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TT-IRT Hybrid Testing Method Applied in the Study of PE 80 Polyethylene Behaviour in the Presence of Simulated Imperfection

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Abstract
When evaluating the composite material properties, Infrared Thermography is a current technique applied to the mechanical testing monitoring. This paper presents a hybrid testing method, applied to studies of mechanical stress behaviour of a thermoplastic material PE 80 polyethylene type, in the presence of simulated imperfection.
Used in combination with the classical destructive TT (Tensile Testing) method, the IRT (Infrared Thermograph) non-destructive method is useful for the evaluation of deformation and failure process of thermoplastics and it may be applied to the notch sensitivity evaluation of one material / product, in fabrication phase and either after one exploitation period.
TT-IRT hybrid method leads to the highlighted and deep understanding of the failure mechanisms of thermoplastic materials, with impact over the uncertain level of the estimation for residual life assessment of the inspected components. Using this method information is obtained regarding the in service exploitation of a component / material, in the presence of different type of imperfection, long time before these act as failures.
The paper presents results obtained by applying this method in ISIM Timişoara on the PE 80 polyethylene pipe, used in transport and distribution infrastructure of pressure fluids.
Keywords: Thermoplastic materials, PE 80 polyethylene, compared imaging, simulated imperfections, TT-IRT hybrid testing.

1. Introduction

Elaboration of the new materials and/or properties improvement in the existing ones represents one of the major priority directions in the research field of thermoplastics and composite material.

Before launching the new product / material on the market, it must be tested in order to asses the in-service using ability for specific exploitation conditions.

Classical destructive testing methods provide data regarding the structure and the toughness characteristics of material in the initial phase, or estimations of those for different service periods in safety conditions.

In order to manufacture a specific product, in many cases the choosing of the material type is influenced by the in time stability of its characteristics. According to this tendency, new examination techniques were developed to study the most recent sort of materials and complete their characterization. Thus, for the deformation evaluation and failure behaviour of polymers hybrid testing techniques may be used which merge classical mechanical testing with nondestructive examination (acoustic emission, thermography, and laser extensometry). Through simultaneous application of these techniques, quantitative evaluation of the properties – morphologies relationships may be performed [1, 2].

In case of composite materials, especially of “sandwich” structure type, active and passive infrared thermography [3] became a current technique to monitor mechanical testing. Active thermography allows the detection and the characterization of exfoliation between layers [4] in different stages of testing and the passive one allows the localization of crack initiation.

However, these characteristics are determined for base materials, for ideal exploitation conditions, respectively. In service, one finds a different situation and deviations from the ideal reference condition appear. The thermal joining processes affect the local characteristics of the material [5], leading in some particular situations to the modification of the long term characteristics of the component.

Also, during the assembly process, when setting into operation, or during the exploitation, deviations from the technological procedure or failures may appear, that are considered unimportant but can affect the residual life of the components.

External factors such as temperature can change the material structure in the joining area. As it is shown in [6], if the crystallization temperature is varied, modifications of thickness average of the stacks of lamellae and respectively the diffusion degree of molecules with lower molecular weight appear. Also, in case of improper joining temperatures (e.g. above 200˚C for polyethylene), there was shown in [7] that the oxidation and chain-session effect attended by dislocations, odour and increase of the carbonyl content.

In the manufacture process or in service, deviation from the reference condition helps the development of imperfections that can affect the designed residual live of the product.

The simulating of imperfections in order to study their evolution under different loading conditions is a fracture mechanics method [8] for the assessment of the in-service ability of some components with imperfections. So, the residual live of components in the structures [9] can be estimated.

2. Working procedure

In this work, for studying the behaviour of PE 80 pipes under mechanical loadings in the presence of plane imperfections, the compared imaging analysis technique of thermographic acquisition images obtained form different types of imperfections, in static tensile loading was used.

During the tensile test, the IR camera was used for monitoring the evolution of the PE 80 specimen degradation. The IR camera software provides changes of the specimen temperature through the test. This NDT examination technique was used for a better understanding of the deformation and the failure process of PE 80 containing simulated defects, during the tensile load.

2.1. Experimental material

For the experimental program, samples extracted from PE 80 polyethylene pipes with simulated imperfection were used. The simulation of the imperfections was performed on the stripe samples extracted from pipes of ϕ 160 $\times$ 15.5 mm. Pipes were sampled by mechanical cutting at the minimal length L min =250 mm and after than stripe samples were extracted of 20.0 mm width. The imperfections were machined by facing or by drilling.

2.2. Experimental program

The experimental program was conceived for highlighting:

2.2.1 Influence of the loading rate on the temperature and the tensile strength of the material without imperfections.

Were tested stripe samples extracted form pipes, loaded with deformation rates in the range 1 - 150 mm/min. The sample temperature was monitorized through the computerized thermography.

2.2.2 Influence of the loading rate on the maximal temperature and the tensile strength of the material with imperfections.

In the same way were tested stripe samples extracted form pipes of 2 mm diameter with hole type simulated imperfections, and the sample temperature and the tensile strength during the test were recorded.

2.2.3 Influence of the type and imperfection dimensions on the tensile strength.

Were tested in standard condition (v=50 mm/min and T=23˚C) sample with simulated imperfections (hole type, nick and V notch), with initial dimension up to 25% from the cross section of the sample.

2.3. Testing methods

The most materials are heated before the failure by mechanical tensile loading. Starting from this observation, within the experimental program for studying the mechanical behaviour of polyethylene in the presence of planar imperfections, the thermography method for highlighting the thermal emission of the sample was used.

Thermography is a non-destructive method which is based on analysis of the temperature distribution on the surface of one body ("hot spot" and "cold spot" analyses). It allows us to visualize and quantify by non-contact measurements the temperature in the target zone.

By this method it is analysed the tested samples thermal image, which distribution is changed during the testing due to the normal heat radiated by the sample in the axial static tensile loading. By infrared computerised thermography the thermal value of the simulate imperfection zone is scanned and according to the obtain value is estimated their severity and development degree [10]. Thermal value is correlated with the local tensile stresses induced by the loading of the sample with/without imperfections.

The method performances do not consist only in the assessment of the simulated defect type severity, but in the fact that it is possible to monitor the propagation simultaneously with the loading answer of the adjacent material.

Study of the material behaviour in the presence of simulated defects is performed on the bases of static tensile tests on specimens extracted from PE 80 pipes with/without simulated imperfection by mechanical machining. Tensile test at the room temperature was performed for tensile strength assessment in order to identify the position and the fracture character, under controlled testing conditions (temperature, loading rate).

2.4. Experimental setup

Experimental setup (figure 1) is:

- Universal tensile test machine: ZD 10/90 Type and EDZ 40 Type
- Thermostat area:
- Infrared thermographic camera: FLIR System A40 Type:
    - Field of view/min focus distance: 24° x 18° / 0.3 m
    - Spatial resolution (IFOV): 1.3 mrad
    - Thermal sensitivity @ 50/60Hz: 0.08°C at 30 °C
    - Focusing: Built-in focus motor
    - Detector type: Focal Plane Array (FPA), uncooled microbolometer
    - Spectral range: 7.5 to 13 µm
    - Temperature ranges: -40°C to +120°C
    - Accuracy (% of reading): ± 2°C or ± 2%
    - Measurement modes: Spot, Area, Isotherm, Difference
    - Automatic emissivity correction: Variable from 0.1 to 1.0
    - FireWire (IEEE-1394): 16-bit image output en control

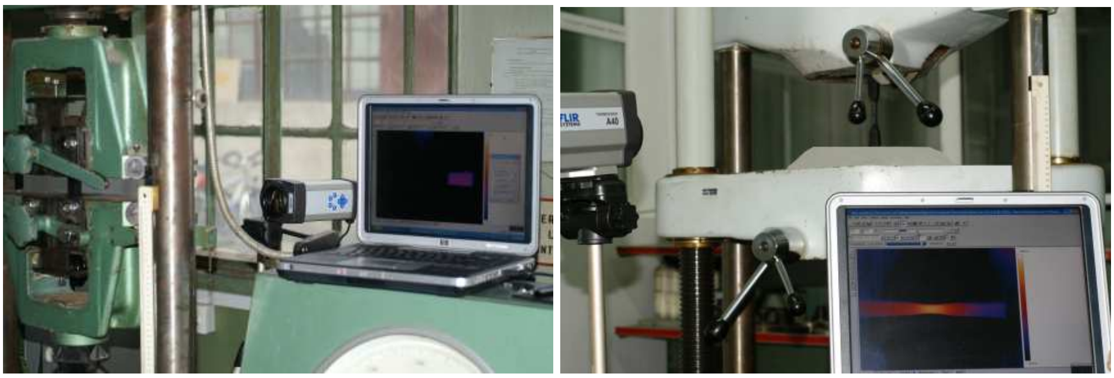

Figure 1. Experimental setup

3. Experimental results

This section deals with an example of application of the TT-IRT method to study the mechanical loading behaviour of the stripe samples extracted form PE 80 polyethylene pipe. Figure 2 presents thermal imagine of the sample recorded during the tensile test (pct. 2.2.1 form experimental program).

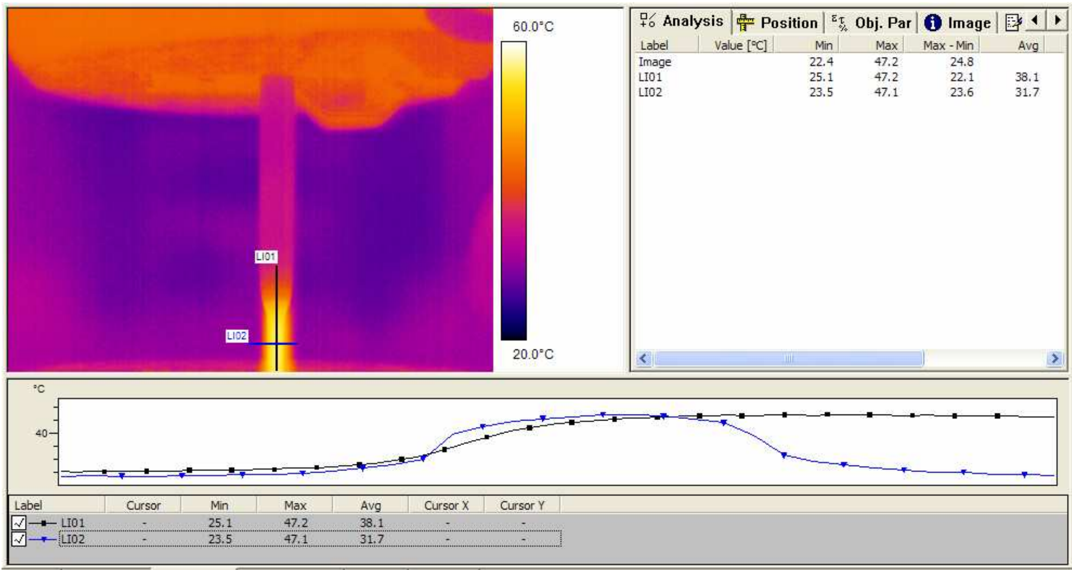

Figure 2. Thermal distribution on two perpendicular directions (LI 01 and LI 02), for the tensile stress sample without imperfections

In this case the failure takes place as stress concentration effect on sample locking area in the grips. Maximal temperature was obtained on the loading axis, in the centre of the sample.

Figures 3 and 4 present the thermal imagine of a sample with holes type simulated imperfection, during the tensile test (pct. 2.2.2 from the experimental program).

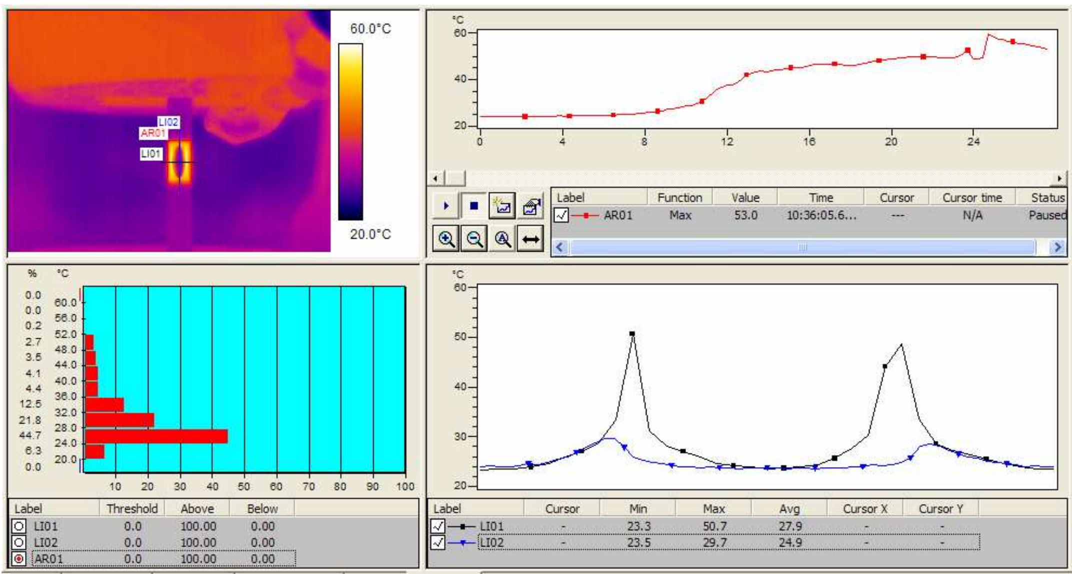

Figure 3. Thermal distribution on two perpendicular directions (LI 01 and LI 02) and in failure zone (AR 01), for a sample with a holes type imperfection placed in the central area

It is observed that the maximal temperature is found on LI 01 direction, in the central area of the minimal cross sections.

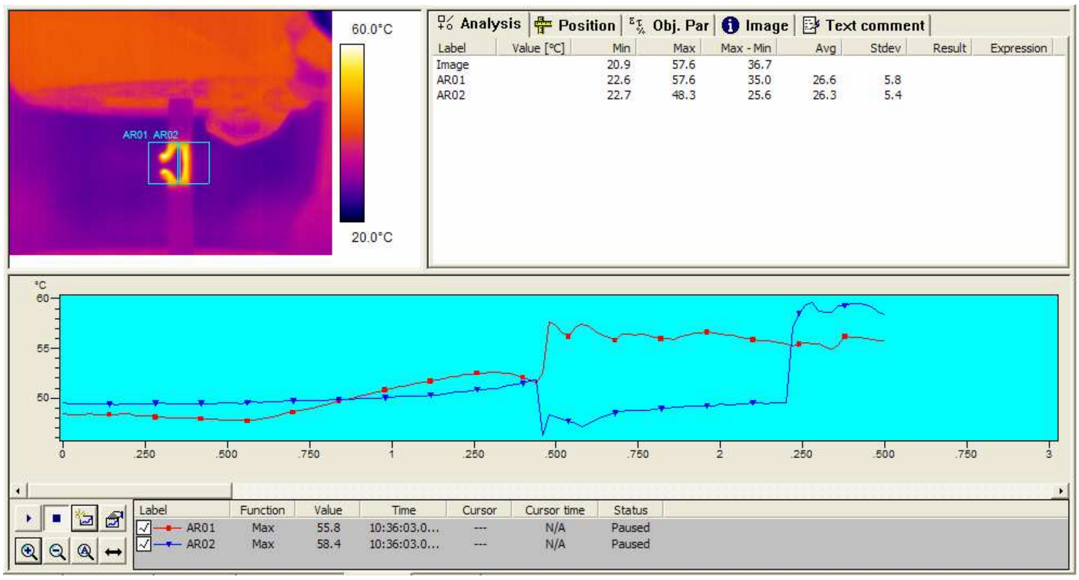

Figure 4. Temperature evolution in failure zones (AR 01 and AR 02), for the sample with a hole type imperfection placed in the central area

In the failure moment, it is observed a rapid increasing of the recorded temperature, due to the fact that in that moment it is possible to reveal the maximal temperature recorded in the centre of the failure cross section.

Figures 5 and 6 present comparative results of the experimental programs form pct. 2.2.1 and 2.2.2.

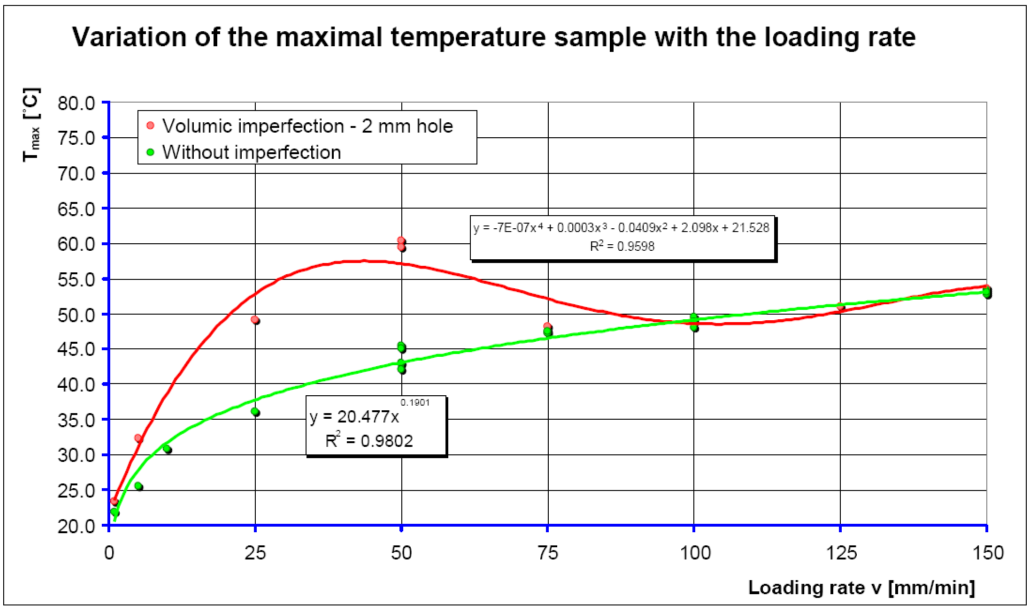

Figure 5. Maximal temperature variation of the sample depending on the loading rate

From figure 5 it is observed that for 50 mm/min loading rate, a hole type defect which fills 10% form the cross section of the sample, determines the increase of the sample local temperature with over 30% as compared with the temperature which is obtained when testing a sample without imperfections.

In the case of thermoplastic materials mechanical properties are significantly falling as the temperature increases. The local heating of the sample with imperfections at the loading rate of about 50 mm/min, determines a reduction of the tensile strength, a fact also underlined by the results of experimental program (figure 6).

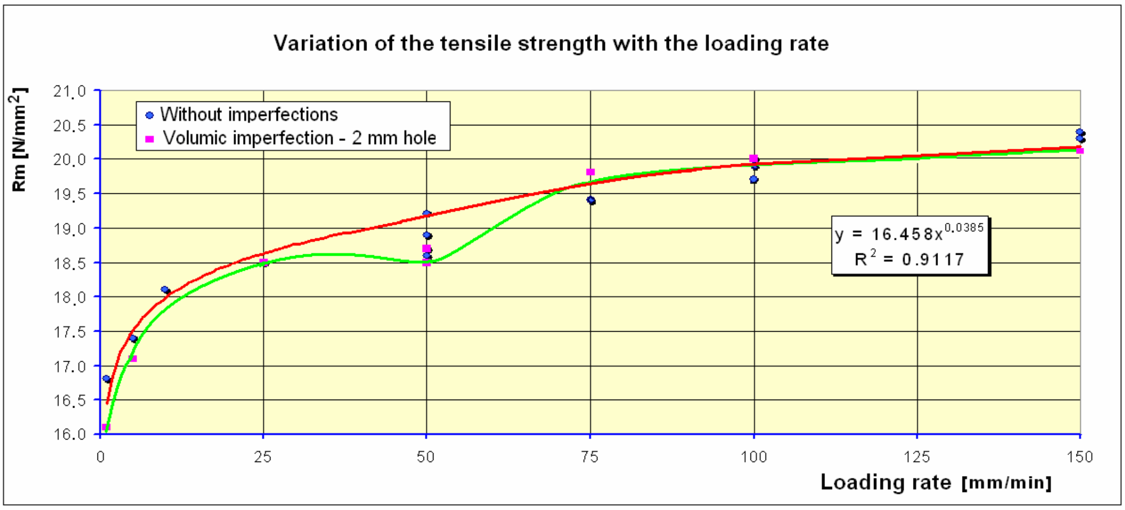

Figure 6. Tensile strength versus the loading rate

The results of the experimental program form pct. 2.2.3 are graphically presented in figure 7. It is observed that for defect dimensions lower than 25% of failure cross section, the hole type imperfections determine additional reducing of the tensile strength as compared with the nick or notch type imperfections. The tensile strength curves versus the size of the simulated defect are of similar shape.

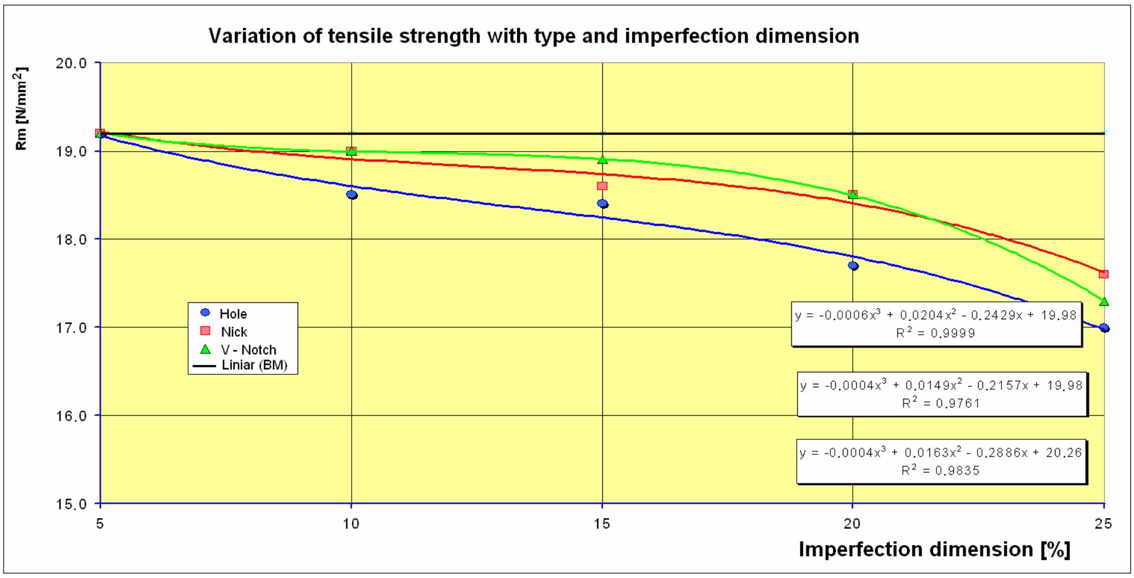

Figure 7. Tensile strength versus the type and dimension of imperfections

4. Conclusion

- In the case of PE 80 polyethylene type, when testing the material considered as homogenous, the loading rate has an important influence on the determined characteristics. The tensile strength increases when the loading rate increases depending on a power function.
- The tensile loading rate influences the maximal temperature of the sample during the testing. For the homogenous material, without imperfections, the maximal temperature increases when the loading rate increase depending on a power function.
- The imperfections of the material lead to a decrease of strength characteristics and a significant local increase of the temperature during the tensile testing, depending on the temperature recorded when testing homogenous materials.
- In the case of materials with moderate imperfections (which occupy 10% from the cross section of the sample), the most accentuated temperature difference, as compared with that of the homogenous material, is obtained at loading rate of about 50 mm/min, a fact that recommends this loading rate to be used when checking the quality of PE 80 polyethylene pipe products.
- Experimental results obtained for the PE 80 thermoplastic material, evince the fact that under standard testing conditions (v=50 mm/min and T=23˚C), imperfections which are smaller or equal with 5% of the sample cross section, are not stress concentrators to determine the sample failure, their effect on the determined mechanical characteristics is neglected.
- Volume imperfections, integrated into the material, with dimensions up to 25% of the sample cross section, decreases more the determined strength characteristics, as compared with those on the surface with similar dimensions (flaws or notches).
- The paper presents an example for the application of the TT-IRT hybrid technique when assessing the PE 80 polyethylene type behaviour at notch and other materials/products, both in the elaboration/ fabrication stage, as well as after a certain service life. Using this method estimations can be obtained regarding the critical defect which leads to the failure as well as information on the in service behaviour of the material in the presence of different type of imperfections, long before they act by producing failures.

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