WAVEFORM AND WAITING TIME EFFECTS ON THE FATIGUE BEHAVIOUR OF REINFORCED POLYAMIDES AND ACETALS

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This work studies the fatigue behaviour of polyamides 6 and 66 reinforced with different degrees of short fibre glass (25 and 35 % by weight). For this purpose an analysis is made on both the influence of waveform type and waiting time on the fatigue behaviour of standardized tensile samples. For the first, a comparison is made between the behaviours obtained from both sinusoidal and square waveforms. For the second, fatigue tests have been performed by secuential blocks of fatigue separated by waiting times. A parallel reference study has been developed on the fatigue behaviour of an acetal resin which is considered to be a functional alternative to using reinforced polyamides in railway fastenings systems.

INTRODUCTION AND AIMS

An important cause of damage in the insulating parts of railway fastenings injected with polymeric materials, with and without reinforcement, is associated with dynamic mechanic processes of fatigue and impact produced by the passing of trains. The thermoplastic materials of the insulating parts are subjected to variable loading, whose periodic repetition causes internal heating in the material, varying its flexibility and its mechanical response to fatigue. The first aim of this work is to characterize the behaviour of these materials when they are submitted to dynamic fatigue processes produced by both sinusoidal and square waveform loads, simulating continuous variable loading and repetitive impacts respectively, Casado et al (1). For safety reasons railway traffic law requires waiting time between two consecutives trains running on the same line. This time may allow the partial dissipation of the internal heat generated by the molecular friction in the polymeric material of these fastening parts and provoke variations in its mechanical behaviour. The second objective of this work is to analyze this effect by comparing conventional fatigue tests with those performed by secuential blocks of fatigue separated by waiting times (Herman et al (2) and Petrault et al (3)). The behaviour observed should contribute to material selection criteria for improving the fatigue resistance of these parts.

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MATERIAL AND EXPERIMENTAL TECHNIQUES

Four materials typically injected into the insulating parts of railway fastenings have been used. They belong to two families of thermoplastic polymers: Polyamide, PA or nylon, reinforced with different percentages by weight of short fibre glass and acetal resin without reinforcement, distributed in the following way:

- Nylon 6 reinforced with 25 and 35% (from now on PS25 and PS35).
- Nylon 6.6 reinforced with 35% (PR35).
- Acetal resin (R).

Normalized injection molded tensile specimens (UNE 53-023-86) were made using the four materials. In the reinforced samples the short fibres run parallely to the longitudinal axis. The dynamic tensile strength (σ_r) was determined for each material by applying a sudden impact loading under tension generated by a square wave form. This represents a displacement rate of 0.22 m/s.

The fatigue tests were performed in a universal mechanical testing machine under load control at a frequency of 5 Hz at room temperature. The tension levels applied ranged from a maximum value ($\sigma_{máx}$) which is varied from one test to another to a fixed minimum value ($\sigma_{mín}$) of $0.05\sigma_r$ to avoid compression and possible bending in the specimens. The initial upper level was $0.90\sigma_r$. The tests were performed until each specimen broke. The $\sigma_{máx}$ value was systematically reduced from one test to another at intervals of $0.10\sigma_r$ until the material withstood 10^6 cycles without breaking. The highest tension variation withstood under these process was denominated $\Delta\sigma_6$. The tests were carried out with both square load and sinusoidal waveforms. Both continuous and interrupted fatigue tests have also been performed, the latter for waiting times of 30 and 180 seconds every 300 cycles.

During the test the following parameters were registered: the specimen´s intrinsic temperature, T, by means of a sensitive resistance located in the specimen´s gauge; the longitudinal variation of the specimen, ΔL, measured with an extensometer; and the total number of cycles applied up to final fracture, N. From the measurement of these parameters it is possible to obtain a continuous evolution of temperature and stiffness, $\Delta\sigma/\Delta L$, throughout each test.

RESULTS

Table 1 shows the σ_r values of the materials studied, as well as the obtained $\Delta\sigma_6$ values which represent their fatigue strength. Figure 1 shows the typical results obtained from the fatigue tests for any material and condition tested. The figure represents both the stiffness and temperature variations of the material with the number of cycles applied for all the tension levels considered. The $\Delta\sigma$-N graphs for PR35 (representative of all the reinforced polyamides) and R tested with the two waveforms can be seen in Figures 2 and 3 respectively.

The waiting time effect on the mechanical behaviour of the materials can be observed in Figure 4, which shows the material´s lifetime as a function of the pause between wave-loading. Figures 5 y 6 show the number of cycles withstood by the material and the corresponding temperature increases as a function of both the applied loading and waiting time.

TABLE 1- σ_r for conditions of impact under tension and $\Delta\sigma_6$ (sinusoidal and square)

Material	R	PR35	PS35	PS25
σ_r (MPa)	81.0	166.8	151.0	140.6
$\Delta\sigma_6$ (MPa) sinusoidal	44.5	58.4	37.5	35.2
$\Delta\sigma_6$ (MPa) square	52.6	58.4	37.5	49.2

ANALYSIS OF RESULTS

The results show that for both the polyamides and the acetal resin the fatigue processes at high load amplitudes provoke a rapid fracture ($<10^4$ cycles) associated with a constant increase in the material´s temperature and a loss of stiffness. When the amplitude level is reduced a state is reached where the temperature and stiffness stabilize, Suresh (4). In this state, 10^6 cycles ($\Delta\sigma_6$) are always reached without breakage. This state, with reference to the breakage tension value, is much lower for PA (0.25-$0.35\sigma_r$) than for R (0.55-$0.65\sigma_r$). However, in absolute values the resistance to breakage of both materials is very close, around 50 MPa of $\Delta\sigma_6$ in the two most resistant situations of each family.

Generally the temperature of the materials increases faster under the sinusoidal rather than square wave form before stabilizing. This temperature rise and crack propagation justify the continued increase in the flexibility of the specimen before rupture. For high load amplitudes an immediate increase in flexibility is observed due to the effect of local fractures. Since temperature starts to rise after a minimum number of cycles, increasing as $\Delta\sigma$ decreases, at high $\Delta\sigma$ values, mechanical processes cause the specimen to fracture too soon to allow a high increase of the intrinsic temperature. For intermediate $\Delta\sigma$ values the temperature increases as $\Delta\sigma$ decreases because the lifetime of the specimen is longer and the flexibility begins to vary quickly with variation in temperature. For $\Delta\sigma$ values close to $\Delta\sigma_6$ a tendency towards thermal stability can sometimes be observed.

This state of thermal evolution justifies that the susceptibility to fatigue processes defined by the $\Delta\sigma$-N curve and the $\Delta\sigma_6$ value is greater with sinusoidal waveform for the acetal resin (Figure 3). Nevertheless, in the case of reinforced polyamide, this susceptibility is greater for high load amplitudes under square waveform. Since they are stiffer and more brittle, the impact of each cycle causes more damage, probably associated with the breakage and slipping of the reinforcing fibres and the matrix "crazing". As $\Delta\sigma$ decreases the effect of the increase in temperature under sinusoidal waveform begins to compensate this state until a balance is established between the effect of both waveforms (the same $\Delta\sigma_6$ values, Figure 2) and even the lesser reinforced polyamides turn out to be more resistant to fatigue under square waveform.

On the other hand, the waiting time between two consecutive wave-loadings allows the dissipation of the material´s internal heat generated by the action of cyclic loadings. In spite of the low thermal conductivity of these materials the small increases in heat dissipation justify the slight extension in the material's fatigue life, defined by N, with longer waiting times which lead, in some cases, to higher $\Delta\sigma_6$ values.

CONCLUSIONS

For both waveforms studied the fatigue behaviour of the reinforced PA is similar at load amplitudes close to the fatigue strength of the materials, where the repetitive impact effect of square wave loading is compensated by the greater heating effect of the sinusoidal waves. However, at higher loads the impact effect in each cycle establishes that these materials are more susceptible to the fatigue mechanisms with square wave than with sinusoidal waves.

For all the amplitude loading levels studied, acetal resin resists the square wave better than the sinusoidal wave loading. The different molecular friction induced on the material by the two types of waves and the greater ductility of this material justifies this.

In spite of the difference in susceptibility and fracture mechanisms the two types of materials show a fatigue resistance which is equivalent in absolute values, thus producing a state of material equality in design terms for this type of loading.

The waiting between two consecutive wave-loadings extends the fatigue life of the materials studied. Lengthening the waiting time could establish higher loads under which $\Delta\sigma_6$ is reached.

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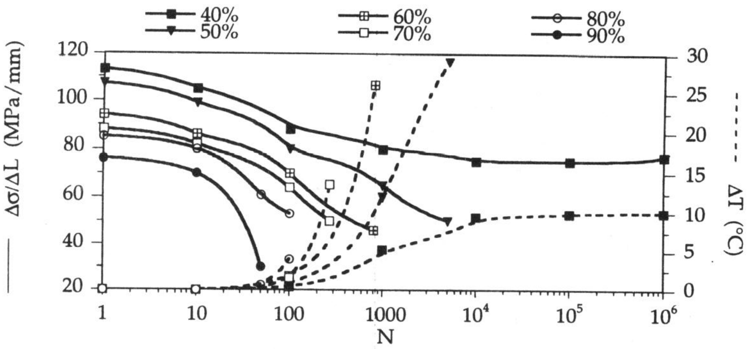

Figure 1. Typical evolution of material Δσ/ΔL and ΔT under fatigue loading

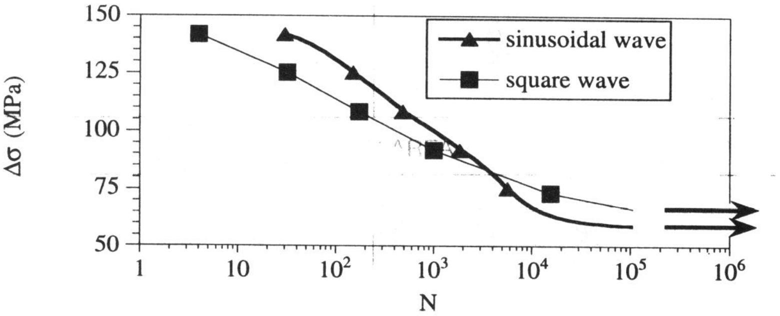

Figure 2. Δσ-N (PR35)

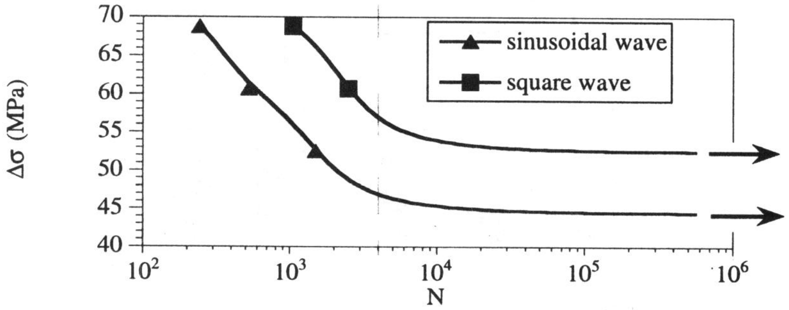

Figure 3. Δσ-N (R)

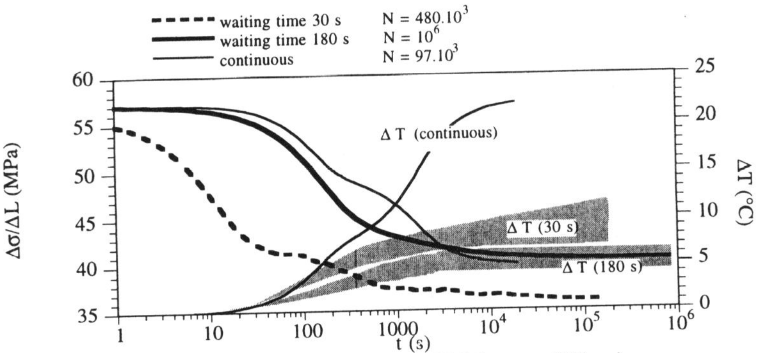

Figure 4. Waiting time effect on PS25 (σ_{max}=40% σ_r)

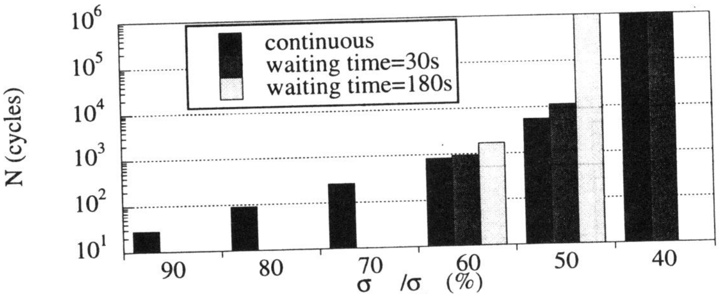

Figure 5. Cycles up to failure for different loadings and waiting times (PR35)

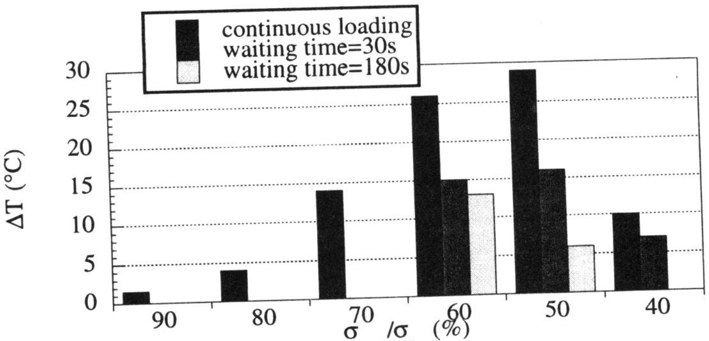

Figure 6. Increase in temperature up to failure for different applied loadings and waiting times (PR35)