Long-term behaviour of GRP pipes

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Abstract

The main objective of the research programme [1] described is the study of creep and relaxation behaviour of glass-reinforced thermosetting (GRP) pipes, in order to find alternative methods to predict the long-term properties, rendering a considerable reduction of the time needed for testing and assuring, as far as possible, equivalent reliability when compared to the existing methods.

Experimental procedures were performed and are presented here, together with discussion of results, as well as predictive methodologies studied.

Introduction

The product life cycle of GRP pipes, used on water supply or sewerage systems, is expected to be around 50 years (or more). Once these structures are to be exposed to complex service environment conditions for diferent combinations of stress, time, temperature, moisture, radiation, chemical, and gaseous environments, the lack of confidence in the prediction of the residual properties in a long-term basis leads to over-design and in-service prototype evaluations and, furthermore, inhibits greater utilization.

Composite materials are systems of two or more materials, in a way that the response is more than the simple addition of individual responses. This introduces complexity and non-linearity, demanding the development of new models to predict long-term properties.

GRP materials exhibit a time dependent behaviour as a consequence of its polymeric matrix viscoelastic nature. Their constitutive equations are, usually, a combination of viscoelastic and viscoplastic models. This time dependent behaviour is studied by three different test methods:

- Initial failure strain tests
- Creep Tests
- Relaxation Tests

By being mostly designed either for gravitational or pressurized transportation of fluids, these GRP pipes are tested under ring deflection and/or internal pressure conditions.

One limitation of the existing methods is the implicit assumption that the mechanisms responsible for the long-term material failure are the same at different levels of load. The failure mechanisms originated by these new methods should be as close as possible to the existing ones in real service conditions. So, it is intended to develop damage phenomena similar to those that lead to long-term loss of integrity and failure.

On this research work, linear and non-linear viscoelastic behaviour models will be, later on, presented. The identification of the model behaviour parameters, based on experimental data analysis, requires a powerful inverse numerical procedure. However, its behaviour is not deterministic due to modelling uncertainties (laws, parameters) and verified material variability. The approach to evaluate confidence level is based on failure probability calculations [2]. A comparison will be made with an approach based upon current standards (EN 705 [3]). An attempt will be made to see the validity of the application of a modified Reiner-Weissenberg criterion on creep rupture prediction [4].

Experimental Programme

The initial failure strain tests were performed, according to EN1226:1999 which describes a method for testing the ability of glass-reinforced thermosetting plastics (GRP) pipes to withstand specified levels of initial ring deflection without displaying surface damage and/or structural failure. Figure 1 shows the test apparatus based in an universal testing machine.

(Figure 1 – Initial failure strain test apparatus)

Five test specimens DN500, SN10.000 (supplier C), were used within this experimental procedure. They were subjected to a deflection sequence as one can see in Figure 2 (thick line).

Figure 2 also shows the ring reaction force evolving during the tests, where deflection was the controlled parameter as pointed before. In Figure 3, one can see the strain *vs* time curves obtained during these tests.

(Figure 2 – Evolution of reaction force with increasing deflection)

(Figure 3 – Evolution of circumferential strain with increasing deflection)

The creep tests conducted intended to determine, by extrapolation, the long-term ultimate relative ring deflection of GRP pipes in wet conditions. These were done with the specimens (supplier C) in a submerged condition with water at room temperature,(see Figure 4) and the diametrically applied force as the controlled and fixed parameter. Different loads have been applied to different test tubes.

(Figure 4 –Designed test machine for creep tests in a ring deflection condition)

Figure 5 shows the deflection evolution until failure occurrence in a log-log scale.

Relaxation tests, in a ring deflected condition were also performed in several specimens from different manufacturers (suppliers A, B, C and D). The setup for these tests is showed in Figure 6.

(Figure 5 - Relative ring deflections increasing during test time)

(Figure 6 - Setup apparatus for ring relaxation tests)

Test pieces used for determining the stress relaxation in a ring deflection condition after saturation were pre-conditioned under water at 50 ºC for 1000 hours.

Figures 7 and 8 show some relaxation curves, obtained for different specimens (different manufacturers) and test conditions as well.

(Figure 7 - Reaction force relaxation behaviour of different specimens submitted to a 11,5% relative ring deflection condition after pre-conditioning of 1000h under water at 50ºC)

(Figure 8 - Reaction force relaxation behaviour of a DN500 SN5000 specimen (supplier B) subjected initially to 21,50% of relative ring deflection and then to 26,60% up to 3000h of test duration (with no pre-conditioning))

Discussion of Results

Data obtained in tests carried out for initial failure strain show an expectable drop of load at each deflection level. However, relaxation tests confirmed that this behaviour tends to be less significant (for most types of GRP pipes) as time increases maintaining the specified level of ring deflection. The reaction force of the specimens appeared to stabilize with time and a clear shape of the curve *load vs. time* could not be obtained in most of the tests despite of being conducted for 1000h and more.

We are also able to say, with the help of acoustic emission monitoring conducted in some of the relaxation tests procedures, that damage mechanisms (matrix cracking), even being detected at initial period of relaxation tests, is not relevant in the long-term structural perspective for the specified levels of relative ring deflection to impose to the test pieces once there are no fibres rupture.

In creep tests these GRP pipes have shown a similar rate of deflection, although being differently charged. Different initial relative ring deflection was detected for different values of load applied (see Figure 9). So, such tests, in which curve scatters were found, make one feel the difficulty in reliably reduce test durations, using the available probabilistic and regression analysis.

One may notice, however, that for each initial relative ring deflection achieved (despite of the correspondent applied load), the mid and long-term behaviour on increasing deflection rate is quite regular, as one can see in results shown in Figure 5.

(Figure 9 - Scattering of initial relative ring stiffness of specimens of same type and manufacturer)

Prediction approach

The existing methods do not take into account a fundamental characteristic of the influence of liquid environment: the slow liquid diffusion at room temperature. Depending on the material’s composition and the thickness of the pipe wall, the specimen saturation can only be obtained after several months. Hence, only the results achieved after several thousands of hours show the influence of the liquid environment [4].

Statistical techniques for data analysis of destructive tests were investigated during last decades. Many of these simple techniques required the logarithms of the data to

a) be normally distributed;

b) produce a regression line with negative slope;

c) have a sufficiently high regression correlation.

When fulfilling the last two conditions, the first one is considered to be unsatisfied. Further investigation resulted in the adoption of the covariance method to treat those tests which present skewed distributions of data [3].

The results from non-destructive tests, such as creep or changes in deflection with time, often satisfy the three conditions and so, in that cases simpler procedures can be used. So, EN 705 [3] specifies procedures suitable for the analysis of data which, when converted into logarithms of the values, have either a normal or a skewed distribution.

The extrapolation using these techniques typically extends the trend from data gathered over a period of approximately 10000h, to a prediction of the property at 50 years.

Methods A and B, described in that document, are to be used to fit a straight line of the form

$$y = a + b \times x \tag{1}$$

where:

y is the logarithm (log) of the property being investigated;

a is the intercept on the y axis;

b is the slope;

x is the logarithm (log) of the time, in hours.

Method C is used to fit data in a second order extrapolated curve.

As said before this involves an implicit assumption that there are no relevant damage mechanisms appearing only after several thousands of hours of in service applications.

So, besides the description of the new alternative test methods, together with a theoretical support, different extrapolations methodologies will be discussed and their validation assessed up to the time scale of the tests done so far.

Conclusions

In GRP's, relaxation and/or creep may induce damage phenomena such as fibre and/or interface rupture. The progressive loss of mechanical properties may lead up to loss of structural integrity (delaminating, cracking, etc).

The fluid effects in the material influence, in a quite distinct way, the data obtained at different times of testing and this circumstance increases the scatter of the data to be used in the extrapolation. This aspect introduces some disturbance in the expected shape of the regression curve.

Other aspects, such as the unstudied possibility of damage initiation in a relevant form, eventually leading to unexpected structural failure, after several months of application *in situ*, make us notice the importance of develop related investigation on damage phenomena.

Reducing these curve scatters by modifying methods and/or procedures have been strong lines in the last research developments. But other interesting points of research, such as accelerating techniques, reliable probabilistic analysis and analytical numerical modeling must also be accounted for.

References

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Figures (by order of appearance in text)

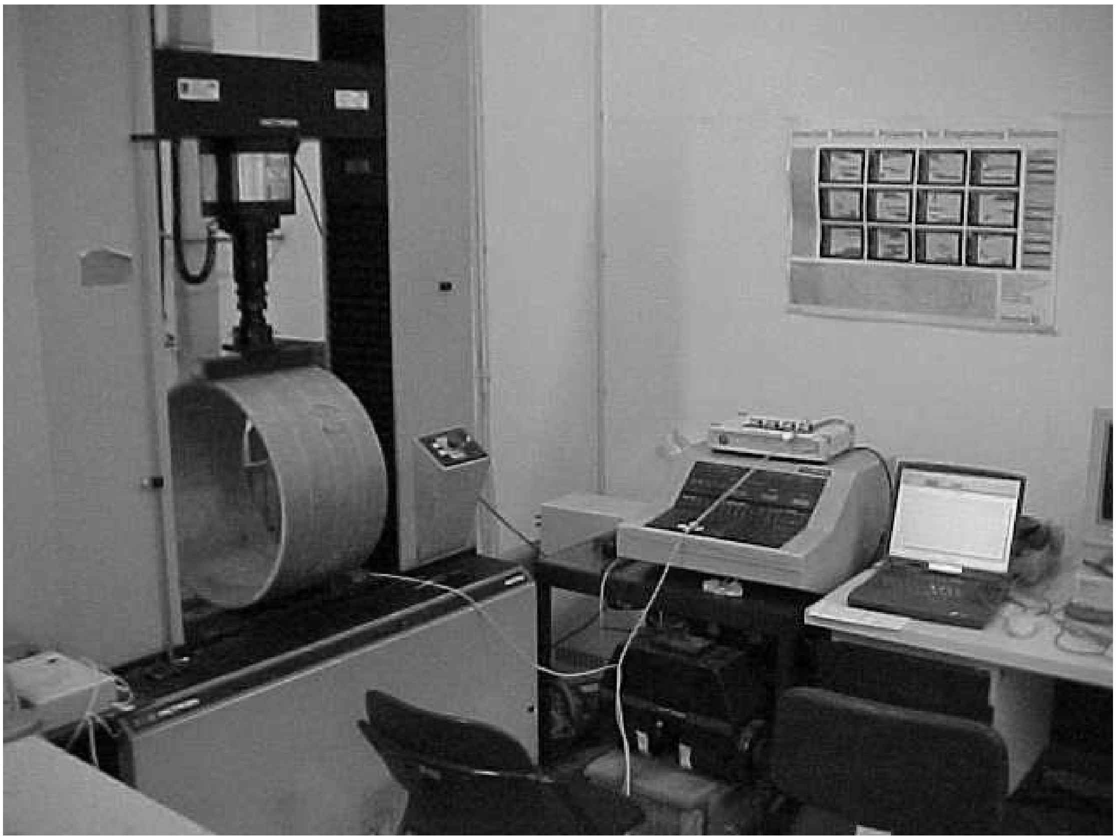

Figure 1 – Initial failure strain test apparatus

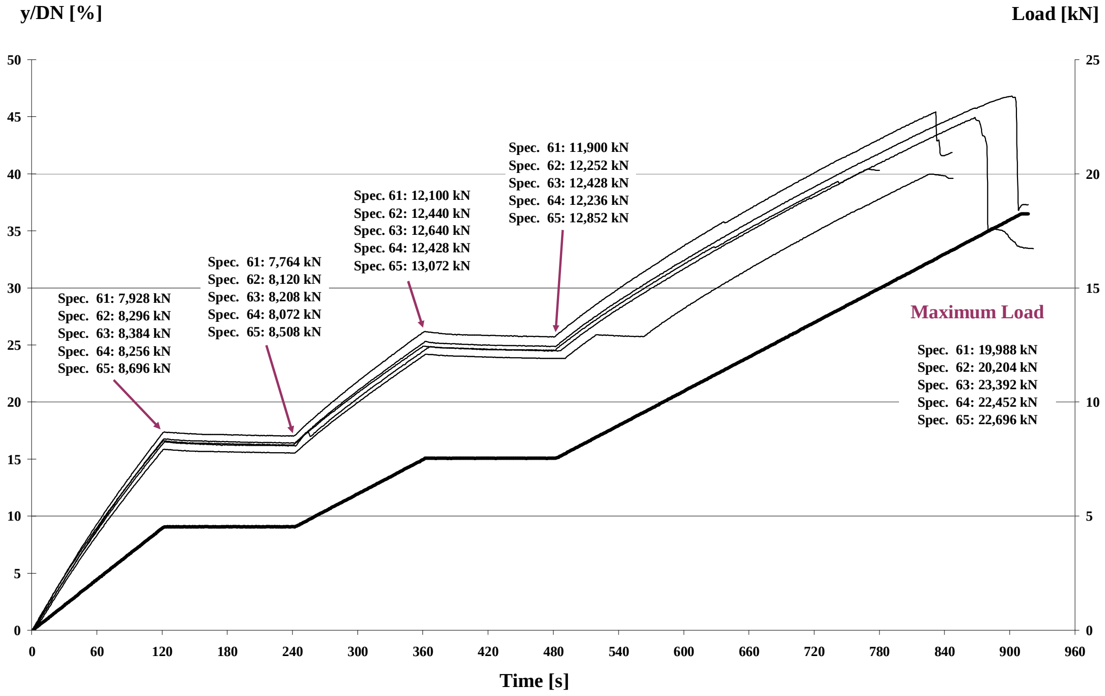

Figure 2 - Evolution of reaction force with increasing deflection

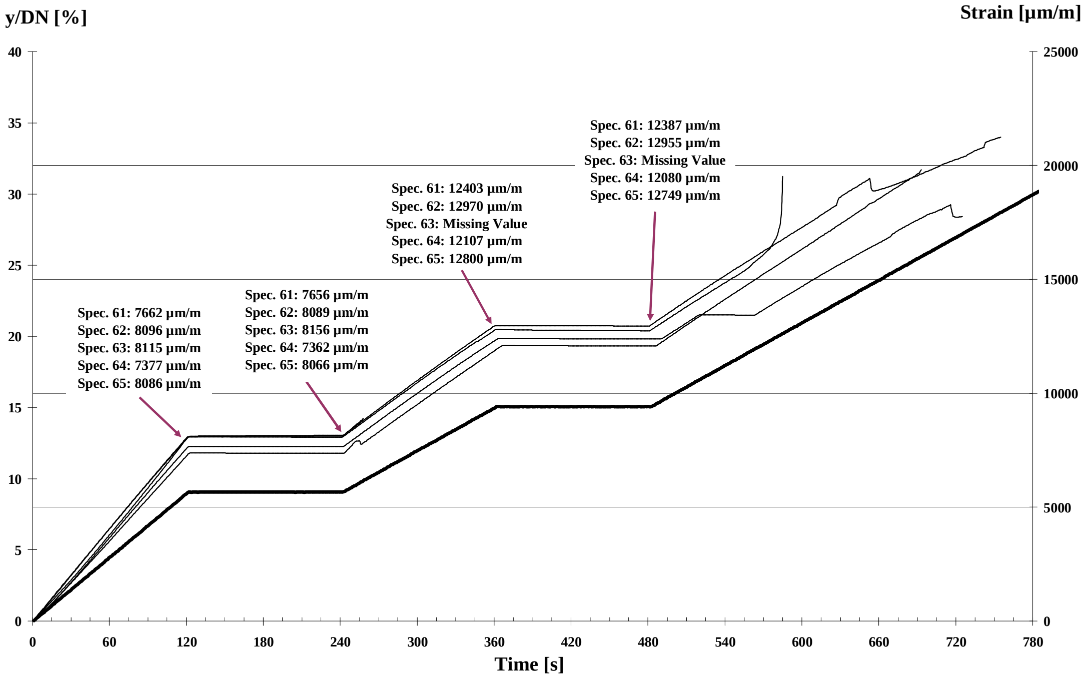

Figure 3 – Evolution of circumferential strain with increasing deflection

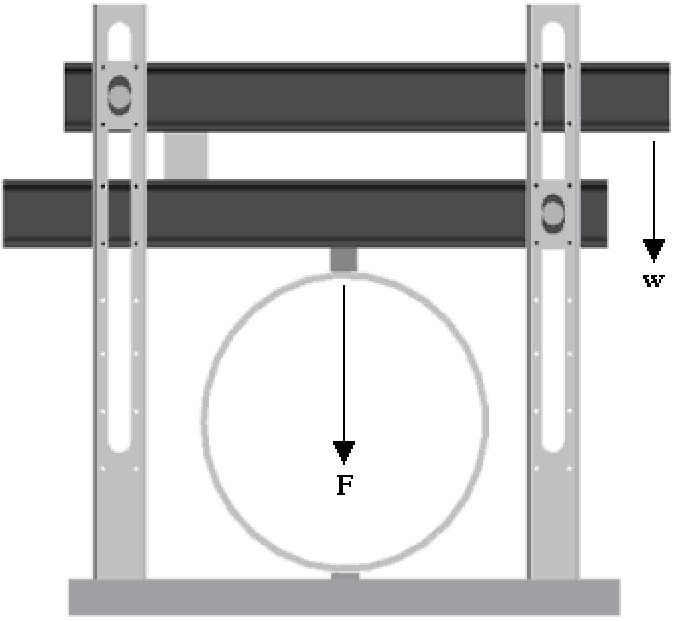

Figure 4 – Ring deflection test machine

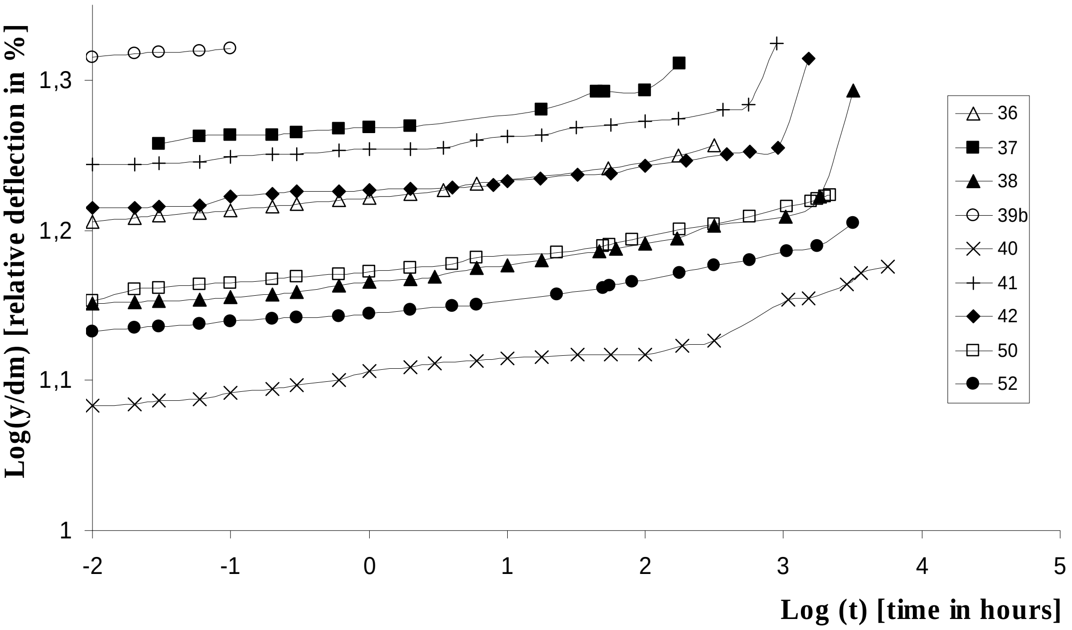

Figure 5 – Relative ring deflections increasing during test time

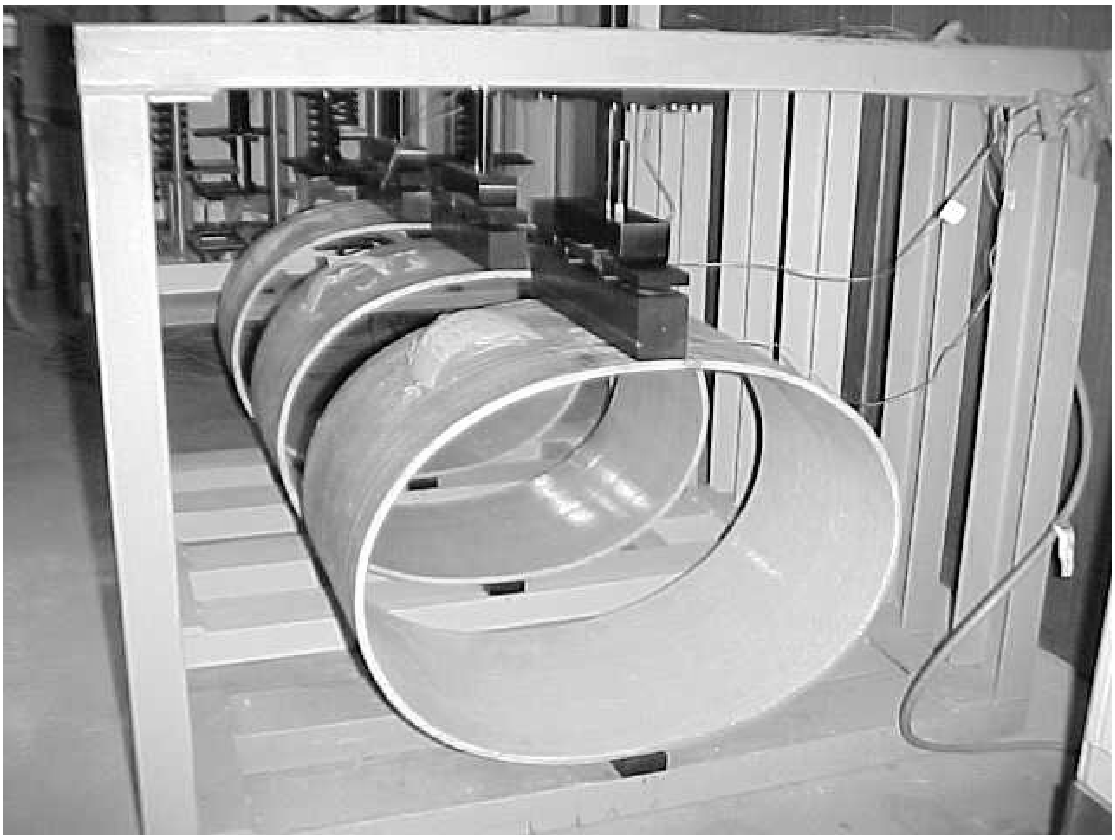

Figure 6 – Setup apparatus for ring relaxation tests

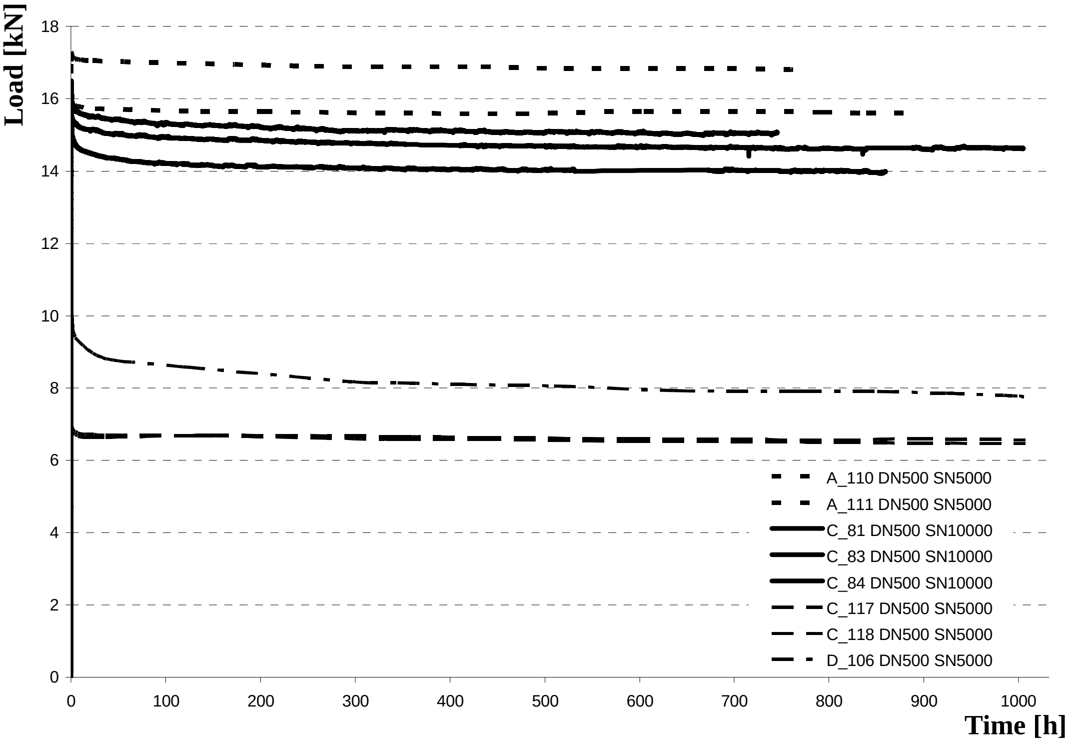

Figure 7 – Reaction force relaxation behaviour of different specimens submitted to a 11,5% relative ring deflection condition after pre-conditioning of 1000h under water at 50ºC

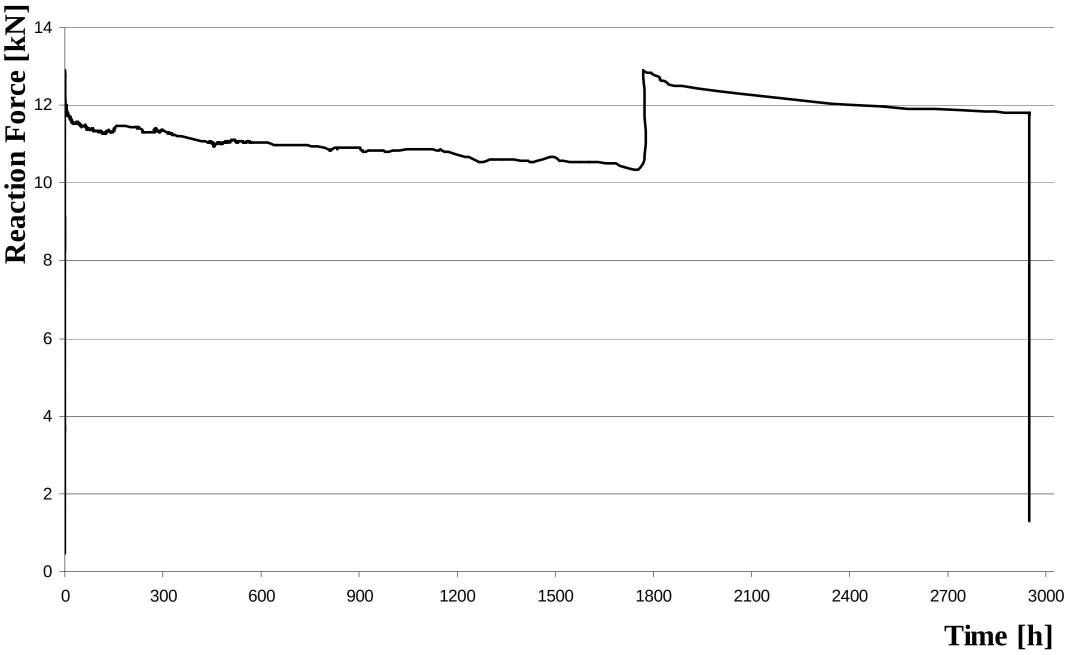

Figure 8 – Reaction force relaxation behaviour of a DN500 SN5000 specimen (supplier B) subjected initially to 21,50% of relative ring deflection and then to 26,60% up to 3000h of test duration (with no pre-conditioning)

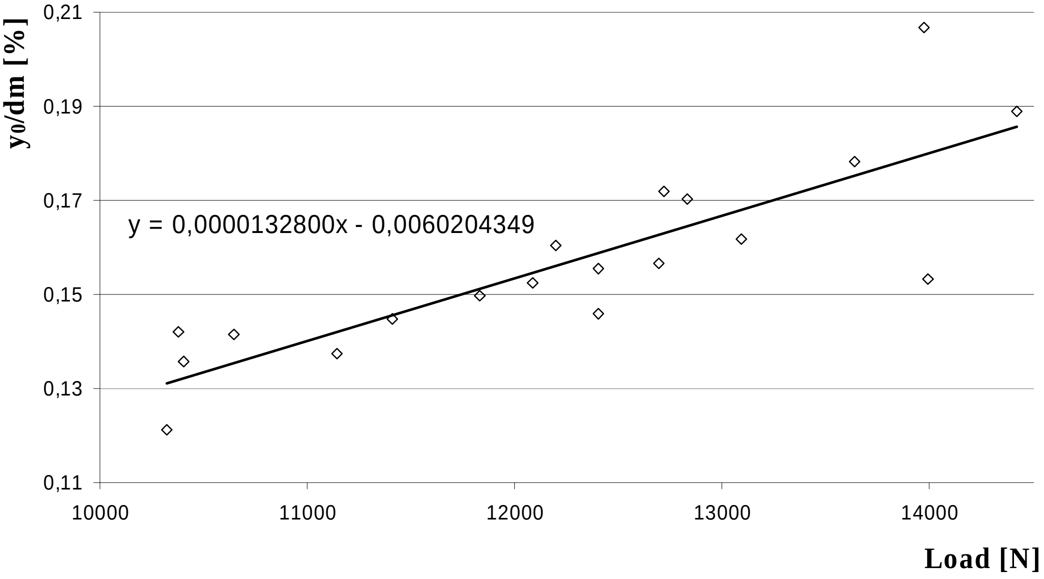

Figure 9 – Scattering of initial relative ring stiffness of specimens of same type and manufacturer