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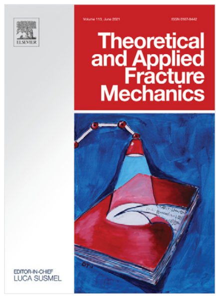

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Effect of residual stresses on the fracture of polypropylene (PPR) pipes

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Abstract

Polypropylene random copolymer (PPR) pipes is one of the most used polymers in the piping systems. Hence the need to more rigorously know their properties and characteristics. In order to investigate the distribution of the residual stresses along the wall and their effect on the fracture of the PPR pipes, an experimental methodology was conducted using tensile tests on a notched specimens machined from these pipes. Furthermore, the three stages of the damage development as well as the critical life fraction (β_c) have been defined, through an adaptation of the Erismann damage model. Finally, the depths corresponding to 50% of the defected pipes reliability for both internal and external defects have been identified.

Keywords: Polypropylene (PPR) pipes, residual stresses distribution, internal and external defects, damage modeling, reliability.

[⋆] Fully documented templates are available in the elsarticle package on CTAN.

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1. Introduction

The polypropylene (PP) is a semi-crystalline thermoplastic polymer with a wide variety of applications. It offers a good combination of cost-effectiveness and physical, mechanical and thermal properties [1, 2]. The global consumption of polypropylene is around 47 million tons per year. In Europe, the consumption per habitant is 17 kg per year [3]. The European production of polypropylene represents 19 % of all produced plastics. The automotive sector uses about 7% of the production of this polymer [4]. During the last decade, polypropylene has been widely used especially for intensive activities, the factor is strongly attributed to the high demands and uses mainly in cold and hot water transportation, food packaging, the automotive industry, the manufacturing of electrical and electronic components. In fact, the polypropylene is a homopolymer that contains only one type of repeating unit which is propylene [6], it has very interesting properties such as a relatively high melting point (171 ^{0}C for a perfectly isotactic PP and 160 ^{0}C for commercial grades), a low density (0.85 to 0.94), a high Young's modulus (1.1 to 1.6 Gpa) and it is relatively inexpensive comparing to other thermoplastics [5]. Meanwhile, its low resistance to impact, its transparency and fragility at low temperatures limit its application [7]. These limitations have encouraged manufacturers to develop copolymers. The propylene random copolymer (PPR) is one of the main types of polypropylene for applications requiring excellent toughness [9], it's obtained through a copolymerization of propylene with ethylene as a comonomer, this process leads mainly to a change in the polymer crystallinity by incorporation, in a controlled manner, of "irregularities" into the macromolecules, As a result, these units act as defects in the Polypropylene chain, which improves considerably their properties by a decrease in the degree of crystallinity, stiffness and melting point of the PP, towards with an increase of the toughness, a reduction of the stiffness and melting temperature [8]. Consequently, the PPR material offers an interesting properties such as transparency, thermal stability, moderate low temperature impact resistance, more flexibility, high resistance to aging and good low temperature mechanical properties, which is suitable for food packaging, medical products and piping systems for domestic and industrial applications [10, 11].

Polypropylene (PPR) pipes are manufactured by extruding the molten raw material across an annular die to form pipes. During the cooling phase, residual stresses take place in the wall, due to the faster cooling of the pipes outside than its inner side. Since the residual tensile stresses improves the faster cracks growth in the pipe wall, they can affect the lifetime of the piping system. Hutár et al. [12] have evaluated numerically the effect of the residual stresses on the lifetime of plastic pipes through an estimation of these stresses effect on the crack behavior in a pressurized Polyethylene pipe. To do so, authors have incorporated the residual stresses in a numerical model of a cracked polymer pipe, in order to estimate the stress intensity factor during the propagation of an axially oriented crack growing from the inside of the pipe towards its wall, and combined it with the experimentally defined creep crack growth kinetics, used for lifetime estimation, to compare the lifetime of cracked pipes with and without residual stresses. However, authors didn't support the results by an experimental validation. Also, the proposed approach can be a reliable tool for the residual lifetime assessment of cracked polymer pipe, and not for the newly produced pipe whom its lifetime is supposed to be defined by the manufacturer. Poduška et al. [13] have studied the distribution of residual stresses along the walls of polypropylene pipes, using two analytical approaches, based successively on the curved beam and thick walled cylinders theories. For the first method, based on the total bending moment described by the change of the curved beam radius of rings, machined from pipe and modified on a lathe by removing layers from the outside and the inside, the residual hoop stress was obtained along the wall. The second method assumed that the hoop and radial stresses should satisfy the equilibrium equation, and the assumption of the change in the inner radius and the circumferential deformation leads to the equation that describes the distribution of the residual tangential stress. The comparison of the obtained results from the two methods showed a good agreement in the area close to the inner surface, while in the area close to the outer surface there was a slight difference. Moreover, authors have performed a numerical simulation using finite element method, the residual stresses were introduced by a variation of the thermal expansion coefficient, then the deflection was numerically calculated in order to get the diameter changes, very good agreement was found between the stress distribution included originally in the numerical model, and that one obtained from the approach based on curved beam theory. Meanwhile, the modification of the rings on the lathe by removing layers from the outside and the inside can introduce residual stresses which possibly affects both analytical and numerical results. In further work, Poduška et al. [14] have investigated and compared the residual stresses distribution in two polyethylene pipes differ in the speed of extrusion, results showed that the extrusion speed doesn't affect the state of the residual stresses since the magnitude of tangential and axial residual stresses were similar for both types of pipes regardless to the difference of the extrusion speed. Then, a finite element model was used to examine the influence of the asymmetrically growing cracks, assumed possibly caused by the presence of the residual stresses, on the fatigue crack growth rates and the number of cycles to the failure of cracked round bar (CRB) specimens. The authors found that the estimated lifetime of specimens with asymmetrically cracks is lower comparing with results for symmetrically growing crack.

On the other hand, some researchers have been interested in the mechanical characterization of the polypropylene (PPR) material using tensile test, In this scope and with the aim of investigation the suitability of polymer pipes for domestic and industrial hot water transportation,in term of physical and mechanical properties, against traditional metallic pipes, Zgoul and Habali [15] have compared cross-linked polyethylene (CLPE) and polypropylene random copolymer (PPR) pipes versus those made of steel and copper. In this context, the authors have performed tensile tests on specimens machined directly from each thermo pipe types (PPR and CLPE) to obtain the stress-strain curves for these materials. Results display a similarity of the mechanical behavior for both thermoplastic pipes (i.e. yield peak followed by necking, stress stabilization and finally hardening at the end of the test), but samples taken from PPR pipes exhibit slightly higher yield stress, ultimate stress, Young's modulus and double elongation at break in comparison with specimens made of CPLE pipes. Nevertheless, Authors didn't study the notch effect on the behavior of these pipes. Papageorgiou et al. [16] have provided a characterization and comparison study of the mechanical properties, using tensile tests, and kinetics of thermal degradation, by the mean of thermogravimetric analysis (TGA), of two categories of the PPR, i.e. a neat PPR and a temperature resistant PPRCT (type of neat PPR reinforced by nucleation of a new crystalline phase). In accordance with ASTM D683, authors have prepared dumbbell shaped tensile test specimens, and tests were conducted on a tensile machine. Then, tensile strength and elongation at break were measured. The results showed that both neat PPR and PPRCT have almost the same yield stress. Moreover, specimens that correspond to the polypropylene temperature resistant (PPRCT) show higher tensile strength, and elongation at break than samples taken from neat PPR, but the Young's modulus for the new material is smaller than the neat PPR. Authors attributed the improvement of the mechanical properties to the new added crystalline phase in the final product making it more ductile than neat polypropylene or its random copolymer (PPR). However, to confirm this fact, an evaluation of the new material's behavior versus the notch were required. Gomez Del Rio et al. [17] have analyzed the effect of temperature and strain rate on the mechanical properties of three types of polypropylene block copolymers with different percentages of ethylene. Their experimental methodology consisted of subjecting dumbbell specimens, made of polypropylene block copolymers, to tensile tests in a range of temperature starting from (-120 ˚C) up to 23 ˚C and velocities of crosshead from 1mm/min to 100mm/min. The authors concluded that the same trend is observed, a significant increase in the yield strength at high deformation rates and at low temperatures with brittle failure at -80 ˚C and -120 ˚C. Xin Chao et al. [18] have used the specific work of the essential work of fracture theory, to study the effects of notch length, notch type (single and double) and the notching method (notching machine and notching by a steel razor blade) on the toughness of a Polypropylene copolymer. The authors have proved that in the mode (I), the notching method has little influence on the results and that the specific work of fracture consumed in the plastic deformation stage are almost equals for the two types of double edge notched test specimens (DENT) and simple edge notched (SENT). Also, the specific work of fracture in the plastic deformation stage in the mode (I) is greater than that one obtained in mode (III), this result was attributed by the authors to the larger quantity of the molecular chains participating in the specimens drawing process in plane stress (mode I) in comparison with out-of-plane stresses (mode III).

In our work, we aim to highlight the effect of residual stresses on the fracture of the PPR pipes, and their distribution along the walls, through an efficient simple experimental methodology, basing on the criticality of internal and external notches.

2. Theoretical background:

2.1. Damage modeling

The damage of a material can be defined as a degradation of its physical and mechanical properties when it's subjected to monotonous or either variable stresses[19]. Originally, theories of damage were developed by Rabotnov [20] and Kachanov [21] to explain the process of continuous deterioration of materials undergoing creep testing. The success of this damage modeling has led to its extension to the damage by fatigue. Chaboche [22] have proposed in 1974 the first model. Theoretical models of damage based only on loading conditions, loading mode and mechanical characteristics of virgin material are present in the literature particularly for fatigue loads [23], in our work we will focus only on two models: Miner model and the Erismann model.

2.1.1. Miner model

The Miner's rule, which is used in this work, is based on the assumption that the failure of the material is caused by a cumulative linear damage, it is the most used damage model in engineering because of its simplicity [23, 24].

The concept of Miner's law leads to a linear sum of the lifetime fraction β_i specific to each type of applied cycle:

$$D = \sum_{i=1}^{k} \frac{n_i}{N_{Ri}} = \sum_{i=1}^{k} \beta_i \quad (1)$$

With:

D: Damage.

n_i: Number of instantaneous cycles.

N_{Ri}: Number of cycles to failure.

The failure of the material occurs when D is equal the unit (D = 1).

2.1.2. Erismann model

Erismann postulates that at any point in the life of a material, an increase in the loading spectrum can be replaced by any other increase without affecting the life of the material. In order to have a possibility of comparison between the "damage indicator" parameters, he offers a standardized representation according to the following relationship [25],[26]:

$$D = \frac{\phi(X) - \phi(X_0)}{\phi(X_R) - \phi(X_0)} \quad (2)$$

With:

$\phi(X_0)$: Defined monotonic function of X.

X: The value of the property.

$0, R$: The index of the beginning and the end of the life.

2.2. Reliability :

The issue of ensuring the industrial activities reliability and safety is considerable since it's related to the safety of goods and people, the availability and performance of industrial systems. Reliability analysis is an essential step in any safety study. Firstly, reliability was used for high-tech systems. Today, reliability has become a key parameter of quality and decision, in the study of most components, products and processes: Transport, energy, buildings, electronic components, mechanical components, etc. Many manufacturers are interested of assessing and improving the reliability of their products during their development cycle (design, manufacture and operation) in order to optimize the report cost/reliability and control the causes of failure. The analysis of reliability in the field of mechanics is a very important tool for characterizing the behavior of the product during its different phases of life, measuring the impact of design changes on the integrity of the product, qualifying a new product and improve its performance throughout its use. Until now, the way of approaching rare events, which can lead to serious consequences such as piping failures, has been essentially deterministic, we define the potential failure modes and we protect ourselves by taking safety factors to keep margins in order to maintain the installations integrity, this approach is used mainly for mechanical analyzes [27, 28, 29, 30]. In our work, reliability will be used to define $\beta_{50\%}$ (the life fraction at 50% of the reliability) of maintenance operations starting of a defected pipe made of PPR material.

3. Experimental methodology:

3.1. Material:

The used material in this work is polypropylene random copolymer, known as PPR. It is manufactured in the form of pipes and fittings for piping systems, intended for the transportation of industrial, chemical and agricultural hot and cold sanitary pressurized fluids. The PPR pipes achieve the application requirements thanks to its different ranges of products which are distinguished by the standard dimensional ratio, linking the outside diameter of the pipe to its thickness, and by the composition of the raw materials used (monolayer pipes made of PPR alone, PPR composites with glass fibers or PPR sandwiches with protective layers of high density polyethylene). PPR piping system can be used in a number of facilities such as houses, large buildings, hotels, hospitals, shopping malls and maritime applications. The main properties of the used PPR raw material are summarized in Tab. 1.

Table 1: Technical properties of the PPR raw material.

Properties	Testing methods	Values at 23°C	Unit
Density	ISO 1183	0.898	g/cm^3
Yield strength	ISO 527	23	N/mm^2
Elongation at break	ISO 527	$\succ$ 50	%
Young's modulus	ISO 527	850	N/mm^2
Melt flow index (MFI) 190 C°/5kg	ASTM D 1238	0.5	g/10 min
Thermal conductivity	DIN 52612	0.24	W/m.k
Melting point	DIN 53736b2	150 - 154	^0C
Charpy impact strength at 23^0 at -30^0C	 ISO 179/1 e A ISO 179/1 e A	 No break 50	 KJ/m^2 KJ/m^2

3.2. Experimental device

The tests were carried out using a tensile machine Fig.(1) with a maximum capacity of 5 KN. In fact, the device consists of a dynamometer with clamps. One of them is fixed, while the other moves at a variable speed exercising an increasing traction force. The machine is equipped with a computer controlled by a software allowing the recording of the results on a test report.

3.3. Specimens preparation:

In order to characterize the behavior of the PPR material, tensile tests were performed on tensile dumbbell specimens, in accordance with ISO 6259- 1 [31]. The specimens were taken from an extruded PPR pipes, with an outer diameter of 63mm and a thickness of 10.5mm, according to the following steps:

- step 1: Measurement and cutting sections of 200 mm length (Fig.2):

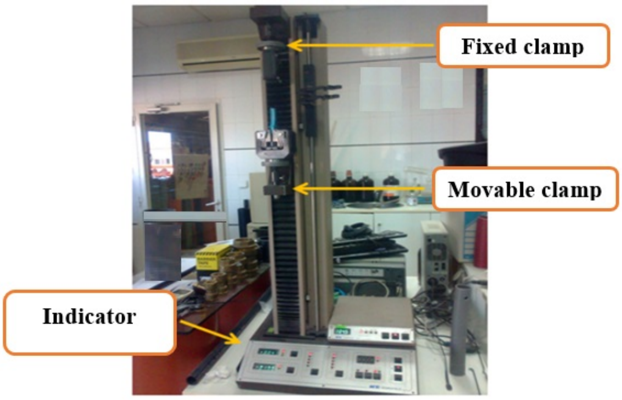

Figure 1: Tensile machine.

Figure 2: Measurement and cutting the required length of a pipe section.

- step 2 : From each section, two strips distributed along the circumference were taken. Then, we used a standardized punch according to the ISO 6259-3 [32] standard, to obtain the shape of dumbbell specimens. Eight

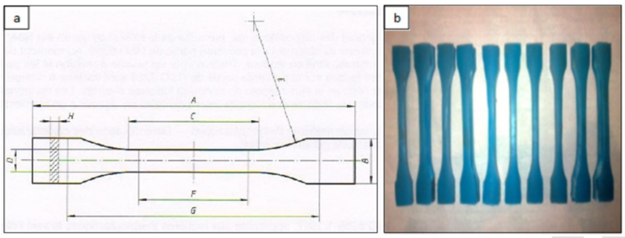

Figure 3: a) Dimensions of specimens, b) Eight specimens.

Table 2: Dimensions of specimens.

Symbol	Description	Dimension (mm)
A	Length overall, min	150
B	Width overall, min	20 ± 0.2
C	Length of narrow section	60 ± 0.5
D	Width of narrow section	10 ± 0.2
E	Radius	60
F	Gauge length	50 ±0.5
G	Distance between grips	115 ± 0.5
H	Thickness	10.5

specimens of 150 mm in length were prepared as shown in Fig.3 and Tab. 2:

With the intention of analyzing the effect of the defects on the tensile strength of PPR pipes, notches were made with a saw blade (Fig.4).

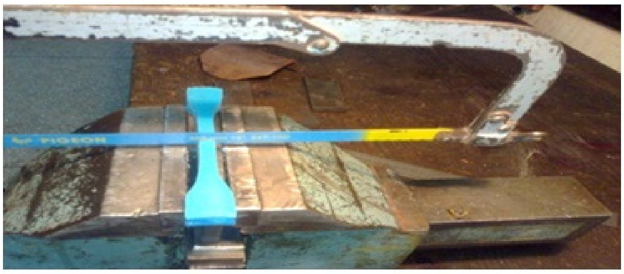

Figure 4: Notching.

A set of twenty specimens was prepared (Fig.5), half of which was notched from the outer side of the pipe to its inside (External notches), while the other half contained the notched specimens from the inner side of the pipe to its outside (Internal notches). The notch depths, called "a", vary between 1 and 9 mm with a step of 1 mm for the both types of notching.

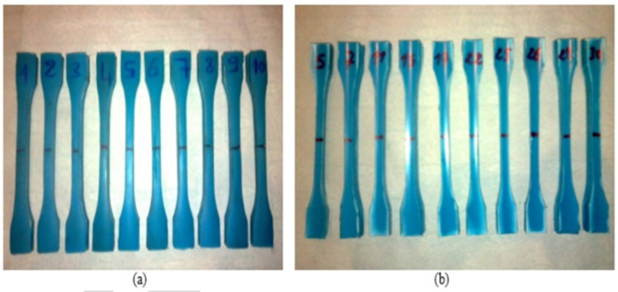

Figure 5: Notched specimens a) from the outside of the pipe to its inside (External notches) b) from the inside of the pipe to its outside (Internal notches).

3.4. Experimental protocol:

According to the guidelines prescribed by the relevant ISO 6259 [31, 32] standards, the specimens were subjected to a tensile force with a crosshead moving speed of 50 mm/min until breaking, a position sensor, incorporated in the movable grip of the machine, allowed the instantaneous plotting of the force-displacement curve [33].

4. Results

4.1. Mechanical characterization of the PPR material behavior:

The purpose of the tensile tests conducted during the study was to determine the mechanical characteristics of the PPR material, according the directives prescribed by the EN ISO 6259-1 and NM ISO standards6259-3 [32, 31], The obtained stress-strain curve is given in Fig.6.

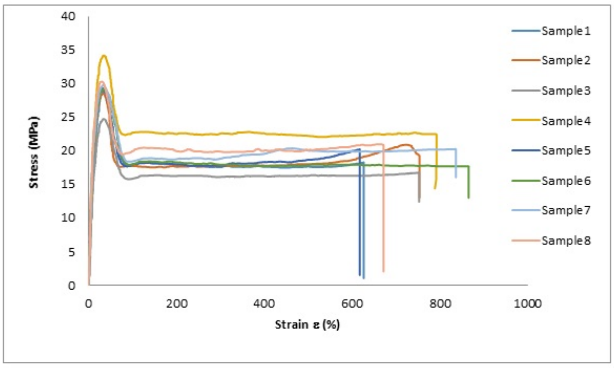

Figure 6: Stress-strain curve of the Polypropylene (PPR) material.

The results display the evolution of the stress-strain curve to failure of PPR material, and the typical behavior of polymers in large deformation. At the beginning of the tests, we noted a proportionality between the applied stress and the deformation, it is the stage of the elastic deformation, and this quasi-linear zone allows us to obtain the Young's modulus and to determine the ultimate stress. The obtained values are comparable to those provided in the literature. The zone of elastic deformation reaches its end at the limit value of the stress beyond which no more proportionality is observed between the applied stress and the deformation, the material begins to deform plastically in a permanent manner, which corresponds to the initiation of the necking in the middle of the specimens. The drop in stress in this zone is explained by the location of the deformation in the necking zone. After stabilization, this necking propagates along the specimens until reaching the both ends. Then, the stress remains constant while the deformation increases significantly until the fracture of the specimen, this phenomenon of structural hardening observed in the thermoplastic polymers is due to the orientation of the macromolecular chains towards the stretching direction.

4.2. Effect of the defects on the PPR material:

With the purpose of highlighting the effect of the defects and the effect of the residual stresses on the fracture of the PPR pipes, a series of tensile tests were performed on the set of specimens notched from the outside of the pipe to its inside (external notches), at different depths, called “a”, ranging from 1 mm to 9 mm. Then, another series of tensile tests were carried out on the set of specimens notched from the inside of the pipes to its outside (Internal notched), at different depths, called “a”, ranging from 1 mm to 9 mm. The evolution of the force-displacement curves as a function of the notch depth “a” for the specimens with external and internal notches are shown respectively in Fig.7 and Fig.8 .

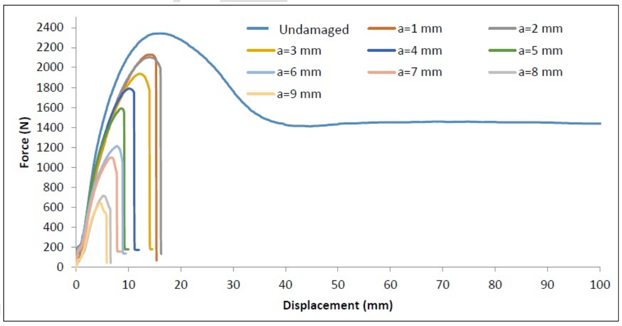

Figure 7: Force-displacement curves of specimens with external notches.

From these figures, we find a gap between the different force-displacement curves as a function of the notch depth. The degradation of the mechanical

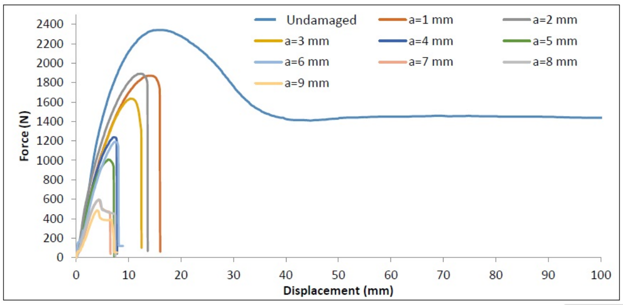

Figure 8: Force-displacement curves of specimens with internal notches.

properties is always significant. The ultimate force and the displacement at break are decreasing more and more with the increase of the notch depth. For unnotched specimens, fracture often precedes local plasticization. While for notched specimens either on the outside of the pipe or its inner side, no longer force stabilization plateau was observed, nor a significant elongation. This may be explained by a cut in the macromolecular chains because of the notches, which prevents the formation of the fibrillar fraction responsible to the progressive hardening caused by the orientation of the macromolecules in the main direction of deformation. As a result, the material loses 98% of its elongation at break due to the existence of the notch. From the studies of J. Karger-Kocsis [34], when the deformability of the molecular network becomes saturated at the end of the crack, the molecular chains break during the necking stage.

4.3. Damage evaluation of the PPR material:

4.3.1. Experimental results of the ultimate force reduction

The evaluation of the ultimate force loss (Fig.9) has a great importance, since it indicates the degree of the material's damage. This section will be devoted to display this quantity as a function of the life fraction β = a/e, with "a" the notch depth and e = 10.5 mm the thickness of the pipe.

The ultimate force for the unnotched PPR material specimen is 2424 N, which is equivalent to a dimensionless force Fur/Fu = 1. The value of the dimensionless ratio Fur/Fu decreases proportionally as a function of the life

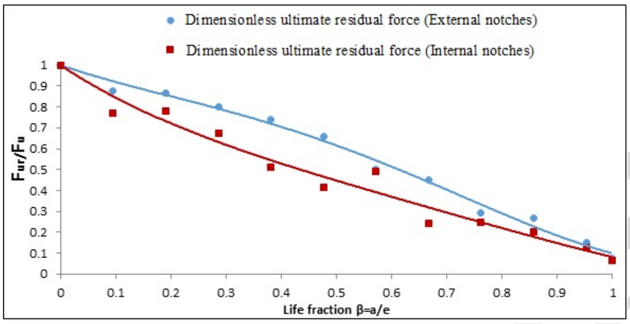

Figure 9: Evolution of the dimensionless residual ultimate forces for external and internal notches.

fraction β. For small depths of the notch ($\beta \prec 0.5$), we note that the notches starting from the inner side of the pipe lead to a decrease in residual dimensionless forces more obvious than the ones who begin from the outer side of the pipes to the inside. For life fractions close to 1 ($0.5 \prec \beta \prec 1$), the values of the dimensionless forces for the two types of notches tend to be closer. For the life fraction equals to 1, the ratio Fur/Fu respectively reach the values of 0.08 and 0.06 for the external and internal notches. the existence of the external notches above that one of internal notches, can be explained by the presence of residual tensile stresses in the inner side of the pipe which helps the opening of the notches, and the abundance of residual stresses prohibiting the opening of the notch in the outside of the pipes. Consequently, the outer side become stronger than the inner one.

4.3.2. Erismann Damage:

As the used damage model in this work is dimensionless, the use of forces instead of stresses is quite preferred for simplification and uncertainties minimization issues. After the parameters adaptation, the expression of the Erismann damage of the PPR material, subjected to static tensile test, can be rewritten in the form:

$$D = \frac{F_u - F_{ur}}{F_u - F_a} \tag{3}$$

With:

F_u: The ultimate force of the unnoched specimen.

F_{ur}: The ultimate residual forces of notched specimens.

F_a: The critical ultimate residual force for the life fraction equals to 1.

Fig.10 illustrates Miner damage and a comparison of the Erismann model for both types of notching as a function of the life fraction β.

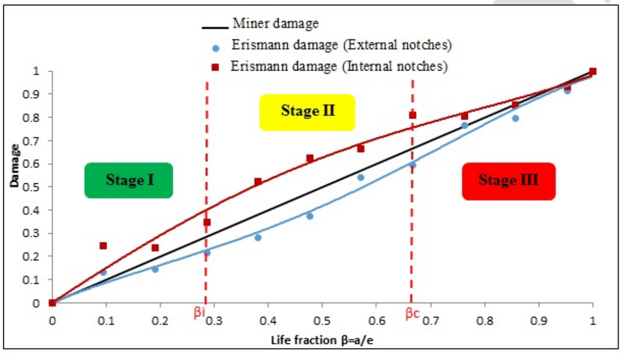

Figure 10: Evolution of the damages for external and internal notches.

The results of the Fig.10 describe the damage evolution as a function of the life fraction. This curve can be divided into three stages. For the damage of the outer side of the pipe, due to external notches, a slowly development was found in the first stage, which corresponds to the life fractions in the interval [0; 0.28], from 0 to a value equals to 0.2. In the second stage [0.28; 0.67], an increase of the damage development was noticed, it moves from the value 0.2 to a value equals 0.6. In the third stage (0.67 $\prec \beta \prec$1), the curve becomes more accentuated towards the top, which means an acceleration near the end of this stage and the failure can happen suddenly. On the other hand, the damage of the inner side of the pipe, due to internal notches, displays a different variation. Since the beginning, the damage progresses significantly from a value of zero to a value near to 0.4 at the end first stage (0 $\prec \beta \prec$0.28). In the second stage (0.28 $\prec \beta \prec$0.67), the damage keeps its notable development and goes from 0.4 up to near 0.8. Finally, the damage grows but in a somewhat slowly manner. This curve is above the Miner damage up to life fractions close to 1 where they cross. Actually, the fast cooling of the pipes outside during the extrusion process, disturbs the crystallization of macromolecules in the outer part of the pipe. Meanwhile, the macromolecules in the inner side have more time to crystalize and find stable positions. Consequently, residual stresses take place along the pipe walls. A comparison of the two damages of external and internal sides of the pipes, revealed that the damage caused by the internal notches is above that one induced by external ones. Thus, it obvious that the internal defects of the pipes are more severe than the externals. In fact, the slow damage development of the pipe external side in the first stage, thickness of the pipes ranged between 0 and 30% of the total thickness starting from the outer side of the pipe, which can be explained by the existence of compression stresses in this area, preventing the opening and the growth of cracks along the pipe wall. The acceleration of the damage in the second and third stages is attributed to the end of residuals compression stresses and the beginning of residual tensile stresses, improving the opening and growth of cracks. On the contrary, the damage due to internal notches, increased considerably in the first and second stages, serving of the residual tensile stresses abundance in this part. The sluggish damage evolution in the third stages is due to the end of this kind of residual stresses and the beginning of the cracks growing inhibiter (i.e. residual compression stresses). Subsequently, starting from the outside of the pipe up to 30% of the wall, the pipes is subjected to residual compression stresses, while the pipe layers ranged from 30% up to the pipe inner surface, are subjected to residual tensile stresses. The proposed distribution of the residual stresses, along the pipe walls, is in a good match with the found results by Poduska [13]. For a defected pipe made of PPR material, the life fraction at the beginning of the second stage "β_i" of damage is considered as a warning for multiplying inspection operations of the defect size, while the life fraction at the beginning of the second stage "β_c" plays an important role in the maintenance strategy, since it is the moment to move to repair actions.

4.4. Reliability

The objective of a damage law is to provide a tool for predicting the life service for any mechanical component subjected to variable stresses. The damage can be described on the one hand by the parameter D (damage) as a function of the notch depth. On the other hand, there is another parameter of a statistical nature makes it possible to follow the material deterioration evolution, this new parameter is reliability R, which represents the material survival probability. If the damage is likened to a probability of failure, reliability can be considered as a complementary function to the damage, the following equation 4 summarizes the relationship between these two parameters[35]:

$$R(\beta) + D(\beta) = 1 \tag{4}$$

With:

R (β): Reliability as a function of the life fraction.

D (β): Damage as a function of the life fraction.

Using this relationship, the evolution of these two quantities can be studied simultaneously as shown in Fig.11.

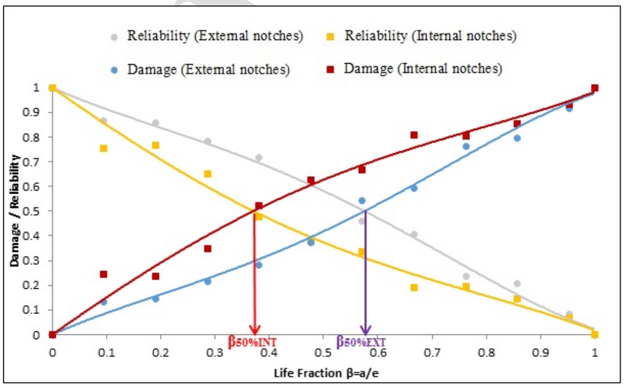

Figure 11: Damage-reliability curves for external and internal notches.

Unlike the damage, the corresponding reliability, whether for external or internal notches, starts with a value of 1, at the absence of damage, and decreases when the depth of the notches increases, the total failure of the material is indicated by a null value. In order to compare the harmfulness of external and internal cracks, the use of 50% reliability is necessary (i.e. the life fraction at 50% of the total reliability of the pipe). For the PPR pipes damaged from the outside, this life fraction is obtained when an external defect reaches 58% of the total thickness of the pipe. Whereas for internal defects, the life fraction at 50% of the reliability is achieved when the pipe is damaged at 38% of its total thickness, which proves the criticality of internal defects versus external ones, and subsequently the proposed distribution of the residual stresses through the pipe walls.

4.5. Conclusion

In order to study effect on the fracture of the polypropylene (PPR) material and their distribution of residual stresses along the wall of pipes made of that polymer, this article presents a simple and efficient experimental methodology. The results of ultimate force at fracture of specimens extracted from pipes, showed a sensitivity of the material to the internal notches in comparison with external ones, this is due to the existence of residual tensile stresses in the inter side of the pipes and the abundance of residual compression stresses in the outer side. The analysis of damage evolution, using Erismann damage model, allow us to propose a distribution of the residual stresses through the pipe's wall, the first third of wall, starting from the outside, is dominated by the residual compression stresses, while the other two thirds of the wall are characterized by the presence of residual tensile stresses, good match with the literature was found. In further papers we aim to develop this work to investigate the magnitude of these residual stresses towards the pipe walls.

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Highlights

- ✓ An estimation of the residual stresses distribution in the walls of polypropylene (PPR) pipes.
- ✓ An investigate on the influence on the residual stresses on fracture of the PPR pipes
- ✓ Criticality comparison of internal and external defects on the so-called pipes.
- ✓ Damage progression stages determination.
- ✓ Specification the critical depth from which these defects become dangerous for both internal and external ones.
- ✓ Identification of the defects depth corresponding to 50% of defected pipes reliability.

Author statement

Hereby, we declare that all authors take responsibility for the content of this work. We confirm contribution to the paper as follow:

Abderrazak OUARDI: Article writing, conception and design, carrying out tests (experimentation), analysis and interpretation of the data, drafting the article and revising it critically for important intellectual content.

Bouchra SAADOUKI: conception and design of the article.

Nadia MOUHIB: Results monitoring, analysis and interpretation of the data, validation of results.

Achraf Wahid: Article writing and revising.

Mohamed ELGHORBA: Methodology, collaboration with the laboratories of testing and study, validation of results.

Conflict of Interest

Please check the following as appropriate:

- ✓ All authors have participated in (a) conception and design, or analysis and interpretation of the data; (b) drafting the article or revising it critically for important intellectual content.

- ✓ This manuscript has not been submitted to, nor is under review at another journal or other publishing venue.

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