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Low cycle fatigue of different polymer types PA, PVC and POM

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ABSTRACT

This research deals with Low Cycle Fatigue (LCF) tests for three types of polymers, polyvinylchloride (PVC), polyoxymethy (POM), and polyamide (PA). The tensile test results showed that advantage cannot be taken from σ_u/σ_y ratio and strain hardening coefficient (n) to estimate polymers behaviour under LCF test. There was a similarity in polymers behaviour with metals in the aspect of total strain, elastic strain and plastic strain curves with total cyclic number (2N). Fatigue strength exponent (b) and fatigue ductility exponent (c) for the polymers recorded values within metals limits. POM polymer showed less softening and greater transition life (N_T). PA polymer exhibits sensitivity to external stress concentration in terms of reduction of transition life (N_T). Softening behaviour of PA polymer increases with lower value of the notch radius.

Introduction

Different types of factors that effected on the mechanical properties of polymers, such as temperature , molecular weight , rate of strain , pressure, and cross linkage and branching .Some of these related to the structure of polymer , another factors related to the environmental factors. Many different polymers subject to the cyclic strains, only cyclic softening is observed although this dependent upon the structure of the polymer (viscoelastic) and poor conductors of heat [1-3]. They are much sensitive to the frequency of alternating loading than the metals. As a result, under cyclic loading, failure may result from thermal rupture and some energy will be dissipated in each cycle. The specimen temperature will rise until the heat generated per cycle is equal to the heat dissipated as a result of conduction, convection and radiation (4-5). Depending on the test temperature , the applied frequency, the stress amplitude, thermal conductivity and specific heat , the temperature may be quickly raise to Tg or to Tm or it may stabilize at some particular value. At relatively high frequencies and stress levels, many polymers may become overheated as a result of the accumulation of hysteretic energy generated during the loading cycles. This energy dissipation produces a significant temperature rise within the specimen, which, in turn, causes the elastic modulus of the material to decrease. Such thermal failure corresponds to the number of loading cycles at a given applied stress range that brings about an apparent modulus decay to 70% of the original modulus of the specimen.

Extreme care should be taken in ranking the fatigue resistance of polymeric materials since the test conditions may affect the measurement of the true or the intrinsic fatigue resistance of the material [6]. Vinogradov [7] Studied time-dependent behavior of polymer systems under cyclic loading conditions. Nylon 6/6 samples have demonstrated no hysteretic heating. Respectively, the observed vibrocreep phenomenon has been attributed to damage development in the material. S. Moisa [8] investigated the hysteretic thermal behaviour of the PA. It was shown that a strong correlation exists between the molecular structure of a polymer and the thermo-mechanical behaviour that characterizes its response to cyclic loading.

The Experimental Work

The materials targeted to be under test in this work were PA, PVC and POM. X-ray diffraction test was done to identify the degree of crystallinity. Tensile specimens were manufactured according to the ASTM D638 and performed in a laboratory temperature of 23±2°C at strain rate of 6 mm/min. The apparatus used for low cycle fatigue test was cantilever type [9]. Fatigue specimens were manufactured and test according to ASTM 606-92. Specimens for each type of polymers manufactured with, r, equal to 16mm (r=2d) (fig.1). Samples with, r, 8mm and 4mm were tested to study the effect of notch on the behaviour of LCF of the PA polymer.

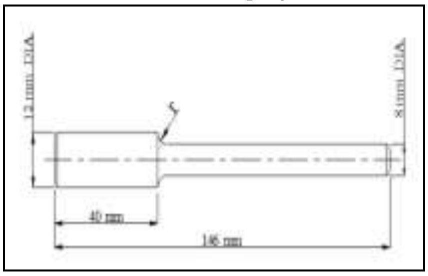

Fig. (1): Fatigue specimen

Results and Discussion

Basically, the low cycle fatigue of metals behaviour can be predicted by the tensile test, specifically by observing the value of σ_u/σ_y. Manson used this ratio to determine the behaviour of the material. When σ_u/σ_y >1.4 the material will be hardened, but when σ_u/σ_y <1.2 the material will be softened. As well as the value of strain hardening coefficient (n), can define the softening or hardening of a material. The material will harden if n>0.2, but if n<0.10, the material will cyclic softening [10-11]. It was observed from tensile test, that the value σ_u/σ_y for polyamide (amorphous) indicated that the behaviour of this polymer will be softening under LCF test. While amount of n, within limits of softening materials (table 1). POM (semi-crystalline) recorded σ_u/σ_y value of 1.62, and n of 0.241.

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Accordingly, the POM will consider to have a hardening behaviour if follows Manson hypothesis. However, all the polymers are found to be softening. PVC (amorphous) behaviour is similar to POM, but differs from POM in value of σ_u/σ_y, which means PVC tends to be softening as migrate polymers. Strain hardening coefficient, n, does not give an indication of the behaviours of polymers POM, PVC and PA, if we depended on Manson hypothesis also. LCF curves for polymers PA, PVC and POM have been similar to LCF curve of metals. The fatigue strength exponent (b) for three types of polymers situated within limits of metals that's usually between -0.05 to -0.12 (table-2). As well as, fatigue ductility exponent (c) remains within metals constant values between -0.5 to -0.7 [10].

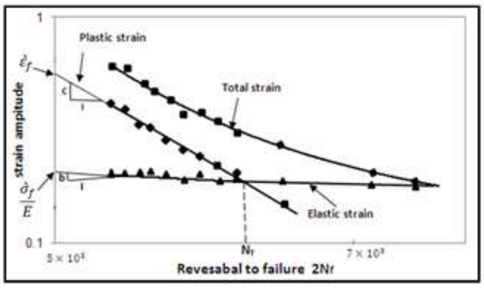

Fig.(2) ; Strain life for PA (un-notch specimen)

For polyamide polymer (fig. 2), the amount of ε'_f is larger than other types, that means it's shown more strain before fracture. This behaviour similar to POM polymer as illustrated in figure (3), while PVC recorded lower ε'_f value (fig. 4). Fatigue strength coefficient (σ'_f) for POM polymer is 677 MPa while it's reached to 656 MPa for polyamide and 406 MPa for PVC polymer. POM polymer showed less softening rather than the other two types of polymers (fig. 5) .The stress concentrations have larger effect on reducing the ε'_f and σ'_f values of PA polymer (table -2). While (b) and (c) values remain within metals limitations (figs.6&7). Stress concentrations having clear effects to increase softening that is meant an accelerated in failure. Elastic and plastic strain retains its linear shape, but plastic strain dropped with increasing radius value (fig. 8). This is a clear indication for lowering the transition life and increasing in softening.

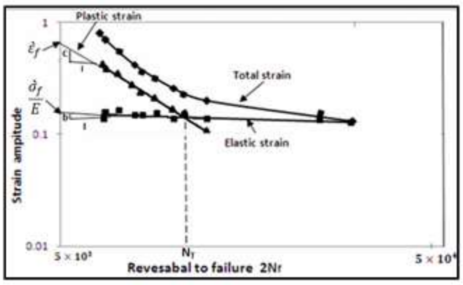

Fig. (3): Strain life for POM

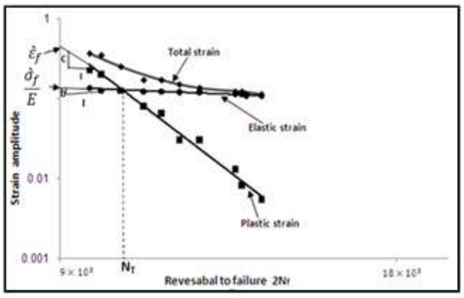

Fig.(4): Strain life for PVC

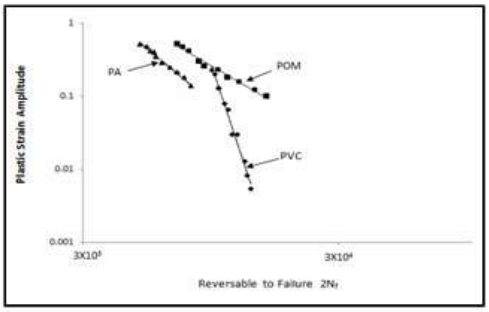

Fig. (5): Plastic strain -life for POM, PVC and PA

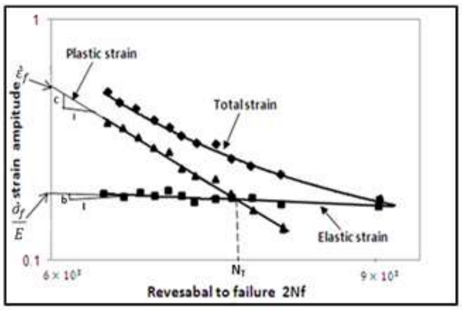

Fig. (6): Strain life for PA (r =8mm)

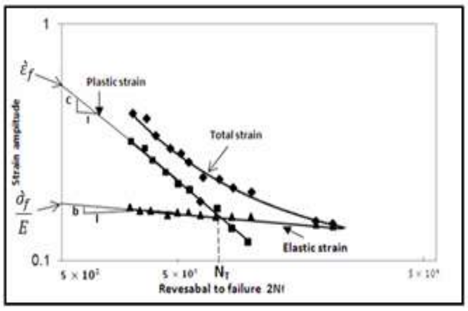

Fig. (7): Strain life for PA (r =4mm)

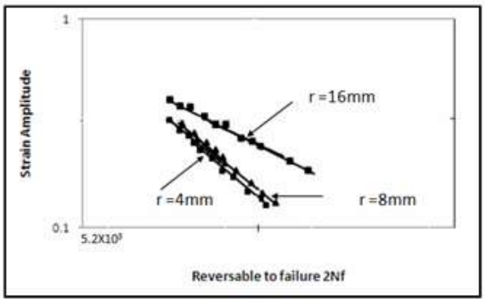

Fig. (8): Effect of notch radius on the plastic strain –life for PA

Conclusion

1. σ_u/σ_y value and strain hardening coefficient (n) cannot be used for estimating LCF behaviour of the polymers PA, PVC and POM.

2. Fatigue strength exponent (b) and fatigue ductility exponent (c) for three types of polymers are mainly within the range of metals and alloys.

3. POM polymer is less softening under LCF than other two types.

4. External stress concentration has clearly effect on increasing softening of PA under LCF test.

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Table (1): Mechanical properties of polymers

Properties / *Polymers*		Yield strength (0.2% offset)	Tensile strength (MPa)	Elongation at fracture (%)	n	K (MPa)
PA	Nominal	45	60	20	-	-
	Experimental	58	68	23	0.105	97
POM	Nominal	45	65-70	15-60	-	-
	Experimental	47	69	16	0.241	99
PVC	Nominal	31	35-62	20-40	-	-
	Experimental	37	40	27	0.176	69

Table (2): Mechanical properties for LCF of polymers

Properties / Polymers	$\dot{\varepsilon}_f$	$\dot{\sigma}_f$ (MPa)	N_T	c	b	n'	K' (MPa)
PA (un-notch)	0.76	656	7325	-0.7	-0.06	0.09	541
PA (r=8mm)	0.73	562	6550	-0.67	-0.055	0.083	579
PA (r=4mm)	0.67	486	5960	-0.56	-0.02	0.052	477
POM	0.724	677	13050	-0.501	-0.087	0.174	300
PVC	0.391	406	10191	-0.601	-0.052	0.0592	429