ACCURACY ANALYSIS FOR CONFORMITY EVALUATION OF LIMIT VALUES. CREEP BEHAVIOR UNDER COMPRESSION OF BURIED PIPES, WITHOUT PRESSURE

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ABSTRACT

A buried plastic pipe undergoes vertical deformation after installation, which tends to stabilize after a period of time not exceeding two years.

The ability of the pipe to meet the limit of deformation under constant load is measured by compression creep test, being important to determine the creep factor correspondent to a pipe deformation of 2 years, obtained by extrapolation.

In this communication an assessment criteria for buried pipes, without pressure, based on the creep behavior under compression is established, taking in consideration the requests of the product standard and the accuracy of the experimental test results established by the evaluation of measurement uncertainties. Considering the non-linear behavior of the mathematical model adopted, measurement uncertainty estimates are obtained using a numerical simulation method (Monte Carlo Method).

Keywords: Creep / Buried structured wall pipes / Accuracy / Uncertainty / Monte Carlo

1. INTRODUTION

A buried plastic pipe buried undergoes deformation, immediately after installation (short-term), as a result of the imposed loads, and during the land settlement period (mid-term) [CEN, 2008] and as a result of the creep of constituent materials which increases over time. The magnitude of this deformation depends on pipe stiffness and on compaction degree of the trench fill material and, to a lesser extent, on other aspects also that also affect the quality of the installation [TEPPFA, 2015], but it has tendency to stabilize at the end of a certain time not exceeding two years [TEPPFA 2015] [CEN 2007], when the maximum deformation is reached, being subsequently retained for its potential life time, which can be over a hundred years.

There is thus an interest to determine the extrapolated creep factor at 2 years in pipes for buried applications, without pressure, by carrying out creep tests according to EN ISO 9967.

The standard EN 13476-3 requests, in its Table 15, that PE and PP pipes tested according to EN ISO 9967 provide creep factors, extrapolated for 2 years, with a value less than or equal (≤) to 4. The certification bodies include this test in its approval scheme and the acceptance or rejection of pipe batches, for product certification purposes, may depend on their creep behavior.

As the integer value "4" is not very explicit with regard to its accuracy, it is necessary to clearly define the acceptance threshold value, in order to clarify acceptable rounding.

Due to several reasons, it should refers to 4,0 and it is obvious that pipes exhibiting a creep factor not exceeding 4,0 complies with standard requests and should be accepted.

However, the requirement establishing a 4,0 limit value can't be justified if the decimal digit was not a significant figure. Indeed, if this digit is already affected by uncertainty, any value between 4.0 and 4.5, considering the respective errors is acceptable.

Thus it is very important to determine the accuracy of the test method to help a decision making about the criteria for acceptance or rejection of the pipes, introducing limit values for.

2. EXPERIMENTAL PROGRAMME

2.1 Materials and equipment

5 different polyethylene and 19 polypropylene sample pipes were tested, amounting to 72 test specimens prepared from new pipes SN8 (stiffness > 8 kN/m2), each result being given by the average of 3 replicates [CEN 2007].

All experimental work has been carried out using a Universal Mechanical Testing Machine Instron, Model 4467, with a 30 kN load cell capacity and Class 0.5 accuracy, at environmental conditions of (23 ± 2) ºC and (50 ± 5) % relative humidity. The test specimens were conditioned, at the normal environmental conditions referred to above, in the test room for at least 24 h.

Figure 1 shows the experimental installation with the equipment currently used for the creep tests.

Fig. 1 – Typical experimental assembly for creep tests: a) overview; b) detail of a specimen under test

2.2 Creep factor extrapolated for 2 years

The creep factor of each sample subjected to a diametrical compression test is given by the following expression [CEN, 2007]:

$$\gamma_i = \left[Y_{2i} \left(0.0186 + 0.025 \frac{y_{0i}}{d_i} \right) \right] \Big/ \left[y_{0i} \left(0.0186 + 0.025 \frac{Y_{2i}}{d_i} \right) \right] \qquad (1)$$

where γ is the creep factor, γ_0 is the value of initial deflection (t = 0 s), Y_2 is the value of the deflection extrapolated to 2 years and d_i the internal diameter of the pipe (where i is the specimen 1, 2 or 3 , to be tested.

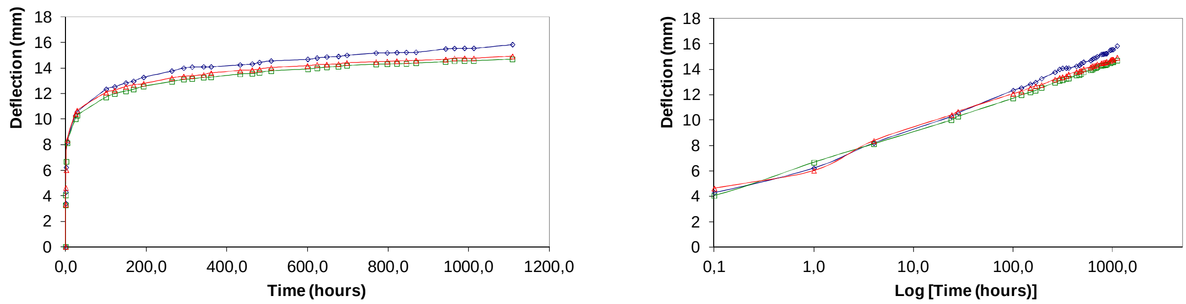
2.3 Results and discussion

Among the 24 samples tested, six had questionable values, ie with specimens showing a creep factor between 4.0 and 4.5, as shown in Table 1. The standard deviations indicated are rounded up.

Table 1 – Experimental values of dubious creep factor of pipes tested

Sample	Polymer	SN, kN/mm^2	DN, mm	Extrapoladed creep factor, $\gamma_{2,i}$				Experi-mental standard deviation	Average standard deviation
				Individual values			Average		
				$Y_{2,1}$	$Y_{2,2}$	$Y_{2,3}$	$\overline{y}_2$		
PE1	PE	8	315	4,1	4,1	3,7	4,0	± 0,2	± 0,1
PP1	PP		250	3,6	4,3	4,3	4,1	± 0,4	± 0,2
PP2			315	4,2	3,7	4,0	4,0	± 0,3	± 0,1
PP3			400	4,2	4,4	4,4	4,3	± 0,1	± 0,1
PP4			800	4,4	4,5	4,5	4,5	± 0,1	± 0,1
PP5			1000	3,7	4,1	4,2	4,0	± 0,3	± 0,2

The figure 2 illustrates a graphical representation of experimental results given by the deflection of a given sample pipe over time.



a) b)

Fig. 2 – Typical plot of the deformation of the pipe specimens during the creep test: a) normal scale; b) logarithmic scale

For the regression, the pipe deflection data sets selected were the points that allow a better correlation coefficient (i.e., closer to 1.0) [CEN 2007].

As the standard establishes $\gamma_2 \leq 4$ (instead of 4,0), there are doubts about the accuracy of the experimental results, because values below 4,5 may be rounded to the nearest whole number (ie, 4) [IPQ 2009].

Furthermore, when reporting the results of measured physical quantity, it is necessary to provide a quantitative indicator of the quality of results, in order to give some information about their reliability. Without such indication, it becomes more difficult to make an option.

For the accuracy of measurements, there are two important contributions: the standard deviation associated with the heterogeneity of the sample, and the uncertainty of the test. It should be realized what is the importance of each contribution for the accuracy of the results.

2.4 Accuracy and uncertainty analysis

The accuracy of the digit immediately after the decimal point can be put in question, since all instruments used in the test are obviously affected by error, which is subjected to spread during the measurement chain.

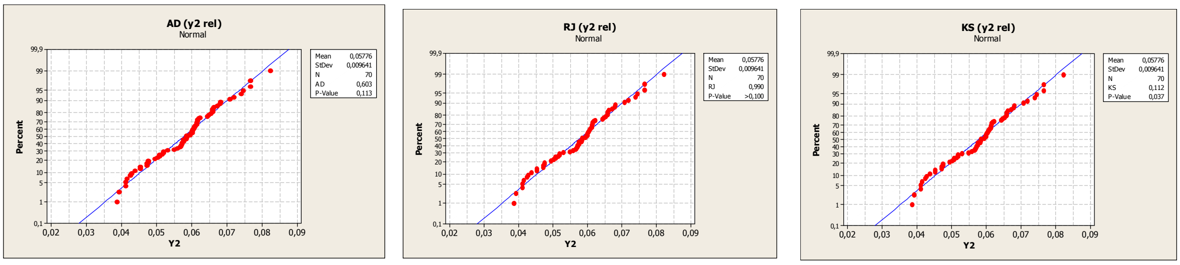
To calculate the uncertainty associated with the experimental determination of the creep factor, the Monte Carlo was adopted.

Aiming the application of a Monte Carlo approach, it is needed to start identifying the type of distribution of each of the variables of equation 1 (two input variables and one output).

The normality may be checked applying the methods of Anderson-Darling, Ryan-Joiner and Kolmogorov-Smirnov, or simply by normal probability plots and values of statistics for each measured variable within the 72 specimens tested, relatively to its pipe diameter.

The normal probability plots and p-values for Y_2 relative (= $Y_{2,i}/d_i$ of eq. 1, from now ahead identified as Y_2) are presented in figure 3

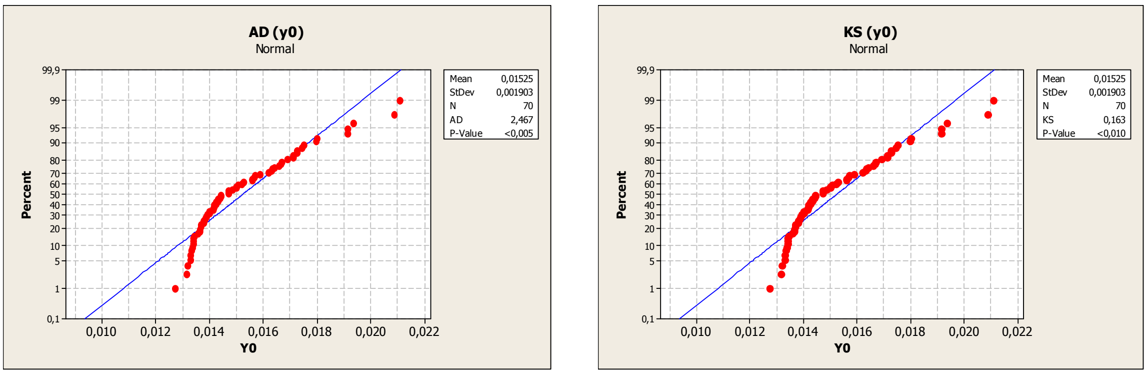
The way the data is near the straight line, the statistical values of RA and RJ and respective p's (greater than 0,05 and even 0,1) suggest normal, except for In the case of K-S test, where p-value (<0,05) leave some doubt.



a) b) c)

Fig. 3 – Normal probability plots for input variable Y_2 rel. according different methods: a) Anderson-darling; b) Ryan-Joiner; c) Kolmogorov-Smirnov

The normal probability plots and p-values for Y_0 relative ($=Y_{0,i}/d_i$ of eq. 1, from now ahead identified as Y_0) are presented in figure 4



a) b)

Fig. 4 – Normal probability plots for input variable Y_0 rel. according different methods: a) Anderson-darling; b) Kolmogorov-Smirnov

The correspondent histogram (figure 5) confirms a non normality behavior for the input variable y_0.

The tests using 14 distributions and two variable transformations (figures 6 to 9), showed that the distribution that best fits the data for Y_0 is the lognormal (figure 9).

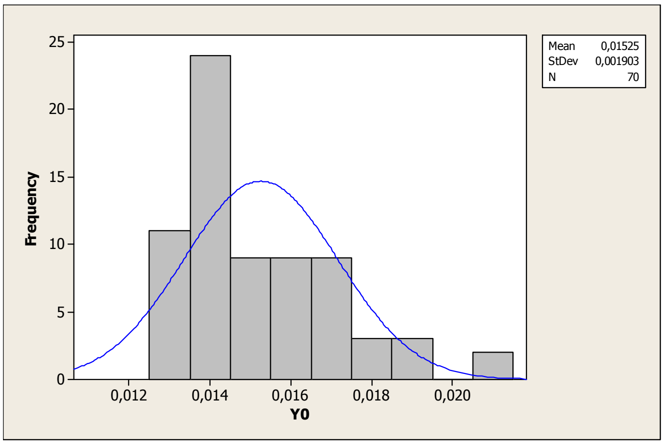


Fig. 5 – Histogram for input variable Y_0 revealing a distribution skewed to the right (skewness > 0) and a narrower peak than would be expected from a normal distribution (Kurtosis > 0).

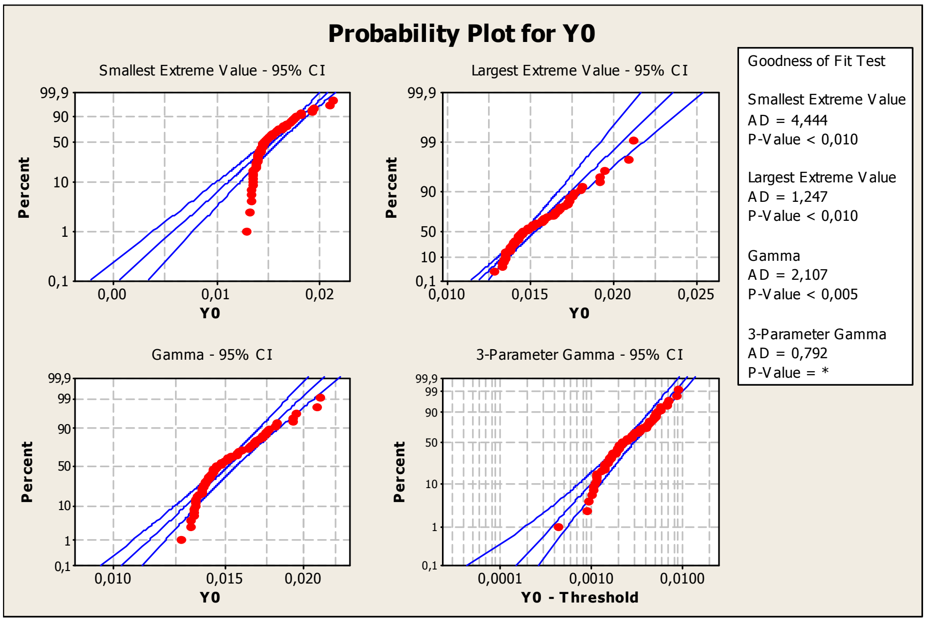


Fig. 6 – Smallest extreme value, largest extreme value, gamma and 3-parameter gamma are no good distributions fits for Y_0

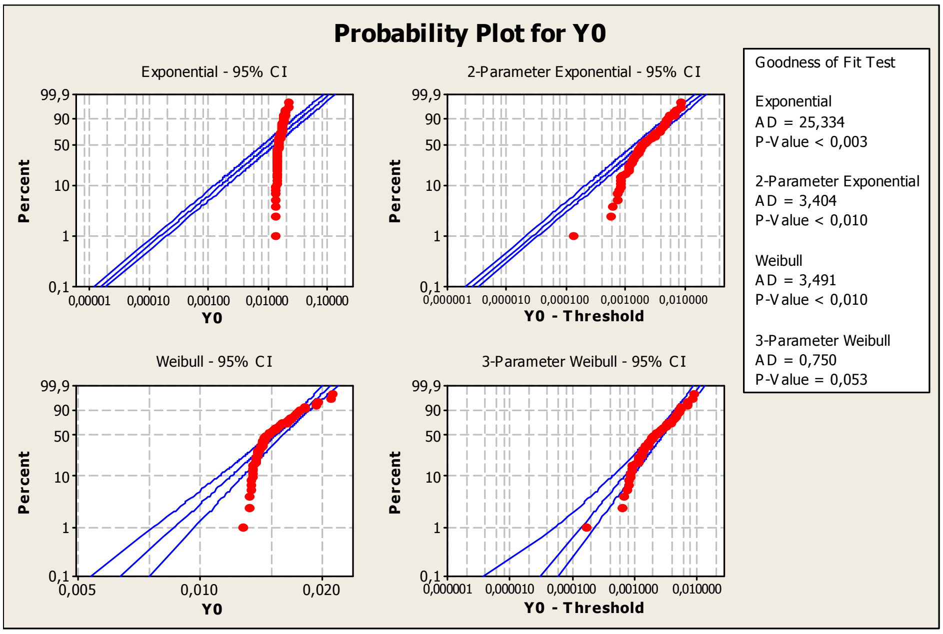


Fig. 7 – Exponential, 2-parameter exponential, Weibull and 3 -parameter Weibull are no distributions good enough for fitting Y_0

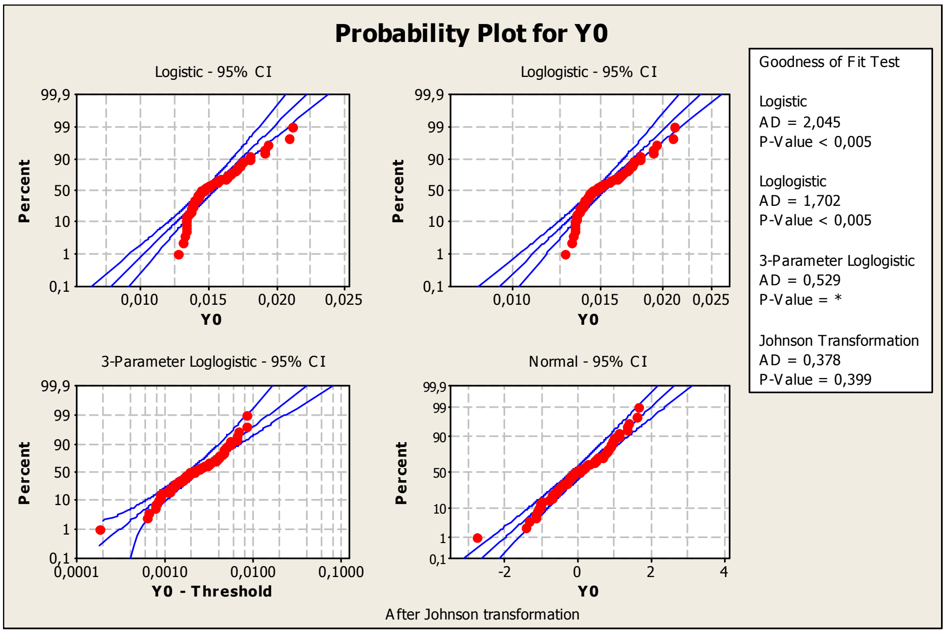


Fig. 8 – Logistic, loglogistic, 3-parameter loglogistic are no good distributions for fitting Y_0. However, after Johnson transformation (function 7,12379 + 1,15662 * Ln(Y_0 - 0,0125307)) the transformed Y_0 follows a normal distribution (showing only one outlier).

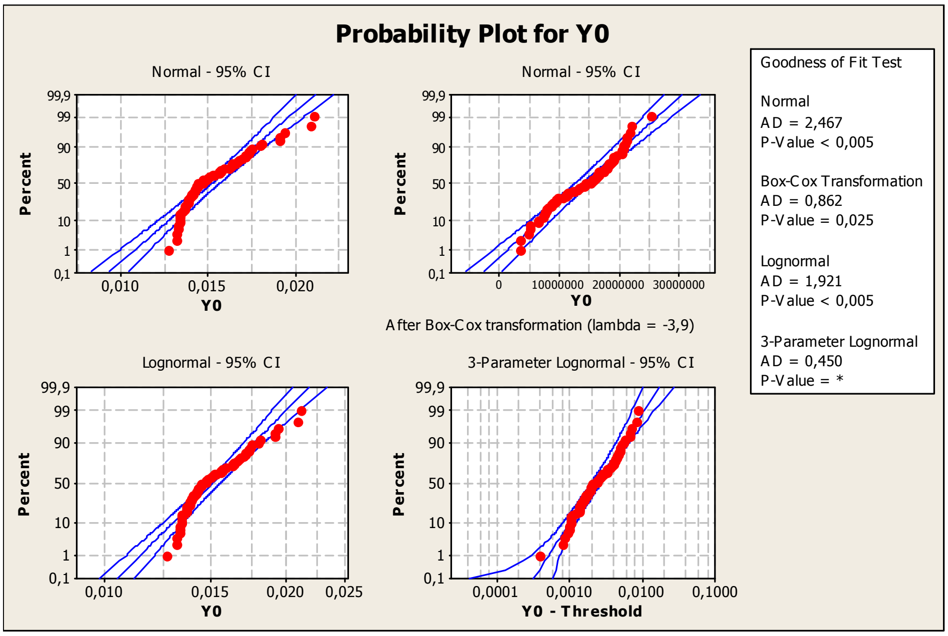
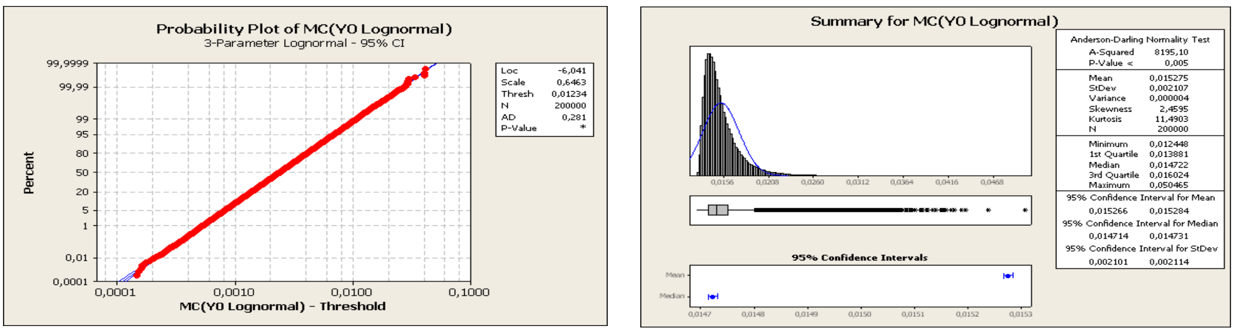


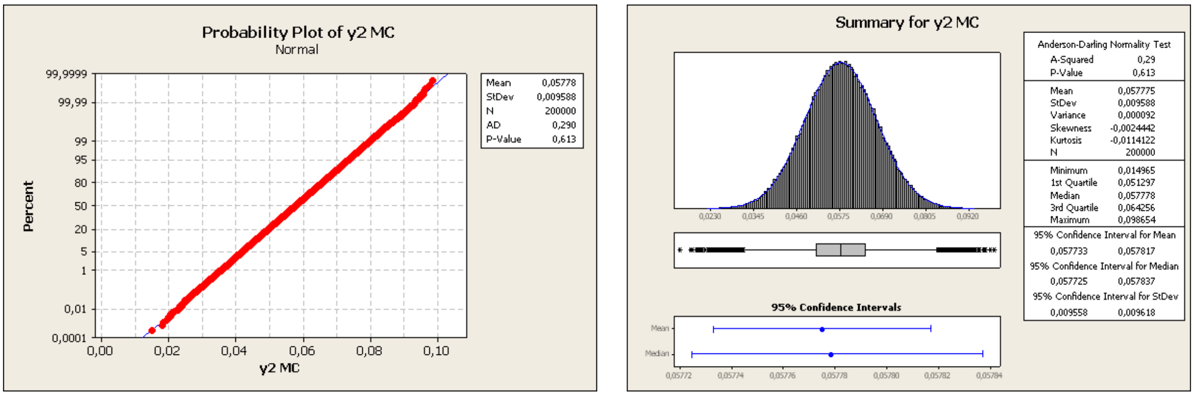
Fig. 9 – Normal and lognormal or even Y_0 after Box-Cox transformation are no good distributions for fitting Y_0. However, a 3-parameter lognormal fits well a straight line for Y_0.

Using the Monte Carlo method, a set of 200000 data points, following the selected distributions were simulated. The input variable Y_2 were simulated for a normal distribution, based on original average value (0,0578) and standard deviation (0,0096), and Y0 with lognormal 3 parameters location, scale and threshold determined on best fit (figure 9) with values -6,04001, 0,64691 and 0,01234 respectively. The normal probability plots of the input variables with the simulated values and summary graphs of the results of the Monte Carlo simulation are shown in figures 10 and 11.



a) b)

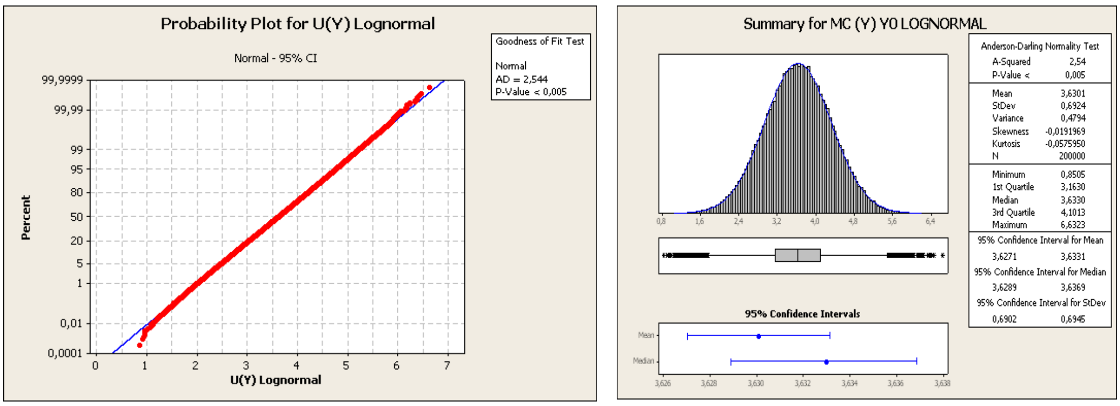
Fig. 10 – Monte Carlo simulation of Y_0: a) normal probability plot (lognormal); b) summary statistics



a) b)

Fig. 11 – Monte Carlo simulation of Y_2: a) normal probability plot (normal); b) summary statistics

Finally, applying the formula of Eq. 1, 200000 Y output data points are calculated from the Monte Carlo simulated input variables (Y_0 MC and Y_2 MC). The normal probability plot of the simulated output variable and respective summary graph statistics are presented in figure 12.



a) b)

Fig. 12 – Monte Carlo simulation of Y: a) normal probability plot (lognormal); b) summary statistics (y ≈ 3,6 ± 0,7)

3. Conclusions

It is shown that uncertainty of Monte Carlo simulated creep factor is very significant (approximately 0,7).

The uncertainty of the creep factor, determined by GUM approach showed a value of 0,4 [Real, 2016], a little different from that was obtained by Monte Carlo approach.

Although these differences, requiring further analysis, it should be assumed that the decimal digit of the calculated creep factor is not a significant digit, because it is probably affected by uncertainty.

In short, for acceptance and rejection of pipe lots based on values determined for the creep factor extrapolated to 2 years, it is proposed the following expeditious criteria:

— Pipe samples that have a creep factor with a value no greater than 4,0 in all specimens and an average value also not higher than 4,0, should be accepted.

— Pipe samples whose creep factor (value given by the average of values obtained in several test specimens) is not greater than 4,0 but at least one of the sample specimens presents a creep factor exceeding the allowable limit for immediate acceptance (4,0), require a repeated testing in 3 new samples taken from the same batch. If it gets a similar result, thus the sample should be rejected.

— Pipe samples having a creep factor with a value greater than 4,5, should be immediately rejected, without further analysis.

— Pipe samples showing a creep factor with a calculated average value between 4,1 and 4,5, should not be immediately rejected without further analysis. In such cases, the test should be repeated on three new samples taken from the same batch, the acceptance criterion being dependent on new results. The decision of acceptance or rejection of values in the limit zone, can be supplemented with the analysis of the standard deviation and eventually of the uncertainty, and the criteria established can be modified accordingly[1].

The conclusions of this work, which proposes an evaluation criterion for acceptance and rejection of pipes, are illustrated in the schematic flow diagram shown in Figure 14.

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[1]: For example, the decision maker may consider that a pipe having a creep factor greater than 4,5, accounted for the positive values of the experimental standard deviation and uncertainty of the test, must be rejected as non-compliant.

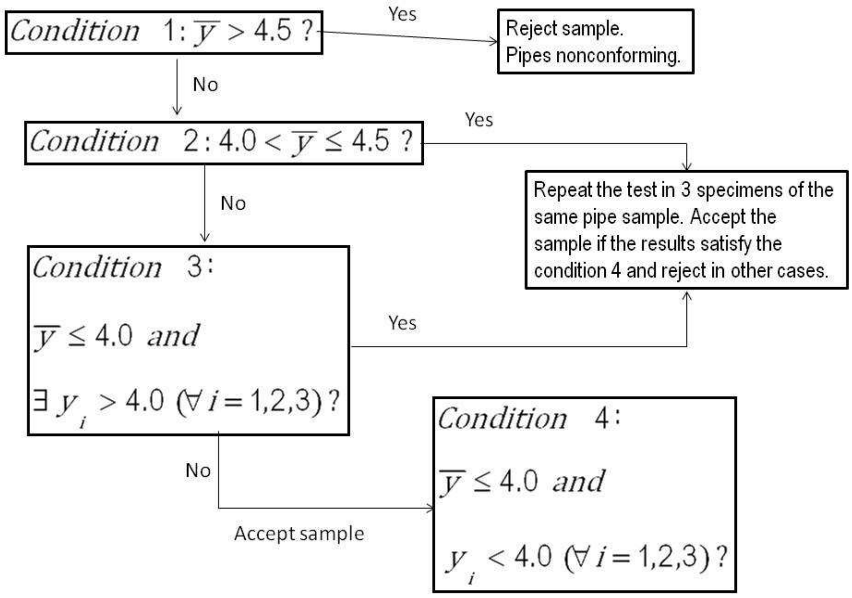

Fig. 14 - Schematic flow chart of the evaluation criteria for acceptance and rejection of buried polyolefin pipes based on creep factor

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