Real Time Ageing of Polymeric Components in Closed Systems

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Abstract: Results from real time ageing of polymeric components in closed systems are discussed and compared with data from accelerated ageing studies. Polymers considered have included polysiloxanes, polychloroprenes, polyurethanes, polyimides and epoxies. The polymeric materials have been exposed to oxidative and reducing atmospheres and radiative, thermal and mechanical stresses. Test conditions and the results of changes in physical and chemical properties are described and related to the chemistry of the materials. Valuable data can be obtained from accelerated ageing studies but real time ageing data are required to support and confirm specific trends in ageing phenomenology.

1. INTRODUCTION

In order to underwrite the performance of polymeric components in nuclear warheads, there must be sufficient scientific evidence to confidently predict the functional lifetime. This ideal can only be achieved through a thorough understanding of the ageing characteristics of the materials. All materials respond to various internal and external stresses which collectively lead to changes in properties which may ultimately result in loss of functional performance. Real time and accelerated ageing studies are undertaken to define a timed period when that functional performance cannot be sustained in order that remedial action can be taken to prevent failure. Real time ageing studies in the prescribed environments allows some measure of confidence to be established and provides data to support accelerated studies and modelling studies.

2. AGEING PROGRAMMES AND ANALYSIS

Ageing programmes are currently undertaken for all components in the warhead. Underwriting performance and safety for polymeric warhead components is based on a detailed understanding of the materials' chemistry and physics together with a knowledge of the warhead environment and the forcing stress factors. A large database of empirical knowledge on real time and accelerated ageing of polymeric materials has been established over the past three decades, which is supported by simple models. These data have been used pragmatically to allow life predictions to be made and confirmed by results from real time ageing of weapon systems. The data are obtained from materials and component testing, characterisation and full scale weapon trials and service life assessment trials which are supported by stockpile laboratory testing, new material laboratory testing and long term storage testing. Underpinning these formal engineering trials, real time and accelerated laboratory ageing and characterisation programmes are undertaken together with analysis of capsule atmospheres and environments. Because similar materials have been used in previous warheads, valuable read-across can be obtained by studies of the breakdown of older weapons both in the UK and US. All results are subject to detailed analysis which includes the statistical significance of variations in results, the effects of batch to batch variation and in some instances the effects of operators. Data must be inherently self-consistent from all these sources to justify scientific confidence in any lifeing statements.
2.1 Variables in component ageing and life

For the technical assessment of lifetime predictions of polymeric components, the total history of the base polymer and formulation additives must be considered. Unlike other manufactured products, nuclear warheads have a slow gestation from concept through engineering drawing to manufacture. Because polymeric organic materials are subject to degradation even in benign storage over long time frames, tracking the history of all the constituent materials in the component is essential, especially if unexpected ageing occurs in a long term storage trial. The real-time age of a component has generally been assumed in the past to be equivalent to the time spent within the weapon. Contributions from pre-assembly and/or post breakdown ageing have not usually been taken into account, although it may be necessary to do so in future since the time between materials procurement and final assembly and delivery may markedly influence the observations. A typical life cycle for a component is shown in Figure 1.

![Figure 1. Real time ageing history of base polymers and additives](image)

Also, because of the batch production of these materials and the time periods involved, batch effects can be more significant than ageing effects. Real time ageing of the polymeric components can be identified from receipt of raw materials, storage, component fabrication, pre-warhead assembly storage, in-service deployment, retirement from service, breakdown and final disposal.

2.2 Accelerated ageing trials

In a typical series of trials (see Table 1), polymeric components will be assembled into warhead configurations in the presence of explosives but without fissile materials. Results from these trials, together with trials using stand alone components aged in ovens, will then be compared with real time ageing in full weapon trials. Degradative mechanisms in polymers have been established and qualitative comparisons are available (Carlson and Wiles 1976, Makhlis 1975) but each component formulation must be examined in detail. Resistance to thermal oxidative degradation is particularly difficult to predict because of the key role of impurities which act as catalysts to trigger the deterioration.

AWE has historically used a pseudo-Arrhenius approach to analyse macroscopic mechanical properties from accelerated ageing trials in which a forcing stress, usually temperature, is applied to the material and a resultant critical functional change is monitored. The methodology of this approach is well documented and the inherent restrictions are understood but, pragmatically, reasonable correlations have been observed between real time and accelerated ageing trials.