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EFFECTS OF SOIL pH ON MECHANICAL PROPERTIES OF GLASS REINFORCED PLASTIC PIPES

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Abstract

Influence of soil pH on the mechanical characteristics of glass reinforced plastic (GRP) pipes type was often investigated in different situations encountered in the field. GRP degradation is directly proportional to the exposure to soil with non-neutral reaction. The theoretical and experimental results lead during time to design standards, which allow the application of GRP pipes in water and soil, so as minimum interferences with the materials used in the manufacture of pipes would appear. Samples of GRP pipe of a certain size are buried in the different areas of the field where the pH is alkaline, acidic, or neutral. After 24 months, samples were dug up / recovered and then subjected to laboratory determinations in GRP pipe factory Subor in Turkey in July 2016, and in Dresden Amitech Factory Laboratory in September 2016. Some other analyses were performed in the OSPA, Iași, Romania Laboratory. For the analysis of such large volume of experimental data, we used the Pearson correlation coefficient. The dependencies among variables were quantified by proposing the index pipe damage. The degradation of the pipeline is directly proportional with the difference between the actual value of soil pH and the neutral pH value. The mechanism of degradation is different in basic and acidic soils. The results obtained in this study can be used in practice to avoid the negative effects of the types of land on GRP pipes behavior.

Key words: circumferential stress, GRP pipes, type of soil, water transport pipe

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1. Introduction

Material generically called GRP (glass fiber reinforced polyester and embedded sand) or GRP (glass reinforced plastic) are specific plastic materials reinforced with high strength fibers. The composition consist in heat curing resin, glass fiber, and sometimes quartz sand (silicon dioxide of at least 98%). The use of thermal curing of the resin is caused by the heat of chemical reactions that form the final shape molecules, which leads to excellent resistance to fire (Da Costa-Mattos et al., 2009).

Other characteristics of the composite GRP are as follows: resistance to chemical aggressions, lightweight, UV-resistant, non-corrosive, electrically insulating permeable to radio frequencies, sound insulator, relatively low cost price (Da Costa Mattos et al., 2016).

Structure is formed from layers of resin and fiber glass, and the interior of quartz sand is mixed with resin. The application of these materials is continuously in successive layers (Aleksander and Ochoa, 2010). After the pipe is formed over the assembly mandrel / steel strip it passes through the heat treatment, a series of chemical processes where all the ends are collected and cut out to the required length (Mazurkiewicz et al., 2017). Pipe ends are calibrated and then the plug is installed. Size range varies between DN100 and DN4000 and standard pressure can be between PN1 and PN32 bar. The length of pipes may vary up to the maximum of the means of transport (typically 18m).

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The composite GRP is used in many fields, such as water and sewage (pipelines, tanks, fittings), automotive and aviation industry, petrochemical energy (pipeline fluid/heat register, wind turbines), sporting goods, electrical, constructions (Toretta et al., 2014). The extensive use of this type of pipe, in its various embodiments, leads to the necessity to investigate their behavior in the land. The phenomena occurring in the mass of the composite are: accelerating abrasion, hardness modifying, delamination, separation of the glass fiber matrix of the resin table, etc. The effect of different pH neutral on the composite is mainly due to the following four events:

- *degradation of the resin weight*: ion exchange resin is involved in the acidic substances, which leads to loss of mass, reflected by the increase in roughness, density and permeability decrease. When exposed to acidic solutions, the effect of weight is loosed. Also, the chemical aggression can occur by breaking the covalent bonds of the polymer, leading to degradation of mechanical strength, without loss of apparent mass.
- *degradation of the fiber glass*: the type of glass fiber it is more or less affected by acidic substances / base. Thus, while T and C fiber resist very well to chemical attack, at the opposite side, fiber type shows extremely sensitive to chemical aggression, either acidic or basic (Mazurkiewicz et al., 2016). The main used glass fiber is the E type (alumino-boro-silicate), with high content of boron, in particular mechanical characteristics, good resistance to most acids, but is affected by the chlorine compounds (and the halogens in general).
- *damage cooperation resin/fiber glass matrix*: the behavior of the composite neizotrop material depends largely to their compatibility. Aggressive environments affect the interaction of the fiber-resin, resulting in the total compromise of the material. This can be prevented by treating the outer surface of the glass fiber with additives adapted to the final application.
- *combined effect of the prior events*: even if separate, the three situations may have a large subcritical synergistic effect which may compromise the ability of the material to correspond to the tasks for which it was produced. There is practically no application, and the composite cannot be adjusted by choosing the correct type of fiberglass or resin.

All four mechanisms described above shows the importance of adapting GRP pipes to working conditions. The degradation mechanisms can be described be the following:

- *Cracks with different degrees of penetration into the mass composition* is due, in the first instance, to mass degradation of the resin, followed subsequently, by the penetration of aggressive agents, ruptures / breakages of glass fiber network;
- *Delamination characterized by separation of layers, leading to cleavage*. This is due to the insufficient compatibility resin/glass fiber, or of pre-existing crack under mechanical stress in the transverse direction. A blatant case of occurrence of delamination is the choice of a resin or fiber glass, with different coefficients of expansion;
- *Local instability* compressive total collapse occurs in an area of limited mechanical strength, and due to inappropriate choice of resin. Composite may retain as apparent because of the fiber glass is still functional, but permeability increases dramatically.
- *Local tensile instability*: total failure is manifested by the resistance to stretching in areas more or less extensive. It is due to the failure of the glass fiber matrix (and therefore the choice of inappropriate type), while the mass of resin presents more than minor cracks.

The cumulative effect of multiple attacks on the composite material (chemical, mechanical, thermal, and environmental) may be referred to the rate of stress accumulation in operation, similar to the aging of the material. The rate of stress depends on: the type of materials used (resin and glass fiber), the geometry and density of the fiber matrix, cyclicality mechanical loads, and environmental factors such as temperature, humidity, physico-chemical characteristics. The presence of moisture amplify the effects of all other aggressive factors. Thus, only after 30 days of immersion of HCl in the solution some decrease in mechanical properties were observed. Barcol hardness decreases by 10% after 60 days and after 90 days the decrease reaches 15%. Charpy impact test of the resistance of the composite shows a decrease of 5% after 60 days of immersion.

One of the effects of the most common practice is the loss of elasticity, which is an apparent improvement in mechanical properties, but with an increased rate of accumulation of stress in operation and weakening resistance to mechanical cyclical loads (like in practice repeated entry pressure of GRP pipes or traffic loads).

Some authors showed that changes in the structure of the material, variations in rigidity, toughness and impact resistance depend on the type of acid and the duration of immersion. If the acid is combined with increasing temperature, Barcol hardness, Charpy impact, and strength are significantly reduced ((Mahmoud and Tantawi, 2003; Rafiee, 2013).

Other authors (Banna et al., 2011), referring to the composite of glass fiber and vinyl ester resin, showed that the results after immersion in 1M H_2SO_4 solution at two different temperatures (25 and 75 degree Celsius) for two different time periods (seven days or 28 days) are extremely interesting. Specifically, after 7 days of immersion, the Barcol hardness increased, and after another 21 days (28 in total) it decreased, but still being higher than the final value of the sample immersed. After the sample is immersed for a period of 28 days, at the end, the structure begins to degrade, occurring an increased surface roughness and cracks.

A group of researchers from the Technical University of Belgrade also studied the behavior of the composition and mechanical properties of the composite GRP changes in acid or alkaline environment (Stamenovic et al., 2011). The conclusion was that the modulus of elasticity in alkaline solution "E" is decreasing with increasing pH. In acid solutions, the initial modulus of elasticity has the tendency to amplify the pH decreases. For both solutions, the conclusion was that the mechanical changes is proportional to the time of immersion.

Some authors also noted a slight increase in average Young Modulus E, a decrease in slightly acidic and alkaline, and the appearance of cracks around the table, presumably due to degradation wires the total mass of the composite glass (Sindhu et al., 2007). Mahmoud and Tantawi (2003) also studied the effect of hydrochloric acid, phosphoric acid, nitric acid, phosphoric acid, and the physical and mechanical properties of the samples of GRP. Samples of pipe were immersed for various time periods (30, 60, 90 days) in solutions with concentrations of 20% at a temperature of 20ºC to 100ºC. Degradation of the properties of the composite material was faster with increasing temperature and concentration or time of exposure. Moreover, the hardness of the composite was less affected as they analyze the material from the outside, so the diffusion of the solution in the matrix of the composite has an important role in the behavior of the material. Aveston and Sillwood (2011) underlined that the acidic environment and the type of glass fiber medium are decisive factors for the resistance of the composite acid. The mechanism of breaking of the fiber in this environment is related to the exchange of ions of sodium, calcium and aluminum on the surface of the fibers with acid protons, respectively. A glass fiber that does not present the respective ions on the surface showed the presence of resistance to acid conditions. Thus, increasing the hardness of the resin in slightly acidic medium, grafted protection using polyester fiber glass, lead to exceptional strength in weak/acid medium, standing out even an improvement of the mechanical characteristics (Averstom and Sillwood, 1982; Mahnoud and Tantawi, 2003). The degradation time was estimated to be below 1% in 10 years, so a very good stability is obtained (Yao and Ziegman, 2006).

The present study aims to clarify the changes in the mechanical properties of the pipe material caused by the effect of the alkaline or acidic soil. In this sense, technical literature and standards do not provide sufficient clarification since the design of the network interfere with manufacturing technology.

2. Case studies

2.1. Areas of testing

Sample of GRP pipe was buried in the Petrom Oil, Zemes in Bacau, Romania, where the pipeline failure rate is higher than average. This is the first experimental area. A second area was delimited on the Sarata River Valley, Solont / Bacau, in an area of land with high salinity. The third experimental area is in the Margineni village, Bacau, in an area of land that has not previously generated problem to GRP pipes.

After 24 months, samples were dug up/recovered of experimental lands and were cut into sections of 40cm length. The free ends of the samples were removed. In July 2016 the samples were subjected to laboratory determinations subordinated by GRP pipe factory in Turkey (structural composition analysis, Barcol test efforts axial or longitudinal) and in the laboratory of the plant Amitech Dresden (rigidity, Barcol test) in September 2016. The pipes were installed on the land and the samples were subjected to laboratory analysis OSPA, Iaşi, Romania.

2.2. Evaluation of circumferential tensile stress change

The circumferential effort was determined using a test machine ZTC 3200, manufactured by Devotrans in Istanbul/Turkey. Specimens obtained by transection of the pipe (typically between 5 and 10 mm width) are fixed in corresponding groove mandrel with a nominal diameter of the pipe, and then subjected to fracture extent. Three pipes were cut in the transverse direction by 5 test pieces (the width and thickness of the pipe were about 7 mm and 4.4 mm, respectively). The results are presented in Tables 1-3. The missing values in tables are due to the read errors of automatic measuring devices. Based on the data obtained the deflection (mm) of the sample for different load (kN) is presented in Figs. 1-3. The charts were obtained for the five samples buried in the neutral, alkaline and acid land.

Table 1. The test results in circumferential tensile – neutral land sample

Sample No.	*T (mm)*	*W (mm)*	*Maximum load (KN)*	*Maximum stress (MPa)*	*Break strength (KN)*	*Failure strain (MPa)*	*Young´s Modulus (MPa)*	*Task flow (kN)*	*Maximum deformation (%)*
1	4.70	6.90	1.66	51.00	1.66	51.04	-	-	21.00
2	4.50	7.50	2.78	82.30	1.92	56.77	841.00	2.47	15.00
3	4.60	8.00	5.40	147.00	4.91	133.32	1240.00	2.89	27.00
4	4.50	6.70	3.91	130.00	3.91	129.64	585.00	3.07	21.00
5	4.60	7.20	4.53	137.00	3.14	94.77	941.00	3.22	18.00
Statistical analysis									
χ	4.58	7.26	3.65	109.00	3.11	93.11	902.00	2.91	21.00
S_i	0.083	0.083	1.47	40.90	1.36	38.87	271.00	0.327	4.70
N_i	1.83	7.06	40.21	37.42	43.82	41.75	30.01	11.22	22.75

T it is the thickness of the pipe wall, W – the width of the sample, λ- the mean of the 5 determinations, S_i - deviation, N_i - percent deviation

Table 2. The test results in circumferential tensile - alkali land sample

Sample No.	*T (mm)*	*W (mm)*	*Maximum load (KN)*	*Maximum stress (MPa)*	*Break strength (KN)*	*Failure strain (MPa)*	*Young´s Modulus (MPa)*	*Task flow (kN)*	*Maximum deformation (%)*
1	4.20	7.50	2.77	87.90	1.94	51.04	726.00	2.61	24.00
2	4.60	7.80	4.44	124.00	2.89	56.77	1060.00	3.80	14.00
3	4.50	7.90	3.65	103.00	3.65	133.32	970.00	2.67	24.00
4	4.40	7.50	4.15	126.00	2.91	129.64	1200.00	2.94	23.00
5	4.10	7.50	3.26	106.00	2.28	94.77	1000.00	2.53	24.00
Statistical analysis									
χ	4.36	7.64	3.65	109.00	2.73	81.38	993.00	2.91	22.00
S_i	0.207	0.194	0.67	15.70	0.659	15.42	173.00	0.523	4.20
N_i	4.76	2.55	18.36	14.42	24.14	18.95	17.43	17.97	19.30

T it is the thickness of the pipe wall, W – the width of the sample, λ- the mean of the 5 determinations, S_i - deviation, N_i - percent deviation

Table 3. The test results in circumferential tensile - acid land sample

Sample No.	*T (mm)*	*W (mm)*	*Maximum load (KN)*	*Maximum stress (MPa)*	*Break strength (KN)*	*Failure strain (MPa)*	*Young´s Modulus (MPa)*	*Task flow (kN)*	*Maximum deformation (%)*
1	4.40	7.40	3.68	113.00	2.57	78.9	960.00	3.14	17.00
2	4.30	7.70	2.50	75.50	2.21	66.79			15.00
3	4.20	7.30	3.42	112.00	2.36	77.05	880.00	3.33	14.00
4	4.50	7.40	2.60	78.00	1.76	52.83	789.00	2.55	11.00
5	4.60	7.00	2.91	90.30	2.91	90.30	829.00	2.80	16.00
Statistical analysis									
χ	4.40	7.36	3.02	93.70	2.36	73.17	865.00	2.95	15.00
S_i	0.158	0.251	0.52	17.90	0.426	14.11	74.00	0.35	2.50
N_i	3.59	3.41	17.07	19.15	18.05	19.28	8.56	11.85	17.16

T it is the thickness of the pipe wall, W – the width of the sample, λ- the mean of the 5 determinations, S_i - deviation, N_i - percent deviation

Centralization of average values of efforts, the maximum strain, Young's Modulus and load at yield are in given in Table 4. The importance of testing circumferential effort is shown by the fact that the tensile stress is found in any part of the line pressure, being basically a measure of the ability of a pipe to resist to internal pressure. In this continuous fiber GRP pipe, the distribution of the tensile stress of the resin mass is different from GRP from segmented glass.

2.3. Checking the maximum effort

A check of the maximum circumference of the effort required by the GRP pipes is expressed by Barlow formula, adapted here in the form of Eq. (1).

$$p_i = 0.02 * \sigma_{\max} * \frac{1}{d_i} \tag{1}$$

where: σ_{max}(MPa) - the circumferential maximum effort; p_i - the minimum initial breaking pressure; d_i(m) - diameter of the pipe.

● For neutral sample we have Eq. (2):

$$p_i = 0.02 * 109.00 * \frac{1}{0.15} = 14.53 barr \tag{2}$$

● For basic (alcalin) sample we have Eq. (3):

$$p_i = 0.02 * 109.00 * \frac{1}{0.15} = 14.53 barr \tag{3}$$

● For acid sample we have Eq. (4):

$$p_i = 0.02 * 93.70 * \frac{1}{0.15} = 12.49 barr \tag{4}$$

All three samples were tested in standard condition, with a minimum acid sample. Tensile stress taken up mainly by the continuous glass fiber, showed a decrease in the values of its degradation, with the permeabilisation of the outer ruler. If the load at which occurs the flow (the behavior of the composite become completely plastic) does not differ significantly from those three samples, on the other hand the maximum deflection, the effort to tear, especially maximum stress (decisive for the resistance of the pipeline internal pressure) undergo a significant degradation in the case of man-made pipe laid in the ground polluted by oil products (with acid).

2.4. Calculation of pipe damage

In order to quantify the effect on composite pipe and applying a measured load flow given in Table 4 (force from which the sample passes from the elastic behavior of the rigid), Eq. (5) will be used (Amaro et al., 2013).

$$Dc = 1 - \frac{F_c^*}{F_c} \tag{5}$$

where: D_c-index of damage to the pipe; F_c*, F_c- task flow basic / acid land or in a neutral land.

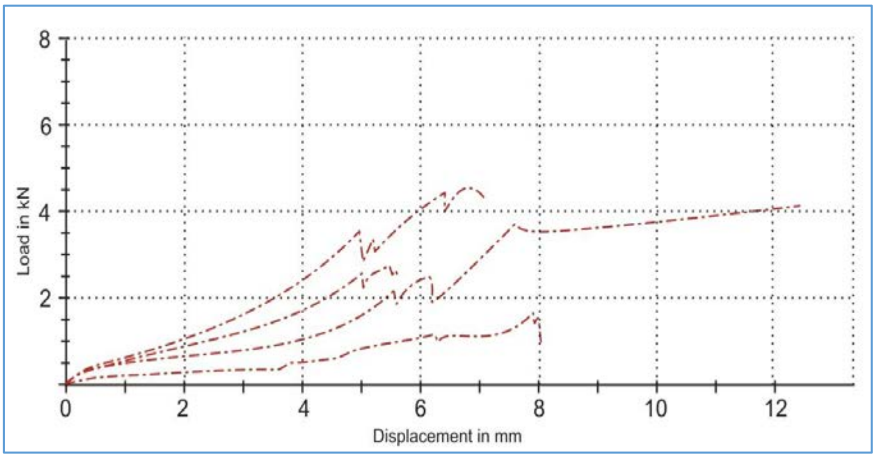

Fig. 1. The deformation of the sample – neutral land

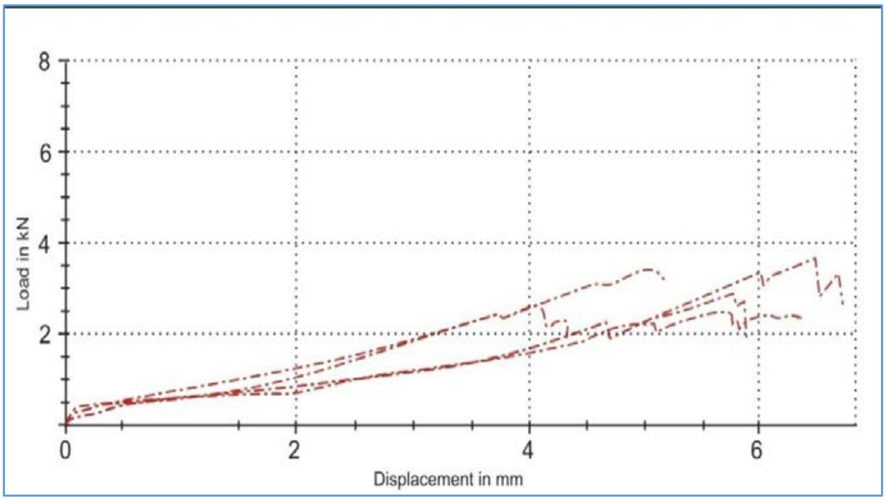

Fig. 2. The deformation of the sample – alkali land

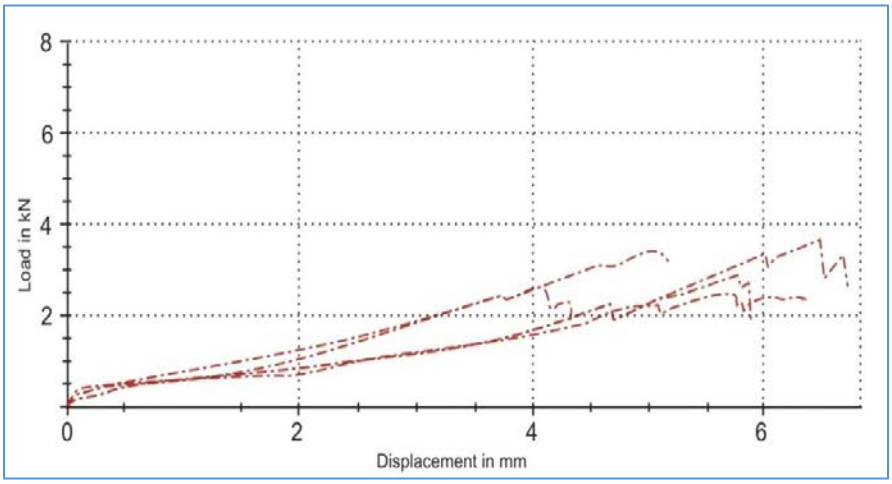

Fig. 3. The deformation of the sample – acid land

Table 4. Characteristics of pipes

Size	*Neutral sample*	*Sample basic land*	*Sample acid land*
Maximum deformation (%)	21.00	22.00	15.00
Break strength (KN)	2.91	2.91	2.95
Young´s Modulus (MPa)	902.00	993.00	865.00
Failure strain (MPa)	93.11	81.38	73.17
Maxim stress (MPa)	**109.00**	**109.00**	**93.70**

● For acid sample we have Eq. (6):

$$Dc = 1 - \frac{F_c^*}{F_c} = 1 - \frac{2.95}{2.91} = -0.01 \tag{6}$$

● For basic (alcalin) sample we have Eq. (7):

$$Dc = 1 - \frac{F_c^*}{F_c} = 1 - \frac{2.91}{2.91} = 0 \tag{7}$$

2.5. Pearson correlation coefficient calculation

By using data from Table 4 and the pH values of the three fields, the Pearson correlation coefficient can be calculated with Eq. (8):

$$r = \frac{\sum_{i=1}^{n}\left(x_1 - \bar{x}\right)\left(y_1 - \bar{y}\right)}{\sqrt{\sum_{i=1}^{n}\left(x_1 - \bar{x}\right)^2}\sqrt{\sum_{i=1}^{n}\left(y_1 - \bar{y}\right)^2}} \tag{8}$$

where $\bar{x}$ and $\bar{y}$ are given by Eq. (9):

$$\bar{x} = \frac{1}{n}\sum_{i=1}^{n} x_i \quad \text{respectively} \quad \bar{y} = \frac{1}{n}\sum_{i=1}^{n} y_i \tag{9}$$

being the average values of *x* and *y* (Renoud and Moubarac, 2009).

Further we obtained the Pearson correlation matrix presented in Table 5. Inserting the measured values in Table 4 and Na^+ concentrations for the three land and Pearson correlation coefficients (Eq. 8) will result in the following Pearson correlation matrix (Table 6).

3. Results and discussion

The relatively high values of the correlation coefficients specific to pH circumferential stretching effort particularly show the influence of pH on the behavior of pressure pipes header. Plasticization pipes is confirmed here (**the correlation between the pH of the soil and the Young's Modulus is 0.975**).

The high value of the correlation coefficient between the concentration of Na^+ ions and Young's modulus once again shows the trend of plasticizing the composite material in the presence of alkaline ions. In the alkaline land, the most important phenomenon that stands out is the increase of Young Modulus in the circumferential direction. This is of exceptional importance, since this changes the behavior of the pipe in a semi-elastic rigid one, giving it the capacity to work in the ground as an independent pipe.

Table 5. pH-correlation coefficients - circumferentially effort

Variables	*pH*	*Maximum deformation (%)*	*Task flow (kN)*	*Young´s Modulus (MPa)*	*Break strenght (KN*	*Maximum stress (MPa)*
pH	1	0.918	-0.858	0.975	0.395	0.858
Maximum deformation (%)	0.918	1	-0.991	0.808	0.726	0.991
Break strength (KN)	-0.858	-0.991	1	-0.723	-0.811	-1.000
Young´s Modulus (MPa)	0.975	0.808	-0.723	1	0.182	0.723
Failure strain (MPa)	0.395	0.726	-0.811	0.182	1	0.811
Maxim stress (MPa)	0.858	0.991	-1.000	0.723	0.811	1

Table 6. Na^+-correlation coefficients - circumferentially effort

Variables	*Na^+ (me/100g)*	*Maximum deformation (%)*	*Task flow (kN)*	*Young´s Modulus (MPa)*	*Break strenght (KN)*	*Maximum stress (MPa)*
Na^+ (me/100g)	1	0.588	-0.858	0.975	0.395	0.858
Maximum deformation (%)	0.588	1	-0.991	0.808	0.726	0.991
Break strength (KN)	-0.476	-0.991	1	-0.723	-0.811	-1.000
Young´s Modulus (MPa)	0.952	0.808	-0.723	1	0.182	0.723
Failure strain (MPa)	-0.129	0.726	-0.811	0.182	1	0.811
Maximum stress (MPa)	0.476	0.991	-1.000	0.723	0.811	1

According to Ancas et al. (2017) "*the increase of the Young's Modulus will affect substantially the circumferential extent of the pipes under pressure. Even if breaking pressure values will not be affected, rigid behavior of the composite pipe will be vulnerable to sudden changes in internal pressure. Pearson correlation coefficients for pH confirm the increase of the Young's Modulus proportional to it"*.

Na^+ content increased stiffness influences in particular pipes. Pearson correlation coefficients show negative acceleration of the degradation of unitary pipes in direct proportion to the amount of Na^+ ions. Changing the Young's Modulus in the circumferential direction (in the sense of increasing the value of the land base) to the modulus of elasticity of the determination of the stiffness (which is slightly decreased land base) (Ancas et al., 2017) can be explained by the fact that the Young's modulus refers here only to the composite material itself (anisotropy noted above), while the modulus of elasticity is closely related to the geometry of the pipe, allowing elastic retention behavior. This is of particular importance because of static calculation based on GRP pipes is the elastic behavior of their cooperation taking into account the land pipeline. Sizing is based on maximum allowable deflection, and not on the maximum allowable effort, as in the case of rigid pipes (concrete, ceramics, and the like).

4. Conclusions

The projected life of GRP pipe (50yars) is affected in the case of pipelines laid in land basic pH. In practice, to avoid the negative effects of some types of land on pipes of GRP noted herein can be made at the design stage by a pedochimic study. Elemental to determine the pH of the soil to the depth of laying, and the presence of ions of Na +, oil residues or other forms of pollution (anthropogenic or not) is absolutely required. When the pH is between 6.5 and 7.5 filler material imported from areas with neutral pH is required. This solution may be sufficient if it is a contamination of the area in which the pH-modifying agent has ceased, as is the case with the oil polluted area in the work man-made. If the case of a massive presence of Na^+ from a natural source (a water valley salt) the filler material would notbe efficient, because it would be contaminated over time.

This situation needs to consider new future design procedures for adapting the networks for applications in lands with pH variations from neutral values.

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