EXPERIMENTAL STUDY OF CREEP BEHAVIOR OF HIGH-DENSITY POLYETHYLENE AND STRESS TRIAXIALITY EFFECT

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In a previous work, we presented a study of mechanical behavior of the high-density polyethylene (HDPE) under several types of stress: tensile, compression, shear and biaxial loading; and we have shown the hydrostatic pressure effect on polyethylene yield behavior [1]. In order to complete it, the creep behavior of this material at different stress level is investigated experimentally at constant strain rate and at ambient temperature.

The first objective is to determine the different stages of creep as a function of the applied stress and to explain the deformation mechanisms of the material occurring during each stage. Similarly, the sensitivity of creep to stress triaxiality is the subject of our investigation by the use of axisymmetric notched bar specimens with different radii.

Keywords: creep test, triaxiality; HDPE, mechanical behavior, strain rate

1. Introduction

The mechanical behavior of HDPE in uniaxial loading has been treated by several authors. Some studies are focalized on viscoelastic and viscoplastic response of this material during uniaxial loading [2-7]. Stress-strain relations have been developed in order to model this behavior [8-11]. On the other hand, the creep behavior of this material remains to be discovered. It is in this context that we were interested in carrying out a series of creep tests at constant imposed stress and at an ambient temperature of 25 °C. The description of creep stages: primary, secondary and tertiary and the stress influence on creep behavior are presented in this work. In addition, the influence of the stress triaxiality will be explored by the use of the notched round bar Specimens with different curvature radii (2, 4, 10 and 80 mm). The geometry of the sample in the center allowed to obtain low and high triaxialities (0.33, 0.44, 0.6 and 0.8) [12-14]. Since the HDPE is a semi-crystalline material, composed of two phases: amorphous and crystalline; deformation mechanisms are more complex than those observed in metals. The

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deformation mechanisms for each creep stage will then be unveiled in results discussion.

2. Material and specimen geometry

The material investigated in this study is a high-density polyethylene (HDPE). The table 1 lists its major characteristics. The specimens used in this study are the same as those used in previous works [1, 13]. Four types of notched round bar specimens with different curvature radii are used. The notch radii are R = 2, 4, 10 and 80 mm, respectively (fig. 1). The specimens are of the same minimum diameter "D" of 5 mm in the gauge sections, the same diameter "d" of 10 mm in the shoulder parts and the same length "L" of 66 mm.

Table 1

Physical properties of studied HDPE

Volumic Mass	930 Kg/m^3
Middle Mean molar mass M_w	310 000(g/ mole)
cristallinity rate X_c	66%
Melt temperature T_f	128,8°C
Indices of fluidity	0,2-1 ;4 g/10(min)

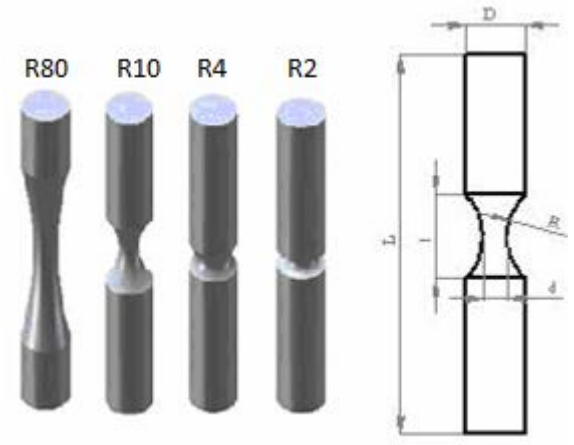

Fig. 1. Notched round bar specimens

3. Experiments and results

3.1. Applied stress levels: 5 MPa and 10 MPa

In first step, we studied the creep behavior of the HDPE under stress level of 5 MPa and 10 MPa. The tests were carried out for the four types of notched round bar specimens with test duration of 1000 seconds at constant strain rate

$\dot{\varepsilon}=10^{-3}$ s^{-1} and at ambient temperature. Fig. 2 shows the general form of creep curves, strain versus time, obtained for these tests. It presents two deformation stages: a primary stage followed by a secondary creep. The first stage also called transitory creep, represented by the parabolic form of the curve, is marked by the appearance of an elastic strain ε_0 followed by a decrease of the strain rate with time. This phenomenon is explained by the fact that the connections of the macromolecular network are not directed and consequently there is no restriction of chain mobility. Under the stress effect, these chains begin to orientate in the load direction and interferences appear between them producing creep strength. Then this resistance induces a decrease of the strain rate. That is the material hardening.

The second stage, also entitled stationary creep, is characterized by stabilization of deformation. It is represented by the linear part of the creep curve. The slope of line describing this part represents the strain rate of material. Called too, minimal strain rate; it corresponds to the most important dimensioning parameter that we can drawn from the creep curve. Subsequently, deformation of molecular chains and crystallites remains stable during this stage.

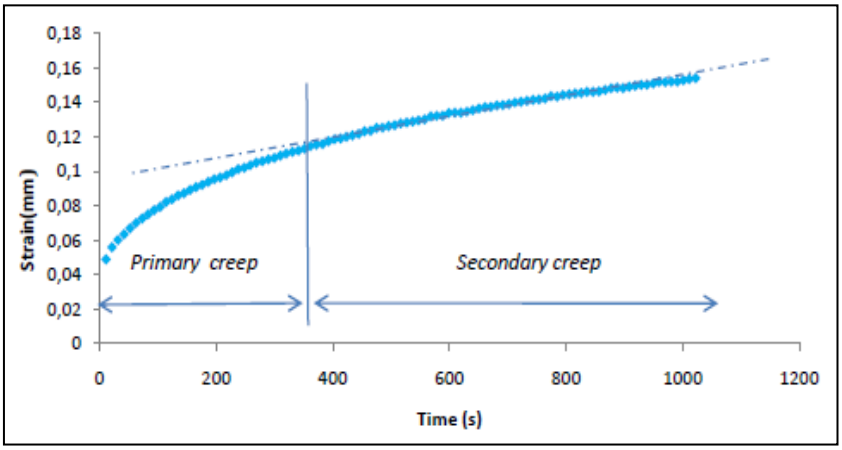

Fig. 2. Creep curve stages

In Fig. 3, 4, 5 and 6 is shown the stress effect on HDPE stress–strain response of R2, R4, R10 and R80 specimens respectively during creep tests at two different stress levels 5 and 10MPa. By comparing the creep curves with imposed stresses 6MPa and 10MPa for all specimen types, we note that the stress effect is similar. The HDPE deformation increases with stress increase. Table 2 shows this influence and we can see that the total deformation after 1000 seconds at 10MPa is more than three times as great as the total deformation at 5MPa. Also, the primary creep duration is increased under stress influence as shown in table 3. Indeed, for R2 specimen for example, the duration of primary creep passes from

186 seconds till 252 for stresses of 5 MPa and 10 MPa respectively. This effect is explained by the fact that at high stress, molecular chains turn and align themselves more, and take more time in this stage. By comparing linear part slopes of the recorded creep curves, we notice an increase with increasing stress (table 4). So, the strain rate of the material is more affected by stress and it's more important at 10MPa. Molecular chains in the amorphous phase endures then an important extension and crystallites endures sliding parallel to chains by heterogeneous shearing.

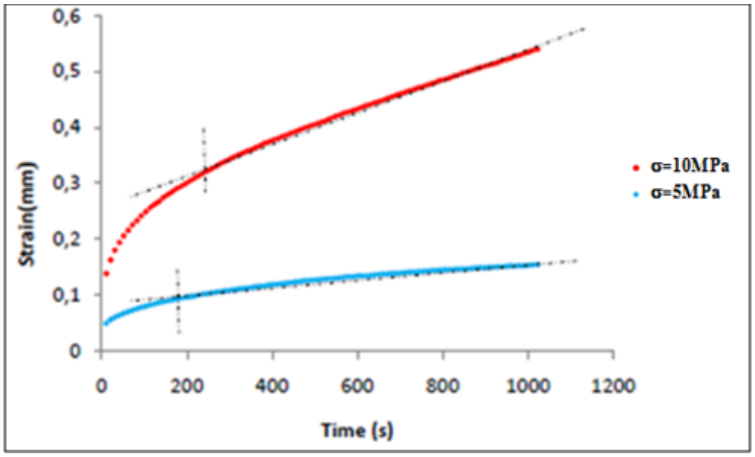

Fig. 3. Strain versus time curves in the creep experiments at two different stress levels for R2 specimen

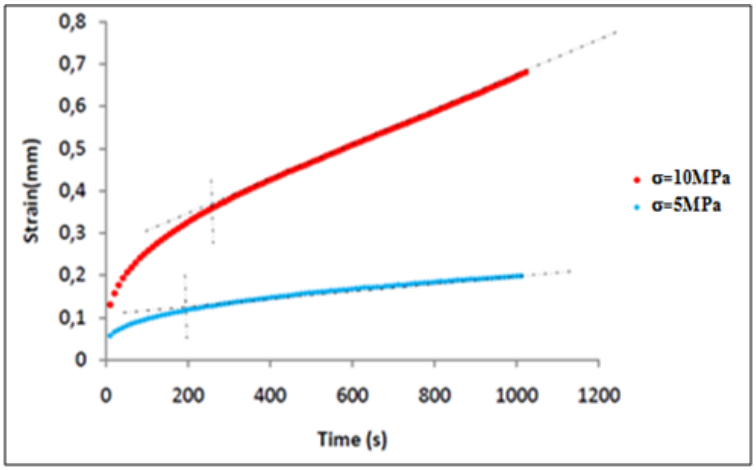

Fig. 4. Strain versus time curves in the creep experiments at two different stress levels for R4 specimen

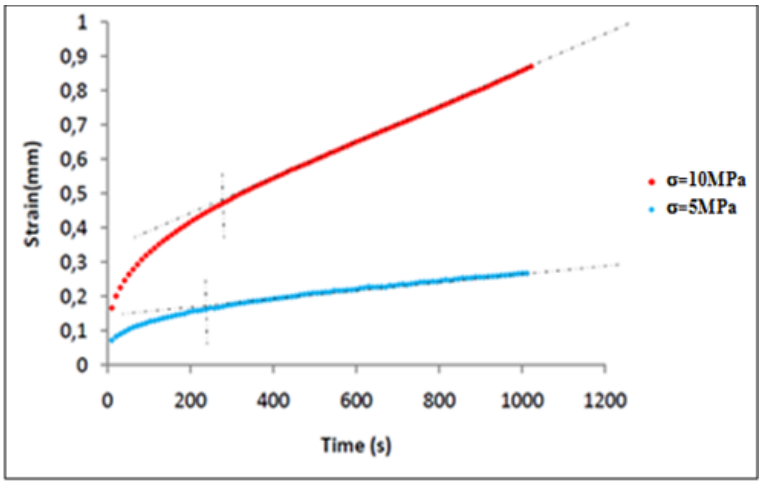

Fig. 5. Strain versus time curves in the creep experiments at two different stress levels for R10 specimen

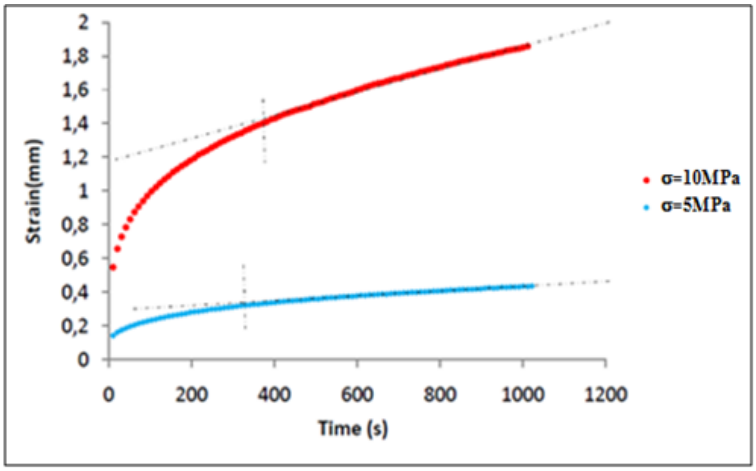

Fig. 6. Strain versus time curves in the creep experiments at two different stress levels for R80 specimen

The creep behavior sensibility of HDPE to the stress triaxiality is investigated by using notched round bar specimens. Developed triaxilities during creep tests are 0.8, 0.6, 0.44 and 0.33 for R2, R4, R10 and R80 specimens respectively. Figure 9 and 10 shows the creep response of HDPE at imposed stress 5MPa and 10 MPa respectively for these four specimen types. As shown in table 2, 3 and 4 the high triaxiality decreases the total deformation of specimen after 1000 seconds of creep. Thus, we registered the lowest values of the deformation for the highest triaxiality 0,8 (Table 2). The same effect is noticed for a primary creep period and for strain rate where we registered the lowest values for the triaxiality 0,8 developed by the curvature radii of 2mm.

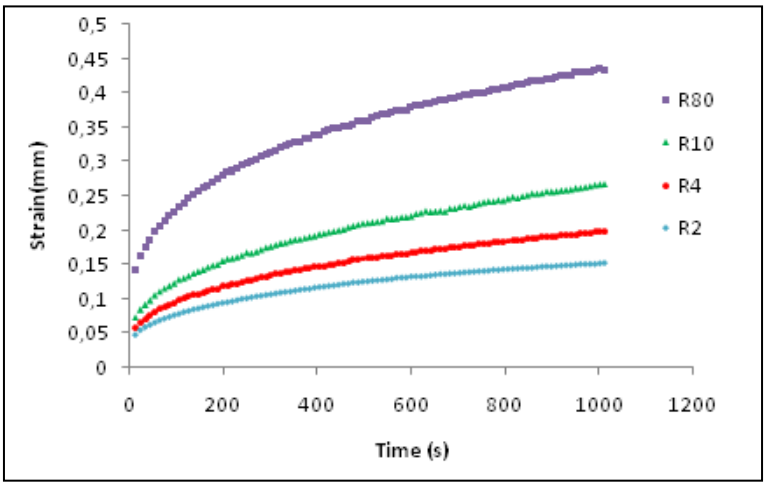

Fig. 7. Strain strain versus time curves in the creep experiments at 5MPa for R2, R4, R10 and R80 specimens

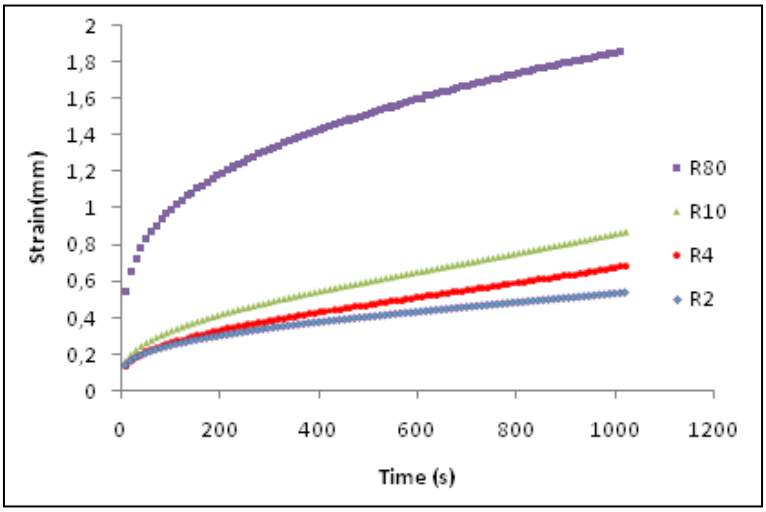

Fig. 8. Strain strain versus time curves in the creep experiments at 10MPa for R2, R4, R10 and R80 specimens

Table 2

Total deformation (mm) after1000 seconds of creep

	σ=5MPa	σ=10 MPa
R=2	186	252
R=4	192	256
R=10	240	280
R=80	328	376

Table 3

Beginnings of secondary creep (seconds)

	σ=5MPa	σ=10 MPa
R=2	0.15	0.53
R=4	0.19	0.67
R=10	0.26	0.85
R=80	0.43	1.84

Table 4

Strain rate $\dot{\varepsilon}.10^{-5}$(mm/s)

	σ=5MPa	σ=10 MPa
R=2	186	252
R=4	192	256
R=10	240	280
R=80	328	376

3.1. Applied stress level: 12 MPa

In second step, we performed creep tests on two types of notched round bar specimens: R4 and R10. The applied stress is 12MPa. Compared with creep under stresses 5 and 10MPa; the creep behavior of HDPE in this case presented a tertiary creep in addition to the primary and secondary creep described previously (fig. 9). During this stage, a fast increase of deformation is observed. In fact, we noticed that the deformation quickly increases for both types of specimens since 24 and 82 seconds respectively in exponential way. Therefore, the duration of the primary and secondary creep is very low compared with that obtained in at 5 and 10 MPa creep stress for the same types of specimen.

It has shown that plastic deformation of semi-crystalline polymers is generally inhomogeneous at micro and macroscopic level, because it involves deformations in both amorphous and crystalline phases [15-21]. It must accommodate the total deformation; the amorphous phase passes the stress in the crystalline parts via the fibrillation phenomenon. Furthermore, cavities form, which pulls an increase of the plastic zone and leads to a strong energy consumption within the material [22-24]. In that case, we attend a material damage during the tertiary creep and a training of necking in the center of specimen. In fact, when the specimen section decreases roughly, the macroscopic stress increases rapidly as the stress creep imposed is constant. Consequently, the material deformation accelerates.

The stress triaxiality influence in this case of imposed stress (12MPa) on creep behavior of HDPE, is more visible on the length of secondary creep. Indeed, its duration for R10 specimen presenting 0.44 triaxiality, is longer than that obtained for R4 specimen developing 0.33 triaxiality (Fig. 10).

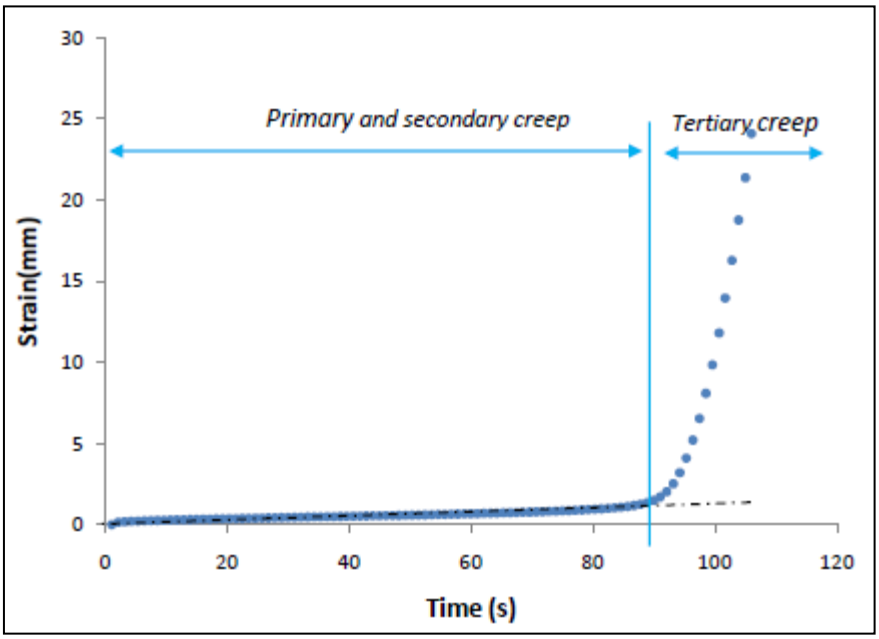

Fig. 9. Creep curve stages at imposed stress 12MPa

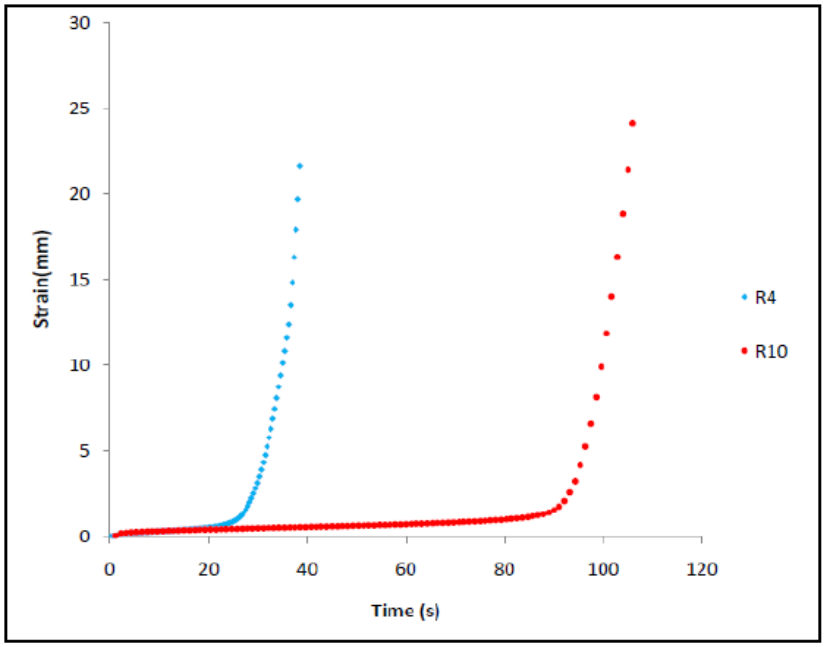

Fig. 10. Strain versus time curves in the creep experiments at 12MPa for R4 and R10 specimens

6. Conclusions

In this work, the imposed stress effect during creep tests of high-density polyethylene was revealed. In fact, it affects the primary creep duration, the material deformation and the material strain rate during the secondary creep. The application of a high stress in creep, equal to 12MPa in this case, led to the appearance of tertiary creep describing the material damage.

Also, we showed the behavior sensibility of the stress triaxiality during creep. However, it involves the duration of the primary creep as well as the stress rate of the material. This influence is more visible in the high creep stress of 12MPa, where we noticed a longer secondary creep in low triaxiality 0.33.

R E F E R E N C E S

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