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Cyclic loading effect on the mechanical behaviour and morphology of the high density polyethylene

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1. Introduction

High density polyethylene (PEHD) pipes are still widely used in the transportation and distribution of natural gas. Updated statistics indicate that more than 90% of the gas-networks are actually made of PEHD, this, could be attributed to its easy setting up procedure, the attractive ratio of its performances to its weight and its attractive cost relatively to its long- term resistance to chemical agents. The mechanical properties of structural pipes made of PEHD have been previously studied by many researchers; investigations dealing with many aspects of their behaviour have been reported in the literature. Variations of the mechanical properties have been investigated [1]. Hamouda et al. investigated the effect of the type of loadings on the behaviour of the polyethylene [2]; the failure mechanism has been studied by Baer [3], Byoung-Ho [4]. The environmental issues were discussed y Zhou [5].

Methods for the determination of strength at failure under impacts and during crack's propagation were developed specifically for this type of material. Pipes used for gas transportation are usually used under working high pressures. Pressure fluctuations makes the load applied to the pipes more dynamic. Under such conditions it is useful to estimate the maximal pressure loads to which such pipes could resist without experiencing any deformations or failure during the serviceability period. Mechanically the PEHD are characterised by the long term hydrostatic strength (LTHS) and by the minimal required strength (MRS), their design should conform to the ASTM D2837 and ASTM D2513 norms.

The most common characterisation mode is presented by the normalised pulling-out (tension) test with constant lengthening (extension) rate. It is however, well known that when a solid is subjected to cyclic stresses, failure could happen for maximal stress corresponding to the values well beyond the loading failure and even at elastic limits: this is well known as the fatigue (weariness). Physically, the application of cyclic stresses to a solid material, including plastic, leads to the evolution of atomic processes and variable molecular which could lead to local microscopic damage.

This paper presents the results of an experimental investigation dealing with the mechanical behaviour of a high density polyethylene grade 80 (PEHD 80), tested under cyclic pulling-out (tension) loading. The effect of the number of cycles and the level of loading upon mechanical properties of the material and its morphology is reported and discussed.

2. Experimental investigation

2.1. Material properties and sample preparation

The type of material considered, is used in the production of pipes, intended to natural gas transportation. These pipes are designed to resist internal loading pressure of 4 bars; they are manufactured by an Algerian Company (Sotuplast Chlef). The high density polyethylene is a thermoplastic derived from hydrocarbons, produced by adding polymerisation, and transformed by extrusion, its main physical properties are presented in Table 1.

Table 1

Physical properties of the PEHD 80

Volumetric Mass, g/cm^3	0.95 to 0.98
Fluidity index (at 190 °C), g/ min	0.75
Back carbon content, %	2.0 to 2.6
Rate of crystallizing (in volume)	73 to 82
Vitreous temperature Tg, °C	125
Melting temperature,°C	137

The samples used for the fatigue tests, are cut from tubes made of PEHD 80, having an external diameter of 40 mm and internal diameter of 32 mm. The cutting was done following the parallel line to the extrusion side. The samples were used without heating nor flattening, using "piece's carrier" as recommended by the NF T54 – 074 norms. The samples shape and detailed dimensions are presented in Figs. 1 and 2 respectively.

Fig. 1 Shape of the samples

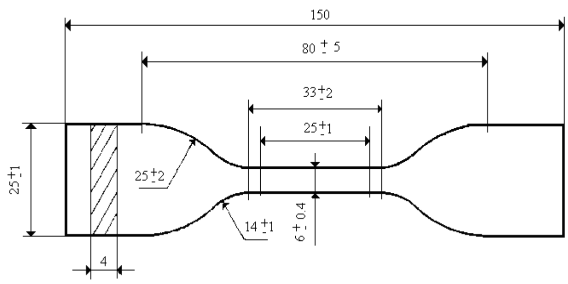

Fig. 2 Detailed dimensions of the sample

2.2. Fatigue tests

Fatigue tests have been conducted using a Universal testing machine (type ZWICK ROELLE Z005), with a loading capacity of 5 kN. This machine is equipped with a computer controlled system for the data recording and data processing (testxpert).

Cyclic-test series at constant rate (speed) of 10 mm/min have been carried following a prescribed displacement for a number of cycles varying between 1 and 10000, corresponding to two levels of loadings, ie. 50% and 70% of ΔL_{se}. Each tests series is followed by a pulling-out loading until failure occurs. The cycling frequency is maintained constant at the value of 2 Hz. It should be mentioned that a simple pulling-out test has been carried out prior to cycling, in order to investigate the effect of the loading rate. Based on the results the maintained a testing rate is 10 mm/min. To investigate the effect of the cycling on the material morphology, observations using optical microscope have been carried out.

3. Results and discussion

The mechanical behaviour of PEHD 80 when subjected to static pulling-out stresses is presented by means

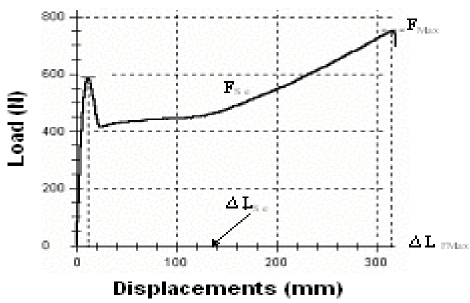

Fig. 3 Load-displacements curve (for v = 10 mm/min)

of load-displacements curve in Fig. 3. At constant rate of loading; the elastic modulus was calculated for the deformation range within of 0.05 to 0.25 %, according to the ISO 527–1: 1993 (F) norms. The experimental values of mechanical properties are presented in Table 2.

Table 2

Mechanical properties of the PEHD 80

E, N/mm^2	$F_{S\,e}$, N	$\Delta L_{S\,e}$, mm	F_{Max}, N	ΔL_{Fmax}, mm
163	585	11.8	750.07	317.02

Figs. 4 and 5 show the mechanical behaviour of PEHD 80 under cyclic pulling-out corresponding to two levels of loading: 50% and 70% of $\Delta L_{S\,e}$. These figures illustrate the fact that high density polyethylene exhibits an elastic behaviour as of the most polymers during cyclic loading. A large hysterics loop is observed for the first cycle, then, it reduces according to the increase of the number of cycles. The present observations were found to be in close agreements to many results reported in the literature, e.g. [6].

Fig. 6 illustrates the progression of loading against the number of cycles. This figure shows a typical cyclic softening of the material from the early stage of loading, which reduces progressively for the following cycles. Beyond 1000 cycles an apparent stability of the material is observed, this, was valid for both levels of loading.

In Fig. 7 the elastic modulus is plotted against the number of cycles. From this figure it could be argued that the linear Young modulus increases three times from the first cycle. This could be attributed to the alignment of lamelas and to the morphological evolution of material [6]. This phenomenon could also be explained by the widening of the "covalent" links proportions, parallel to the direction of stresses, which causes increases of the elasticity modulus [7].

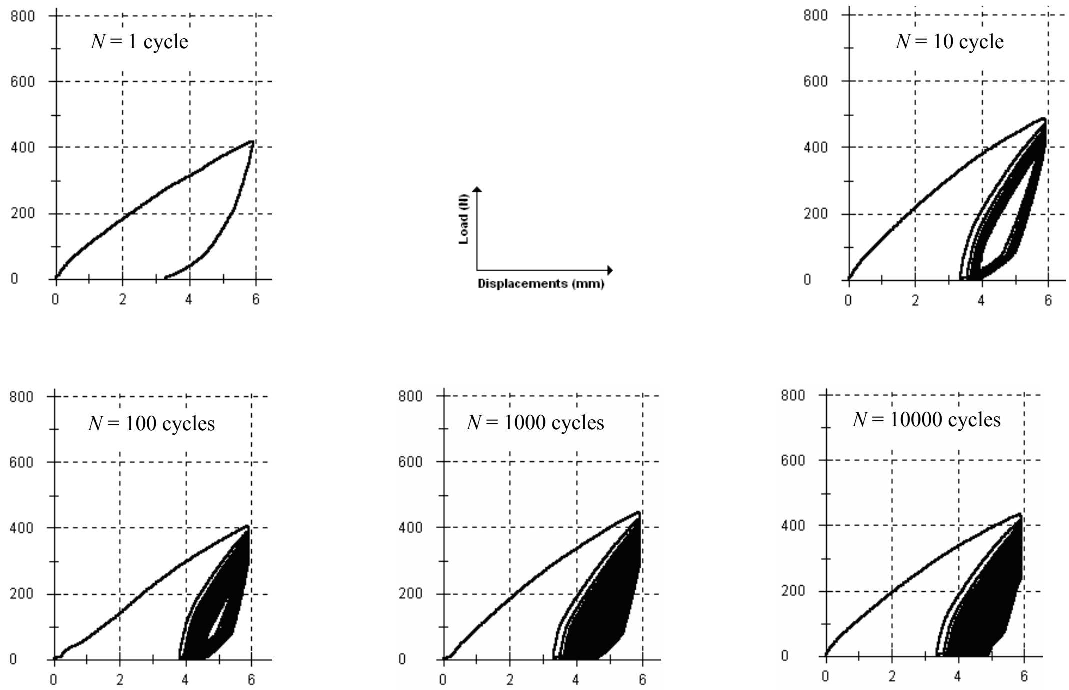

Fig. 4 Load-displacements curves (for a loading level of 50% $\Delta L_{S\,e}$)

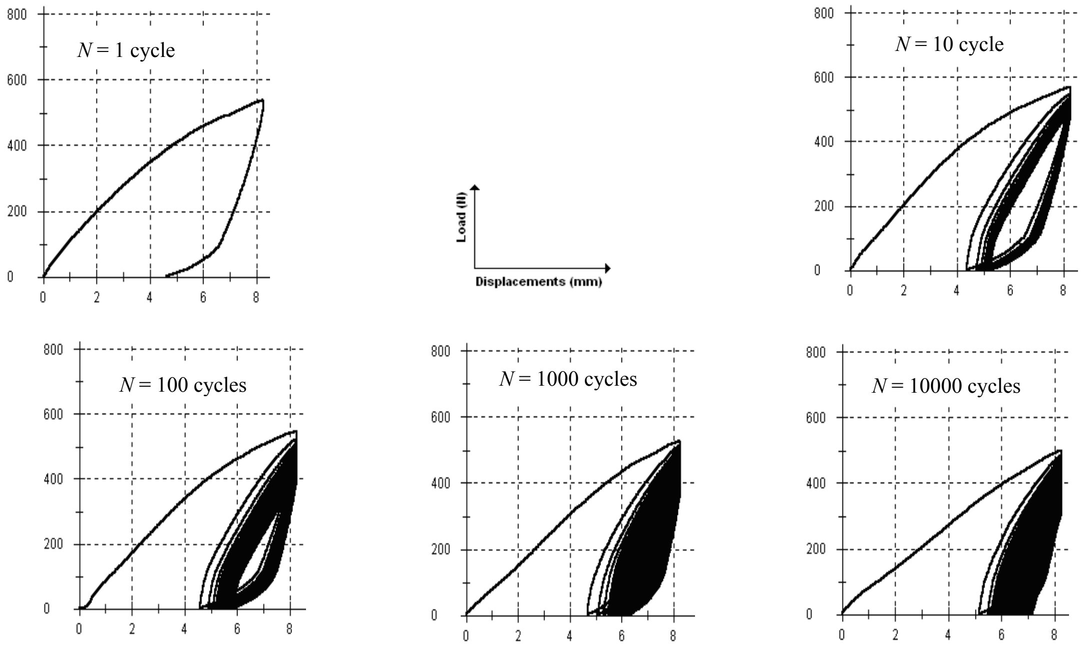

Fig. 5 Load-displacements curves, (for a loading level of 70% $\Delta\ L_{S\,e}$)

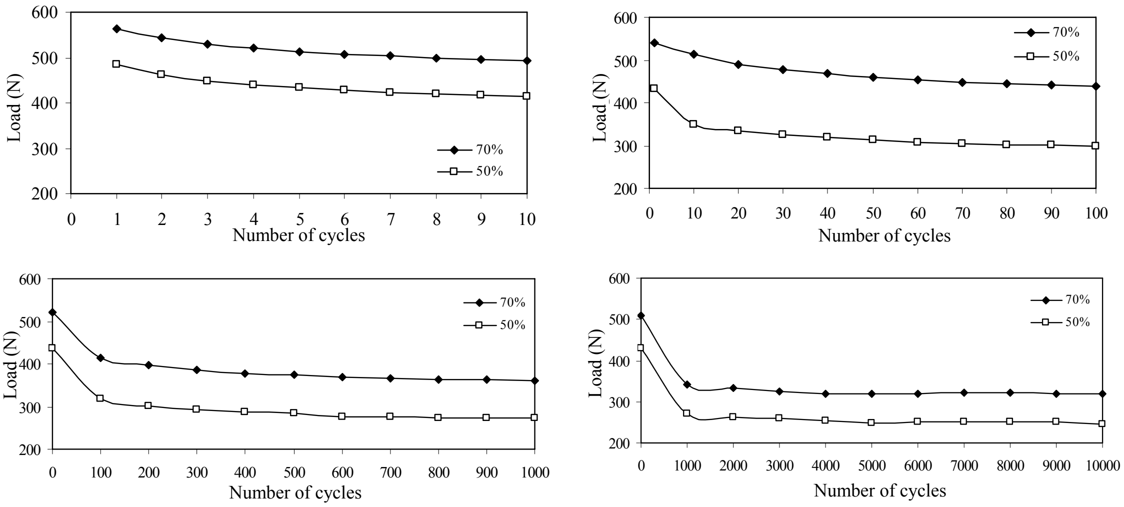

Fig. 6 Cyclic loadings against the number of cycles, (for level of loading 50% and 70% $\Delta\ L_{S\,e}$)

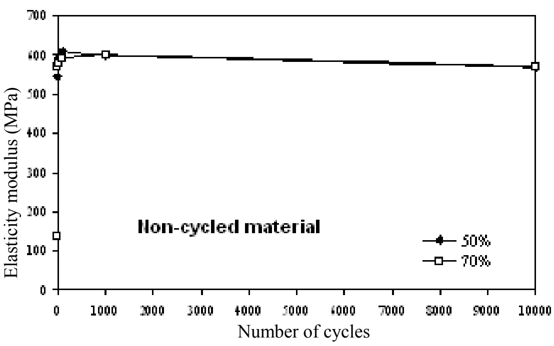

Fig. 7 Elasticity modulus against number cycles (for level of loading 50% and 70% $\Delta\ L_{S\,e}$)

Observations using the optical microscope of the PEHD 80 for noncycled and cycled structures, illustrated in Figs. 8 and 9, for different level of loadings, show clear orientation of lamellas towards the direction of loadings. The increasing level of alignment is more pronounced for the samples of the material cycled 100 times. The increase of the level of loading leads to an increase of the lamellas alignment, mainly for the level 70% (Fig. 9, b). Figs. 8, d and 9, d show that at 1000 cycles, the structure follows a lamellas pack rearrangement with lower density and better orientation, compared to the noncycled structure.

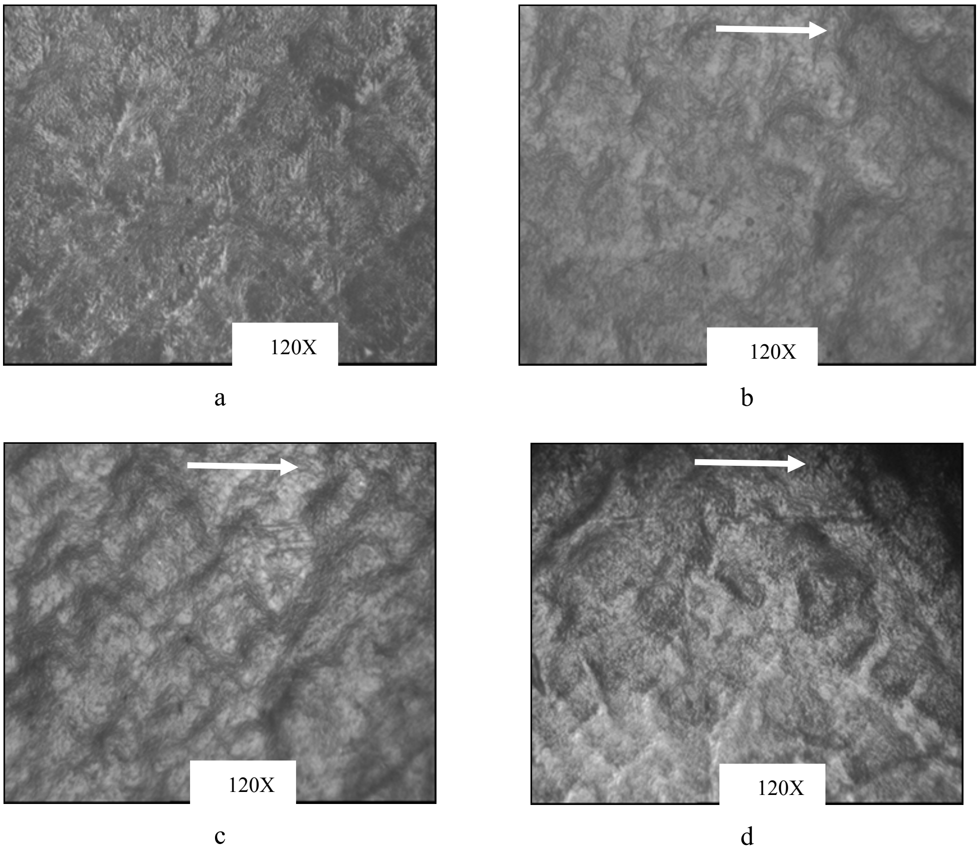

Fig. 8 Structures of the PEHD 80: (a) noncycled, (b) 1 cycle, (c) 100 cycles and (d) 1000 cycles (for loading level of 50%ΔL_{Se})

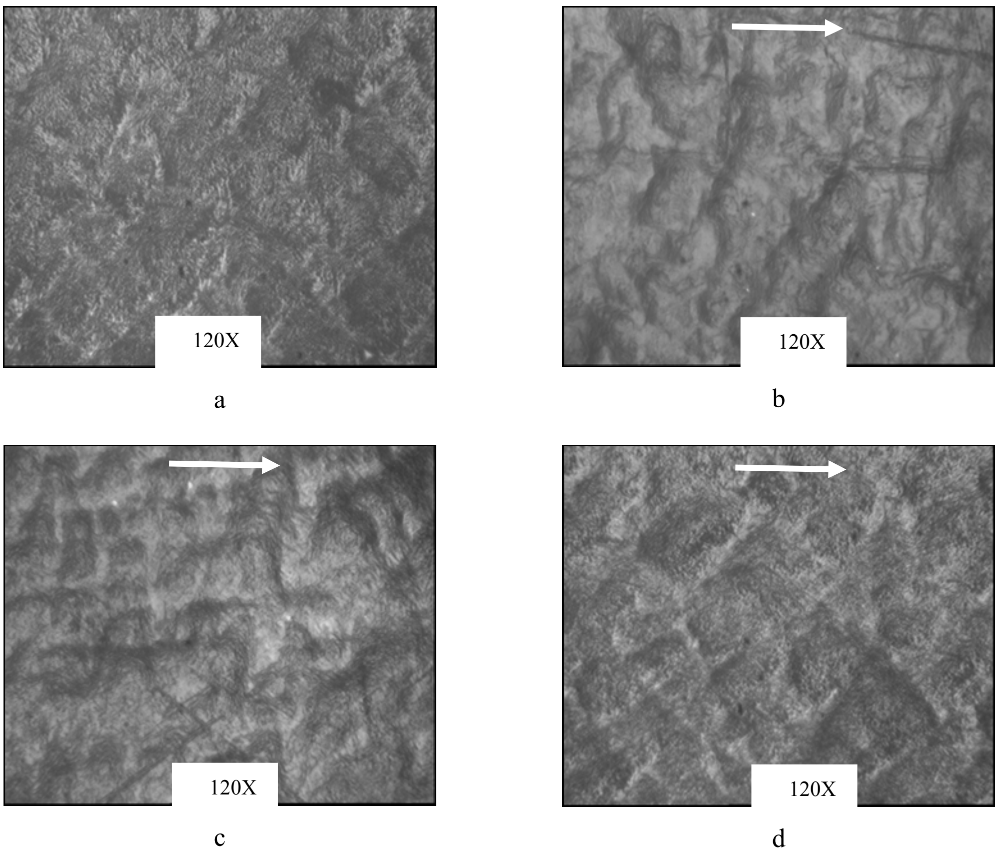

Fig. 9 Structures of the PEHD 80 (a) noncycled, (b) 1 cycle, (c) 100 cycles and (d) 1000 cycles (for loading level of 70%ΔL_{Se})

4. Conclusion

The present research work is a part of the comprehensive experimental investigation on mechanical behaviour of high density polyethylene PEHD 80 under cyclic loading.

The cycling of the PEHD80 leads to a considerable increase of the elasticity modulus from the first cycles. Cyclic softening of the material for the first 1000 cycles was observed, followed by cyclic stability beyond this number of cycles.

Optical microscopic observations illustrate a crystalline lamellas orientation parallel to the axis of applied load, the alignment degree is a function of the level of loading mainly for the 1000 cycles.

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CIKLINĖS APKROVOS POVEIKIS DIDELIO TANKIO POLIETILENO MECHANINĖMS SAVYBĖMS IR MORFOLOGIJAI

R e z i u m ė

Didelio tankio polietileniniai vamzdžiai (PEHD 80) iki šiol plačiai naudojami gamtinėms dujoms transportuoti ir paskirstyti. Eksploatacijos metu juos veikia vidinis bei atmosferos slėgiai, grunto poslinkiai, jais tekančio skysčio dinaminės jėgos. Šie įtempiai sukelia dideles vamzdžių medžiagos deformacijas ir keičia jos mechanines savybes. Šiame darbe eksperimentiškai tyrinėta ciklinės apkrovos įtaka PEHD 80 markės vamzdžių funkcionavimui. Bandymų metu bandiniai buvo tempiami iki suirimo. Tempimo kreivės, apibūdinančios PEHD 80 vamzdžių mechanines savybes, rodo, kad pirmųjų bandymų ciklų metu formuojamos didelės histerezės kilpos, kurios, didėjant ciklų skaičiui, mažėja. Nustatyta, kad ciklinė apkrova didina medžiagos linijinį standumą ir ciklinį sipnėjimą. Stebint mikroskopu matyti, kad makromolekulių grandinės išsidėsčiusios tempimo kryptimi.

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CYCLIC LOADING EFFECT ON THE MECHANICAL BEHAVIOUR AND MORPHOLOGY OF THE HIGH DENSITY POLYETHYLENE

S u m m a r y

High density polyethylene pipes (PEHD 80) are still widely used in the distribution and transportation of natural gas. While in use, these materials are exposed to internal pressures, to earth pressures, to soil movements and to the dynamic effect of the liquid displacements. These stresses induce inevitably, considerable deformations of the tube's material and affect its mechanical properties. In the present work, the effect of cyclic loading on the behaviour of PEHD 80 tubes is experimentally investigated. Samples are tested to cyclic loadings followed by the pulling (tension) until failure of the material. The curves expressing the mechanical behaviour obtained indicate clearly that the PEHD 80 exhibits large hysteretic loops for the first loading cycles, and then the loops decrease according to the increase of the cycle number. It was concluded that cyclic loading causes a considerable increase in the linear stiffness and the cyclic softening of the material. At microscopic levels, the observations have showed parallel orientation of the macromolecular chains to the tension axis.

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ВЛИЯНИЕ ЦИКЛИЧЕСКОЙ НАГРУЗКИ НА МЕХАНИЧЕСКИЕ СВОЙСТВА И МАРФОЛОГИЮ ПОЛИЭТИЛЕНА БОЛЬШОЙ ПЛОТНОСТИ

Р е з ю м е

Полиэтиленовые трубы (PEHD 80) изготовленные из полиэтилена большой плотности, до сих пор широко используются в газопроводах. Во время эксплуатации они подвергаются воздействиям внутреннего и атмосферного давлении, сдвигам грунта, динамическим силам протекающей жидкости. Возникшие напряжения при этом вызывают большие деформации материала трубы, которые меняют ее механические свойства. В работе экспериментально исследуется влияние циклической нагрузки на функциональность труб газопровода марки PEHD 80. Во время экспериментов образцы нагружались до разрушения. Диаграмы деформирования, характеризующие механические свойства труб марки REHD 80, показывают, что во время первых циклов формируются большие петли гистерезиса, которые при увеличении числа циклов уменьшаются. Установлено, что циклическая нагрузка увеличивает линейную жесткость и циклическое разупрочнение образца. На уровне микроскопических исследований цепи макромолекул распределяются по направлению растяжения.

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