STRAIN LIFE FAILURE OF HDPE,PP AND PMMA POLYMERS +

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Abstract:

The present work comprises the low cycle fatigue testing for three types of polymer materials, high density polyethelen (HDPE), polyproplene (PP) and polymethyl methacrylate (PMMA). The LCF tests carried out using standard specimens of cantilever beam type. The results confirmed that the behavior of the strain life of polymers is similar to behavior of the strain life of metals (ductile). The HDPE and PP recordedthevalues of fatigue strength exponent (b) and the fatigue ductility exponent (c) within the general limitation of the ductile metals. The results confirmed the number of transition cycle (N_T) are most convergence between the HDPE and PP whereas noted, there is large difference between these materials with PMMA , and the plastic strain of PMMA are zero ,this mean that the material is not ductility.polymethyl methacrylate polymer exhibits sensitivity to external stress concentration in terms of reduction of total strain amplitude with lower value of the notch radius.

عمر فشل الانفعال لأنواع البوليمرات (PE,PMMA,PP)

علي احمد علي

المستخلص:

اشتمل البحث على اختبار فشل الكلال بعدد دورات منخفضة لثلاثة أنواع من المواد البوليمريةالبولي اثيلين عال الكثافة والبولي بروبلين إضافةإلى البولي مثيل ميثاكرليت. اجري الاختبار على عينات قياسية من النوع المسند من جهة واحدة(cantilever beam). أكدت نتائج الفحص ان شكل منحني الكلال للبوليمرات مشابه الى حد ما لشكل منحني الكلال منخفض الدورات للمعادن.سجل البولي اثيلين والبولي بروبلينقيماً لأس معامل متانة الكلال (b) وقيماً لأس معامل مطيلية الكلال (c)ضمن حدود المعادن المطيلية. أكدت النتائج ايضا ان هناك تقاربا كبيرا في العمر الانتقالي بين المادتين المذكورتين اعلاه بينما لوحظ ان هناك تباينا كبيرا بين تلك المادتين ومادة البولي مثيل ميثاكرليت حيث انه لايوجد أي تمثيل للانفعال اللدن للبولي مثيل ميثاكرليت، وذلك لان المادة غير مطيلية . اظهر بوليمرالبولي مثيل ميثاكرليت تأثره بمركزات الاجهادات السطحية من حيث انخفاض الانفعال الكلي مع زيادة انخفاض قيمه نصف قطر الحز.

Introduction :

Polymeric materials subjected to cyclic loading are highly susceptible to fatigue failure, which often precedes monotonic or creep failures at similar applied load levels. Substantial effort has thus been devoted to understand the mechanisms underlying the fatigue

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failure of this class of materials and to obtain predictive capabilities for their service life. Early attempts to characterize the fatigue failure in polymers were inspired by similar works for metals and were generally empirical in nature. Fatigue life test results were generally presented in the form of S-N curves. But these curves are of limited use in practical situations as, unlike metals, the crack initiation life for these materials are often short compared to the fatigue crack propagation life[1].Nowadays polymers are being used increasingly for load bearing industrial applications and higher fluid pressures in transportation pipes.

A Ductile failures are most often related to large deformations, plastic strainsin metals, and irreversible strains in polymers. These conditions can ariselocally in the vicinity of notches or severe bending. When ductile failure occurs, the strains often become too large for the smallstrain perturbation hypothesis to remain valid: for metals the plastic strainat rupture is usually larger than 0.1 forpolymers it may reach much larger values corresponding sometimes to a fewhundred percent[2]. Polymer fatigue behavior is generallysensitive to environment (including testtemperature), molecular weight, molecular density،and aging. Additionally, for polymer،fatigue resistance increases as crystallinity increases.S. K. Ruddy [3] was taking three insulation polymers, PVC, XLPE and PPE, for studying their mechanical properties and strain fatigue lives. PVC and XLPE are ductile and exhibit significantly more elongation prior to breaking, while PPE exhibits brittle behavior. The durability of XLPE under strain fatigue testing was the largest, followed by PVC and PPE. The strain fatigue lives of PVC and XLPE decreased drastically at -40 °C and demonstrated a noted increase at 65 °C compared to fatigue lives at room temperature. This trend was not observed in PPE where the strain fatigue life showed improvement at both lower and higher temperatures. It is conjectured that the intrinsically brittle PPE exhibited a higher craze resistance at -40°C in comparison to that at room temperature.Pei Chen [4] Studied the fatigue behavior of conduit polymer materials, nylon 6, polypropylene (PP) and calcium carbonate filled black colored polypropylene PP (blk)) under different strain ranges and temperature conditions. Besides room temperature (25 °C) tests, low temperature (-40 °C) tests and high temperature (125 °C) for nylon 6, 65 °C for PP and PP (blk)) tests are also performed.Mena I. Souliman and Kamil Kaloush [5] studies the assessment of the extended fatigue life for rubber and polymer modifiedasphalt mixtures using flexural bending beam fatigue test, the results from the beam fatigue tests indicated that the asphalt rubber and polymer modified gap graded mixtures would have much longer fatigue life compared with the conventional mixtures.

The various topics of fracture and fatigue of polymershave been discussed in [6]. Largest portion of theseinvestigations was oriented on fatigue performance ofvarious polyamides (PA 6, PA 66, PA 46, etc.) and significantlyless study were oriented on fatigue of HDPE, PP and PMMA [7]. The number of published article on low cycle fatigueof plastics is very limited. . The purposes of this paper is to investigatelow cycle fatigue characteristics of HDPE, PP and PMMA.

The Experimental Work:

The materials targeted for being under test in this work are Polyethylene (High Density),polymethylmethacrylate,andPolypropylene, X-ray diffraction test has been done to identify the degree of crystallinity.Polymeric tensile specimens (PE, PMMA and PP) manufacture according to the international standards (ASTM), taking with consideration that diameter of the machine portion shall be 60% of the original nominal diameter. To ensure specimen alignment in the screw machine jaws, a rod of 10 mm has been chosen to fulfill the condition that diameter which was formed not less than 60 %, that is equal to the 6mm(figure 1)[8]. The apparatus using in this test is Gunt Universal testing machine type WP300. The specimen surface was grinding with emery paper ASTM grid 800,1200 taking into account that final grinding stage done with ASTM grid 2000in the same direction of tensile axis .The tensile test performed in a laboratory temperature of 23±2°C at strain rate 6.2mm/min as illustrated figure (2).

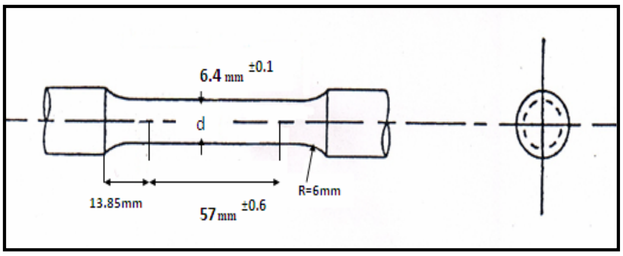

Fig. (1); Tensile test specimen.

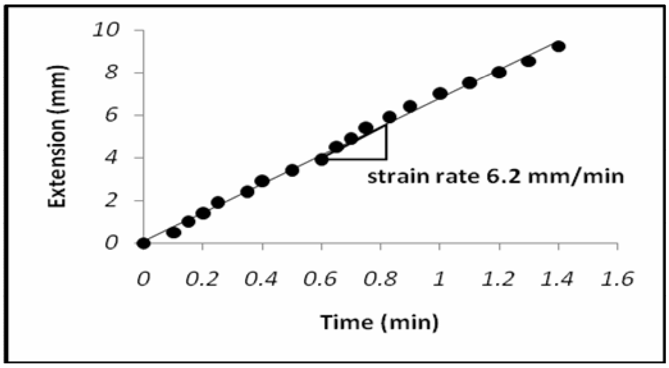

Figure (2) Extension-Time Curve

The apparatus used is cantilever type (WP 140 Fatigue Testing). Fatigue specimens were manufactured and test according with ASTM 606-92. Sixteen to twenty specimens test for each type of polymers with “r” equal to 16mm (r=2d) (fig.3)[9]. The specimen surface was grinding with emery papers and polishing with 0.3µm alumina suspension.The specimen was test under fatigue strain down to yield strain. Also sixteen to twenty samples test with “r” equal to 8mm and 4mm to study the effect of notch on the behavior of LCF of the PMMA polymer.

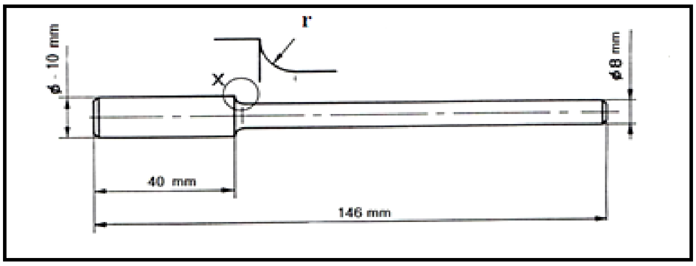

Fig. (3): Fatigue specimen

Results and Discussion:

1- Tensile test

Tensile strength and elongation percentage, have been identified from engineering stress-strain curve for three types of polymers.After that were drawn true stress-strain curve to compute strain hardening coefficient (n) and strength coefficient (K) (table1).

Table (1): Mechanical properties of thepolymers

Properties / *Polymers*		Proportional limit (MPa)	Tensile strength(MPa)	Elongation % at fracture	n	K(MPa)
PE	Nominal[10]	15	20-40	100-1000	-	-
	Experimental	16	21	120	0.23	42
PP	Nominal[10]	20	30-40	100-600	-	-
	Experimental	21	37	105	0.277	50
PMMA	Nominal[10]	55-75	55-75	3-5	-	-
	Experimental	67	67	4	-	-

Figure (4) shows a curve for tensile of Polyethylene (High Density),the so-called (AC) toe region at the beginning of the curve must be noted here. That does not represent a property of material it is an artifact caused by take up of slack and alignment or seating of the specimen .In order to obtain correct values of such parameters as modules, strain and offset yield point , this artifice must be compensated for to give the correct zero point on the strain or extension axis [9].When (B) that's illustrated in the curve, it's the corrected zero strain point from which all extensions or strain must be measured including the yield offset (BD).

Observed from tensile test, the value $(\sigma_u/\sigma_y=1.31)$ for Polyethylene indicated that the behavior of this polymer will be softening under LCF test. While amount of n=0.23, which is within limits of softening materials.Also Manson did not indicates any importance to the value of (K) in determining behavior of materials but it represents the value of stress needed to attain (ε(( ). In access of Polyethylene at ε((the value of K=42 MPa(figure 5).

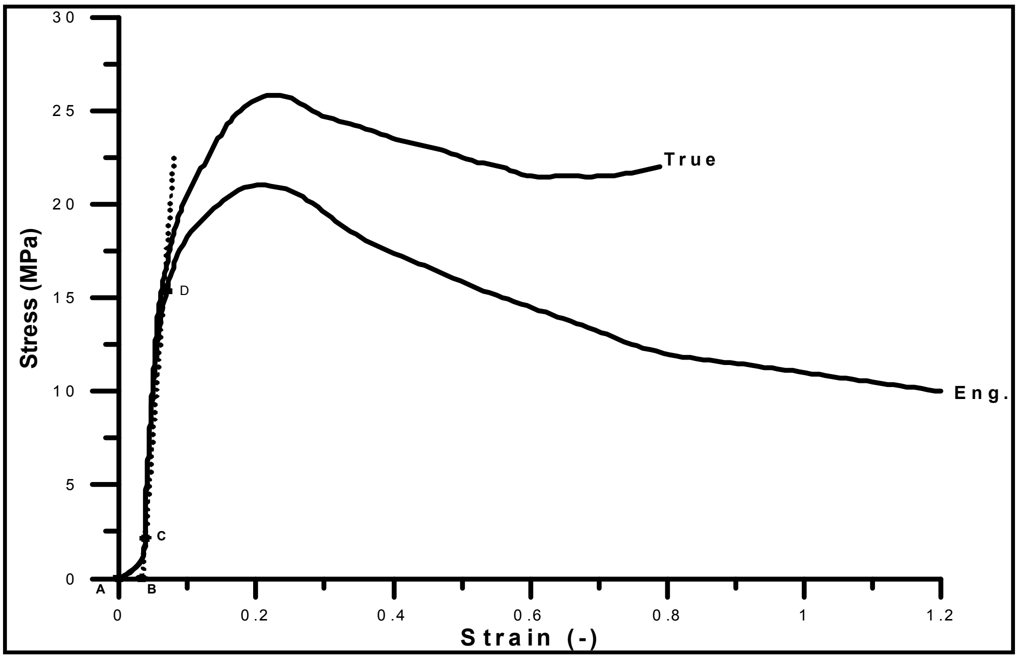

Fig.(4): Stress-Strain Curve of Polyethylene

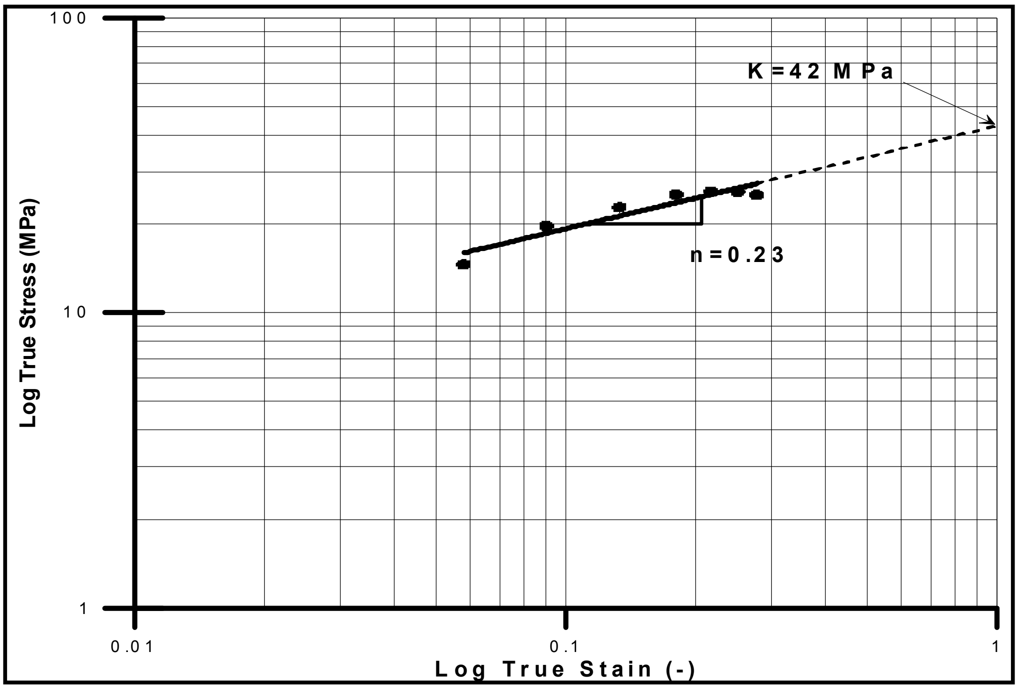

Fig.(5): True stress- strain of Polyethylene

The stress-strain curve of PP(fig.6) consists of one region only. A value of (σ_u / σ_y=1.76) has been recorded and a value of n=0.277, k=50MPa as shown in figure (7). Accordingly, the PP is considered to have a hardening behavior as metals. However, all the polymers are found to be softening. At relatively higher stresses and frequencies, hysteretic heating affects the physical and mechanical properties of the polymer. This effect is a combined consequence of the fact that most polymers demonstrate high internal damping and low thermal conductivity, heat generated from mechanical fatigue cannot be dissipated to the surroundings and the polymer temperature rises throughout the test [11].

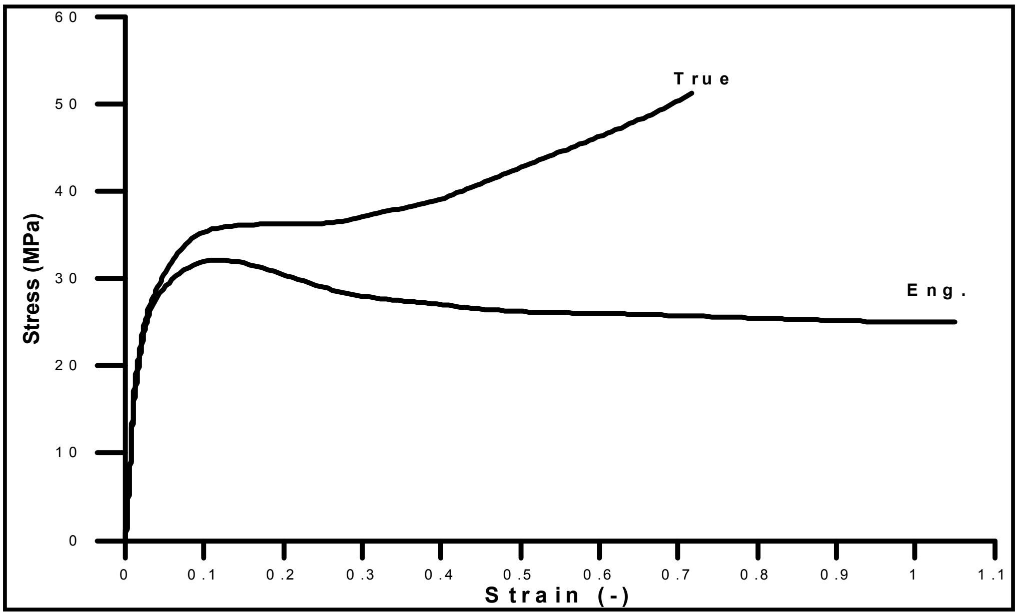

Fig.(6): Stress-Strain Curve of Polypropylene

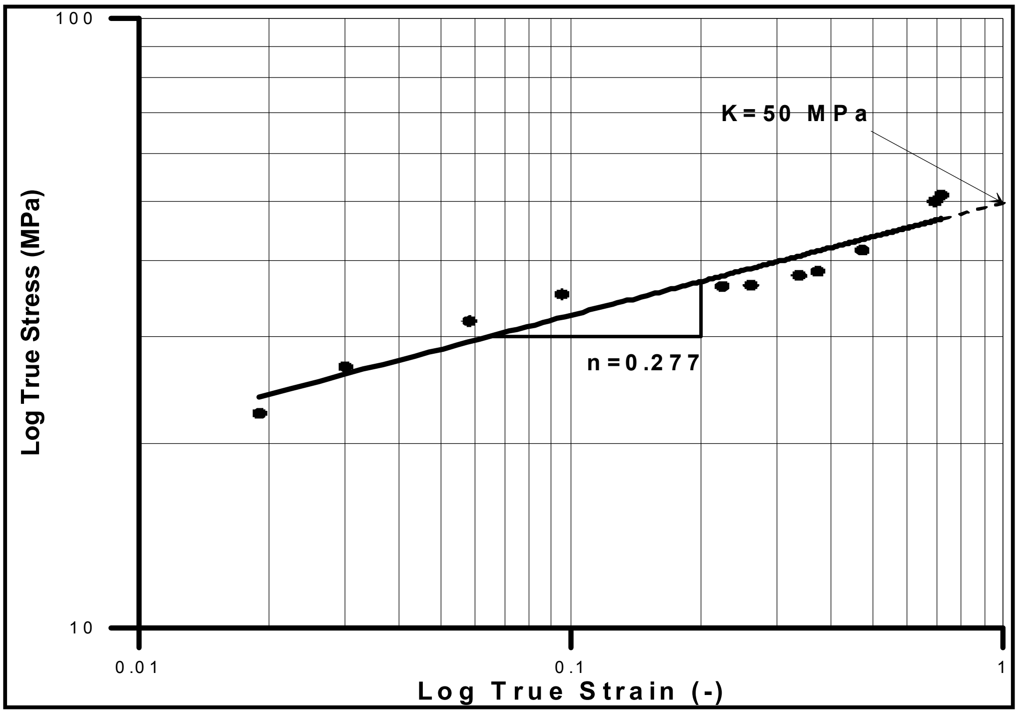

Fig.(7): True stress- strain of Polypropylene

PMMA behavior is similar to PP, which consists of one region. But different from PP & PE in value of $(\sigma_{u} \equiv_{y}=1)$ that's mean the PMMA material is not a tough ductile material, but brittle, then the stress straincurve of the material may look like the idealized curve presented in (Figure 8)

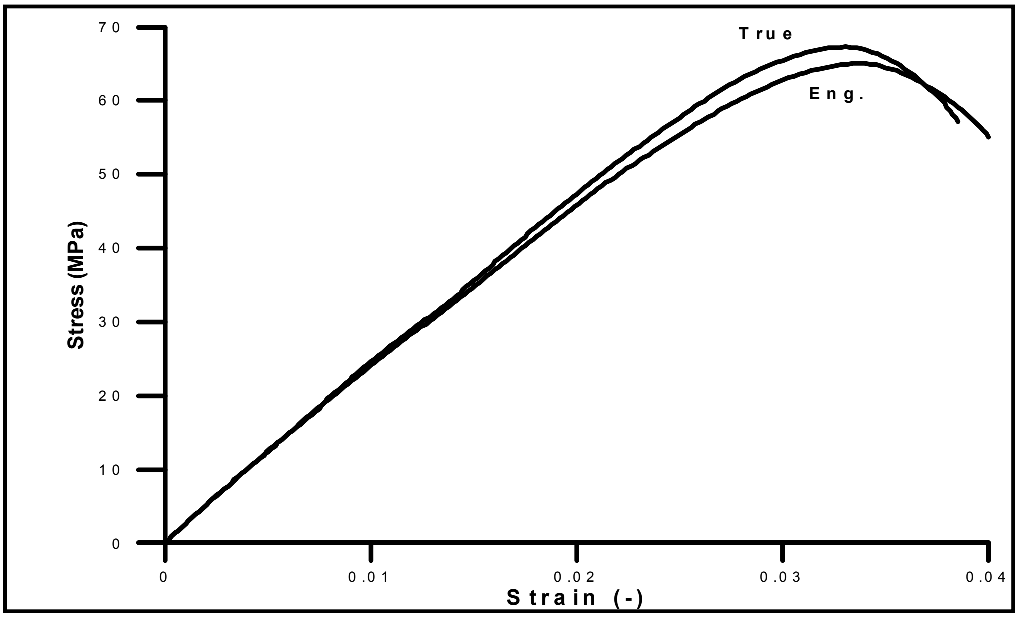

Fig.(8): Stress-Strain Curve of PMMA

2- Strain Life Curves

The true stress-strain curves are used to define the applied true strain that employed to plot the Strain Life Curve (Low Cycle Fatigue Curves). The amplitude stress for every condition is determined from its equivalent true stress. True stress is obtained from total true strain using secondary axis (0-1) (fig. 9). The total true strain data is analyzed into two components to be plotted in the same graph (*log-log*); total strain, elastic strain and plastic strain components versus reversals to failure “2N”.

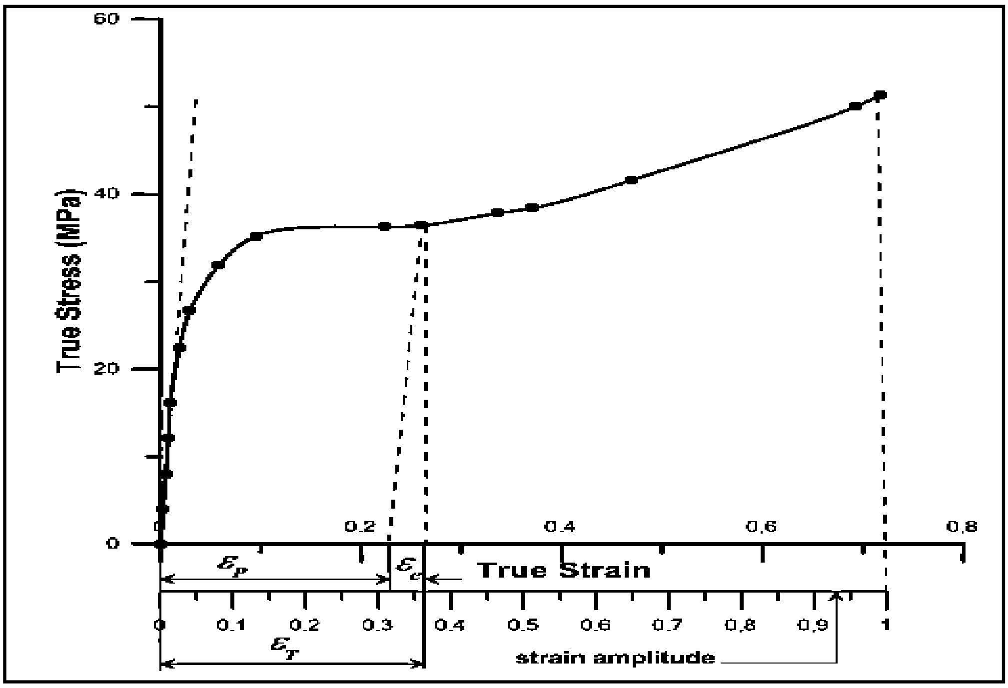

Fig. (9); True stress-strain graph

The form of Strain Life curve for polymers PE, PP and PMMA has been similar to Strain Life curve of metals, when draw the relation between strain amplitude and number of cycles. Whereas total strain curve take parabola shape while elastic (ε_e) and plastic strain (ε_p) taking linear forms. The fatigue strength exponent (b) for two types of thermoplastic material situated within limits of metals that's usually between (-0.04 to -0.15) (table 2). Also, thefatigue ductility exponent(c) for HDPE and PP polymersremains within metals constant values between (-0.3 to -1.0) [12-13-14]. In polyethylene polymer as show in figure (10) , the amount of $\acute{\varepsilon}_f$ =0.23 larger than other types, this meaning its shown more strain before fracture this behavior similar to PP polymer as illustrated in figure (11). But PP recordedlower value $\acute{\varepsilon}_f$ =0.122.

Table (2): Mechanical properties for LCF of polymers

Properties / Polymers	ε'_f	c	σ'_f/E	b	k' (MPa)	n'	N_T
PE	0.23	-0.78	0.085	-0.043	55	0.055	27800
PP	0.122	-0.7	0.028	-0.052	36	0.074	25500
PMMA	-	-	-	-	-	-	

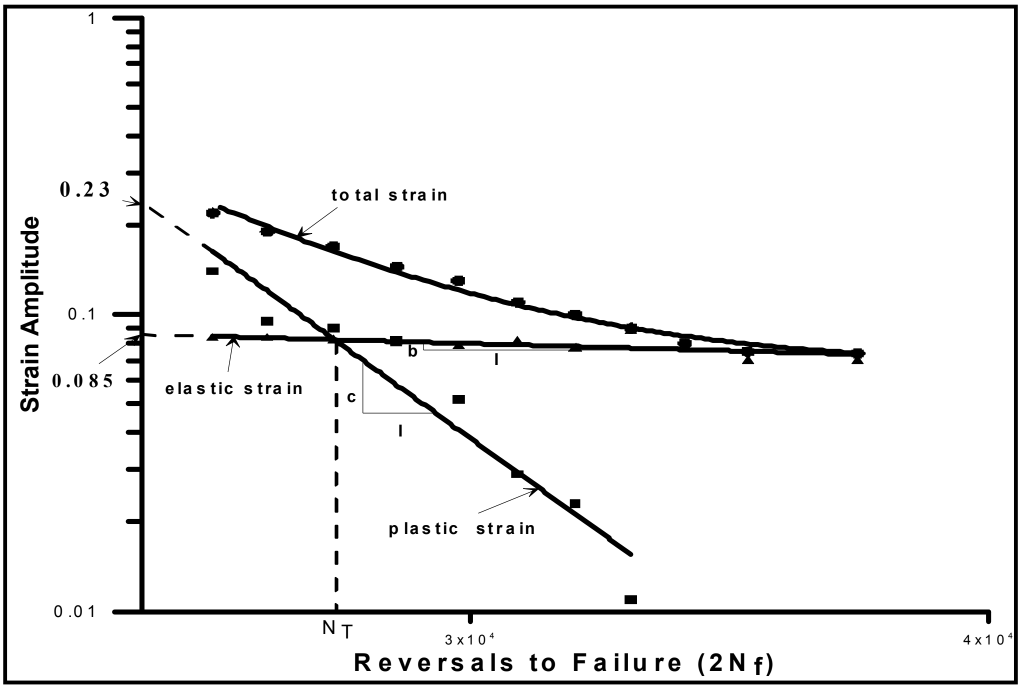

Fig.(10):Strain life for HDPE

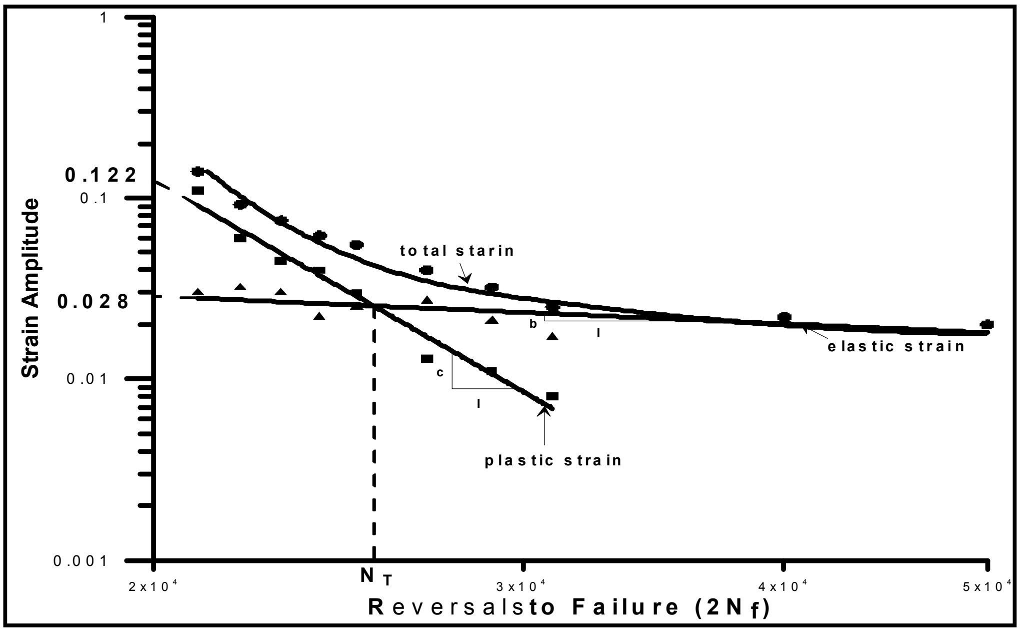

Fig.(11):Strain life for PP

Which concluded from tensile test, the PMMA is tough material. This means, the plastic strain is zero. Therefore the total strain is equal to elastic strain. Figure (12) show the total strain life curve and the effect of un-notch specimen at fillet radius 4,8 and 16 mm. we noted that, the total strain are decreased when the stress concentration increased

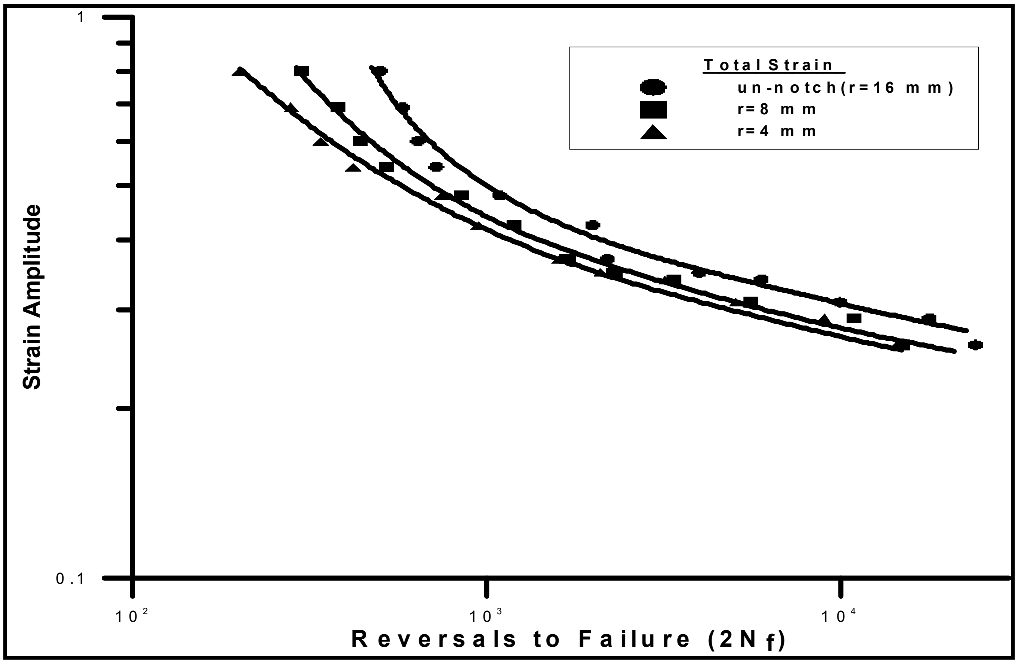

Fig.(12):Strain life for PMMA

It is essentially notice that (N_T)value which represent the number of cyclesat which plastic deformation will be equals to elastic deformation has, it's recorded highest value in PE (N_T =27800) at total strain equals to 0.163, follows PP amounted value of N_T =25500 at total strain equal to 0.05 as illustrated in figure 11. Whereas Polypropylene had lowest value. On the other hand, cyclic strain hardening exponent (**n'**) for HDPE and PP indicated within limits values that Manson will be referred between (0.10-0.25). Fig. (13) shows the relationship between the plastic strain and cycles for HDPE&PP polymers, which noted that the HDPE is softer than PP.

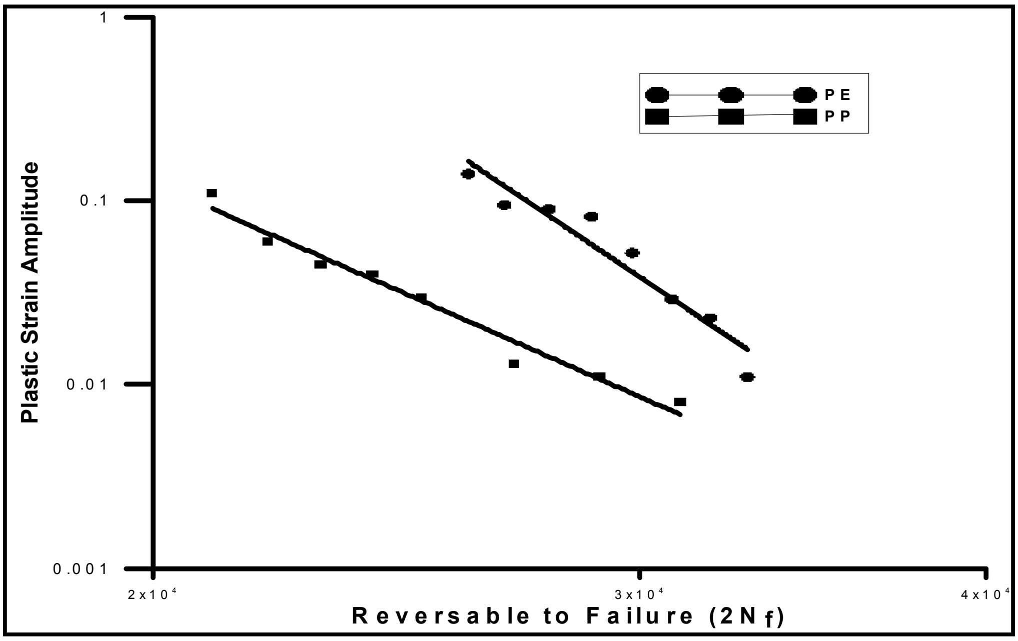

Fig.(13): plastic strain life for PP and HDPE

Conclusions :

1. The fatigue strength exponent (b) for HDPE is greater than PP polymers, this means the HDPE is softer than the other polymers(PP and PMMA).
2. The number of transition cycle (N_T) for HDPE is less than PP polymers , this mean the PP is the best in life from HDPE and PMMA polymers.
3. The value of plastic strain life for PMMA is zero, therefore the total strain life is equal to elastic strain only and represents only in strain life curves.
4. The cyclic strain hardening exponent (**n'**) for both polymers (HDPE and PP) indicated within limits values of metals.

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