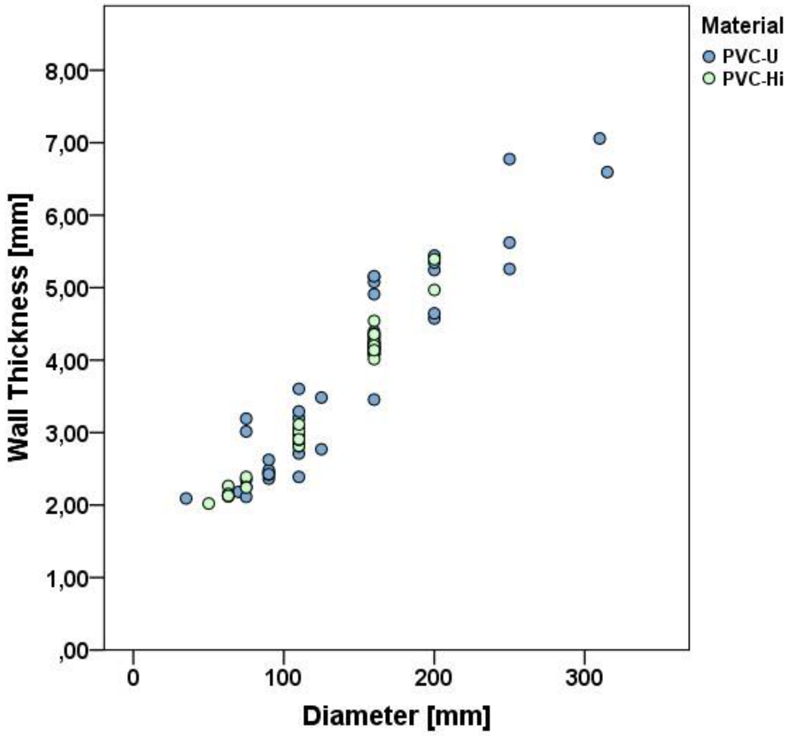

Figure 8: Wall thickness versus diameter of the analyzed PVC pipes.

PRODUCER

When also adding the component of producer another trend becomes visible, see figure 9.

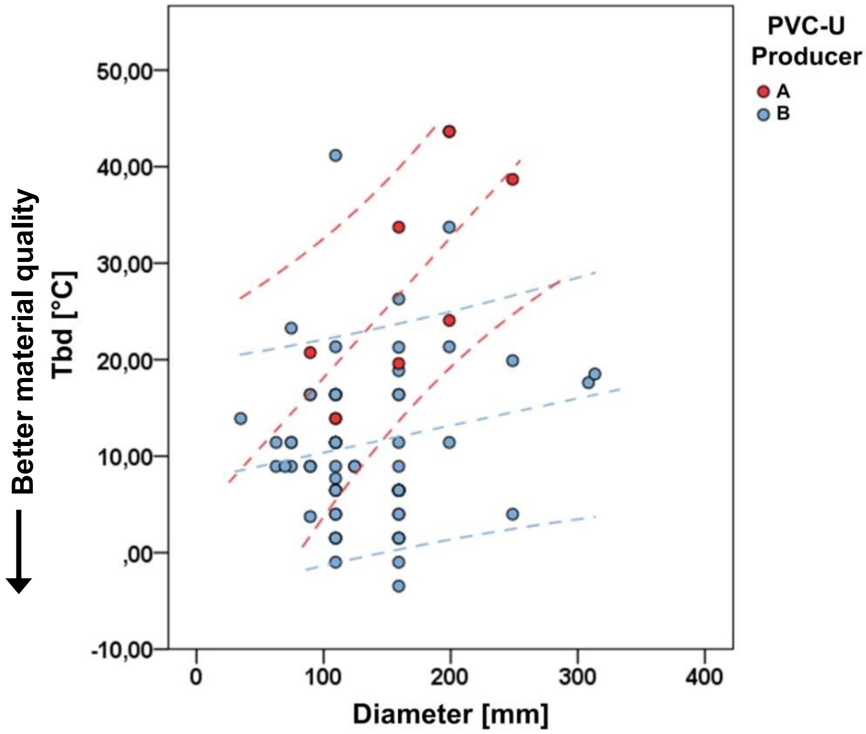

Figure 9: Brittle-ductile-transition-temperature (T_{BD}) of old PVC-U pipes versus diameter differentiated by producer.

Figure 9 presents the same data points as figure 7, but now also a distinction between producer A and B has been made. By adding the distinction between the producers, part of the scatter in figure 5 can be explained. It seems that the old PVC-U pipes of producer A have a steeper increase of the T_{BD} with increasing diameters than the pipes of producer B.
Finally it has to be noted that in an absolute way, thick walled pipes can take more energy before breaking than thin walled pipes. However if these pipes are hit with a surplus amount of energy, during digging for example, these pipes will more often break in a brittle way.

It is important to realize that with this method the distinction between the material quality of know PVC pipe populations can be made.
It is also important to realize that in this paper mainly old PVC pipes are discussed, which for marketing purposes might be less relevant. This information is very relevant for the Dutch Distribution System Operators however, since they can use this information for refining their replacement strategies of old pipes.

In figure 10 the T_{BD} of the old PVC-U pipes is plotted differentiated by producer.

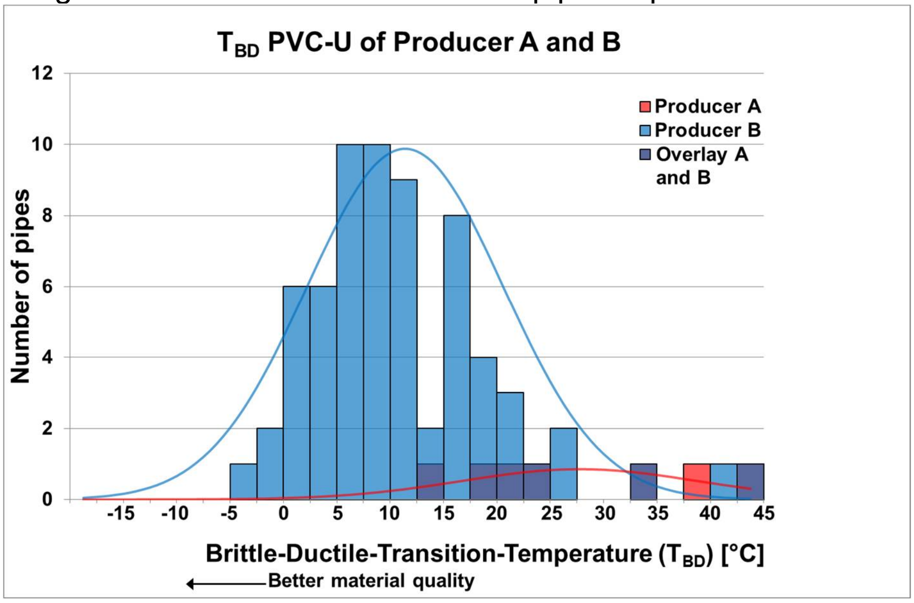

Figure 10: Significant difference in T_{BD} between old PVC-U pipes of producer A and B.

Although less pipes of producer A have been tested than producer B, the difference between the two populations is clearly visible. Statistical analysis confirms this, there is a significant difference between both populations. The old PVC-U pipes of producer A have on average a higher T_{BD}. In practice this means that the pipes of producer B will stay ductile at lower temperatures and therefore have a better resistance to impact at lower temperatures.

Important to mention is that these results only apply to old PVC-U pipes. It does not apply to pipes of PVC-Hi (both old and new). There is no significant difference between the quality of PVC-Hi pipes of producer A and B, see figure 11.

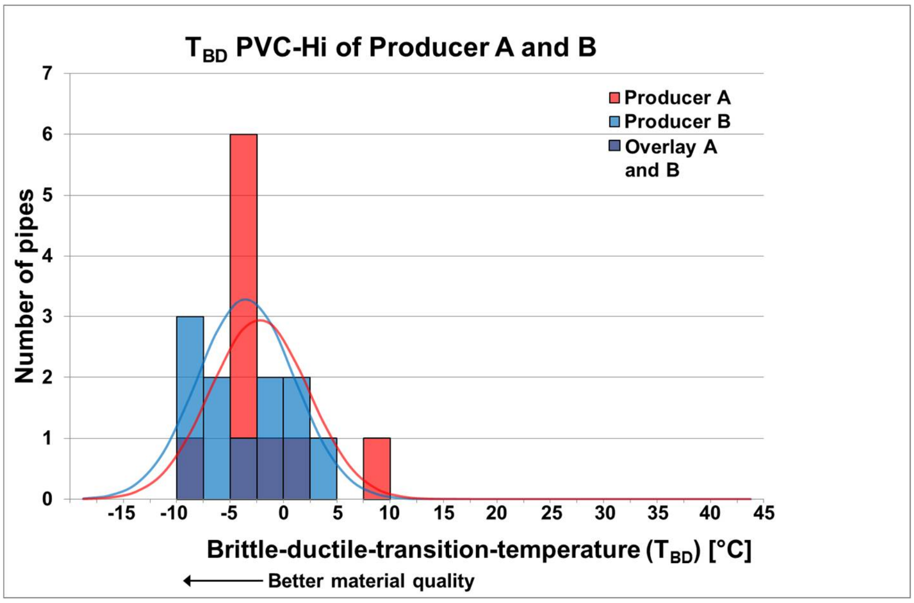

Figure 11: No significant difference in T_{BD} between old PVC-Hi of producer A and B.

INFLUENCE OF TIME

The influence of time (production date or installation date) on the material quality of PVC was made visible by plotting the T_{BD} against the year of installation in figure 12.

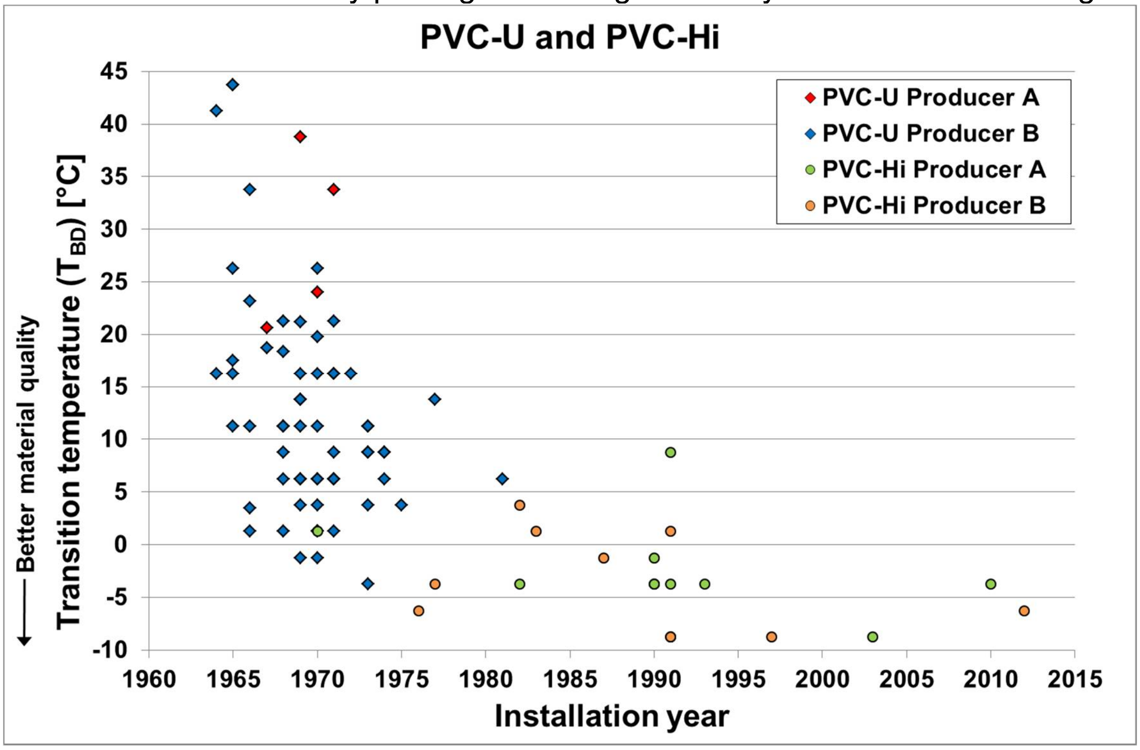

Figure 12: Brittle-ductile-transition-temperature versus installation year.

From figure 12 can be seen that the newly produced PVC-Hi pipes are of better material quality than the old PVC-U pipes. Also the conclusion is drawn that the PVC-U pipes themselves have improved over the time period in which they were installed. From 1974 it was not allowed anymore to install PVC-U in the Dutch gas grid, with the exception of 2 data points, this shift is clearly visible. The figure also suggests that the PVC material has actually been continuously improved over time. This is because the production process was continuously improved. One could still argue that figure 10 represents aging. From previous aging test in earlier research however, it was shown that almost no aging takes place during the installation time in the ground [8],[9]. The differences observed here are therefore better explained by improvements in production.

Replacement strategies based on installation year can therefore be recommended. Though not because pipes age in the ground, but because the quality of PVC gas pipes produced later in time is better.

CONCLUSIONS

Based on the previous the following conclusions can be drawn:

- The improved impact test (with added heating and cooling) is able to distinguish sub populations of PVC pipes in the Dutch gas grid, based on material quality. The DSOs can use this information to optimize their replacement prioritization.
- PVC-Hi has on average a better resistance to impact. However a well-produced PVC-U pipe can be as good as an average PVC-Hi pipe.
- In the Netherlands a significant material quality difference of old PVC-U pipes can be seen between two producers.
- A larger diameter and therefore a thicker pipe wall seems to negatively influence the material quality of PVC-U by elevation the T_{BD}. Especially pipes from one producer have this effect. Although pipes with ticker walls can dissipate more absolute energy they will break more often in a brittle way under a surplus of energy, occurring during mechanical digging damage.
- PVC pipes which are produced later in time have a better material quality, irrespectively who the producer was.

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REFERENCES

[1] Data received from Dutch gas Distribution System Operators (DSOs) over 2015.
[2] VGN announcement, Withdrawal test specifications for pipes of unplasticised PVC for gas pipes, GAS year 94, p78, (1974).
[3] R.J.M. Hermkens, *PVC Pipes in Gas Distribution*, PPXIV, Budapest, 2008.
[4] Netbeheer Nederland, *Storingsanalyse Nestor Gas 2015 (Dutch)*.
[5] ISO 13802, Plastics -- *Verification of pendulum impact-testing machines* -- Charpy, Izod and tensile-impact testing, 1999.
[6] J. Weller et al, *Tensile impact experiments of PVC-U at a wide range of temperatures*, Presented on Plastic Pipes XVI in Barcelona, 2012.
[7] J. Weller et al, *Plastic sheet material: an excellent protection of PVC pipes against UV-degradation*, Presented on Plastic Pipes XVII in Chicago, 2014.
[8] H.A. Visser, *Residual lifetime assessment of uPVC gas pipes*, PhD Thesis, University of Twente, Enschede, 2009.
[9] F.L. Scholten et al, *Residual quality of excavated UPVC gas and water distribution pipelines*, Plastic Pipes XVIII, Berlin 2016.

