Acoustic Emission Studies on Composite Eliptic Spring Elements

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Abstract. Composite Elliptic spring elements were subjected to AE studies. The AE studies clearly indicate the nature of fatigue damage growth. The spring elements started emitting acoustic waves from the very beginning of the fatigue tests. The analysis of characteristic curves of AE signal showed a burst type emission during the initial stages of fatigue. The AE signal parameters of UDR/WRM laminate type-1 spring elements reach their peak at around 27,000cycles. During this period continuous type of AE signals were observed. This continuous type signals could consist of numerous infinite burst type emission and these kinds of signals are different from the burst type signals recorded during the early part of the fatigue life. Once the peak is crossed some continuous and some burst type emission have been observed.

Keywords: AE, UDR/WRM.

1 Introduction

The overall fatigue damage to a structure is generally expressed in many ways such as by S-N plots, modulus degradation plots and by using suitable mathematical models. The latter (type and rate of damage progression) can be evaluated by monitoring the fatigue process continuously from the start of the experiment. This can be efficiently accomplished by nondestructive testing techniques such as Acoustic Emission (AE) technique. Unlike other techniques the AE technique can be effectively used to evaluate the status of the material under stress. Also, this AE technique is sensitive to different failure mechanisms which can occur in the laminate.

So, in the present study, the fatigue characteristics of the composite elliptic spring elements was evaluated using suitable fatigue testing method and the AE was recorded simultaneously (both are described in detail in the experimental procedure section).

2 Observations on Acoustic Emission

As already stated, continuous change in the material status during the fatigue loading can be assessed on-line by picking up the acoustic emission signals emitted from the spring

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element. Typical observations and analysis on the variation of AE signal characteristics with fatigue cycles are presented in this section.

The variation of ring down counts (RDC) and rise time (RT) with fatigue cycles for UDR/WRM laminate type-1 spring elements are presented in the Figs. 1 and 2 respectively.The total number of counted pulses indicate the nature of influence inflicted on the material by the applied stress. The RDC characteristic curve shows higher

The polymeric composites are known to possess isolated pockets of strength and weakness zones due to its anisotropy. The presence of weak pockets or spots in composites could be attributed mainly to the following.

i. Presence of voids
ii. Misalignment of the fibre bundle.
iii. Insufficient wetting of the fibres and other possible defects during the winding process.

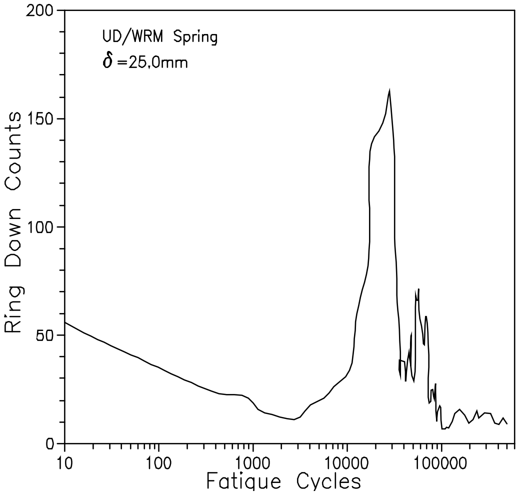

Fig. 1 Variation of ring down counts with fatigue cycles for laminate type-1 spring elements

The damage to the spring element starts by the initiation and formation of some cracks at the weak pockets of the composites. Normally in composites though the applied stresses are well within the failure limits, the weak pockets can give rise to higher stress intensity at some locations and could initiate the failure.

The RDC shows a downward trend as the fatigue cycling proceeds. This continues upto about 3000 cycles. Similar to RDC, RT also decreases upto about 3000 cycles and thereafter it tends to increase (Fig. 2). The fall in both RDC and RT can be attributed to the occurrence of burst signal due to the initiation of brittle fracture. This type of brittle fracture results in a sudden rapid (burst) AE signal, which tends to die down quite quickly. As a result of this, the number of times the AE wave crossing the threshold voltage reduces leading to the reduction in RDC. Similarly, because of the burst type emission, the time taken to reach the peak also reduces leading to the reduction in RT values. These burst type AE signals can arise due to fibre/matrix debonding, matrix cracking and possible fibre breaking due to misorientation. This trend is continued (upto 3000 cycles) till such time the above defects cease to exist.

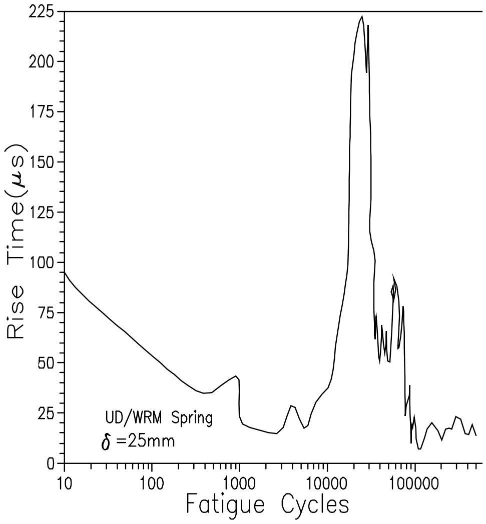

Fig 2 Variation of RT with fatigue cycles for laminate-1 type spring elements

Above 10,000 cycles the RDC starts increasing quite rapidly reaching its peak around 27,000 cycles. A similar increase in RT is also observed. Any increase in the RDC and RT would normally mean that the emission is associated with deformation mode of failure. The increasing trend of the RDC and RT suggests the occurrence of micro-mechanical deformations or damage which results in continuous type of AE signals. These continuous type signals can also consist of many infinitesimal discrete or burst type emission. These types of signals generally take a long time to die-down (or to fall below the preset threshold voltage permanently) unlike burst type signals. Once the initial weak pockets get exhausted the stress will be re-distributed within the spring element laminate. At this state the spring element will tend to retain its structural compatibility and will exert maximum resistance to the applied load, since all the weak pockets have already been consumed. This can be treated as a phase wherein the composite spring element may assume a state of compatibility to receive the load.

On attaining required compatibility (structural adjustment) to take up the load, the material can undergo microscopic deformation without any cracking or failure. With further fatigue testing on, the material is able to exhibit good resistance to deformation, as indicated by the increasing magnitude of AE signal characteristics (RDC and RT). As a result of this, the RDC and RT increases. This increase in RDC and RT indicate the accumulation of micro-mechanical damage within the material with fatigue cycles.

The degradation of the laminate, could lead to the occurrence of higher order damage processes. (such as fibre failure and matrix cracking etc.) These fracture processes are generally associated with brittle type failure. These brittle fracture processes result in the emission of burst or discontinuous type of AE signals. As already explained these burst type signals consists of lower order magnitude of RDC and RT.

After the peak though there is a rapid reduction in the emission of RDC and RT values it never ceases. However again the RDC and RT increases (a small peak) around 55,000 cycles. This rise in RDC and RT is attributed to the emission of continuous type AE signals.

It can be observed from the Figs. 1 and 2 that for the rest of the fatigue life, this kind of oscillating trend in AE signal continues. The signal never vanishes or ceases completely and continues to exist throughout the fatigue testing. This mixed trend indicates that though the stiffness reduction continues, the spring never loses its ability to take up or resist the applied load.

The variation of number of AE events with the fatigue cycles is illustrated in the Fig. 3. In a broad sense an AE event can be taken as the occurrence of a single fracture or failure process of any magnitude. This analogy could be applicable only in the case of isotropic materials and in case of composite materials, this need not be applicable.

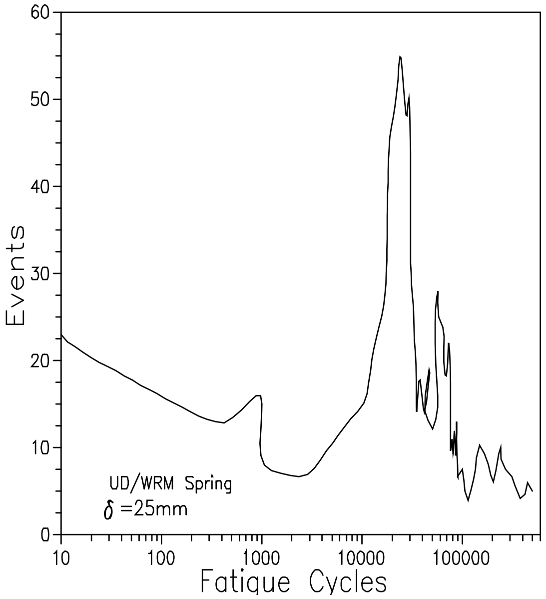

Fig. 3 Variation of AE events with fatigue cycles

From this Fig. 3 it can be seen that, at the start of the experiment more number of events occur and they continue to decrease upto 3000 cycles. During this test range, events of discrete nature occur. During the AE peak region, the events are quite high and this is due to the continuous and coherent emission of acoustic waves from the spring laminate.

Variation of event duration (ED) with the fatigue cycles for the laminate type-1 spring element is presented in the Fig. 4. It can be observed that the Fig. 4 also shows a similar trend of variation as other parameters throughout the entire fatigue test range. The event duration indicates the activation period of each event of energy release or AE. The occurrence of this kind of damage or deformation is usually indicated as a continuous event by the instrument (limitation of the instrument).

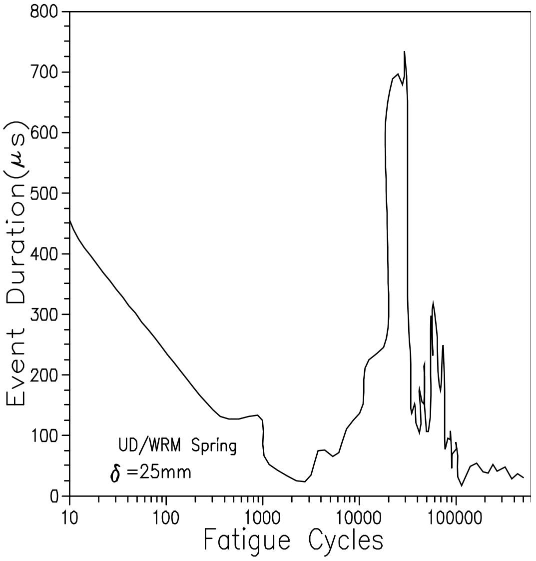

Fig. 4 The event duration characteristics of UDR/WRM spring elements

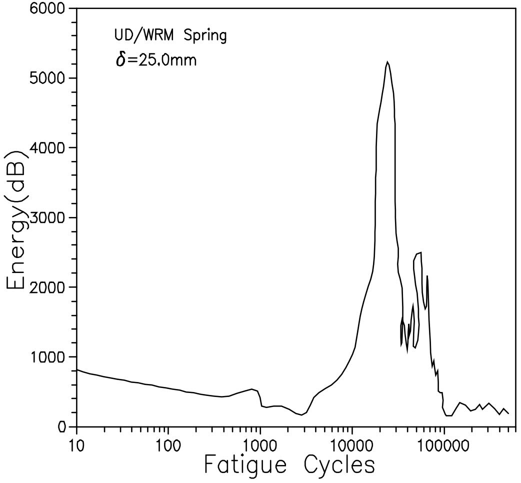

Fig. 5 Variation of Energy for UDR/WRM spring elements with fatigue cycles

The variation of energy with the fatigue cycles for the UDR/WRM laminate type-1 spring element is presented in the Fig. 5. Energy is a parameter which can be directly related to the amount of energy released by each microscopic and macroscopic failure event. Since energy is directly proportional to the area under AE wave form, its value is directly proportional to the AE signal characteristics such as RDC and RT.

Referring to the above results (from Figs. 1 to 5) the effectiveness of AE to indicate or identify even the occurrence of local failures or fissures is seen in the occurrence of the following.

1.low RDC 2.low RT 3.low ED 4. low event 5.low energy

3 Results of AE Studies for UDR Spring Elements

The variation of RDC with fatigue cycles for the UDR laminated spring element has been presented in the Fig. 6. There is a overall similarity between the AE signal characteristic curves of UDR and UDR/WRM laminate type-1 spring elements.

Despite this similarity there are some differences. They can be listed as follows.

(i) Overall magnitude of the signal parameters.
(ii) Width of the AE peak.

The explanations provided for the typical signal characteristics of UDR/WRM laminate type-1 spring element, can be considered to be applicable to the present case also.

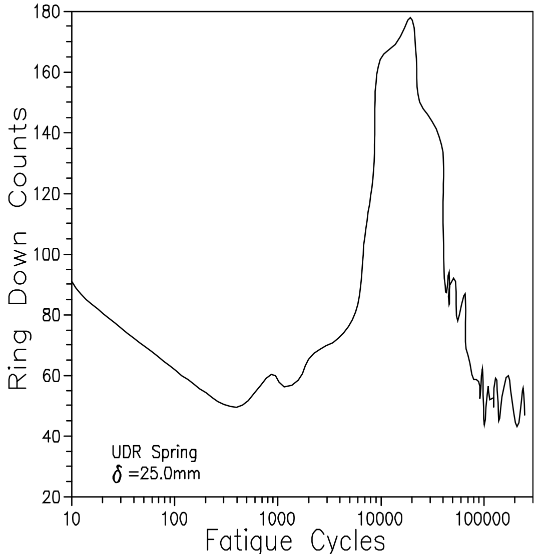

Fig. 6 The RDC characteristics of the UDR spring element

In the case of UDR spring elements, the RDC and other signal parameters have considerably higher values than the UDR/WRM laminate type-1 spring element. This could be explained as below:

As already described, for UDR spring element, the crack propagation is quite uninhibited in the direction parallel to the fibres. This results in a greater amount of fatigue damage. The size or volume of the fatigue damage could be much less in the case of UDR/WRM laminate type-1 spring elements.

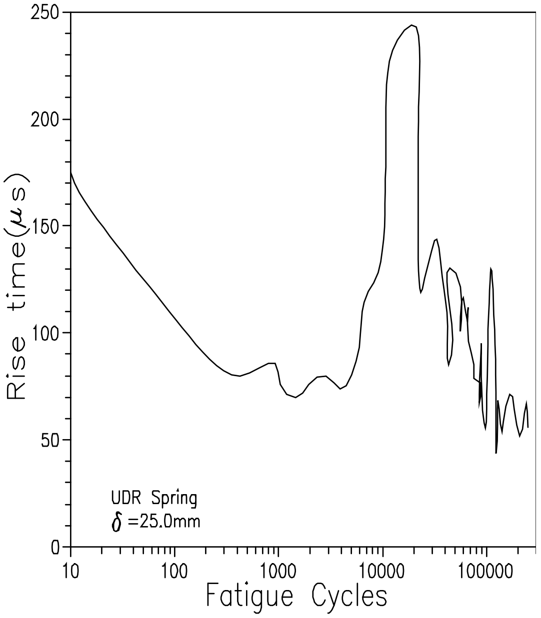

Fig. 7. The RT characteristics of the UDR spring element

It can be observed that UDR spring elements reach peak RDC values quite early (in terms of number of cycles) compared to that of UDR/WRM laminate type-1 spring elements. Generally, UDR springs reach peak values around 20,000 whereas the laminate type-1 spring element reaches the peak value around 30,000 cycles. This indicates that laminate degradation or material distress as a result of fatigue cycling occurs quite early for UDR springs than UDR/WRM laminate type-1 spring elements.

After the peak region, the variation of signal parameters is quite similar to that of UDR/WRM laminate type-1 spring elements. However, the magnitude of signal parameters continues to be higher than that of laminate type-1 spring elements. Similar to Figs. 6 and 7 the variation of AE signal parameters such as ED and energy are also illustrated in Figs. 8 and 9 respectively. The analysis of the AE data recorded during the fatigue tests show that the Kaiser effect is not present as far as these studies are concerned. This can be explained as below:

The stiffness of the spring continues to reduce with each cycle of fatigue. This indicates that the maximum load to which the spring is subjected to reduces with each cycle. However, the AE emission continues. Thus the Kaiser effect is clearly defied.

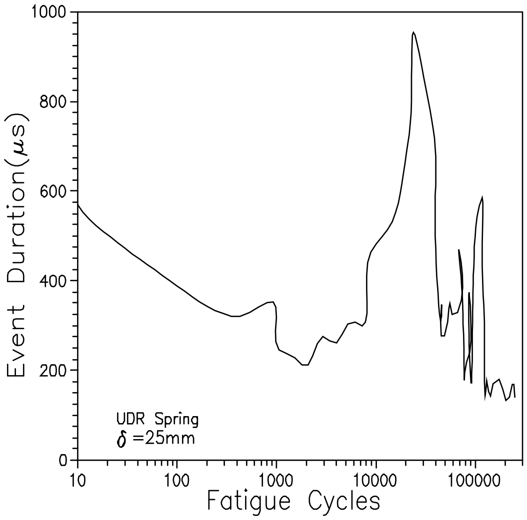

Fig. 8 The ED characteristics of the UDR spring element

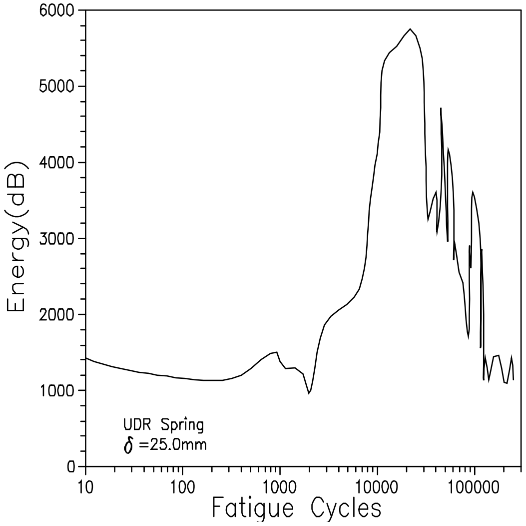

Fig. 9 The variation of energy with fatigue cycles.

Effectiveness of AE technique in identifying the fatigue behaviour of composite elliptic spring elements - A correlation between the fatigue and AE characteristic curves

Typical observations on the fatigue performance of composite springs (both laminate type-1 and UDR spring elements) are presented in the Fig. 10. Referring to the Fig. 10 it can be seen that first visible sign of stiffness reduction appears after around 400 cycles. Referring to the illustration on AE signal parameters presented in Fig. 11 it can be seen that around 400 cycles, the AE parameters RDC, RT, ED, events and energy register a small rise indicating onset of deformation mode (continuous signals).

During 10,000-25,000 range, there was smaller reduction in the stiffness for laminate type-1 spring elements. Over this period, the structure of the material ought to have reached required compatibility; there by it experiences an increasing order of deformation without any material damage. This is illustrated (Fig. 11) in the rising trend of the AE parameters over this range of fatigue cycling.

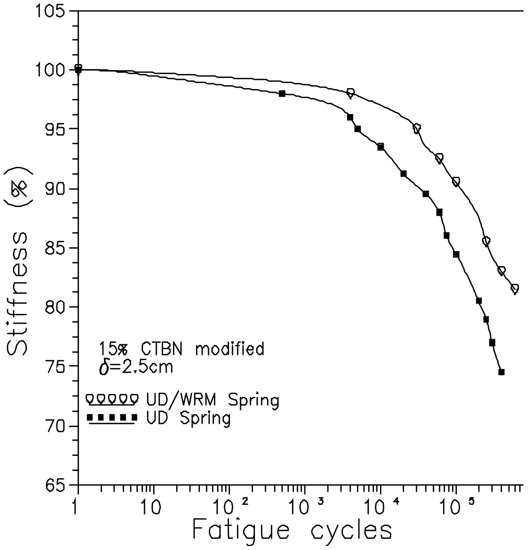

Fig. 10

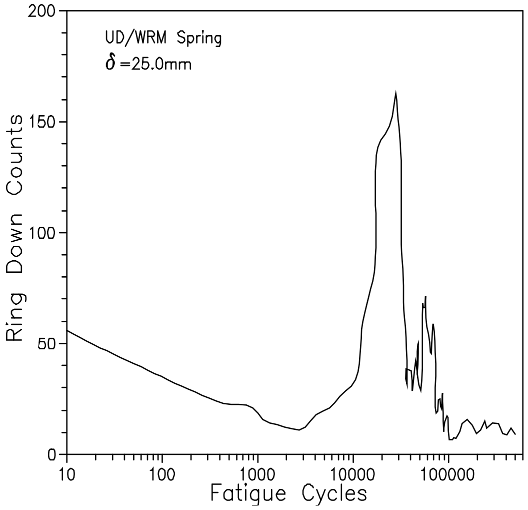

Fig.11

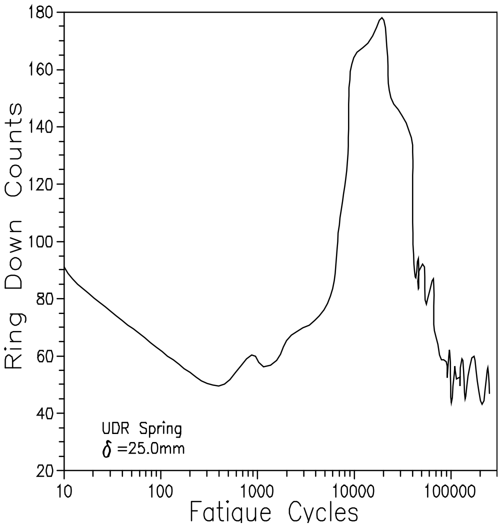

Fig. 12

Figs. 10, 11 and 12 give a comparison between the nature of variation of fatigue and AE characteristics of the spring elements

In the case of UDR springs also, similar trend of good correlation between the stiffness reduction and AE signal parameter were observed. For example, the change in the stiffness over the fatigue-cycle range of around 10,000-30,000 is clearly indicated by crest widening of AE signal parameters (Fig. 12) over the corresponding fatigue-cycle range. The occurrence of higher order AE signal parameters (Fig. 12) for UDR spring elements indicate that such springs experience relatively higher order of material damage and degradation.

4 Summary Of The Results

The AE studies clearly indicate the nature of fatigue damage growth. The spring elements started emitting acoustic waves from the very beginning of the fatigue tests. The analysis of characteristic curves of AE signal showed a burst type emission during the initial stages of fatigue. The AE signal parameters of UDR/WRM laminate type-1 spring elements reach their peak at around 27,000cycles. During this period continuous type of AE signals were observed. This continuous type signals could consist of numerous infinite burst type emission and these kinds of signals are different from the burst type signals recorded during the early part of the fatigue life. Once the peak is crossed some continuous and some burst type emission have been observed.

The signal characteristics of both UDR and laminate type-1 spring elements have been compared. The overall magnitude of the signal parameters of the UDR spring elements were found to be higher. The UDR spring element reaches the peak AE values earlier in terms of fatigue cycles, than the laminate type-1 spring elements. Also, the AE peak of UDR spring elements were found to be broader than that of laminate type-1 spring elements.

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